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## SPECIAL ISSUE ON ENVIRONMENT

IC Centre for Governance
New Delhi

**Special Issue on Environment**
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The IC Centre for Governance has been set up with the objective of collective thinking and acting on important issues of governance. It believes that public governance is too serious a matter to be left entirely to the state and that the involvement of the civil society is not only desirable but also essential. The Centre seeks to strengthen the capacity of civil society and government for ensuring good governance.

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The papers in this special issue of the journal of governance have undergone a peer-review process.



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# EDITORIAL

The Ministry of Environment, Forest and Climate Change, Government of India is pleased to collaborate with the IC Centre for Governance in bringing out the special edition of the Journal of Governance on various facets of environment. The papers in this journal are contributions of sector-specific experts presenting their views on multiple aspects of environmental governance. These papers have gone through a peer review process.

Environmental governance in India has significantly improved under the guidance of Hon'ble Prime Minister Shri Narendra Modi with focus on objectivity, transparency, ease and speed of doing responsible business while ensuring development without destruction. The result of good governance speaks for itself.

Environment does not mean the same thing to everybody. There is a spectrum of positions and views on environment, but many find it hard to describe all that the environment encompasses. To me personally, environment means the air we breath; the water we drink; the rivers and the forests and the countless life forms which inhabit the land and the water and the air of the world. It also means cultures and customs, the very diversity of life, including humanity, and so on and so forth. The description is nearly endless, making the canvas of environment very broad.

India, with only 2.4 per cent of the world's land area, 4 per cent of the world's freshwater resources, using 6 per cent of world's primary energy, is supporting around 18 per cent of the global human population and one of the largest cattle populations in the world. India is a megadiverse country, both culturally and biologically. We have four global biodiversity hotspots, 7-8 per cent of all recorded species, the world's largest tiger and Asiatic elephant populations, ten bio-geographic and 15 agro-climatic zones, 37 UNESCO world heritage sites and 22 official languages with several local dialects.

India's rising economy and young demography bubbling with energy, exuding confidence and teaming together for innovations, offer many bright, creative and fascinating opportunities for the 21$^{st}$ century of the world, where stagnation of economies and ideas are prevalent. It is this budding young critical mass which offers hope not only for India but also for the world. Through them, India seeks to promote multi-faceted cooperation among the countries of the world for sustainable development. With this backdrop, India is aspiring to overcome poverty, conserve the environment and continue pursuing sustainable lifestyles based on lessons gleaned from our long and illustrious history and vibrant culture.

India has a long history and tradition of harmonious co-existence between man and nature. Respect for nature is an integral part of our value system. We represent a culture that calls our planet Mother Earth. India in many ways represents one of the few ancient civilizations and cultures that have unbroken yet dynamic traditions. Nature has taught us to understand how natural systems which are cyclical have sustained over the ages. The people of India developed lifestyles that matched the local conditions. Types of houses, food habits, clothing, livelihoods, forms of medicine all matched the climate of the region. The ascetic influence on our culture encourages an attitude of frugality as opposed to profligacy. It is important to note that it is not poverty; rather it is culture that makes people consume only as much as they want to eat or switch off lights when they go out. This is the very foundation of sustainable development, around which 17 Sustainable Development Goals have been designed. This cardinal principle also defines the broad contours of our national developmental framework.

Since the 1760s, as industries started flourishing and rumbling, and becoming the engines of development, forests were recklessly cut to meet the insatiable timber appetite, and the earth's mineral and metal resources were tapped to their tipping point to keep the industrial revolution going and sustain the profligate lifestyles of rich nations. This form of development model is now outdated and out-fashioned. Today, nations have a choice to take a cleaner, greener and safer path of development without harming the Mother Earth. In fact, countries should endeavour to enhance their natural resources while growing sustainably. This is what India is striving to achieve.

India speaks from a position of strength and experience when it comes to addressing global challenges, be it ozone layer depletion, biodiversity loss, land degradation, single-use plastics, use of hazardous chemicals, migratory feathered friends and marine species, environmental impact assessment and climate change. Now that developing nations are wanting to liberate their population from the shackles of poverty, disease, malnutrition, illiteracy and wake up to the developmental challenges, India's journey is a model which provides a good reference point to the world demonstrating that leapfrogging to a cleaner and greener future is possible.

India has done path-breaking groundwork in all fields which embody measures to address climate change mitigation and adaptation. Sun and other renewable sources of energy have the potential of meeting our growing energy demands with low or no carbon emissions. India has shown and invested in the unlimited potential of harnessing solar energy between Tropic of Cancer and Tropic of Capricorn by setting up International Solar Alliance, an international treaty which became operational on 6$^{th}$ December 2017. Domestically, we are implementing one of the world's largest renewable installed energy programme. In the last four years, our solar power capacity has grown by nearly eight times, with all renewable sources constituting more than 21 per cent of the country's installed power generation capacity and over 10 per cent in the electricity mix.

The agricultural sector is vital to India's economy and food and nutritional security. Over half of the Indian population is engaged in agriculture and allied activities while contributing around 15 per cent of the Gross Value Added (in 2017-18). The poor marginal farmers in developing countries cannot be burdened with mitigation policies and measures. Industrial agriculture is not prevalent in India. Our emissions in this sector are survival and not luxury emissions. The burden of mitigation has to be borne by developed countries who have the necessary financial and technical wherewithal, and who had through the Convention promised the world at Rio, Kyoto and Paris to combat climate change. The world can tackle the challenge of climate change, provided the developed countries deliver on their promises. In the agriculture sector, India's focus is on adapting to the increasing climate variability for which a number of initiatives are being implemented including climate proofing of villages; distribution of soil health cards; manufacturing of neem coated urea; promotion of high density plantation material and micro-irrigation; integrated cropping practices; online trading platform; crop insurance schemes etc. The mass scale implementation of these measures will make a difference in addressing the problem of climate change which requires enhanced and sustained financial support.

The waste sector accounts for only 3 per cent of the country's GHG emissions. The country is taking ameliorative measures to handle all types of waste including, solid municipal, industrial, hazardous, biomedical, plastic, construction & demolition and e-waste. Swachh Bharat Abhiyan, a nation-wide cleanliness campaign has become a people's movement. These measures are not only reducing our carbon footprint but also improving the overall health and well-being of 1.21 billion Indians.

Pollution is a matter of concern in cities and towns and is caused due to the introduction of contaminants into the environment *viz.* air, water and soil that may cause an adverse change in ambient conditions. India has taken a series of steps to address issues related to water pollution, air and vehicular pollution, industrial pollution, etc. in cities, towns and metropolises. It is done through the establishment of 101 continuous ambient air quality monitoring system in 57 cities, and a manual system of monitoring air quality covering 303 cities. We also have in place a robust roadmap for mitigation of air pollution laid down with directions to all State Pollution Control Boards. For abatement of pollution in the Ganga river, online monitoring is established, to check discharge of industrial effluents. The country has also achieved significant progress in reducing pollution from industries like paper and pulp, sugar and distilleries in the Ganga basin.

Climate change adds to our already growing developmental pressures. Climate change has impacted the distribution, growth and timing of seasonal activities of many plant species while posing threats to mangroves, seagrass beds, coral reefs and salt marshes. Degradation of biodiversity impacts ecosystem services, which directly and adversely affects local livelihoods as well as the national economy and security. However, India is committed to resolute action against climate change as a global champion. Climate change is a global action problem and has to be addressed through positive concerted actions on the ground by all countries working together based on their respective capabilities. India's Nationally Determined Contributions (NDCs) are a rare combination of our traditional values and present-day aspirations. They are robust, practical and doable actions to promote low carbon growth.

Against the given backdrop and despite all round outstanding success achieved during the last four years, there is a widespread feeling among the public at large of the missing connect with nature. It seems like society lacks awareness and does not generally translate learning into action. Learning by doing is found to be lacking among school and college students despite multiplicity of seminars, workshops, conferences and computer studies. Everyone talks about the environment, but no one does anything about it. I mean, we need to be finding ways to combat the erosion of nature's intrinsic potency and qualities to heal herself with the clear understanding that nature protects only if she is protected. We need to remember that in this age of plastics, computers, missiles, and human society's ambition to colonise the Moon and Mars; we still depend on green plants for oxygen and food. Therefore, there is a pressing need for reviving, in a common man, a sense of belonging towards and connect with nature.

India's over 5000-year-old culture enjoins us to look at the whole world and all that it sustains – living and non-living – as a family, co-existing in a symbiotic manner. Following this path, India is maintaining a "*Samanvay*" between its rich traditional heritage and modernity while ensuring no negative impact on the environment. India is committed to the conservation of nature while meeting the basic as well as aspirational developmental needs of its population.

Hope the readers and interested stakeholders will enjoy reading the issues raised in the journal, and strive to partner with the Government to jointly address them for ensuring good governance and sustainable development of the country's tangible and intangible resources.

**C K Mishra**
**Guest Editor**

# Environmental Governance in India: Issues, concerns and opportunities

Prabhat Kumar[1]

Environmental governance is one of the emerging challenges facing the contemporary world. It is the means by which society determines and acts on goals and priorities related to the management of natural resources. Efficient environment governance at all levels is significant for finding solutions to challenges such as pollution, waste management, climate change, ozone layer depletion and biodiversity loss. This includes appropriate environmental, social and legal frameworks at local, regional, national and global levels that are a prerequisite for good environmental governance.

India has a long history and tradition of seeking harmonious co-existence between humans and nature. Respect for Nature is an integral part of our ethos and value system. We represent a culture that calls our planet 'Mother Earth'. As one of our ancient texts says; "Keep Pure! For the Earth is our Mother! And we are her children!". India in many ways represents one of the few ancient civilizations and cultures that have relatively unbroken traditions. Thus, Indians have believed and practised the science and art of living in harmony with Nature and it is important that we continue to do so.

India, a mega-diverse country, both culturally and biologically, with 2.4 per cent of the world's land, 4 per cent of global freshwater resources and consuming only 6 per cent of world's primary energy, is supporting around 18 per cent of the global human population. India's rising economy and young demography offer many novel, creative and fascinating opportunities for the 21st century. With this backdrop, the country is aspiring to overcome poverty, conserve the environment and continue pursuing sustainable lifestyles based on lessons gleaned from our long and illustrious history and vibrant culture.

Economic growth, and particularly consumerism, has led to intensive use of resources such as water, energy and materials, as well as extensive waste generation. Users value the input resources (water, energy and materials) at less than their environmental costs, which leads to their over-exploitation.

Against this backdrop, a strong focus on environmental governance, roughly defined as formal and informal interactions between the state, market and civil society, is critical. Environmental governance is aimed towards the formulation and implementation of policies in response to environment-related issues, to attain environmentally sustainable development. It refers to the decision-making processes involved in ensuring environmental welfare and advocates sustainable development as the supreme consideration for environmental management

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practices. Good governance is a product of four main drivers: public sector management, accountability, existing legal framework and accessibility and transparency of information. Thus, good environmental governance needs to be driven by informed policy making, with the help of a transparent and accountable bureaucracy that is focussed on working for the public good, with public participation.

Economic and environmental protection pose a critical trade-off to any developing country, and India is no exception. The approach to governance is based on the ideals of pluralism, equity and diversity, and thus, political, institutional and socio-cultural systems face numerous challenges when it comes to environmental governance. The growing Indian economy requires balancing economic growth while also preserving the environment and wisely using natural resources.

Environmental governance first emerged as a political issue in India barely 25 years after independence, following the United Nations Conference on Human Environment and Development (Stockholm Conference of 1972). This conference was instrumental in generating awareness about the global environment and led to the establishment of the United Nations Environment Programme (UNEP). The Stockholm Convention led to a slew of developments in Indian environmental legislation. The National Environmental Planning and Coordination Committee was set up in 1972, followed by the enactment of the Water (Prevention and Control of Pollution) Act 1974 to ensure that existing water resources are preserved through proactive efforts. India also set up pollution control boards at the centre and state levels to ensure compliance of the Water Act. In 1976, the Constitution of India incorporated environmental concerns into the Fundamental Rights, Directive Principles and Fundamental Duties of India, through the 42nd Amendment. In 1980, India enacted the Forest (Conservation) Act, and in 1981, the Air (Prevention and Control of Pollution) Act. The Bhopal Gas Tragedy in 1984 triggered enactment of the Environment (Protection) Act 1986 which brought together the above-mentioned Acts under a single umbrella Act. All the Acts saw the formulation of subsequent 'Rules', which provide procedural instructions to help with compliance of the Acts.

The trend of international conventions triggering formulation of National Acts and policy statements has been repeated through the years. The Brundtland Commission Report, 1987, that explored the interconnections between social equity, economic growth and environmental issues, and the United Nations Conference on Environment and Development, in 1992 (also known as the Earth Summit), led to the formulation of the National Conservation Strategy and Policy Statement on Environment and Development followed by the Environment Impact Assessment (EIA) Notification in 1994, which was amended over the years and was revised in 2006 (EIA Notification 2006). The National Environment Policy of 2006 encapsulated the spirit of sustainable development in the policy statement for environment. The Policy also internalized key approaches of the Ramsar Convention on Wetlands, the Convention on Biological Diversity, the Convention on Migratory Species and the United Nations Framework Convention on Climate Change (UNFCCC).

India further implemented Principle 10 of the Rio Declaration (1992) through the Right to Information Act (RTI) in 2005. The RTI Act has been instrumental in increasing transparency and accessibility to information. This has enabled civil society organisations, non-governmental organisations (NGOs) and the general public to become aware of environmental issues in the country. Similarly, the Convention on Biological Diversity in 1992 saw the enactment of the Biological Diversity Act in 2000 for effective conservation, and at the same time, help communities benefit from any commercial exploitation of the bioresources that they have conserved.

The 'wise use principle' of Ramsar Convention was brought within the regulatory architecture in the form of Wetlands (Conservation and Management) Rules, 2017 and the design on Ministry of Environment, Forest and Climate Change (MoEFCC) flagship programme on wetlands, notably the National Programme on Conservation of Aquatic Ecosystems.

## Current policy framework in India

The 'precautionary principle' envisaged under the Environment (Protection) Act, 1986 forms one of the pillars of environmental governance in the country. This requires actions to be taken on a precautionary basis, without necessarily waiting for unambiguous proof or complete information, prior to any issue reaching the stage of affecting the environment and the health of the citizens.

This has led over the past few decades to a shift in the government's approach from an emphasis on pollution mitigation to proactive measures to prevent pollution. A series of national plans demonstrate the intent of incorporating environmental aspects into development. The National Forest Policy (1988), The National Conservation Strategy and Policy Statement on Environment and Development (1992), and The Policy Statement on Abatement of Pollution (1992) are demonstrations of this intent. Articles 21, 48-A and 51-A (g) of the Constitution mandating a national commitment to a clean environment, led to the formulation of a National Environment Policy (NEP) in 2006 to ensure a common perspective in different sectoral and non-sectoral approaches to environmental management. In addition to the Acts and Rules mentioned previously, India's governance framework also responds to global environmental issues like depletion of the ozone layer, in the form of legislative Acts like the Ozone Depleting Substances (Regulation and Control) Rules in 2000.

In the Indian context, public participation (Principle 10 of the Rio Declaration) has played a role in the success of policies. In 1998, the EIA Notification was amended in order to include "public hearing" as an important part of the environmental clearance procedure for development projects. The democratic nature of Indian governance has often been seen in the form of strong and vocal environmental movements. Public interest litigations have aided local communities and civil society organisations drive better implementation of protective measures for the environment.

The Supreme Court of India used to hear all environment-related cases until the National Green Tribunal (NGT) was established under the National Green Tribunal Act 2010. The Tribunal is aimed at delivering focussed and expeditious measures on environment-related cases. India is the third country in the world (after Australia and New Zealand) to have such a focussed legal body for environment-related cases. The Tribunal has become a forum where environmental clearances can be challenged, thus empowering the general public of India. This ensures that improper conduct of the public hearings, insufficiency of public consultations, faulty EIA reports, concealment of information by the industries, etc. are checked and reduced. Thus, it can be said that the Indian Judiciary has enhanced environmental jurisprudence in India.

## Transforming good governance into smart governance

India is in the midst of a profound transformation that is moving the country to the centre stage in many areas of global interaction. A vibrant democracy that is home to over one-sixth of the world's population, India's modernisation has been gathering speed and new policies have been introduced to unleash further growth.

While a number of increasingly stringent acts, rules, procedures and regulatory measures are being introduced over time, they nevertheless fall short of their intended goals and targets in a number of ways due to political, social, economic, operational and capacity constraints. Despite the many proactive measures taken up by the government, it is also increasingly realised that environmental performance has not been fully able to match the pace of development in a sustainable manner.

Technology can of course critically assist in good governance or smart governance as the combination is often referred to. Past techniques and methodologies historically implemented in other countries can be leap-frogged with new smart solutions. But technology alone, or smart-governance alone, cannot perhaps solve the basic problem that environmental governance must deal with. While acknowledging that environmental governance is constantly being stepped up, it is clear that the direction and pace of development constantly reframe the challenges that it has to face. The solution lies perhaps in not considering this a failure but part of a process of learning by doing. This is especially necessary since the development is not always a systematic, predictable or deterministic process. Both its pace and direction are subject to considerable uncertainties and this would require that environmental governance must learn to deal with these uncertainties that emerge over time.

Indeed, what constitutes an environmental issue itself sometimes undergoes a transformation – chemicals in established use are found to be pollutants, standards of use are made more stringent over time with new scientific information, new information and data give rise to new concerns, or new threats and concerns emerge over time. Particularly in a developing country, such changes are often very rapidly leading to considerable disorientation in environmental governance. In short, environmental governance cannot be but a dynamic process, adapting to constantly changing as well as radically new challenges. And as a dynamic process, it will also be subject to learning by doing over a period of time.

Recent measures, such as introduction of real-time air and water pollution monitoring system, popularly known as Continuous Emission Monitoring System (CEMS); or introduction of PARIVESH, (**P**ro-**A**ctive and **R**esponsive facilitation by **I**nteractive, **V**irtuous and **E**nvironmental **S**ingle-window **H**ub), an online, single-window green clearance tracking system, are the real game changers. We need end-to-end systems to monitor polluting actions, legislative control and regulatory actions. Good governance for the pollution domain would be effective if steps are taken at city and state levels. Grass root level governance will be more efficient in implementing the measures and practices. An efficient way of doing so is by scaling up and integrating the existing smart practices with new and complimenting measures, including the adoption of appropriate technologies.

## Some key sectoral issues

1. **Land** – Land remains the most important economic, social, and cultural resource for the vast majority of Indians. While the acquisition of land is regarded as a "bottleneck" in the process of economic development, ownership of land also provides a measure of security to a vast section of the population. Predictably then, disparities over land is the most widespread and inflexible of all minor and local conflicts in India. Legal disputes over land are the most important factor responsible for clogging of cases in courts, both in terms of the number and the pendency of cases. However, with countless colonial and post-colonial central and state laws dealing with land reforms to land acquisition, forest laws to laws applicable to Scheduled Areas, from laws promoting and regulating urban development to laws dealing with

evacuee, enemy, ancestral and religious property, it may be prudent to further streamline existing laws and create a comprehensive database on "land laws" for effective governance.

Alienation of land is, of course, part of the process of the transformation of land use, which is one of the fundamental processes that set in motion a cascading array of environmental transformations. Regulating land use is a larger, more complex question than the regulation of conflicting claims on land. The loss of land which is the basis of particular ecosystems, such as wetlands, coastal land or beaches, the conversion of land from agricultural use of particular kinds to buildings and construction, the degradation of the quality of land due to soil erosion, poor drainage or other anthropogenic causes, all of these are examples of land use change that have serious environmental impacts. Regulating land use change is a major challenge, and there has only been some marginal impact so far. While wetlands and coastal zones have been brought under some kind of regulation, the land in many other ecosystems is protected only by the cover provided by other regulation such as that of forests or wildlife. Wetlands rarely find mention as a land use class, and is mostly prone to classification as a 'wasteland' to be developed for a productive use. This glaring loophole has been used rampantly by developers to convert natural wetlands into infrastructure development areas.

The difficulties in regulating land use change is a very typical instance of the difficulties of environmental governance, especially arising from the intersection of the economic and social dimensions with the environmental dimension. While it is widely and readily recognized it is not easily dealt with, particularly because of the complex economic and social processes that are at the heart of these transformations.

2. **Urbanization** – The other great challenge that India faces is urbanization. It is worth noting that one of the largest shifts in the planning process of urban centres in world history is projected to occur in India in the next few decades. A transition of such scale places unprecedented pressure on energy, water and other natural resources which provide the necessities and amenities to a growing population. How then, can India urbanize in a manner where energy, food and water needs are met, the local and global environment is preserved and the energy and economic security are not put at risk. The 'Smart Cities' Mission, launched in 2015, puts a welcome emphasis on integrated planning and provision of urban services (including power, water, waste and mass transportation), even though it possesses considerable challenge of coordinated delivery across different branches and levels of the government. In addition, the National Urban Policy Framework is currently under preparation (the draft is being consulted widely), focuses on holistic urban development keeping in mind environmental and ecological challenges. The National Urban Sanitation Policy 2008 emphasises on access to sanitation and open defecation free urban communities. This has been instrumental in bringing focus on the need for greater efforts towards sewerage management following required environmental standards. Finally, there is an increasing focus on Faecal Sludge and Septage Management (FSSM) in order to address the need for smaller cities and parts of urban areas not covered by networked systems.

3. **Air pollution** – According to the World Health Organisation's global ambient air quality database, nine out of 10 people on earth live in the misery of highly polluted air (WHO 2018a). India is no exception with the world's second largest population base of 1.21 billion (in 2011) and a disproportionately low amount of natural resources to sustain its people. As per the database, 11 out of 12 most polluted cities in terms of air quality (fine particulate matter, PM 2.5) are located in India (WHO 2018b). Air quality index exceeds the prescribed national standards in almost

every major city, and three-quarters of the country's population is exposed to poor air quality (Balakrishnan *et. al* 2019).

Most of the PM 2.5 related pollution comes from combustion-based activities fuelled by coal in industry and power plants; diesel and petrol in the vehicle segment, and biomass burning predominantly in rural areas for cooking needs. In addition, dust on the roads and constant vehicular movement adds to the PM 10 woes (UrbanEmissions.info 2016). Besides, unorganised activities such as waste burning, celebratory firecracker activities, and seasonal events such as stubble fires give a hard time finding an appropriate solution. Meteorology also plays an important role here, as pollution is not limited to source areas alone, and pollutants can even travel several miles to impact distant locations.

The impact of consistently high exposure to pollution is disastrous in terms of health and economic costs. According to some estimates, crop burning alone in the northern plains of India causes an estimated economic loss of USD 30 billion annually, as it leads to acute respiratory infections measured by frequency of reported hospital visits (PTI 2019).

Earlier this year, in January 2019, the government ramped up its efforts against air pollution through a nationwide launch of the National Clean Air Programme (NCAP). Indeed, it is a welcome step, as it addresses the challenge with a clear target of 20 to 30 per cent reduction in PM 10 and PM 2.5 concentration by 2024 from the base year 2017 (PIB 2019). Source apportionment studies in the selected 102 cities will be conducted by expert technical agencies like IITs, CPCB etc. in a phased manner.

On an optimistic note, it shall be treated as a good starting point, but adding more clarity beyond targets would be certainly useful. Regardless of all the impressive anti-pollution measures adopted by the Government, air quality, in several instances, appears to be worsening by the day. The solution appears to be in smart-governance and public awareness. For instance, India does not have sufficient air quality monitoring stations to inform policies and track progress regularly. As of 2019, 731 air quality monitoring stations are operational covering 312 cities/towns out of over 5000 cities (CPCB 2018a). Thus, most cities either completely lack the monitoring capacity or have poor information to arrive at any concrete decision. Moreover, the majority of these stations can't monitor PM 2.5 pollutant and face frequent calibration issues (Upadhyay 2019). A model of smart governance may also address this challenge before setting any new goals towards air quality improvement.

Since air pollution monitoring and control measures are made available only for major cities, it gives an impression that the small towns and villages are free from pollution. This may prevent the adoption of local mitigation measures.

Given this background, it is imperative to strengthen and reinforce several public institutions which lack the required technical and workforce capacity to implement environmental governance. For instance, State Pollution Control Boards (SPCBs) generally lack capacity to conduct source apportionment studies. Only the Central Pollution Control Board (CPCB) and some other research institutions can undertake these. Thus, considering the growing air pollution problem in major cities, there is an urgent need to build capacity across the relevant institutions.

Another major concern behind policy implementation is the poor institutional capacity to handle big-ticket reforms. SPCBs face a huge capacity crunch in terms of trained manpower, lack of technical resources, high administrative burden, and specialised professionals from IT and legal sector (Centre for Science and Environment 2009). It is impossible for the SPCBs to adequately monitor the progress of current mandates and programmes without having IT-enabled systems. Extended Green Node (XGN) is a tried and tested model of smart governance, where states including Gujarat have managed to reduce their administrative burden by a significant margin. Within a few years of operation, they have managed to regulate the air and water inspection across industries in a streamlined manner. Besides, it has helped these States to keep a digital record of emissions reported by industries every month. This model can easily be replicated across all the States to further analyse and inform policies by making use of real-time information collected from industries with little effort.

Finally, the quality and accuracy of the reported data is always a point of investigation. Realising this, in 2014, CPCB issued a directive to 17 categories of industries identified as the most polluting industries. This precisely addresses the prime challenge of the lack of transparent information and is undoubtedly a great preventive measure. CPCB has now expressed its intention to expand this measure to other categories of polluting industries as well. Before we proceed ahead and take required steps, we must not overlook the questions raised on equipment quality and authenticity of data. There is no laboratory available in the country to carry out an authentic calibration and certification of Continuous Emission Monitoring System (CEMS) equipment. Certainly, quality of information should come under scrutiny; otherwise many industries must have been found non-compliant with the norms after CEMS implementation. The government needs to fix the issues around testing and calibration of CEMS before the expansion of scope and coverage of CEMS installation.

4. **Water** – Water bodies are popularly recognized from pre-historic times as the lifeline of civilisations. This is very true in the context of India being an agrarian economy, and a large population relying on agriculture and allied activities. In the modern period, even industry and power generation activities suffer severe impact due to the unavailability of water. According to the World Resource Institute's statistics, "between 2013 and 2016, 14 of India's 20 largest thermal utilities had shutdowns due to water shortages (WRI 2018)."

In 2018, a NITI Aayog report revealed statistics on the state of the water crisis in India. It suggested that: 600 million people face high-to-extreme water stress; 75 per cent of households do not have drinking water on premises. Around 84 per cent rural households do not have piped water access; 70 per cent of our water is contaminated. India is currently ranked 120 among 122 countries in the water quality index. It further stated that every year 200,000 Indian lives are lost due to contaminated water or inadequate supplies. The situation is likely to get worst, as 40 per cent of the Indian population will have no access to drinking water by 2030 (NITI Aayog 2018). The NITI Aayog introduced the Water Index in 2018, built on 28 key performance indicators related to irrigation, drinking water, and other water-related sectors. By linking fiscal tranfers to States with performance on water index (within other considerations), a mechanism for incentivizing good water management has been enabled.

Water is a 'State' subject in India. Hence governance is dispersed and complex. Aside from SPCBs, India has multiple bodies at central and state level to look after conservation and corrective measures, namely – National Water Board, National Water Council, Municipal bodies, Central Water Commission, Central Ground Water Board, etc. The focus of these bodies is predominantly towards augmenting supply systems, while the possibilities of promoting productive water-use efficiency is not a mainstream subject yet (Gaur 2016). This can be understood from the fact that despite being a water-scarce country, India's agriculture including its exports is highly water-intensive according to the Water Footprint Network (WFN) statistics. There is an increasing trend to use nature-based solutions instead of hard engineering solutions to meet present-day water challenges. Role of wetlands has been primary in meeting objectives of flood control, augmenting water supply and enhancing groundwater recharge. The discourse on 'nature-based solutions' or 'hybrid solutions' is yet to find a mainstream place.

On the supply side, the issue of the clean-up of the Ganga is in the limelight. The Ganga Action Plan (GAP) originally launched in 1986 has a record of poor implementation within an extensive institutional architecture. It could not find desired success because of curtailed budgetary support, and implementation bottlenecks. In addition, lack of public participation and difficulty in tackling non-point sources of pollution in the past had led to poor water quality in river Ganga (Dutta 2017).

*Namami Gange*, a flagship programme initiated by the central government in 2014, seeks to address past failures and improve governance decisions. Some of the good governance lessons are:

- Bringing States on-board through State-level committees. This ensures sustained maintenance of treatment facilities along the bank of Ganga;
- It has an extensive focus on sanitation and prevention of open defecation coupled with Swachh Bharat Mission. More than 90 per cent of villages along the river have been already declared open defecation free.

Despite these successful measures, governance challenges in the form of land availability are still to be resolved.

Looking at a broader canvas, statistics from the CPCB suggests that the number of polluted river stretches in India are 351, and 31 States and Union Territories have rivers and streams that do not meet water quality criteria (CPCB 2018b). What kind of governance measures should be adopted to tackle this massive problem? Acts and legislations need to be aligned to treat water and sanitation as part of a common water cycle. The same needs to reflect in the mandate and coordination activities of agencies at both national and state levels. Recognition of the role of non-state actors in the maintenance and protection of 'commons' is critical. This justifies the pluralism and the collaborative governance aspects discussed previously. In addition, pollution of rivers is associated with the lack of technology for water treatment and the behavioural pattern of discharging wastewater directly in freshwater streams. Thus, technology should be part of effective governance mechanisms, and nowhere is it more evident than in the case of water.

The following specific measures could also be useful:

- **Optimisation of water use:** The agriculture sector is the prime cause as well as a sufferer of water-use inefficiencies in India. Unchecked, unmetered water use coupled with energy-subsidies allows overexploitation of surface and groundwater and is often leading to shortages for the domestic and industrial sectors. Experts believe that judicious use of water as per requirement would be good for both the soil and the crop. Across the States, governance reforms have to break the various barriers to overcome this challenge.

- **Data for better coordination and clarity:** Regulatory and governing agencies generally lack adequate and usable information on water resources within the country. Besides, multiple agencies across the centre and state jurisdiction work in silos without appropriate coordination to address a common set of issues. A centralised data repository would be an efficient way to tackle the coordination barrier (Kishore 2017). The Central Ground Water Board (CGWB) has a total of 22,339 observation wells to monitor groundwater, i.e. one well for a 147 square kilometre grid (CGWB 2016). Expansion of monitoring network and continuous monitoring of surface water and groundwater bodies would assist strict implementation of relevant measures.

5. **Waste management** – India generates approximately 62 million tonne of waste on an annual basis, out of which hardly 20 per cent gets treated and around 50 per cent may go to landfills. Major categories of waste include e-waste (15 million tonne), hazardous waste (7.90 million tonne), plastic waste (5.6 million tonne) and biomedical waste (0.17 million tonne) (PIB 2016). Waste management is predominately governed by the Solid Waste Management Rules (2016) along with a range of other rules: Plastic Waste Management Rules (2016); E-waste Management Rules (2016); Bio-medical Waste Management Rules (2016); Construction and Demolition Waste Management Rules (2016); and, Hazardous and Other Wastes (Management and Transboundary Movement) Rules (2016). This demonstrates that we have a very robust set of rules covering almost everything classified as waste, but implementation and regulation are quite challenging. The smallest unit to be governed over here is each individual household, not to mention the commercial and industrial activities. Despite a large network of municipal bodies in the country, segregation of waste and thereupon separate collection, transport, disposal/treatment requires close monitoring and strict regulation, which is a daunting task. Waste management needs to figure much higher in the priorities and fund allocation of the governance hierarchy at all levels. A maintenance and auditing system needs to be in place to keep a check on the challenges mentioned as these aspects are almost entirely ignored by the municipal bodies.

Strict enforcement with appropriate penal provisions is part of the fundamental solution structure to tackle the miseries of waste generation in India. Beyond this, an incentive-based approach to managing waste across the value chain would be useful. Informal workforce plays a very important role in the entire waste management value chain. A governance system that recognises them as valuable stakeholders may prove to be more beneficial. All of this shall be achieved by empowering municipal bodies and SPCBs. At the same time, rapid mechanisation is essential to ensure that human lives are not put at risk through the carrying out of hazardous tasks in sanitation and waste management. This issue is worth noting, being carried forward expeditiously in several ways in the country today. This transformation also carries a profound social message that social, caste discrimination in this kind of labour will now come to a permanent end.

Another measure is to start converting waste into a useful resource. The 'money-in-the-waste' has to be realized through recycling and energy generation processes. India's recent test with plastic derived biodiesel and aviation fuel is a great example of need driven innovation. Similar attempts must be promoted for ever-growing electronic waste (e-waste) in India. E-waste is an excellent source of plastic, base metals and a wide range of exotic minerals which does not get produced in India. Suitable incentives to the recycling industry and pilots to commercial operation at economies of scale are being explored.

6. **Green clearances** – Green clearance procedures (environment and forest clearance) are among the most effective governance instruments adopted by several major economies across the world. The underlying concept remains the same whereas operational aspects may vary in certain countries. In India, the Environment Impact Assessment Notification – 2006 by the Ministry of Environment, Forest and Climate Change

(MoEFCC) requires prior environmental clearance from the concerned authorities before starting any developmental activity. The depth of assessment and approval authority (state, centre, or both) is largely determined by the nature and scale of the proposed activity. Any project activity which necessarily requires a diversion of forest land entails additional clearance procedure from forest authorities. Similarly, additional procedures are applicable in case of the project falling closer to a protected (wildlife) zone or coastal areas.

The governance system for environmental clearance is quite robust and follows global best practices as it involves stakeholder consultation (in the form of public hearing) as well. The entire procedure may take time, depending upon nature of application and severity of the impact. Involvement of forest clearance makes the scrutiny process more cumbersome. A study suggests that the majority of projects face delay at the EIA, public hearing and expert appraisal committee stages. In many cases, non-compliance of 'terms of reference (TOR)' incorrect or insufficient information submission by the project proponents (or their consultants) has remained a major cause of delay (Chaturvedi *et al*. 2014).

Speeding up the environmental approvals have been one of the priority tasks undertaken by the government as a part of the policy to ease business and development in the country since 2014. While the environmental parameters to be scrutinized and protected remains the same, the procedures have been digitized and made time-bound. Single window environmental clearance tracking system known as PARIVESH is to be seen as the latest improvement and evident measure in this direction (PIB 2018). The average time taken for environment clearance has come down to a mere 170 days from 600 days (Dasgupta 2018).

Earlier, a study conducted by the Council on Energy, Environment and Water (CEEW) in 2014 suggested the following measures to improve the governance around green-clearances (Chaturvedi *et al*. 2014):

- Creation of an Environmental Clearance Service Cell within MoEFCC to assist project developers in adhering to the specified guidelines as per the Terms of Reference (ToR), to assist in getting clearances across various departments and ministries, and as a manager of detailed information system aimed at regular monitoring and analysis of projects at the individual level and from a macro perspective.
- Overhauling the public hearing process to a longer-term public participation process that seeks to build public trust, address concerns and institutionalize EIA follow-up process for a smoother conclusion of the public participation process
- Creation of an Environmental Clearance Information System (ECIS) within MoEFCC for regular reporting, analysis and monitoring of projects, both at the level of individual projects and all projects taken together within different categories.

## India and climate governance

The United States and China together account for a disproportionate share of global greenhouse gas emissions and are indeed the titans of global warming. In 2014, the US President Barack Obama and the Chinese President Xi Jinping announced complementary efforts to limit emissions, paving the way for the Paris Agreement. And yet, with President Trump's planned withdrawal from the Paris Accord, and the mutual mistrust between the US and China fueled by trade issues, the climate future is generally seen as being quite uncertain.

The climate policy has acquired a special status even in the domestic arena for India. The formation of the Prime Minister's Council on Climate Change brought together high-level officials to develop a detailed coordinated plan to tackle issues related to climate change in India. The outcome, the National

Action Plan on Climate Change (NAPCC), consisting of eight national missions, provides support to climate policy-oriented governance. The eight national missions focus on the areas of solar energy, energy efficiency, sustainable habitat, water, the Himalayan ecosystem, forestry, agriculture and knowledge for climate change. The missions aim to integrate a broad set of environmental objectives into the appropriate policy areas.

India has nearly 18 per cent of the world's population and yet its share of global GHG emissions is only around 3 per cent. Therefore, per capita, GHG emission in India is around 1/4 of the global average. India's per capita GHG emission in 2014 was 1.8 tonne $CO_2e$ (MoEFCC 2018), which is far lower than that of developed countries. Therefore, labelling India among the largest emitters in absolute terms is clearly mistaken, since this ignores the size of our population. As a matter of fact, India has been at the forefront of promoting sustainable lifestyles.

In terms of global climate governance, India has ratified the Paris Agreement, which aims to limit the increase of global average temperatures to well below 2°C and make efforts to limit it to 1.5°C by reducing greenhouse gas emissions. India has an ambitious goal of achieving 175 GW of renewable energy capacity by 2022. This goal is being achieved by several proactive policies being implemented as a part of India's National Action Plan on Climate Change, which includes the National Solar Mission. Other initiatives include National Offshore Wind Energy Policy 2015, Priority Sector Lending 2015, and the Renewable Energy Certificates (RECs) Scheme. REC scheme mandates power distributors to increase their power procurement from renewable energy sources. To engage the large scale industries with high Specific Energy Consumption (SEC), Perform, Achieve and Trade (PAT) scheme was launched under the National Mission for Enhanced Energy Efficiency. It sets SEC targets for a number of designated consumers. The scheme encourages firms to lower their energy consumption to achieve the Bureau of Energy Efficiency (BEE) specified targets, to earn Energy Savings Certificates (ESCerts) which they can use to trade at a later stage.

India's Nationally Determined Contribution (NDC) includes, among other things, fiscal policies in the climate action domain. For instance, a cess on domestically produced and imported coal has been used towards National Clean Energy and Environment Fund (NCEEF). The other new policy initiatives also aim to strike a balance between the existing trend of economic development and overall environmental welfare. The transparency and MRV protocol required as per the United Nations Framework Convention on Climate Change (UNFCCC) is increasingly getting recognized in some government departments. However, since $CO_2$ needs to be evaluated economy-wide, the reduction of reporting gaps require that the governance gaps in administrative capacity, technical know-how and financial support are expeditiously addressed.

## Conclusion

Environmental governance is increasingly becoming contested and divisive and needs to move forward to cooperative solutions which require promotion of greater dialogue, understanding and patience – a call on all actors. Without such cooperation matters will come to a head and crisis will ensue. It also requires a deep interdisciplinary understanding of science, economics and policy aspects to ensure that environmental regulations are fair and implementable. Such capacity requirements need to be strengthened in public institutions.

Any policy or action of governance that is aimed at social equity, public welfare and sustained economic development, has to be fully supported by the three pillars – the legislature, the executive and the judiciary. These three build necessary checks and balances, not through acrimony but through a systematic process of mutual understanding, cooperation and course-correction, where required. In India, the role of each of these pillars of democracy has to be lauded where environmental governance is concerned, even though much remains to be seen in actual manifestation in the field. Science and technology, print and electronic media, formal and informal educational systems also play their role in policy implementation and delivery.

Governance thus benefits from two-way interaction with all stakeholders, to create the right ambient conditions for life and livelihood of the people and the safeguarding of all living and non-living entities – which is the essence of environmental governance.

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SECTION ONE

# Conserving and managing living natural resources

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# Conserving and managing living natural resources

India has a rich culture and an ever-evolving, vibrant tradition of holding every form of life in high esteem. Indeed, even seemingly unliving aspects of nature, the mountains and the rocks, the forests and the rivers, all are imbued and rather permeated with divine significance. Our myriad gods and goddesses, and other heavenly beings are found at various locations and are believed to take on different forms of life and non-life which makeup nature in her infinite beauty, grandeur and mystery. From life to the very end of individual existence, we have customs which teach us to give back to nature whatever we have taken from it, in one form or the other.

The nations of the world are at different stages of development, but it must be clearly understood by all that the earth belongs as much to the least of our brethren as it does to the most affluent and the powerful. The developed countries of the day attained their position of technical and industrial superiority through their exploitation over centuries of the bounties of the earth – whether these lay within or outside of their lands.

At a time, when the world is losing forests and mangroves, these are slowly but steadily on the ascendancy in India. India's deforestation rate per unit population is lowest in the world. The present government has checked fiscal deficit and is equally determined not to allow any ecological deficit. To accomplish this, India has taken significant measures for forest conservation and enhancement in the last decades. The National Forest Policy, 1988, the harbinger of the green movement in the country, proposed to bring 33 per cent of India's geographical area under forest and tree cover. It also focused on "conserving the natural heritage of the country by preserving the remaining natural forests with their vast variety of flora and fauna, which represent the remarkable biological diversity and genetic resource of the country". Green India Mission (2010) under the National Action Plan on Climate Change took a holistic view on greening that goes beyond tree planting to achieve carbon sequestration targets while undertaking activities for biodiversity enhancement, ecosystem restoration and economic security of local communities. The Mission aims at improving ecosystem services from 10 million hectares of forest/non-forest lands and enhance $CO_2$ sequestration by 50 to 60 million tonne (MT) annually by 2020.

India's Nationally Determined Contributions (NDCs) to United Nations Framework Convention on Climate Change (UNFCCC), 2015, targets to create an additional carbon sink of 2.5 to 3 billion tonne of $CO_2$ equivalent through additional forest and tree cover by 2030. As per India's State of Forest Report, 2017, the total forest and tree cover of the country is 24.39 per cent of the total geographical area and the total carbon stock has been estimated to be 7,083 MT. The area under mangroves has increased. Synergy and linkages among Panchayats (Extension to Scheduled Areas) Act, 1996, the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 and National Forest Policy can further strengthen the management of forests in the country. Massive afforestation efforts are being undertaken to buffer our natural forests from demands on the forest by setting off a forest-based economy to attract more investments in the sector.

India's forests are teeming with wildlife. The population of Tigers, Lions, Elephants, one-horned Rhino has increased. The population of endangered species such as Gangetic Dolphin, Dugongs, Snow Leopard, Vultures and Great Indian Bustard are being revived. This goes on to show that their respective habitats are protected and healthy. It is also important to note that human-wildlife conflicts are increasing, and new frontiers are adding to the challenge, and so are the efforts towards transforming a mundane, drab compensation regime into conservation partnerships based on India's age-old tradition of living in harmony with nature.

Biodiversity is the foundation of life on Earth and is key to survival, health and perpetuation of all life. Biodiversity is a strategic asset and occurs at three levels, genetic, species and ecosystem. Mankind needs healthy biodiversity for its basic needs such as food, fiber, fuel, fodder, medicine and shelter as well as to ensure effective ecosystem services, mitigation of climate change and disaster risk reduction. In this age of plastics, satellites, computers and man's ambition to colonize extraterrestrial species human beings continue to be the guests of green plants on Earth. Man is unable to replicate Photosynthesis – a process of food production by plants. The loss of biodiversity constraints and counteracts economic and sustainable development.

The global fight to stop biodiversity loss is at a critical juncture. The species extinction rate today is several times more than the natural background rate. The continuation of the current human-induced extinction rate may cause the global ecosystem to collapse due to reduced biological complexity. One of the challenges facing biodiversity is our lack of knowledge about Earth's biological wealth. Hence taxonomy as a discipline and the cadre of taxonomists need strengthening.

The wetlands regime in India is diverse, ranging from high altitude glacial lakes of the Himalayas, swamps and marshes of the Terai, floodplains and ox-bow lakes of the Gangetic–Brahmaputra alluvial plains, saline flats of the Great Indian Desert, network of reservoir and tanks of the Deccan and extensive mangrove marshes and coral reef areas straddling the coastline. According to the 2013 National Wetlands Atlas, the country has 15.26 million ha wetlands, equivalent to 4.6 per cent of the geographical area. Wetlands conservation draws strength from India's rich legacy of environmental preservation enshrined in various policies, legislation and regulatory regimes. In 2017, under the Environment (Protection) Act, 1986 the Wetlands (Conservation and Management) Rules, 2017 were notified, providing the national regulatory architecture for these ecosystems. The regulatory framework for wetlands is complemented by laws and regulation on fishery, biodiversity, wildlife, forest and coastal zone.

Multilateral environment conventions including Convention on Biological Diversity and its Nagoya Protocol on Access and Benefit-sharing, Cartagena Protocol on Biosafety and its Nagoya-Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety and other biodiversity-related Conventions and Agreements facilitate global governance on biodiversity-related issues.

Our international and domestic commitments, along with our good governance in biodiversity management is the reason why India speaks from a position of strength in the global arena. India is living and leading by example. The country has surpassed achieving the global Aichi target of 17 per cent of terrestrial area-based conservation. India's development story so far shows that development can be environment-friendly and need not come at the cost of green assets. As our economy grows further, and as pressure on natural ecosystems increases, we need to ensure that our principles of biodiversity conservation are mainstreamed in our development practices. To do so, there is a need to strengthen research and development initiatives using modern biotechnological tools which hold a number of possibilities and untapped prospects.

It is ironic that the very science and technology which warns us of the dangers of environmental degradation should in large part, have been responsible for perpetuating the problem and bringing us to this pass. All modern day comforts and gadgets brought to us as fruits of science and technology are generated through industrial processes which emit pollutants that end up as harmful wastes to which we are yet to come to terms with. The need is to harness the combined strength of science and technology to take the bull of pollution by the horn, tackle biodiversity loss, arrest climate change and regenerate the perpetual sustaining capacity of our lands and waters.

The profligate lifestyles of the human society have been, and indeed, continue to be wasteful of the limited resources of our stressed and ravaged planet. Today, it is becoming increasingly clear to all of us, thinking and conscious, rich, poor, developed, developing and emerging economies that the prime challenge before humanity is to find ways and means to hold on to the earth's dwindling resources and strive towards sustainable development to fulfil the needs of our people for a quality life. It must also be unambiguously understood and clearly remembered that a cocoon of luxury will not shield us from the reverberations of the changing climate, species loss, land degradation, ozone depletion etc. Therefore, the challenge at hand requires striking a balance between the needs of national development and that of planetary conservation.

This section contains nine papers covering contemporary conservations themes like use of remote sensing in forest mapping; the impact of fisheries bycatch on conservation and livelihoods; capacity-building for biosafety; access and benefit sharing of genetic resources; protected area management; wetlands and waterbirds in Central Asian Flyway; invasive alien faunal species in India; invasive alien plants in India and conflict between wildlife and people.

**Guest Editor**

# Remote sensing in forest mapping, monitoring and measurement

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## Abstract
India has a vast forest cover. In this article, we briefly trace the history of India's forests management and explain India's efforts in remote sensing based monitoring of forests and describe recent developments in the applications of satellite remote sensing with relevance to the governance of India's forests.

## Keywords
*Forest, Forest Cover, Remote Sensing, Fire, Biomass, Forest Structure, Canopy Cover, Governance.*

## Introduction
India is committed to action towards combating climate change and adopting a low carbon emission pathway while meeting all the developmental challenges that the country faces today. India's Nationally Determined Contribution (NDC) include a reduction in the emissions intensity of its GDP by 33 to 35 per cent by 2030 from the 2005 level and the creation of an additional carbon sink of 2.5 to 3 billion tonne of $CO_2$ equivalent through additional forest and tree cover by 2030. India has taken a lead role in the implementation of the Convention on Biological Diversity (CBD) through the adoption of the Strategic Plan in its support. India has also adopted the Aichi Biodiversity Targets, for implementing action plans for conservation and sustainable use of biodiversity.

The two international commitments on biodiversity and climate change converge around natural forests and their sustainable management.

Tropical forests are exceptionally carbon dense and highly productive, and thus play a major role in the cycle of terrestrial carbon, being at the same time sinks and sources of atmospheric $CO_2$. Around 3.9 billion hectares of the Earth's land surface (or about 30.6 per cent) is covered by forests (MacDicken *et al.* 2016). Forest canopies are the main gateways regulating the exchange of energy, carbon and water vapour between terrestrial ecosystems and the atmosphere (Seidel *et al.* 2011). It is estimated that around 40 per cent of forest carbon is contained in the aboveground biomass (AGB) of trees. In order to mitigate climate change, strategies and instruments for reducing carbon release in the atmosphere from tropical forests have

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been launched, including the Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Forest Degradation (REDD+), which aim at financially backing tropical countries for avoided deforestation and forest degradation.

Forest and carbon monitoring have been consistently considered as one of the priorities during the previous Conference of Parties (COPs) of the United Nations Framework Convention on Climate Change (UNFCCC), including COP21 that was held in Paris in 2015. Remote sensing tools that have yielded notable advances regarding the monitoring of deforested surfaces are seen as a cornerstone of the MRV systems (Measuring, Reporting and Verification) that is seen as being essential to the success of REDD+. Although tropical deforestation accounts for the largest share of carbon emissions from terrestrial ecosystems, degradation is increasingly emerging as a sizable and important source of carbon emission from tropical forests, especially in the Indian context. Forests are highly diverse and complex; and comprehensive, quantitative characterization is an on-going challenge. Credible, transparent monitoring solutions that comply with leading international standards are needed to fulfil our international commitments under the NDC, for claiming compensatory payments as part of REDD+ mechanisms and as well as to achieve and to perform on our national forest sector priorities

Remote sensing and Geographic Information System (GIS) are complementary technologies that, when combined, enable improved mapping, monitoring and management of forest resources (Franklin 2001). India's vision for space-based remote sensing is to be "second to none in the application of advanced technologies to the real problems of man's society" in the words of the founder of India's space programme, Dr Vikram Sarabhai. Remote sensing has found strong application in the monitoring and inventory of forests in India.

In this paper, we describe India's efforts in remote sensing based monitoring of forests. We have chosen a subset of applications of relevance to the governance of forests.

The government organized a National Meet on "Promoting Space Technology based Tools and Applications in Governance & Development", held on 7 September 2015 in New Delhi. The Workshop (Energy and Environment) session identified projects for the application of geospatial techniques for good governance in the Ministry of Environment, Forest and Climate Change. The Workshop recommended that geospatial techniques should be applied to i) annual automated forest monitoring system ii) forest biomass estimation using Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LiDAR)-based remote sensing iii) assessments of forest fire and agriculture stubble burning. In addition to these applications, the national forest cover mapping of the country was also discussed.

Our discussion begins with a brief account of the history of Indian forestry to the beginning of the satellite age and presenting a brief overview of remote sensing methods alongside describing applications relevant to forest governance.

## A brief history of forestry in India

In pre-colonial India, there was a little or no centralised control over what one extracted from the forest. The sustainable use of forest resources by surrounding dwellers was regulated, sustained and institutionalised by a number of cultural and religious mechanisms. Population density in the late seventeenth century was about 35 persons per square kilometre and the acreage under permanent tillage in Mughal times has been estimated to have been only 27 per cent of the landmass (Sivaramakrishnan 2009). The population was largely small endogamous groups that did not occupy the same location for long periods, and in general, the rural landscape of India, before the advent of the eighteenth century was dominated by mostly second-growth and some old growth forest, and large swaths of savannah. Intensive agriculture was to be found in discrete and discontinuous patches surrounded by these woods and grasslands (Guha 2006).

To the British colonial masters, India was a vast and immeasurable national resource, and till their departure, in the middle of the nineteenth century, there was a sustained invasion on India's forests. The Railways, introduced in 1853, led to immense exploitation of Indian forests and resources for the expansion of the railways, where wood was necessary for sleepers and also as fuel for smelters that made the rails and the locomotives.

Forsyth (1871) provides a fascinating account of forest change in Central India before the formation of the Central Provinces in 1861 and the establishment of forest department for the control and management of forest resources. The study documented a "death blow" to the teak in the northern parts of the Central Highlands following an announcement of the advent of governmental management and conservation. The study documented "all that were worth anything were saved by the forest department in after years. They were not the hundredth part of those that were cut, which should probably be reckoned by millions rather than thousands". Rangarajan (1996) estimated the requirement of 2 mega tonne of wood over two decades of railway expansion (1860–1880). Iron smelting fuelled by charcoal is estimated to have been about 15 mega tonne of wood in the pre-colonial times.

The fate of the forests of Central India was descriptive of the rest of the country and the Forest Department was eventually formed when the British Government became aware that the magnificent forests of India and Burma were being worked by private enterprise in a 'reckless and wasteful manner'. The Indian Forests Act of 1865 and subsequently 1878 came into being. The 1878 Act ensured that the state could demarcate and 'reserve' tracts of forests for its exclusive use. The administration of forests contingent on strategic imperial interests, while continuing to be 'profitable' continued till Independence.

The two World Wars saw India's forests being requisitioned for the imperial cause to meet the huge demand of teak to build ships for the Imperial Navy and timber for bridges, wharves and other uses. The impact of the two World Wars on India's forests was very severe.

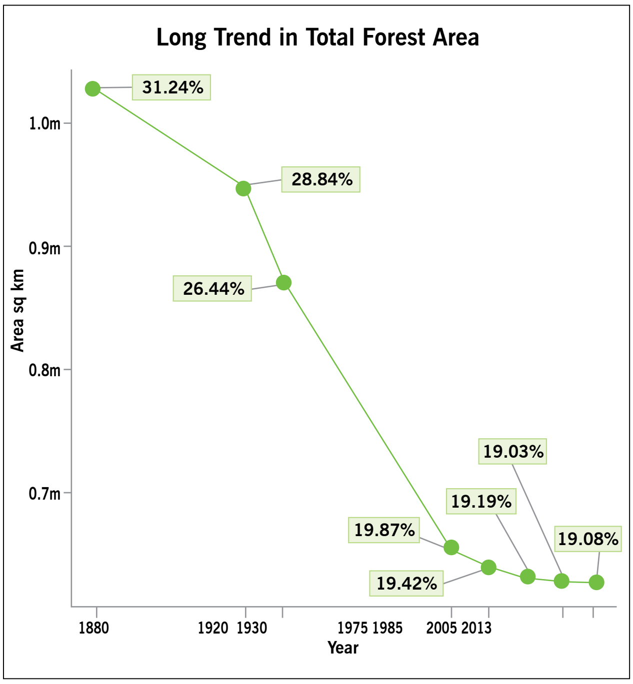
Post-Independence, control over India's forest passed into the hands of a different state: independent India, with the departure of the British and the abolition of the aristocracy (*zamindari*) system in the 1950s. However, forest resource continued to be perceived as integrally tied to the economic development of the state. India's forest resources were seen as an integral element of the country's economic base and the efforts to increase food production in the early decades.

Haeuber (1993) studied the planning and management of forests in the early decades following Independence. In the first five year plan period, increasing agricultural production was a primary thrust of developmental efforts and one of the vehicles of increasing the area under cultivation was through the conversion of culturable wastelands, much of which was either forest or "land covered in miscellaneous trees and groves". Around 2.7 million acres of forest land is estimated to have been converted to plough agriculture in the period. This aggressive expansion continued until the fourth plan period. Culturable wastelands were also cleared for river valley projects, establishing industries and laying roads and 6,81,000 ha were converted from 1951 to 1972. From the fifth five year plan (FYP) Green Revolution strategies modernized Indian agriculture and agricultural extension was discarded as a strategy for increased agricultural production. In the fifth FYP, however, the advice of a USAID study recommending the replacement of a mixed tropical hardwood species with desirable species such as eucalyptus, pine and teak destined for export was adopted and the focus shifted to production forestry with uniform industrial cropping system, created after clear-felling and cutting back of all growth, except of the species chosen for dominance.

It was the passing of the Forest (Conservation) Act of 1980 by India's Parliament that arrested the pace of conversion of forest land to non-forestry use and limited further fragmentation of India's remaining forests. The Act prohibited the change of the legal classification of forest land or of clearing forest land for any purpose other than reforestation without the approval of the Central Government.

Till the early 1980s, few maps of India's forest were produced. Spatial assessments of the extent of forests became possible only with the first national forest cover monitoring carried out for 1972-75 and 1981-83 time periods using LANDSAT Multi-spectral scanner (MSS) data by National Remote Sensing Centre (NRSC), then NRSA. During the British period, forest surveys were undertaken using traditional survey methods as part of forest reservation; these large-scale maps distinguished forests from other land cover and also had details on tenurial arrangements. Prior to the availability of satellite remote sensing imagery, aerial photographs have been used for many decades, and quantitative and qualitative forest characteristics have been mapped using stereo photogrammetry techniques with aerial photographs since the 1940s.

**Figure 1: History of change in India's forest area from 1880**




Reddy *et al.* (2016) carried out a multi-source study on forest cover in India over eight decades. In combination with Richards *et al.* (1994), we can spatially describe the history of change in India's forests for well over a century. Figure 1 shows the long term trend in India's forest area.

## Forest structure

Quantifying and reporting the extent of forest resources is one of the primary objectives of forest resource assessments across geopolitical scales (e.g. local, regional, national and international). In addition to describing the area of forests, it is necessary to describe the composition and the structure of forests. Forest composition refers to the biodiversity of an ecological system, including the variety of genes, species, communities, and ecosystems (Reddy *et al.* 2015; Roy *et al.* 2012).

Forest structure, the architectural arrangement of plant material is considered just as important in characterising a forest as its composition. Ecological research and effective forest management need accurate information on the forest structure to understand the biochemical, physiological and biogeochemical processes within a forest, and to serve as a quantifiable basis to track changes in the forest as a result of natural processes or management actions. Stand density (e.g., stems $ha^{-1}$), basal area ($m^2ha^{-1}$), dominant height (m), and measures of canopy extent/crown cover,

**Forest definitions**

The definition of word 'forest' differs from country to country and region to region based on the vegetation type, composition, altitude, objectives of management and land use among others. Lund (2006) notes that there are over 800 definitions worldwide.

The Forest (Conservation) Act of 1980 does not define 'forest' or 'forest land'. The Hon'ble Supreme Court of India has defined the term 'forest land' as understood in the dictionary sense ('large area of land covered with trees and plants, usually larger than a wood, or the trees and plants themselves'), and also any area recorded as forest in the Government records irrespective of the ownership. While use or tenure are viable ways of defining forest for legal and administrative uses, for the spatial assessments of forests and plantations it is relevant to examine land cover based definitions of the forest.

A commonly used global definition by the United Nations Food and Agriculture Organization (FAO) is 'land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 per cent, or trees able to reach these thresholds in situ' for reporting area under forests under Forest Resources Assessment (FRA). It does not include land area with trees that is predominantly under agricultural or urban land use (FAO 2010).

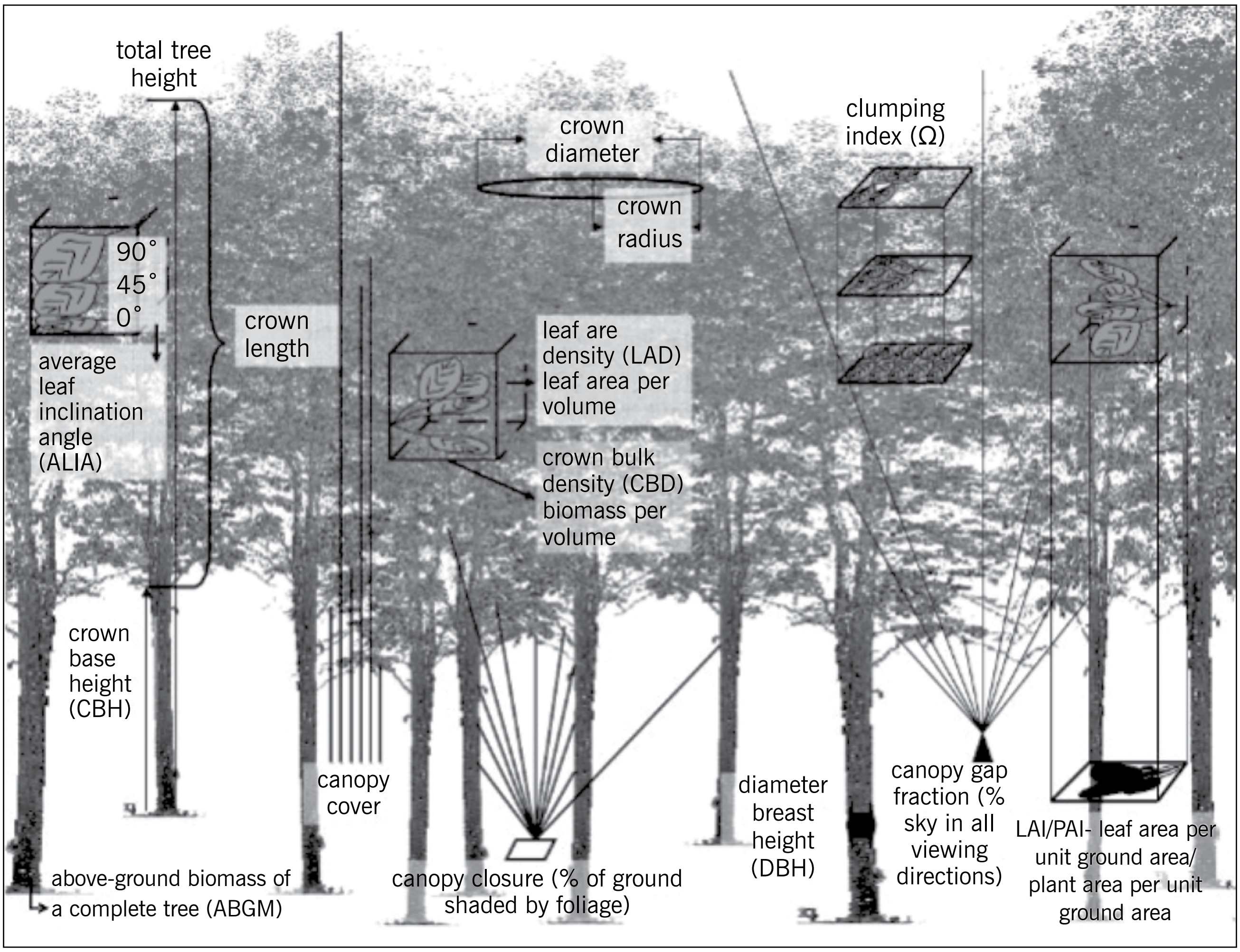
The Forest Survey of India (FSI) defines forest cover as 'all lands more than one hectare in area, with a tree canopy density of more than 10 per cent, irrespective of ownership and legal status' (FSI 2017). There is no distinction between "natural" and planted trees/ tree crops; there is no inclusion of tenurial, land use or legal status. As a consequence, this definition includes bamboos, orchards, coconut and palm trees plantations.

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCCC), which commits its Parties by setting internationally binding emission reduction targets. The Kyoto Protocol was adopted in Kyoto, Japan, in December 1997 and entered into force in February 2005. India is committed to the Kyoto Protocol in the first commitment period (2008–2012) and has ratified the second commitment period (2013-2020). The forest definition under the protocol is as follows

"*Minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30 per cent with trees with the potential to reach a minimum height of 2–5 m at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10–30 per cent or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest*" (IPCC 2001).

The commonalities are in specifying a minimum areal extent, a threshold for canopy cover and a height specification which the vegetation (trees) is expected to have or have the potential to attain.

**Figure 2: Major structural characteristics of the forest canopy (Seidel *et al.* 2011)**




Foliage Projected Cover (FPC, per cent) and Foliage Branch Projected Cover (FBPC, per cent) are structural variables that are often used to characterise forests in support of inventory and mapping programs, management strategies and conservation activities (Fig. 2). A stand is an area of forest or woodland whose structure or composition is different from adjacent areas. Management actions, thinning, harvesting, canopy lifting are typically implemented at the stand level, forest inventory and the assessment of structure is also carried out at the stand level because they can inform on-ground management. Stand structure is commonly defined in terms of two components in the ecological literature—stand structural attributes and stand structural complexity (McElhinny *et al.* 2005). See Table 1.

Forest canopies regulate the exchange of energy, carbon and water vapour between terrestrial ecosystems and the atmosphere. The structure of a forest canopy influences the quantity, quality and spatial and temporal distributions of light in the stand, which in turn affects the presence or absence of ground vegetation and influences temperature, relative humidity, and the physiological activity of tree components and many other organisms within a forest (Seidel *et al.* 2011). Because of the complexity of the 3D forest canopy structure, most canopy measurement research has focused on parameters that may serve as a surrogate for the 2D or 3D canopy structure, such as leaf area index (LAI), average leaf inclination angle (ALIA), aboveground biomass (AGBM), canopy clumping index (Ω) or foliage density.

**Table 1: Attributes used to characterise stand structure (McElhinny *et al.* 2005)**

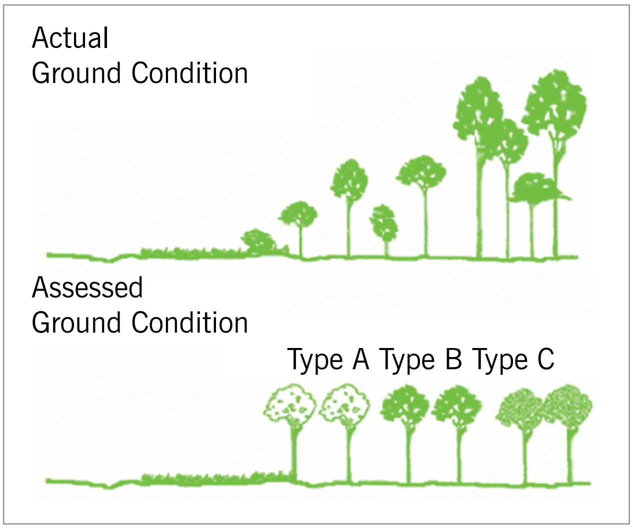
| Stand Element | Attribute |
|---|---|
| Foliage | Foliage height diversity |
| | Foliage density within different strata |
| Canopy Cover | Canopy Cover |
| | Gap size classes |
| | Average gap size and proportion of canopy in gaps |
| | Proportion of tree crowns with broken and dead tops |
| Tree diameter | Tree Diameter at Breast Height (DBH) |
| | Diameter distribution |
| | Number of large trees |
| | Tree size diversity |
| Tree height | Height of overstory |
| | Horizontal variation in height |
| | Median height |
| Tree spacing | Stem density |
| Biomass | Basal area |
| | Volume |
| Composition | Diversity |
| | Richness |
| | Relative abundance |

## Canopy cover

The importance of canopy cover for forest inventory has increased since the FAO established the 10 per cent canopy cover for defining forest lands. Canopy cover is the only structural parameter that is mapped as part of the wall to wall biennial mapping carried out nationally in India and forms the sole basis for a number of management and conservation decisions. We examine this parameter in detail in this section.

Canopy cover refers to the proportion of the forest floor covered by the vertical projection of the tree crowns. This is analogous to the use of the term 'cover' by ecologists to refer to the proportion of the ground area occupied by the above-ground parts of plants. Canopy closure or canopy density is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point.

**Figure 3: Canopy cover on ground and assessed using remote sensing**




Tree height does not affect canopy cover as the vertical projection of the crown alone is assessed (Rikimaru *et al.* 2002). This is shown in Figure 3. Canopy closure will increase beneath progressively taller trees as more and more of the sky hemisphere is obscured.

Canopy cover was historically assessed from aerial photographs to make estimates of the timber volume of a stand. Rapid visual assessments have conventionally been made by using a crown density scale. This consists of a series of standard squares containing black dots that cover from 5 to 95 per cent of the area. The level of cover on this scale that most resembles the canopy cover seen on the aerial photograph is then selected. It should be noted here that the measurement of 'canopy cover' from aerial photographs incorporates angles other than the vertical (Jennings *et al.* 1999). With multispectral imagery, the radial displacement of tree crowns is proportional to the distance from the nadir viewing point causing the partial (or total) obstruction of portions of a tree's crown or nearby

## Remote sensing: An introduction

As noted earlier, the mapping or monitoring of forests prior to the advent of satellite remote sensing was largely based on the in-situ enumeration of forest resources. The process is time-consuming and expensive and has been revolutionised with the advancements in availability and analysis of remotely sensed data used in conjunction with Geographical Information Systems (GIS). These tools can vastly reduce time costs and improve upon precision and accuracy.

Campbell and Wynne (2011) defined remote sensing as "as a means of acquiring information about an object of interest without actually coming into contact with the object". This data is collected using sensors mounted typically on airborne or satellite-borne platforms (newer and more compact sensors are flown on UAVs/drones). In forestry, the objects of interest are usually tree canopies or the gaps between the canopies. Remote sensing systems use either passive or active sensors to acquire data on an object in an area of interest. The most commonly used sensors are passive optical sensors, which sample reflected light in the visible, near and middle-infrared portions of the electromagnetic spectrum. Increasingly there are efforts to apply active sensors like Synthetic Aperture Radar (SAR) which help overcome limitations of cloud cover and topography.

These sensors can be used for a variety of forestry applications, but the basis is general information on the amount of foliage or the biochemical properties of vegetation. Passive systems with capabilities in the thermal region of the spectrum are used to detect active fires. Active systems, for example, include sensors that emit microwave pulses and record the backscatter from targets and are better suited to providing information on woody biomass and forest structure. Another active optical sensor is known as Light Detection and Ranging (LiDAR) which makes use of high energy laser pulses whereby the sensor measures the distance between the sensor and a target on the earth which is recorded as point cloud that replicates the three-dimensional structure of the area surveyed.

Optical remotely sensed data from passive sensors are a result of a complex series of interactions between the electromagnetic radiation emitted by the sun, reflected from the earth's surface and received by a sensor. Multispectral sensors typically sample reflected radiation at discrete positions within the electromagnetic spectrum. The signal from the sensor is converted into digital numbers that is transmitted to a ground receiving station.

The data acquired by remote sensing instruments are characterised by its spatial, spectral, radiometric and temporal resolution (Lillesand *et al.* 2014). Spatial resolution describes the ability to "resolve," or discern fine detail in an image and plays an important role in determining the type and quality of information that can be extracted from an image. The spectral resolution refers to the number and width of discrete wavelength ranges sampled by a sensor. The sensitivity of the sensor to the magnitude of the electromagnetic energy determines its radiometric resolution, the greater the radiometric resolution of a sensor, the higher the ability to differentiate small changes in reflected or emitted energy. The temporal resolution is the frequency with which data can be collected over a given area.

### Scale and grain

There is no single natural scale at which ecological phenomena should be studied; systems generally show characteristic variability on a range of spatial, temporal, and organisational scales. There are several concepts of scale, we list those relevant to our context The cartographic concept of scale is a ratio scale, that relates size of the feature on the map to its "real world" dimension, the areal unit at which data is aggregated or a a problem analysed (taluk, district, state, national etc.) is the analysis scale while the phenomenon scale describe the size and duration of processes (synoptic, meso-scale, global)

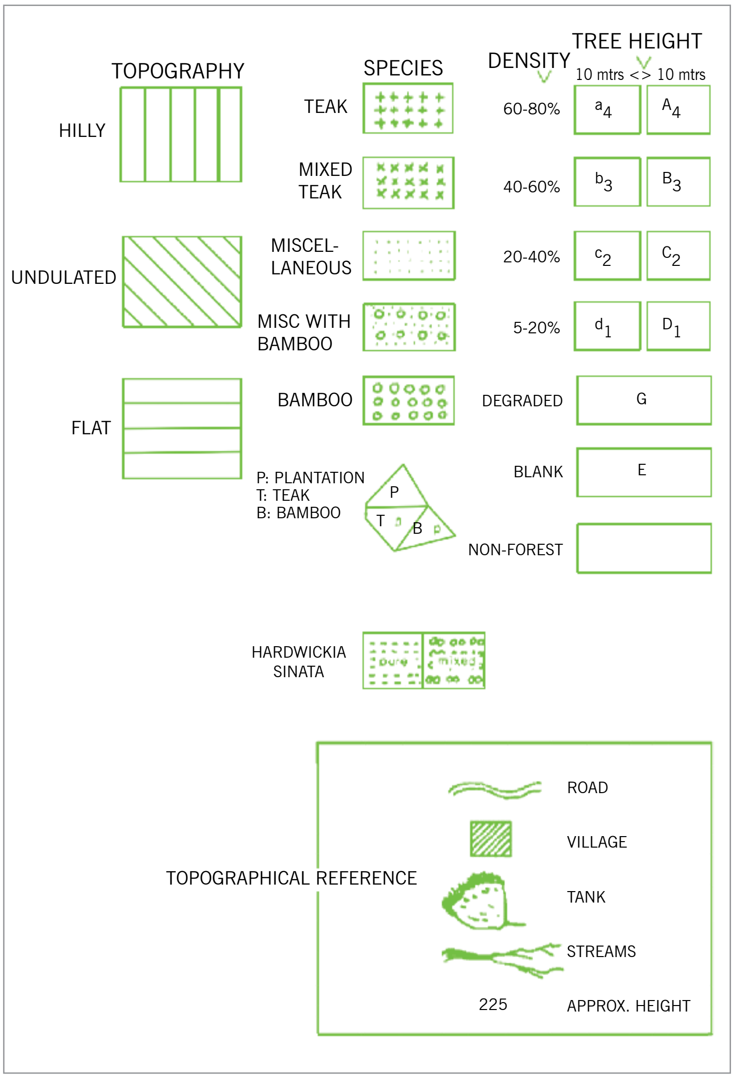
Two scale concepts are very important in the context of remote sensing of forests 'grain' and 'extent'. Grain is the size of the individual units of observation; i.e., the smallest entities that can be distinguished. As mentioned before, the grain size for a forest used in India is 1 hectare (100 × 100 m). Field investigations of tree numbers, biomass have shown that the plot size contributes significantly to the error budget and uncertainty and that for tropical forests a size of at least 1 ha is necessary. In order to study the structural and functional properties of the forest, units smaller than 1 ha is likely to be inappropriate. In many contexts, scale emerge from smaller or larger scale phenomena, which leads to the notion of a 'hierarchy of scales' in which smaller phenomena are nested within larger phenomena, for instance, local economies are nested within regional economies, rivers are nested within larger hydrologic systems. 'Tree Scale' phenomena are however not 'forest scale' phenomena, because of spatial heterogeneity (Li and Reynolds 1995) which is both a product and determinant of ecological processes. Spatial heterogeneity has been shown to be an influence on the pattern and temporal distribution of plants and animals (Brown 2003; Massé and Côté 2012; McCleery *et al.* 2018). Forest canopies vary on spatial scales (from centimeters to kilometers) as well as on temporal scales (from seconds to decades) (Bongers 2001).

It is important to distinguish the grain size for the unit of observation from the spatial resolution of the data used to observe it, which for raster lattice data and satellite data, is the pixel size. For mapping and monitoring forests, a fine-grained map would structure information into 1 ha units, whereas a map with an order of magnitude coarser resolution would have information structured into 10 ha units. It is, however, relevant to use very high-resolution data (< 1m pixel size) to study forest as 1 ha units (Couteron *et al.* 2005; Reddy *et al.* 2017). Extent is the spatial domain over which the system is studied and for which data is available.

canopy gaps. This results in the overestimation of canopy cover. Shadowing from the configuration of the illumination and the viewing angle and terrain conditions exacerbate the bias.

Gatziolis (2012) compared photo-interpretation and LiDAR-based estimates of canopy cover using a large number of ~ 1 ha "plots" covering a wide range of vegetation and topography conditions. The "plots" were established on 1m airborne imagery acquired by National Agriculture Imagery Program (NAIP). A grid of 105 regularly-spaced points was interpreted as belonging either on a tree crown or background objects, and estimates of plot canopy cover were obtained as the ratio of tree points to the total. They concluded that the photo interpretation (PI) approach was both biased and imprecise. Relative to LiDAR-based methods, the PI method suffers from underestimation at low levels of canopy cover low while overestimating canopy at high canopy cover.

**Figure 4: Legend for forest map (from Unni 1983)**




Obliquely acquired LiDAR from Terrestrial Laser Scanners (TLS) have been used to estimate canopy gap fraction, providing results comparable to those from hemispherical photographs (Danson *et al.* 2007; Seidel *et al.* 2012). TLS has the advantage that they also provide additional information about the horizontal and vertical structure of vegetation and holds the promise for highly accurate and precise characterization of the tree and stand structure. However, they are time-consuming and expensive. The data from these methods supplements data from aerial LiDAR. It can replace data from Airborne Laser Scanning (ALS) which is expensive and extremely difficult to acquire in India because of policy restrictions. The equipment has become miniaturized, portable and relatively inexpensive for additional work to improve data collection protocols and methods of analysis and also to generate comparisons with field methods (Fiala *et al.* 2006; Korhonen *et al.* 2011) for inventory (Liang *et al.* 2016) as well as the structure and biophysical parameters.

Historically, aerial photographs visually interpreted by trained interpreters were used to map the structural properties of forests, with the earliest applications dating to the 1920s. Photo-interpretation of small-scale photographs were often used in tropical forest inventory, to delineation of forested land, discern broad forest types, and facilitates the exclusion of areas in which marketable species do not occur to serves for a stratification ahead of ground sampling - thus increasing sampling efficiency - either by reducing the sampling error for an equal sampling intensity or by reducing the sampling intensity required for the same level of sampling error. The units for interpretation were the trees themselves, but aerial photographs have proved much less useful in the tropics than in temperate zones, where information on individual tree and stand heights, a number of trees per unit area, crown characteristics, crown widths and stand volumes per species (Howard and Lanly 1975). The best method for the estimation of tree volumes from aerial photography is to divide the growing stock into more homogeneous strata (with strata being defined by multiple parameters including type, species, management, height etc.). The use of crown coverage was found to be useful in the tropics particularly after the development of stereoscopic interpretation (Nyyssönen

1962). In India, five or more canopy classes (see Figure 5) were recorded (Tewari and Singh 1983; Unni 1983).

With the launch into orbit of the Earth Resources Technology Satellite 1 (the first of the Landsat series of satellites), canopy cover could be mapped from remotely sensed imagery from space platforms. Smedes *et al.* (1970) distinguished three levels of coniferous forest canopy density (40-95 per cent; 15-40 per cent; and 0-15 per cent). Heller (1975) mapped crown closure with ERTS-1 satellite data as a level III parameter and attempted to distinguish healthy pine defined as canopy cover > 50 per cent. Madhavan Unni *et al.* (1985) compared the digital classification of multispectral data obtained from LANDSAT from an airborne multispectral scanner with photo-interpretation techniques. The classes mapped combined topography, species (Figure 4). Canopy density and tree height for use as the first stage for a multistage sampling design for quantitative evaluation of forest resources.

They make a call for the use of enhanced data from future satellites 'to make analysis and interpretation easier, more detailed and accurate' and for developing methods for texture analysis, integrating the multi-temporal data and incorporating topographic information from other sources into the analysis. These methods have since been developed and applied to quantitatively estimate forests in India and globally.

## Remote sensing applications in forestry: Indian context

*Forest Cover mapping in India*

Quantifying and reporting the extent of forest resources is one of the primary objectives of forest resource assessments across geopolitical scales (e.g. local, regional, national and international). The first national forest cover monitoring in India was carried out for 1972-75 and 1981-83 time periods using LANDSAT Multispectral scanner (MSS) data by the National Remote Sensing Centre (NRSC then NRSA). The Government of India established the Forest Survey of India (FSI) which has adopted the technology and carried out forest cover monitoring in India every two years since 1987.

**Table 2: Canopy density classes in the SFR**

| Class | Description |
|---|---|
| Very Dense Forest | Tree canopy density > 70 per cent |
| Moderately Dense Forest | Tree canopy density > 40 per cent |
| Open Forest | Tree canopy density > 10 per cent |
| Scrub | Canopy density < 10 per cent |
| Non-forest | All other land and water |

Since the late eighties, observation capability has been continually enhanced by the India Space Research Organization (ISRO), and there have

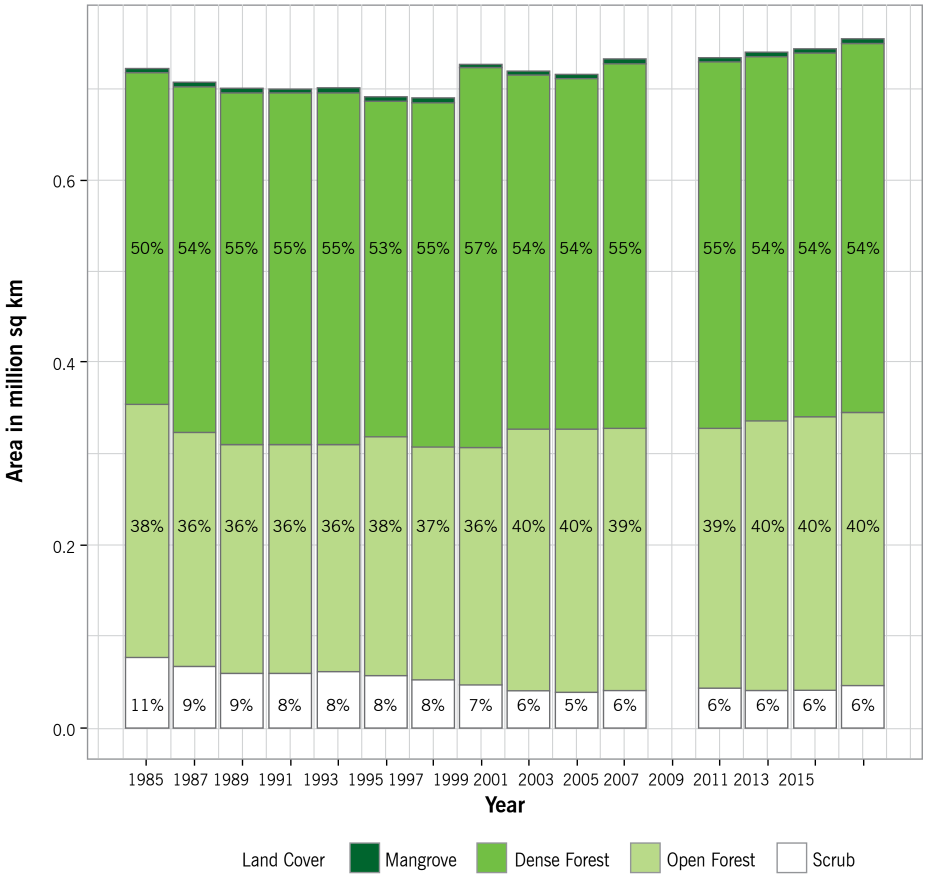
**Table 3: State-wise forest areas (in square km) from recent SFR**

| | Year | 2003 | 2005 | 2007 | 2009 | 2013 | 2015 | (areas in sq. km) | |
|---|---|---|---|---|---|---|---|---|---|
| **S.No.** | **Assessment** | **SFR 2005** | **SFR 2007** | **SFR 2009** | **SFR 2011** | **SFR 2015** | **SFR 2017** | **Change between SFR 2015 and SFR 2017** | **Change as per cent of 2003** |
| 1 | Andhra Pradesh | 44,412 | 45,231 | 46,670 | 46,389 | 24,357 | 28,147 | 4154 | 9.35 |
| 2 | Arunachal Pradesh | 67,692 | 67,472 | 67,484 | 67,410 | 67,321 | 66,964 | -728 | -1.08 |
| 3 | Assam | 27,735 | 27,758 | 27,692 | 27,673 | 27,671 | 28,105 | 370 | 1.33 |
| 4 | Bihar | 5,573 | 6,807 | 6,804 | 6,845 | 7,291 | 7,299 | 1726 | 30.97 |

| | Year | 2003 | 2005 | 2007 | 2009 | 2013 | 2015 | (areas in sq. km) | |
|---|---|---|---|---|---|---|---|---|---|
| **S.No.** | **Assessment** | **SFR 2005** | **SFR 2007** | **SFR 2009** | **SFR 2011** | **SFR 2015** | **SFR 2017** | **Change between SFR 2015 and SFR 2017** | **Change as per cent of 2003** |
| 5 | Chattisgarh | 55,992 | 55,929 | 55,678 | 55,674 | 55,621 | 55,247 | -745 | -1.33 |
| 6 | Delhi | 174 | 177 | 177 | 176 | 180 | 192 | 18.41 | 10.58 |
| 7 | Goa | 2,164 | 2,156 | 2,212 | 2,219 | 2,219 | 2,229 | 65 | 3.00 |
| 8 | Gujarat | 14,814 | 14,604 | 14,620 | 14,619 | 14,653 | 14,757 | -57 | -0.38 |
| 9 | Haryana | 1,576 | 1,604 | 1,594 | 1,608 | 1,586 | 1,588 | 12 | 0.76 |
| 10 | Himachal Pradesh | 14,359 | 14,666 | 14,668 | 14,679 | 14,683 | 15,100 | 741 | 5.16 |
| 11 | Jammu and Kashmir | 21,273 | 22,689 | 22,537 | 22,539 | 22,538 | 23,241 | 1968 | 9.25 |
| 12 | Jharkhand | 22,569 | 22,722 | 22,894 | 22,977 | 23,473 | 23,553 | 984 | 4.36 |
| 13 | Karnataka | 35,246 | 36,200 | 36,190 | 36,194 | 36,132 | 37,550 | 2304 | 6.54 |
| 14 | Kerala | 15,595 | 17,284 | 17,324 | 17,300 | 17,922 | 20,321 | 4726 | 30.30 |
| 15 | Madhya Pradesh | 76,145 | 77,739 | 77,700 | 77,700 | 77,522 | 77,414 | 1269 | 1.67 |
| 16 | Maharashtra | 47,514 | 50,661 | 50,650 | 50,646 | 50,632 | 50,682 | 3168 | 6.67 |
| 17 | Manipur | 17,259 | 16,952 | 17,280 | 17,090 | 16,990 | 17,346 | 87 | 0.50 |
| 18 | Meghalaya | 16,925 | 17,205 | 17,321 | 17,275 | 17,288 | 17,146 | 221 | 1.31 |
| 19 | Mizoram | 18,583 | 18,600 | 19,183 | 19,117 | 19,054 | 18,186 | -397 | -2.14 |
| 20 | Nagaland | 14,015 | 13,665 | 13,464 | 13,318 | 13,044 | 12,489 | -1526 | -10.89 |
| 21 | Odisha | 48,353 | 48,755 | 48,855 | 48,903 | 50,347 | 51,345 | 2992 | 6.19 |
| 22 | Punjab | 1,545 | 1,660 | 1,664 | 1,764 | 1,772 | 1,837 | 292 | 18.90 |
| 23 | Rajasthan | 15,821 | 16,012 | 16,036 | 16,087 | 16,086 | 16,572 | 751 | 4.75 |
| 24 | Sikkim | 3,262 | 3,357 | 3,359 | 3,359 | 3,358 | 3,344 | 82 | 2.51 |
| 25 | Tamil Nadu | 23,003 | 23,314 | 23,551 | 23,625 | 23,844 | 26,281 | 3278 | 14.25 |
| 26 | Telangana | | | | | 21,759 | 20,419 | * | * |
| 27 | Tripura | 8,123 | 8,173 | 7,985 | 7,977 | 7,866 | 7,726 | -397 | -4.89 |
| 28 | Uttar Pradesh | 14,127 | 14,346 | 14,341 | 14,338 | 14,349 | 14,679 | 552 | 3.91 |
| 29 | Uttarakhand | 24,460 | 24,493 | 24,495 | 24,496 | 24,508 | 24,295 | -165 | -0.67 |
| 30 | West Bengal | 12,389 | 12,970 | 12,994 | 12,995 | 16,805 | 16,847 | 4458 | 35.98 |
| 31 | Andaman and Nicobar | 6,807 | 6,663 | 6,662 | 6,724 | 6,711 | 6,742 | -65 | -0.95 |
| 32 | Chandigarh | 15 | 17 | 17 | 17 | 17 | 22 | 6.56 | 43.73 |
| 33 | Dadra and Nagar Haveli | 221 | 216 | 211 | 211 | 213 | 207 | -14 | -6.33 |
| 34 | Daman and Diu | 8 | 6 | 6 | 6 | 9 | 20 | 12.49 | 156.13 |
| 35 | Lakshadweep | 25 | 26 | 26 | 27 | 27 | 27 | 2.1 | 8.40 |
| 36 | Puducherry | 42 | 42 | 50 | 50 | 50 | 54 | 11.67 | 27.79 |
| | | 6,77,816 | 6,90,171 | 6,92,394 | 6,92,027 | 6,97,898 | 7,07,973 | 30,157 | 4.45 |

* included as part of united Andhra Pradesh for comparison with 2003

**Figure 5: Proportions of cover classes over three decades of SFR**




been parallel improvements in forest monitoring with respect to the scale of mapping and parameters monitored. Since 1999, IRS – LISS III data is being used for the biennial assessments carried out by the Forest Survey of India (FSI). Presently the assessment brings out changes in four levels of forest crown density (Table 2), forest to non-forest and non-forest to forest conversions. The results are published as the State of the Forest Report (SFR), with the most recent being released in 2017 (fifteenth in the series).

The minimum mappable unit (MMU) in the assessment is 1 ha. FSI uses a hybrid classification methodology for the national forest cover reporting.

The SFR 2017 details the preparation of an error matrix, 4,152 points were selected randomly and high resolution merged satellite data was used to assess the density class for a buffer of 1 ha around the selected point (FSI 2017). SFR 2017 makes a mention that the field inventory data was also used in the accuracy assessment. User accuracy for the forest/non-forest classification is reported at 97.5 per cent and 87.9 per cent respectively, and user's accuracy for the density class is also very high ranging from 88.66 per cent (for scrub) to 92.04 per cent (for open forests). Results of the recent State of the Forest Reports (SFRs) are summarized in Table 3.

## Trends in forest cover mapping in India

The satellite-based monitoring of India's forest cover shows an increase of 4.45 per cent in just over a decade. At the state level, the largest changes

[1] $r = \frac{1}{(t_2 - t_1)} \text{In} \frac{a_2}{a_1}$ where a2 and a1 are forest areas at time t1 and t2 respectively (Puyravaud 2003)

area are seen in West Bengal and Bihar (>30 per cent of the area under forest cover in 2003), while 3 states show a gain of nearly 10 per cent or higher. The northeastern state of Arunachal Pradesh is the only state showing a loss in cover greater than 10 per cent. In general, the North Eastern states show low to negative gains in forest cover.

The total forest area has been steadily increasing over the years. In 1985 the total forest area was 6,42,041 sq km which has increased to 7,07,873 sq km in SFR 2017. Over the three decades, the annual rate[1] of increase in forests was 0.33 per cent. The increase in the area follows a similar trend for both dense (annual rate of increase 0.37 per cent) and open forests (0.26 per cent). The relative areas of scrub (annual rate of decrease 1.71 per cent) to forest area showed a steady decrease till SFR 2003 and then remains steady with a small increase in SFR 2017.

The area under forest and scrub classes and their proportions over the entire series of the SFR is shown in the figure above. For the purpose of consistency over the entire period of reporting from SFR 1987, the dense and very dense forest categories have been combined as dense forests. SFR 2001 (reported for the year 1999) changed the method and scale of forest monitoring, and this shows up in the graph as an increase in area over the previous SFRs. This reporting period also has the highest proportion of area recorded in the dense forest categories. For over a decade the proportions under the various forest classes and scrub have remained fairly stable and constant while the total forest area has increased.

Even while the wall to wall mapping of India's forest shows no reduction in forest cover for over a decade (SFR 2005 – SFR 2017), several authors (Gilbert 2012; Puyravaud *et al.* 2010; Ravindranath *et al.* 2012) have cautioned that India's native forest are declining, and that the increase in forest area is probably through plantations and have called for enhanced forest mapping techniques that can distinguish plantations and orchards from forests. Hansen *et al.* (2013) used satellite data (30 m spatial resolution) to map global forest loss (2.3 million square kilometers) and gain (0.8 million square kilometers) for the period from 2000 to 2012. The tropics were the only climate domain to exhibit a trend, with forest loss increasing by 2101 sq km per year. Their study shows that India has a net tree loss for the period and notes that India reports significant forest gains that are not readily observable in their time-series satellite imagery. However, their definitions of forests and methods of mapping tree cover are significantly different from the methods employed by FSI.

Ravindranath *et al.* (2012) mention that it may be possible to use forest tree canopy density as an indicator of forest status and that a change in the mapped category from a higher crown class to lower crown class, could be treated as forest degradation. While canopy cover can also be used to predict stand volume as there is a nearly linear relationship between the area occupied by its crown and the basal area of its trunk for growing trees, it does not hold as trees reach biological maturity. In natural forest and mixed species stands the relationship between canopy cover and biomass is poor (Jennings *et al.* 1999).

## Discussion on canopy cover mapping

Forests canopies are dynamic, continuously varying, three-dimensional structures that display substantial heterogeneity in their spatial arrangement at many scales. Spectral datasets are relatively insensitive to the three-dimensional structure of forest vegetation. It is necessary to have coincident field measurements (Falkowski *et al.* 2005), and carefully quantify the relationship between the remotely sensed data and three-dimensional forest structure must be quantified and understood; this is particularly true for large area studies or national mapping efforts. Alexander *et al.* (2013) applied data from airborne LiDAR scanners (ALS) to the estimation of canopy cover and canopy closure in small 5-m radius plots and showed that ALS-based canopy closure is a reasonable indicator of understory light availability. Smith *et al.* (2009) make a compelling case for the use of LiDAR in the development of landscape-scale estimates of forest canopy cover. They show that 22 per cent in their comparison of LiDAR and multispectral derived canopy cover is due to sensor limitations, plots that are shrub-dominated, or have canopy gaps and larger openings (Hopkinson and Chasmer 2009). Their results show that even in the absence of trees, spectral-based estimates continue to report canopy cover as the sensor spectral bands used are sensitive to the presence of herbaceous vegetation, shrubs, seedlings, saplings, and other sub-canopy vegetation. Rikimaru *et al.* (2002) also observed that spectral data capture information on the total biomass regardless of the density of the trees or forest.

Frequently satellite datasets with high spatial resolution (1–4 m pixel size) are employed to calibrate or validate estimates of canopy cover from coarser resolution multispectral satellite data. While the estimation of structural parameters of tropical forest from remote sensing observation remains a challenge, texture based methods such Fourier-based textural ordination (FOTO) Couteron *et al.* (2005; 2007; 2012; 2013) with very high spatial resolution data and Fractional Cover Analysis are very promising. The FOTO method ordinates digital images along coarseness-fineness texture gradients in a way congruent with the visual appraisal. Such methods are not successful with the retrieval of forest structure with spatial resolutions coarser than 2.5m, with the coarser resolutions having pronounced bias in estimation over higher resolution datasets (Reddy *et al.* 2017). These efforts suggest that quantitative methods applied to very high spatial resolution data sets along with conjunctive field studies are probably of relevance in developing large, reliable training sets required for the application of data mining techniques to the estimation of canopy cover from multispectral satellite data. Karlson *et al.* (2015) showed that the simultaneous use of spectral, texture, and phenology variables were necessary for the spatial estimation of canopy cover with low error rates. Airborne small-footprint LiDAR (light detection and ranging) sensors can provide canopy cover estimates that are comparable to the most accurate field-based estimates (Korhonen *et al.* 2011). The uncertainty of LiDAR estimated canopy cover is about 10 per cent RMSE (Arumäe and Lang 2018; Moeser *et al.* 2014), this leads to a 15 per cent error when these estimates are used for volume estimations.

It is also important to underscore the point that low canopy density or open forests are not "less important" in an ecological context. For instance, studies have shown that the spatial variation of the woody cover appears to be important in maintaining the diversity and functionality of relatively open forests and savannahs. Climate controls on vegetation also limit canopy density. For instance, in the northwest arid parts of India, we can only have low canopy density forests due to dry climatic regimes. McCleery *et al.* (2018) results emphasize that heterogeneity at relatively broad scales supports higher biodiversity relative to more homogenized areas. Carefully designed studies that go beyond the local/plot scale to understand how animal communities across taxonomic groups change across a gradient of tree cover at different spatial scales are needed to clearly understand the importance of open forests and scrubs to wildlife conservation. Mathai (1999) found that the highest abundance of all the ungulate prey species of the tiger in his study at Panna National Parks was in habitats that provide

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[2] An additional advantage of aerial LiDAR is that it is relatively insensitive to the phenological stage, of the trees as the pulse footprint is typically about 30 – 50 cm because of divergence from typical flying heights which interact with both leaves and fine stems (Arumäe and Lang 2018).

an ecotone of grassland and woodland and that the only successful cubbing of a tiger at the time of his study was in these relatively open habitats. Canopy density is not a good predictor of the number of trees on the ground (Dörgeloh 1998) in open systems or forests with multiple strata.

The national monitoring of forest cover is an important activity in mapping and monitoring India's forest cover. It is important however that a multisensor – multi-phase data approach combining three-dimensional data from UAV and aerial LiDAR[2] along with data from conjunctive field studies and multi-temporal multispectral data sets are needed for effective monitoring. Ahmed *et al.* (2015) showed that LiDAR offers an accurate and consistent means for obtaining reliable canopy structure measurements and that transects of LiDAR data could be integrated with frequently acquired and spatially comprehensive optical remotely sensed data. Their study used a machine learning technique (RF), to estimate LiDAR measured canopy structure using a time series of Landsat imagery in coastal temperate forests. Korhonen *et al.* (2015) fused information from optical satellite imagery, LiDAR data strips and data from field plots to achieve an accurate direct estimation of the forest canopy cover(CC) and they found a strong correlation between LiDAR-based CC and spectral satellite features (ALOS AVNIR-2). They recommend that as it is important to obtain sufficient training data covering the entire range of canopy cover, the forest area estimation should be done before the CC estimation, rather than vice versa. Matasci *et al.* (2018) used Landsat and LiDAR data to map forest structural attributes (including canopy cover) across Canada's boreal forest representing 2010 conditions. They used Landsat surface reflectance pixel composites and their associated spectral and change-related features with a NN imputation approach that uses RF as a base method. They developed reliable estimates of the average aboveground biomass and gross stem volume at a 30-m spatial resolution.

Forest canopy cover is a continuous variable, and it would be more appropriate to predict forest canopy density in a continuous variable, rather than categories, which allows assessing the performance of predictions in terms of random and systematic error components (Joshi *et al.* 2006). More detailed classes would facilitate additional structural inferences on structural parameters across the range of forest types, topography and disturbance regimes encountered in India. New approaches that combine cloud computing and deep learning techniques are likely to be very useful to have automated approaches and reduce the time and effort in the preparation of spatial estimates of canopy cover at a national scale on an annual basis.

It is also clear that a distinction between forests, plantations and orchards is vital for the protection and conservation of natural forest systems. It is also extremely relevant to point out the need for parameters in addition to canopy cover, and the use of ecologically relevant indices and parameters to evaluate the "value" of open forests and scrubland for the management and governance of forests on sound ecological and wildlife principles and to relate canopy cover to other useful and necessary forest attributes (tree density, basal area, girth class distribution etc).

We conclude that while meeting the purpose of a national monitoring of forests, the adoption of better methods for field data collection, additional remote sensing data sources, particularly point clouds from terrestrial, UAV and aerial platforms and newer methods of data processing and analysis are necessary for the spatial mapping of forest canopy cover at the national level. This would ideally be combined with RS and field efforts to gather data on a large set of parameters to produce spatial descriptions of the state of the forest that are relevant and useful for governance, management and conservation and preservation measures that are strongly rooted in accurate and precise data.

**Table 4: Forest and carbon statistics 1880 – 1980 (Richards *et al.* 1994)**

| Detail | 1880 | 1920 | 1950 | 1970 | 1980 |
|---|---|---|---|---|---|
| Forest Total (sq km) | 10,26,820 | 9,47,930 | 8,25,380 | 7,43,050 | 6,45,920 |
| Per cent of TGA | 32.12 | 29.65 | 25.82 | 23.24 | 20.20 |
| Scrub Total (sq km) | 9,98,570 | 10,14,240 | 9,59,320 | 8,45,580 | 9,08,770 |
| Per cent of TGA | 31.23 | 31.72 | 30.01 | 26.45 | 28.43 |
| Total C in Forest Cover | 7,940 | 6,766 | 5,473 | 4,316 | 3,426 |
| Total C in Scrub Cover (Million tonne) | 372 | 360 | 281 | 191 | 203 |
| (TGA 319703 sq km) | | | | | |

Geospatial layers on multiple forest attributes produced through data from the improved spatial and spectral resolution satellites (both current and planned) can provide spatially consistent, transparent and accurate data for forest inventory and monitoring efforts.

## Forest carbon and biomass

Forests contain about 80 per cent of global terrestrial above-ground carbon stocks in their vegetation and soils, and also exchange large quantities of carbon with the atmosphere through photosynthesis and respiration playing an important role in the global carbon (C) cycle. Estimations of forest biomass and its change are important for assessing historical and present anthropogenic C releases from forests and also in evaluating the possibilities of future potential C sequestration. Forested areas can behave as a source of atmospheric carbon when they get disturbed by human or natural causes and an atmospheric carbon sink during the re-growth after disturbance, and hence they can be managed to alter the magnitude and direction of their C fluxes.

A discussion of the methods and uncertainty of forest carbon in India is provided by Jha *et al.* 2017. Briefly, national level forest inventories provide the most extensive and accurate field observations of forest biomass. Several methods exist to estimate spatial biomass from using different remotely sensed data. The gold standard of biomass measurement is the highly labour intensive, destructive technique of harvesting trees and weighing the various fractions, after oven drying all the material. This approach is used to construct allometric equations which relate tree biomass to easily measurable parameters (e.g., Girth at Breast Height (GBH) and Tree height). Biomass is usually estimated over plots by using allometry or destructive methods to get the biomass density. These measurements are regionalized using remote sensing data based parametric, non-parametric or data mining methods.

Richards *et al.* (1994) had reported forest cover and carbon estimates for 1980, at the state level using historical data on forest area and relating it to a population-based biomass degradation model. Their approach estimated that forest and woodland/scrub-covered nearly a third of the country in the late $19^{th}$ century and that the carbon content reduced by 56 per cent in that period (Table 4).

## National spatial biomass estimation

To describe and understand the terrestrial carbon cycle over India, a comprehensive study through "National Carbon Project" (NCP) has been taken up under the ISRO – Geosphere-Biosphere Programme (IGBP). The major goals of NCP are:

- Assessment of Carbon Pools, Fluxes and Net Carbon balance for terrestrial biomes in India;
- To establish an observational network and

create remote sensing-based spatial databases for modelling and periodic assessment of net carbon balance in India.

A part of the Vegetation Carbon Pools Project (VCP) is a component activity of the NCP initiated in 2007. As part of the project, an optimal phytomass density observation, modeling and mapping approach for national-scale forest carbon pool assessment was developed. The field sites were inventoried with a well-defined sampling protocol and marked as permanent sample plots for further monitoring. Four subplots were inventoried at each field site to facilitate area weighted phytomass estimation and multi-resolution remote sensing based regional estimates. This data was analysed to assess the change in biomass over India from 1990 to 2010.

The growing stock information for 1994 was computed from a national field inventory carried out by FSI (FSI 1995). Field inventory data collected in 2009–10 as part of a national forest inventory carried out for the ISRO-GBP National Carbon Project (Dadhwal *et al.* 2009) were used for the 2010 period. The inventory used a design-based approach to select sample sites of 250 × 250 m on the basis of spatial data (based on forest types, forest canopy density and NDVI obtained through satellite data). A total of 6028 plot of 0.1 ha size was used for analysis for the 2010 time period. Forest C density was estimated at a 5 km grid cell level, by using a stratify-and-multiply approach (Goetz *et al.* 2009). India's forest cover increased by 5.74 Mha during the 16 years of study period. Despite increasing populations and large dependence of rural communities on forest resources for their various needs, India has successfully managed to increase its forest cover over past two decades through various conservation and afforestation efforts by the government. India's forest cover grew at 0.22 per cent per year over 1990–2000, and at the rate of 0.46 per cent per year over 2000–2010. Mean forest carbon density has increased from 61.14 Mg $ha^{-1}$ in 1994 to 64.08 Mg $ha^{-1}$ in 2010. National forest C estimated for 1994 and 2010 as 3911.78 and 4368.03 TgC, shows a net increase of 456.26 TgC in 16 years. Growing populations increases the biomass demand and pressure on Indian forest but, the conversion of forest lands for other uses has declined since 1980. This is mainly due to the effective implementation of measures to control deforestation of natural forests.

## LiDAR-based biomass estimation

Vegetation biomass is commonly defined as the amount of organic matter in living and dead plant materials expressed as dry weight per unit area (S. Brown 1997). Forest biomass is a key biophysical property that describes the carbon content of the forest.

The most accurate way of estimating biomass is using extensive field measurements, especially using destructive sampling (Gibbs *et al.* 2007; UNFCCC 2009). However, field measurements are typical, expensive and time-consuming. The destructive sampling approach – which is not always practical and can sometimes not be applied due to various environmental regulations. To overcome these limitations, foresters and ecologists have developed indirect methods for estimating biomass density, typically using empirically developed allometric equations derived from destructive samples that allow the estimation of tree biomass density from more readily measured proxies, such as diameter at breast height (DBH) and height (Whittaker and Woodwell 1968). Small-scale field measurements are then up-scaled to Aboveground Biomass (AGB) estimations over a larger area using remotely sensed datasets (Couteron *et al.* 2012; Lu 2006).

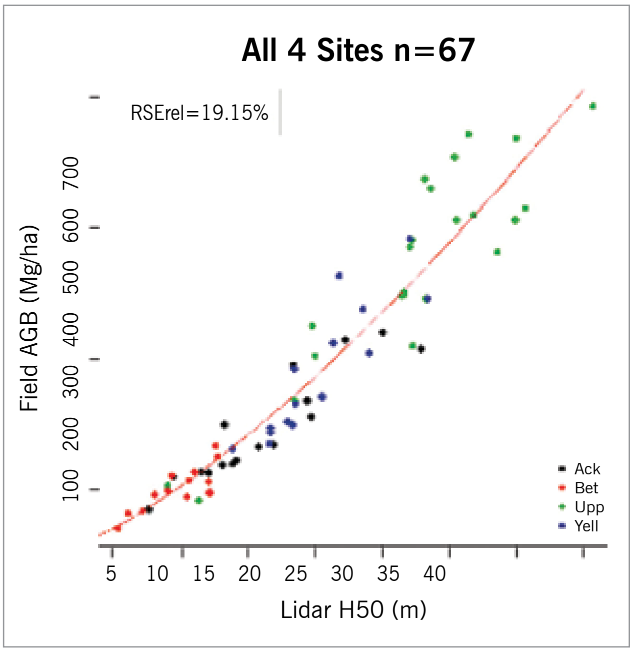
Remotely sensed data (multispectral and panchromatic optical, microwave) have a long

[3] Stereo optical data or interferometry using microwave data are exceptions

history of application in the characterization as well as in the quantitative and qualitative descriptions of forests. A number of approaches have been developed to map carbon stocks and AGB from satellite remote sensing observations (Goetz *et al.* 2009). Satellite optical sensors such as from IRS, LandSat and SPOT with varied spatial, spectral and radiometric resolutions have been used for biomass estimation, typically establishing per-pixel relationships between field-measured biomass and variables derived from remote sensing data (e.g. reflectance, vegetation indexes, Leaf area Index, vegetation cover). Several studies have used information derived from the pixel neighbourhood (texture) to develop relations with biomass. These studies showed that spectral responses of vegetation were useful in biomass estimation where forest structure was simple while texture based methods had a greater relevance with an increase in forest complexity (Couteron *et al.* 2005; Pierre Ploton *et al.* 2012).

However, the main challenge for optical and radar data is the insensitivity or saturation of remotely sensed signals at moderate to high biomass levels (Waring *et al.* 1995). Biomass estimation using optical satellite data is limited to forests with relatively low biomass because of sensor saturation beyond canopy closure (at about 150 $tha^{-1}$). These methods are strongly influenced by vegetation phenology and external factors such as the atmosphere, topography and acquisition parameters. In the microwave spectrum, signal attenuation from the forest canopy, as the canopy becomes denser, causes backscatter to correlate negatively with forest biomass after reaching a maximum value (Mermoz *et al.* 2015). Further, to monitor biomass change due to deforestation and degradation, optical or microwave data are not sufficient since the difference in reflectivity together with natural variations between forest and degenerated forest is often not significant (DeFries *et al.* 2002). Image-based techniques, from optical or microwave sensors, can usually[3] describe

**Figure 6: Pan Indian height based allometry for tropical forest**




only the horizontal distribution of biomass and not its vertical components, a complex issue in multi-layered forests. The emergence of LiDAR in the late 1990s has provided new insights in quantifying vegetation distribution in both vertical and horizontal directions and aided in estimating several biophysical parameters from the individual tree level to landscape scale (Coops *et al.* 2007; Lefsky *et al.* 2007). LiDAR remote sensing is very valuable for the retrieval of forest structure as it can directly measure canopy structure. The retrieval of forests stand structure parameters over tropical forests from remotely sensed data is of primary importance for estimating global carbon stocks in above-ground biomass (Grace 2004).

The potential of LiDAR for vegetation biomass retrieval was demonstrated nearly three decades ago using airborne profiling LiDAR systems (Nelson *et al.* 1988). In the recent past, several studies have proven that LiDAR remote sensing provides high accuracy in characterizing vegetation structures such as height (Chen 2010; Dubayah *et al.* 2010) crown size (Riaño *et al.* 2003), basal area (Means *et al.* 2000; Næsset 2002) all of which are strongly related to AGB. It has also been proven to be very useful in the estimation of forest biomass as it does not saturate even at very high biomass levels -1300 Mg/ha (Means *et al.* 1999).

During the last decade usage of LiDAR for biomass estimations grew rapidly across the globe, mainly due to the increasing availability of data, advancements in sensors and research leading towards new methodological developments integrating geometric and physical-based LiDAR features to better exploit the wealth of information for different applications in forestry (Fleming *et al.* 2015; Koch 2010).

As part of the ISRO effort to establish reference biomass sites in the country to reduce uncertainty in the estimation of terrestrial above ground forest biomass. Five sites in different Indian forest ecoregions were selected for developing biomass estimates using aerial LiDAR and large permanent plots. The sites include Uppangala (Karnataka, Evergreen), Yellapur (Karnataka, Evergreen/ Deciduous), Betul (Madhya Pradesh, Central Indian Teak), Achanakmar (Chattisgarh, Sal forest) and Sundarbans (West Bengal, mangroves). The study used biomass measured from large 1 ha tree mapped plots and successfully established a relationship that can be used to spatially estimate biomass in India's tropical forests using a power law relationship with a single parameter viz median canopy height derived from a LiDAR CHM. The relationship is strong across the entire range of biomass encountered in the country (figure 6).

Information from LiDAR has been combined with other remote sensing sources and data from National Forest Inventories in many countries (Fernández-Landa *et al.* 2018). The existing dataset, such as nationwide lidar flights, IRS multi- and high-resolution imagery, and permanent field plots, as well as NFI, could be combined to drastically reduce inventory time and costs. An added advantage of these methods is spatially explicit predictions.

The Global Ecosystem Dynamics Investigation (GEDI) is designed to produce high-resolution full waveform LiDAR observation of the 3D structure of forests globally. Data from GEDI will enable the high-resolution characterization of vertical canopy structure and vastly improve existing capability and understanding of carbon and water cycling processes, biodiversity, and habitat. The GEDI instrument has three lasers that produce eight parallel tracks of observations. Each laser will illuminate a 25 m footprint. Footprint is to be separated by 60 m along the track and an across-track distance of about 600 m between each of the eight tracks. GEDI is expected to be operational over a nominal 24-month mission length following the launch in 2019. Interferometry from the ISRO – NASA joint NISAR mission is designed to map biomass and biomass change globally. Both missions are designed with open data policies. It is important to develop the processing ability and the reference field sites to develop models to study forest height, biomass and the horizontal-vertical structure of vegetation from these data sets. The data sets are expected to produce a quantum leap in our understanding of forests and in effective monitoring and management.

## Forest loss

In an earlier section, we presented the national wall to wall mapping effort carried out by FSI, which use a hybrid methodology to report changes in forest cover biennially. NRSC has developed methods for the automated identification of the loss of forest cover at annual time scales using multi-spectral, multi-temporal satellite data. In this section, we briefly present observations on the conversion of forest to non-forested land using the automated approach with IRS AWIFS satellite data.

The area under forests in India is relatively stable over the past three decades. The changes that do occur are fine scale and small. The majority of these changes are gradual and develop over a period of several months. Much of India's forests

**Figure 7: Integrated Forest Z score of a pixel exhibiting change over 2005-2012**

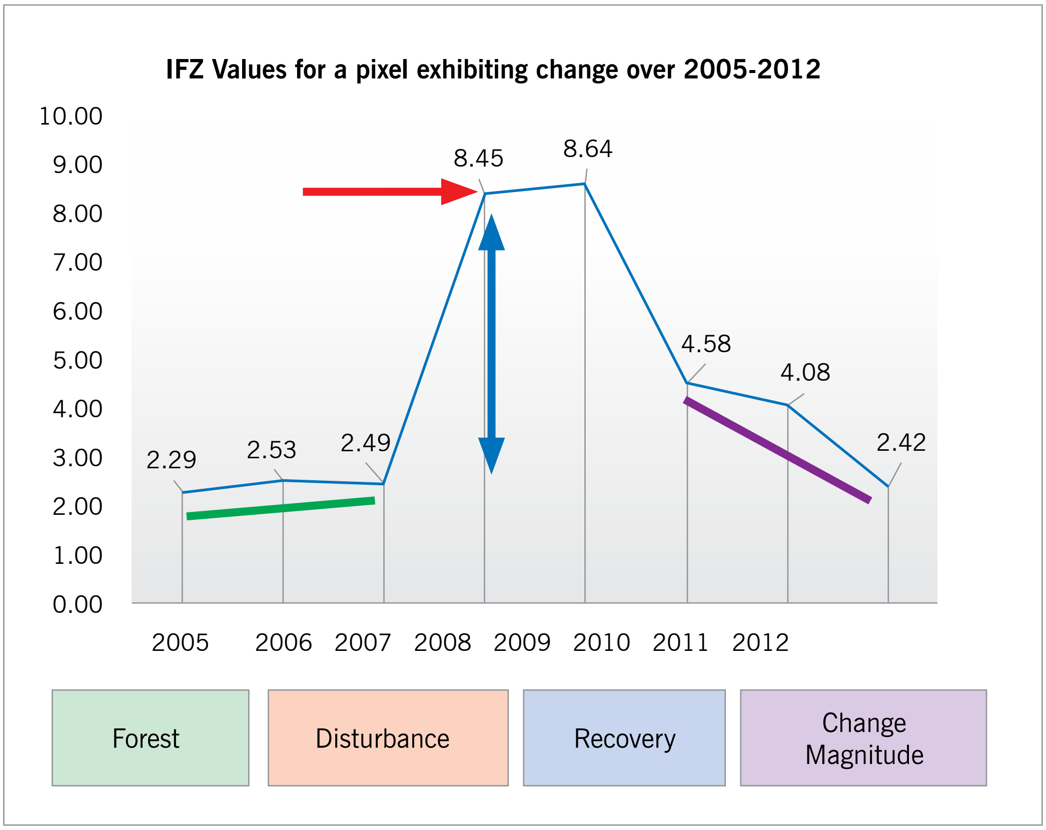



exhibit dramatic phenological variations across seasons. From a remote sensing perspective, there are additional "transient changes" from factors such as cloud cover, missing data, or ground fires among others. Distinguishing "true" change from seasonal, phenological and transient changes is a challenge to the remote sensing based detection of a change.

## Advanced Wide-Field Sensor (AWiFS)

The Advanced Wide-Field Sensor (AWiFS) is a medium resolution multispectral sensor with a relatively high temporal resolution. The sensor is carried by ResourceSat-1 (launched on October 17, 2003) and ResourceSat-2 (launched on April 20, 2011). These platforms operate in a near-polar sun-synchronous orbit at a mean altitude of 817 km.

AWiFS has four spectral bands and it acquires surface data in the visible, near infrared and short wave infra-red regions of the electromagnetic spectrum. It has a spatial resolution of 56 m and a radiometric resolution of 12 bits (10 bits for R-1 AWiFS). The swath is 740 km with a repeat cycle of 5 days.

The automated approach employs a trajectory based change detection algorithm, and changes are detected through the simultaneous analysis of all imagery available in the annual temporal stack for a given tile.

The detection leverages peak green season imagery which has desirable characteristics for change detection, i) forest vegetation is among the darkest of vegetated surfaces because of shadowing within and between canopies and the absorption of light by canopy vegetation, and ii) undisturbed forests typically display stable spectral signature relative to other vegetated land cover (e.g., agricultural crops) which displays seasonal and interannual variations.

Most forest disturbance events result in abrupt spectral changes due to sudden reduction and

**Figure 8: Detection of forest loss at annual scale along with the year of change**

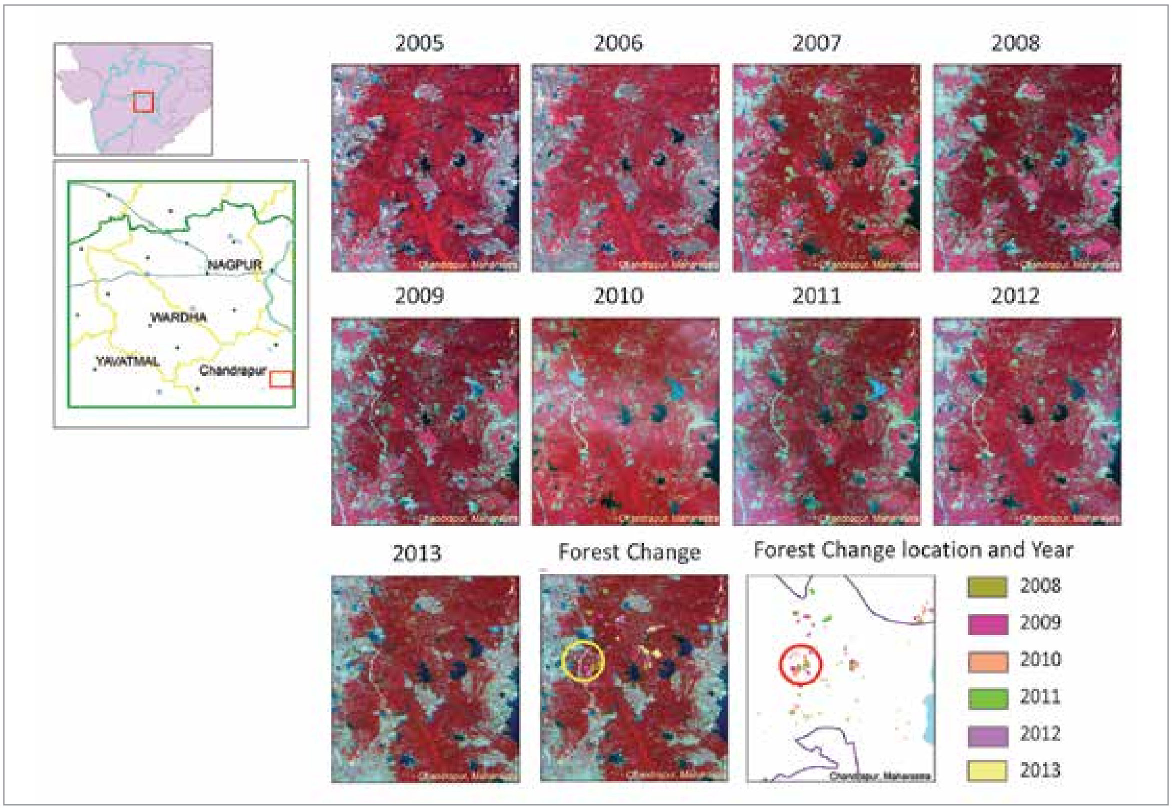



**Table 5 : Sensor wise total active fire detections in fire season 2018**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MODIS | 1671 | 3856 | 21472 | 9529 | 3492 | 243 | 39 | 52 | 86 | 209 | 295 | 568 | 41512 |
| VIIRS (375m) | 10534 | 23774 | 161419 | 35737 | 31334 | 1908 | 224 | 345 | 938 | 2109 | 2840 | 4146 | 275308 |

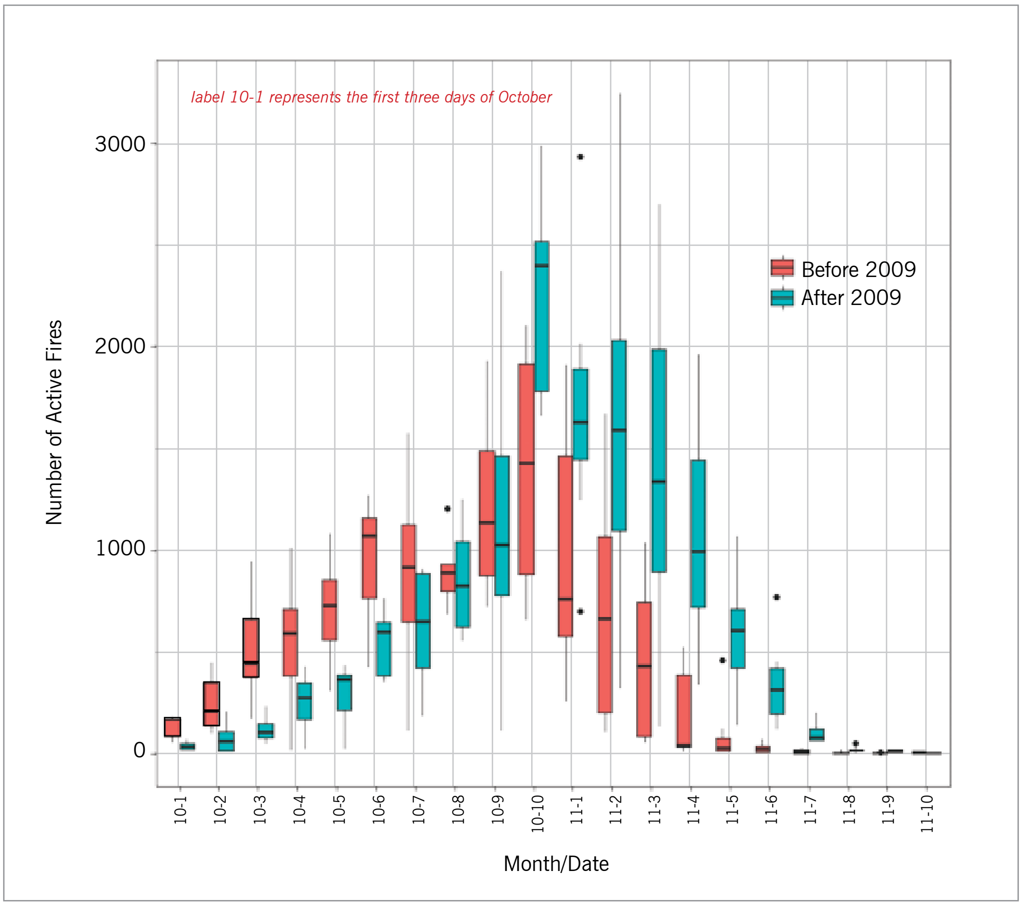
removal of forest canopy cover and woody biomass. The automated methodology uses statistics collected from forest samples identified in the imagery to characterize the likelihood of pixel being forested – the integrated forest z-score (IFZ). A detailed account of the processing of satellite data and methods of the calculation of the IFZ are not presented here. Tracking the temporal pattern of the IFZ using satellite observations well characterized for its geometric and spectral characteristics enables inferences on the current state of a pixel.

Figure 7 illustrates the temporal pattern of IFZ in a pixel exhibiting change. A steady state is seen from 2005-2007 when the pixel remains unchanged (Forested) and then a sudden rise in IFZ during 2008 (disturbance due to forest loss) and recovery due to secondary vegetation was also observed after 2010.

The current algorithm can effectively delineate the location and timing of a change in a temporal stack of satellite data. Figure 8 shows an example of the ability of the algorithm to detect different change locations shown with satellite imagery from 2008 to 2013.

Validation of identified loss locations is possible from either field verification or through the use of corroborative high-resolution imagery of relevant time periods.

**Figure 9: Date wise pattern of active fire detection in Punjab (2003-2016)**




The automated approach has been operationally used in five national operational cycles. The results have been shared with FSI and all State Forest Departments.

## Field validation of forest loss alerts

Field verification of forest loss sites detected with this approach was done in Telangana and Andhra Pradesh. Ground validation was done using android application and high-resolution images from *Bhuvan*, the ISRO geo-visualization portal. Field teams observed that several detected areas in different districts were recent forest clearings. Forest loss on the ground was found due to timber extraction, selective logging, clearing activities and plantations etc.

## Fire

About 55 per cent of India's forest cover is subjected to fires each year, causing an economic loss of over 440 crores rupees apart from other ecological effects. The FSI estimated that 1.45 million hectares of forest are affected by fire annually with 6.17 per cent of the forests prone to severe fire damage. Satellite observations have been the only source of observations on fires on a global scale. Hotspots have been observed from a variety of sensors AVHRR, ATSR, TRMM VIRS, MODIS and the geostationary satellites GOES and MSG.

Active forest fire monitoring using satellite data has been carried out from 2006 as part of the Disaster Management Support Program of ISRO. The activity provides timely information on fires to state forest department users across India for forest fire control and management activities. Active fire monitoring uses satellite data from the MODIS flying on the TERRA and AQUA spacecraft and Visible Infrared Imaging Radiometer Suite data from the Suomi National Polar-orbiting Partnership (SNPP-VIIRS). Satellite data is received and processed at National Remote Sensing

Centre, Shadnagar campus, Telangana in near real-time using Science Process Algorithms (SPAs) obtained from the Direct Readout Portal (https://directreadout.sci.gsfc.nasa.gov). The algorithms used are described by (Csiszar *et al.* 2014; Giglio *et al.* 2003, 2016; Schroeder *et al.* 2014).

Active forest fire location information is also disseminated to FSI and user state forest departments through email and Short Message Service (SMS) to the respective forest beat guards (in several states those provided the phone numbers) within half an hour of satellite overpass. The active fire information is also published on *BHUVAN* (http://bhuvan-noeda.nrsc.gov.in/disaster/disaster/disaster.php#). Table 5 shows the active fires detected in 2018. Post fire burned area assessments are carried out using the AWiFS sensor flown on the IRS ResourceSat 1 and two satellites for specific fire events.

The fire product dissemination is through Bhuvan. Alerts are sent through email to the primary user – Forest Survey of India (FSI). Fire alerts are sent by SMS to several states (Andhra Pradesh, Telangana, Madhya Pradesh, Maharashtra, and Himachal Pradesh).

The fire products are based on a well-characterized algorithm and are high confidence detections. Field validation by direct observation is difficult given the variability and dispersed distribution of fires. Controlled fires are used for validation but more frequently corroborative satellite data is used in validation studies after carefully allowing for time and sensor differences (spatial and spectral) Schroeder *et al.* (2008) showed that while there are omission errors, the fire data users interested in larger biomass burning events may find both MODIS and GOES to have reasonably high rates of successful detections.

Information on active fires is also useful for detection of the regional patterns in agricultural burning. In 2018, district wise daily active fire detection count/total (consolidated for all passes) from TERRA & Aqua MODIS (1km) and SNPP VIIRS (375m) were provided for Indian states in the Indo-Gangetic plain *viz.*, Punjab, Haryana, Rajasthan and Uttar Pradesh. These data can be used for detecting village/taluk level patterns and studying the temporal behaviour of fires. Figure 9 shows the difference in the pattern of detections over Punjab. There is a marked shift in the number of fires in the later part of the season which correlates with the introduction of a policy that regulated the transplanting of paddy.

Fires in India are exclusively anthropogenic in origin. This is evident from examining the seasonal and diurnal pattern of fires using long term satellite data. Forecasting or predicting fire locations is thus not possible. There are two aspects to the forecast, ignition risk and ignition probability. Fire Danger Ratings are based on static and dynamic conditions such as temperature, humidity, wind and the dryness of the landscape are useful to understand the ignition risk; the higher the fire danger rating, the more dangerous the conditions. They are determined as a function of fuel properties, weather, topography and human intervention derived from satellite remote sensing and ground-based measurements

Methods to arrive at a fire danger rating primarily include the development of fuel models which range from simple to complex systems analysis. Parameters such as dry biomass load and associated moisture condition are primary requisites for a fire to occur. In practice, live fuel load and moisture are spatially derived from satellite-derived vegetation index proxies. Dead fuel load and moisture are related to short-term and long-term weather/climatic conditions. Based on this criterion, fire danger associated with a forest ecosystem is assessed. Application of available FDR models developed for other countries to Indian context without adaptation and validation is not appropriate.

The development of dynamic fire danger rating using satellite remote sensing data and field-based observations (fuel availability and condition, micro meteorology etc.) and measurements can be modelled in collaboration with agencies such as FSI and State Forest Departments to develop the region-specific capability.

Satellite remote sensing assets with observations over India do not provide a true monitoring capability which would require observation at ~ 1 km spatial resolution in the thermal bands using a geostationary platform to generate fire observations at intervals of less than 30 minutes. Such a capability is not available for fire monitoring over India and is a requirement for the future.

The spatial and seasonal pattern of occurrence forest fires is well understood with the availability of reliable detections from the MODIS sensor (October 2000 onwards). However, the ecological and economic consequences of fires, as well the quantification of aerosols and pollutants from these fires or their dispersal are not adequately understood and needs research attention. We suggest that these are priority area for future work for researchers to address in the future.

## Conclusion

Satellite remote sensing has been operationally used in India for several decades. The satellite-based monitoring of India's forest has contributed to informing policy and effective conservation and protection of India's forests. Newer methods of analysis of satellite remote sensing data have led to the development of automated approaches to the detection of forest change. The reliable and confident detection of a change from a forested to a non-forested state is now realizable at annual time scales. The need of the future is to improve i.e. further reduce the temporal scale to sub-annual scales and improve the sensitivity of the analysis to detect subtle changes in fractional cover. The availability of three dimensional data from active sensors particularly waveform LiDAR from the GEDI mission and microwave data in the L- and S-bands from the ISRO-NASA NISAR mission offer exciting new possibilities for the characterization of India's forest vegetation.

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# Conservation and livelihood implications of trawler bycatch: Towards improved management

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**Abstract**

Mechanised fishing such as trawling was introduced in India in the 1950s to target high-value catch, driven by foreign interests. Trawling changed the face of Indian fisheries; while it caused an immense growth in marine production, it also brought about several environmental impacts. Bycatch, which is the incidental capture of non-target species, is one such consequence. Bycatch-related mortality is a major threat to marine wildlife such as turtles, cetaceans and sharks. In addition, juvenile fish and non-commercial species constitute a significant portion of bycatch in Indian fisheries. Although once discarded, these are increasingly sold to meet the rising demand for seafood and other products, as well as to offset the declining catches of high-value species. Trawling is increasingly shifting towards a biomass-driven fishery, with bycatch playing a significant role in the industry today.

Fisheries management in India has long focused on production and maximising catch, with conservation and sustainability as secondary concerns. Few regulations exist to mitigate and manage bycatch, with limited enforcement of the same. With the growing economic value of bycatch, fishers have little incentive to comply with these regulations. Management is further affected by a governance system that spans the Fisheries Department, under the Ministry of Agriculture and Farmers' Welfare, which aims to maximise production, and the Forest Department, under the Ministry of Environment, Forest and Climate Change which focuses on wildlife conservation.

This bycatch-driven fishery is not only a threat to marine biodiversity but is also unsustainable in the long-term, endangering the livelihood and food security of millions in the fishing community. A holistic approach that looks at the supply-demand drivers of bycatch can be key in regulating the fisheries sector. We also emphasise the scope and need for improvement in management, starting with appropriate policy reforms that account for the present bycatch economics in the country. While trawl fishing is the root of these problems, attempts to directly manage, reduce or even ban trawling have been met with little success.

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Addressing bycatch will not only alleviate some of these threats but may also be a means of better managing the trawl industry itself.

**Keywords**

*Bycatch, Trawling, Conservation, Management, Livelihoods.*

## Background

The mechanisation of fisheries sector India in the early 1950s represented a turning point for the industry in the country. First introduced as part of the erstwhile Indo-Norwegian project (Gerhardsen 1958; Mathews 2005), trawl fishing aimed to increase food production and protein availability, as well as to target high-value catch such as shrimp, cephalopods and certain finfish (Jayasankar *et al.* 2000). High returns facilitated the spread of trawling across the coastline over the subsequent decades. Concurrently, as the economic gains from trawling became more evident, the focus of these fisheries gradually shifted from food production to foreign exchange, with shrimp especially exported in large quantities (Bhathal 2005).

Along with other advancements such as improved engine efficiency and boat capacity, trawling brought about an enormous growth in marine fish production (Somvanshi 2001) from 0.5 million tonne in the 1950s to 3.9 million tonne in 2012 (Dineshbabu 2013). This was a strong contrast to the subsistence-based fisheries in the country pre-1950. Mechanised crafts (trawlers and purse seiners) currently number 54,073 and account for about 75 per cent of the total marine fisheries production, which is a significant fraction considering that they constitute only 24 per cent of the total marine vessels in the country. The remaining 25 per cent of production is shared between 1,67,377 motorised and traditional fishing crafts, constituting 76 per cent of Indian marine fishing vessels (CMFRI 2015; Department of Animal Husbandry 2015).

While mechanised fisheries contributed to increased economic growth (Sathiadhas 2005), it introduced a host of ecological impacts in Indian waters. Trawling has led to the destruction of benthic communities and habitats like seagrass beds and coral reefs (Dayton *et al.* 1995; Kumar and Deepthi 2006). Trawl fishing has also been linked with depletions and collapses of fish populations globally (Myers *et al.* 1997) as well as in India (Mohamed *et al.* 2010). There is no dearth of evidence for the ill-effects of trawling, yet it remains one of the most widespread forms of fishing. Given the scale, economics and complex socio-political issues around trawling, any attempts to regulate or reduce this fishery have met with little success, calling for a more ancillary approach to the problem.

Bycatch is a central issue in trawling today. Traditionally defined as the non-targeted portion of the catch incidentally captured in fishing gear, bycatch is an inevitable component of the non-selective trawl nets (Alverson *et al.* 1994). It includes a diverse range of marine wildlife, from megafauna such as cetaceans, turtles and sharks, to invertebrates like crustaceans and molluscs. Fisheries bycatch constitutes one of the biggest threats to sea turtles (WWF 2017), with high mortality rates reported from different fisheries globally, including Odisha (Gopi *et al.* 2006; Pandav *et al.* 1997) and other states on the mainland coast of India (Shanker and Choudhury 2006). Many species of sharks and other elasmobranchs are declining due to fishing pressure (Dulvy *et al.* 2008), with half the global landings attributed to bycatch (Stevens *et al.* 2000). Over half the species in the Arabian Sea have been assessed as threatened (Jabado *et al.* 2018). These charismatic species have become flagships for marine conservation and bycatch management.

In tropical developing nations like India, trawlers apply nets with very small cod-end mesh sizes to maximise catch (Davies *et al.* 2009; Kumar and Deepthi 2006). This results in the capture of a large volume of juveniles as bycatch, particularly in shrimp

**Figure 1: Distribution of crafts and marine fisheries production between mechanised and non-mechanised fishing vessels in India. Data from Central Marine Fisheries Research Institute (2015) and Department of Animal Husbandry, Dairy and Fisheries (2015).**

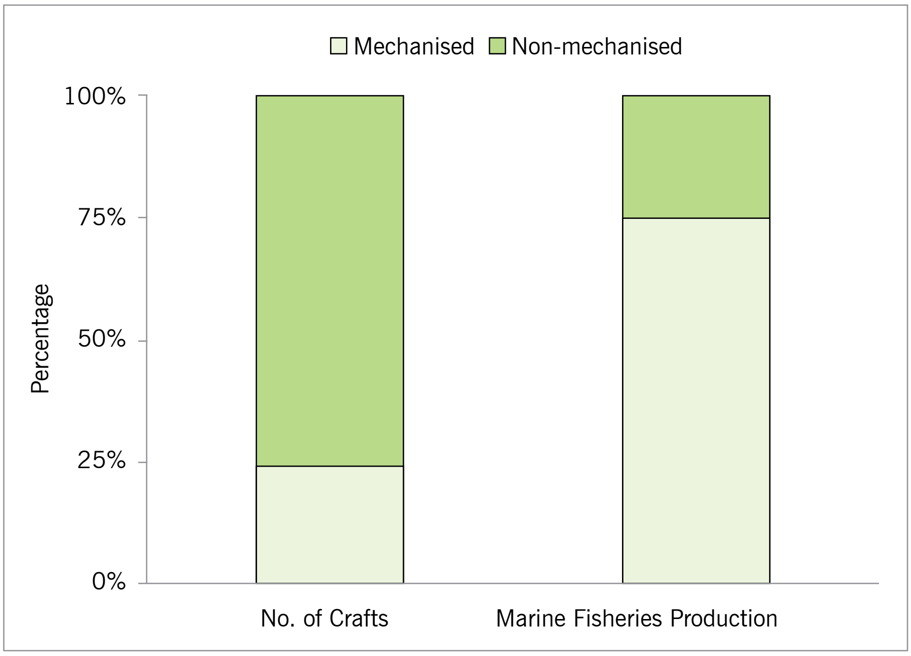
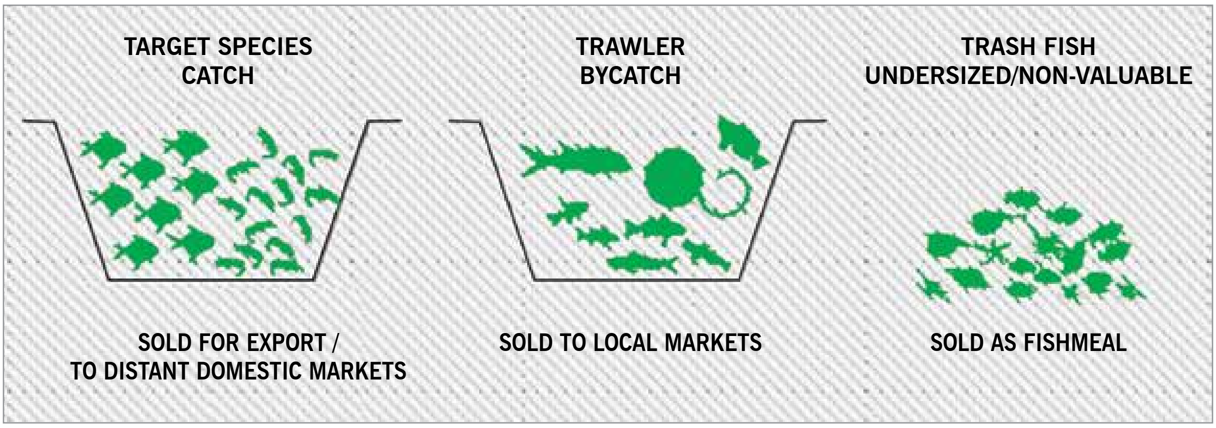



**Figure 2: Different types of trawler catch. Adapted from Lobo (2012).**




trawlers as exploitable quantities of shrimp occur in the same habitats used by juvenile fish (Bhathal 2005). This growth overfishing, i.e. capturing fish before they can grow, can potentially compromise the recruitment, and hence population growth, of the species (Funge-Smith *et al.* 2005). Trawler bycatch comprises 56–93 per cent of the total catch across the different maritime states in India (Kumar and Deepthi 2006). It is ever-present, irrespective of the presence and abundance of the target species. Increasing fishing pressure in India has resulted in overfishing and fishing down the food web (Bhathal and Pauly 2008), depleting inshore resources and increasing bycatch (Sathiadhas 2005).

Bycatch has emerged as a major conservation issue globally. Not only is it in need of immediate and serious action but tackling the bycatch problem may be a means of better managing the trawl industry itself. In this article, we broadly define bycatch as the entire range of non-target organisms, from megafauna to juvenile fish. We

**Figure 3: Catch of one haul of a trawler** (Photo: Chetan Rao)

provide a brief account of the transformation of the trawl fisheries in India which has made bycatch a critical issue. We subsequently discuss limitations in the current fisheries management and provide recommendations for ameliorating management of bycatch, which can be beneficial for both coastal and marine biodiversity, as well as for the sustenance of local livelihoods.

## Transformation of trawl fisheries

Due to minimal regulation, the early period of trawling was characterised by unchecked exploitation of marine ecosystems and large volumes of catch (Devaraj and Vivekanandan 1999). The huge quantities of inevitable bycatch were largely discarded due to a lack of commercial value (Alverson *et al.* 1994). The initial high supply, coupled with a rising human population, urbanisation and changes in macroeconomics of the country, increased consumption of and hence the demand for seafood (Aswathy *et al.* 2012; Salagrama 1998). At the same time, the export market for fish increased, with India's marine export rising from 0.3 million tonne in 1995 to 1.4 million tonne in 2017 (MPEDA, 2018). Trawl fisheries underwent major developments in the 1990s in response to this demand and high competition, with new areas of growth such as deep-sea fishing, expansion of target species with the introduction of the pelagic trawl and immense capital investments (Dineshbabu 2013; Salagrama 1998).

Perhaps one of the most notable transformations is reflected in the utilisation of bycatch. Quantum of discards have reportedly lowered over the past few decades, both globally and in the country (Dineshbabu *et al.* 2014; Kelleher 2005). This is because new markets for previously non-commercial or under-utilised species opened up. Hence numerous bycatch species started being commercially sold, either fresh or dried, to cater to these markets (Aswathy *et al.* 2012).

However, it was the industrial demand that spurred the growing utilisation of bycatch (Clucas 1997; Dineshbabu *et al.* 2014). Juveniles and small non-commercial bycatch species found an application as 'trash fish'. This refers to a mix of fish and invertebrates that have little to no direct commercial value and are sold primarily for fishmeal preparation, used as aquaculture and livestock feed (Funge-Smith *et al.* 2005). India has seen massive growth in the poultry and aquaculture industries over the past two decades, greatly fuelling the demand for trash fish and bycatch, particularly from the mechanised fishing sector (Lobo *et al.* 2010). Trash fish landings were more than 50,000 tonne on the north-west coast of India in 2011, comprising an average of 33 per cent of a trawler's landed catch (Dineshbabu 2013). Trash fish links fisheries with poultry and numerous other industries, making bycatch a multi-sectoral issue. What started as a supply-driven industry now appears to be largely driven by demand from a rapidly growing market.

However, the ocean is far from an unlimited resource. Given the initial, unrestricted phase of trawling, many nearshore fishing grounds at present are either overexploited or rapidly reaching that state (Devaraj and Vivekanandan 1999). Indian waters presently support far more fishers and vessels than capacity, leading to declines in many high-value species and increasing effort per fishing boat (Devaraj and Vivekanandan 1999; Salim *et al.* 2014). While trawling in India was always a multi-species fishery, it has gradually transformed into one that targets, captures and utilises everything in its path, driven by quantity rather than quality. Bycatch is playing an increasingly significant role in this scenario and may presently be sustaining an otherwise declining trawling industry (Lobo *et al.* 2010).

## Implications of a bycatch-driven fishery

Overexploitation of fisheries has serious impacts on marine ecosystems and hence local livelihoods. With bycatch supporting the prolongation of trawling, this practice may continue beyond the point of collapse of the target species, with little chance of recovery (Lobo *et al.* 2010). Declines of high-value species have been documented along the coastline, such as silver pomfret and whitefish along the south-west coast of India (Mohamed *et al.* 2010). Commercial bycatch is predominantly composed of small-sized species (Lobo 2012), which tend to be more productive and relatively resistant to fishing (Jacobsen *et al.* 2013). However, prolonged unchecked harvesting may be detrimental to their populations as well. Furthermore, trawling continues to pose a threat to vulnerable marine biodiversity such as turtles and sea snakes. For instance, high mortalities from trawling and subsequent declines in certain sea snake species have been documented on the west coast (Rao *et al.* 2017).

Impacts of this overexploitation are not restricted to trawl fishers. There are 4 million fisherfolk in the country and millions more employed in allied activities (Department of Dairy, Animal Husbandry and Fisheries 2015). 61 per cent of Indian fishers are below the poverty line (Ghosh and Lobo 2017). Declining fish populations put the long-term livelihood of this entire community at risk, particularly small-scale fishers who are highly dependent on inshore fish resources for their livelihood and food security.

## Bio-economic management strategy

Economics and technology, rather than ecological principles, have largely determined how the marine ecosystem has been exploited (Hall *et al.* 2000). This stems from a long-held view by managers of marine life as 'produce' rather than wildlife (Sridhar and Namboothri 2012). Marine fisheries management across the globe has therefore been geared towards production and maximum yield, with conservation matters such as bycatch as a secondary concern.

Maximum sustainable yield, known commonly as MSY, has long been one of the guiding principles of fisheries management globally. MSY is the maximum level at which a resource can be safely and routinely exploited without long-term depletion (Maunder 2008). However, MSY has faced multiple critiques (Larkin 1977; Ramesh and Namboothri 2018), some of these being its disregard for natural fluxes in fish populations, and its treatment of complex ecological systems as simple economic problems to maximise profit, resulting in poor management strategies. In spite of these and many other criticisms, MSY remains a key paradigm in fisheries management globally, including India. This profit-based strategy has allowed the growth and dominance of mechanised fishing in the country. There is a limited scope for the effective management of bycatch, sustainability, equitable distribution and other environmental and social matters in this framework.

## Regulations of bycatch

With this bio-economic view, the main focus of Indian fisheries policy has long been to promote development, generate food and foreign exchange and reduce conflicts among sectors. Regulation and control of fishing effort and bycatch are relatively recent concerns. (Bhathal 2005). Multiple legislations, as well as technological innovations, have been developed in this regard. Mechanised fishing is prohibited within 5-10 km from the shore by the Marine Fisheries Regulation Acts of the different maritime states (Datta 2013). A minimum mesh size of 35 mm for the cod end (40 mm in Gujarat) is stipulated for trawler nets (Mohamed 2015). The state of Kerala has also legally specified minimum landing sizes for many commercial species (Basheer 2017). While these policies deal with the bycatch of juveniles and under-sized individuals, regulations such as seasonal and spatial closures aim to control the overall scale and intensity of fisheries (Datta 2013).

Bycatch reduction devices (BRDs) are structures inserted in fishing gear to reduce capture or enable the escape of non-target species from fishing nets (FAO 2002). Various BRDs such as the Turtle Excluder Device (TED) have been developed across the world for trawler nets to mitigate bycatch. In India, the Central Institute of Fisheries Technology (CIFT) has developed and tested BRDs such as the Juvenile Fish Excluder and Shrimp Sorting Device (JFE-SSD), focusing on reducing bycatch with minimal impacts on the catch of the high-value species (Pravin *et al.* 2013). Several states such as Odisha and Andhra Pradesh have policies mandating the use of BRDs (TEDs in particular), due to high rates of sea turtle mortality (Boopendranath *et al.* 2008).

With these seemingly comprehensive regulatory measures, commonly used across the globe in fisheries management, why is the bycatch problem still persistent? Implementation and enforcement of these regulations in Indian fisheries are inadequate, hindered by shortage of staff, poor monitoring and motivation (Johnson 2010). Most regulations are plagued with low compliance, with trawlers using nets with the cod ends as small as 8 mm, and frequently fishing illegally in shallow inshore waters despite prohibition (Kumar and Deepthi 2006). While most threatened megafauna (sea turtles, marine mammals and some species of elasmobranchs) are protected under the Wildlife (Protection) Act (Ministry of Environment and Forests 1972), there are few strategies in place to reduce their incidental capture. On-ground application of BRDs is nearly negligible; for instance, although mandated by law, trawlers in Odisha hardly use TEDS due to concerns of its potential impact on the catch (Rao 2011).

However, enforcement may well be a secondary issue. The source of this problem is that the existing regulations are not very relevant in the present fishing scenario. With the current biomass-based fisheries, there is little incentive for fishers to minimize bycatch. It is therefore not surprising that bycatch reduction measures are met with little success. We emphasize the necessity for a revision of the entire approach to bycatch management. With the lines between catch and bycatch becoming increasingly blurred, these traditional categories of target catch and bycatch are no longer applicable, particularly for trawl fisheries (Lobo 2012). The entire spectrum of the catch should be adequately monitored, and regulations applied across all species, not just the high-value or charismatic ones. Furthermore, management approaches need to account for the economic role of bycatch and align the conservation of marine ecosystems with the interests and livelihoods of the fishing community.

We suggest that a comprehensive understanding of the present supply-demand dynamics in fisheries may be crucial in designing informed and effective strategies. Present regulations on fishing effort and gear impose a single standard across a range of fisheries. Bycatch rates, species and utilisation varies greatly with region, fishery, gear and local social and cultural norms. A 'one size fits all' approach may therefore not be the most effective at managing bycatch (Squires and Garcia 2018). Detailed research on the supply side of fisheries can provide a better understanding of these nuances and variations, and aid in framing more appropriate, case-specific regulations for bycatch management rather than broad legislation. Secondly, further investigation on the demand side is vital, focusing on the industrial drivers of fishing. Stronger controls on these driving forces paired with regulations on the supply end of the chain may be more efficient in tackling the fisheries problem in the country. For example, transparency and regulations on the use of fishmeal as feed in aquaculture can help better manage this portion of the catch (Huntington and Hasan 2009).

## Integrated governance

Governance of fisheries and related aspects is shared between the Fisheries Department of the Ministry of Agriculture and the Forest Department of the Ministry of Environment, Forest and Climate Change (Lobo 2012; Project Seahorse 2017). The former aims to maximise production, with its primary tasks including fisheries development, production and welfare of the fisher community (Bhathal 2005). The Forest Department, in contrast, focuses on biodiversity and wildlife conservation. In the marine context, the department is responsible for the preservation of endangered species and vulnerable habitats such as turtles, corals reefs and mangroves, guided by the Wildlife Protection Act (Ministry of Environment and Forests 2006). Fisheries impacts such as bycatch span the duties of both departments.

Furthermore, fisheries monitoring and management within the Ministry of Agriculture and Farmers Welfare occurs across two centre-run institutes – The Central Marine Fisheries Research Institute (CMFRI) and the Fishery Survey of India (FSI) – as well as the state fisheries departments. While each of these bodies has a set of specific responsibilities, there is overlap in certain tasks such as catch data collection. Improved coordination across agencies and departments can facilitate the greater allocation of effort and resources towards bycatch (Bhathal 2005; Hornby *et al.* 2015; Sridhar and Namboothri 2012).

## The way forward

Trawl fishing is one of the biggest marine threats across the globe. While there have been attempts at bringing about an outright ban on this form of fishing, this seems to be an unrealistic option given the sheer scale, ubiquity and complexity of trawling. The best practical solution is a policy intervention for immediate and effective regulation to curb trawling and mitigate its various impacts. Bycatch is one of the major consequences of trawling and is now emerging as one of its driving forces as well. Successful bycatch regulation can result in better management of trawl fisheries. In this article, we assessed the mechanised fisheries and bycatch scenario in India and detailed their negative impacts on biodiversity and livelihoods.

We suggest that a more holistic and interdisciplinary approach to bycatch management is urgently needed, starting with a larger focus on bycatch and conservation within fisheries management in the country. Trawling is increasingly shifting to a biomass-based, demand-driven fishery, and policies need to be reformed to address this. Better research on the supply-chain drivers of trawling can lead to improved and more relevant bycatch measures over the entire fisheries chain and related industries. Greater cohesion and structure within and between governing bodies responsible for fisheries is also essential in strengthening bycatch management efforts. These measures can be instrumental in tackling the bycatch problem and alleviate the threat to marine ecosystems as well as the livelihood and food security of millions in the country.

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# Genetically modified organisms and biosafety regulations in India: Status and capacity building initiatives

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**Abstract**
Modern biotechnology is used to distinguish newer applications of biotechnology, such as genetic engineering and cell fusion from more conventional methods such as breeding, or fermentation and has several applications in numerous fields *viz*. healthcare, food, agriculture, biofuels, insects, animals, marine, industry and environment. Scientific advances in modern biotechnology have resulted in the development of genetically engineered organisms also referred to as genetically modified organisms (GMOs) or living modified organisms (LMOs). As there is a never-ending progression seen in this technology, the number of GMOs/LMOs and commercial products derived thereof have been increasing each year. In parallel, there are increasing debates about safety concerns among various stakeholders related to their impact on health, environment and biodiversity. Many countries with active biotechnology research programmes including India have put in place biosafety regulations to deal with these safety issues. An international agreement, i.e. Cartagena Protocol on Biosafety (CPB) has also been negotiated under the aegis of Convention on Biological Diversity (CBD) to regulate transboundary movement of LMOs. Biosafety capacity building is needed so as to ensure that institutional capacities and professional competence are in place to effectively regulate the latest technologies and products.

The Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal ministry for implementation of the national biosafety regulations in India as well as the international agreements relevant to biodiversity and LMOs. The Ministry has undertaken several initiatives for biosafety capacity building in the country through national and international resources and collaborations. This paper gives an account of the global and national status of GMOs/LMOs, biosafety regulations and capacity building initiatives in India.

**Keywords**
*Biosafety, GMOs, LMOs, GM Crops, Cartagena Protocol on Biosafety, Capacity Building.*

## 1. Introduction

Breakthroughs in modern biotechnology have led to improved understanding of the genetic basis of living organisms. It has enabled us to develop products and processes useful to human and animal health, food, agriculture and industry. One example of modern

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biotechnology is genetic engineering, which has prominence in view of its potential. Genetic engineering (GE) is the technique of removing, modifying or adding genes to a DNA molecule in order to change the information it contains. By changing this information, genetic engineering changes the type or amount of proteins an organism is capable of producing. This principle is used in the production of novel drugs, vaccines, foods, biofuels and the development of improved plants.

Since the release of the first product, i.e. human insulin derived from GE bacteria in 1982 followed by commercialization of genetically modified (GM) crops in the mid-90s, products and processes involving modern biotechnology have been extensively used for the benefits they provide. Adequate safety standards and regulations have been established in many countries to ensure the safe use of GMOs and the products derived from them. Transboundary movement, transit, handling and use of living modified organisms (LMOs) is regulated as per provisions of Cartagena Protocol on Biosafety (CPB), an international agreement under the aegis of Convention on Biological Diversity (CBD) (Secretariat of the Convention on Biological Diversity (SCBD), 2000). Biosafety capacity building is crucial to enable countries for the implementation of national and international commitments for ensuring the safe and sustainable use of GMOs.

India has always supported the adoption of pioneering science and technologies across various sectors. Biotechnology is one of the key thrust areas identified by the Government of India, for promoting research, development and its innovative applications. India has also been an early mover in the development of a regulatory system to ensure biosafety evaluation of GMOs. Rules for the manufacture, use, import, export and storage of hazardous microorganisms, genetically engineered organisms or cells, were notified in 1989 under the Environment (Protection) Act (EPA), 1986. These rules are supported by guidelines that are regularly updated. India is also a Party to the CBD and CPB. MoEFCC being the nodal Ministry for implementation of biosafety regulations in India has taken up several initiatives for capacity building of multiple stakeholders including regulators, scientists, enforcement agencies, students, media, etc. This paper provides an update on global and Indian status of GMOs, particularly GM crops, Indian biosafety regulations and capacity building initiatives.

## 2. Status of GMOs

The practical reach of GMOs encompasses a wide range of applications due to the possibilities to express virtually any kind of coding sequence from different sources. Sequences from mammals or any other animals, plants, fungi, bacteria or even sequences synthesized *in vitro* can be introduced and expressed in other organisms. The genetic manipulation using modern biotechnology techniques is more precise and outcomes more certain over other methods resulting in faster production of organisms with desired traits. Commercial applications of GMOs are primarily in the area of healthcare and agriculture, as indicated below:

### 2.1 Healthcare

Applications in healthcare include medical products derived or produced from GMOs and also GMOs that are intended to be used as medicinal agents. These include hormones, growth factors, vaccines, monoclonal antibodies, etc., collectively referred to as biologics or biopharmaceuticals. These products are being successfully used to prevent, treat and cure many incurable diseases using novel methods of treatment and diagnosis.

It has been reported that 374 individual biopharmaceutical products containing 285 distinct active biopharmaceutical ingredients have been approved until July 2018 (Walsh 2018). Most of these products are being used as therapeutics in various forms across the world. Notable target indications for approved therapeutics include diabetes, haemophilia, hepatitis, myocardial infarction and various cancers. It may be noted that biosimilar versions of many of these products have been approved subsequent to the patent expiry. Table 1 provides the 20 top-selling biopharmaceuticals products in 2017 at the global level.

It has been projected that biotechnology products will represent 31 per cent of the market in 2024 from 25 per cent in 2017 (Evaluate Pharma World Preview 2018). Similarly, within the world's top 100 products, biotechnology products will represent 52 per cent of sales in 2024 from 49 per cent in 2017 (Figure 1). This change is indicative of the increasing reliance on the accessibility of novel drug targets through biotechnology interventions.

Production of biopharmaceuticals produced using GMOs has seen robust growth in India particularly biosimilars. Regarding the status of approved recombinant therapeutics in India, many of the above therapeutically distinct products have been approved for marketing through imports/indigenous manufacture (Table 2).

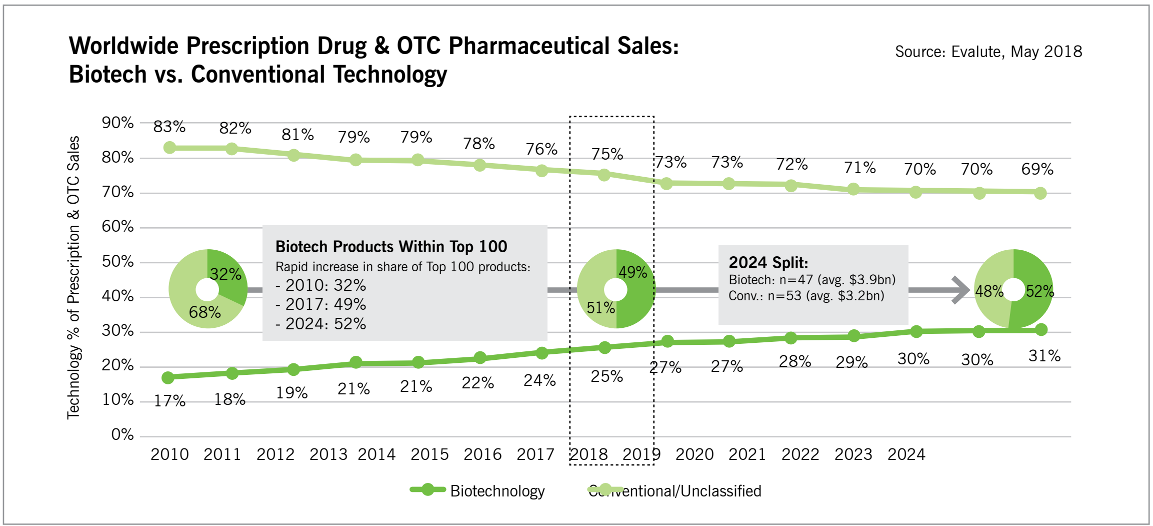
There are more than 30 companies involved in marketing/manufacture of recombinant therapeutics in India. In addition, there is

**Table 1: 20 top selling biopharmaceuticals products in 2017**

| Rank | Product | Sales, 2017 ($ billions)* | Year first approved |
|---|---|---|---|
| 1 | Humira (adalimumab; anti-TNF) | 18.94 | 2002 |
| 2 | Enbrel (etanercept; anti-TNF) | 8.34 | 1998 |
| 3 | Rituxan/MabThera (rituximab; anti-CD20) | 7.78 | 1997 |
| 4 | Remicade (infliximab; anti-TNF) | 7.77 | 1998 |
| 5 | Herceptin (trastuzumab; anti-HER2) | 7.39 | 1998 |
| 6 | Avastin (bevacizumab; anti-VEGF) | 7.04 | 2004 |
| 7 | Lantus (insulin glargine) | 6.72 | 2000 |
| 8 | Eylea (aflibercept; anti-VEGF) | 5.93 | 2011 |
| 9 | Opdivo (nivolumab; anti-PD-1 receptor) | 5.79 | 2014 |
| 10 | Neulasta (pegfilgrastim) | 4.53 | 2002 |
| 11 | Stelara (ustekinumab; anti-IL-12 & IL-23) | 4.01 | 2009 |
| 12 | Keytruda (pembrolizumab, anti-PD-1) | 3.81 | 2014 |
| 13 | Prolia/Xgeva (denosumab, anti-RANKL) | 3.54 | 2010 |
| 14 | Lucentis (ranibi- zumab; anti-VEGF) | 3.38 | 2006 |
| 15 | Novolog/Novorapid (insulin aspart) | 3.31 | 1999 |
| 16 | Soliris (eculizumab; anti–C5 complement protein) | 3.14 | 2007 |
| 17 | Simponi (golimumab; anti-TNF) | 2.94 | 2009 |
| 18 | Humalog mix 50:50 (insulin lispro) | 2.86 | 1996 |
| 19 | Xolair (omalizumab) anti-IgE | 2.75 | 2003 |
| 20 | Aranesp/Nesp (darbepoetin alfa) | 2.62 | 2001 |

*Financial data from La Merie Business intelligence.
*Source: Walsh (2018) Biopharmaceutical benchmarks 2018*

**Figure 1: Projections on the share of biopharmaceuticals in 2024**




*Source: EvaluatePharma® 2018 (www.evaluate.com/PharmaWorldPreview2018)*

**Table 2: Recombinant therapeutics in India**

| S.No. | Molecules | Therapeutic applications |
|---|---|---|
| 1 | Human insulin | Diabetes |
| 2 | Erythropoietin | Treatment of anaemia |
| 3 | Hepatitis B vaccine (recombinant surface antigen-based) | Immunization against Hepatitis B |
| 4 | Human growth hormone | Deficiency of growth hormone in children |
| 5 | Interleukin 2 | Renal cell carcinoma |
| 6 | Granulocyte Colony Stimulating Factor | Chemotherapy-induced neutropenia |
| 7 | Granulocyte Macrophage Colony Stimulating Factor | Chemotherapy-induced neutropenia |
| 8 | Interferon 2Alpha | Chronic myeloid leukaemia |
| 9 | Interferon 2Beta | Chronic myeloid leukaemia, Hepatitis B and Hepatitis C |
| 10 | Interferons Gamma | Chronic granulomatous disease and Severe malignant osteopetrosis |
| 11 | Streptokinase | Acute myocardial infarction |
| 12 | Tissue Plasminogen Activator | Acute myocardial infarction |
| 13 | Blood factor VIII | Haemophilia type A |
| 14 | Follicle stimulating hormone | Reproductive disorders |
| 15 | Teriparatide (Forteo) | Osteoporosis |
| 16 | Drerecogin (Xigris) alpha | Severe sepsis |
| 17 | Platelet Derived Growth Factor (PDGF) | Bone marrow induction and osteoblasts proliferation |
| 18 | Epidermal Growth factor (EGF) | Mitogenesis and organ morphogenesis |
| 19 | Eptacogalpha (r-F VIIa) r-coagulation factor | Haemorrhages, congenital or acquired haemophilia |
| 20 | Bevacizumab | Treatment of various cancers, including colorectal, lung and kidney cancer, |
| 21 | Trastuzumab | Treatment of breast cancer |
| 22 | Rituximab | Treatment of many lymphomas, leukaemias, transplant rejection and some autoimmune disorders. |
| 23 | Darbopoetin alpha | Treatment of anaemia |

| S.No. | Molecules | Therapeutic applications |
|---|---|---|
| 24 | Human Serum Albumin | Treatment of liver disease with ascites. |
| 25 | Insulin Glargin | Treatment of Type I Diabetes Mellitus |
| 26 | Insulin Lispro | Treatment of Diabetes Mellitus |
| 27 | Insulin Aspart | Treatment of Diabetes Mellitus |
| 28 | Met-hu-GCSF | Chemotherapy induced neutropenia |
| 29 | Peg-r-metHu-GCSF | Chemotherapy induced neutropenia |
| 30 | Human Interferon alpha 2b | Treatment of Chronic Hepatitis B |
| 31 | Peg-Interferon alpha-2b | Treatment of Chronic Hepatitis B |
| 32 | Human INF beta-1a | Treatment of multiple sclerosis (MS) |
| 33 | Peg Human GCSF | Chemotherapy-induced neutropenia |
| 34 | Human PDGF-BB-beta-TCP | Bone marrow induction and osteoblasts proliferation |
| 35 | r-Hu-Chorionic Gonadotropin Hormone | Role in Pregnancy |
| 36 | Hemophilic factor IX | Treatment of haemophilia |
| 37 | Cetuximab | Treatment of metastatic colorectal cancer and head and neck cancer. |
| 38 | Luteinising Hormone | Treatment of Reproductive disorders |

*Source: http://geacindia.gov.in*

significant research and development underway in both private and public sector organizations. India has made significant progress in the production of biosimilars. As per a report by ASSOCHAM India in 2016, India had the highest number of biosimilars approved in the world (Figure 2).

## 2.2 Agriculture

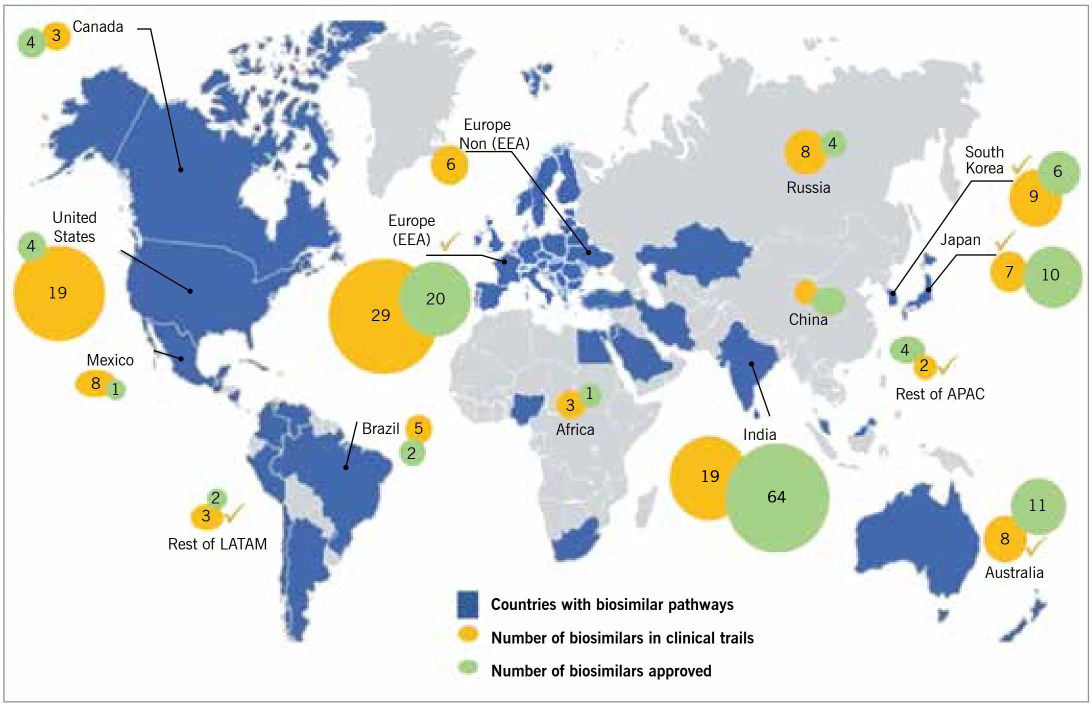
The application of modern biotechnology started in the 1990's and the first GE plant was approved in 1994 (Redenbaugh et al. 1992). In 1996, only 1.7 million hectares (ha) of GM crops were planted in six countries: USA, China, Canada, Argentina, Australia and Mexico. The area under cultivation of GM crops increased to 189.8 million ha in 2017 in 28 countries grown by 17 million farmers globally (ISAAA 2017) (Figure 3). In addition, additional 41 countries have granted regulatory approvals for GE plants for import as food and feed use.

Table 3 provides a list of 16 GM crops that have been cultivated in 28 countries. In addition, beans, sugarcane and eucalyptus have been approved in Brazil and are expected to be planted in near future.

Approval for commercial planting and use of GM crops follows years of study involving laboratory and green house research, confined field trails (CFTs), peer reviews and government regulatory procedures. The areas of crop improvement currently being targeted include resistance to a variety of pests, pathogens and weed control agents, improvement in nutritional content and enhanced survival during environmental stress. As novel products will be available for commercialization in the coming years, it is expected that the global area and number of farmers planting GM crops will continue to rise.

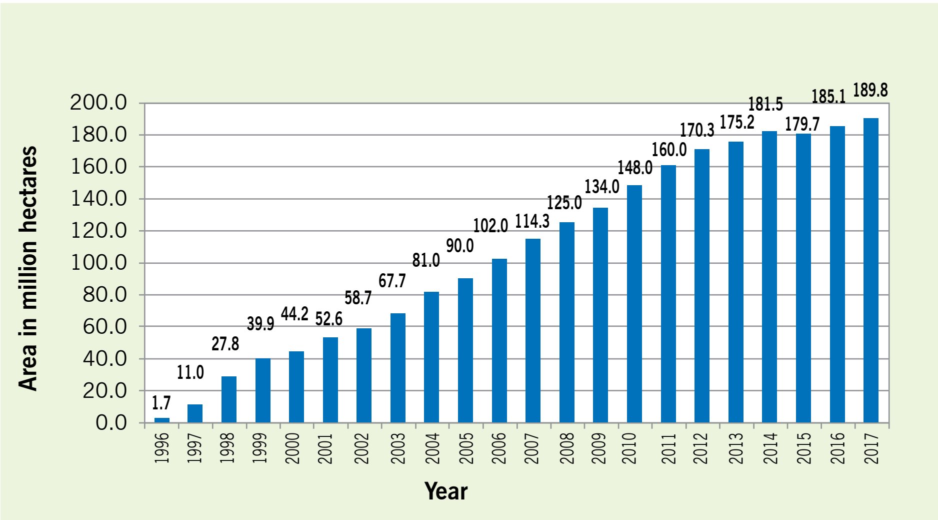
In India, Bt cotton is the only GE plant approved for commercial cultivation. The total area under Bt cotton has increased from 0.05 million hectares in 2002 to 11.40 million hectares in 2017 (Figure 4). Bt cotton is cultivated in more than 90 per cent of the area under cotton. Cotton production in India tripled from 13 million bales in 2003 to 35 million bales in

**Figure 2: Biosimilars approved in various countries**[2]




*Source: ASSOCHAM Report on Biosimilars – How can we realize the $ 240 Bn Opportunity (2016)*

**Figure 3: Global Area of Biotech Crops, 1996 to 2017**




*Source: ISAAA. 2017. Global Status of Commercialized Biotech/GM Crops in 2017*

2016. India ranked first in the global cotton production in 2016. The production of cotton seed and its by-products as oil and seedmeal has also increased manifold. The increase in production of cotton-based oil increased from 0.46 million tons in 2002-03 to 1.50 million tons in 2016-17 (ISAAA 2017).

India has a very rich and innovative R&D pipeline as several public and private sector institutions are involved in the research and development of GM crops in the country. Bt brinjal and GM mustard are the two products which have undergone extensive safety assessment processes in the country and are under regulatory consideration.

[2] Map is for illustration purpose only.

**Table 3: Approved GE plants in various countries in 2017**

| S.No. | GE Plant | Traits/Uses | Countries where approved |
|---|---|---|---|
| 1 | Alfalfa | Herbicide tolerance | USA, Canada |
| 2 | Apple | Anti-bruising and anti-browning | USA |
| 3 | Beet pepper | Virus Resistance | China |
| 4 | Canola | Herbicide tolerance and improved protection against weeds | Canada, USA, Australia, Chile |
| 5 | Carnation | Modified flower colour and herbicide tolerance | Australia, Columbia |
| 6 | Cotton | Improved insect protection, herbicide tolerance and improved protection against weeds | Australia, USA, China, Mexico, South Africa, China, Argentina, India, Columbia. Burkina Faso, Sudan, Pakistan, Brazil, Myanmar, Paraguay, Costa Rica |
| 7 | Egg Plant (Brinjal) | Insect resistance | Bangladesh |
| 8 | Maize | Improved insect protection and herbicide tolerance for efficient weed management. | Canada, USA, Argentina, Brazil, South Africa, Uruguay, Philippines, Chile, Columbia, Honduras, Spain, Portugal, Paraguay, Cuba, Czech Republic, Romania, Slovakia, Vietnam |
| 9 | Papaya | Virus resistance | USA, China |
| 10 | Petunia | Modified flower color | China |
| 11 | Poplar | Insect resistance | China |
| 12 | Potato | Improved quality, anti-bruising and anti-browning | USA, Canada |
| 13 | Soybean | Improved insect protection and herbicide tolerance for efficient weed management. | USA, Argentina, Canada, Paraguay, Mexico, Bolivia, Brazil, Chile, South Africa, Romania, Uruguay, Costa Rica |
| 14 | Squash | Resistance against watermelon mosaic virus and zucchini yellow mosaic virus | USA |
| 15 | Sugar beet | Herbicide tolerance | USA and Canada |
| 16 | Tomato | Delayed Ripening, Virus resistance | China |

*Source: ISAAA's GM Approval Database. http://www.isaaa.org/gmapprovaldatabase/.*

**Figure 4: Area under Bt cotton cultivation in India**

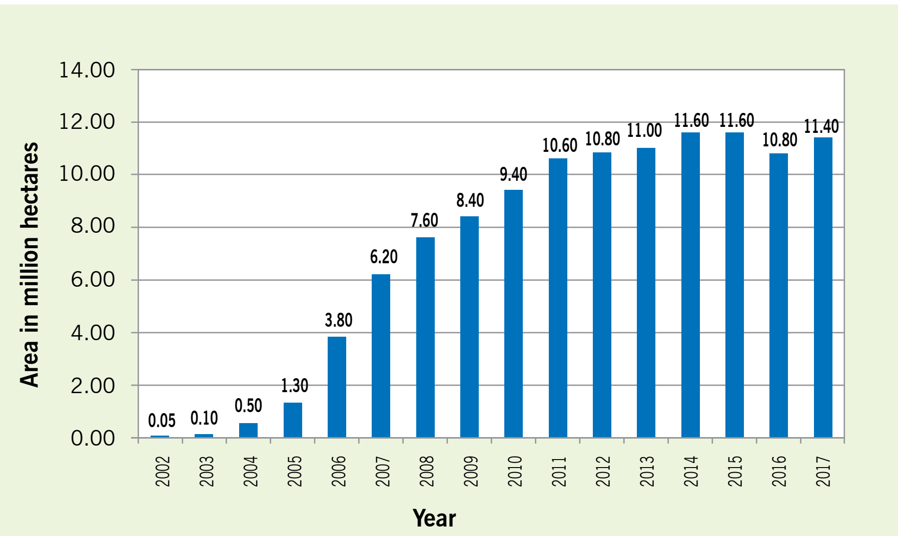
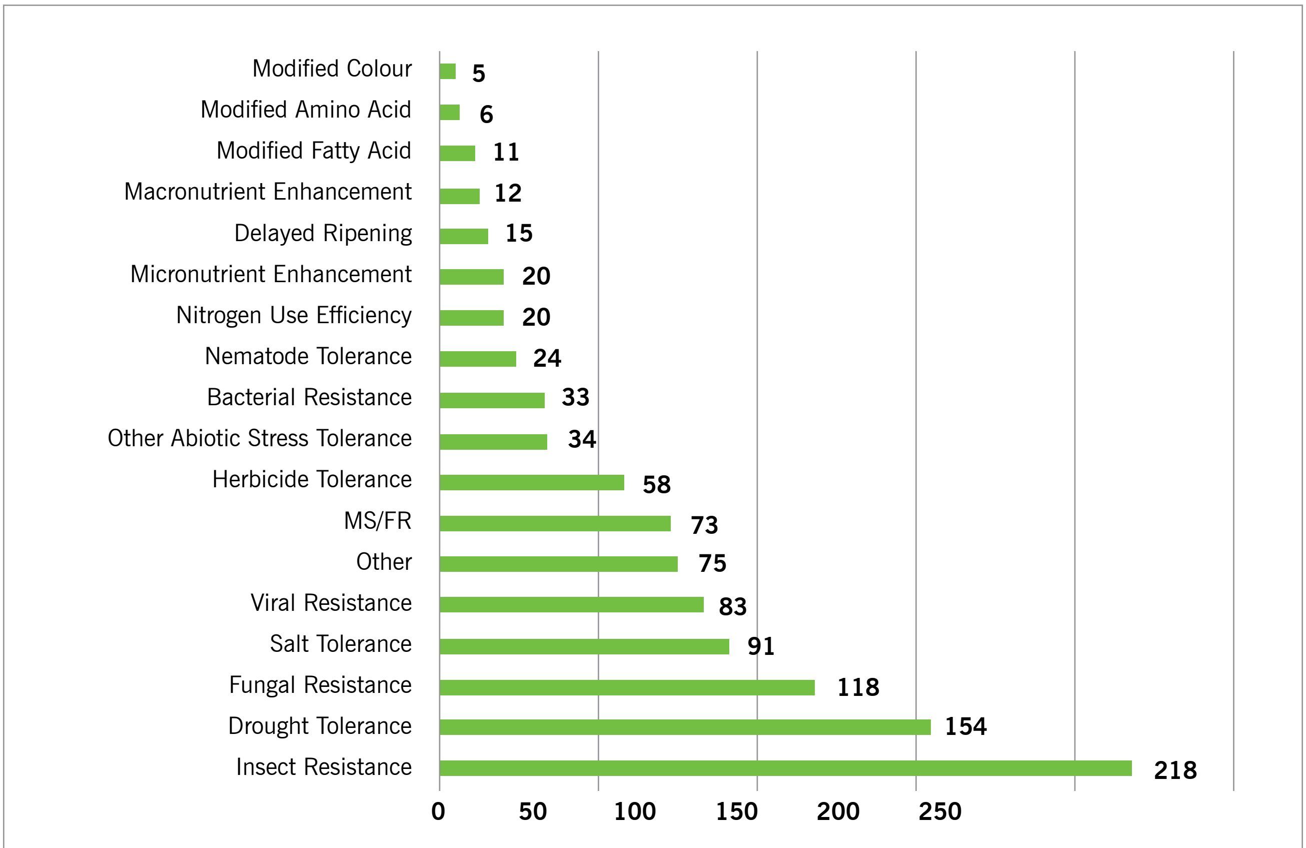


**Table 4: List of crop species in the R&D pipeline in India**

| | | | |
|---|---|---|---|
| *Amorphophallus* | *Cenchrus* | *Lathyrus* | Rice |
| Apple | *Centaurea depressa* | Lucerne | Rubber tree |
| *Arabidopsis* | Chickpea | Maize | Safflower |
| Areca nut | Chili | Mango | Scented rose |
| *Brassica caranata* | Cocoa | Medicinal plants | Sesame |
| *Brassica juncea* | Coconut | *Melia* | Sorghum |
| *Brassica napus* | Coffee | Millet | Soybean |
| *Brassica nigra* | Common bean | Morus sp. | Spinach |
| *Brassica rapa* | Cotton | Mung bean | Stevia |
| *Bacopa monnieri* | Cowpea | Mustard | Sugarcane |
| Bamboo | Cumin | *Ocimum sanctum* | Sunflower |
| Banana | *Dendrobian* | Oilseed *brassicas* | Sweet potato |
| Black gram | *Dolichos* | Okra | *Swertia spp.* |
| Black pepper | *Eleusine coracana* | Onion | *Switennia mehagony* |
| Brahmi | Eucalyptus | *Panicum* | Tea |
| *Brassica spp.* | Field pea | Papaya | Teak |
| Brinjal | Finger millet | Pearl millet | Tobacco |
| Broccoli | Foxtail millet | *Pennisetum* | Tomato |
| Cabbage | Garden pea | *Phalaris minor* | *Triticale* |
| Capsicum | Ginger | *Phillanthus* | Turmeric |
| Cardamom | *Gmelina* | *Picorhhiza kurroa* | Vegetables |
| Cassava | Green gram | Pigeon pea | Watermelon |
| Castor | Ground nut | Pomegranate | Wheat |
| Casuarina | Guava | Poplar | *Withania somnifera* |
| *Catharanthus* | Isagbol | Potato | |
| Cauliflower | Jatropha | Red pepper | |

*Source: MoEFCC 2016, Genetically Engineered Plants in the Product Development Pipeline in India*

**Figure 5: Aggregated responses for traits that are being studied in R&D programmes in MoEFCC survey (2016)**




*Source: MoEFCC 2016, Genetically Engineered Plants in the Product Development Pipeline in India*

In one of the surveys conducted by MoEFCC in 2014 under the UNEP/GEF supported Phase II Capacity Building Project on Biosafety, over 85 different plant species were identified as being used in experimental work, including plants used for food, livestock feed, fiber fuel and dietary or medicinal purposes (MoEFCC 2016). A comprehensive list of all of the crop species identified by respondents in the survey is placed in Table 4 and various traits under development are shown in Figure 5.

Out of the above, more than 20 plants with varying traits such as hybrid seed production, insect resistance, herbicide tolerance, abiotic stress tolerance, nutritional enhancement etc. are under various stages of field trials. A list of GE plants for which confined field trials have been approved in the period 2013-2017 is placed below:

**Table 5: An indicative list of GE plants approved for confined field trials in India in 2013-2017**

| S.No. | Plant | Trait | Organization |
|---|---|---|---|
| 1. | Brinjal | Insect resistance | - Indian Agricultural Research Institute<br>- Maharashtra Hybrid Seeds Company Private Limited (MAHYCO)<br>- Bejo Sheetal Seeds |
| 2. | Cabbage | Insect resistance | - Sungro Seeds |
| 3. | Castor | Insect resistance | - Indian Institute of Oilseeds Research |
| 4. | Cauliflower | Insect resistance | - Sungro Seeds |
| 5. | Chickpea | Abiotic stress tolerance, insect resistance | - Indian Institute of Pulses Research<br>- International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)<br>- MAHYCO |
| 6. | Corn | Insect resistance, herbicide tolerance | - Monsanto<br>- Pioneer<br>- Dow Agrosciences |
| 7. | Cotton | Insect resistance, herbicide tolerance | - Central Institute of Cotton Research<br>- MAHYCO<br>- Dow Agrosciences |
| 8. | Groundnut | Virus resistance, abiotic stress tolerance | - ICRISAT |
| 9. | Mustard | Hybrid seed production | - University of Delhi South Campus |
| 10. | Okra | Insect resistance | - MAHYCO |
| 11. | Papaya | Virus resistance | - Indian Institute of Horticultural Research |
| 12. | Pigeon pea | Insect resistance | - Indian Institute of Pulses Research<br>- MAHYCO |
| 13. | Potato | Tuber sweetening, fungal resistance | - Central Potato Research Institute |
| 14. | Rice | Insect resistance, diseases resistance, hybrid seed production, nutritional enhancement | - Indian Agricultural Research Institute<br>- Tamil Nadu Agricultural University<br>- Bayer Bioscience Private Limited<br>- MAHYCO<br>- BASF India Ltd. |
| 15. | Rubber | Abiotic stress tolerance | - Rubber Research Institute of India |
| 16. | Sorghum | Insect resistance, abiotic stress tolerance | - Indian Institute of Millets Research |
| 17. | Sugarcane | Insect resistance | - Sugarcane Breeding Institute |

| S.No. | Plant | Trait | Organization |
|---|---|---|---|
| 18. | Tomato | Insect resistance, virus resistance, fruit ripening | - Indian Institute of Vegetable Research<br>- National Research Centre on Plant Biotechnology<br>- MAHYCO |
| 19. | Watermelon | Virus resistance | - Indian Institute of Horticultural Research |
| 20. | Wheat | Effect of mutant strains Azotobacter | - National Research Centre on Plant Biotechnology |

*Source: Biosafety Resource Kit 2018*

In addition to the above applications, efforts are underway for testing of GE male sterile mosquitoes. Development of GE silkworms is also being actively pursued and multi-location trials in contained facilities have been undertaken.

## 3. Biosafety regulations in India

India has a systematic and structured regulatory framework for biosafety evaluation of GMOs and products thereof. The biosafety regulations for GMOs were notified, way back in 1989, corresponding to the initiation of research activities involving modern biotechnology in the country. The apex rules for regulation of all activities related to GMOs are notified under Environment (Protection) Act, 1986. In addition, there are other acts, rules and policies which are also applicable to these organisms. An overview of key legal instruments is as under:

**Box 1: Definition of genetic engineering in Rules, 1989**

The gene technology and genetic engineering have been defined as follows in the text of the Rules, 1989.

(i) "Gene Technology" means the application of the gene technique called genetic engineering, include self-cloning and deletion as well as cell hybridization;

(ii) "Genetic engineering" means the technique by which heritable material, which does not usually occur or will not occur naturally in the organism or cell concerned, generated outside the organism or the cell is inserted into said cell or organism. It shall also mean the formation of new combinations of genetic material by incorporation of a cell into a host cell, where they occur naturally (self-cloning) as well as modification of an organism or in a cell by deletion and removal of parts of the heritable material.

*Source: Rules 1989 (http://geacindia.gov.in)*

### 3.1 Manufacture, Storage and Import of Hazardous Chemical Rules, 1989

In India, the MoEFCC introduced the Environment (Protection) Act, 1986 as umbrella legislation to provide a holistic framework for the protection and improvement to the environment. After that a series of Rules were notified to address various problems such as hazardous chemicals, hazardous wastes, solid wastes, biomedical wastes etc. In connection with the use of micro-organisms and application of gene technology, the MoEFCC notified the "Rules for manufacture, use/import/ export & storage of hazardous microorganisms/ genetically engineered organisms or cells, 1989" as per powers conferred by Sections 6, 8 and 25 of Environment (Protection) Act, 1986. These rules are very broad in scope essentially covering the entire spectrum of activities involving GMOs and products thereof. The definition of gene technology and genetic engineering as per Rules, 1989 is given in Box 1. Rules, 1989 also apply to any substances and products etc., of which such cells, organisms or tissues thereof form a part. New gene technologies apart from genetic engineering have also been included.

Rules, 1989 are implemented by MoEFCC jointly with the Department of Biotechnology (DBT), Ministry of Science and Technology and state governments. Six Competent Authorities, their composition and roles have been notified in the Rules. While the Recombinant DNA Advisory Committee (RDAC) is advisory in function, the Institutional Biosafety Committee (IBSC), Review Committee on Genetic Manipulation (RCGM) and Genetic Engineering Appraisal Committee (GEAC) are responsible for regulating function. State Biotechnology Coordination Committee (SBCC) and District Level Committee (DLC) are for monitoring purposes (Figure 6). The functions of these committees may be seen in Table 6.

The interactive mechanisms between committees have also been provided in Rules,

**Figure 6: Six statutory committees under Rules, 1989**

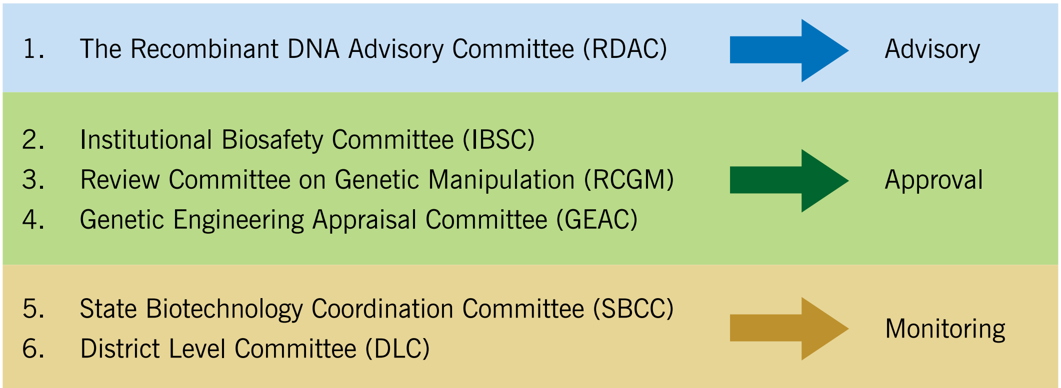



**Table 6: Functions of statutory committees as per Rules, 1989**

| Statutory Committee | Function | Housed at |
|---|---|---|
| **rDNA Advisory Committee (RDAC)** | Review developments in biotechnology and recommend appropriate safety regulations for recombinant DNA research, use and applications | Department of Biotechnology, Ministry of Science and Technology |
| **Institutional Biosafety Committee (IBSC)** | Responsible for ensuring adherence to safety guidelines for experimentation at a designated location | All organizations engaged in activities involving GMOs |
| **Review Committee on Genetic Manipulation (RCGM)** | Review all ongoing rDNA projects and approve experiments falling in risk category III and above; also responsible for bringing out manuals of guidelines for the conduct of GMO research and use | Department of Biotechnology, Ministry of Science and Technology |
| **Genetic Engineering Appraisal Committee (GEAC)** | Authorized to review, monitor and approve all activities including import, export, transport, manufacture, use or sale of GMOs and products thereof from environment angle | Ministry of Environment, Forest and Climate Change |
| **State Biotechnology Coordination Committee (SBCC)** | Monitoring and supervision at the state level | Concerned state Governments |
| **District Level Committee (DLC)** | Supervision and compliance at district level | |

1989. All IBSCs are required to review the applications and submit their recommendations and reports to RCGM. RCGM reviews and gives its recommendation for large scale activities, field trials and environmental release to GEAC. In addition to the above, various sub-committees and expert committees are constituted by RCGM and GEAC on a case by case basis. Such committees comprise of experts from various disciplines drawn from public sector institutions to prepare and review various guidelines and biosafety data. Central Compliance Committees are also set up for monitoring of confined field trials on a case by case basis. An example of the functioning of the regulatory system for confined field trials and environmental release of GE plants is illustrated in Figure 7.

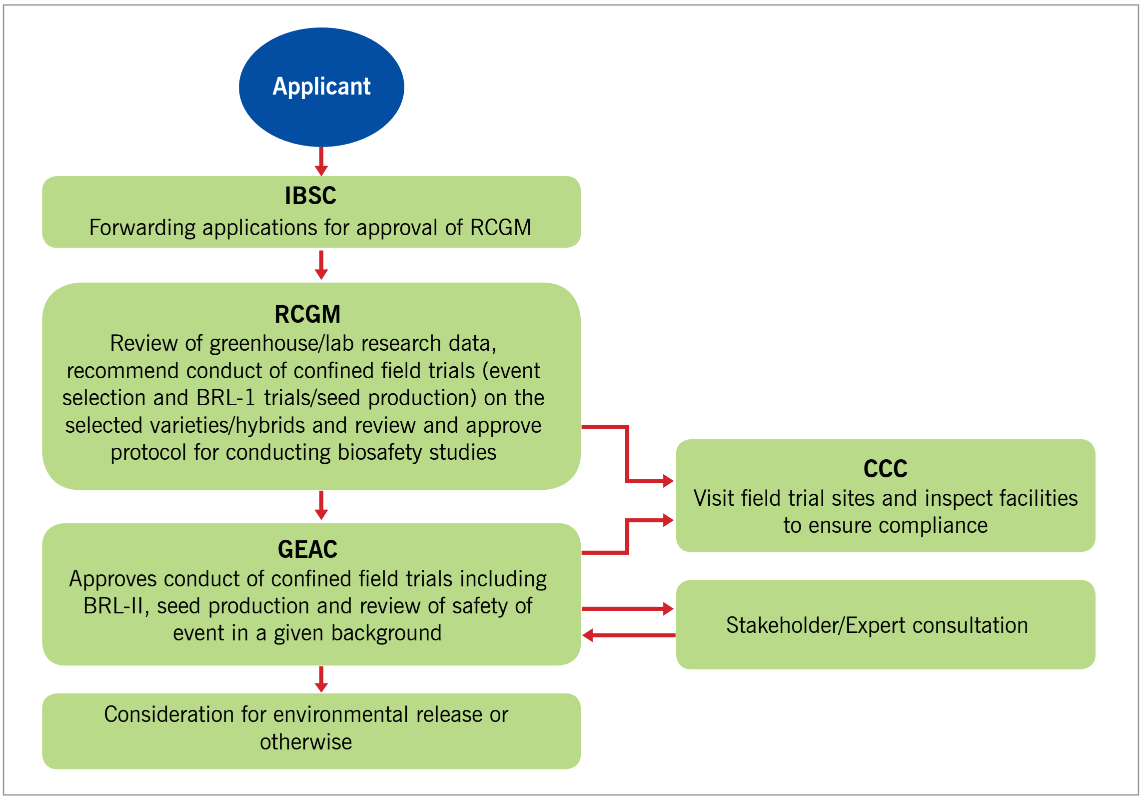
Rules, 1989 provide for compliance of the biosafety safeguards and any violation and non-compliance in this area attracts punitive actions provided under the EPA, 1986.

Various notifications have also issued under Rules, 1989 from time to time to address issues such as empowering Seed Inspectors/Seed Analyst/ Laboratories notified under Seed Act under Environment (Protection) Act, 1986, exempting certain categories of recombinant pharmaceutical products, GM foodstuff, ingredients in foodstuff and additives from the purview of Rules, 1989.

### 3.2 Plant Quarantine (Regulation for import into India) Order 2003

Regulation of import of germplasm/ GMOs/ transgenic plant material for research purpose is governed under the Plant Quarantine Order, 2003 notified by the Ministry of Agriculture and Farmers Welfare, Government of India. National Bureau of Plant Genetic Resources (NBPGR) has been designated as the Competent Authority to issue import permits for import of seeds for research purposes after getting permission under Rules 1989 and to receive import material from customs

**Figure 7: Procedure for approval of confined field trials and environmental release of GE plants**



authorities for quarantine inspection. The suppliers of the transgenic material are required to certify that the transgenic material has the same genes as described in the permit and that these transgenic materials do not contain any embryogenesis deactivator gene sequence.

### 3.3 Food Safety and Standards Act, 2006

Food Safety and Standards Authority of India (FSSAI) regulates the manufacture, storage, distribution, sale and import of food which includes GM food as per the Food Safety and Standards Act, 2006. The "genetically modified food" has been defined in the Act as the food, which is produced through techniques in which the genetic material has been altered in a way that does not occur naturally by mating or having an adequate human intervention or both. Techniques of Genetic Engineering or modification include, but are not limited to recombinant DNA, cell fusion, micro and macro injection, encapsulation, gene deletion, addition and doubling.

### 3.4 Supporting guidelines for GMOs

Rules, 1989 are supported by a series of guidelines issued by MoEFCC and DBT. These guidelines provide for safety assessment procedures to be followed at various stages of development of GMOs, i.e. research, confined field trials, food safety assessment and environmental risk assessment. Issuance of guidelines by regulatory authorities in India corresponds to the research and development activities. Recombinant DNA Safety Guidelines are primarily focussing on research and development activities on GMOs, shipment and importation for laboratory research etc. These guidelines were adopted in 1990 within a year of notification of Rules, 1989. These guidelines provided guidance on containment measures to be followed for various categories of organisms based on risk category. The guidelines have been recently updated in 2017 and provide for appropriate practices, equipment and facilities necessary for safeguards in handling organisms, plants and animals.

As the active research was initiated on transgenic plants in the late nineties in India, "Guidelines for research in transgenic plants" were issued in 1998 by DBT to provide required guidance. The guidelines also provide for the design of a greenhouse and safeguards to be followed in field trials. Guidelines and Standard Operating Procedures for the conduct of confined field trials of regulated GE Plants were issued by DBT and MoEFCC in 2008.

Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered (GE) Plants were prepared by the Indian Council of Medical Research (ICMR) and adopted by RCGM and GEAC in 2008. These guidelines provide guidance on principles and steps on the food safety assessment of GE plants and are based on guidelines and principles of Codex Alimentarius Commission, 2003 (Codex 2003 a&b). The guidelines include three appendices on dossier preparation checklist, Codex Alimentarius principles for the risk analysis of foods derived from modern biotechnology, safety assessment of foods derived from GE plants modified for nutritional or health benefits and food safety assessment in situations of the low-level presence of GE plant material in food. A series of accompanying protocols have been prepared by DBT.

MoEFCC in association with DBT adopted a set of three documents to strengthen the environmental risk assessment (ERA) of GE plants in India in 2016. These include Guidelines for the ERA of GE Plants, 2016; ERA of GE Plants: A Guide for Stakeholders and Risk Analysis Framework 2016. The Risk Analysis Framework is based on the problem formulation approach. Concepts and principles of risk assessment, risk management and risk communication have been explained in the Risk Analysis Framework. Guidelines for ERA of GE plants have been prepared in consonance with Annex III to the Cartagena Protocol on Biosafety.

Guidelines have been prepared for biopharmaceuticals and biosimilars by DBT and Central Drugs Standard Control Organization (CDSCO). All these guidelines are listed in Box 2 and can be accessed at http://geacindia.gov.in.

4. **Capacity building initiatives**

Capacity building in biosafety in India has been commensurate with developments in biotechnology, biosafety regulations in the country and commitments under the international agreements. Efforts have been led by MoEFCC, DBT and Ministry of Agriculture and Farmers Welfare. Other stakeholders such as research institutions, science academies, industry associations etc. have also supported

**Box 2: Biosafety guidelines for GMOs**

- Recombinant DNA Safety Guidelines, 1990 (updated in 2017)
- Revised Guidelines for Research in Transgenic Plants, 1998
- Guidelines for generating preclinical and clinical data for rDNA vaccines, diagnostics and other biologicals, 1999
- Guidelines and Standard Operating Procedures (SOPs) for Conduct of Confined Field Trials of Regulated GE Plants, 2008
- Guidelines and Handbook for Institutional Biosafety Committees (IBSCs), 2011
- Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered Plants, 2008 (Updated in 2012)
- Protocols for Food and Feed Safety Assessment of GE Crops, 2008
- Guidelines on Similar biologics: Regulatory requirements for Marketing Authorization in India, 2012 (updated in 2016)
- Guidelines for Environmental Risk Assessment (ERA) of GE Plants, 2016
- Risk Analysis Framework, 2016
- ERA of GE Plants: A Guide for Stakeholders, 2016

**Figure 8: List of publications for promoting capacity building**

these initiatives. Preparation of regulatory guidelines and resource documents to support regulatory committees and improve understanding of technology developers has been an ongoing process. More than 300 awareness and training workshops for concerned stakeholders have been organized by the government, since the approval of *Bt* cotton. India has implemented two projects supported by the Global Environment Facility (GEF), i.e., the World Bank/GEF Project from 2004-2007, and UNEP/GEF Project from 2012-2016. The first project focused on strengthening implementation of biosafety regulatory framework in general and Phase II project focused on four key thrust areas, viz., Risk Assessment and Risk Management, Handling Transport, Packaging and Identification, Socioeconomic Considerations and Public Awareness. These areas were aligned with the Framework and Action Plan for Capacity Building for the Effective Implementation of the Cartagena Protocol on Biosafety (2012-2020) (SCBD 2013) (Box 3) and Strategic Plan for CPB for the period 2011-2020 (SCBD 2010) (Box 4).

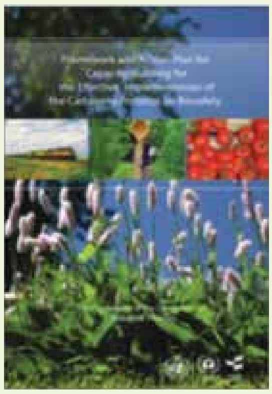
Some of the key achievements are highlighted below:

i. **Regulatory guidelines**

Development of a GE plant takes place in a stepwise process. Scientists investigate potential beneficial traits, identify genes and carry out genetic transformations in research labs and green houses. For advancing research, confined field trials (CFTs) are conducted in a real-life environment. Safety assessment studies are undertaken for securing regulatory approval in the country where the plant will be grown, and/or its products consumed by humans or animals. The final step is commercial production (Figure 9).

As a result of consistent efforts by MoEFCC, DBT and other agencies, state-of-the-art

**Box 3: Action plan for strengthening the capacity building initiatives under the Cartagena Protocol on Biosafety**



- Develop capacity-building materials and guidelines on mainstreaming biosafety into NBSAPs and national development plans
- Organize sub-regional training on mainstreaming biosafety into NBSAP and development plans, making use of the above e-learning module and toolkit (Activity 97), in collaboration with partners
- Support selected developing countries to implement pilot projects to develop and apply practical measures and approaches for integrated implementation of the Cartagena Protocol and the CBD at the national level and share emerging good practices and lessons learned
- Organize training courses in risk assessment of LMOs
- Develop e-learning modules on risk assessment of LMOs
- Organize regional and sub-regional training courses to enable Parties to implement the LMO identification requirements of paragraph 2 (a) of Article 18 and related decisions
- Organize workshops on sampling, detection and identification of LMOs
- Organize online discussions and knowledge-sharing sessions through the Network of Laboratories on the detection and identification of LMOs
- Organize sub-regional workshops on public awareness and education concerning LMOs
- Develop, in collaboration with relevant organizations, training materials on sampling, detection and identification of LMOs
- Develop learning materials on public awareness and education concerning LMOs
- Organize workshops to raise awareness of the Nagoya-Kuala Lumpur Supplementary Protocol on Liability and Redress

*Source: http://bch.cbd.int/protocol/cpb_otherpubl.shtml*

**Box 4: Strategic Plan for the CPB 2011-2020**


- The Strategic Plan for the CPB for the period 2011-2020 was adopted by the Parties to the Protocol in October 2010 in Nagoya, Japan. It comprises a vision, a mission, five strategic objectives and twenty-three operational objectives

**VISION**

Making biodiversity adequately protected from any adverse effects of LMOs

**MISSION**

Strengthen global, regional & national action and capacity in ensuring an adequate level of protection in the field of the safe transfer, handling and use of LMOs that may have adverse effects on the conservation and sustainable use of biological diversity

**Strategic Objectives**

The focal areas underlying the five strategic objectives are as follows:

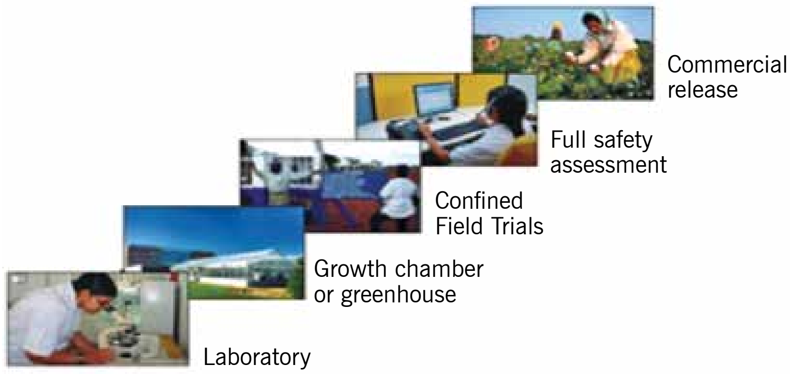
- Facilitating the establishment and further development of systems for the implementation of the Protocol
- Capacity-building
- Compliance and review
- Information sharing
- Outreach & cooperation

For each strategic objective a number of operational objectives, expected outcomes and indicators are outlined.

- All Parties are required to allocate adequate human and financial resources to expedite the implementation of the Strategic Plan.
- A mid-term evaluation of the Strategic Plan has been carried out in conjunction with third assessment and review of the effectiveness of the CPB at the COP-MOP 8 in 2016.
- A final evaluation of the Strategic Plan will take place at the COP-MOP 10 in 2020

*Source: http://bch.cbd.int/protocol/cpb_factsheets.shtml*

**Figure 9: Stepwise process of development of a GE plant**




guidance is available for each step of the development process of a GE plant (Box 5). These guidelines and protocols based on internationally accepted principles have been prepared by expert committees followed by extensive consultations with stakeholders.

Several resource documents have been prepared from time to time to support the effective implementation of the guidelines by technology developers, members of regulatory committees and other stakeholders. These include series of crop specific biology documents, monitoring manual for confined field trials, multi-country comparison of information and data requirements for the ERA assessment, post-release monitoring etc.

ii. **Training and sensitization of stakeholders**

Training, is one of the key elements for capacity

**Box 5: Biosafety guidelines for GE plants**

**Contained use (DBT)**
- Recombinant DNA Safety Guidelines, 1990 (Updated in 2017)
- Revised Guidelines for Research in Transgenic Plants, 1998

**Confined field trials (MoEFCC and DBT)**
- Guidelines for Conduct of Confined Field Trials of Regulated GE Plants, 2008
- Standard Operating Procedures (SOPs) for CFTs of Regulated, GE Plants, 2008
- Guidelines for Monitoring of Confined Field Trials of Regulated GE Plants, 2008

**Food safety assessment (DBT and ICMR)**
- Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered Plants, 2008 (Updated in 2012)
- Protocols for Food and Feed Safety Assessment of GE Crops, 2008

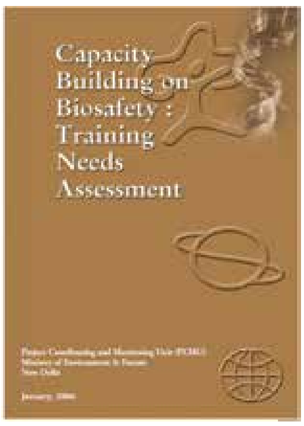
**Environmental safety assessment (MoEFCC and DBT)**
- Guidelines for Environmental Risk Assessment (ERA) of GE Plants, 2016
- ERA of GE Plants: A Guide for Stakeholders, 2016

**Box 6: Crop specific biology documents**

Crop specific biology documents are useful reference for conducting CFTs and safety assessment. Biology documents provide an overview of pertinent biological information on the untransformed (i.e., conventional or non-transgenic) species as a comparator against which GE plants are evaluated during the safety assessment process. These documents define the baseline information which serves as a resource tool for planning of CFTs by the developers, researchers and regulatory agencies.

MoEFCC and DBT prepared five biology documents on cotton, okra, rice, maize and brinjal in 2008. Eight additional biology documents on Sorghum, Mustard, Potato, Papaya, Chickpea, Pigeon pea, Tomato and Rubber.


building of various stakeholders, several initiatives have been undertaken by MoEFCC and DBT at central, state and institutional levels. To ensure systematic training programs, a Training Needs Assessment Survey was undertaken by MoEFCC in 2006 in association with Biotech Consortium India Limited (BCIL) to assess the requirements of various stakeholders in the public and private sectors specifically for GE crops. The priority areas for training were identified and accordingly, the training programmes/ workshops were conducted under the project. The training programmes, workshops and hands-on training have been undertaken in partnership with research institutions, state agriculture and environment departments, state agricultural universities, customs and quarantine agencies etc. Regulators and scientists from the public sector have also been



provided training in key regulatory agencies of other countries with functional regulatory system and institutions through various exchange programmes.

iii. **Publications**

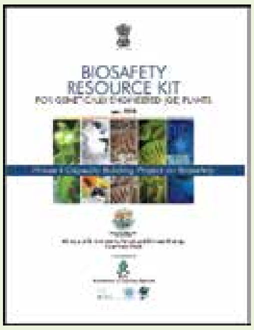
Several publications covering key issues have been prepared as part of the capacity building to inform the stakeholders about the key features of GMOs and regulatory aspects. These include manuals, resource documents, primers, and information kits. These documents have also been translated into multiple Indian languages for enhancing outreach at the grassroots level. A most recent publication is the Biosafety Resource Kit prepared by MoEFCC as part of the Phase II Capacity Building Project on Biosafety (Box 7).

iv. **Detection capacities**

The detection and identification of LMOs are important for national authorities in the enforcement of biosafety regulations. Strengthening institutional infrastructure for detection of LMOs has been one of key areas. While several organizations were funded from time to time, four laboratories were shortlisted after a technical audit by an international consultant. These laboratories have been strengthened in terms of facilities, equipment and trained manpower by MoEFCC. In 2017, the laboratories were designated as National Referral Laboratories to detect the presence or absence of LMOs/GMOs under the Seeds Act, 1966 (MoAFW 2017) (Box 8).

Detection methodologies have been demonstrated to multiple stakeholders from enforcement agencies viz. customs, plant quarantine, food safety inspectors, agriculture officials and scientists by conducting hands-on sessions in approximately 50 training and sensitization programmes organized under the Phase II Capacity Building Project.

**Box 7: Biosafety Resource Kit: Updated 2018**




Biosafety Resource Kit consisting of five brochures was first prepared in 2015 on key issues related to GE plants under the UNEP/GEF supported Phase II Capacity Building Project on Biosafety. The kit consists of five brochures to provide basic information on frequently asked questions, confined field trials, the regulatory framework in India, Cartagena Protocol on Biosafety, and useful information/databases on safety assessment. An updated version of the Biosafety Resource Kit has now been prepared for circulation among relevant stakeholders by MoEFCC and Biotech Consortium India Limited (BCIL).


*v.* **Digital systems**

Initiatives for the use of the digital system in biosafety regulations to increase ease of operation, transparency and information outreach include setting up of a new website with provision for e-application and processing and e-monitoring of confined field trials of GE plants. In addition, e-learning courses have been prepared on various guidelines including confined field trials, institutional biosafety committees and environmental risk assessment of GE plants.

## 5. Way forward

All the above efforts have helped in strengthening biosafety management system in India with a view to ensure an adequate level of protection in the field of safe transfer, handling and use of LMOs. While the use of LMOs in healthcare products is well accepted, India's regulatory experience with commercialization of GM crops is limited to Bt cotton, whereas Bt brinjal and GM mustard are still under regulatory consideration. Several innovative crop/trait combinations relevant to Indian agriculture are in the pipeline. However, polarized debates among the stakeholders require extensive outreach efforts for sharing factual information. Research efforts are also underway in new and emerging biotechnologies such as gene editing, synthetic biology etc. and accordingly, new policy interventions and regulatory capacities for assessment of technologies are required. Strengthening the implementation of rules and regulations at the level of states and local bodies is also a priority area. To conclude, India is a vast country with a large population and active biotechnology research programmes across the country need extensive capacity building efforts to ensure the safe and sustainable use of LMOs in the country.

**Box 8: National referral laboratories for detection of LMOs**

1. DNA Fingerprinting and Transgenic Crop Monitoring Lab (DFTCML), Guntur, Andhra Pradesh
2. ICAR-National Bureau of Plant Genetic Resources (NBPGR), New Delhi
3. Export Inspection Agency (EIA), Kochi, Kerala
4. Punjab Biotechnology Incubator (PBTI), Mohali, Punjab

2 THE GAZETTE OF INDIA : EXTRAORDINARY [PART II—SEC. 3(ii)]

MINISTRY OF AGRICULTURE AND FARMERS WELFARE

(Department of Agriculture, Cooperation and Farmers Welfare)

NOTIFICATION

New Delhi, the 15th November, 2017

**S.O. 3604(E).**—In exercise of the powers conferred by sub-section (1) of Section 4 of the Seeds Act, 1966 (54 of 1966), read with clause (c) of Rule 5 of the Seeds Rules, 1968, the Central Government hereby declares the following laboratories as the National Referral Laboratories to detect the presence or absence of Living Modified Organisms and Genetically Modified Organisms under the said Act with effect from the date of publication, for the whole of India, namely:—

(i) DNA Fingerprinting and Transgenic Crop Monitoring Lab (DFTCML), Guntur (Andhra Pradesh);

(ii) ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa Campus, New Delhi;

(iii) Export Inspection Agency (EIA), Kochi Laboratory (Kerala);

(iv) Punjab Biotechnology Incubator (PBTI), Mohali (Punjab).

[F. No. 13-127/2017-SD.-IV]

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# Genetic resources and Access and Benefit Sharing: India's experience

J. Soundrapandi[1]

## Abstract

The Convention on Biological Diversity (CBD), adopted during the Earth Summit was held between 3-14 June 1992, at Rio de Janeiro, as expressed in its Article 1, provides for the conservation of biological diversity; the sustainable use of its components; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources, transfer of relevant technologies and funding. Based on the principle of national sovereignty and equity, the CBD establishes that benefits from using genetic resources shall be shared fairly and equitably with the provider of the resources, in return for providing access – the concept known as ABS. It is widely acknowledged that the most innovative contri-bution of CBD is probably its third objective: *the fair and equitable sharing of the benefits arising out of the utilization of genetic resources* and the associated provisions thereon. India's commitment to CBD resulted in the enactment of the Biological Diversity Act (BDA), 2002. BDA imbibes the objectives of the CBD. India is a forerunner in having established a full-fledged three-tier institutional structure at National, State and Local level to implement ABS mechanism in the country. India is, in fact, the first among the megadiverse countries to come up with a law on ABS and very few among the parties to CBD to take the initiative. This article aims to provide an overview of India's experience *viz-a-viz* the implementation of the Biological Diversity Act, 2002.

## Keywords

*Biological Diversity Act, Nagoya Protocol, National Biodiversity Authority, State Biodiversity Board, Biodiversity Management Committee, Access and Benefit Sharing.*

## Introduction: Convention on Biological Diversity (CBD)

The Convention on Biological Diversity (CBD) that was adopted during the Earth Summit held on June 5, 1992, at Rio de Janeiro was the first comprehensive global agreement addressing all aspects relating to biodiversity. In pursuance to the CBD, India enacted the Biological Diversity (BD) Act in 2002, and notified the Rules in 2004, through an extensive consultative process initiated in 1994. India was one of the first few countries to have enacted such comprehensive legislation on biodiversity. The BD Act mandates its implementation through a decentralized system with the National Biodiversity Authority (NBA) at the national level, State Biodiversity Boards (SBBs) at each State level and Biodiversity Management Committees (BMCs) at local bodies level.

The CBD was inspired by the world community's growing commitment to sustainable development.

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It represents a dramatic step forward in the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources. The Convention was opened for signature on 5 June 1992 at the United Nations Conference on Environment and Development (the Rio "Earth Summit"). It remained open for signature until 4 June 1993, by which time it had received 168 signatures. The Convention entered into force on 29 December 1993, which was 90 days after the 30 ratification.

Article 1 and 15 of CBD contain the fundamental concepts of Access and Benefit Sharing (ABS). This concept is operationalized by the supplementary agreement to the CBD, i.e., Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits arising from their Utilization. Nagoya Protocol aims at the fulfilment of the third objective of CBD which is "the fair and equitable sharing of the benefits arising out of the utilization of genetic resources".

As a party to CBD, India enacted the Biological Diversity Act, 2002 and the Biological Diversity Rules, 2004. The main objectives of the Biological Diversity Act, 2002 are:

- Conservation of biological diversity;
- Sustainable use of its components;
- Fair and equitable sharing of the benefits arising out of the utilisation of genetic resources.

Internationally, both CBD and Nagoya Protocol recognize the sovereign rights of States over their natural resources. They have entrusted the member states to come up with national legislations to regulate and establish the ABS mechanism.

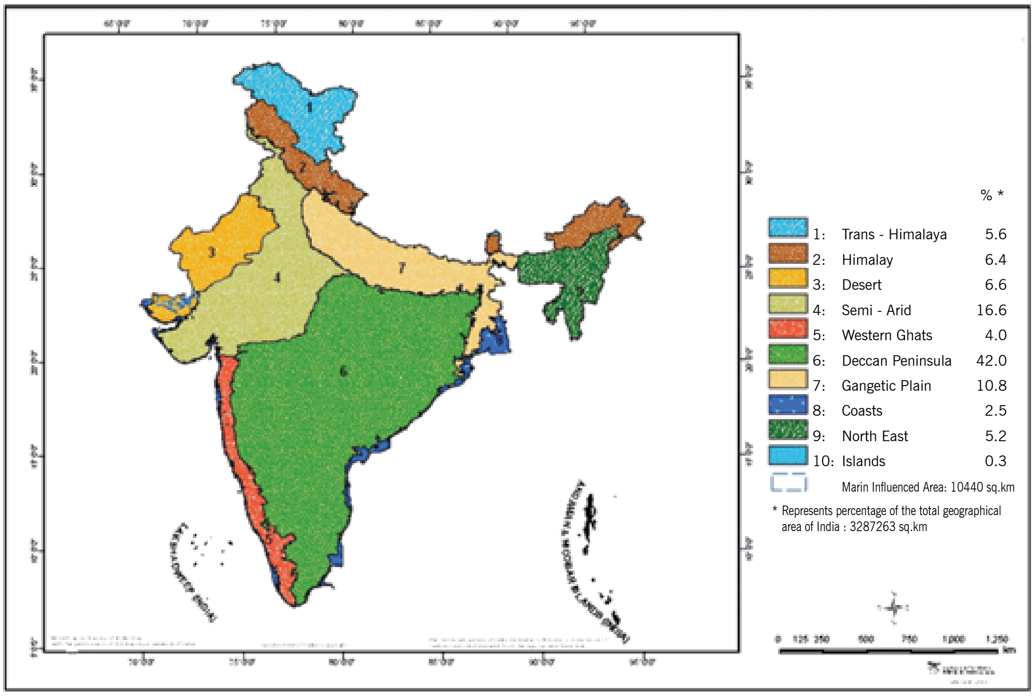
## India – A mega diversity country

India is one of the 17 mega-biodiverse countries of the world covering an area of about 329 million hectares which is 2.4 per cent of the world's land area. The country accounts for nearly 7-8 per cent of the world's recorded species which includes 48,655 species of plants and over 1,00,000 species of animals in ten bio-geographic regions. India is also rich in traditional and indigenous knowledge, coded as in ancient Indian Systems of Medicine and also informal, as it exists in oral traditions and folklore.

From the biodiversity standpoint, India has 65,222 insect species, 3,364 fish species, 407 amphibian species, 584 reptile species, 1,340 bird species and 427 mammal species, of which 18.4 per cent are endemic and 10.8 per cent are threatened (MoEF 2014). The country is home to at least 18,465 species of vascular plants, of which 26.8 per cent are endemic. It has been estimated that at least 10 per cent of the country's recorded wild flora is on a threatened list, many of the species on the verge of extinction. Nearly 6,500 native plants are still used prominently in the indigenous healthcare systems.

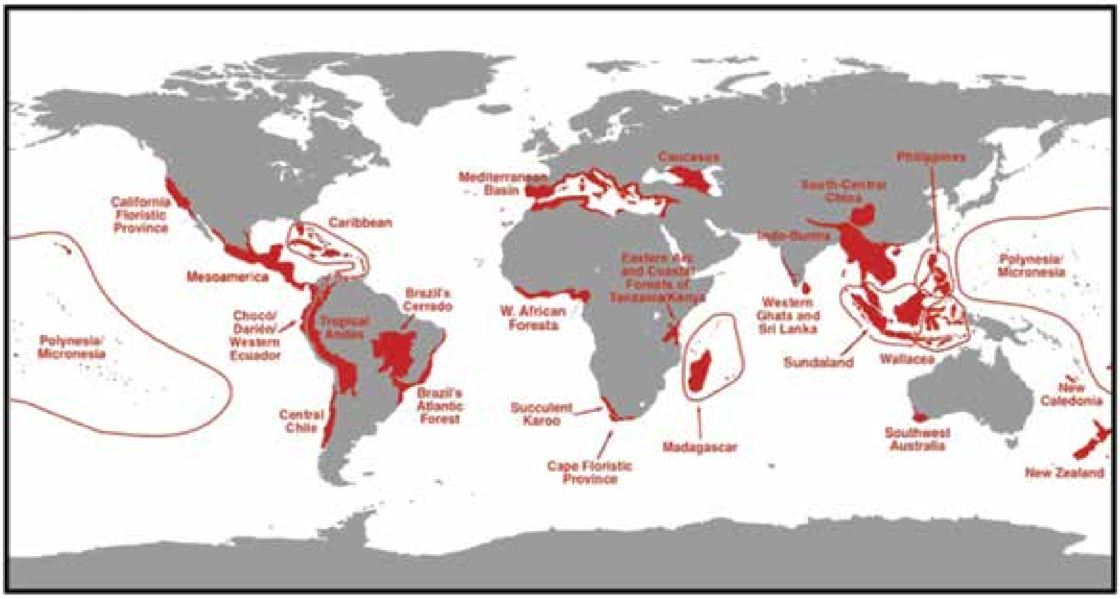
India also has a rich cultural heritage going back thousands of years. Much of Indian biodiversity is intricately related to the socio-cultural practices of the land. Unfortunately, due to population explosion, climate change and lax implementation of environmental policies, several species are facing the threat of extinction. Not only does this affect the food chain, but also the livelihood and the culture of millions of Indians who depend on local biodiversity. India's vast demographic diversity is both good and bad for its biodiversity. Good for biodiversity, because this human diversity has resulted in a plethora of customs, traditions and rituals in the context of native species. Plants and animals are considered sacred, find mentions in mythological stories and are used in religious rituals. Bad, because of the enormous pressure the human population puts on the natural resources. These deep associations between biodiversity and culture present us with a unique opportunity for their conservation.

**Figure 1 : Biogeographic Classification of India**




*Source: (Rodgers, Panwar and Mathur, 2000)*

**Figure 2 : Global Biodiversity Hotspots**




*Source: Conservation International (2013)*

Four of the 35 globally identified biodiversity hotspots, namely the Himalaya, Indo-Burma, the Western Ghats-Sri Lanka and Sundaland are in India. The key criteria for determining a hotspot are endemism (the presence of species found nowhere else on earth) and degree of threat (Conservation International 2013).

i. The Himalaya: Western and Eastern Himalaya form part of a Himalayan global biodiversity hotspot.
ii. The Western Ghats: Part of Western Ghats-Srilanka global biodiversity hotspot.
iii. North-East: Part of Indo-Burma global biodiversity hotspot.
iv. Nicobar Islands: Part of the Sundaland (including Nicobar group of Islands) global biodiversity hotspot

**Table 1: The diversity of flora in India and the World**

| SI. No. | Type | Number of known Species | | Percentage of occurrence in India | Number of Endemic Species in India | Number of Threatened Species in India |
|---|---|---|---|---|---|---|
| | | World | India | | | |
| I | **Flowering Plants** | | | | | |
| 1. | Gymnosperms | 1,021 | 79 | 7.73 per cent | 12 | 7 |
| 2. | Angiosperms | 2,68,600 | 18,386 | 6.84 per cent | ca. 4303 | 1700 |
| II | **Non-flowering Plants** | | | | | |
| 1. | Bryophytes | 16,236 | 2,748 | 16.92 per cent | 629 | ca. 80 |
| 2. | Pteridophytes | 12,000 | 1,289 | 10.74 per cent | 66 | 414 |
| III | **Others** | | | | | |
| 1. | Viruses and Bacteria | 11,813 | 1,170 | 9.90 per cent | Not Known | Not known |
| 2. | Algae | 40,000 | 7,357 | 18.39 per cent | 1924 | Not known |
| 3. | Fungi | 98,998 | 15,115 | 15.26 per cent | ca. 4100 | ca. 580 |
| 4. | Lichens | 17,000 | 2,511 | 14.77 per cent | ca. 520 | Not known |
| **Total** | | **4,65,688** | **48,655** | – | | |

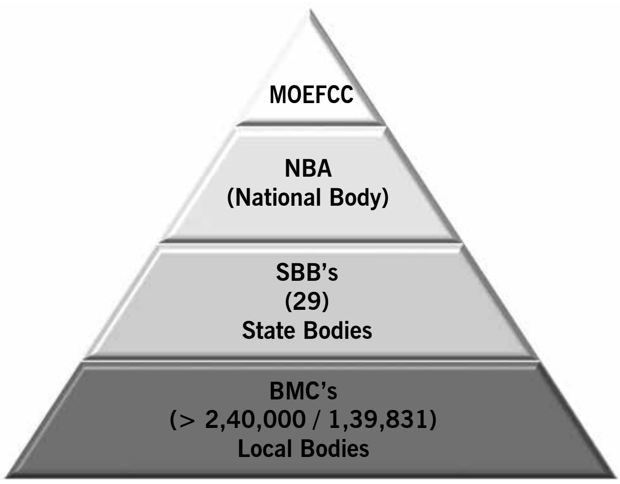
*Source: http://www.bsienvis.nic.in/Database/Floral_Statistics_of_India_2017_26352.aspx*

**Table 2: Diversity of fauna in India and the World**

| Faunal diversity in India (Group) | World (number of species) | India (number of species) | (per cent) in India |
|---|---|---|---|
| Mammals | 5,853 | 427 | 7.29 |
| Birds | 10,357 | 1,340 | 12.93 |
| Reptiles | 10,450 | 584 | 5.58 |
| Amphibians | 7,667 | 407 | 5.30 |
| Fishes | 34,362 | 3,364 | 9.78 |
| Insects | 10,53,578 | 65,222 | 6.19 |
| Molluscs | 84,978 | 5,205 | 6.12 |
| **Grand Total (Protista + Animalia)** | **15,66,353** | **1,01,167** | **6.45** |

*Source: Director, ZSI; http://zsienvis.nic.in/SiteMap.aspx*

**Figure 3: Institutional structure**




*Source: www.nbaindia.org*

India has a very rich range of faunal diversity, which is still far from completely documented. Over 1,00,000 species of fauna have been reported from India, a little over 6 per cent of the world's reported animal diversity. There is considerable variation in the representation of different phyla and subphyla, with the percentage of species in India varying from as low as 1 per cent (*Diplura*) to as high as about 23 per cent (*Echiura*). However, much of this variation is due to several minor phyla and subphyla, which are primarily marine, and might reflect inadequate species documentation rather than real differences. Among the more speciose phyla or lower taxa, India has between 4 and 12 per cent of the global species.

## Biological Diversity Act of India

As a signatory to the CBD, India enacted the Biological Diversity Act in 2002, and notified Biological Diversity Rules in 2004, to give effect to the provisions of the Convention. The Act is implemented through a three-tiered institutional structure at the national, state and local levels. The National Biodiversity Authority (NBA) has been set up in October 2003 at Chennai.

The NBA among other things deals with all matters relating to requests for access by foreign individuals, institutions or companies, and transfer of results of research to any foreigner. The State Biodiversity Boards (SBBs) constituted by the State Governments deal with all matters relating to access by Indians for commercial purposes. The institutions of self-government are required to set up Biodiversity Management Committees (BMCs) in their respective areas for conservation, sustainable use, documentation of biodiversity and chronicling of knowledge related to biodiversity and mainly for collecting/implementing ABS.

### Genesis of the concept of Access and Benefit Sharing (ABS)

The genesis of the concept of benefit sharing arose from the recognition of interconnectedness between the lives of the communities and their ecosystems and the growing concern of the impacts of bio-prospecting and biopiracy. Various international and national legal and institutional instruments and frameworks have been developed to support the concept of ABS. At the international level, the legal framework for protection of Plant Genetic Resources and traditional knowledge is spread over a range of international conventions, protocols and guidelines which include the CBD, Nagoya protocol, Bonn guidelines, the World Intellectual Property Organization (WIPO), UN Declaration on Rights of Indigenous People (2007) and International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).

All the three objectives of the CBD are interlinked. The CBD recognizes the importance of the Local Communities (LCs) way of life and their traditional knowledge with respect to use and conservation of natural resources and encourages various institutions to work in association with the LCs in terms of management of natural resources and give them due credit for the traditional knowledge they possess. It also encourages the institutions to help safeguard the rights of such communities with respect to preservation of their bio-cultural heritage.

### Bonn Guidelines, 2002

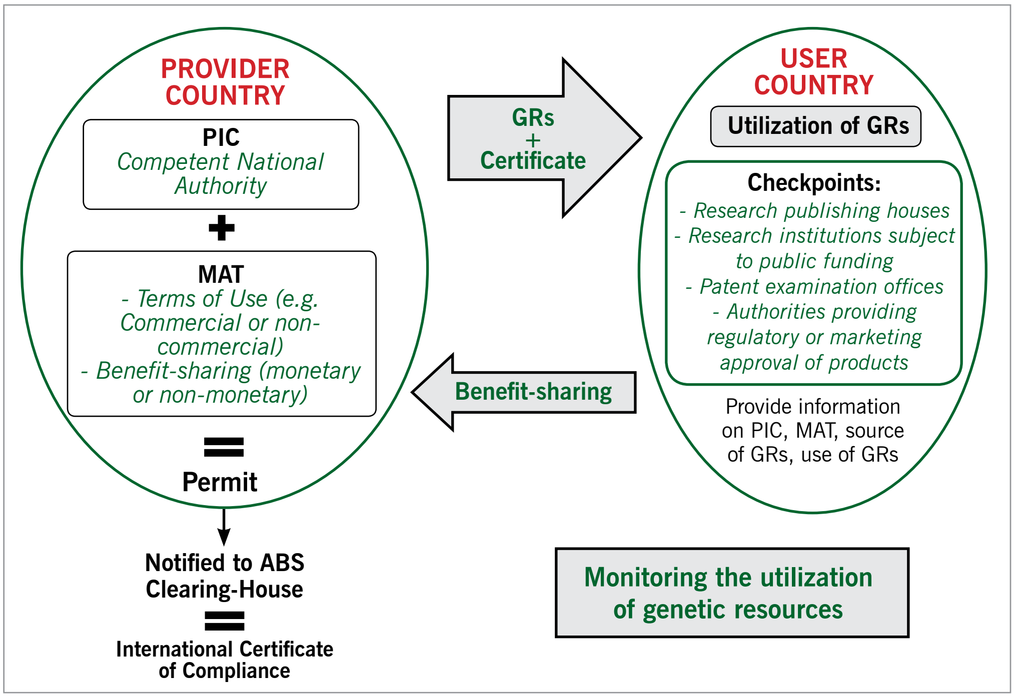
One of the significant outcomes of CBD's work on ABS is the development of the "Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization," at the October 2001 meeting of the Ad hoc Open-ended working group on Access and Benefit Sharing held in Bonn (CBD Secretariat 2002), which was adopted at the sixth meeting of the Conference of the Parties (COP) held in April 2002 in the Hague (COP decision VI/24). The guidelines provide details of an overall strategy and the essential steps, elements and principles to be adopted in developing access and benefit-sharing regimes by Parties and stakeholders.

### Nagoya Protocol, 2010

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (hereinafter Nagoya Protocol) was adopted on 29 October 2010 in Nagoya, Japan under the CBD. Adoption of the Nagoya Protocol was undoubtedly a much-awaited milestone achievement of the international community, particularly the Parties to the CBD.

The Nagoya Protocol on ABS is the instrument for the implementation of the access and benefit sharing provisions of the CBD. The Nagoya Protocol applies to genetic resources within the scope of Article 15 of the CBD and to the benefits arising from the utilization of such resources. The Protocol also applies to traditional knowledge

**Figure 4: Nagoya Protocol on ABS – A schematic representation**




*Source : www.cbd.int*

associated with genetic resources within the scope of the Convention and to the benefits arising from the utilization of such knowledge.

## India's legislative framework and implementation mechanism

The Biological Diversity Act gives effect to the various provisions of the CBD. The Act also addresses access to genetic resources and associated traditional knowledge so as to ensure equitable sharing of benefits arising out of the use of these resources and knowledge to the country and the people.

The Act provides for setting up of a three-tier structure at the national, state and local levels, for its implementation. The National Biodiversity Authority (NBA) located at Chennai deals with all matters relating to requests for access by foreign individuals, institutions or companies, and transfer of results of research to any foreigner. While granting approvals, NBA imposes conditions which secure equitable sharing of benefits arising out of the use of biological resources and associated knowledge. These benefits could include monetary gains, grant of joint ownership of IPRs, transfer of technology, an association of Indian scientists in research and development, and setting up of venture capital funds etc. Further, the NBA's approval is also required before seeking any IPR based on biological material and associated knowledge obtained from India. The NBA also has the power to oppose the grant of IPRs in any other country on biological resources or associated knowledge obtained or derived from India.

The State Biodiversity Boards (SBBs) constituted by the State Governments deal with all matters relating to access by Indians for commercial purposes. The Indian industry is required to provide prior intimation to the concerned SBB about the use of biological resources. The SBB has the power to restrict any such activity which violates the objectives of conservation, sustainable use and equitable sharing of benefits.

Section 3, 7 and 23 of the Biological Diversity Act empowers the NBA and SBBs respectively to grant approval for access to genetic resources and associated knowledge as applicable.

**Table 3: The scope of Biological Diversity Act, 2002**

| Resources | Activities |
|---|---|
| Biological resources and Associated knowledge | Access for<br>- Research<br>- Commercial utilization<br>- Bio-survey and bio-utilization |
| | Intellectual Property Rights (IPRs) |
| | Transfer of research results |
| | Transfer of already accessed biological resources/associated knowledge |

**Table 4: Activities regulated under the Biological Diversity Act, 2002**

| Activities | Persons u/s 3 (2) | Persons u/s 7 |
|---|---|---|
| Research (S. 3) | NBA | NA |
| Bio-survey and Bio-utilization (S. 3) | NBA | SBB |
| Commercial utilization (S. 3) | NBA | SBB |
| Intellectual Property Rights (S. 6) | NBA | NBA |
| Transfer of research results (S. 4) | NBA | NBA |
| Third party transfer of already accessed bioresources/ knowledge (S.20) | NBA | NA |

*Source: http://nbaindia.org/uploaded/act/BDACT_ENG.pdf*

The participation of local communities is ensured through Biodiversity Management Committees (BMCs). These are institutions of self-government that are required to be set up in their respective areas for conservation, sustainable use, documentation of biodiversity and chronicling of knowledge relating to biodiversity. Section 41(1) of the Act mandates BMCs to document biological diversity found in the jurisdiction in the form of People's Biodiversity Registers (PBRs) and chronicle Traditional Knowledge (TK) related thereto. These PBRs are a powerful tool in securing benefits for the local communities as benefit claimers.

The NBA and SBBs are required to consult the concerned BMCs on matters relating to the use of biological resources and associated knowledge within their respective jurisdictions. This mandatory consultation of BMCs by NBA and SBBs ensures formulization of prior informed consent by the communities through the involvement of BMCs in the decision-making process. The BMCs may also levy a collection fee for collecting biological resource from their respective areas.

The legislation provides for exemptions: to local people and community for free access to use biological resources within India; to growers and cultivators of biodiversity, and vaids and hakims to use biological resources; through notification by Central Government of normally traded commodities so as not to adversely affect trade of these items; for collaborative research through government sponsored or government approved institutions subject to overall guidelines and approval of the Central Government; and to value-added products.

## Regulation of access under the Biological Diversity Act, 2002

Chapter II of the Biological Diversity Act of 2002 deals with the Regulation of Access to Biological Diversity. Section 3 of the said Act deals with persons who are not to undertake Biodiversity-related activities without approval of the National

Biodiversity Authority. Section 3(1) of the Act is applicable to the persons mentioned in subsection (2) of Section 3 which includes (a) a person who is not a citizen of India; (b) a citizen of India, who is a non-resident as defined in clause (30) of section 2 of the Income-tax Act, 1961; (c) a body corporate, association or organization which is not registered in India or incorporated or registered in India under any law for the time being in force which has any non-Indian participation in its share capital or management.

Section 3(1), the Biodiversity Act states that *"no persons mentioned in Section 3(2) as stated above shall obtain any biological resources occurring in India or knowledge associated thereto for research or for commercial utilization or for bio-survey and bio-utilization without the approval of NBA.*"

Section 4 deals with the transfer of results of research to certain persons without the approval of the NBA. The provision states that "*No person shall, without the previous approval of the National Biodiversity Authority, transfer the results of any research relating to any biological resources occurring in, or obtained from, India for monetary consideration or otherwise to any person who is not a citizen of India or citizen of India who is non-resident as defined in clause (30) of section 2 of the Income-Tax Act, 1961 (43 of 1961) or a body corporate or organisation which is not registered or incorporated in India or which has any non-Indian participation in its share capital or management."*

Section 5(1) lays out the instance where the earlier Sections 3 and 4 regulating access do not apply. Section 5(1) is about certain collaborative research projects and the non-applicability of Sections 3 and 4 to such projects. The Section states that *"The provisions of sections 3 and 4 shall not apply to collaborative research projects involving transfer or exchange of biological resources or information relating thereto between institutions, including Government sponsored institutions of India, and such institutions in other countries, if such collaborative research projects satisfy the conditions specified in sub-section (3)."*

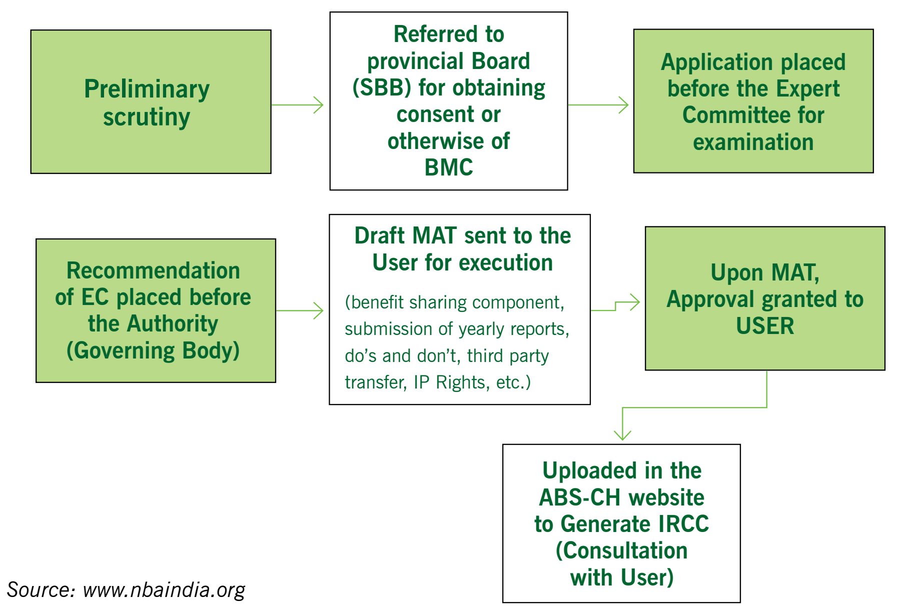
Subsection 3 of Section 5 states what collaborative research projects for the purpose of Section 5(1). Projects that: (a) conform to the policy guidelines issued by the Central Government in this behalf; (b) be approved by the Central Government would be considered as collaborative research projects for Section 5(1).

Section 5(2) further is about collaborative research projects which are based on agreements that were concluded before the commencement of this Act. It states that *"All collaborative research projects, other than those referred to in sub-section (1) which are based on agreements concluded before the commencement of this Act and in force shall, to the extent the provisions of agreement are inconsistent with the provisions of this Act or any guidelines issued under clause (a) of sub-section (3), be void."*

Section 6 of the Biological Diversity Act talks about prior approval from the NBA before an application for Intellectual Property Rights is made. Section 6(1) states that *"No person shall apply for any intellectual property right, by whatever name called, in or outside India for any invention based on any research or information on a biological resource obtained from India without obtaining the previous approval of the National Biodiversity Authority before making such application".*

The provisos to Section 6(1) state that *"if a person applies for a patent, permission of the National Biodiversity Authority may be obtained after the acceptance of the patent but before the sealing of the patent by the patent authority concerned"* and *"that the National Biodiversity Authority shall dispose of the application for permission made to it within a period of ninety days from the date of receipt thereof."* The subsections to Section 6 cover other aspects related to Intellectual property rights in relation to the Biodiversity Act.

**Figure 5 : Process of applications**




*Source: www.nbaindia.org*

## Procedures for access

The main function of the NBA is to deal with requests for access to genetic resources and traditional knowledge by foreign institutions or individuals and also the transfer of research to foreign nationals. The NBA can approve subject to any regulations or conditions as it deems fit including the imposition of charges by way of royalty [Section 19(3) of BD ACT]. Any persons mentioned above making an application for access to genetic resources, TK or a patent must make the application under the form and payment prescribed [Section 19(1) and (2) of BD ACT].

The NBA on the receipt of the application can make enquires as it deems fit and if necessary consult an expert committee constituted for this purpose. After doing the above, it can approve subject to certain conditions and regulations as discussed above. In cases where the application is rejected by the NBA, it must record the reason for the same in writing. It is stated in the BD Act that it is required that the NBA shall have to give an opportunity of being heard to the person affected if it passes an order for rejection and give public notice in cases where approval has been granted [Section 19(4) of BD ACT].

**Table 5 : Types of access applications to the NBA and the application fee**

| Type | Fee |
|---|---|
| Application for Access to Biological Resources and Associated TK (Form I) | Rs. 10,000 |
| An application seeking approval for transferring results of research (Form II) | Rs. 5000 |
| Application for seeking prior approval of the NBA for applying for Intellectual Property Right (Form III) | Rs. 500 |
| Application for 3rd party Transfer (Form IV) | Rs. 10,000 |

*Source: http://nbaindia.org/content/26/59/1/forms.html*

The request for access to biological resources or traditional knowledge is required to be made to the NBA in the prescribed Forms listed at the end of the Biodiversity Rules, 2004. Once the request is accepted, agreements in the prescribed format are signed between the NBA and the applicant. Today, agreements between the NBA and the applicant require payment of royalty fee which changes on a case to case basis and is regulated by the ABS Guidelines 2014 (NBA 2014). When NBA grants approval for research or for commercial utilization or for transfer of results of research or for Intellectual Property Rights or for third party transfer, a charge equivalent to 5 per cent of accrued benefits is applied, out of which half of the amount is retained by the NBA and the other half may be passed on to the concerned SBB for administrative charges [Section 15(a)] 95 per cent of the accrued benefits are supposed to go to the concerned BMC(s) and/ or benefit claimers [Section 15(b)].

## Procedure for granting approvals for access under the BD act and ABS guidelines

***Access to biological resources and/ or associated traditional knowledge for research or bio-survey and bio-utilization for research***

Persons who intend to obtain access to biological resources and/or associated traditional knowledge for research or bio-survey and bio-utilization for research would need to apply to the National Biodiversity Authority (NBA) in Form I of the Biological Diversity Rules, 2004 accompanied with a fee of INR 10, 000 in form of a cheque or demand draft drawn in favour of the Authority [Regn. 1(1)]. After being satisfied with the application, the NBA can enter into a Benefit Sharing Agreement with the applicant that would be deemed as a grant of approval [Regn. 1(2)]. In cases where the application is for a biological resource having high value, the Benefit Sharing Agreement may contain a clause to the effect that the benefit-sharing shall include an upfront payment by the applicant, of an amount as agreed between the NBA and the applicant [Regn. 1(2) Proviso].

***Procedure for access to biological resources, for commercial utilization or for bio-survey and bio-utilization for commercial utilization***

Persons intending to obtain access to biological resources including access to biological resources harvested by Joint Forest Management Committee (JFMC)/ Forest dweller/Tribal cultivator/Gram Sabha, would need to apply to the NBA in Form-I of the Biological Diversity Rules, 2004 accompanied with a fee of INR 10, 000 in form of a cheque or demand draft drawn in favour of the Authority or to the SBB, in such form as may be prescribed by the SBB, as the case may be, along with Form 'A' annexed to these regulations [Regn. 2(1)].

After the application is submitted to the NBA or SBB, they can enter into a Benefit Sharing Agreement with the applicant if satisfied with the application. In such instances, entering into the Benefit Sharing Agreement by the NBA or SBB with the applicant would be deemed to be the grant of approval for the access to the biological resource. This access is in relation to commercial utilization, bio-survey and bio-utilization for commercial utilization [Regn. 2(2)].

***Procedure for transfer of results of research relating to biological resources***

If a person intends to transfer the results of research relating to biological resources that occur in or are obtained from India to persons who are not citizens of India, are non-residents or a body corporate/association/organization not incorporated or registered or which is incorporated but has any non-Indian participation in its share capital or management, has to apply to the NBA. The application has to be made in Form II of the Biological Diversity Rules, 2004 accompanied by a fee of INR 5,000 in form of a Bank draft or Cheque drawn in favour of the Authority. The evidence has to be provided to the NBA by the applicant for access to the biological resource and TK involved in research [Rule 17(1) & 17(2) BD Rules 2004]. Every application received by the NBA should be decided upon by the Authority as far as possible within a period of three months from the receipt of the same [Rule 17(3) BD Rules 2004].

If the NBA is satisfied with the application, it can enter into a Benefit Sharing Agreement with the applicant which would be deemed as the grant of approval [Rule 17(4) & 17(5) BD Rules 2004]. If the Authority does not approve an application, it has to record the reasons for it in writing [Rule 17(6) BD Rules 2004].

***Procedure for obtaining Intellectual Property Rights (IPR)***

Persons who intend to obtain any IPR in or outside India for any invention that is based on any research or information on any biological resource that is obtained in India will have to make an application to the NBA in Form III of the BD Rules, 2004 accompanied by a fee of INR 5,000 [Rule 18(1) & 18(2) BD Rules 2004]. Just as the procedure for transfer of results of research relating to biological resources, persons who are not citizens, non-residents or body corporates not incorporated/registered or having any non-Indian participation have to provide evidence of approval from the NBA for access of the biological resource or TK used in the research leading to the invention [Regn. (8) Guidelines on ABS, 2014].

The NBA after appraising the application and collecting any additional information that may be required would grant the approval on the basis of merit within a period of 3 months as far as possible from the receipt of the application [Rule 18(3) BD Rules 2004]. The Authority must record the reasons in case of rejection of the application and must give an opportunity of hearing to the applicant before passing the order for rejection [Rule 18(6) BD Rules 2004].

But persons applying for any right under the Protection of Plant Varieties and Farmers' Rights Act, 2001 (53 of 2001) shall be exempted for making an application to the NBA [Regn. (8) Guidelines on ABS, 2014].

***Procedure for transfer of accessed biological resource and/or associated knowledge to third party for research/commercial utilization***

If a person intends to transfer the biological resources and/or associated TK which has earlier been given access to by the NBA, to a third party for commercial utilization or for research would have to apply to the NBA in Form IV of the BD Rules 2004 accompanied by a fee of INR 10,000 in form of Bank draft or cheque drawn in favour of the Authority [Rule 19(1) & 19(2) BD Rules 2004].

The Authority shall after collecting any additional information, decide upon the application as far as possible within a period of six months of receipt of the same [Rule 19(3) BD Rules 2004].

The approval to access shall be in the form of a written agreement duly signed by the authorized officer of the Authority and the applicant [Rule 19(5) BD Rules 2004].

***Revocation of access or approval***

The NBA or SBBs may either on the basis of any complaint or suo moto withdraw the approval granted for access and revoke the written agreement due to the certain conditions, like when the person who has been granted approval has failed to comply with the terms of the agreement or conditions of access granted.

The approval can also be revoked on account of public interest or for protection of environment and conservation of biological diversity [Rule 15(1) BD Rules 2004]. The Authority, under the BD Rules, is required to send a copy of every order of revocation issued by it to the concerned State Biodiversity Board and the Biodiversity Management Committees for prohibiting the access and also for assessing the damage, if any caused and take steps to recover the damage [ Rule 15(2) BD Rules 2004].

***Appeals by the persons aggrieved by any determination of benefit sharing***

Any persons who are aggrieved by an order or determination of benefit sharing by the NBB or SBB can file an appeal to the High Court within 30 days of the date of communication of the order to him/her (Section 52 BD ACT, 2002). The High Court may extend the period of filing the appeal for not more than 60 days, provided that it is satisfied that the appellant was prevented by sufficient cause from filing the appeal within the said period.

***Penalties***

According to the Biological Diversity Act, 2002, a person who contravenes or abets the contravention of provisions that deal with the undertaking of Biodiversity-related activities [Section (3) BD ACT, 2002], transfer of results of research [Section (4) BD ACT, 2002] and applying for intellectual property rights [Section (6) BD ACT, 2002] without approval of National Biodiversity Authority, shall be punishable with imprisonment for a term which may extend to five years, or with fine which may extend to ten lakh rupees. [Section 55(1) BD ACT, 2002] In cases where the damage caused exceeds INR 10,00,000, the fine may be commensurate with the damage caused, or with both.

Persons who contravene or abets the contravention of provisions that deals with prior intimation to be given to the SBB for obtaining biological resource for certain purposes [Section (7) BD ACT, 2002] or any orders passed by the State Biodiversity Board under Section 24(2) of the BD Act, 2002 are punishable with imprisonment for a term which may extend to three years, or with fine which may extend to INR 5,000,00 or with both [Section 55(2) BD ACT, 2002].

***Access and Benefit Sharing (ABS) Regulations, 2014 and experiences***

India's ABS Regulations provide a clear benefit-sharing mechanism to be followed by the NBA/ SBBs, with respect to access to biological resources for various activities as enshrined in the Act. The Regulation provides for legal certainty, clarity and transparency, options of benefit sharing for different users with graded percentage, upfront payment and apportioning of accrued benefits to the community/village level authority. The Regulations provides for a minimum of 0.1 per cent if the annual gross ex-factory sale of a product is within INR 1.00 crore and 0.2 per cent for sales above INR 1.00 crore and below INR 3.00 crore.

The notified guidelines envisage that when the biological resources are accessed for commercial utilization, the user shall have the option to pay the benefit sharing ranging from 0.1 to 0.5 per cent at the graded percentages of the annual gross ex-factory sale of the product minus government taxes.

Further, the Regulation 3(1) in the guidelines provides that if the trader sells the biological resource purchased by him to another trader or manufacturer, the benefit-sharing obligation on the buyer, if he is a trader, shall range between 1.0 to 3.0 per cent of the purchase price and between 3.0 to 5.0 per cent, if he is a manufacturer.

The benefit sharing mechanisms notified under the guidelines on access to biological resources and associated knowledge and benefits sharing regulations, 2014 are as follows:

**Table 6: Commercial utilization: (Regn. 4)**

| Annual Gross ex-factory sale of the product | Benefit sharing component |
|---|---|
| Up to Rupees 1,00,00,000 | 0.1 per cent |
| Rupees 1,00,00,001 up to 3,00,00,000 | 0.2 per cent |
| Above Rupees 3,00,00,000 | 0.5 per cent |

ii. Transfer of results of research, the benefit-sharing obligation is 3.0 to 5.0 per cent of the monetary consideration (Regn.7).

**Table 7: Intellectual Property Rights: (Regn.9)**

| | |
|---|---|
| If applicant himself commercialize the process/product/ innovation | 0.2 – 1.0 per cent of Annual Ex-factory gross sale (minus govt. taxes) |

| | |
|---|---|
| If applicant assigns/ licenses the process/ product/ innovation to a third party for commercialization | 3.0 – 5.0 per cent of the fee received in any form. And 2.0 – 5.0 per cent of Royalty |

iv. Transfer of accessed bioresources and Associated Knowledge (AK), the benefit-sharing obligation is 2.0 to 5.0 per cent (following sectoral approach) of any amount and / or royalty received from the transferee. (Regn. 12)

v. Where the trader sells the biological resource purchased by him to another trader or manufacturer, the buyer, (Regn. 3)
   a) *if he is a trader – pay 1.0 to 3.0 per cent of the purchase price.*
   b) *If he is a manufacturer – pay 3.0 to 5.0 per cent of the purchase price.*

vi. If the buyer submits proof of benefit sharing by the immediate seller in the supply chain –
*The buyer shall be only on that portion of the purchase price for which the benefit has not been shared in the supply chain. (Reg. 3)*

vii. In cases of biological resources having a high economic value such as sandalwood, red sanders, etc. –
The benefit sharing may include an upfront payment of not less than 5.0 per cent, on the proceeds of the auction or sale amount, as decided by the NBA or SBB, as the case may be. (Reg. 3(3))

viii. If the sale is through auction, the successful bidder or the purchaser shall pay the amount to the designated fund, before accessing the biological resource.

## Recent success stories on ABS implementation

### *Involving Biological Resources*

As per the Biological Diversity Act, 2002, a non-Indian (foreign) company requires to obtain prior approval before accessing any biological resources in India for the purpose of research or commercial utilization among other activities from the NBA. Accordingly, an agricultural company in Europe which is into production and marketing of bio-stimulants and fertilizers which has a subsidiary company in India approached the NBA. Through its subsidiary, it applied for prior approval from the NBA as it has foreign participation in its share capital and management.

The subsidiary company was primarily involved in research, development, marketing, and commercialization of products such as seeds, fertilizers and pesticides for the betterment of agriculture, health and environment. It applied to the NBA in March 2017 in Form I of the Biological Diversity Rules, 2004, which is the prescribed application form for access to biological resources for the purpose of research. Along with the application, it also submitted documents as a proof of procuring necessary environmental clearances from the concerned state pollution control board and also having an authorized license to be a wholesale dealer of selling fertilizers.

The activity for which the approval was sought was to undertake sampling which aims to collect Plant Growth Promoting Micro-Organisms (PGPMs) from soil samples for the possible development of a product as a sustainable solution for agricultural practices. PGPMs are primarily bacterial and fungal strains that produce bioactive compounds or, phytohormones, and help host plants in the acquisition of nutrients. The duration proposed was three years and the quantity of soil to be collected was around 1.5 kg. The estimated amount of investment for the activity was INR 1 million.

NBA started processing the application. In the process, PIC in the form of consent from the concerned state biodiversity board was obtained after consultation with the concerned biodiversity management committees. An internationally recognized permit was issued by the NBA and the Internationally Recognized Certificate of Compliance (IRCC) was generated. ABS Agreement containing the mutually agreed terms (MAT) and the benefit-sharing component was signed on December 2017 with a condition that in case of change of intent which is to commercialize in case of successful outcome of the research, the Applicant will inform the NBA and the necessary approval for the intended commercial activity will be procured.

In May 2018, as per the clause agreed upon in the benefit-sharing agreement for conducting research, the company approached NBA for a change of intent from research to commercial utilization. The company sought prior approval from the NBA, after the successful outcome of research, to access the microorganisms from their own collection for the purpose of commercial utilization to produce biofertilizers for use in eco-friendly agriculture. The company had proposed to develop 10 different products from 10 different bacterial and fungal species and sought approval separately. NBA considered all the applications submitted by the company and procured the necessary consent from the concerned state biodiversity board after consultation with the concerned biodiversity management committees. The request for approval has been considered and is in the process of signing a benefit-sharing agreement for all the applications.

Since the activity concerned involved research leading to commercialization, an upfront payment was mandated as a benefit-sharing component for access. The benefit sharing was calculated based on the upfront payment guidelines developed by the NBA. The amount was paid by the company to the NBA as an upfront payment. The benefit-sharing component for commercial utilization has been decided in accordance with the Guidelines on Access to Biological Resources and Associated Knowledge and Benefit Sharing Guidelines, 2014 and will be included in the mutually agreed terms in the benefit-sharing agreement.

***M/s Brasif case***

The Brazilian firm, *viz* M/s Brasif S.A made a request to NBA for access to 4000 bovine embryos and imported the same to Brazil for conducting zoo-technological research as required under the BD Act. NBA, being a regulatory authority, after consulting the Gujarat State Biodiversity Board and other related scientific departments on the request, approved the form of agreement on Mutually Agreed Terms subject to payment of upfront payment *i.e. 5 per cent of the equivalent cost of production o*f embryos. The benefit-sharing amount thus realized from the user is being defrayed to benefit claimers/ custodians.

In the instant case, though Gir and Kankrej breeds were from Gujarat province and Ongole from Andhra Pradesh province, the user accessed the embryos of these breeds from Gujarat through a trust which collected the breeds from different parts of the country. The provisions of the BD Act provide that where benefit claimers are not identified, benefit sharing amount shall be used to support conservation and sustainable use of biological resources and to promote livelihoods of the local people from where the biological resources are accessed. Accordingly, the BS amount is being shared between Andhra Pradesh and Gujarat in the ratio of 60:40 which will be utilized for the purpose of research, conservation and sustainable use of the concerned breed. Besides the BS amount should be earmarked for undertaking activities such as conservation, increasing the number of registered animals of the breed, supplying semen to farmers free of cost, conducting cattle shows, training and awareness programmes, and health camps of animals,through credible agencies including Breeders' Association; and constitution of BMCs and documentation of People's Biodiversity Registers in the areas where these breeds are originally reported from.

***Red sanders***

Similarly, as per the regulation relating to benefit sharing for the biological resources of high economic value like red sanders and sandal wood, the NBA granted approvals for access to red sanders to 59 foreign buyers, who participated in the auctions held by the Government of Andhra Pradesh/ Department of Revenue Intelligence. In this process, NBA realized around INR 66.05 crore as benefit sharing component from the foreign buyers of which NBA, as a first instalment, distributed a sum INR 3.00 crore to the Andhra Pradesh Forest Department through Andhra Pradesh State Biodiversity Boards for protection and conservation of Red Sanders. This benefit sharing is as per the recommendation of the Expert Committee on Red Sanders with the approval of the Authority and remaining amount is being channelized to the concerned stakeholders.

***Involving biological resources and associated traditional knowledge***

One of the National research institutes in India undertook research programmes for the sustainable utilization of tropical plant resources and had a well-integrated multidisciplinary R&D system dealing with conservation, management and sustainable utilization. This institute sought to obtain a patent for a novel polyherbal formulation which uses biological resources from India as well as traditional knowledge from an individual traditional healer from Kerala, India.

In this regard, it applied to the NBA in May 2018 in Form III of the Biological Diversity Rules, 2004, which is the prescribed application form for obtaining prior approval of NBA before applying for a patent using research or information on biological resources obtained from India. The invention used six biological resources accessed from India and was on a polyhedral formulation with multiple therapeutic effects relating to the use of traditional knowledge taken from a traditional healer in Kerala. As required, the prior informed consent of the traditional healer for disclosing the information on conducting preclinical study was procured and so an agreement was signed in 2009 by the institute with the traditional healer for the purpose of transferring traditional knowledge about the biological resources used in the formulation as well the knowledge on the anti-diabetic, hepato-protective and anti-fatigue properties. The Institute after signing an agreement with the traditional healer carried out the clinical study during the period from 2009 to 2014. The objectives of the preclinical studies were to scientifically evaluate the anti-diabetic, hepatoprotective and anti-fatigue properties as claimed by the traditional healer.

Apart from this, the ultimate objective of the preclinical study was to develop a single drug/ herbal formulation which possesses anti-diabetic, hepatoprotective, anti-fatigue and anti-oxidant effects. The preclinical studies carried out by the institute showed that the polyherbal formulation possesses significant anti-diabetic, hepatoprotective, anti-fatigue and anti-oxidant properties as claimed by the traditional healer. Based on the study, a patent application was filed in India.

Since the activity concerned involved information and traditional knowledge of biological resources, a benefit-sharing component for the patent had been decided by NBA in accordance with the Guidelines on Access to Biological Resources and Associated Knowledge and Benefit Sharing Guidelines, 2014 and mutually agreed terms have been included in the benefit-sharing agreement. The process is underway and soon will be concluded.

## Implementation barriers

India is one of the few countries in the world that has an operational, legal framework to deal with the objectives of the CBD, including ABS. However, the challenge remains to ensure that the objective of the BD Act is appropriately understood by the relevant Ministries and stakeholder groups. BD

Act and Rules require non-Indians to get the prior approval of the NBA when engaging in activities as laid out in Sections 3,4,6 and 20. Indians are also required to get prior approval of the NBA while applying for intellectual property rights based on Indian biological resources and associated knowledge.

BD Act, which is the cornerstone of biodiversity governance in the country, especially on the fronts of sustainability and equity, unfortunately suffers from serious ambiguities in its regulatory as well as punitive mechanisms despite it being in existence for over a decade and a dozen cases having been brought under it before various dispute resolution forums. The two critical issues in the Act's regulatory mechanism are: (a) what is regulated; and (b) who are obligated to share benefits under the Act. These two issues have been brought before various adjudicatory forums by the user companies who have challenged the legality of the show-cause notices issued to them by different State Biodiversity Boards (SBBs).

Bhutani and Kohli (2016) broadly classified the litigations with respect to BD Act from 2004-2016 under five categories. These include cases of 'biopiracy' that highlight violations, to those seeking biodiversity conservation and overall implementation of the BD Act, while contesting interpretations of definitions (such as biological resources and normally traded commodities) and disputing the applicability of ABS requirements. ABS issue tops the list of areas/issue(s) contested under the BD Act. The MoEFCC, under powers conferred to it under section 48 of the BD Act issued an Office Memorandum in September 2018, thus providing an opportunity to all such entities which are required to obtain prior approval of the Authority for undertaking activities as specified under sections 3,4 and 6 of the Act and regulate them in a manner that enhances implementation of the Act.

The absence of a mechanism to deal with biodiversity offences is another procedural injustice posed by the BD Act. Of late, the judiciary is stepping in to develop jurisprudence on sustainable and equitable governance of biodiversity. In a landmark judgement, in the Divya Pharmacy vs Union of India and others case (Writ Petition (M/S) No. 3437 of 2016), the High Court of Uttarakhand held that SBB has powers to demand Fair and Equitable Benefit Sharing from the user, in this case, the Divya Pharmacy in view of its statutory function given under Section 7 read with Section 23 of the Act and the NBA has got powers to frame necessary regulations in view of Section 21 of the Act.

Developing clarity among the users of biological resources on Act provisions regarding ABS, especially what the Act covers and what it exempts is identified as the foremost implementation barrier. Current efforts are on to provide a predictable and flexible approach to ABS and to reduce undue regulatory oversight.

## Conclusion

Having established a well-regarded legislative framework, India stands on a strong footing to implement the Nagoya Protocol. Although India is making steady progress in the implementation of ABS, there are lots of practical challenges which need to be addressed by building capacities and bringing in robust legal, policy and administrative frameworks in place. The current framework is rapidly evolving and there is a long way to go to ensure more successful ABS stories are made and the objectives of the CBD and the Biological Diversity Act are fulfilled to their fullest extent.

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# Protected areas management in India: Challenges and way ahead

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**Abstract**

Protected Areas (PAs) are the cornerstone of most conservation strategies around the world. Globally, 2,36,204 terrestrial and inland water PAs have been established. However, these PAs face a variety of threats *viz.*, development pressures, anthropogenic pressures, mining and quarrying, and tourism. In addition to these threats, climate change, desertification, invasive species and human-wildlife conflicts pose challenges to protected area management. For effective management of the PAs in the country, a landscape centric approach is required that promotes coherence and connectivity between PAs and also mainstreams biodiversity across sectors. In order to assess the efficacy of management of PAs in the country these are being subjected to a global Management Effectiveness Evaluation (MEE) process. Till date, India has conducted the MEE of 330 PAs with the overall mean MEE score of 60.27 per cent, which is higher than the global mean MEE score of 56 per cent. Despite all odds, India's PA management is successful in many aspects in meeting conservation goals. Enabling policies backed by good governance and adequate funding support are essentially needed for effective management of PAs to meet conservation goals for the sustainable future of the planet.

**Keywords**

*Protected Areas, Governance, Management Effectiveness Evaluation, Threats, Biogeographic Zones, India.*

**Introduction**

A Protected Area (PA) has been defined as "*a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (IUCN 2008). It protects biodiversity, maintains ecosystem health and provides a range of ecosystem services such as food, clean water, medicinal resources, mitigation of climate change and natural disasters, and also form an integral part of the cultures and livelihoods of local communities (Hockings 2003, UNEP-WCMC and IUCN 2016). PAs are the cornerstone of most conservation strategies around the world as they are India. So far, 2,36,204 terrestrial and inland water PAs have been established worldwide, with terrestrial PAs covering about 15 per cent of global land and marine PAs covering almost 7 per cent of the global ocean (UNEP-WCMC, IUCN and NGS 2018). According to the Convention on Biological Diversity (CBD) Strategic Plan and global Aichi Biodiversity Targets, Aichi Biodiversity Target 11 states that '*By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas,*

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*especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of PAs and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes'*. This apparently ambitious target is being pursued by the member nations signatory to the CBD in consonance with their own National Biodiversity Strategies and Actions Plans (NBSAPs and NBAPs). In harmony with the Aichi Targets, India too has developed its 12 National Biodiversity Targets (NBTs) as part of the National Biodiversity Action Plan (NBAP) along with associated indicators and monitoring framework for reporting on progress towards the goals of biodiversity conservation (https://www.cbd.int/doc/world/in/in-nbsap-v3-en.pdf). Of the 12 NBTs, National Biodiversity Target - NBT6 spells out the objective of conservation and management of PAs in India i.e. "*Ecologically representative areas under terrestrial and inland water, and also coastal and marine zones, especially those of particular importance for species, biodiversity and ecosystem services are conserved effectively and equitably based on PA designation and management and other area-based conservation measures, and integrated into the wider landscapes and seascapes covering over 20 per cent of the geographic area of the country by 2020"***.**

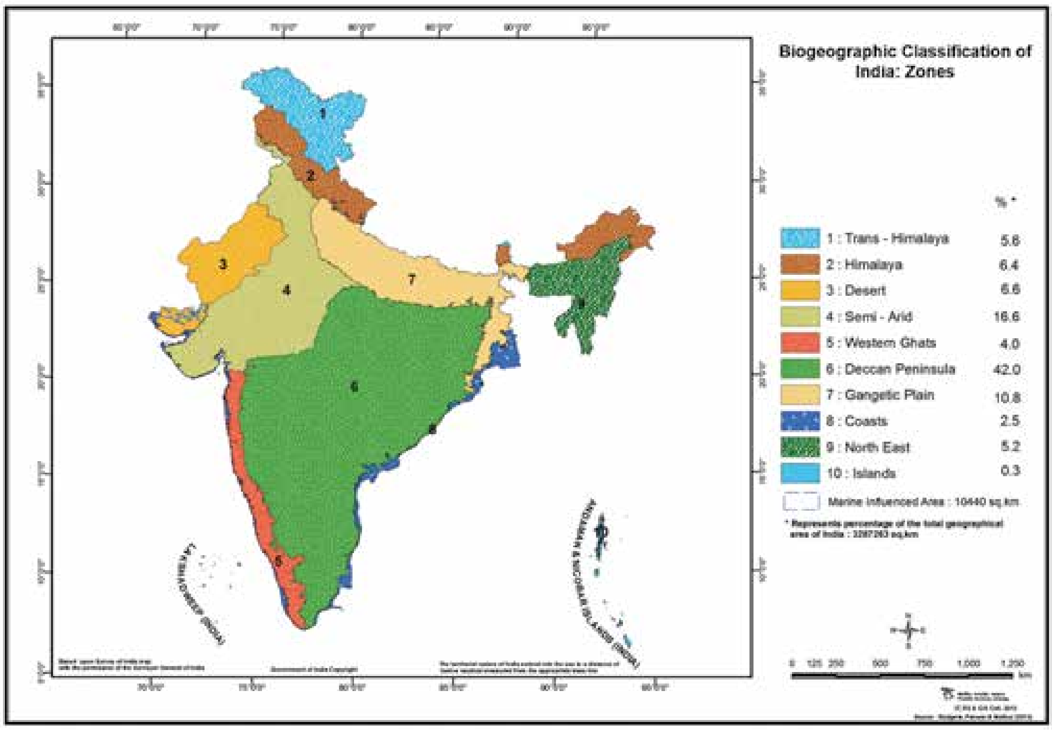
In India, under the Wildlife (Protection) Act, 1972, four legal categories of PAs are recognised *viz.* National Parks, Wildlife Sanctuaries, Conservation Reserves and Community Reserves. From a network of 54 National Parks covering 21,003 km$^2$ and 373 Sanctuaries covering 88,649 km$^2$, giving a combined coverage of 1, 09,652 km$^2$ or 3.34 per cent of the country's geographical area in 1988, the network has grown steadily. Currently, there are 868 PAs (105 National Parks, 550 Wildlife Sanctuaries, 87 Conservation Reserves and 127 Community Reserves) covering 165,088 km$^2$ or 5.02 per cent of the country's geographical area. India has identified Marine PAs (MPAs) as part of the PA coverage in the country with 25 MPAs in the peninsular region and 106 MPAs in the islands. In addition to the PA network, the managed forests under the State Forest Departments also contribute towards wildlife conservation. India has over 20 per cent of the total geographical area under managed forests and thus under effective nature conservation, thereby exceeding the target of 17 per cent envisaged in Aichi Target 11.

These National Parks and Wildlife Sanctuaries provide the range of benefits and services as described in the foregoing text and are also amongst the last refuges for a host of incredible biodiversity and wildlife, amongst them many large and charismatic species such as the tiger and elephant. Despite a human population of 1.3 billion, India is ranked among the 17 mega-biodiverse countries in the world. India supports nearly 60 per cent of the world's wild tigers and the largest population of the Asian elephant. The country is home to about 5,000 species of endemic plants.

## Threats to Protected Areas

However, these PAs face a variety of threats that exert pressures on their integrity and long-term viability. The key challenges include development pressures, industrial expansion, anthropogenic pressure of dependent communities, mining and quarrying, and tourism. Moreover, recent threats in the form of climate change, desertification, invasive species, marine pollution and spurt in economic development are posing major challenges to the conservation of marine biodiversity that needs to be addressed. Human-wildlife conflict is more of a challenge in areas outside the PA network. With a rich diversity of flora and fauna, illegal trade has emerged as one of the most serious threats to wildlife in the country. PAs in the aquatic realm also face a range of biotic and abiotic threats notably from over-exploitation of fish resources, discharge of wastewater and industrial effluents, siltation, sand and boulders mining, invasive species, fertilizers and pesticides load in the water. The drivers to biodiversity loss, both direct and

**Table 1. Threat assessment in Biogeographic Zones of India**




| | | |
|---|---|---|
| 1. | Trans-Himalaya | Livestock pressure, Tourism, Exotic plantations, Medicinal plants & Non-timber forest product (NTFP) extraction, Poaching, Human-animal conflict, Climate change. |
| 2. | Himalaya | Climate change, Deforestation, Invasive species, Medicinal plants & NTFP extraction, Fire, Land use change, Development & urbanisation, Mining, Energy (hydel), Tourism. |
| 3. | Desert | Invasive species, Land use change, Livestock pressure, Grassland degradation, Mining. |
| 4. | Semi-arid | Land use change, Mining, Livestock pressure, Grassland degradation, Poaching. |
| 5. | Western Ghats | Invasive species, Exotic plantations, Encroachment, Mining, Medicinal plants & NTFP extraction, Livestock pressure, Poaching, Fire, Pathogens & disease transmission, Climate change. |
| 6. | Deccan Peninsula | Deforestation, Grassland degradation, Invasive species, Development & urbanisation, Mining, Pathogens & disease transmission, Interbreeding of wild species with domesticated stock. |
| 7. | Gangetic Plain | Deforestation, Grassland degradation, Invasive species, Development & urbanisation, Mining, Land use change, Pollution & Eutrophication, Livestock pressure, Poaching. |
| 8. | Coasts | Climate change, Pollution, Development & urbanisation, Mining, Tourism, Aquaculture, Invasive species. |
| 9. | North-east | Deforestation, Agriculture (shifting cultivation), Mining, Energy (hydel), Poaching, Climate change. |
| 10. | Islands | Climate change, Invasive species, Tourism, Development & urbanisation. |

*(Source: Adapted from MoEFCC, 2014)*

indirect, include a range of attributes such as high rate of human population growth, increasing urbanization, technological change-induced effects and development (Parikh *et al.* 2012). The demands of growing human populations, presently estimated to be *ca.* 1.3 billion (http://worldpopulationreview.com), for food, medicine, fibre, fodder, fuel and shelter coupled with rapid economic growth is increasing the pressure on biodiversity and ecosystems throughout the country to almost unmanageable proportions. Land use changes fueled by intensification of agriculture and urbanization are causing unprecedented changes in all landscapes and threatening the survival of a large number of wild animals and plant species. In a study carried out by Roy *et al.* 2012 using geospatial characterization, it was reported that 49.63 per cent of the geographic area of the country was under low fragmentation; 21.89 per cent under medium and 5.16 per cent was under high fragmentation. Threats to biodiversity occur across all ten biogeographic zones in India from the Trans-Himalaya to the coasts and islands, with some of these such as land use changes, deforestation, shifting cultivation, invasive species, mining, hydropower, and climate change being more pronounced in some zones than in others (Table 1).

## Management of Protected Areas

India's National Wildlife Action Plan (NWAP) 2017-2031 reiterates the need to address the conflicts between development and conservation and reconcile the two and mainstream conservation into development planning across sectors (MoEFCC 2017). The NWAP for the first time recognizes the concern relating to climate change impacts on wildlife, by integrating actions that need to be taken for its mitigation and adaption into wildlife management planning processes. India's foray into spatial biodiversity planning also known as conservation planning dates back to mid 1980s and started with the preparation of 'Biogeographic Classification of India' to establish a network of PAs on a biographically representative basis (Rodgers and Panwar, 1988; Rodgers Panwar and Mathur 2002) and to provide area-based conservation approaches at the landscape level. A national level assessment of biological richness was undertaken for the first time using spatial data on a 1:50,000 scale to identify and map potential biodiversity-rich areas in the country (Roy *et al.* 2012). It is using these spatial planning frameworks that India has further rationalized the identification of gaps in PA coverage and guided development of the network of PAs.

## Landscape approach

It is increasingly well recognized that wildlife conservation has to go beyond PAs to the larger landscapes in which these are embedded. A landscape is defined as 'a large tract of land constituted by a mosaic of interacting land uses with people and the impacts of their activities as the cornerstone of its management' (MoEFCC 2017). Whereas PAs together with reserve forests and protected forests legally protect over 20 per cent of the country's area for bio-resource management, the adjoining areas, mainly comprised of production areas and human settlements, are often beyond the purview of dedicated biodiversity management interventions. Multiple agencies are tasked with regulating or promoting land use in these areas, which makes coordination amongst them a key challenge. Land use practices in these landscapes are not only often competing but may even be inadvertently in contradiction to biodiversity management and conservation goals. The matrix in which the PAs are embedded is increasingly degraded and fragmented by land use change and development pressures from roads, rail and other linear infrastructure development, mining and urbanization to name a few. Large-landscape dependent species such as the tiger and elephant traverse this adjoining matrix which is often inhospitable and leads to situations of human-wildlife conflicts. In view of the loss in connectivity between wildlife habitats, the long-term persistence of these wild species is threatened.

Therefore, a landscape approach that aims to pursue an integrated and comprehensive method of management covering the entire matrix of land use forms, including PAs, in a given landscape will go a long way in taking multiple competing demands into account such that viability of species populations into the future is ensured. At the level of management planning for PAs, a landscape approach to management allows ecosystem-level conservation actions at the existing internal smaller nested spatial scales of management/ administration such as PAs and territorial forest divisions as well as larger units to achieve conservation goals at the largest spatial scale possible in practical terms. Landscape-level conservation of species must be seen as maintaining or enhancing genetic exchanges between metapopulations and significantly improving the prospects of their long term persistence (MoEFCC 2017).

## Conservation beyond Protected Areas

As described in Aichi Target 11 in the foregoing, area-based measures for conservation include not only formally designated PAs in the above four categories but also "Other Effective Area-Based Conservation Measures" (OECMs). OECMs that have now become part of Aichi Biodiversity Target 11 can play an important role in promoting coherence and connectivity of PA networks as well as in mainstreaming biodiversity into other land and sea uses and across sectors. The incorporation of OECM in Target 11 reflects the recognition that areas beyond the conventional or legally notified PAs can play an effective role in *in-situ* conservation of biodiversity. OECMS are considered to play an important part in "conserving important ecosystems, habitats and wildlife corridors, supporting the recovery of threatened species, maintaining ecosystem functions and securing ecosystem services, enhancing resilience against threats, and retaining and connecting remnants of fragmented ecosystems in developed areas" (IUCN WCPA 2018). In the context of India, there are areas beyond the formal PA network that contribute to biodiversity conservation. These include Important Bird and Biodiversity Areas (IBBAs), Community Conserved Areas (CCAs), sacred groves, Biosphere Reserves, wetlands, Biodiversity Heritage Sites, Elephant corridors, among several other which contribute to the conservation of biodiversity. Such areas can play an important role in improving the suitability of the landscape matrix, improving connectivity and providing secure refuges to species beyond PAs. Yet, the presence of effective management regimes in these areas, as also in the case of PAs, is the crucial factor in ensuring sustenance of wild species and their habitats for long-term conservation of biodiversity.

## Management effectiveness in Protected Areas and beyond

Evaluating and improving the effectiveness of PA management has become a priority throughout the conservation community. An important step in this process is the carrying out of an assessment of current status and management of the PA, to understand better what is and what is not working, and to plan any necessary changes as efficiently as possible. Assessment of management effectiveness has emerged as a key tool for PA managers and is increasingly being required by governments and international bodies. International organizations working with PAs such as IUCN and its World Commission on PAs (WCPA), the World Bank, the Global Environment Facility as well as NGOs such as WWF and The Nature Conservancy have taken the lead in both promoting the importance of management effectiveness as an issue, and in providing the technical development and support needed to underpin this effort.

The term 'management effectiveness' reflects three main themes of PA management, *viz.* the design issues relating to both individual sites and PA systems; the adequacy and appropriateness of management systems and processes; and the delivery of PA objectives including conservation of values.

There are many reasons why people want to assess management effectiveness (Hockings *et al.* 2000). These different purposes may require different assessment systems and varying degrees of detail. Funding bodies, policymakers and conservation lobbyists may use the results to highlight problems and to set priorities, or management agencies may use them to promote better management policies and practices. Managers may wish to use the results of evaluations to improve their performance or to report on achievements to senior managers, the government or external stakeholders (Hockings *et al.* 2006). Local communities and other stakeholders, including civil society, need to establish how far their interests are being taken into account. The increased emphasis on evaluation is in part due to changes in society, especially the increased demand for accountability, transparency and demonstrated 'value for money' (Hockings *et al.* 2006).

***Management Effectiveness Evaluations (MEE) Framework***

The precise methodology used to assess effectiveness differs between PAs and depends on factors such as the time and resources available, the importance of the site, data quality and stakeholder pressures. The differing situations and needs for PAs thus require different methods of assessment. As a result, a number of assessment tools have been developed to guide and record changes in management practices. A uniform theme has been provided to these assessments by the IUCN WCPA Framework for assessing the management effectiveness of PAs, which aims both to give overall guidance in the development of assessment systems and to encourage basic standards for assessment and reporting (Hockings *et al.* 2006). The framework sees management as a process or cycle with six stages or elements, *viz.* establishing

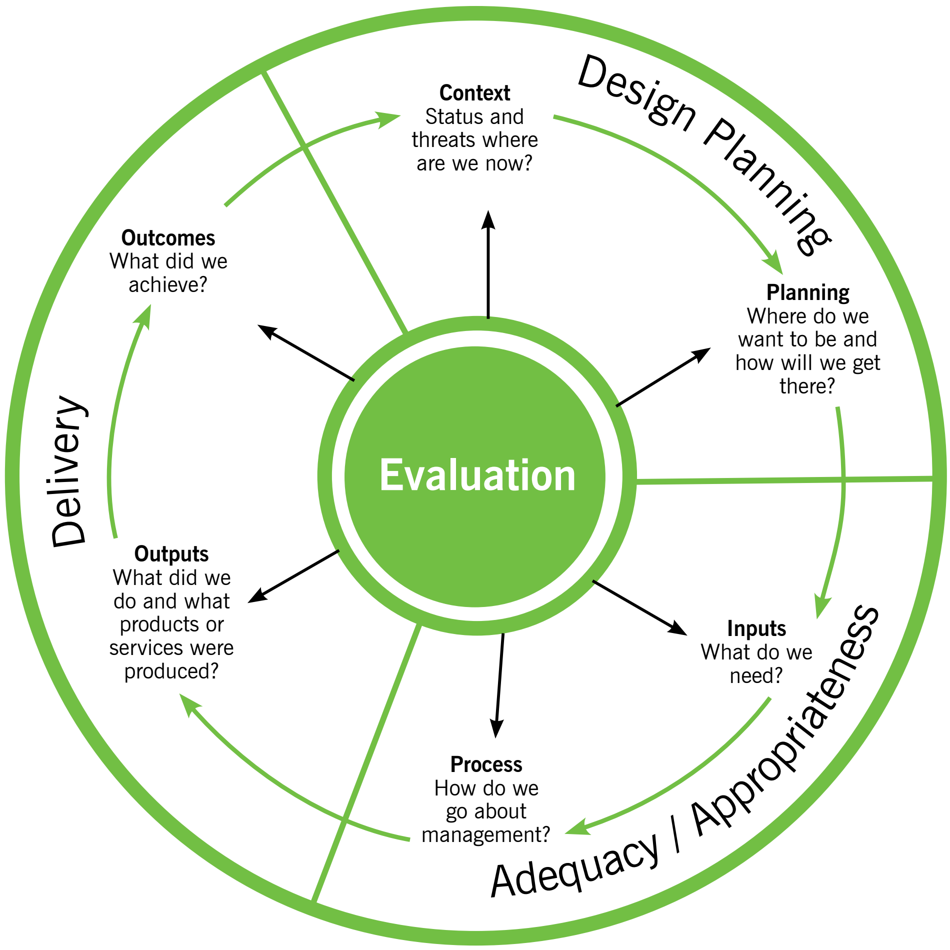



**Figure 1. IUCN WCPA Framework (Hockings *et al.* 2006)**

**Table 2: Abstract of MEE exercises conducted in India (2003 - 2018)**

| S.No. | Type of Approach | Application in India |
|---|---|---|
| 1 | In-depth, Evidence-based assessment<br>World Heritage Sites | 03 World Heritage Sites (WHS) (2003-2008), *viz.*,<br>Keoladeo WHS, Rajasthan, India<br>Kaziranga WHS, Assam, India<br>Chitwan WHS, Nepal |
| 2 | Rapid Expert-based scorecard<br>National Parks and Wildlife Sanctuaries | MEE of 125 PAs from 2006-2014: a report published in 2015<br>MEE of 80 PAs in 2015-2017: a report published in 2017<br>MEE of 125 PAs in 2017-18: draft report submitted in 2018<br>MEE of 146 PAs in 2018-19: Initiated in October 2018 |
| 3 | Comprehensive system-wide, Peer-based assessment<br>TIGER RESERVES NETWORK | MEE of 28 Tiger Reserves in 2006: completed<br>MEE of 39 Tiger Reserves in 2010: completed<br>MEE of 43 Tiger Reserves in 2014: completed<br>MEE of 50 Tiger Reserves in 2018: completed and draft report ready |

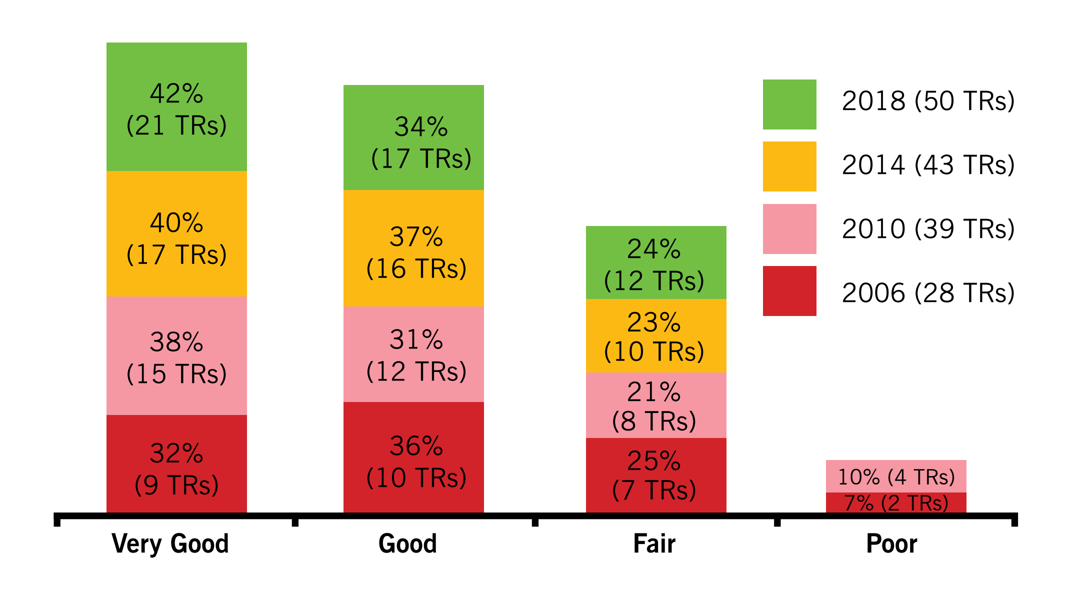
the context of existing values and threats; progress through planning, allocation of resources (inputs), as a result of management actions (process), eventually produces goods and services (outputs), that result in impacts or outcomes (Figure 1). For assessment of each of the six elements of the MEE framework, specific criteria have been developed for evaluation in tiger reserves (32 criteria), as well as for national parks and wildlife sanctuaries (30 criteria) in India. Each 'Headline Indicator' had four possible answers, 'poor', 'fair', 'good' and 'very good' to choose for evaluation. As per Indian MEE context, the foundation of MEE process is based on the presence of a Management Plan along with management systems in place.

***MEE process in India***

India is among the select countries in the world that have institutionalized the MEE process. India made a beginning in evaluating the management effectiveness of its world heritage sites, national parks, wildlife sanctuaries and tiger reserves in 2006 (Mathur, 2008). Three Natural World Heritage sites in South Asia, namely Keoladeo National Park, Rajasthan, Kaziranga National Park, Assam and Chitwan National Park, Nepal were evaluated in 2002-2007 as part of the IUCN-UNESCO 'Enhancing Our Heritage' project. The MEE of national parks and wildlife sanctuaries was initiated in 2006 and till 2018, 330 sites have been evaluated.

Further the process of evaluation is ongoing for a list of 146 National Parks and Wildlife Sanctuaries in the country during 2018-19. This list also includes the 25 PAs which were first evaluated in 2005-06 and now under repeat cycle of evaluation, Under India's Project Tiger, management effectiveness assessment of Tiger Reserves (TRs) was conducted. Four repeat cycles of evaluation of Tiger Reserves Network has been made after every four years from 2006 to 2018 in India. This process is the most significant approach for tiger conservation and associated landscape connectivity conservation and management. The first cycle includes 28 TRs in 2006; second cycle included 39 TRs in 2010, the third cycle includes 43 TRs in 2014 and fourth cycle includes 50 TRs in 2018. The abstract of MEE exercises conducted in India is given in Table 2.

**Figure 2: Results of four cycles of evaluation of Tiger Reserves in the country through MEE process**




## Results and outcomes of MEE process in India

Over the years, the outcomes of the MEE process have demonstrated that despite all odds, India's PA management is successful in many aspects in meeting conservation goals. By combining the results of MEE of 330 PAs of India, the overall mean MEE score is 60.27 per cent which is higher than the global mean MEE score of 56 per cent. Of the six elements, 'context' performs best (around 64 per cent), followed by planning (around 60 per cent). As per the recent MEE results, the indicator 'Safeguarding biodiversity values' has the best performance followed by 'Assessment of threats' whereas '*NGO Support*' followed by '*Population trends of endangered species*' are the underperforming indicators. Region-wise, South-Indian PAs are performing better in comparison to Eastern and North-eastern PAs in India.

India has further institutionalized the MEE process for evaluation of our Tiger Reserves and a 4-year cycle is in operation. Indian MEE has also been aligned with the 4-year All India Tiger Population Estimation. The MEE results of Indian Tiger Reserves are impressive. The overall mean MEE score of 50 Tiger Reserves evaluated in 2018 is 70 per cent which is much higher than all MEE results at the national and global level. The results of four cycles of evaluation of Indian Tiger Reserves are shown in Figure 2. Similar to PAs results, here also, element-wise 'context' is a better performing an element of 73 per cent followed by 'input' of 72 per cent. In the case of Tiger Reserves, the Tiger Conservation Plan is the core of the MEE assessment, which is similar to the Management Plan of PAs. Almost 80 per cent of our Tiger Reserves have Tiger Conservation Plans, which is one of the indicators among '32 headline indicators'. Identification of values, financial support from State and Central Government are other better performing indicators, whereas we need to pay more attention on some issues like biotic interference in the core area, the inadequacy of trained manpower, threat abatement etc. for tiger conservation. There are also some new emerging concerns such as climate change, development in the surrounds of TRs, human-wildlife conflicts, strengthening and diversification of Tiger Conservation Foundation (TCFs), invasive species etc.

To better institutionalise the MEE process, there is a need to enhance the participation of a range of relevant stakeholders, disseminate the findings and bring appropriate changes in policy, governance and management to enhance the effectiveness of management of Tiger Reserves. Tiger Range countries also need to be encouraged to adopt and adapt the Indian MEE to secure the conservation of tiger and its landscapes across its entire global range.

## Conclusions and way ahead

Despite the threats and challenges faced by PAs in India, their critical role in fulfilling conservation goals needs to be emphasised. At the same time, opportunities for enhancing management effectiveness through good governance have to be strengthened. PA governance should include the elements of "participation, innovation, respect and benefit sharing" (Borrini-Feyerabend 2013). Participation involves the effective participation of relevant stakeholders, including local and indigenous communities, from planning and decision-making stages of the management process. Innovation indicates creating opportunities for new types of governance for PAs to be effectively managed and promoted through various mechanisms including PAs governed by government agencies; PAs under shared governance; private PAs; and community conserved areas. Respect implies ensuring regard and respect for the rights, livelihood needs, contributions and support for conservation of people living in and around PAs, and recognition and incorporation of traditional knowledge, practices and institutions of local communities. Fair and equitable sharing of benefits (as outlined in the central aims of the CBD; *https://www.cbd.int/intro/default.shtml*) related to access to natural resources, including genetic resources should be ensured for local and indigenous peoples. Their free and prior informed consent must also be sought for issues of access to resources, as well as for resettlement and rehabilitation outside PAs. Enabling policies backed by good governance and adequate funding support are essentially needed for effective management of PAs to meet conservation goals for the sustainable future of the planet. The MEE process has provided insights into the management strengths and weaknesses of the PAs. While the strengths have to be maintained, the weaknesses have to be plugged. Similarly, there is a range of 'immediate actionable points' which need to be addressed through management interventions. Undoubtedly, the MEE process has provided a very powerful mechanism to effectively manage and monitor the valuable natural heritage of India.

## Acknowledgements

We are very grateful to the Ministry of Environment, Forest and Climate Change, Government of India for sponsoring the Management Effectiveness Evaluation (MEE) of PAs in India that has *inter-alia* helped India to establish its leadership in this thematic area of governance and management of PAs.

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# Wetlands and waterbirds in Central Asian Flyway: An overview of status, management and conservation priorities for India

Ritesh Kumar[1]

**Abstract**

Indian wetlands, located at the heart of Central Asian Flyway, play a crucial role in sustaining populations of migrating waterbird species. Several wetlands of high ornithological significance have been designated as protected areas to reduce anthropogenic pressures. A range of policy and regulatory measures have also been put in place to protect the waterbird species and habitats.

The global population trends for most waterbird species sighted in India are declining, and significant shortfalls of protected area coverage for migratory species considering their requirements for protection across each of their seasonal ranges have been noted in India and at the flyway scale. Balancing the needs of habitat conservation with livelihoods in wetlands is seldom easy, particularly beyond protected areas. The decline in natural wetlands in India poses a significant challenge to waterbird conservation. Effective conservation planning for migratory waterbirds needs to be based on explicit accounting for the movement of the individual as separate conservation features, and on conservation strategy developed on the basis of linkages between these features. New models of community engagement and resource stewardship in the management of wetlands may need to be considered for this purpose. Efforts towards monitoring waterbird population and distribution need substantial intensification, as reliable population estimates shall ensure that Ramsar site designation is based on robust data, and the site network is representative and relevant for the needs of waterbird conservation.

**Keywords**

*Central Asian Flyway, Migration, Waterbirds, Wetland Wise-use.*

## The Central Asian Flyway and its Waterbirds

Ecologically dependant on wetlands, migratory waterbirds connect continents, hemispheres, cultures and societies through their seasonal movements (Kirby *et al.* 2008). The flyway concept is used to link sites and ecosystems into a single functional unit in order to enable waterbirds to complete their migration cycle (Boere and Stroud 2006). Defined as the "the entire range of a migratory bird species (or a group of related species or distinct populations of a single species) through which it moves on an annual basis from the breeding ground to non-breeding areas, including intermediate resting and feeding places as well as in the area in which birds migrate", flyways can be

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considered at multiple scales ranging from single species to multi-species migration systems, and even in political terms as global regions subject to shared international conservation activity (Boere and Stroud 2006). Threats in any part of the migration system can adversely affect the population of entire migratory species, and thereby conservation and management actions need to be coordinated across sites, habitats, seasons and political jurisdictions (Runge *et al.* 2015).

Migratory waterbirds play an essential role in wetlands they inhabit at different stages in their life cycle, by contributing to resource fluxes, biomass transfer, nutrient export, food-web structure, and even shaping cultural relationships (Laura *et al.* 2017), and thereby population dynamics of waterbirds is often used as an indicator of wetlands ecosystem health (Péron *et al.* 2013). Conserving species movement as a process is an equally important goal as conserving migratory species (Runge *et al.* 2014).

The Central Asian Flyway (CAF) is one of the nine global waterbird flyways, comprising migratory routes from the northernmost breeding grounds in Siberia to southernmost non-breeding grounds in the West and South Asia, The Maldives and British Indian Ocean Territory (CMS 2005). Covering at least 279 populations of 182 migratory waterbird species, the flyway spans 30 countries of North, Central and South Asia and Trans-Caucasus (CMS 2019). The critically endangered Sociable Lapwing *Vanellus gregarius*, vulnerable Black-necked Crane *Grus nigricollis* and Indian Skimmer *Rynchops albicollis*, Bar-headed Goose *Anser indicus*, and Brown-headed Gull *Larus brunnicephalus* are restricted mainly to the CAF region (Mundkur 2005). In its current delimitation, there is considerable overlap between the migratory populations of CAF with East Asian- Australasian Flyway and West Asian-East African Flyway (Szabo and Mundkur 2017).

India is located at the heart of CAF. Nearly 71 per cent of the migratory waterbirds of the CAF use India as a stopover site[2]. Sustaining the health of Indian wetlands is thus crucial for maintaining the waterbird populations within the Flyway. Conservation of migratory waterbirds and wetlands has received considerable attention in national policy-making and programmes, as well as international commitments. However, much remains to be done for ensuring a healthy network of wetlands and securing healthy populations of migratory waterbirds in India and the CAF region.

This paper presents an overview of the various measures taken for conservation of waterbirds and wetlands in the country, including the suite of intergovernmental cooperation mechanisms and legal instruments that have been put in place for the said purpose. Gaps and challenges in implementing the programmes are discussed, along with recommendations on priority actions. The scope of the article is limited to waterbirds and does not include land birds which are vital and integral components of bird diversity of the country and CAF. Also, the article does not attempt to review the extensive science on Indian waterbirds and wetlands and limits itself to the issues related to management and governance.

## Waterbird monitoring and conservation in India

India is endowed with a rich bird diversity given her unique biogeographical settings, heterogeneity of physical features, and climate variations. There are an estimated 1,263 species of birds in the country covering 23 orders and 107 families (Jayadevan *et al.* 2016). The number of waterbird species in India has been assessed to be 245 representing

[2] Kumar et al (2005) list 128 species of migratory waterbirds in India. This forms 71 per cent of total migratory waterbird species reported in CAF by CMS, i.e. 182 species (CMS 2005).

seven orders and 21 families (Kumar *et al.* 2005). Of these, 128 species are migratory (including eight partly resident species).

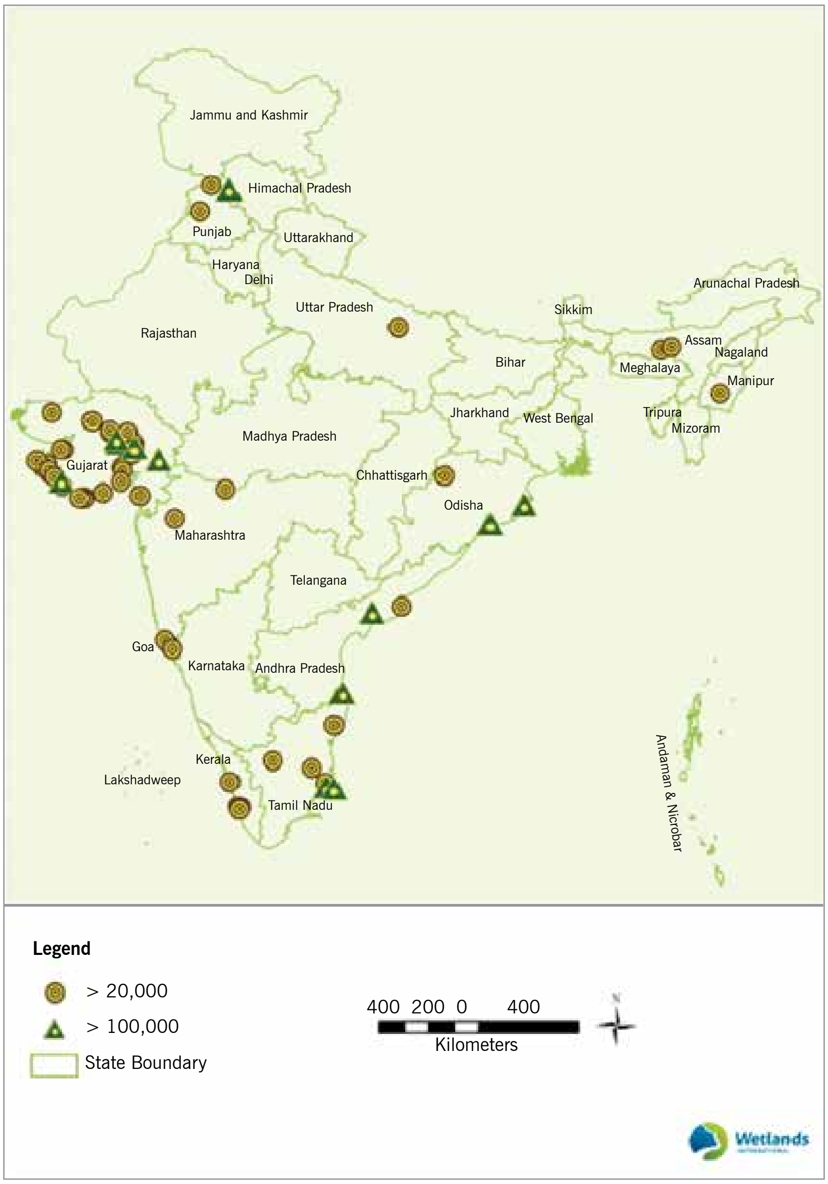
Bird ringing, since last century, has internationally been a vital source of information on the seasonal movement of bird species and spatial and temporal course of migration (Bairlein 2003; Berthold and Terrill 1991). Such studies were initiated in India in the 1920s, and formalized into an organized scheme for bird banding through a collaboration between Bombay Natural History Society (BNHS) and World Health Organization in late 1950s as part of regional initiative to investigate the probable role of waterbirds in transmission of diseases linked with arthropod-borne viruses (Balachandran 1998). Studies on bird migration were continued as part of ecological studies in Keoladeo National Park (Bharatpur, Rajasthan) and Point Calimere (Tamil Nadu) (Szabo and Mundkur 2017). In addition to traditional methods of placing metal rings on waterbirds, techniques such as collar flagging, neck collars, satellite telemetry, and geolocators have also been used in recent times. In 2007, BNHS established a Bird Migration Study Center in Point Calimere to act as a node for bird migration studies. The data from the over three thousand recoveries from ringing have been compiled in the form of Indian Bird Migration Atlas (Balac handran *et al.* 2018), presenting valuable information on migratory routes adopted by birds ringed in India (though several maps in the publication need modification). Some interesting recoveries documented in the atlas, such as recovery of Little Stint ringed in Point Calimere from the Arctic, Greater Flamingo ringed in Ashk Island, Iran recovered from several sites in northwest, west and peninsular India, and Grey Heron ringed in southern Kazakhstan from Udupi, Karnataka, present valuable insights into the movement patterns of waterbirds (Balachandran *et al.* 2018). Long-term bird migration studies at sites such as Chilika testify the crossover of migratory bird species between CAF and East Asian Australasian Flyways (Balachandran *et al.* 2009), signifying the high ornithological value of the wetland from a flyway conservation perspective.

Since 1987, the Asian Waterbird Census (AWC) has been collating information on mid-winter population from 25 countries of Asia, within the framework of International Waterbird Census coordinated by Wetlands International (Mundkur *et al.* 2015). Counts from India form a significant proportion of total sites covered in the census. During 2006-15, waterbird counts from as many as 1,400 wetlands were recorded by this volunteer network. Sixty-six sites recorded more than 20,000 waterbirds (Map 1), which includes 12 sites having counts exceeding 0.1 million. As many as 274 sites were noted to have more than 1 per cent of the biogeographic population of at least one species (Map 2). In states such as Kerala, the mid-winter counts under the AWC have been institutionalized through active state government support creating a repository of long-term trends in waterbird population and distribution data (Nameer *et al.* 2015). However, the overall count consistency and coverage have been a matter of concern in this volunteer-driven enterprise (Urfi *et al.* 2005). More recently, platforms like eBird have emerged as tools for converting count data into species distribution models and beyond (Wood *et al.* 2011).

The Bird Life International, under its Important Bird and Biodiversity Areas (IBA) programme, has enabled the creation of an inventory of a network of sites, protection and management system which is significant for the long-term viability of naturally occurring bird populations (BirdLife International 2019). Under the Indian IBA programme, 544 sites have been identified, wetlands being the most significant category accounting for 27 per cent of the sites (Rahmani *et al.* 2016).

Decades of work on Indian birds and passion of stalwarts such as Padma Vibhushan Shri Salim Ali

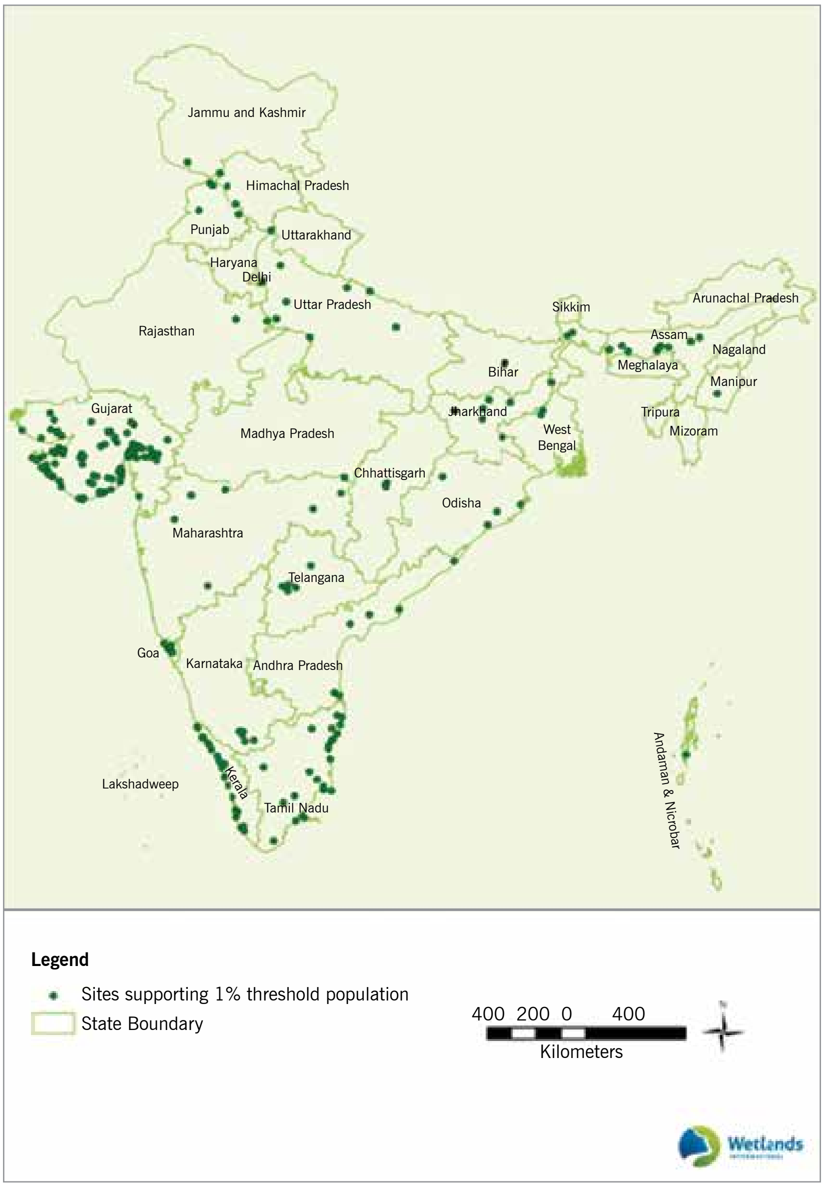
**Map 1 (a): Wetlands where >20,000 and > 0.1 million waterbirds were recorded atleast once in Asian Waterbird Census during 2006-15 (Data Source: Asian Waterbird Census, Wetlands International)**




have laid the foundation of a network of wetland protected areas supporting large congregation of waterbirds. Vedanthangal, Keoladeo, Khijadiya and Ranganathittu were designated as protected areas under the colonial laws and regulation. A primary strategy for management of wetland protected areas has been controlling human disturbances on the habitat and managing the habitat, particularly vegetation and water regimes by the requirements of the target species and populations. The current network of protected areas in India presently consisting of 771 sites (WII 2018), includes nearly 275 wetlands.

The Wildlife (Protection) Act, 1972 is the crucial regulation protecting wildlife, including waterbirds. Twelve waterbird species are listed under the Schedule I of the Act, and the rest placed under Schedule IV. The classification in the different schedules, however, needs a reconsideration as several threatened waterbirds with declining population have been excluded from the Schedule I and II which provide for the highest level of protection to the species (Gopi *et al.* 2014). The Biological Diversity Act, 2002, and the rules thereunder empower the Central and State Governments to notify species which are on the

**Map 2: Wetlands where counts of atleast one species exceeded the known 1% population threshold during 2006-15 (Data Source: Asian Waterbird Census, Wetlands International)**




verge of extinction or likely to become extinct in the near future as 'threatened species' and prohibit or regulate collection thereof for any purpose and take appropriate steps to rehabilitate and preserve those species.

In several cases, the establishment of protected areas has resulted in violent conflicts due to curtailment of access to local communities (refer Lewis 2003 for a discussion on the case of Keoladeo National Park). The 2002 amendment of the Act introduced provisions for conservation reserves and community reserves, which integrate local communities and even private organisations in protected area management. Since then, a number of wetlands have been designated into the category, key being Charidhandh (Gujarat), Gharana, Hokera, Hygam, Mirgund and Tso Moriri (Jammu and Kashmir), Kokkare Bellur, Aghnashini and Puttenhalli (Karnataka), Kadalundi (Kerala), Ropar and Keshopur Chhamb (Punjab), and Asan and Jhilmil (Uttarakhand).

Beyond Protected Area designation, the extensive research on population and distribution of waterbirds conducted since the seventies has evolved into species and habitat conservation initiatives. Research on the habitat of globally endangered Greater Adjutant *Leptoptilos dubius* (Rahmani *et al.* 1990; Singha *et al.* 2003) has led to local action for species conservation in Assam and Bihar (Toomey 2016). Similarly, long term studies on habitat preferences of Sarus crane *Antigone antigone* (Sundar 2011) have materialized into community-level species conservation programme supported by the government, civil society and communities.

Globally, waterbirds have been in continuous decline since the 1980s (Gardner and Finlayson 2018). The global population trends for most waterbird species sighted in India are declining (Gopi *et al.* 2014). Considerable shortfalls of protected area coverage for migratory species considering their requirements for protection across each of their seasonal ranges have been noted for India (Runge *et al.* 2015), exposing the species to a multitude of threats. Agriculture intensification and expansion, overgrazing and development projects stand out as a significant threat for IBAs in the country (Rahmani *et al.* 2016). The threats of poaching, trapping, hunting, land use change, disturbances in feeding and breeding areas, and linear infrastructure development continue to exert significant pressure on waterbird populations and habitats (Gopi *et al.* 2014; Rahmani *et al.* 2016; Mundkur 2017).

## Wetlands conservation in India

The wetlands regime in India is diverse, ranging from high altitude glacial lakes of the Himalayas, swamps and marshes of the Terai, floodplains and ox-bow lakes of the Gangetic–Brahmaputra alluvial plains, saline flats of the Great Indian Desert, network of reservoir and tanks of the Deccan and extensive mangrove marshes and coral reef areas straddling the coastline. As per the 2011 National Wetlands Atlas, the country has 15.26 million ha wetlands, equivalent to 4.63 per cent of her geographical area (Panigrahy *et al.* 2012). The immense contribution of wetlands ecosystems to water, food and climate security, and inextricable linkages with cultural and recreational values have been highlighted in several publications (for a recent summary refer to Kumar *et al.* 2017).

Wetlands such as Point Calimere (Tamil Nadu), Chilika (Odisha), Keoladeo (Rajasthan), and islands of Gujarat have a spectacular congregation of waterbirds. Similarly, Sultanpur (Haryana), Kurra Jheel and Chambal (Uttar Pradesh and Madhya Pradesh), Kokkare Bellur (Karnataka), Nellapattu and Pulicat (Andhra Pradesh), Chitragudi, Kanjirankulam, Kunthangulam (Tamil Nadu), Sunderbans (West Bengal), Deepor and Orang (Assam) are outstanding for globally threatened waterbird species (Islam and Rahmani 2008). Wetlands form three of the five flyway bottleneck sites in the CAF region, namely Nalsarovar and Marine National Park (Gujarat) and Doyang (Nagaland) (Rahmani *et al.* 2016). It is but natural that wetlands conservation policy and programming as we see today in India drew its roots from recognition of their roles as waterbird habitats, drawing in parts from waterbird centric-wetlands conservation movements in Europe and North America (Maltby 2009). Wetland conservation draws strength from India's rich legacy of environmental preservation enshrined in various policies, legislation and regulatory regimes. The Indian Constitution encapsulates this spirit, notably in its Article 51–A (g) stating that "it shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife and to have compassion for living creatures."

Within the federal set-up, wetlands conservation and sustainable management are placed within the mandate of the Ministry of Environment, Forest and Climate Change (MoEFCC). Wetlands conservation was initially led by wildlife values, and several predominantly wetland landscapes such as Keoladeo, Harike, Kaziranga and Manas were declared as wildlife sanctuaries and national parks (IUCN Category II protected area). In 1986, the ministry established the National Wetlands Programme to provide an overarching national policy framework and financial assistance to the state governments for the implementation of site management plans (MoEF 1992). In 1992, the Ministry constituted a National Committee on Wetlands, Mangroves and Coral Reefs to advise the government on appropriate policies and action programmes for conservation of wetlands, research and training needs, and collaboration with international agencies (MoEF 1992). In 2001, the National Lake Conservation Programme was carved out of the former programme to address pollution issues in urban and peri-urban water bodies through interception, diversion and treatment of pollution load (MoEF 2008a). Since March 2013, the two programmes have been merged into the National Programme on Conservation of Aquatic Ecosystems (NPCA). Beyond NPCA, wetlands located within protected areas are funded under the centrally sponsored scheme titled Integrated Development of Wildlife Habitats (IDWH), whereas mangroves and coral reefs receive funding through a still separate funding stream. As of December 2018, over 250 wetlands have been covered under these national programmes, a majority (58 per cent) of which are protected areas, designated for biodiversity values, primarily waterbirds.

The National Environment Policy of 2006 lays down specific policy elements for wetlands (MoEF 2006). Wetlands have been identified as components of 'freshwater resources', and the recommended policy actions for wetlands conservation include integration in developmental planning, management based on prudent use strategies, promotion of ecotourism, and implementation of a regulatory framework. India's National Wildlife Action Plan (2017-2031) identifies conservation of inland aquatic ecosystems as one of the 17 priority areas and envisages the development of a national wetlands mission and a national wetlands biodiversity register as key interventions (MoEFCC 2017). Integration of wetlands in river basin management has been identified as a strategy for the management of river systems (MoWR 2012). The National Water Policy (2012) recommends adoption of a basin approach for water resources management and identifies conservation of river corridors, water bodies and associated ecosystems as an essential action area (MoWR 2012). The National Action Plan for Climate Change includes wetlands conservation and sustainable management in the National Water Mission and the Green India Mission (MoEF 2008b).

Wetlands receive protection from a number of central enacted rules and regulation. Provisions of the Indian Forest Act, 1927, the Forest (Conservation) Act, 1980 and the Indian Wild Life (Protection) Act, 1972 define the regulatory framework for wetlands located within forests and designated protected areas. Similarly, in 2017, the Ministry notified the Wetlands (Conservation and Management) Rules under The Environment (Protection) Act, 1986 (EP Act). As per the provisions of these Rules, State Wetlands Authorities have been constituted as the main policy and regulatory bodies within states. Several State Governments (notably West Bengal, Odisha, Kerala, Manipur, Assam and Rajasthan) have also enacted their legislation pertaining to wetlands.

Further, under the EP Act, coastal wetlands are protected under the Coastal Regulation Zone (CRZ) Notification (2018) and its amendments and the Island Protection Zone (IPZ) Notification 2011. The Environment (Protection) Rules, 1986 under the EP Act, empowers the Central government to prohibit or restrict the location of industries and carrying on of processes and operations in different areas including wetlands. The Indian Fisheries Act, 1897, The Water (Prevention and Control of Pollution) Act, 1974, and The Biological Diversity Act, 2002 provide instruments for regulating various development threats on wetlands. The Coastal Aquaculture Authority Act, 2005 prohibits the conversion of natural coastal wetlands such as mangroves, salt pans, estuaries and lagoons for aquaculture. Further, under the Biological Diversity Act, 2002, the Central Government can issue directives to State Governments to take immediate ameliorative measures to conserve any area rich in biological diversity, biological resources and their habitats especially when the area is being threatened by overuse, abuse or neglect. The said Act also gives State Governments the powers to notify areas of biodiversity importance as biodiversity heritage sites.

Management of wetlands is carried on the basis of integrated management plans, which strive to conserve species habitats as well as provide for livelihood needs of dependent communities. Basin level restoration plans supported for Loktak (Manipur), Chilika (Odisha), Dal and Wular (Jammu and Kashmir), and Bhoj (Madhya Pradesh), have required coordination across sectors, and involvement of multiple agencies. The significant role of stakeholder engagement, particularly local communities has been brought out in most of the management plans. Ecological restoration of Chilika, and its transformation from a Ramsar Site enlisted within Montreux Record to an award-winning site with Ramsar Wetland Conservation Award and Evian Special Prize in 2002 have been possible through an enabling gover-nance mechanism and sound science-based to guide integrated management (Pattnaik and Kumar 2016).

Balancing the needs of habitat conservation with livelihoods in wetlands is seldom easy, particularly beyond protected areas. A case is that of Kolleru (Andhra Pradesh), one of Asia's largest heronries of Spot-billed pelicans *Pelecanus philippensis,* was nearly completely decimated by the spread of aquaculture since the nineties (Sellamuttu *et al.* 2012). Analysis of occupancy patterns in seasonally flooded agriculture landscapes has indicated declines in a number of Sarus crane in areas of increasing population density and agriculture intensification (Sundar 2011).

The natural wetlands have continued to degrade in India on account of various anthropogenic pressures, despite a marginal increase in human-made wetlands (Kumar *et al.* 2017). A significant driver of wetland loss has been a failure in mainstreaming the wetlands ecosystem services and biodiversity in developmental planning. This has led to sectoral approaches being adopted for wetlands management, conversion for alternate usages, pollution, species invasion and over-extraction of resources.

## International cooperation

India is a signatory to several international conventions which directly or indirectly support wetlands and waterbird conservation. Key amongst these are the Convention on Wetlands (Ramsar Convention), the Convention on the Conservation of Migratory Species of Wild Animals (CMS), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on Biological Diversity (CBD). In 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals.

Concerns over declining populations of waterbirds and their habitats, wetlands, underpinned the development of an International Convention on the Conservation of Wetlands of International Importance especially as Waterfowl Habitat (also known as the Ramsar Convention) on 2 February 1971 (Finlayson 2012; Matthews 2013). Commitments of Contracting Parties to the Convention include designation of at least one wetland to the List of Wetlands of International Importance or the Ramsar List. The vision of the List is to 'develop and maintain an international network of wetlands which are essential for the conservation of global biodiversity and for sustaining human life through the maintenance of their ecosystem components, processes and benefits/services (Ramsar Convention Secretariat 2012). Of the nine criteria that can be used to designate a Wetland of International Importance (also called Ramsar Site), criterion 5 (a wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds) and criterion 6 (a wetland should be considered internationally important if it regularly supports 1 per cent of the individuals in a population of one species or subspecies of waterbird) specifically cater to the needs of waterbird conservation.

The 1 per cent criterion at flyway level remains one of the most original contributions of the Convention towards the development of a network of wetlands providing for habitat needs of long-distant migrants (Kuijken 2006). At the time of writing this paper, the 170 Contracting Parties of the Convention had designated 2,335 wetlands to the network covering 249.6 million ha. Of these, 713 wetlands fulfilled criterion 5, and 838 wetlands criterion 6. India ratified the Convention in 1982 and had designated 27 wetlands to the Ramsar Site network.

The 'wise use' approach of the Ramsar Convention is globally recognized as the central tenet of wetlands management. The approach acknowledges that restricting wetland loss and degradation requires incorporation of linkages between people and wetlands, and thereby emphasizes that human use of these ecosystems on a sustainable basis is compatible with conservation (Finlayson *et al.* 2011). Wise use is defined in the Convention text as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development". The approach calls for maintaining wetland values and functions in order to ensure maintenance of the flow of benefits from wetlands (their ecosystem services) from an inter-generational equity point of view (Finlayson *et al.* 2011; Pritchard 2016).

The Convention on Biological Diversity (CBD), emerging from the 1992 Earth Summit, provides a framework for safeguarding ecological underpinnings of development. The Convention Contracting Parties, *inter alia*, commit to the development of national biodiversity strategies and action plans and integrate these into broader national plans for environment and development. India ratified the CBD in 1994. In line with the CBD Strategic Plan 2011–2020, India has formulated 12 National Biodiversity Targets. Wetlands find direct reference under Target 3 (Strategies for reducing the rate of degradation, fragmentation and loss of natural habitats are finalized and actions put in place by 2020), Target 6 (ecologically representative areas on land and in inland waters, as well as coastal and marine zones, especially those of particular importance for species, biodiversity and ecosystem services, are conserved effectively and equitably), and Target 8 (by 2020, ecosystem services, especially those related to water, human health and livelihoods and wellbeing are enumerated, and measures to safeguard them are identified).

The Convention on Conservation of Migratory Species of Wild Animals (also known as Bonn Convention) provides a global platform for conservation and sustainable use of migratory species and their habitats. The Convention provides a legal foundation for an internationally coordinated mechanism for conserving migratory species, including waterbirds, throughout their migratory range. India is a signatory to the Convention since 1983 and has also acceded several agreements within the framework of the Convention, such as for Siberian Crane, birds of prey (raptors) and others.

In 2018, the MoEFCC adopted a National Action Plan for Conservation of Migratory Waterbirds and their Habitats along the Central Asian Flyway.

The long-term goal of the National Action Plan is to arrest population decline and secure habitats of migratory bird species. In short-term, the action plan seeks to halt the downward trends in declining meta-populations and maintain stable or increasing trends for healthy populations by 2027 (MoEFCC 2018).

## Gaps and challenges

The declining health of wetlands poses significant challenges for maintaining a network of wetlands habitats which can provide for life-cycle needs of migrating waterbirds. Six major gaps and challenges are listed in this section, which limits the effectiveness of various conservation initiatives.

Firstly, while protected areas continue to be a primary focus of conservation efforts, there is limited effort placed on wetlands located outside the protected area network. Outside the protected area network, management needs to strike a balance between addressing the livelihood needs of wetland-dependent communities with that of securing habitat values, including that of waterbirds. Participatory and adaptive wetlands management approaches are of high value in such settings, the implementation of which has been severely constrained by capacity and governance gaps at multiple levels.

Secondly, for a country with diverse wetland regimes as India, the current list of 27 Ramsar Sites is an under-representation of the ornithological significance of wetlands. Using waterbird population criteria alone, 135 potential Ramsar Sites have been identified (Islam and Rahmani 2008). However, designation alone is of limited value, if commitments related to ensuring wetlands wise use and maintenance of ecological character are not met.

Thirdly, there are challenges related to sectoral policy coherence. The National Water Policy and the National Water Mission speak about water security without recognising the role wetlands play in ensuring the same. The role of wetlands as natural water infrastructure and capability to deliver water management objectives is not incorporated. Similarly, within climate change policies, the risks of mal-adaptation for wetlands is not factored in. Wetlands do not find a mention in agriculture policy, despite the sector being the largest consumer of water and a source of nutrients.

Fourthly, for wetlands to provide their full range of ecosystem services and support waterbird habitats, their water needs need to be integrated within any plan for water use and management within the river basin and coastal zone they are located in. Water and sediments provide the physical templates within which these ecosystems evolve and function. To maintain the desired level of ecological health and functioning, wetlands require sufficient water of adequate quality, at the right time and in the right pattern (Ramsar 2010). The protected area based management approaches seldom take into account the need for integrating wetlands within water and land use planning within the landscape they are situated within. Cases like that of Keoladeo highlight the consequences as well as deep political ecology associated with securing water for wetland functioning (Lewis 2003).

The fifth challenge is related to achieving robust research management interface. Much of the work on waterbird species is descriptive, focused on individual and species within protected areas and key wetlands. Research on waterbirds beyond nests and beyond protected areas can play a significant role in setting management regimes for wetlands at the landscape scale (Gopi *et al.* 2014). Such research, however, is minimal.

Finally, systematic waterbirds and wetlands monitoring are crucial for effective conservation planning and management decision-making. The data on waterbird population and distribution within India and at flyway scale remains patchy. The fifth edition of Waterbirds Population Estimates contains CAF level population trend information for 73 species, a majority of which (68 per cent) do not have known trend estimates. There is no idea about trend quality for 71 per cent of species, and another 25 per cent do not have quality assessments (WI 2012). Poor data quality has consequences for the implementation of waterbird related criteria for the designation of new Ramsar Sites.

## Priorities for action

Effective conservation planning for migratory species, including migratory waterbirds, need to be based on explicit accounting for the movement of the individual (Runge *et al.* 2014). Different parts of movement cycle (such as breeding grounds, non-breeding grounds, stopover sites, migration corridors) may need to be treated as separate conservation features (rather than managing distribution of each species as a single conservation feature), and conservation strategy developed on the basis of linkages between these features (Martin *et al.* 2007; Shuter *et al.* 2011). The existing protected areas may need to be complemented by wetlands conserved through mechanisms of national and international designation and managed to meet the needs of waterbirds while providing for the dependence of local communities. New models of community engagement and resource stewardship may need to be considered, which provide wetland-dependent communities with a direct stake in wetlands conservation and wise-use.

Priority needs to be accorded to the conservation of wetlands habitats, through better implementation and enforcement of existing regulatory regimes. By incorporating wetlands within the land use classification system, a regulatory check on illegal encroachment and conversion of wetlands for various purposes can be made. Equally urgent is the need to develop the human capacity for integrated management of wetlands, by considering the different wetlands features and drivers governing these features. Particular attention needs to be given to the incorporation of climate vulnerability of wetlands in management planning processes, and integration of wetlands within climate change mitigation and adaption programmes.

There is a pressing need to increase the waterbird population and distribution monitoring efforts. Reliable population estimates will ensure that Ramsar site designation is based on robust data, and the site network is representative and relevant for the needs of waterbird conservation. Wherever possible, waterbird monitoring may be institutionalized within the wetlands monitoring programmes, so that information on long term trends is generated as a part of the assessment of changes in wetland ecological character.

Lastly, the success of flyway-scale conservation is dependent on collaborative efforts between range countries. Implementation of commitments under the existing international conservation frameworks forms the cornerstone for such collaboration. Developing insights into connections between species migration and ecosystem services across spatial scales may provide collaboration opportunities for species across political borders. Frameworks such as telecoupling (Liu *et al.* 2016; Laura *et al.* 2017) may help define economic mechanisms to icentivize ecosystem services received due to habitat protection actions in distant areas.

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Map 1 (a): Wetlands where >20,000 and > 0.1 million waterbirds were recorded atleast once in Asian Waterbird Census during 2006-15 (Data Source: Asian Waterbird Census, Wetlands International)

Map 2: Wetlands where counts of atleast one species exceeded the known 1 per cent population threshold during 2006-15 during 2006-15 (Data Source: Asian Waterbird Census, Wetlands International)

# Invasive alien faunal species in India

C. Raghunathan[1], K.C. Gopi[2] and Kailash Chandra[3]

## Abstract

Invasive Alien Species are potential threats across the world during the recent times due to the adverse impact on the native species population by means of competition for space and resource partition. Rapid development and globalization are considered as a most proficient anthropogenic aspect of spreading invasive species beyond its native range of distribution along with natural factors by means of intentional and unintentional ways. The documentation on invasive alien faunal species of India is a recent initiative and as a result, a total of 154 species are listed including 56 species under five groups from the terrestrial/freshwater ecosystem and 98 species under eight groups from marine ecosystem were reported from India. A thorough investigation on the invasive alien faunal species is required to be made in Indian context to evaluate the quantum of devastation on the native faunal species population as well as to safeguard the native species along with biodiversity as a whole.

## Keywords

*Invasive Fauna, Marine and Terrestrial Ecosystem, India.*

## Introduction

In general, the invasive species are a potential threat to the ecosystem as they alter the species composition, cause biodiversity loss and compete with native species for space and food if they established well in their introduced range. In recent past, the invasive species become a matter of great attention, as it causes negative impact on the food security, human health, trade and economic development of the recipient country (Drake *et al.* 1989, Parker *et al.* 1999, Mack *et al.* 2000, Mooney 2005, Pimentel *et al.* 2005, Charles and Dukes 2007, Herron *et al.* 2007, Pejchar and Mooney 2009). The occurrence of invasive species was recognized globally since 1900 especially after the commencement of global trade. It has been estimated that invasive species pose the second largest threat to the biodiversity of the native species next to human-mediated climate change. According to Global Invasive Database, 1517 species are causing serious damages in their non-native range across the world, of which 39 per cent of species were of intentional introduction while 26 per cent introduced unintentionally and 20 per cent introduced both intentionally as well unintentionally, whereas, 13 per cent species from unknown sources. The database mentioned that 31 per cent of the invasive species were introduced outside of their geographical region.

The corridors for bio-invasion across the continent are ship mediated introduction, besides that horticulture and nursery trade also plays a vital role upon it. The countries with high industrialization and small islands are the main recipient of the invasive species. Presently Central Asia and Africa are prone to the introduction of non-native species

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as the industrialization is happening in massive mode. As a result of rapid industrialization and development, since the year 2000, seaborne trade is also increasing multi-folds, and presently sea route carries 90 per cent of the global trade and it handles 15 billion tons of cargo every year. This causes the ballast water-mediated bio-invasion in higher extent as every 24 hours about 10,000 species are carried in the ballast water and moving around (Anil *et al.* 2002) the globe and these species getting transferred to one geographic region to other regions.

The global biodiversity database indicated that about 8.7 million species are taxonomically validated, of which 2.2 million species from the ocean. Since Linnaeus 1758 i.e., over 260 years, only 1.2 million species are taxonomically catalogued. Further, it is estimated that about 86 per cent species exists in terrestrial and 91 per cent species in marine ecosystems ye to be described. Under this circumstances, it is pre-requisite to inventorize the native species of fauna and flora to distinguish other species as non-native or invasive. Considering the threats of invasive alien species, Convention Biological Diversity (CBD) also set an agenda under Aichi Biodiversity Target-9 to ensure the measures to prevent the introduction and establishment of IAS and to be by 2020 in which India is a party to it.

## Literature review

The differentiation in faunal communities is documented way back in 1800s based area-wise distribution. Schmarda (1853) postulated 21 ecoregions to demonstrate faunal diversity while Sclater (1857) proposed only six regions across the globe. Woodward (1851-1856) mentioned 27 terrestrial ecoregions and 18 marine ecoregions across the globe. Recently, Spalding *et al.* (2007) stated 12 major areas to denote characteristic features of marine faunal communities. India is blessed to high biodiversity in different ecosystems including mountains, forests, grasslands, mangroves, lakes, rivers, wetlands and coastal and marine habitats.

The studies on the invasive species in Indian territories are not well documented and it has been reported sporadically over the period especially since the 1960s. The studies pertaining to invasive species in Indian context on amphipods from east and west coast (Sivaprakasam 1969, 1977), molluscs (Karande and Menon 1975), wood boring molluscs (Santhakumaran 1976), fouling faunal communities (Rao and Ganapati 1978), hydromedusae in west coast (Santhakumari 1997), marine bio-invasion in general (Anil 2002, 2003; Goankar *et al.* 2010), bryozoans (Soja 2006, 2007, Mankeshwar *et al.* 2015), snowflake coral *Carijoa riisei* from Gulf of Mannar, and Andaman and Nicobar Islands (Padmakumar *et al.* 2011; Divya *et al.* 2012; Raghunathan *et al.* 2013), jellyfish in southwestern coast (Galil *et al.* 2013), ctenophore and scyphozoans (Prasade *et al.* 2015, 2016), ascidians (Renganathan 1981, 1984; Meenakshi 2005, 2009; Jaffarali *et al.* 2009, 2010, 2015; Swami *et al.* 2011; Tamilselvi *et al.* 2011; Meenakshi and Senthamarai 2013; Jaffarali and Tamilselvi 2016; Jhimli *et al.* 2015, 2017); and crustaceans (Dev Roy and Nandi 2017) are worth mentioning.

## Invasive fauna in India

Thorough consultations of literature, as well as from the understanding of the nature of species distribution, as of now 154 species of fauna in India are listed as Invasive Alien Species. Among them, 56 species belonging to 5 groups are reported from terrestrial/freshwater ecosystem while 98 species under eight groups from the marine ecosystem (Table 1).

**Table 1: Invasive alien faunal species reported in India**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **TERRESTRIAL ECOSYSTEM** | | | | | | |
| S.No. | Groups | | | | | | Total |
| 1. | Arthropoda | | | | | | 31 |
| 2. | Pisces | | | | | | 19 |
| 3. | Reptilia | | | | | | 1 |
| 4. | Aves | | | | | | 3 |
| 5. | Mammalia | | | | | | 2 |
| | **Subtotal** | | | | | | **56** |
| | **MARINE ECOSYSTEM** | | | | | | |
| S.No. | Groups | West coast | East coast | Peninsular Indian coasts | All coasts including islands | Indian waters *(no specific distribution record)* | Total |
| 1. | Cnidaria | 5 | 1 | 2 | 3 | | 11 |
| 2. | Ctenophora | 3 | | | | | 3 |
| 3. | Mollusca | 2 | | 2 | 1 | | 5 |
| 4. | Annelida | 13 | 1 | | 1 | 1 | 16 |
| 5. | Arthropoda | 8 | | 4 | | 14 | 26 |
| 6. | Bryozoa | 2 | 2 | 2 | | | 6 |
| 7. | Entoprocta | | | | | 1 | 1 |
| 8. | Ascidia | 4 | 13 | 1 | 12 | | 30 |
| | **Subtotal** | **37** | **17** | **11** | **17** | **16** | **98** |
| | **GRAND TOTAL** | | | | | | **154** |

The terrestrial/freshwater invasive fauna includes 19 species of insects, 19 species of freshwater fishes, one species of reptile, three species of birds and two species of mammals (Table 2).

**Table 2: Terrestrial and freshwater exotic/invasive alien species of India**

| S.No. | Species Name | Common Name |
|---|---|---|
| | **Insects** | |
| 1. | *Cryptotermes dudleyi* (Banks, 1918) | West Indian Dry Wood Termite |
| 2. | *Coptotermes gestroi* (Wasmann, 1896) | The Asian subterranean termite |
| 3. | *Frankliniella occidentalis* (Pergande, 1895) | Western Flower Thrips |
| 4. | *Thrips parvispinus* (Karny, 1922) | – |
| 5. | *Aleurodicus disperses* (Russel, 1965) | The Spiralling Whitefly |
| 6. | *Aleurodicus rugioperculatus* (Martin, 2004) | Rugose Spiraling Whitefly |
| 7. | *Eriosoma lanigerum* (Hausmann, 1802) | Woolly Apple Aphid |
| 8. | *Wahlgreniella nervata* (Gillette, 1908) | Strawberry Tree Aphid |
| 9. | *Heteropsylla cubana* (Crawford, 1914) | Subabul Psyllid |
| 10. | *Icerya purchasi* (Maskell, 1878) | Cottony Cushion Scale |
| 11. | *Orthezia insignis* (Browne, 1887) | Lantana Bug |
| 12. | *Paracoccus marginatus* (Williams and Granara de Willink, 1992) | Papaya Mealy Bug |
| 13. | *Phenacoccus parvus* (Morrison, 1924) | Lantana Mealybug, |
| 14. | *Phenacoccus solenopsis* (Tinsley, 1898) | Cotton Mealybug |
| 15. | *Phenacoccus madeirensis* (Green, 1923) | Madeira Mealybug |
| 16. | *Pseudococcus jackbeardsleyi* (Gimpel and Miller, 1996) | Jack Beardsley Mealybug |
| 17. | *Pineus pini* (Macquart, 1819) | Woolly pine aphid |
| 18. | *Quadraspidiotus perniciousus* (Comstock, 1881) | San Jose Scale |

| | | |
|---|---|---|
| 19. | *Leptocybe invasa* (Fisher & La Salle, 2004) | Blue Gum Chalcid/Eucalyptus All Aasp |
| 20. | *Quadrastichus erythrinae* (Kim, 2004) | Erythrina Gall Wasp |
| 21. | *Monomorium pharaonis* (Linnaeus, 1758) | Pharaoh Ant |
| 22. | *Xyleborus volvulus* (Fabricius, 1775) | Ambrosia Beetle |
| 23. | *Hypothenemus hampei* (Ferrari, 1867) | Coffee berry borer |
| 24. | *Spodoptera litura* (Fabricius, 1775) | Ladde Purugu (Telgu). |
| 25. | *Phthorimaea operculella* (Zeller,1873) | Potato tuber Moth |
| 26. | *Tuta absoluta* (Meyrick,1917) | Tomato Pinworm. South American. Tomato leaf miner |
| 27. | *Plutella xylostella* (Linnaeus,1758) | Diamond-Back Moth |
| 28. | *Aedes aegypti* (Linnaeus, 1762) | Yellow Fever Mosquito |
| 29. | *Culex quinquefasciatus* (Say, 1823) | Southern House Mosquito |
| 30. | *Bactrocera dorsalis* (Hendel, 1912) | Oriental Fruit Fly |
| 31. | *Liriomyza trifolii* (Burgess, 1880) | Serpentine Leaf Miner |
| | **Freshwater Fishes** | |
| 1. | *Carassius auratus* (Linnaeus, 1758) | Gold Crucian Carp |
| 2. | *Cyprinus carpio* (Linnaeus, 1758) | Common Carp |
| 3. | *Ctenopharyngodon idella* (Valenciennes, 1844) | Grass Carp |
| 4. | *Hypophthalmichthys molitrix* (Valenciennes, 1844) | Silver Carp |
| 5. | *Hypophthalmichthys nobilis* (Richardson, 1845) | Bighead Carp |
| 6. | *Tinca tinca* (Linnaeus, 1758) | Green Tench |
| 7. | *Piaractus brachypomus* (Cuvier, 1818) | Red Bellied Pacu |
| 8. | *Clarias gariepinus* (Burchell, 1822) | African Sharptooth Catfish |
| 9. | *Pangasianodon hypophthalmus* (Sauvage, 1878) | Suchi Pangas Catfish |
| 10. | *Pterygoplichthys disjunctivus* (Weber, 1991) | Vermiculated Sailfin catfish |
| 11. | *Pterygoplichthys multiradiatus* (Hancock, 1828) | Sailfin catfish |
| 12. | *Pterygoplichthys pardalis* (Castelnau, 1855) | Amazon Sailfin catfish |
| 13. | *Gambusia affinis* (Baird & Girard, 1853) | Mosquito fish |
| 14. | *Gambusia holbrooki* (Girard, 1859) | Mosquito fish |
| 15. | *Oncorhynchus mykiss* (Walbaum, 1792) | Rainbow Trout |
| 16. | *Salmo trutta* (Linnaeus, 1758) | Brown Trout |
| 17. | *Salvelinus fontinalis* (Mitchill, 1814) | American Brook Charr |
| 18. | *Oreochromis mossambica* (Peters, 1852) | Mossambique Tilapia |
| 19. | *Oreochromis niloticus* (Linnaeus, 1758) | Nile Tilapia |
| | **Reptilia** | |
| 1. | *Trachemys scripta* (Schoepff, 1792) | Yellow-bellied Slider Turtle, Common Slider |
| | **Aves** | |
| 1. | *Columba livia* (Gmelin, 1789) | Pigeon |
| 2. | *Sturnus vulgaris* (Linnaeus, 1758) | Starling |
| 3. | *Zosterops japonicus* (Temminck & Schlegel, 1845) | Japanese white-eye |
| | **Mammalia** | |
| 1. | *Equus asinus* (Linnaeus, 1758) | Donkey, African wild ass |
| 2. | *Rattus exulans* (Peale, 1848) | Pacific rat, Polynesian rat |

The marine invasive faunal communities including 11 species of cnidarians, three species of ctenophorans, five species of molluscs, 16 species of annelids, 26 species of arthropods, six species of bryozoans, one species of entoprocta and 30 species of ascidians are reported from Indian waters (Table 3).

**Table 3: Marine exotic/ invasive alien species of India**

| S. No. | Taxonomic Group(s)/Name | Common Name | Nativity/ Range | Introduction/ Distribution in India | Remarks/References |
|---|---|---|---|---|---|
| | **Phylum CNIDARIA** | | | | |
| | Class SCYPHOZOA<br>Order RHIZOSTOMEAE<br>Family MASTIGIIDAE | | | | |
| 1. | *Phyllorhiza punctata* Lendenfeld, 1884 | Australian Spotted Jellyfish | Australia and Phi-llippines | Gulf of Mannar | Invasive worldwide, Proficient at invading new zones<br><br>Sarvanan *et al.* 2016, Fofonoff *et al.* 2017, Sarvanan *et al.* 2016 |
| | Family CEPHEIDAE | | | | |
| 2. | *Marivagia stellata* Galil and Gershwin, 2010 | | Indian Ocean | Kerala | Invasive into the Mediterranean Sea through Suez Canal, Kerala Coast is established as its origin from Indian waters.<br><br>Galil *et al.* 2013, Galil *et al.* 2010 |
| | Order SEMAEOSTOMEAE<br>Family PELAGIIDAE | | | | |
| 3. | *Pelagia noctiluca* Forsskal, 1775 | The Mauve stinger | Europe | Kerala, Tamil Nadu | Invasive throughout oceanic waters negatively impacts aquaculture, invasive in its native range, not common in coastal waters<br><br>Kramp 1961, Ramakrishna and Sarkar 2003; Purcell 2005 |
| | Family CASSIOPEIDAE | | | | |
| 4. | *Cassiopea andromeda* Forsskal, 1775 | Upside-down jellyfish | Indo west Pacific | East and West coast of India, Andaman Islands | Invasive worldwide, transferred through Suez canal to Mediterranean Sea, Aegean Sea, Levantine Sea, no poisonous effect.<br><br>Rao 1931, Menon 1930 and 1936, Kramp 1961, Ramakrishna and Sarkar 2003, Venkataraman *et al.* 2012, Prasade *et al.* 2016 |
| | Class HYDROZOA | | | | |
| | Order LEPTOTHECATA<br>Family BLACKFORDIIDAE | | | | |
| 5. | *Blackfordia virginica* Mayer, 1910 | Black Sea jellyfish | Black Sea | Mumbai, Bassein Creek estuarine complex in India | Found in estuarine habitat in 13 countries, Argentina, Brazil, Bulgaria, China, France, India, Cuba, Canada, Mexico, Guatemala, Jamaica, Mexico, Portugal, Russia, South Africa, Spain, Ukraine, and the United States, fast and efficient nature of reproduction, transported by shipping vectors<br><br>Santhakumari *et al.* 1997; Kimber 2014 |
| | Family EIRENIDAE | | | | |
| 6. | *Eugymnanthea* sp. | | | East Coast of India | Raju *et al.* 1974, Anil *et al.* 2002 |
| | Order ANTHOATHECATA<br>Family TUBULARIIDAE Goldfuss, 1818 | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 7. | *Ectopleura crocea*<br>Agassiz, 1862 | Pink-mouth hydroid | The Atlantic coast of North America | East and West coast of India | Extended from Mission Bay, California to Alaska, introduced to Australia, New Zealand, Europe, the Mediterranean, the Azores, Madeira, and South Africa.<br><br>Mammen 1963, Gravely 1927, Nagale and Apte, 2013, http://invasions.si.edu/nemesis/ |
| | Family BOUGAINVILLIIDAE Lütken, 1850 | | | | |
| 8. | *Bimeria vestita*<br>Wright, 1859 | | The Firth of Forth, Scotland | East and West coast of India | The distribution includes both western and Eastern side Atlantic ocean, the Mediterranean and Black Seas, the Indian Ocean, and the East Pacific from Mexico to Chile<br><br>Annandale 1907, Mammen 1963, Fofonoff *et al.* 2017 |
| | (Soft Coral)<br>Class ANTHOZOA Ehrenberg, 1834<br>Subclass OCTOCORALLIA Haeckel, 1866<br>Lamouroux, 1812<br>Family CLAVULARIIDAE Hickson, 1894 | | | | |
| 9. | *Carijoa riisei*<br>Duchassaing and Michelotti, 1860 | Snowflake coral | Western Atlantic Ocean, South Carolina to Brazil | Andaman and Nicobar Islands, Gulf of Kachchh, Gulf of Mannar, Thiruvanathapuram, Kanyakumari and Goa | Dhivya *et al.* 2012, Raghunathan *et al.* 2013<br>Padmakumar *et al.* 2011<br>Patro *et al.* 2015,<br>Nandakumar 2016 |
| | (Sea anemone)<br>Class ANTHOZOA Ehrenberg, 1834<br>Subclass HEXACORALLIA Haeckel, 1896<br>Order ACTINIARIA Hertwig, 1882<br>Family DIADUMENIDAE Stephenson, 1920 | | | | |
| 10. | *Diadumene lineata*<br>Verrill, 1869 | Orange striped anemone | Japan, Hong Kong | West Coast of India | Worldwide distribution<br><br>Parulekar, 1968, Saunders *et al.*, 2013, Lin and Weir, 2016, Fautin *et al.* 2009, Hancock *et al.* 2017 |
| | (Scleractinian coral)<br>Class ANTHOZOA Ehrenberg, 1834<br>Subclass HEXACORALLIA Haeckel, 1896<br>Order SCLERACTINIA<br>Family DENDROPHYLLIIDAE Gray, 1847 | | | | |
| 11. | *Tubastrea coccinea*<br>Lesson, 1829 | Orange cup coral | Brazil, Caribbean Sea, Gulf of Guinea, Gulf of Mexico | Andaman and Nicobar Islands, Gulf of Mannar, Gulf of Kachchh and Lakshadweep | Venkataraman 2006,<br>Caerio 1999, Pillai and Patel 1988 |
| | **Phylum CTENOPHORA** | | | | |
| | Class NUDA<br>Order BEROIDA<br>Family BEROIDAE | | | | |
| 12. | *Beroe ovata*<br>Bruguiere, 1789 | | Atlantic coasts of North and South America | West coast of India | **Biological control over ctenophore species** ***Mnemiopsis*** **and** ***Pleurobrachia***<br><br>Chopra 1960, Purcell *et al.* 2001, Shiganova *et al.* 2014, Volovik and Korpakova 2004 |

| | | | | | |
|---|---|---|---|---|---|
| 13. | *Beroe cucumis*<br>Fabricius, 1780 | Pink slipper comb jelly | Atlantic waters | West coast of India | Predator of *Pleurobrachia*<br><br>Robin *et al.* 2009, Shiganova *et al.* 2014 |
| | Class TENTACULATA<br>Order PLATYCTENIDA<br>Family CTENOPLANIDAE | | | | |
| 14. | *Vallicula multiformis*<br>Rankin, 1956 | | Jamaica | Gulf of Kachchh | Distribution includes Brazil, Bermuda, California, Madeira, the Canary Islands, Cuba, Hawaii, Caribbean, Europe and southeast Atlantic<br><br>Rankin 1951<br>Marcus 1957<br>Prasade *et al.* 2015 |
| | **Phylum MOLLUSCA** | | | | |
| | Class GASTROPODA<br>Order NUDIBRANCHIA<br>Family POLICERIDAE Alder and Hancock, 1845 | | | | |
| 15. | *Thecacera pennigera*<br>Montagu, 1813 | Winged thecacera | Atlantic coast of Europe | Kerala coast | By ballast waters, invasive to Australia, Tasman Sea, United States<br><br>Nandakumar 2016 (www.thehindu.com) |
| | Class BIVALVIA<br>Order MYDIA<br>Family DREISSENIDAE Gray, 1840 | | | | |
| 16. | *Mytilopsis sallei*<br>Recluz, 1849 | Caribbean false mussel | Atlantic waters | East and west coasts of India | Ganapati *et al.* 1971, Karande and Menon 1975, Raju *et al.* 1988 |
| | Order MYDIA<br>Family TEREDINIDAE Rafinesque 1815 | | | | |
| 17. | *Lyrodus medilobatus*<br>Edmonson, 1942 | | Indo-Pacific, Hawaiian Island, New Zealand, Australia, Virginia, Bermuda | West coast of India | Santhakumaran 1986 |
| | Family PHOLADIDAE Lamarck, 1809 | | | | |
| 18. | *Martesia striata*<br>Linnaeus, 1758 | Striated wood paddock | Native range is unknown | East and West coast of India, Lakshadweep | Wood-boring, Worldwide distribution, occurs naturally in the Atlantic, Pacific and Indian<br>Oceans, invasive to England, Ireland, Pearl Harbour, Hawaii, dispersed passively or by ship or by driftwood<br><br>Nair and Dharmaraj 1983, Surya Rao and Subba Rao 1991, Ravinesh and Biju Kumar 2015, Cevik *et al.* 2015, Nawrot *et al.* 2015 |
| | Order MYTILIDA<br>Family MYTILIDAE Rafinesque, 1815 | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 19. | *Perna perna* Linnaeus, 1758 | (Brown Mussel) | The Red Sea, East coast of South Africa | West coast of India, Tamil Nadu | Introduced by ballast water to India from Oman region 100 years ago, Invasive to Mediterranean Sea, North America, Gulf of Mexico, it resembles native species *Perna viridis*<br><br>Kuriakose and Nair 1976, Mahapatro *et al.* 2015, Kesavan *et al.* 2009 Shanmugam and Vairamani, 2009, Sreekanth *et al.* 2015, Clement *et al.* 2013, Harkantra and Rodrigues, 2004, Parulekar *et al.* 1984, Menon and Pillai 1996, www.thehindu.com/article16643556.ece, Nawrot *et al.* 2015 |
| | **Phylum ANNELIDA** | | | | |
| | Class POLYCHAETA<br>Order SABELLIDA<br>Family SERPULIDAE Rafinesque, 1815 | | | | |
| 20. | *Ficopomatus enigmaticus* Fauvel, 1923 | Australian Tube worm | Australia | Indian Ocean | Chandramohan and Aruna 1994 |
| 21. | *Protula tubularia* Montagu, 1803 | Bristle worm | Native range is unknown | Mumbai | Gaonkar *et al.* 2010 |
| 22. | *Hydroides elegans* Haswell, 1883 | | Indo-Pacific | East coast of India | Mahapatro, *et al.* 2015 |
| | Order PHYLLODOCIDA<br>Family GLYCERIDAE Grube, 1850 | | | | |
| 23. | *Glycera longipinnis* Grube, 1878 | | Philippines | Mumbai | Gaonkar *et al.* 2010 |
| | Family NEREIDIDAE Blainville, 1818 | | | | |
| 24. | *Neanthes cricognatha* Ehlers, 1904 | | New Zealand | Mumbai | Gaonkar *et al.* 2010 |
| 25. | *Nereis falcaria* Willey, 1905 | | | Mumbai | Gaonkar *et al.* 2010 |
| 26. | *Perinereis nuntia* Lamarck, 1818 | | Gulf of Suez | Mumbai | Gaonkar *et al.* 2010 |
| | Order TEREBELLIDA<br>Family CIRRATULIDAE Carus, 1863 | | | | |
| 27. | *Protocirrineris chrysoderma* Claparede, 1868 | | | Mumbai | Gaonkar *et al.* 2010 |
| | Family COSSURIDAE Day, 1963 | | | | |
| 28. | *Cossura coasta* Kitamori, 1960 | | Greece | Mumbai | Gaonkar *et al.* 2010 |
| | Family MALDANIDAE Malmgren, 1867 | | | | |
| 29. | *Petaloproctus terricolus* Quatrefages, 1866 | | San Sebastian, South West Africa | Mumbai | Gaonkar *et al.* 2010 |
| | Order EUNICIDA<br>Family LUMBRINERIDAE Schmarda, 1861 | | | | |
| 30. | *Lumbrineris japonica* Marenzeller, 1879 | | Japan | Mumbai | Gaonkar *et al.* 2010 |
| 31. | *Lumbrineris bifilaris* Ehlers, 1901 | | The Pacific Ocean | Mumbai | Gaonkar *et al.* 2010 |
| | Family ONUPHIDAE Kinberg, 1865 | | | | |
| 32. | *Onuphis eremita* Audouin & Milne Edwards, 1833 | | Atlantic Ocean | Bay of Bengal, Mumbai | Fauvel 1953, Gaonkar *et al.* 2010 |

| | | | | | |
|---|---|---|---|---|---|
| 33. | *Onuphis holobranchiata* Marenzeller, 1879 | | Japan | Mumbai | Gaonkar *et al.* 2010 |
| | Order SPIONIDA<br>Family SPIONIDAE Grube, 1850 | | | | |
| 34. | *Scolelepis squamata* Muller, 1806 | | Gulf of Mexico and the Caribbean Sea | Mumbai | Gaonkar *et al.* 2010 |
| 35. | *Malacoceros indicus* Fauvel, 1928 | | Australia | Mumbai | Gaonkar *et al.* 2010 |
| | **Phylum ARTHROPODA** | | | | |
| | Subphylum CRUSTACEA<br>Class MALACOSTRACA<br>Order ISOPODA<br>Family CIROLANIDAE Dana, 1852 | | | | |
| 36. | *Cilicaea lateraillei* Leach, 1818 | | Indonesia, Philippines, Sri Lanka, South Africa, Red Sea, Australia | Arabian Sea | Venugopal and Wagh 1987, Anil *et al.* 2002 |
| 37. | *Cirolana harfordi* Lockington, 1877 | | | Indian waters | Anil *et al.* 2003<br>Exotic |
| | Family SPHAEROMATIDAE Latreille, 1825 | | | | |
| 38. | *Paradella dianae* Menzies, 1962 | | Pacific coasts of North and Central America | India | Anil *et al.* 2003, Roy and Nandi 2017<br>Exotic |
| 39. | *Sphaeroma serratum* Fabricius, 1787 | | | India | Anil *et al.* 2003, Roy and Nandi 2017<br>Exotic |
| 40. | *Synidotea laevidorsalis* Miers, 1881 | | Australia, California | India | Anil *et al.* 2003, Roy and Nandi 2017<br>Exotic |
| | Order AMPHIPODA<br>Family STENOTHOIDAE Boeck, 1871 | | | | |
| 41. | *Stenothoe gallensis* Walker, 1904 | | China, Sri Lanka | East and West coast of India | Walker 1904, Venugopal and Wagh 1986, Anil *et al.* 2003<br>Exotic |
| 42. | *Stenothoe valida* Dana, 1852 | | Brazil, Australia | Indian waters | Shyamasudari 1997<br>Exotic |
| | Family ISCHYROCERIDAE Stebbing, 1899 | | | | |
| 43. | *Jassa falcata* Montagu, 1808 | | Black sea, British coast and Ireland coast | Indian waters | Shyamasudari 1997<br>Exotic |
| 44. | *Jassa marmorata* Holmes, 1905 | | Native distribution is unknown; first described from Rhode Island, the North Atlantic | Indian waters | It is introduced to Western North America, South America, South Africa, Australia, New Zealand, China, Japan, and Russia, Exotic<br><br>Anil *et al.* 2003, Fofonoff *et al.* 2017 |
| 45. | *Ericthonius brasiliensis* Dana, 1853 | | Atlantic Ocean at Rio de Janeiro | East and west coasts of India | Venugopal and Wagh, 1986<br>Exotic |
| | Family MAERIDAE Krapp-Schickel, 2008 | | | | |

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| 46. | *Quadrimaera pacifica* Schellenberg, 1938 | | Australia, Madagascar, North Pacific Ocean, Panama, Republic of Mauritius | East and west coasts of India | Venugopal and Wagh 1986, Anil *et al.* 2002<br>Exotic |
| 47. | *Elasmopus rapax*, Costa, 1853 | | Gulf of Califorinia | Indian waters | Shyamasudari 1997 |
| | Family PODOCERIDAE Leach, 1814 | | | | |
| 48. | *Podocerus brasiliensis* Dana, 1853 | | Atlantic Ocean at Rio de Janeiro and Brazil | East and West coast of India | Venugopal and Wagh 1986, Shyamasudari 1997, Anil *et al.* 2003 |
| | Family COROPHIIDAE Leach, 1814 | | | | |
| 49. | *Monocorophium acherusicum* Costa, 1853 | | Europe | Indian waters | Shyamasudari 1997 |
| | Family CAPRELLIDAE Leach, 1814 | | | | |
| 50. | *Paracaprella pusilla* Mayer, 1890 | | Brazil | Indian waters | Reported from many marinas on the Atlantic and Mediterranean coasts, Australia, Hawaii, Exotic<br><br>Mayer 1890, Guerra-Garcia 2010, Alarcon-Ortega 2015 |
| | Order DECAPODA<br>Family PENAEIDAE Rafinesque, 1815 | | | | |
| 51. | *Penaeus vannamei* Boone, 1931 | | Eastern Pacific coast | India | Dev Roy 2007, Wakida-Kusunoki *et al.* 2011<br>Worldwide distribution, Introduced for aquaculture purpose, Exotic |
| | Class HEXANAUPLIA<br>Infraclass CIRRIPEDIA<br>Order SESSILIA<br>Family BALANIDAE Leach, 1806 | | | | |
| 52. | *Amphibalanus amphitrite* Darwin, 1854 | | The West Pacific and Indian Oceans from Southeastern Africa to Southern China. | Mumbai | Invaded to the Eastern Pacific (Panama-California), Northwestern Pacific (Korea-Japan-Russia), Southwestern Pacific (including New Zealand and Southern Australia), (Hawaii Islands, Western Atlantic (Caribbean-Long Island Sound), and Northeastern Atlantic (Germany-England-France).<br><br>Bhatt and Bal 1960, Anil *et al.* 2003, Fofonoff *et al.* 2017 |
| 53. | *Amphibalanus eburneus* Gould, 1841 | | The Western Atlantic from the southern Gulf of Maine to Venezuela | Indian waters | Invasive to the Northeast Atlantic, the Indian Ocean, Northwestern Pacific and the Northeastern Pacific, compete with cultured oysters<br><br>Anil *et al.* 2003, Fofonoff *et al.* 2017 |
| 54. | *Fistulobalanus pallidus* Darwin, 1854 = *Balanus amphitrite* var. *stutsburi* | | West coast of Africa | West coast of India | Wagh 1974, Anil *et al.* 2003<br>Exotic |
| 55. | *Megabalanus tintinnabulum* Linnaeus, 1758 | | The North Sea | Indian waters | Anil *et al.* 2003<br>Harmful species, Exotic |
| 56. | *Megabalanus zebra* Russell *et al.*, 2003 | | China | Indian waters | Anil *et al.* 2003 |

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| | Class HEXANAUPLIA<br>Subclass COPEPODA<br>Order CALANOIDA<br>Family CALANIDAE Dana, 1849 | | | | |
| 57. | *Nannocalanus minor*<br>Claus, 1863 | | | Mumbai | Gaonkar *et al.* 2010 |
| 58. | *Cosmocalanus* sp. | | | Mumbai | Gaonkar *et al.* 2010 |
| | Family PARACALANIDAE Giesbrecht, 1893 | | | | |
| 59. | *Paracalanus* sp. | | | Mumbai | Gaonkar *et al.* 2010 |
| | Family TORTANIDAE Sars, 1902 | | | | |
| 60. | *Tortanus* sp. | | | Mumbai | Gaonkar *et al.* 2010 |
| | Order HARPACTICOIDA<br>Family TACHIDIIDAE<br>Sars, 1909 | | | | |
| 61. | *Euterpina acutifrons*<br>Dana, 1847 | | | Mumbai | Gaonkar *et al.* 2010 |
| | **Phylum BRYOZOA** | | | | |
| | Class GYMNOLAEMATA<br>Order CTENOSTOMATIDAE<br>Family VESICULARIIDAE | | | | |
| 62. | *Amathia verticillata*<br>delle Chiaje, 1822 | | The Mediterranean Sea | Chennai, Vishakhapatnam, Cuddalore, Palk Bay, Colachal and Mumbai | Distributed worldwide from Mediterranean to tropical, subtropical environments within the Atlantic and Indo-Pacific Oceans<br><br>Robertson 1921,<br>Ganapathi and Satyanarayana Rao 1968, Nair *et al.* 1992,<br>Swami and Udhayakumar 2010,<br>Bhave and Apte 2012, Yedukondala Rao and RakeshSarma 2013, Pati *et al.* 2015, Prince Prakash Jebakumar *et al.* 2017, Fofonoff *et al.* 2017 |
| | Order CHEILOSTOMATIDA<br>Family BUGULIDAE Gray, 1848 | | | | |
| 63. | *Bugula neritina*<br>Linnaeus, 1758 | | Mediterranean and American seas | West and East Coast of India | Cosmopolitan, potential to be a fouling pest<br><br>Robertson 1921, Menon and Nair 1967, Subba Rao and Sastry 2005, Ryland *et al.* 2011 |
| 64. | *Bugulina stolonifera*<br>Ryland, 1960 | | Swansea, Wales; Northwest Atlantic | West coast of India | Extended from New Hampshire to the Gulf of Mexico, Bermuda, and Jamaica, introduced to the West Coast of the United States, Panama, Hawaii, Australia, New Zealand, China, India, Brazil, Argentina, and Europe.<br><br>Shrinivaasu *et al.* 2015, Fofonoff *et al.* 2017 |
| 65. | *Bugulina flabellata*<br>Thompson in Gray, 1848 | | The Northeast Atlantic, from southern Norway to Morocco and the Mediterranean Sea. | East coast of India | The distribution includes Australia, New Zealand, India, Brazil, Argentina and Chile<br><br>Menon and Nair 1967, Shrinivaasu *et al.* 2015, Fofonoff *et al.* 2017 |

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| | Family CRYPTOSULIDAE Vigneaux, 1949 | | | | |
| 66. | *Cryptosula pallasiana* Moll, 1803 | | Atlantic , from Norway to Morocco, Mediterranean and Black Seas, Nova Scotia to Florida | West coast of India | The most competitive fouling organisms in ports<br><br>Shrinivaasu *et al.* 2015, Molnar *et al.* 2008, http://www.exoticsguide.org/images/c_pallasiana_lg_b.jpg |
| | Family MEMBRANIPORIDAE Busk, 1852 | | | | |
| 67. | *Membranipora membranacea* Linnaeus, 1767 | Coffin box | Eastern Canada, Nova-Scotia | East coast of India | Resembles to native bryozoan *Electra pilosa*, forms crust on algae, Proliferation in the Gulf of Maine has already destroyed entire kelp forests<br><br>Shrinivaasu *et al.* 2015, waves-vagues.dfo-mpo.gc.ca/Library/365586., Fofonoff *et al.* 2017 |
| | **Phylum ENTOPROCTA** | | | | |
| | Family BARENTSIIDAE | | | | |
| 68. | *Barentsia ramosa* Robertson, 1900 | | Pacific, California, Belgium | Indian Ocean | Satyanarayana Rao *et al.* 1988 |
| | **Phylum CHORDATA** | | | | |
| | (Ascidian)<br>Class ASCIDIACEA<br>Family ASCIDIDAE | | | | |
| 69. | *Ascidia sydneiensis* Stimpson,1855 | | Indo-Pacific and Atlantic ocean, Sub Antarctic region, East South America | Tuticorin port- Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 70. | *Ascidia gemmata* Sluiter, 1895 | | Indo-West Pacific | Tuticorin port – Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 71. | *Phallusia nigra* Savigny, 1816 | | Panama, USA, Indo-Pacific, Atlantic and the Mediterranean | Tuticorin port – Gulf of Mannar and Andaman and Nicobar Islands | Tamilselvi *et al.* 2011, Jhimli *et al.* 2015 |
| 72. | *Phallusia arabica* Savigny, 1816 | | Indo West Pacific and North east Atlantic | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 73. | *Phallusia polytrema* Herdman, 1906 | | Indo-West Pacific Region, East South America, Pan tropical throughout the Caribbean | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| | Family PYURIDAE | | | | |
| 74. | *Herdmania pallida* Savigny, 1816 | | Atlantic Ocean, Indo-West Pacific and the Mediterranean: Sub Antarctic region. | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |

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| 75. | *Microcosmus curvus* Tokioka, 1954 | | Pacific ocean | Tuticorin port - Gulf of Mannar | Tamilselvi*et al.*, 2011 |
| 76. | *Microcosmus squamiger* Michaelsen, 1927 | | Indo-Pacific, Southwest Atlantic and the Mediterranean Sea,: Sub Antarctic region | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 77. | *Microcosmus exasperates* Heller, 1878 | | Indo-West Pacific, Atlantic Ocean and the Mediterranean: East Africa, SubAntarctic, southeast America | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011, Jaffar Ali *et al.* 2015 |
| 78. | *Herdmania momus* Savigny, 1816 | | Mediterranean Sea. North Atlantic Ocean, Federal Republic of Somalia, Mozambique | South western coast of India | Jaffar Ali *et al.* 2015 |
| | Family PEROPHORIDAE | | | | |
| 79. | *Perophora formosana* Oka, 1931 | | Indo-West Pacific and Atlantic Ocean | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 80. | *Ecteinascidia garstangi* Sluiter, 1898 | | Madagascar, South Pacific Ocean | South western coast of India | Jaffar Ali *et al.* 2015 |
| | Order STOLIDOBRANCHIA<br>Family STYELIDAE Sluiter, 1895 | | | | |
| 81. | *Eusynstyela tincta* Van Name, 1902 | | Atlantic Ocean and Indo West Pacific: East South America | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 82. | *Styela canopus* Savigny, 1816 | | Indo Pacific, Atlantic Ocean and the Mediterranean: South and South east America, | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011, Renganathan 1981 |
| 83. | *Symplegma oceania* Tokioka, 1961 | | Indo-West Pacific | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 84. | *Symplegma viride* Herdman, 1886 | | Atlantic Ocean, Indo West Pacific and the Mediterranean: Sub Antarctic East South America | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 85. | *Botryllus schlosseri* Pallas, 1766 | | South Africa - Alexander Bay and Durban Bay | South western coast of India and South eastern coast of India – Tamil Nadu | Jaffar Ali *et al.* 2015<br>Jaffer Ali *et al.* 2009 |

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| 86. | *Botrylloides magnicoecum* Hartmeyer.191 | | Indo-West Pacific and Western Central Atlantic | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 87. | *Botrylloides leachii* Savigny, 1816 | | Northeast Atlantic, Indo West Pacific and Mediterranean and Black sea: Australia and Europe | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011, Jaffar Ali *et al.* 2015 |
| 88. | *Botgrylloides chevalense* Herdman, 1906 | | Eastern Indian Ocean: India | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| | Family DIDEMNIDAE | | | | |
| 89. | *Didemnum psammatodes* Sluiter, 1895 | | Indo-West Pacific and Eastern Atlantic; Subantarctic region, Malaya and West Africa | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 90. | *Didemnum candidum* Savigny, 1816 | | North Pacific Ocean | South eastern coast of India – Tamil Nadu | Jaffer Ali *et al.* 2009 |
| 91. | *Didemnum fragile* Sluiter, 1909 | | Australia | South western coast of India | Jaffar Ali *et al.* 2015 |
| 92. | *Lissoclinum fragile* Van Name, 1902 | | Indo-Pacific and Western central Atlantic | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 93. | *Diplosoma listerianum* Milne-Edwards, 1841 | | South Africa – Alexander Bay, Durban Bay, Lange Baan Bay | South western coast of India | Jaffar Ali *et al.* 2015 |
| 94. | *Trididemnum clinides* Kott, 1977 | | Indo-West Pacific | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| | *Tridemnum savignii* Herdman, 1886 | | Indo-Pacific and Western Central Atlantic | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| | Family POLYCITORIDAE | | | | |
| 95. | *Eudistoma viride* Tokioka, 1955 | | Western Central Pacific and Indian Ocean | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 96. | *Aplidium multiplicatum* Sluiter, 1909 | | Indo-West Pacific | Tuticorin port - Gulf of Mannar | Tamilselvi *et al.* 2011 |
| 97. | *Polyclinum glabrum* Sluiter, 1895 | | Central Indo Pacific | South western coast of India | Jaffar Ali *et al.* 2015 |

## Conclusion

The Earth's flora and fauna today is the outcome of a grand-scale change in their form and diversity due to the dynamic process of evolution that has been undergoing over hundreds of millions of years. Although the ecosystems and their biodiversity have been undergoing changes naturally, the human activities have influenced this process with some changes in the biodiversity from the normal, natural course. Such changes have augmented since the recent, past decades of the Anthropocene. The introduction of alien species and their impacts on native biodiversity has been one, among other, major man-made drive that has elicited changes in the biodiversity, and posed a threat of biodiversity loss. Global trade and transport have moved plants and animals much easier from one part of the earth to the other. The phenomenon of species introductions, either by intent, inadvertent, or accident, from one geographical region to the other is very common and frequent. But, the fact of the matter is the concern that the species introduced to non-native habitats and home environments sometimes establish and proliferate in the new habitat. Those new entrants, once established, threaten native biodiversity, and become the so-called invasive alien species.

The conservational measures are depending upon the monitoring programmes and strategic goals to overcome the biological damages. Identification of invasive alien species and the evaluation of the ecological impact of the species are prerequisite to understanding bio-invasion in a proper way. Further, it is required to identify the route of transmission from one area to another in order to restrict their dispersal. Studies on the reproductive biology of those species along with status survey and monitoring are required in a periodical basis to control the population growth. Identification or discovery of biological controlling agent can be the best practice to manage the devastation of invasive species for long-term effect as chemical control and mechanical controlling practices are short term. Further, it is high time to sensitize the people to make awareness about the impact of invasive species in the ecosystem of introduced range to safeguard and conservation of native biodiversity for sustainable utilization.

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# Governing the greens: Invasive Alien Plants in India

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**Abstract**

Plants, when invade and dominate a new bio-geographical area, are termed as Invasive Alien Plant Species (IAPS). These plants compete with the native species and pose a major threat to the ecology and economy in invaded regions. They lower the biodiversity, cause a major change in vegetation distribution and the ecosystem structure. Though this phenomenon has been occurring since long, the problem of invasion gained momentum in the last about two decades because of fast global economic growth. The magnitude of the impact varies depending on the geographical features of the area, population density and type of landscape. It is well known that the areas invaded by alien plants attract alien dependent fauna. The latter could serve as an initial carrier of plant propagule, but primary invaders, by and large, are the plants. Thus, the invasion by plants, the producers, is a basic issue, since all other life forms are dependent on them. Therefore, invasion by alien plants assumes primary focus of researchers, managers and policymakers. The ecological impacts of IAPS on terrestrial ecosystems have attracted the attention of researchers, managers and policymakers the world over. As per the reports of the World Conservation Union (IUCN), the Convention on Biological Diversity (CBD) and the Global Invasive Species Programme (GISP), IAPS spread in new environments are detrimental to human and national interests. The real challenge is to control their spread for meeting the objectives of the CBD and save the local, national and global ecology from destruction. The paper tries to identify the major invasive exotic plant species, including aquatic weeds, trees and woody shrubs, which have impacted severely in India, apart from identifying the newly invaded exotic plants which may pose a threat if not managed at the earliest. It has also attempted to access the risks and economic impacts apart from the management efforts in India and at the global level.

**Keywords**

*Invasive Alien Plants, Biodiversity, Ecozones, Parthenium, Lantana, Ageratum, Eichhornia, Prosopis, Chromolaena, Mikenia*, *Noninvasive.*

## Introduction

Plants, animals and microbes, like human being tend to spread their areas of the establishment. The regulatory mechanisms of different countries can check the transboundary movement of human-being alone. Plants, animals and microbes do not recognize the political boundaries on the Earth surface. For them, environmental barriers are the only restrictions for spread and establishment. In the native biogeographical zones, they remain in harmony with other biota of the community. However, the phenomenon of transboundary

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movement of biological organisms to areas other than their zones of origin where they overpower and affect the native species and the ecosystem amounts to an invasion. Such organisms that establish and monopolize the exotic habitat affecting the native community and ecosystem are referred to as Invasive Alien Species (IAS).

The phenomenon is seen in every type of biological organism including human being. It starts with the entry of, may be, one or a few individuals. Initially, the natives generally ignore (rather they welcome) such an entry for a period (lag phase) that may vary from a short to long duration depending on the available resources and the aggressive characteristics of the invader and the extrinsic factors of the invaded area. By the time the native communities experience the impact of the exotic invader, the latter gets established itself to give stiff competition to the natives.

As per Kathuria and Singh (2012) of the estimated 256 vertebrate extinctions, 109 (42.5 per cent) extinctions occurred due to biological invaders and 70 (27.3 per cent) have been caused by human exploitation (Cox 1993, as referred in Olson 2006: 178). Nearly 40 per cent of the endangered or threatened species in the United States alone are estimated to be at risk of extinction on account of Invasive Alien Species (Wilcove *et al.* 1998). It was estimated that population of about 77 per cent of the native fish species declined on account of the introduction of 31 alien fish species in Europe, North America, Australia and New Zealand (Ross 1991). Likewise, there are several insect species that invade non-native areas and cause havoc to the ecosystem. The same is true with microbial pathogens, e.g. bird flu, eye flu. The Swine flu caused by the H1N2 influenza virus originated in Pigs in 2000 in Mexico was initially seen affecting humans in 2009. From Mexico, it invaded almost the world over including India (Gibbs *et al.* 2009)

## Plant invasion

Among all the biological organisms, the invasion by alien plants assumes primary focus of researchers, managers and policy makers since all other forms of biota are dependent on them. When plants invade an exotic area, they grow and establish faster there because of the absence of any threat from their established prey. In nature, on the other hand, the predator-prey relationship keeps the species density in balance. This article is an attempt to focus on the invasion of alien plant species.

Invasive Alien Plants pose a major threat to the ecology and economy by homogenizing the vegetation and threating biodiversity. Though this phenomenon has been occurring since long, the problem of plant invasion did not engage sufficient attention in India and elsewhere. It gained momentum only in the last about three decades. The magnitude of impact varies from place to place depending upon the geographical features, landscape and a population density of the area invaded.

The concern of Invasive Alien Plant Species (IAPS) has become global since they pose major threat to the ecology and economy of invaded regions (Drake *et al.* 1989; Parker *et al.* 1999; Mack *et al.* 2000; Mooney 2005; Charles and Dukes 2007; Herron *et al.* 2007, Pejchar and Mooney 2009; Kohli *et al.* 2009; Bhatt *et al.* 2012; Shibu *et al.* 2013). The situation becomes serious when they invade especially the forest and Hill ecosystems. They cause a major change in vegetation at a global level and threaten biodiversity. The magnitude of impact varies depending on the geographical features of the area, population density and type of landscape (Kohli *et al.* 2009). Therefore, this issue has attracted the attention of researchers, managers and policymakers the world over. As per the reports of World Conservation Union, the Convention on Biological Diversity and the Global Invasive Species Programme, Invasive Alien Species proliferate and spread in new environments and are detrimental to human and national interests. The real challenge before humanity is to control the spread of invasives for meeting the objectives of CBD and save the local, national and global ecology from destruction. For such reasons, the problem of IAPS has been addressed under Article 8(h) of the CBD. This being a priority area demanding urgent policy decisions and all societies, CBD focused the year 2009 on the theme of IAS to celebrate International Biodiversity Day.

The invasions and spread to native and non-native areas are not a new phenomenon. However, their rate and dimensions of spread have increased in the recent past. The fundamental drivers facilitating enhanced rate of invasion, especially to exotic (alien) regions, can be grouped into four categories: (a) Anthropogenic interests – economical, ornamental interests etc., (b) Global warming/Climate change – wind velocity or change in the pattern of wind direction (c) Enhanced international trade, tourism and transport due to opening up of economy and better movement facilities (d) Changed land use pattern and habitat fragmentation.

Because of over-exploitation and homogenization of biota by humans, it become difficult to identify the area of origin of a species or its path/route of transfer to the alien area. To address this problem, three potential pieces of evidence are sometimes helpful: (a) Paleontological data which is time consuming, difficult, very expensive and not sure (b) Biogeographical approach, i.e. by a range of distribution pattern which also is neither precise nor sure. For instance, the tree *Dipterocarpus* forms a dominant component of tropical evergreen forests in the Indo-Malayan region. One is uncertain if it came to India from Malaysia or *vice-versa,* and (c) As per N.I.Vavilov, a Russian geneticist who launched a worldwide crop plant exploration programme, a geographical region which shows the greatest genetic diversity is the center of origin of it.

Many organisms invade new areas. The process starts with the entry of propagule (seed/cutting/ spore) by any process (aided by wind, water, biota or human) at the site beyond its original geographic range. These invaders reproduce (vegetative or sexual means) and colonize. The successfully colonized species expand their area and spread into the resident flora, adapt and adjust in the new environs, pass many life-cycles and get naturalized like natives (Table 1). It is not that all invaders are successful. A question arises, what makes them successful? It is the combination of (a) the intrinsic factors (e.g. genetic makeup including its ecological amplitude, life-cycle, no size and weight of seeds, flexibility in reproduction and regeneration,

**Table 1: Some terms with meaning and examples of plants**

| Terms | Meaning of the term | Example |
|---|---|---|
| Native or indigenous Species | A species available in the area of its origin | Mango in India or Kangaroo in Australia |
| Exotic or Alien species | A species outside the bio-geographical area of its origin or habitat | Eucalyptus, Poplar in India or shesham in the USA |
| Naturalized species | Alien species with self-replacing populations | Eucalyptus, Poplar in India |
| Invasive Species | A species which spreads to cover a large area and makes its unending kingdom at the cost of other species | Doob grass in the USA |
| Invasive Alien Species | A species whose introduction in an area outside its natural range of origin threatens the ecosystems, habitats, or species with socio-cultural, economic and/ or environmental harm and/or harm to human health | Water hyacinth, *Lantana* and *Ageratum* in India |
| Introduced species | Species which are brought to new area deliberately by man for his interest | Ageratum, Mikania, Eucalypts in India |

defense structures (physical or chemical)) and (b) the extrinsic / environment factors of the area invaded (e.g. edaphic (soil) and climatic conditions, lack of predators etc.) that determine the invasive potential of the invader and vulnerability of alien invaded area.

## Major impacts of invasion

It is considered that the impact of alien plant invasion on the diminishing global biodiversity is second only to habitat fragmentation and has, thus, become one of the major global issues of concern. The IAS affect native ecology and ecosystem integrity by (a) Altering hydrology, fire regimes, nutrient cycling, pathogenicity; (b) Competing with native plants affecting the dependent insects, birds, animals etc. and reducing biological diversity; (c) Changing structure and composition of native communities and (d) Altering natural vegetation development, thereby affecting the ecosystem services and the economy of the area. Further, the economic costs due to alien invasion are also enormous though not widely studied (Pimentel *et al.* 2005).

**Box 1: Introduced exotics could be harmful if not checked timely**

*Opuntia stricta,* a native of South America, was introduced into Australia in 1839 as food for Cochineal insects used in the production of dye. The plant escaped to nearby areas and, by 1926, it engulfed about 24 m ha of fertile land. To manage the growth and spread of *O.stricta*, *Cactoblastis* was brought in. By 1933, 90 per cent of it was controlled.

## Plausible theories of Invasion

Why invasion by alien plant species gets successful in a new area where natives are already established? As per Ramakrishnan (1991), there are two mutually inclusive theories that attempt to address this question.

(a) Theory of Balance of Nature: Different populations in a community interact with other populations as well as and within themselves (competition, allelopathy, predation, parasitism and mutualism). These interactions tend to maintain some sort of multi-species equilibrium by discouraging predominance and/or extinction of any particular species. It follows the oscillatory mechanism between predator and prey.

(b) Theory of Non-Equilibrium or Individualistic Species Response: Assemblage of different populations in a habitat is considered flexible and external factors acting on them determine their success. The physical environment is in the phase of change, though temporary. Species respond to the change by shifting their intensities of occurrence or expanding or shrinking their geographic range. However, it does not explain the invasion of plants from non-contiguous regions. Usually large scale, frequent and intense disturbance of ecosystem results in invasion (e.g. *Eupatorium, Mikinia, Lantana*)

## Drivers of the spread of plants

Frequency and strength of dispersal vector (e.g. wind velocity/direction or appendages), physical characteristics of the new habitat (e.g. topography of the area) and adaptive character of species (e.g. appendages, seed number, size, weight and germinability) govern the success strength of the species to establish in a new area.

## Alien plant invasion in Indian region

India, one of the 12 Vavilov's centres of origin of cultivated plants with ten biogeographic regions, is known for its rich biodiversity. Of the 35 Biodiversity Hotspot zones of the world, India supports four hotspots including Sundaland region. In addition, a wide range of latitude, longitude and altitudinal range, long coastal line, diversity in climate and socio-cultural factors, apart from universal anthropogenic reasons, have contributed to "large-scale" invasion by plants, animals and micro-organisms. Obviously, though it supports

**Table 2: Dispersal mechanism that aids the spread of plants**

| | Vectors | Dispersal mechanism | Examples |
|---|---|---|---|
| 1 | Autochory (Unaided dispersal) | No adaptation or appendages for dispersal which even herbivore do not consume. They fall nearby and spread slowly. If the plant is tall, the dispersal is a little away. | Small seed like of grasses-*Panicum, Bromus,* |
| 2 | Active Autochory (Explosive Dehiscence) | Seeds project out with force from the pod on drying. The seeds get dispersed with force to distant places. | *Cardamine hirsuta* |
| 3 | Anemochory (Wind Dispersal) | Seeds with a morphological adaptation which assist flight and easy dispersal by wind. | *Soncus, Asclepias, Acer* |
| 4 | Ecto-zoochory | Dispersal of sticky propagules/appendages hooked to the Animals. | *Xanthium* |
| 5 | Endozoochory (Endo Internal) | Undigested seeds with hard seed-coat that come out with the bird droppings and germinate at the new place. | *Ficus* |
| 6 | Hydrochory | Dispersal by Water – streams, flood flow. | |
| 7 | Introduction by Man | For meeting economic/personal interests/ tourism/ transport, propagules get transferred to non-native areas. | *Lantana, Mikania Ageratum*, |

rich floral and faunal diversity including endemic species, it also reflects a high rate of habitat degradation due to which opportunist invasive species can easily establish themselves. Due to its diverse climatic and environmental conditions, the country or the whole Indian subcontinent is highly vulnerable to biotic invasion, especially of plants. Moreover, expanding the population, high rate of trade and transport, opening up of the economy and fast rate of development coupled with the movement of people further aid the accidental and intentional entry of plant species in this region. The recent fast rate of economic growth of the country, apart from inadequate execution of quarantine measures, is also expected to leave its mark on the loss of plant diversity and increased introduction/ invasion of alien plant species propagules. Here loss of biodiversity on account of alien invasives could have far reaching consequences.

A number of economically important crops and ornamental species are introduced plants which have proved really beneficial to the human race. However, many such introduced plant species initially considered valuable have become a nuisance and difficult to manage. For instance, *Lantana camara* – a South American shrub introduced in several non-native areas for its hardy nature and ornamental value now is known to be a worst invader in 80 countries of the world. Some plants like *Parthenium hysterophorus (*Batish *et al.* 2012*)* and *Eupatorium odoratum* (Tripathi and Yadav 2012) invaded accidentally. Many of the introduced plants in India such as Eucalypts and Poplars along with some of the purposeful introductions, e.g. *Lantana camara, Ageratum conyzoides* (Kaur *et al.* 2012) *Prosopis juliflora* and *Mikania micrantha,* later became invasive and weedy (Bhatt *et al.* 2012). Some of the species which were introduced to help human society for agriculture later became invasive. For instance, the golden apple snail which was introduced into Asia from South America in 1980 for cultivation as a high-protein food source, escaped into the rice fields where it feeds voraciously on rice seedlings, causing significant crop damage (Naylor 1996). Controlling it has become a problem.

However, like many other countries, India also lack data on the total area occupied by alien plants and even on a total number of such species in each state/UT. Being a signatory to CBD, India is also seriously attempting to control IAPS in this era of globalization and economic integration. Consequently, a number of invasive species have made their abode in the Indian subcontinent.

Following are some of the possible reasons for the greater invasion potential in India:

a. The fast economic growth coupled with enhanced tourism and trade is expected to result in more transboundary inflow of exotic species into India and thus, homogenization of flora and fauna.
b. A fast increasing population that migrate frequently and carry seeds/propagules of invasive plants from one place to another.
c. Poor execution of Quarantine rules and easily available seeds of exotic plants from unregulated plant nurseries.
d. Lack of awareness even in the educated section of society about the ecological impacts of exotic plants.
e. Availability of fragmented/disturbed habitats or species-poor regions that serve as an invitation for invasive alien species.
f. Presence of different seasons and wide climatic ranges from temperate to tropical favour exotic plant species to establish in India.

## Salient attributes of invasive plants

There are several attributes of invasive plant species that enable them to spread in the alien environment.

Some of the very significant features that make them hardy and successful in alien areas include:

a. *Fast growth regeneration and reproduction*: IAPS are credited with high regenerative potential (*Parthenium*), better growth and reproductive traits and thus they spread very fast in invaded regions. They may even have special organs for vegetative reproduction such as stolons (*Ageratum*) or root suckers (*Lantana*), rhizomes, bulbs and turions.

b. *Better adaptability to diverse environmental conditions*: IAPS are successful because of their wide range of ecological amplitude that enables them to survive even under stressed conditions. They often modify growth patterns in response to changing the environment like soil conditions, moisture status, and/or limited space.

c. *Absence of natural enemies or predators*: The IAPS in the new geographical area remain devoid of their natural predators or pest that co-evolve with them in their native environment. In the absence of their predators, they form huge monocultures. Absence of natural enemies forms the basis of *Natural Enemies hypothesis* as given by Heirro and Callaway (2003).

d. *Allelopathic property:* The release of toxic chemicals into the environment hampers the growth and establishment of native flora and establishes many alien plants like *Parthenium hysterophorus* (Kohli and Rani 1994; Kohli *et al.* 2012), *Lantana camara* (Sharma and Raghuvansh, 2012; Kohli *et al.* 2004, 2009) and *Ageratum conyzoides* (Kohli *et al.* 2004, 2006, 2009, 2012). Chemicals are reported to possess strong allelopathic (Kohli *et al.* 2012; Batish *et al.* 2009a and b; Singh *et al.* 2002a and b) to the competitive advantage over natives. This property of IAPS forms the basis for *Novel Weapon hypothesis* (Heirro and Callaway 2003).

e. *Efficient seed dispersal mechanism:* Normally IAPS produce very light and small-sized seeds in huge numbers with or without appendages for better and efficient dispersal to far off areas.

## Major invasive alien plants in India

Invasive alien weeds like *Ageratum conyzoides*, *Eupatorium adenophorum*, *E. odoratum*, *Lantana camara, Mikania micrantha* and *Parthenium hysterophorus* have caused ecological havoc in the terrestrial ecosystems by establishing their un-ending kingdom destroying the natives whereas *Eichhornia crassipes, Salvinia molesta* and some

*Ipomoea* species in the freshwater ecosystems do not leave other flora in the body (Raghubanshi *et al.* 2005). Unfortunately, despite several known invasive plants in India, there is no complete document showing the exact status of invasive plants. As per an estimate, about 18 per cent of Indian flora are adventive aliens, of which 55 per cent are from America, 30 per cent from Asia and 15 per cent from Europe and Central Asia (Nayar 1977). Reddy's (2008) survey reported 173 invasive plants species belonging to 117 genera and 44 families. Based on such reports, it is estimated that Tropical America (74 per cent) and Tropical Africa (11 per cent) contribute the maximum to the invasive flora of India.

Kohli *et al.* (2004, 2006) studied the status of invasive alien plants in the northwestern Shivalik range of the Himalayan region and documented three invasive weeds – *A. conyzoides*, *P. hysterophorus* and *L. camara* in the region causing considerable harm to the precious biodiversity. Several reasons including fragile soil, intense anthropogenic activity, tourism, pollution, rapid industrialization / urbanization and livestock dependent lifestyle of the aboriginals such as *gaddi* or *Gujjar* community are responsible for increased invasion of alien plants and declining of biodiversity in the region (Kohli *et al.* 2009). Khuroo *et al.* (2007) reported 571 alien plant species belonging to 352 genera and 104 families from Kashmir Himalayas and these trace their origin from Europe, Asia and Africa. Negi and Hajra (2007) reported 308 woody and 128 exotic herbaceous species from Doon Valley of North-Western Himalayas of which many are harmful invasives that have created several environmental, socio-economic and health problems.

It is also strongly felt that India has already crossed the lag-phase of invasion by several alien species. Any delay in combating the precarious situation would lead to a national ecological disaster.

Nearly sixty IAPS has been reported from the Indian region (Table 3). Majority of these species are from Tropical America, Australia, Africa, Europe and even the Asian region. Most of these IAPS, irrespective of their nativity, belong to Asteraceae, while Poaceae, Solanaceae and Fabaceae also predominate. Further, the invasive plants are represented in all life forms – herbs, shrubs, tree, climbers/vines, grasses and aquatic plants. Of the most imperative invasive plants that have created havoc on a number of habitats, herbaceous weeds like *Ageratum conyzoides* and *Parthenium hysterophorus*, shrubs like *Lantana camara* and *Chromolaena odorata*, trees like *Prosopis juliflora* and *Leucaena leucocephala*, vine like *Mikania micarantha* and aquatic plants like *Eichhornia crassipes* are the most dangerous ones. They were introduced to an alien environment either by human for some purpose or accidentally got introduced through the import of agricultural/horticultural material, human beings, ballast water etc.

## Major noxious invasive plants species in Himachal Pradesh (Indian Himalayas)

Based on a two-year systematic quadrate field study on the IAP load in the state of Himachal Pradesh under the framework of Dr B. P. Pal National Environment Fellowship of the MoEF, it was seen that in the lower and middle altitude ranges of outer Shivalik hills of the Himalayas, about 9.3 per cent of the total vegetation were of alien species. Of the alien flora, about 70 per cent constituted three species namely, *Parthenium hysterophorus, Ageratum conyzoides* and *Lantana camara* (Kohli *et al.* 2004, 2006, 2009*)*. Incidentally, South America is the area of origin of each of these three species. Of the 42 major IAPS reported, 24 are originated from South America and/or southern part of North America (Kohli *et al.* 2004, 2006).

***Parthenium hysterophorus*** L. (Asteraceae) is a highly aggressive and adaptive fast maturing, annual or short-lived perennial herbaceous weed of wide ecological amplitude (Kohli and Daizy 1994). It completes four cycles in a year and propagates

**Table 3: List of prominent invasive alien plant species in Indian subcontinent**

**(Arranged as per alphabetic order of family)**

| Family name | Botanical Name and Common name | Nativity | Life-form |
|---|---|---|---|
| Amaranthaceae | *Chenopodium album* (Lamb's-quarters) | Europe | Herb |
| | *Alternanthera philoxeroides* (Alligator weed) | South America | Aquatic herb |
| Amaryllidaceae | *Zephyranthes citrina* (Yellow rain lily) | Central & South America | Herb |
| Apocynaceae | *Cryptostegia grandiflora* (Rubber vine) | Madagascar | Vine-climber |
| Araceae | *Pistia stratiotes* (Tropical duckweed) | South America | Aquatic Plant |
| Asparagaceae | *Asparagus densiflorus* (Asparagus fern) | South Africa | Herb |
| Asteraceae | *Ageratum conyzoides* (Billy goat weed) | Tropical America | Herb |
| | *Ambrosia artemisiifolia* (Small ragweed) | USA,Canada,Mexico | Herb |
| | *Anthemis cotula* (Stinking mayweed) | Europe | Herb |
| | *Chromolaena odoratum* (Siam weed) | Central South America | Shrub |
| | *Cirsium arvense* (Creeping thistle) | Europe | Herb |
| | *Eupatorium adenophorum* (Crofton weed) | Central America | Shrub |
| | *Eupatorium cannabinum* (Hemp-Agrimony) | British Isles | Herb |
| | *Gymnocoronis spilanthoides* (Senegal tea plant) | South America | Aquatic plant |
| | *Leucanthemum vulgare* (Oxe-eye daisy) | Europe | Herb |
| | *Mikania micrantha* (Mile-a-minute weed) | Tropical America | Vine/ Climber |
| | *Partheniumhysterophorus* (Ragweed parthenium) | Central America | Herb |
| | *Sphagneticola trilobata* (Singapore daisy) | South America | Herb |
| | *Synedrella vialis* (Straggler daisy) | South America | Herb |
| | *Tagetes minuta* (Mexican marigold) | Tropical America | Herb |
| Azollaceae | *Azolla pinnata* (Mosquito fern) | Not Specific | Aquatic plant |
| Bignoniaceae | *Macfadyena unguis-cati* (Cat's claw vine) | Central America | Climber |
| Cabombaceae | *Cabomba caroliniana* (Green cabomba) | South America | Aquatic plant |
| Convolvulaceae | *Ipomoea aquatica* (Water spinach) | China | Climber |
| | *Merremia peltata* (Merremia) | Africa | Climber |
| Elaeagnaceae | *Elaeagnus umbellate* (Japanese Silverberry) | China, Korea, Japan | Tree/Shrub |
| Euphorbiaceae | *Ricinus communis* (Castor bean) | Northeastern Africa | Tree/Shrub |
| | *Sapium sebiferum* (Chinese tallow) | China | Tree |
| Fabaceae | *Acacia farnesiana* (Sweet acacia) | Trop. America | Tree/Shrub |
| | *Acacia mearnsii* (Black wattle) | Australia | Tree |
| | *Acacia melanoxylon* (Blackwood acacia) | Australia | Tree |
| | *Leucaena leucocephala* (Wild tamarind) | Tropical America | Tree |
| | *Mimosa diplotricha* (Giant sensitive plant) | South America | Climber/Shrub |
| | *Mimosa pudica* (Touch-me-not) | South America | Herb |
| | *Prosopis juliflora* (Mesquite) | C.S. America | Tree |
| | *Ulex europeus* (Gorse) | Europe | Tree |
| Hydrocharitaceae | *Hydrilla verticillata* (Water thyme) | Asia, North Australia | Aquatic plant |
| Limnocharitaceae | *Limnocharis flava* (Yellow velvetleaf) | South America | Aquatic plant |
| Melastomataceae | *Clidemia hirta* (Koster's curse) | South America | Shrub |
| | *Miconia calvescens* (Velvet tree) | Tropical America | Tree |
| Moraceae | *Broussonetia papyrifera* (Paper mulberry) | China | Tree |
| Myrtaceae | *Eugenia uniflora* (Surinam cherry) | South America | Tree |
| | *Psidium guajava* (Apple guava) | Central South America | Tree |

| | | | |
|---|---|---|---|
| Onogranaceae | *Ludwigia peruviana* (Peruvian primerose willow) | South America | Aquatic plant |
| Poaceae | *Arundo donax* (Giant cane) | Indian subcontinent | Grass |
| | *Imperata cylindrica* (Cogon grass) | Asia/Africa–doubtful | Grass |
| | *Paspalum vaginatum* (Seashore paspalaum) | North America | Grass |
| | *Pennisetum clandestinum* (Kikuyu grass) | Tropical Africa | Grass |
| | *Phalaris arundinacea* (Reed canary grass) | Europe | Grass |
| | *Spartina alterniflora* (Smooth cord grass) | South America | Grass |
| Pontederiaceae | *Eichhornia crassipes* (Water hyacinth) | South America | Aquatic plant |
| Rubiaceae | *Coffea arabica* (Arabic coffee) | Africa | Shrub |
| | *C. canephora* (Robusta coffee) | Africa | Shrub |
| Solanaceae | *Physalis peruviana* (Cape gooseberry) | South America | Shrub |
| | *Solanum mauritianum* (Wild tobacco tree) | South America | Tree |
| | *Solanum sisymbriifolium* (Tricky night shade) | South America | Herb |
| | *Solanum viarum* (Tropical soda apple) | South America | Shrub |
| Salviniaceae | *Salvinia molesta* (Water fern) | South America | Aquatic plant |
| Verbenaceae | *Lantana camara* (Wild sage) | Tropical America | Shrub |

through vegetative and sexual means and spreads through small wind-blown seeds, water/flood current, road-side vehicles and transport. It lacks predators and grazers. It is seen throughout India, common in unattended areas, wastelands, grasslands, crop fields, roadsides, and railway tracks, banks of water streams, residential colonies, orchards, forests, playgrounds, parks, lawns and gardens (Aneja 1991). The plant is covered with epidermal cell extensions – trichomes that contain parthenium which causes skin allergy in man and is toxic to livestock. Wherever this alien plant invades, it spreads and makes its monoculture strand, smothering the native vegetation because of its strong allelopathic character with lots of phenolic acids. Also, its strong, lightweight huge seed bank in the soil. It competes and overpowers the local vegetation. This causes fodder famine in the area. Since neither insects nor herbivores feed on it, food chain, trophic structure and so the ecological balance gets disturbed severely. While comparing the different ecological indices between invaded and uninvaded areas, *Parthenium* was seen to change the domination by 72 per cent and lowered the diversity by over 40 per cent (Table 4).

*Parthenium hysterophorus*

***Ageratum conyzoides*** L. (Billy goat, Neela phulnu, Blue goat weed) (Asteraceae)

It is also a native of tropical America and has spread to India, Korea, China, Japan etc. It smells like a goat, first noted by a shepherd Billy in Australia. Thus, the name Billy goat. This weed created havoc in Kangra valley in the late 1980s. It destroys the area invaded. Small farmers had to abandon their croplands. For that reason, locals called it *ujardu* (means devastator). It is a soft herb spreading and regenerating vegetatively through stolon and reproducing through enormous minute lightweight seeds and vegetative means. Like *Parthenium*, it is also a strong Allelopathic (Batish *et al.* 2006) with wide ecological amplitude. It invades wastelands, water channels, roadsides, pasture, orchards, forest, open spaces, gardens, agricultural lands, railway

**Table 4: Impact of *P. hysterophorus* on plant diversity**

| Parameters | Uninvaded Control | Invaded | Change ( per cent) |
|---|---|---|---|
| Total Species | 61 | 38 | (–) 37.70 |
| Average Fresh Biomass (g/m$^2$) | 412.45 ± 20.51 | 222.60 ± 18.03 | (–) 46.03 |
| Average Dry Biomass (g/m$^2$) | 296.84 ± 13.72 | 124.88 ± 9.43 | (–) 57.93 |
| Margalef Index of Richness ($R_1$) | 4.87 ± 0.10 | 3.45 ± 0.07 | (–) 29.15 |
| Simpson's Index of Dominance (λ) | 0.10 ± 0.02 | 0.36 ± 0.08 | (+) 72.22 |
| Shannon's Index of Diversity (H') | 2.93 ± 0.08 | 1.74 ± 0.22 | (–) 40.61 |
| Diversity Number ($N_1$) | 14.95 ± 2.20 | 5.50 ± 1.17 | (–) 63.21 |
| Diversity Number ($N_2$) | 10.06 ± 2.14 | 2.88 ± 0.67 | (–) 71.37 |
| Index of Evenness (Es) | 0.80 ± 0.04 | 0.56 ± 0.08 | (–) 30.00 |
| Similarity Index | 66.74 ± 10.78 | | |
| Dissimilarity Index | 33.26 ± 10.78 | | |

tracts. This also replaces grasses in pastures leading to fodder famine as no animal or insect feeds on it (Batish *et al.* 2009a and 2009b, Kohli 1994a). It interferes with the growth and yield of crops (Singh *et al.* 2003).

While comparing the various relevant ecological indices between invaded and uninvaded areas in Himachal Pradesh, *Ageratum* was seen to change the domination in invaded area by 60 per cent and lowered the plant diversity by over 41 per cent and likewise, all parameters.

*Ageratum conyzoides*

### ***Lantana camara*** L. (Verbenaceae)

***Lantana*** is perhaps the best example of intentional introduction for ornamental value from Tropical America, which later became the worst invader weed in 80 countries of the world (GISD 2007). It is now rated as one of the worst invasive alien weed identified by the Global Invasive Species Database and is also included in the top hundred invasive species of the world (GISD 2010). In India, it was introduced at the beginning of 19th century as an ornamental plant in Calcutta Botanical Gardens by Lord Cornwallis. From there it escaped to forests. It is now found widespread in almost the whole of the Indian subcontinent and has encroached even high altitudes (> 1700 m) of the Himalayas (Kohli *et al.* 2006). *Lantana* is a serious invader of forests (particularly open canopy), grasslands, agricultural land, overgrazed lands, roadsides, railway tracks, along canals any vacant areas in the urban land and protected areas causing implications on the

*Lantana camara*

**Table 5: Impact of *A. conyzoides* on plant diversity**

| Parameters | Uninvaded Control | Invaded area | per cent change |
|---|---|---|---|
| Total Species | 81 | 55 | (–) 32.10 |
| Average Fresh Biomass (g/m$^2$) | 612.83 ± 36.01 | 372.68 ± 40.41 | (–) 39.19 |
| Average Dry Biomass (g/m$^2$) | 449.26 ± 19.97 | 231.54 ± 17.08 | (–) 48.46 |
| Margalef Index of Richness | 6.29 ± 0.46 | 3.96 ± 0.50 | (–) 37.04 |
| Simpson's Index of Dominance | 0.06 ± 0.03 | 0.15 ± 0.004 | (+) 60.00 |
| Shannon's Index of Diversity | 3.81 ± 0.31 | 2.24 ± 0.24 | (–) 41.21 |
| Diversity Number ($N_1$) | 20.97 ± 0.97 | 10.30 ± 0.85 | (–) 50.88 |
| Diversity Number ($N_2$) | 14.29 ± 1.30 | 6.09 ± 0.15 | (–) 57.38 |
| Index of Evenness (Es) | 0.84 ± 0.01 | 0.71 ± 0.002 | (–) 15.48 |
| Similarity Index | 52.12 ± 7.64 | | |
| Dissimilarity Index | 47.88 ± 7.64 | | |

**Table 6: Impact of *L. camara* on plant diversity**

| Parameters | Uninvaded Control | Invaded area | per cent change |
|---|---|---|---|
| Total Species | 72 | 41 | (–) 43.06 |
| Average Fresh Biomass (g/m$^2$) | 495.75±13.78 | 317.54±11.86 | (–) 35.95 |
| Average Dry Biomass (g/m$^2$) | 335.07±12.36 | 198.09±12.42 | (–) 40.88 |
| Margalef Index of Richness | 7.20 ± 0.26 | 4.38 ± 0.16 | (–) 39.17 |
| Simpson's Index of Dominance | 0.06 ± 0.03 | 0.16 ± 0.01 | (+) 62.50 |
| Shannon's Index of Diversity | 3.29 ± 0.05 | 1.98 ± 0.04 | (–) 39.82 |
| Diversity Number ($N_1$) | 23.51 ± 1.02 | 13.03 ± 0.58 | (–) 44.58 |
| Diversity Number ($N_2$) | 16.26 ± 0.98 | 9.19 ± 0.87 | (–) 43.48 |
| Index of Evenness (Es) | 0.84 ± 0.01 | 0.72 ± 0.01 | (–) 14.29 |
| Similarity Index | 65.79 ± 4.55 | | |
| Dissimilarity Index | 34.21 ± 4.55 | | |

vegetation structure and dynamics (Kohli *et al.* 2004; Sharma and Raghubanshi 2007) Its woody forms make impenetrable thickets replacing the natives. Like *Parthenium* and *Ageratum*, this is also a strong Allelopathic weed producing enormous seeds in berries which are toxic to man.

While comparing the various relevant ecological indices between invaded and uninvaded areas in Himachal Pradesh, *Ageratum* was seen to change the domination in invaded area by over 62 per cent and lowered the plant diversity by about 40 per cent and likewise, all parameters.

***Chromolaena odorata* L. - Synonym *Eupatorium odoratum* (Asteraceae)**

*Chromolaena* is another strong invasive weed that originated in North America. It is presumed to have entered into India as an ornamental plant in 1925 (National Focal Point for APFISN 2005). It is also included in the list of top hundred worst invaders (GISD 2010). It has assumed the proportion of the most obnoxious weeds in the Western Ghats as well as North Eastern India. It is a strong Allelopathic, a property that imparts its aggression in overpowering the native vegetation, agricultural crops and commercial

*Chromolaena odorata*

plantations, especially coconut, rubber, coffee and tea plantations (Singh 1998). It also causes allergy and asthma to inhabitants. Seeds of this weed remain in the upper layer of the soil and a few in the deeper layers (Tripathi and Yadav 2012). They remain viable and easily germinate with the start of favourable conditions.

### ***Mikania micrantha*** mile-a-minute or bitter wine (Asteraceae)

*Mikania* is a perennial fast-growing climber originally from Central and South America. It was introduced in 1940 in India to cover tea plantation floor and for camouflaging the soldiers and the airfields during the Second World War (Randerson 2003). Wherever it invades, it thickly shades out light for the tree or plants it climbs and smoothers

*Mikania micrantha*

the area to establish its unending kingdom (Tripathi *et al.* 2012). It is now a very noxious and most widespread weed in the plantations and forests of Pacific region especially in Southern and Northwestern parts of India (Muniappan and Viraktamath 1993). Its large viable seeds that it produces are dispersed by wind and through other vectors. Its quick regenerative potential makes its control difficult.

### ***Prosopis juliflora*** (Swartz) D.C. (Mimosaceae)

*Prosopis* is a small woody tree or woody shrub native of Mexico. In the Indian subcontinent it was brought to the province of Sind in Pakistan in 1877 (Muthan and Arora 1983; Pandey *et al.* 2012). Perhaps from there, it spread to Gujarat where it was initially promoted to produce Charcoal. However, the invasive and hardy characters of it changed the floristic diversity of the region. Its widespread to all types of places including forests, residential, urban, rural, wastelands, community lands and croplands compelled Government to check its

*Prosopis juliflora*

spread. It was declared as a noxious weed and as per legal provisions under the Indian Forest Act (1927), it was made mandatory for any person to take prior permission for transportation of the *Prosopis*. Later, to promote its use for charcoal production, in 2004, the Government withdrew the provision of transit pass except within 2 km of the coast or 1.6 km from the reserved forest (Pandey *et al.* 2012).

### IAPS in the Western and Eastern Ghats

In the Western Ghats – one of the four biodiversity hotspots of India (Rao and Sagar 2012) reported 12 worst terrestrial invasive alien weeds. Of these 12, four belonging to the family Astreaceae (*Ageratina adenophora, Chromolaena odorata Mikania micrantha* and *Parthenium hysterophorus*) are severely affecting the native vegetation and its diversity. Other herbaceous plants namely *Alternanthera paronychioides* (Amaranthaceae), *Cassia uniflora* (Caesalpiniaceae), *Hyptis suaveolens* (Lamiaceae), *Ipomoea fistulosa* (Convolvulaceae), *Ricinus communis* (Euphorbiaceae), shrubs namely *Lantana camara* (Verbenaceae) and *Prosopis chilensis* (Mimosaceae) and freshwater aquatic weed *Eichhornia crassipes* (Pontederiaceae) have caused massive biodiversity loss.

### Invasive plant in the Indian Ocean (The Western Ghats)

*Kappaphycus alvarezii* is a very fast growing tropical red alga of the marine ecosystem with resilient morphology and extremely successful vegetative propagation (Edward and Bhatt 2012). In the Western Ghats of India, it is a strong destructive invasive alien species (Doty 1996). The alga merges into the tissue of coral with a strong attachment to persist in high wave energy environment (Woo *et al.* 1989; Woo 1999). The alga spreads mainly by fragmentation and can overgrow and kill coral by smothering, shading it from sunlight and abrasion. Being a source of carrageenan, a sulphated Polysaccharide, it is widely used in pharmaceutical and food industry. Because of the commercial use, it is widely grown by self-help groups and sold to food and pharma industry. However, the health and growth of seagrasses, corals and thus, fish production and diversity are getting severely affected. This is also affecting the income of fishermen. To supplement their diminishing income, they cultivate more Kappaphycus, little realizing the long-term harm it causes to the species diversity of corals and fishes. As per Edward and Bhatt (2012), it is the impact on coral reefs and seagrass beds which will ultimately affect the dependent fisher folk's livelihood drastically. The loss is also to the environment because of the disappearance of native species and the instability of coasts due to the loss of habitats like coral reefs and seagrass beds.

### IAPS in the Eastern Ghats

While in the Eastern Ghats, of the 648 plant species identified, only 47 (7.25 per cent) are reported invasive aliens. *Eriobotrya japonica* and *Annona squamosa*, among the trees, *Lantana camara, Opuntia stricta, Chromolaena odarata* and *Ageratum conyzoides* among herbs are the serious problematic invasive alien weeds in the forests of southern Eastern Ghats (Parthasarathy *et al.* 2012).

### Invasive alien trees and woody shrubs

Among different life forms in the plant kingdom, tree species possessing invasive characters are recognized as one of the greatest threats to the ecological and economic well-being of the ecosystems (Belote and Jones 2009; Richardson and Pyšek 2012). It is because the trees are ecologically dominant, large-sized and long-lasting. Thus, their management, compared to other species, is difficult. Consequently, invasion by woody species can lead to drastic changes in the community structure and functions, biomass distribution, litter fall and decomposition rates in the ecosystems (Jackson *et al.* 2002; Richardson *et al.* 2011). Though the trees are introduced from one geographical area to another for several beneficial purposes, this practice has enhanced owing to the opening up of the economy, increased tourism and globalization (Krivanek at al. 2006; Rejmánek and Richardson 1996; Richardson and Rejmánek 2011).

## Diversity of invasive trees and woody shrubs

The total number of invasive alien trees and woody shrubs is not known. As in the case of herbaceous plants, different plant scientists differ in their assessments. Haysom and Murphy (2003) estimated at 443 species while Richardson and Rejmánek (2011) provided a global list of 622 trees and woody species as Invasive. According to an updated global database of invasive plants, a total of 751 species are invasive (Rejmanek and Richardson 2013). Besides these reports, there are certain databases such as Global Invasive Species Database (GISD) managed by the Species Survival Commission of IUCN through its Invasive Species Specialist Group, Centre for Agriculture and Biosciences International (CABI – an online open-access database) and Germplasm Resource Information Network (GRIN, managed by the US Department of Agriculture) that contain vital information on the invasive species. Based on these databases and as reported in scientific literature, 140 trees and woody shrubs have been identified as alien invasive and widely distributed. They belong to 45 taxonomic families of angiosperms, including the only family Pinaceae that belongs to gymnosperms. Among these, Fabaceae (formerly Leguminosae, one of the largest families) is represented by 36 taxa followed by Myrtaceae by 9 and Pinaceae by eight taxa (Table 7). Other important families include Salicaceae, Moraceae, Oleaceae, Rosaceae, Bignoniaceae Meliaceae, Rhamnaceae and Euphorbeaceae. Around 22 families are represented by single tree species.

## Distribution in geographical area / Ecozones, purpose and modes of introduction

The plausible reason for this uncertainty as regards the alien or native character of a plant species is that plants do not recognize political boundaries. Instead, a combination of temperature and precipitation

**Figure 1: Ecozones (Modified from https://en.wikipedia.org/wiki/Ecozone)**

**Table 7: Number of invasive tree species by families**

| Families[a] | No. of invasive species |
|---|---|
| Fabaceae | 36 |
| Myrtaceae | 9 |
| Pinaceae | 8 |
| Salicaceae | 6 |
| Rosaceae | 7 |
| Moraceae, Oleaceae | 5 (each) |
| Bignoniaceae, Meliaceae, Rhamnaceae, Euphorbiaceae, | 4 (each) |
| Aceraceae, Pittosporaceae, | 3 (each) |
| Anacardiaceae, Annonaceae, Apocynaceae, Arecaceae, Casuarinaceae, Elaeagnaceae, Lauraceae, Proteaceae, Urticaceae, Melastomataceae | 2 (each) |
| Berberidaceae, Betulaceae, Chrysobalanaceae, Clusiaceae, Combretaceae, Ericaceae, Myrsinaceae, Onagraceae, Paulowniaceae, Phyllanthaceae, Piperaceae, Poaceae, Rhizophoraceae, Rubiaceae, Rutaceae, Sapindaceae, Simaroubaceae, Tamaricaceae, Ulmaceae, Verbenaceae, Goodeniaceae, lamiaceae | 1 (each) |

*a: All families except Pinaceae are angiospermous*

determines their distribution. Therefore, the perspective of their origin and intrusion needs to be looked in respect of Ecological Zones (Ecozones) rather than nation or continent-wide. On the planet earth, 7 Ecozones (Figure1) have been recognized.

## Invasive alien trees in India

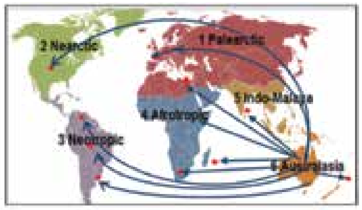
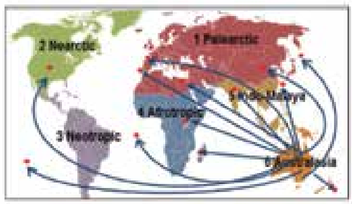
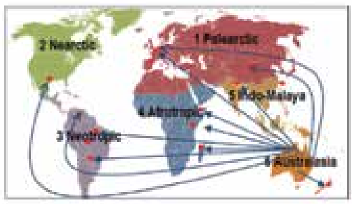
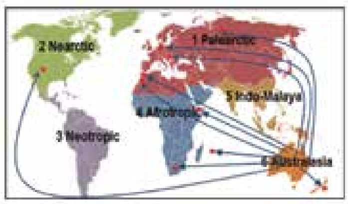
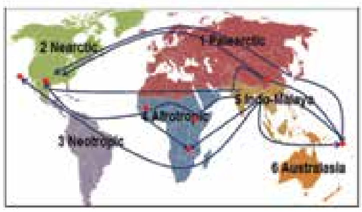
Of the 140 trees and woody shrubs reported to be invasive in the world, 20 (Table 8) native species of other ecozones are found invasive in India.

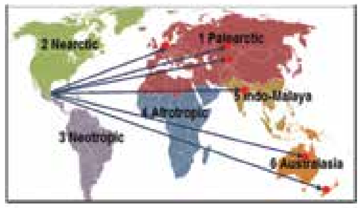
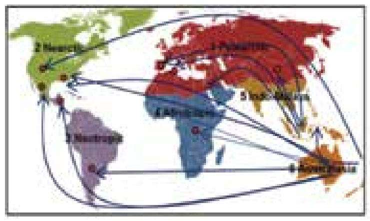
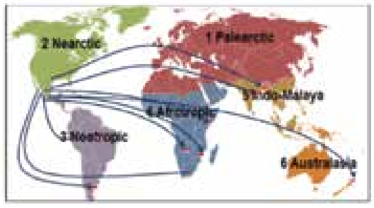
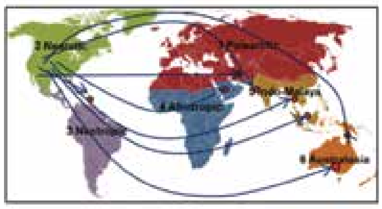
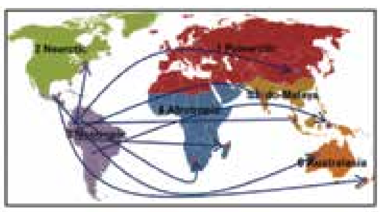
## Neo-Invasive weeds

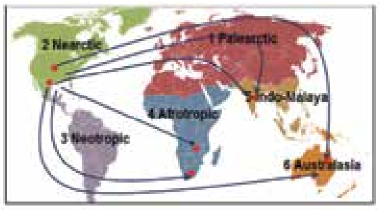
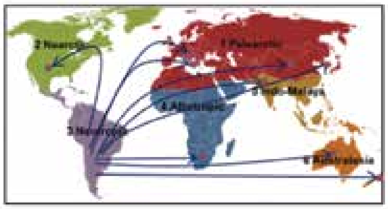
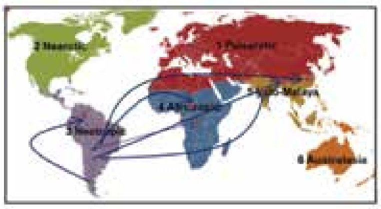
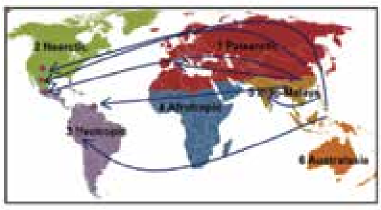
IAS could be managed successfully during their lag phase. After their successful colonization and naturalization, it becomes extremely difficult to control them. This implies that the new invasive alien species should be under constant focus for timely management of their spread. Some of such neo-invasive species still in their lag phase of establishment in India include the following:

*Tagetes minuta*

**Table 8: Invasive Alien Trees and woody shrubs in India, their dispersal vector, means of spread and path of invasion**

| S. No. | Tree species/ Family/ Nativity | Introduced/naturalized range | Dispersal | Means of spread | Path of invasion |
|---|---|---|---|---|---|
| 1. | *Acacia dealbata* Link<br><br>(Fabaceae)<br><br>Australia | Ethiopia, Lesotho, Mozambique, Madagascar, Mauritius, Zimbabwe Uganda, La Réunion, Switzerland, South Africa, Tanzania, Romania, Italy, France, Portugal, Azerbaijan, China, Georgia, India, Nepal, Sri Lanka, USA, Costa Rica, Argentina Guatemala, , Chile, New Zealand | Birds, Insects water | Seeds, roots and suckers |  |
| 2. | *Acacia longifolia*<br><br>(Andrews) Willd.<br>(Fabaceae)<br>Australia | Argentina, Australia, Brazil, Colombia, Dominican Republic, India, Indonesia, Israel, Italy, Kenya, Mauritius, Myanmar, New Zealand, Portugal, La Reunion, South Africa, Spain, Sri Lanka, USA, Uruguay | Wind, water Man | Seeds |  |
| 3. | *Acacia mearnsii* De Wild.<br><br>(Fabaceae)<br>Australia | China, Cook Islands, France, India, Israel, Italy, Japan, Madagascar, New Zealand, Portugal, La Reunion, Saint Helena, Seychelles, South Africa, Spain, Swaziland, Taiwan, Tanzania, Uganda, USA, Zimbabwe | Rodents and birds | Seeds |  |
| 4. | *Acacia melanoxylon* R. Br. ex Ait. f.<br><br>(Fabaceae)<br>Australia | Argentina, Belgium, Bhutan, Bolivia, Brazil, Chile, China, Colombia, Ethiopia, France, India, Kenya, Lesotho, Mauritius, New Caledonia, New Zealand, Pakistan, Peru, Portugal, La Reunion, Saint Helena, South Africa, Spain, Sri Lanka, Swaziland, Tanzania, USA, Uruguay, Venezuela | Birds | Seeds |  |
| 5. | *Acacia retinodes* Schltdl.<br>(Fabaceae)<br>Australia-Tasmania | Ethiopia, South Africa, India, Indonesia, Russian Federation (Asia), France, Great Britain, Italy, Portugal, Romania, Spain, Mauritius, Cyprus, New Zealand, USA | Man, other animals | Seeds |  |
| 6. | *Borassus flabellifer* L.<br>(Arecaceae)<br>Tropical Africa | India | Man | Seeds, stem cuttings, root sucker |  |
| 7. | *Broussonetia papyrifera* (L.) Vent<br>(Moraceae)<br>China, Japan Thailand, Korea, | Ghana, India, Pakistan, New Guinea, Philippines, USA, Tanzania, Uganda, Zimbabwe | Birds and small Animals | Seeds, stem cuttings, root sucker |  |

| | | | | | |
|---|---|---|---|---|---|
| 8. | *Elaeagnus umbellata* Thunb. (Elaeagnaceae) China, Korea, Japan | USA, India and Afghanistan | Birds and Man | Seeds |  |
| 9. | *Lantana Camara* L. (Verbenaceae) Central & South America | Invaded 60 countries including Africa, S. Europe, Middle-East, India, tropical Asia, Australia, New Zealand, USA, as well as many Atlantic, Pacific and the Indian Ocean islands | Birds and Man | Seeds and vegetative means |  |
| 10. | *Melaleuca quinquenervia* (Cav.) S.T. Blake (Myrtaceae) Australia, Indonesia, New Caledonia | Bermuda, Brazil, Panama, Mexico, Trinidad Tobago, Suriname, Costa Rica, Nicaragua, Carrabin and Pacific islands, Madagascar, , New Zealand, Palau, Puerto Rico, Haiti, La Reunion, Saint Lucia, Saint Vincent, Grenadines, Italy, Turkey, France, China, Hong Kong, **India,** Taiwan, Philippines, Fiji, Caicos Islands, Egypt, USA Senegal, Uganda, | Birds | Seeds |  |
| 11. | *Pinus patula* Schiede ex Schltdl. & Cham. (Pinaceae) Mexico | Kenya, Malawi, Mozambique, Zambia, Zimbabwe, South Africa, Swaziland, Tanzania, Uganda, Colombia, southern Brazil, Argentina, Nepal, India, Hawaii (USA), South Africa, Zimbabwe, Botswana, Malawi, Madagascar and New Zealand | Wind | Seeds |  |
| 12. | *Pinus radiata* D.Don (Pinaceae) Mexico, USA | India, Taiwan, Turkey, Kenya, South Africa, Sudan, Zimbabwe, Argentina, Chile, Columbia, Ecuador, Peru, Europe, Australia, New Zealand | Wind | Seeds |  |
| 13. | *Prosopis glandulosa* Torr. (Fabaceae) South-west Mexico | Saudi Arabia, Burma, India, Pakistan, Puerto Rico, southern Africa and Australia | Water, Animal | Seeds |  |
| 14. | *Prosopis juliflora* (Sw.) DC. (Fabaceae) Mexico, Peru Colombia, Ecuador, | Bermuda, British Virgin Islands, Cayman Islands, French Polynesia, Reunion, Saint Helena, India, Nepal, Burma, Indonesia, Australia | Water, Animal | Seeds |  |

| | | | | | |
|---|---|---|---|---|---|
| 15. | *Prosopis velutina* Wooton (Fabaceae) Mexico, USA | India, Botswana, Namibia, South Africa, Haiti and Australia | Wind, Water, Birds and Animals | Seeds |  |
| 16. | *Prunus campanulata* Maxim (Rosaceae) China, Taiwan, Vietnam | Australia, Hawaii, India, Japan, New Zealand, United Kingdom, USA | Birds | Seeds |  |
| 17. | *Psidium cattleianum* Sabine (Myrtaceae) Brazil, Uruguay | China, India, Japan, Malaysia, Philippines, Sri Lanka, Comoros, Gabon, Madagascar, Mauritius, Reunion island, South Africa, USA, Caribbean Islands, Brazil, Colombia, Uruguay, Venezuela, France, Spain, UK, Australia, New Zealand, Fiji, Samoa. | Birds | Seeds, Root sprouts |  |
| 18. | *Robinia pseudoacacia* (L.) (Fabaceae) USA | South Africa, China, Japan, Korea, Cyprus, Italy, Turkey, India, Pakistan, Australia, New Zealand, Chile, Uruguay and Europe | Wind | Seeds |  |
| 19. | *Sesbania punicea* L (Fabaceae) Brazil, Uruguay Argentina, Paraguay, | Africa, South America, India | Wind, Birds | Seeds |  |
| 20. | *Triadica sebifera* *Sapium sebiferum* L. (Euphorbiaceae) East.China, Japan, Taiwan | India, Sudan, France, USA, Puerto Rico, Costa Rica, Taiwan, Martinique, entire Gulf coast North Carolina | Water, Birds | Seeds Root sprouts |  |

***Tagetes minuta* L. (Asteraceae)**

A native of South America, this species was introduced into India for its essential oil and medicinal use. It escaped from the cultivated areas and acquired a weedy habit. It grows luxuriantly in disturbed sites of Shiwalik range of Himalayas, particularly in orchards, wastelands and croplands. It spreads fast at the cost of native species. Now, it is a troublesome weed of crops lands. Its volatile as well non-volatile allelochemicals inhibit crops growing in its vicinity.

***Chenopodium murale* L.** Known also as nettle-leaf goosefoot, Australian spinach, green fat hen, sowbane, swinebane, wall goosefoot and Jangli Bathu, (Chenopodiaceae). It is native to Africa and temperate Asia. Now it is a common weed in north India, especially in winter season in wastelands, roadsides and agricultural fields, particularly in the fields of mustard, potato, wheat and gram.

*Chenopodium murale*

***Broussonetia papyrifera* syn. *Morus papyrifera* L. (Moraceae)**

A deciduous fast growing shrubby tree native to eastern Asia (Japan), commonly known as Paper Mulberry or Golden Mulberry. How it entered India is not known. It invades disturbed forests and unattended land spreads very fast smothering the native vegetation.

***Hyptis suaveolens* (L.) (Pig-nut) (Lamiaceae)**

It is another weed native of America that has invaded southern India, especially dry open locations. It spreads very fast through seeds that remain dormant in the soil for a year. It overpowers the local vegetation and creates a severe loss to biodiversity.

*Hyptis suaveolens*

***Zephyranthes citrina* (Amaryllidaceae)**

It is a yellow coloured, late summer flowering, soft ornamental weed native of America and naturalized in Hawaii. How and when it came to India is not known. However, this prolific growing light demander has lately invaded gardens and vacant lands.

*Broussonetia papyrifera*

*Zephyranthes citrina*

### *Argemone maxicana* (Papaveraceae)

An annual herb with bright yellow alkaloid toxic sap is native of Mexico and now is widely naturalized in India invading fast. It invades agricultural fields after the harvest of crops.

*Argemone maxicana*

### *Anthemis cotula* L. (Asteraceae) Stinking chamomile

*Anthemis,* an aromatic herb, native of southern Europe (Erenberg 1999) is a neo-noxious weed in Kashmir-Himalaya, especially under disturbed habitats. Because of prolific reproductive ability and strong allelopathic property, high phenotypic variability and synchrony with environmental conditions, it easily overpowers native vegetation. (Reshi *et al.* 2012). This IAPS has drastically reduced the biodiversity of the invaded ecosystem.

### *Alternanthera philoxeroides* Griseb. Alligator weed (Amaranthaceae)

*Alternanthera* is another new invasive, native of Southern part of North America, South America-Argentina, Brazil, Paraguay and Uruguay. It is another neo-invasive weed, especially in south India. It grows luxuriantly near water bodies and adversely affect the flow of water due to the dense mat created from its clusters of stems. It competes with native vegetation and causes fodder famine in the area, apart from decreasing the biodiversity.

### *Ipomoea carnea* L. (Convolvulaceae)

An evergreen flowering shrub, native of South America, has invaded Asia, especially Indian sub-continent, Africa and North America. It prefers fallow lands and shallow wetlands. Because of the presence of alkaloids, no grazer or browser eats it. It regenerates very fast. Therefore, there should be every effort to control it, though so far it has not given success.

### Invasive alien macrophytes of freshwater

As per Shah and Reshi (2012), 223 alien aquatic plant species representing 116 genera from 60 families are present in India. Most of these hydrophytes are native of Europe (37.12 per cent) or Asia (25.28 per cent). Of the alien macrophytes, about 10 per cent each have come from South and North America. Close climatic suitability of the biogeographical region is believed to be the reason. It is also believed that most of the introductions were the result of frequent intercontinental voyages driven by economic and commercial interests (Khuroo *et al.* 2007). Most of the aquatic macrophytes remain on the fringes of the littoral zones of lakes and wetlands. Rooted floating-leaf plants dominate shallow waters, while the submerged ones get to occupy deeper waters. These invasive species make a thick mat on the eutrophic water rich in organic matter. The decreasing depths of water bodies, primarily due to siltation/ sedimentation and catchment flow results into invasion load increase. The most widely distributed troublesome aquatic invasive species in India include *Eichhornia crassipes*, *Potamogeton crispus, P. nodosus, Azolla pinnata, Ceratophyllum demersum, Cyperus* spp.*, Hydrilla verticillata, Ipomea aquatica, Lemna minor, Monochoria vaginalis, Myriophyllum spicatum, Nymphoides peltatum, Phragmites australis, Najas gramineum, Pistia stratiotes, Sparganium ramosum, Sagittaria sagittifolia, Salvinia molesta, Trapa bispinosa, Typha angustata* and *Vallisnaria americana.* The invasion load not only affect the fish and other aquatic fauna and impair the water quality, but it also alters nutrient cycling. Water flow replaces native plants, decreases water retention, and feed resource value for fish and birds apart from reducing the water oxygen levels following their decay (Shah and Reshi 2012). There is no adequate information and focus on the invasive alien aquatic plant species in Indian wetlands.

Some of the noxious invasive hydrophytes that have created disorder like condition are briefly dealt herewith.

### *Eichhornia crassipes* (Mart) Solms Water hyacinth (Pontederiaceae)

*Eichhornia crassipes*, is a widely distributed species native of tropical and sub tropical South America, with broad leaves floating on the water surface due to air-filled long, spongy and bulbous stalks underneath. In India, it got introduced as an ornamental plant in 1890 during the British rule. It is now a serious problematic weed throughout India. It reproduces and regenerates by way of runners/stolons and supports bright coloured flowers. This fastest growing plant forms a thick mat that doubles its area on the water surface in a fortnight. The weed has a wide ecological amplitude with temperature ranging from 10 to 30°C and pH from 5 to 7.5. It does not grow in alkaline waters. Once introduced, it covers the wetlands and blocks sunlight for other aquatic lifeforms leading to death and disrupting the food chain. The decay of biota underneath depletes dissolved oxygen. The wetland becomes an ideal breeding ground for mosquitoes and snails that host parasitic flatworms. It lowers the productivity of lakes and ponds, apart from interfering in boating, water-sports and other activities.

### *Potamogeton* (Potamogetonaceae)

Of the several widely spread *Potamogeton* genus (nativity unknown), *P. crispus* L., *P. lucens* L., *P. Natans* L., and *P. nodosus* Poir are invasive aquatic species throughout Jammu and Kashmir (Ganie *et al.* 2012) overpowering micro and macro vegetation of freshwaters.

### *Salvinia molesta* Mitc. Water Moss (Salviniaceae)

It is an invasive fern commonly used to repel oil from the water surface due to its hydrophobic trichomes. In warm and humid climate like in Kerala, it has become a neo-invasive weed. It forms a mat on the water surface and smoothers the aquatic diversity. *Cyrtobagous salviniae*, a weevil, is known to control its spread.

### Economic impact of IAPS

Unfortunately there exists insufficient study on the impact of IAPS in the world in general and in India in particular. Valid reasons advanced are that though invasion by plants is not a new phenomenon, the science or attention to it has been drawn rather late. Now the resource economists, scientists and even the Governments world over have started evaluating the direct and indirect economic impact of invasion. It is now argued that economic problems due to IAPS get aggravated because of commercial dynamism and enhanced trade and transport. For cost-cutting, several means of quarantine measures get ignored. Further, negative external externalities and free-ride incentives also play their adverse economic impact (Singh and Kathuria 2012).

Bio-economic or eco-economic models (Adams and Lee 2013) that estimate the economic impact and the value of IAPS in the natural area keep varying with situation and conditions. Economists, in general, use cost-benefit analysis tool to determine net benefits of introduction on new species. In case of the managed and human-made system, it is understandable. In natural ecosystem, particularly in the context of IAPS, the economic studies, especially ecological services, intangible benefits, costs on restoration efforts, normally remain ignored.

The invasive plant species displace native flora, eliminate food, fodder and cover for wildlife apart from threatening rare species. The areas invaded by weeds like *Parthenium, Ageratum* and *Lantana* densely congregate the area leaving hardly any other vegetation for the herbivores to graze or browse. This results in fodder famine.

In Kangra valley, in the late 1980s, the farmers had abandoned their croplands because *Ageratum* had invaded their farms. This weed in vernacular was called "*Ujardu*" meaning devastator. Questions on the plight of the farmers of the area were raised in Indian Parliament. While trying to find the reason of devastation in a short span, it was seen that this weed is very strongly allelopathic (Singh *et al.* 2002a, 2003; Kohli *et al.* 2006; Kaur *et al.* 2012). It releases certain chemicals like Phenolic acids which are not only toxic to other native plants but pollutes the soil as well.

The identification of the problem of IAPS is relatively new. Perhaps for this reason, enough studies on the direct impact of invasion on the economy of any country are not established as yet. Indirect impacts are speculated.

These IAPS result in changing the ecosystem functions and thus, cost dearly the resource management. When an economically useful species is introduced in a non-native biogeographical zone, the importers argue that the economic benefits would overweigh the ecological harms. They count only the tangible direct economic harms ignoring the indirect ecological services and intangible effects (Kathuria and Singh 2012).

## Risk assessment

In view of man's interest in fast economic growth over the desired sustainable pace of growth, the opening up of the economy, enhanced resource use, increased travel and transport, export and imports and exotic interests, the biological invasion is, unfortunately, getting to be an undesired necessary evil. It, therefore, becomes extremely important to preempt the possible risks of our actions. Ecologists are now focusing on the risk assessment of species, developmental actions and the region of high threats of invasion. However, a few countries make use of the risk assessment protocols (Reshi and Rashid 2012). Traits of the plants, propagule pressure, dispersal mechanism biogeographical range, climatic variability, cultivation practices, fallow land areas, anthropogenic interests, weak ecosystem dynamics, disturbance factor etc. generally influence the probability of invasion of alien species (Rouget and Richardson 2003; Lockwood *et al.* 2005 and Catford *et al.* 2009).

## Management efforts

Realizing the urgent dire need of combatting the invasion of exotic plant species, the Ministry of Environment, Forest and Climate Change took the initiative and commissioned a 3-year research project for the Indian Himalayan Region. It has identified seven serious research groups working on the theme of Invasive alien plants. The Ministry under its National Mission on Himalayan Studies programme sponsored for a coordinated research project "Invasive Alien Plants in the Himalayan States: Status, Ecological Impact and Management". Apart from the primary focus of evaluating the IAPS load in each of the 12 states of the Indian Himalayas based on ground truthing, it will undertake the following specific tasks with respect to IAPS:

a. Identifying Invasive Alien Vascular Plant Species and preparing a complete inventory of IAPS
b. Map their distribution with GPS in the whole range of Himalayas
c. Monitor the rate and mode of spread (including vectors responsible) and ground truthing
d. Assessment of area occupied by different IAPS
e. New potential invaders or the candidate species having the potential for invasion
f. Genetic adaptability of exotic species in their new environment
g. Value and risk assessment from IAPS or potential invasive aliens
h. Disappearance of native plant species and impact on biodiversity
i. Mode and mechanism of overpowering natives by aliens
j. Effective means of management and control of invasive aliens
k. Economic and ecological dimensions of biodiversity loss on account of IAPS
l. Preparing protocols for prediction, early detection and risk assessment of alien invasive plant species for each region
m. Selection of at least 10 most noxious IAPS from different areas and consolidation of all available information including their biology, itemizing at the same time the knowledge gaps
n. Identification of a cross-sectoral group to assess the situation in the form of case-studies on these species, and also to formulate workable management strategies aiming to prediction, prevention and control.

In addition to the above focus, the data so generated will be useful for additional benefits for evaluating:

a. Path and mechanism of invasion including succession
b. Economic implications of Biological Invasion
c. Value addition and sustainable utilization of bioresources for the livelihood of local communities
d. Policy and legislative mechanisms for management/eradication/mitigation
e. Consolidation of available information on IAPS in a database.

## Management efforts at Global level

Globalization has many benefits, but a harmful consequence of this trend is the movement of organisms (insects, pathogens, lower plants, herbs, shrubs, trees, fishes, birds, wild animals etc.) from their native places to alien habitats. Species established in alien environments often exhibit explosive population growth resulting in severe impacts on the natives. Worst affected are the forest ecosystems and thus the ecological and economic impairment. This problem is being experienced worldwide, especially in the developing world and the islands.

Therefore, a single Government alone cannot implement the potential solutions effectively unless there are international cooperation and collaboration among the ecologists and support from the respective Governments. International Union of Forest Research Organizations (IUFRO) with headquarter in Austria with the initiative of the author organized an International Task Force with 23 scientists from different countries representing different field of specializations (plants, insects, nematodes, fishes, pathogens, birds, economists, risk assessors etc.) for a term of 5 years (2014 to 2019).

The objective of the interdisciplinary, international team of the Task Force has been to interact for (a) Understanding the drivers of biological invasions, characterize their effects, especially on forest, and develop strategies for minimizing future invasions and their impacts (b) Synthesizing knowledge among disparate fields studying various aspects of biological invasions in forests and (c) Integrating knowledge among various disciplines for developing comprehensive approaches of managing invasions in different parts of the world.

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# Conflicts between wildlife and people: An ecological, social and policy perspective

Raman Sukumar[1]

## Abstract

The escalating conflicts between wildlife and people in recent decades in the country calls for an urgent understanding of the underlying causes of such conflicts and a policy framework for mitigation and management of conflicts. Wildlife-human conflicts result in human deaths, loss to agricultural crops, livestock and property, as well as unnatural deaths of wildlife species. The ecological causes of such conflicts can be traced to a complex interplay of factors related to the historical patterns of land-use by people resulting in habitat loss, degradation and fragmentation, the behavioural and foraging ecology of wildlife species, environmental variability especially with respect to climate, and the diverse nature of wildlife-human interactions rooted in local culture or religious beliefs. A comprehensive policy framework for conflict management has to incorporate ecology, sociology, economics and amended legislation to ensure that both people and wildlife are not adversely impacted. The policy framework should be developed after rational debate among stakeholders, and take a landscape-scale and species-specific approach with clearly articulated goals of wildlife conservation.

## Keywords

*Wildlife, Conflict, Habitat Loss, Landscape Approach, Wildlife Conservation.*

## Background

Wildlife has increasingly come into conflicts with people in India in recent decades, with negative consequences for agriculture, livestock, property and human lives. While the most publicised conflicts involve the larger charismatic animals such as elephants and tigers, a host of other animals including leopards, monkeys, nilgai and wild pig have also been in chronic and widespread conflict with human interests. The worst sufferers in this conflict are forest dwellers and subsistence farmers living along the periphery of forested areas or in small enclaves within forests. The conflicts have also spread much beyond forested areas in recent years. At the same time, many animals are also injured or are killed in the course of their interface with people. It is important to understand the ecological reasons for this conflict, its increase in recent decades and come up with a comprehensive policy framework for minimizing such conflicts. Otherwise, we risk reaching a situation of such serious magnitude of wildlife-human conflicts from where it would be very difficult to return to tolerable levels without taking extreme management measures.

A rather simplistic and clichéd narrative of wildlife-human conflicts is often dished out in the popular media. Humans have intruded into and degraded

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or destroyed the habitat for wildlife, and the latter are now fighting back for their survival. There are elements of truth in these statements. Over a historical timescale, wildlife habitats in India have been gradually lost or their ecological attributes transformed resulting in enhanced wildlife-human conflicts. But the story is far more complex when you look at trends in recent decades, which is the time scale more relevant to present-day policy and management needs.

## Factors responsible for wildlife-human conflicts

A suite of factors drives wild herbivores to raid agricultural crops and, in the process, come into severe conflicts with people, resulting in both human and animal deaths. A simple way of categorizing the factors enhancing conflicts is to place them under factors that "*push*" wildlife away from their "natural habitats" (usually forests) into areas largely settled and cultivated by people and those that "*pull*" wildlife from their natural habitats into the human-production landscape. One may, of course, ask what is "natural habitat" really? Why should we relegate wildlife only to the boundaries of what we consider "their natural habitat"? Shouldn't wildlife be allowed to live where it pleases them? I shall return to these questions later in this article. First, I shall illustrate the *push* and the *pull* factors with the example of the elephant, the species that I am most familiar with in relation to its conflicts with people.

The *push* factor clearly operates when elephants lose their natural habitat rapidly, as happened in north-western Assam during the 1990s. Large swathes of forest were felled, settled and cultivated within a short period, during a socio-political movement for a separate homeland, rendering several hundred elephants homeless. As a result, conflicts between elephants and agriculture escalated immediately over a wide region as the homeless elephants began wandering into habitations and cultivated fields as far south as the town of Tezpur along the banks of the Brahmaputra. The role of fragmentation in promoting elephant-human conflicts is also evident in east-central Indian states such as Jharkhand and Odisha where mining and other forms of developmental activity have made deep inroads into the natural forest. This entire region, including neighbouring Chhattisgarh and southern West Bengal, witnesses severe elephant-human conflicts today. Habitat degradation is more difficult to define, but we can consider this as a process of depletion of natural forage resources for elephants.

Contrary to public perception, selective logging of moist forest or even limited extent of shifting cultivated increases the carrying capacity of the habitat, thereby attracting elephants and enhancing conflicts with agriculture. When forest land is under intense pressure from mining for minerals, or extraction of biomass for fuelwood, fodder and consumption, this obviously depletes the forage resources for elephants and other wildlife. In recent years (beginning around 2004), the highly invasive plant, *Lantana camara*, has extensively spread in southern Indian forests; this could have also reduced palatable forage for elephants and forced some of them to seek resources outside forest areas. Such cases clearly constitute habitat degradation.

We must not fail to look at the other side of the coin. There are many forests that are extensive, not necessarily degraded, and provide sufficient resources for elephants; yet some or many elephants resort to raiding cultivated crops. Here, the *pull* factor may be operating. The main factor that "pulls" elephants into crop fields is the abundant quantity of food, be it paddy, millets, or sugar cane, available. Elephants also develop a taste for jackfruit or selective parts of trees such as coconut. Cultivated cereals are more nutritious than wild grasses as they can provide more protein and certain minerals such as sodium and calcium (Sukumar 1989). With better irrigation facilities and changing cultivation patterns, elephants now have abundant water in village tanks and small dams outside forests. In regions where farmers earlier cultivated a single rain-fed crop in a year, they now cultivate two or even three crops in a year. Why should an elephant settle for plain bread when it could more easily partake of tastier cake in the supermarkets that people have nurtured so close to forest areas?

The *push* and the *pull* factors are not mutually exclusive but may operate in unison. This can be seen when the climate becomes adverse as with a severe or a prolonged drought. When southern India experienced in 1982 one of the worst droughts of the last century, several elephant family groups left the forests of Hosur (Tamil Nadu) and Bannerghatta (Karnataka) the following year and marched into the Chittoor forests of Andhra Pradesh where wild elephants were unknown for the past several centuries (Sivaganesan and Bhushan 1986). A similar event happened in erstwhile Bihar (now Jharkhand) when a clan of about 50 elephants made a deep foray into southern Bengal in 1987 following drought the previous year. In both cases, the drought may have been the proverbial last straw, as human extractive pressures on forests in the south, and mining or clearing of forests in Jharkhand made them unsustainable for elephants during a difficult year.

Wandering through human habitation and cultivated fields obviouslybrings its associated risks as an elephant may be injured or even killed by people. Nevertheless, the urge to feast on easily available, abundant and nutritious food overcomes considerations of risk, especially for a creature that can think its way out of challenging situations. This is where some fundamental aspects of biological evolution also begin to kick in – when male elephants are on the threshold of becoming adult, they need to begin a course of bodybuilding in order to grow bigger and stronger than their compatriots and potential competitors for mating opportunities with females in oestrus, and use their energy reserves to come into "musth" when they can achieve the overarching goal of reproduction more successfully (Sukumar and Gadgil 1988; Chiyo *et al.* 2011). These young bulls also need to bid farewell to their families and seek their fortunes in another land with strange families they may have never encountered before; otherwise, they risk mating with their close relatives and eventually their genes fading into biological oblivion through inbreeding. The subadult bulls disperse, often through agricultural landscapes, and form coalitions with other bulls especially older ones to learn the tricks of raiding crops. The biological stage is set for conflicts between elephants and people. Female elephants and their families are not so willing to take risks in venturing into the human domain, in spite of the temptation, because they also need to care for the safety of their young, but when the climate turns adverse, or the habitat becomes patchy or degraded and can no longer cater to their resource needs, they too are eventually forced to take the plunge into the cultivated supermarkets.

A little appreciated factor in the escalation of wildlife-human conflicts is ironically the success of conservation efforts resulting in increasing populations of many wildlife species. Elephant populations have increased over the past four decades in certain regions (such as the south and the north) and have spread into the broader agricultural landscape. Herbivores such as nilgai and black buck have multiplied several-fold in central and northwestern India during this period (Chauhan and Singh 1990). One may, of course, argue that some of these species are only asserting their historical population numbers or densities. Nevertheless, such wildlife population growth contributes to increased conflicts in landscapes under higher human densities and more intensive agriculture.

## The nature and trends in wildlife-human conflicts

It would be illuminating to consider the nature and trends in conflicts between some of the more prominent wildlife species and people.

The elephant is perhaps the most reported animal when it comes to its impacts on people and agriculture. Not a day passes by without a report in the media about an elephant or a group of elephants ravaging cultivated crops, breaking into houses in search of food (or liquor), entering a town or even a city or, worse still, killing a person. The elephants themselves have also been at the receiving end. Some years ago, the struggle for survival of "Siddha", injured when he stumbled at a roadside ditch while making a foray to raid crops and eventually became immobilizedalong the shores of the Manchanbele dam near Bengaluru, generated a fan club and a wave of public sympathy in Karnataka. The most recent narrative which has gripped the minds of the public is that of the bull elephant "Chinnathambi" (younger brother) that was in conflict with agriculture in Coimbatore district of Tamil Nadu, was captured and relocated inside a national park but returned to its original haunts, and has recently been again captured for retention in captivity.

Notwithstanding the perceptions of the urban class, largely insulated from conflicts with animals (the exception being monkeys or pigeons of nuisance value to high-rise apartments), the ground realities for farmers facing the brunt of conflicts with elephants are quite different. Herds of 50-100 elephants routinely mow down vast swathes of standing paddy crop in southern West Bengal. What began as a seasonal movement of about 50 elephants from the Dalma region of Jharkhand during 1986-87 has grown into a population of 150-200 elephants today, with many of the animals becoming resident in a region which had not seen wild elephants for at least a couple of centuries. In the year 2015 alone, 71 people were killed in encounters with elephants, a startling figure of one person for every two or three elephants. Some years ago when I had visited the districts of Medinipur and Bankura with a team of senior officials to suggest mitigation measures, a village sarpanch asked us "We understand that these elephants are coming to West Bengal because of disturbance to their habitat from mining activity in Jharkhand. How are we to blame for a problem in another state? Why should we have to endure the ravages of these elephants and spend sleepless nights for several months guarding our fields? Any night our houses may also be demolished by these elephants." We had no rational answer to these anguished questions.

The magnitude of increase in elephant-human conflicts can be gauged from a simple statistic, namely, the number of people killed by free-ranging elephants in recent decades. During the early 1980s, I had compiled data from across the country which suggested that about 150 people were killed annually by wild elephants, mostly when elephants came to settlements and cultivated fields within forest areas or along its periphery to raid crops. From that number, the figures have steadily increased over the years, reaching a peak of over 500 human deaths by the year 2015-16.

In recent years, there have been several highly publicised incidents of the tiger coming into direct conflict with people, and the rather painful process of capturing or eliminating the offending animal, in many states including Maharashtra, Karnataka, Kerala, Madhya Pradesh, Rajasthan and Uttar Pradesh. The National Tiger Conservation Authority has a "standard operating procedure" in place to deal with tigers which are in conflict with people; while most states meticulously follow the prescribed guidelines, some of the field operations end in controversy. The case of "Avni" in Tadoba (Maharashtra) which allegedly killed about a dozen people and was eventually shot dead in November 2018 perhaps generated more controversy than almost any other case of a similar nature. Most scientists and conservationists agree that the tigress had to be eliminated; the controversy was over how the animal was tracked and shot by a private team of hunters rather than by the government machinery. The alternative viewpoint is that Avni should have been monitored closely and awareness created among the villagers to facilitate co-existence.

Leopards are widespread across the country, having made their homes not only in forests but in sugar cane fields, tea gardens, the suburbs of towns and cities, and practically anywhere they find secure cover to raise their cubs and find food (Athreya *et al.* 2016). A full-grown leopard entering an apartment building or a shopping mall is not uncommon in the Mumbai-Thane region. The most serious direct conflicts with people occur in hill states such as Uttarakhand and Himachal Pradesh. In states such as Maharashtra, several instances of leopards attacking people have been traced to some misguided captures and release of the animals at seemingly distant locations which are believed to be "natural habitats"; in many cases the animals have either colonized the nearby agricultural areas or have tended to move back to the original place of capture, resulting in attacks on people (Athreya *et al.* 2007).

The Asiatic lion was largely confined to the Gir National Park in Gujarat for over a century until its population exceeded about 250-300 individuals. It then began to disperse over a much larger area, the so-called Greater Gir Landscape and is presently distributed over about 20,000 sq.km. This region obviously encompasses a predominantly human use habitat under cultivation and pastoralism. Surprisingly, conflicts are still relatively low for various reasons; lions rarely prey upon people, while predation on livestock is compensated for by the government. More importantly, the lions keep the populations of wild ungulates such as the nilgai within limits tolerated by the farmers who see this as a positive benefit of having lions in their midst. While it is too early to say how long this co-existence will last, it is conceivable that this region could witness an escalation of lion-human conflicts in future, especially under adverse climatic periods (as was the case during the drought of 1986-87, see Saberwal *et al.* 1994). Presently, over 650 lions inhabit the Great Gir Landscape, a conservation success for a species which is believed to have numbered only about a dozen individuals at the turn of the 20th century (Singh 2017).

While the large charismatic mammals have attracted a disproportionate share of the attention on wildlife-human conflicts, the creature which is possibly the most chronic and widespread destroyer of crops is the lowly wild pig (though that distinction surely belongs to rodents which are estimated to destroy a full tenth of India's crop production). Several states from Uttarakhand to Tamil Nadu have permitted the culling of wild pigs outside the forest areas under strict supervision. One would have thought that killing wild pigs would attract the least bit of attention from conservationists and activists (many farmers across the country are anyway quietly killing them and even consuming pig meat), but there has been opposition to this as well.

## A policy framework for the management of wildlife-human conflicts

The government has tried out a number of methods to reduce, eliminate or mitigate conflicts between various wildlife species and people, with limited success in most cases. These include compensatory (*ex gratia*) payments for damage to crops (especially by elephant) or killing of livestock or people, capture of problem animals and their relocation in the wild or retention in captivity, drives to chase offending animals from human habitation, culling (killing in a few instances), and barriers (including trenches, electric fences, walls and highly expensive mechanical fences) to confine animals within forests or prevent them from entering cultivated fields. The actions so far have been largely reactionary and not based on attaining clearly articulated goals of wildlife conservation and conflict mitigation. Conflicts thus continue to perpetuate and escalate beyond levels of tolerance in an otherwise relatively tolerant society.

The suite of management options to deal with wildlife-human conflicts has never been rationally debated taking into consideration what science tells us about the biology and population dynamics of the animal, the imperatives of wildlife managers who have to deal with conflicts on a regular basis, the needs and opinions of the stakeholders (typically farmers, tribals and other rural people) most affected by conflicts, the economics of various mitigation measures and, most important in our context, the cultural significance of each wildlife species across our vast land. It is time for us to prepare a comprehensive policy framework for the management of wildlife-human conflicts. True, there is a "standard operating procedure" and an ecology-based policy framework (Karanth and Gopal 2005) for dealing with "problem" tigers and there are "action plans" or "mitigation methods" for some other species, but these are not necessarily based on an overarching policy framework that has been arrived at after public discussion, debate and analysis.

In addition to creating 'Protected Areas' (especially the categories of National Parks, Wildlife Sanctuaries and Tiger Reserves) which has largely served their purpose of saving many endangered species from extinction and even reversing population trends), India also needs to focus on the concept of sustainable landscapes encompassing multiple land-use. The categories of Conservation Reserves and Community Reserves, both of which fall under the ambit of the Wildlife Protection Act have to be given special thrust with financial incentives. Given its large human population, India needs to actively engage people in the broader goals of biodiversity conservation and wildlife conflict mitigation, especially under the ongoing regime of a changing climate. We also need to have clear policies on how different wildlife species are managed within these landscapes as well as outside the landscapes. Many of these concepts have been incorporated into the National Wildlife Action Plan for 2017-32 but have to be actively pursued in conservation planning and implementation.

The Karnataka Elephant Task Force set up by the Hon'ble High Court of the state made out a case in its 2012 report for defining three zones for taking management decisions; these were (a) Elephant Conservation Zone comprising almost entirely of intact forested or natural lands, (b) Elephant-human Coexistence Zone which include areas at the interface of forests and human settlement or agriculture with potential for some animal-human conflicts, and (c) Elephant Removal Zone encompassing all areas outside these two zones where settlement and agriculture is predominant (KETF 2012).This recommendation by a team of experts was an explicit recognition that just as we need to keep some natural lands free of any human activity or disturbance (such as "core zones" of protected areas), it is also important not to allow elephants beyond certain defined conservation boundaries because of their great destructive potential. Such a framework for zoning conservation landscapes would also apply to other large mammals such as the tiger which can come into serious conflicts if allowed to move into human-dominated areas beyond boundaries defined by scientific assessments taking ecology and people into consideration. In spite of the High Court of Karnataka endorsing this recommendation in its Citation (of 8th October 2013), the state has never actually attempted to develop such a geography-based conservation framework.

The criteria adopted for landscape-scale management will vary across wildlife species. One cannot apply the same criteria for the elephant and the wild pig (ubiquitous across a wide spectrum of land-use categories), nor for the tiger and the leopard (much more widespread and adaptable to human-production habitats). I would suggest that we need to draw fairly clear lines when it comes to the largest land herbivore and the most-feared carnivore, but apply other criteria for managing conflicts with other creatures. Wildlife and people cannot be completely separated, but we have to arrive at tolerable levels of co-existence with different wildlife species for defining the type of management action to adopt based on regional considerations. There is also an urgent need to build capacity among the frontline forest staff for actively managing wildlife species which come into conflict with people; some capacity exists in some states for some species, but not necessarily to the extent needed in a rapidly changing environment.

In May 1980, I was surveying the forests and villages in the Satyamangalam Forest Division of Tamil Nadu with the aim of setting up a study of elephant ecology. On my first day in the field, I did not come across wild elephants but rather saw a man killed by an elephant. Since that day I have been clear in my mind that we need to pursue wildlife conservation with a human face, as though both wildlife and people matter.

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SECTION TWO

# Managing waste and turning it into a resource

SECTION TWO

# Managing waste and turning it into a resource

Limited segregation at source as well as inadequate infrastructure and facilities for eco-friendly waste disposal are two major reasons why urban and peri-urban India is gradually getting converted into a big dump yard. Our soil, water, air and ecosystems are getting polluted and becoming unlivable.

This is anti-thesis of India's tradition, culture and way of living. Throughout history, there are examples, including from our earliest civilizations of Mohenjo-Daro, Harappa and Mauryan period which display effective functional waste management systems. Over the years, the waste management practices have not kept pace with the amount and kinds of waste generated by mankind.

Municipal solid waste, plastic waste, e-waste, construction and demolition waste, biomedical waste and hazardous waste have become a cause of concern. The Government of India amended its Waste Management Rules in 2016 underlining the concept of "Extended Producer Responsibility (EPR)". The implementation of these Rules needs to be strengthened while institutionalizing the concept of segregation at source, recycling, reuse and eco-friendly disposal of waste. What is needed is that each and every individual reduces wastes, mindfully segregates, and responsibly delivers it to the appropriate disposal facility. Society at large needs to move towards bringing behavioural changes shunning its callous attitude towards littering and apathy towards waste. There is a need to think innovatively and develop customized decentralized waste management solutions.

On 2$^{nd}$ October 2014, Prime Minister Shri Narendra Modi launched Swachh Bharat Abhiyan as a tribute India could pay to Mahatma Gandhi on his 150$^{th}$ birth anniversary in 2019. Prime Minister has been stressing on the basic fact that "Clean India is a Healthy India, Prosperous India". Cleanliness is visible as the Mission has made an impact on people's consciousness.

On the World Environment Day - 2018, the Indian Government pledged to ban all single-use plastics by 2022. Several 'Green Startups' have come up across the country to handle different kind of wastes as commercially profitable ventures. Effective waste management also helps maintain resource use efficiency to meet the growing needs of the Indian population.

Human civilizations have evolved through the ages based on the abundance of natural resources. The intelligent *Homo sapiens* spread all over the globe and learnt to not only grow food and domesticate animals but also to exploit the locally available materials and services for energy, safety and comfort. Wood, mud and stone and in more recent past minerals and glass provided him efficient tools, shelter, carts, vessels and even hand-held weapons.

The discovery of plastics, a bare 50 years ago, opened new vistas for the creation of novel goods and even substitution of exhaustible natural materials with cheaper synthetic products. To an extent, plastics even helped in the conservation of nature's bounties such as timber and metals.

However, the culture of use-and-throw found a willing partner in plastics. The plastics in our life are now proving a bane for our environment. Single-use plastics are turning the ingenious human-made asset into a liability for the planet. While in the West discarded plastic goods are exported to be dumped elsewhere, nearer home we can see used bottles, trays, bags and containers strewn all over the land and water. A stage has come when the health conscious humans may have water, food and beverages free from microbial and inorganic contaminants, but may still have plastics on their platter. Microplastics have already reached our bottled water and table salt.

Time may not be far when someone throwing a fishing line or a net in the sea may catch a lot of plastics, but no fish.

The challenge is before us! Options are open.

This section contains five papers covering contemporary themes like the circular economy, EPR for plastics, e-waste management, converting indigenous waste carbon sources to useful products and policy framework for fostering resource efficiency in India.

**Guest Editor**

# Circular economy

Prasad Modak[1]

## Abstract

Circular Economy (CE) has been a paradigm that has been recently introduced and adopted across the world. Countries like Australia, Japan, the EU and China have made significant progress by formulating CE related policies, strategies and regulations. This has helped in reduction of resource consumption, reduction of residues to landfills and the reduction of associated environmental and social impacts. Adoption of CE has led to increased investment flows, more competitiveness, emergence of innovative business models and generation of employment. CE has also assisted in moving towards the Sustainable Development Goals and help meet the targets related to sustainable production and consumption and reduction of Greenhouse Gas (GHG) emissions.

This paper introduces the concept of CE and traces its evolution. It presents the gradual shift in the environmental governance of India from the initial limited focus on the management of residues to the management of resources along with residues in a holistic manner. In adopting CE, the informal sector is expected to play a critical role, especially on repair, refurbish, remanufacture and recycling. Various programs on skill development by the National Skill Development Corporation (NSDC) and obligations such as Corporate Social Responsibility (CSR) and Extended Producer Responsibility (EPR) are expected to play an important role in strengthening of the informal sector. The paper ends by summarizing the efforts taken by the Government of India, especially by the NITI Aayog, to formulate a national strategy on resource efficiency and circular economy.

## Keywords

*Circular Economy, Resource Efficiency, Sustainable Consumption and Production, Sustainable Development Goals.*

## Introduction

India faces many environmental problems today. Our limited resources are under threat due to intensive depletion and serious degradation. Further, we realize that risks to our resource security are compounded due to looming threats of climate change. Policies and strategies to respond to these challenges need mainstreaming of sustainability across all developmental sectors.

Strangely and oddly enough, the national governments, particularly the Ministries of Environment, in most countries of the world, have focused more on the management of residues rather than management of the resources. Legislation was evolved to set limits on the residues that will have to be met prior to disposal, but not much attention was given on the limits of extraction of resources and resource pricing based on life cycle considerations. Our approach has not been balanced.

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More recently, however, there has been a realization that addressing both resources and residues in a holistic manner is necessary. In addition to enforcement of legislation on residues, approaches that recognize and encourage resource efficiency are also important. Generation of residues must be reduced in the first place. Material flows should be "circular" to the extent possible across the life cycle of products so as to conserve our virgin resources and reduce the import of materials. An era of circular economy is now on the agenda that is expected to be transformational to make India a globally competitive, resource secure country. This paper introduces the concept of circular economy in this context and traces its evolution. In the end, it summarizes the steps taken by the Government of India for mainstreaming circular economy with suggestions for the way forward.

## Our narrow focus on management of residues

Extraction of resources and their utilization leads to the generation of residues. We realized that residues when not properly disposed of could lead to considerable damage to the humans and the ecosystems. There were severe economic implications both on damage and restoration. Many of the impacts were found to be long-term and irreversible and further compounded with risks that were not easy to anticipate.

Most national governments including India, followed a precautionary approach following "do no harm principle" in setting the limits. Limits on residues became stricter over the years as our understanding of the adverse impacts and risks to the environment improved. Over the years, advances were made in the monitoring of pollutants in the residues e.g. metals. Technologies were developed that could be economically used for the treatment of complex and hazardous residues (e.g. plasma-based incineration, advanced bioremediation etc.) These advances made tightening of the limits on residues possible. Over a period of time, the legislation on residues expanded and became more comprehensive to address the acceptable levels of contaminants even in the products. The emergence of eco-labels that specified such limits (e.g. safe limits of formaldehyde in baby infant clothing) is an example.

**Figure 1(a): Select Environmental Legislations – 1970's to 1980's**

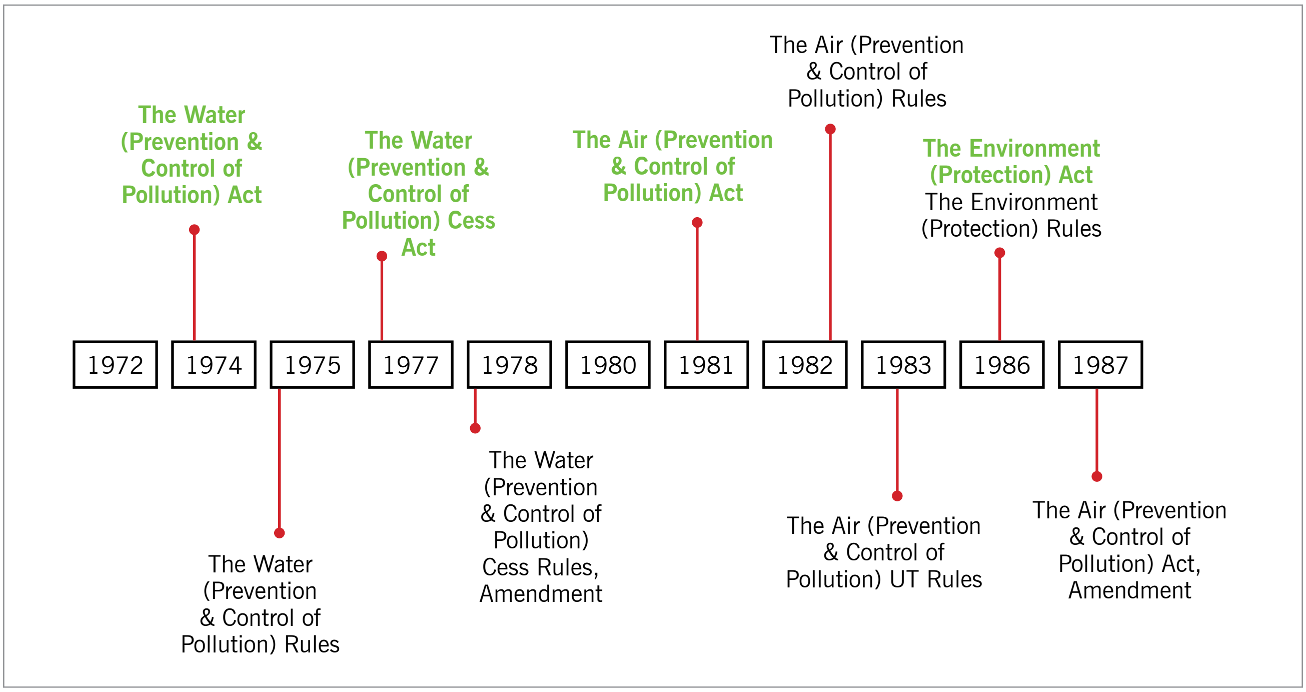


**Figure 1(b): Select Environmental Legislations and Rules - 1980's to 1990's**

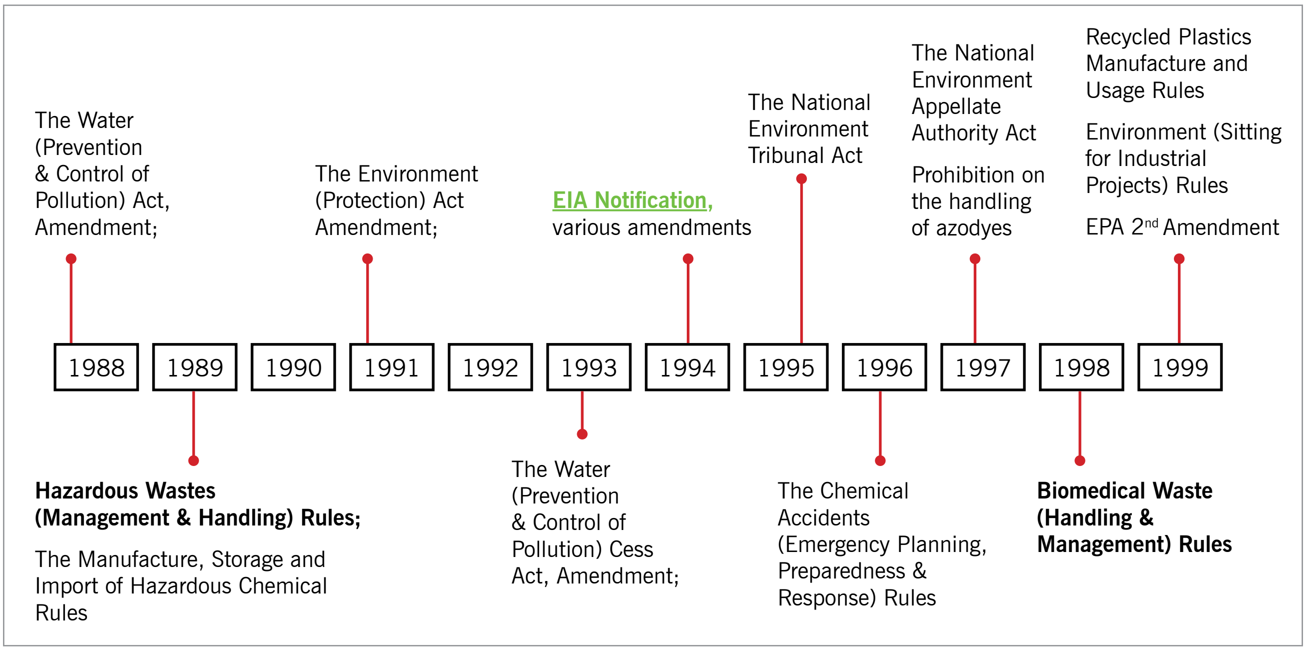
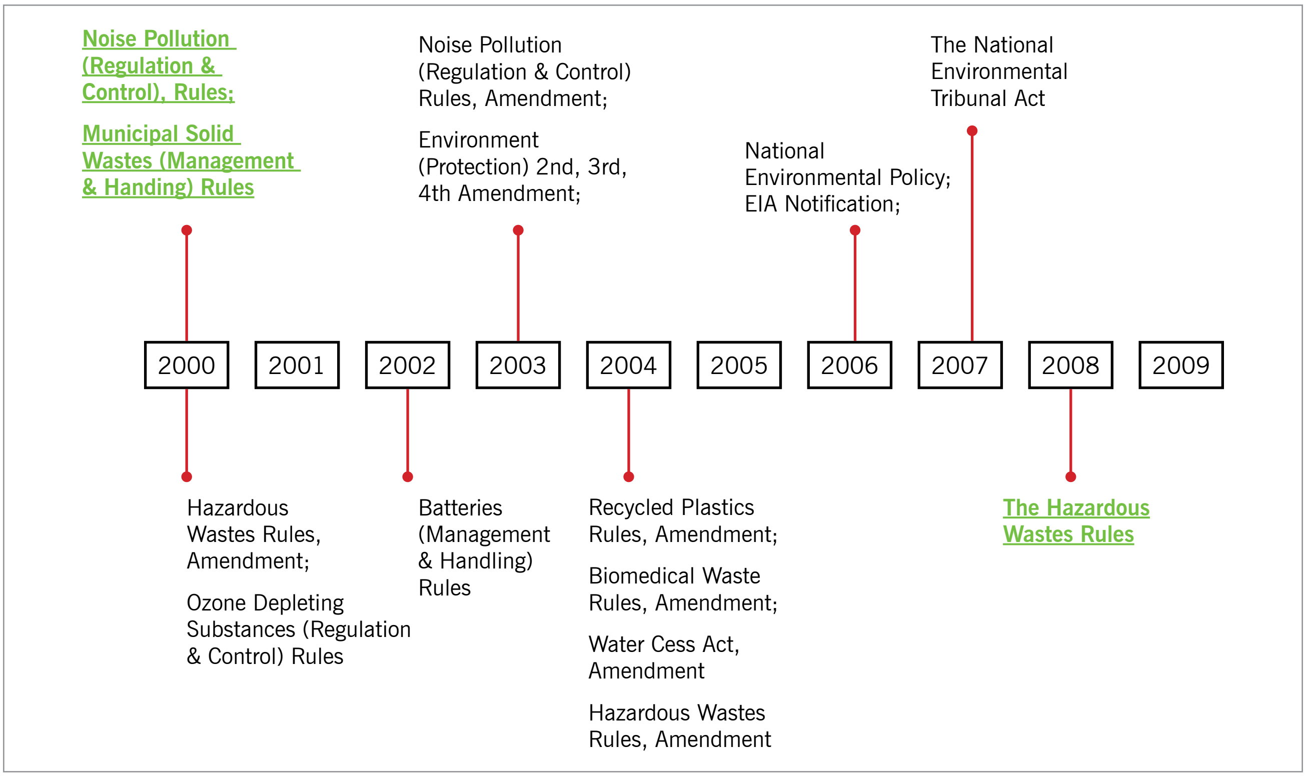
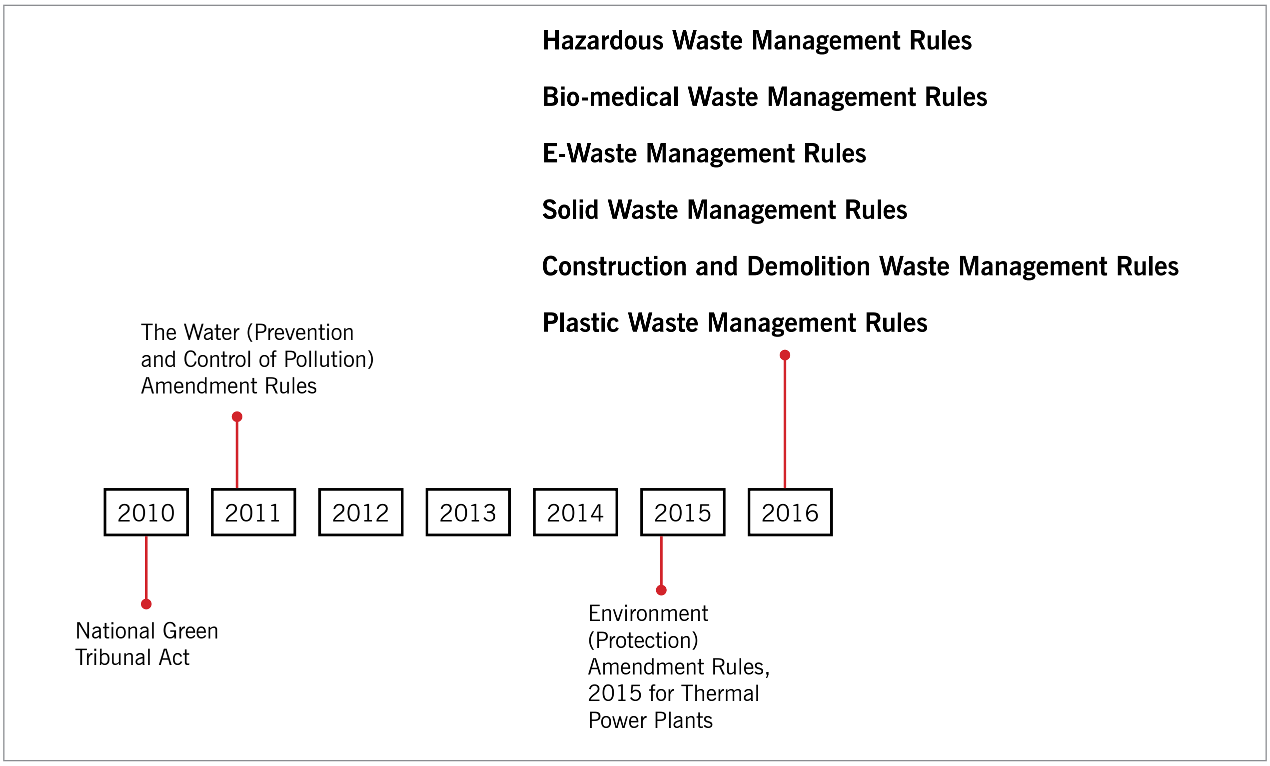



**Figure 1(c): Select Environmental Legislation and Rules - 2000 to 2009**




Having framed the legislation and limits or standards on the residues and products, India established institutions for monitoring and enforcement. Procedures and practices of documentation were also laid down. India initially began with addressing wastewater as the residue but soon air emissions, solid and hazardous wastes were included. In the last two decades, specific residues such as municipal solid wastes, construction and demolition wastes, plastic waste, electronic (e) waste were addressed by setting limits and requirements for safe disposal. Consequently, the investments on the end of pipe management of residues increased. Figures 1 (a), 1 (b), 1 (c) and 1 (d) show a trail of the legislations

**Figure 1(d): Select Environmental Legislation - 2010 to 2016**




in India that focused on the environment and the management of residues.

Unfortunately, since the institutions (i.e. the Pollution Control Boards) made responsible for monitoring and enforcement were overloaded, compliance to the standards or limits on residues was not satisfactorily achieved. The resources continued to be degraded.

## The transformation

The polluters realized that to reduce cost of the end of pipe treatment and remain competitive, efforts were required to reduce generation of residues at the source. Concepts such as waste minimization and pollution prevention therefore emerged and the polluters did every effort to reduce residue generation by deploying better housekeeping and practicing reuse, recycling, recovery to the extent possible. This required a behavioural change, application of management systems, use of productivity improvement tools and adoption of modern technologies. The investments for management of residues essentially moved upstream leading to "ecological modernization". Unlike end of pipe investments, the "upstream" investments had a payback or economic returns. Strategies such as Cleaner Production (CP), Eco-Efficiency (EE), Green Productivity (GP) and Resource Efficient Cleaner Production (RECP) emerged. These strategies showed a link between resources (in specific the resource use efficiency) and the residues that could be converted as a resource. **Box 1** provides the working definitions of these concepts.

In India, National Center for Cleaner Production (NCPC) was established at the National Productivity Council (NPC) with the assistance of United Nations Environment Programme (UNEP) and United Nations Industrial Development Organization (UNIDO) in 1994-1995. The NCPC at NPC is no more active today. Subsequently, Gujarat Cleaner Production Centre (GCPC) was established by the Industries Department of the State Government with the technical support of UNIDO to realize cleaner production potentials in Gujarat. The GCPC is still very active.

The Ministry of Environment, Forest and Climate Change (MoEFCC) promoted Waste Minimization Circles (WMC) in Small and Medium Enterprises (SME) with the help of NPC. This program, supported by the World Bank, was initiated in 1995-1996 and around 100 WMCs were established across the country. This program demonstrated the economic and environmental benefits of waste minimization and led to several success stories amongst the SMEs. The NPC under the support of Asian Productivity Organization (APO) implemented several demonstration projects in the SMEs to showcase the advantage of Green Productivity approach that led to not only waste minimization but also to improvements in resource efficiency and productivity. More recently, India launched a program on RECP with the support of UNIDO and UNEP with the Ministry of Energy, Ministry of Planning, Ministry of Finance, MoEFCC and Ministry of Industry as the partners. Through the several demonstration projects, the concept that "pollution prevention pays" was proven and established the economic and environmental importance of resource efficiency.

Box 1: **Working Definitions of CP, EE, GP and RECP**

**Cleaner Production:** ".. The continuous application of an integrated environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment .."[2]

**Eco-efficiency:** " .. measured as the ratio between the (added) values of what has been produced (e.g. GDP) and the (added) environment impacts of the product or service (e.g. $SO_2$ emissions) .."[3]

**Green Productivity:** " .. a strategy for enhancing productivity and environmental performance for overall socio-economic development. Green Productivity was considered as the application of appropriate productivity and environmental management policies, tools, techniques, and technologies in order to reduce the environmental impact of an organization's activities .."[4]

**Resource Efficient Cleaner Production:** "… continuous application of preventive environmental strategies to processes, products, and services to increase efficiency and reduce risks to humans and the environment. RECP works specifically to advance production efficiency, management of environment and human development[5]

Gradually, the importance of product design was understood that connected resources and residues across the life cycle. Understanding of Life Cycle impacts of the products made us realize that we must think of both resources and residues at every stage of life cycle, i.e. extraction, transportation, processing, packaging, distribution, use, disposal. The two R's (viz. Resources and Residues) were thus integrated with the opportunities of Redesign, Reuse and Recycle. Innovation was an important outcome of the eco-design.

Unfortunately, in India, the importance of green products to influence sustainable consumption and production is not understood even today. While our focus on residues slowly moved towards addressing minimization of residues through resource efficiency, we remained weak on the strategy of eco or sustainable product design and sustainable public procurement. Our eco-labelling program "Eco-mark" that was initiated as early as in 1991 did not have much impact. There are only a handful schools in India today who teach sustainable product design. Recently, the Ministry of Finance has set up Task Force on Sustainable Public Procurement (SPP) and plans to develop a national action plan by the end of 2019. This is indeed a welcome move.

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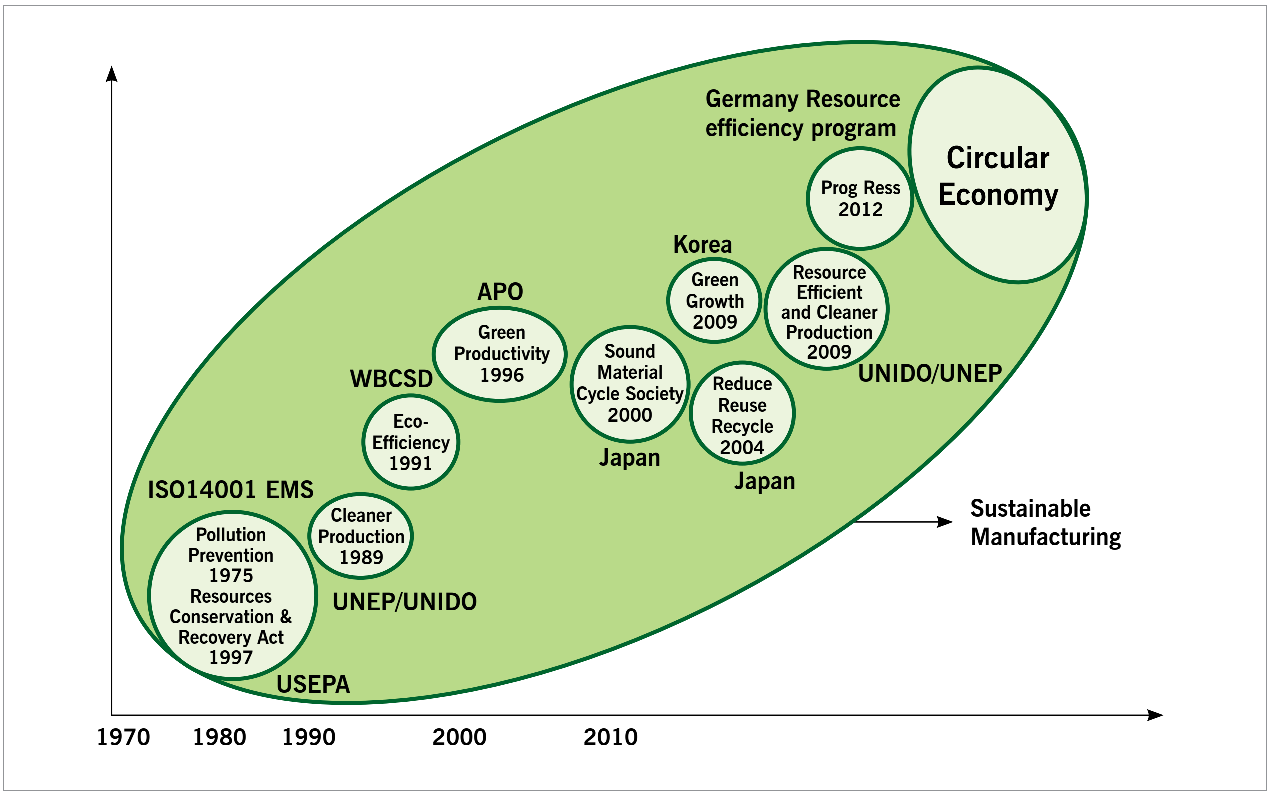
[2] http://www.unep.fr/scp/cp/
[3] https://sustainabledevelopment.un.org/content/documents/785eco.pdf
[4] https://www.apo-tokyo.org/publications/wp-content/uploads/sites/5/ind_gp_aasd-2002.pdf
[5] https://www.unido.org/our-focus/safeguarding-environment/resource-efficient-and-low-carbon-industrial-production/resource-efficient-and-cleaner-production-recp

**Figure 2: Evolution of the concept of circular economy**




## Emergence of circular economy

Circular economy offers a platform for all stakeholders to get involved in sustainable and inclusive development. In addition to addressing environmental sustainability, circular economy improves businesses competitiveness, generates employment, increases green investment flows, builds on partnerships and helps in establishing transparent and inclusive governance.

Figure 2 shows the evolution of the concept of the circular economy. Box 2 provides working definitions.

The concept of circular economy added additional 3Rs namely- Repair, Refurbish and Remanufacture. These 3Rs introduced four significant components viz. social (employment), enterprise, innovation and investments — the 6Rs help towards achieving the Sustainable Develop ment Goals (SDGs). Besides, once material flows become circular, compliance becomes of interest to every stakeholder across the life cycle. See Figure 3.

## Repair, Refurbish and Remanufacturing and the concept of inner and outer circles

When we think of the circularity of material flows, we need to understand "outer" and "inner circle" approaches. See Figure 4.

The "outer circle" approach creates a closed loop of materials through recycling. In the case of electronic goods, this means recovering of precious metals lodged in our gadgets, something only feasible with sophisticated technology, requiring a scale and where large companies profit.

The "inner circle" approach is essentially following the route of repair, refurbishing and remanufacturing. It is the inner circle approach where we transform our living from the single-use and throw away culture. When we follow inner circle approach, it helps us to save money, conserve our resources, generate employment and come up with innovations. We extend a product's life cycle through reuse. The inner circle is people-centric and it is for citizens and supports small companies.

**Box 2: Working definitions of RE, SRM and CE**

**Resource Efficiency (RE)** or **resource productivity**, is the ratio between a given benefit or result and the natural resource use required for it. While the term "resource efficiency" is predominantly used in business, product or material context, "resource productivity" as a term is used in an economy-wide, national context[6].

**Secondary Raw Materials (SRM)** are recycled materials that can be used in manufacturing processes instead of or alongside virgin raw materials.[7]

The **Circular Economy (CE)** is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used, again and again, thereby creating further value.[8]

**Figure 3: 6Rs of circular economy**

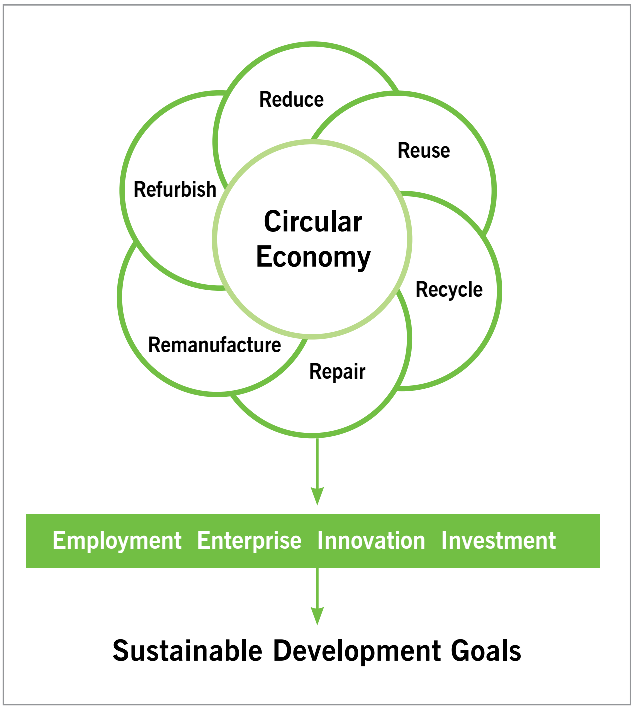
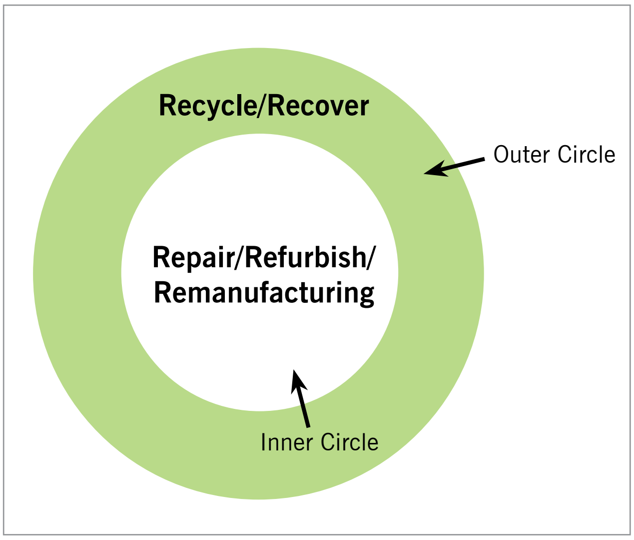



**Figure 4: Concept of inner and outer circles in circular economy**




Repair is a restoration of a broken, damaged, or failed device, equipment, part, or property to an acceptable operating or usable condition. Repair can involve replacement. Refurbishing is refinishing and sanitization (beyond repair) to serve the original function with better aesthetics. Repaired and refurbished products, although in good condition, may not be comparable with new or remanufactured products. In remanufacturing, the product is resold with performance and specifications comparable to new products.

Remanufactured or refurbished products can help companies compete at a lower price with cheaper or lower quality competitors, without reducing quality, due to the resource savings realised, allowing firms to secure greater market share. Economic incentives and disincentives, as well as enforcement of legislation on EPR, play an important role to move the inner circle.

Unfortunately, the inner circle approach to material circulation does not find much space in both public

[6] Strategy Paper on Resource Efficiency, 2017, NITI Aayog: http://niti.gov.in/writereaddata/files/document_publication/Strategy per cent20Paper per cent20on per cent20Resource per cent20Efficiency.pdf
[7] Strategy for Secondary Raw Materials, 2016, European Parliament: http://www.europarl.europa.eu/legislative-train/theme-new-boost-for-jobs-growth-and-investment/file-strategy-for-secondary-raw-materials
[8] Circular economy: definition, importance and benefits, European Parliament: http://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits

and scientific discussions. We speak more about recycling or the outer circle approach to achieve circularity. We need both – but former should get a preference. Given our traditions and massive informal sector, we need to provide support to strengthen the inner circle approach towards a circular economy.

## Circular economy in India

India is estimated to become the fourth largest economy in the world in about two decades. This economic growth is, however, going to come with challenges such as urbanization with increased vulnerability (especially due to climate change), poor resource quality and scarcity and high level of unevenness in the socio-economic matrix due to acute poverty. India, if it makes the right and systemic choices, has the potential to move towards positive, regenerative, and value-creating development. Its young population, growing use of IT, increasing emphasis on social and financial inclusion as well as the emerging manufacturing sector can make this happen. For this, the conventional linear 'take, make, dispose' model of growth must change and an enabling policy framework at the national and sectoral level needs to be evolved.

The recent report by the Ellen MacArthur Foundation on India[9] shows that a circular economy path to development could bring India annual benefits of INR 40 lakh crores (USD 624 billion) in 2050 compared with the current development path – a benefit equivalent to 30 per cent of India's current GDP. Following a circular economy path would also reduce negative externalities. For example, Greenhouse Gas emissions (GHGs) would be 44 per cent lower in 2050 compared to the current development path, and other externalities like congestion and pollution would fall significantly, providing health and economic benefits to Indian citizens. This conclusion was drawn based on high-level economic analysis of three focus areas *viz*. cities and construction, food and agriculture, and mobility and vehicle manufacturing.

The Ministry of Environment, Forest and Climate Change (MoEFCC) of Government of India has set up the India Resource Panel (InRP) in 2016 to examine the material and energy flows across key sectors following a life cycle approach and to assess resource efficiency. Sectors such as Construction, Automobiles, Iron & Steel and Metals were considered, and key cross-cutting areas were examined. Recommendations of InRP were taken up by India's NITI Aayog and is expected to develop a national framework to foster and support India's circular economy. For this purpose, NITI Aayog had prepared strategy papers for Steel, Aluminium, C&D waste and E-waste sectors and drafted a Status Paper with cross-sectoral recommendations to action on Resource Efficiency and Circular Economy. In all these papers, strengthening the informal sector on repair, refurbish, remanufacturing and recycling have been underscored. It is necessary that the Government encourages partnerships between the informal and the formal sectors and facilitates common or zonal residue recycling facilities. Here the National Skill Development Corporation (NSDC), Industrial Estate Authorities and Corporate sector will play a crucial role and will need to work in partnership.

In order to align with the National level action plan, State-level circular economy plans are also encouraged by NITI Aayog, at the States of Telangana, Orissa and Goa. More recently, the MoEFCC has established a Resource Efficiency Cell with the support of The Energy and Resources Institute (TERI). An EU delegation on circular economy recently visited India for potential

[9] Circular economy in India: Rethinking growth for long-term prosperity, Ellen MacArthur Foundation at https://www.ellenmacarthurfoundation.org/publications/india

collaborations and this event is expected to lead to business to business partnerships.

## Way forward and concluding remarks

The Government of India has embarked on several iconic projects to improve and expand its infrastructure (transport, cities and energy) and undertake ecological modernization of important sectors such as water, agriculture and food. The 100 Smart Cities program, Make in India initiative, *Swachh Bharat Abhiyan* (Clean India), *Namami Gange* (Ganga River Action Plan), Interlinking of Rivers, Climate Resilient Agriculture, etc. are a few examples. In these mega projects, Foreign Direct Investment is encouraged, and these investors are asking for good practices on Environmental and Social Governance (ESG) apart from conventional compliance. In all these projects, the mainstreaming circular economy is going to be extremely relevant.

Resource management in India is in the purview of the relavant ministries of the Government of India, e.g., water, energy, agriculture. Coordination between the ministries needs to improve to visualize a "systems" perspective where resources and residues are integrated. While there are already provisions made to promote RE/CE in some of the national policies, it is necessary that a harmonized overarching national policy on RE/CE is evolved building upon the existing policies to address multiple sectors. Such a policy framework should address various life cycle stages and the material flows to ensure closing of the loop and involvement of the key stakeholders.

Promotion of circular economy cannot be steered solely by the Government. It requires a partnership approach where the markets (consumers, retailers) and investors are also involved. The new paradigm of the circular economy should address both resources and residues, across the life cycle and strike G-B-F-I-C (Government, Business, Financing Institutions, and Communities) partnerships.

Circular economy is thus a concept that brings management and resources and residues together in the interest of economy, livelihoods and the environment. If implemented properly, it will spur innovation and stimulate investments. circular economy is India's hope towards smart and sustainable growth.

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# Extended Producer Responsibility for plastics – Indian and Global perspectives

Vaibhav Rathi[1], Kundan Burnwal[2], Jai Kumar Gaurav[3], Ashish Chaturvedi[4]

**Abstract**

World production of plastic expanded from about 2 million in 1950 to 335 million in 2016. It is expected that production will triple by 2050. Consequently, the production of virgin plastics is inherently linked to climate change and generated $CO_2$-equivalents of approximately 400 million tonne of greenhouse gas (GHG) emissions in 2012. Consumption of plastics in huge volumes is also a cause for environment pollution because of its unchecked disposal. In the last 70 years 6.3 billion tonne has been discarded, most of which is still around in landfills, oceans, in animals and even humans. There is an urgent need to close the loop for linear utilisation of plastics, especially for packaging. One of the most effective policy principles to close this loop is Extended Producer Responsibility (EPR). Under EPR, producers are made responsible for the end-of-life phase of post-consumer products. Application of the EPR principle has unlocked remarkable gains across many industrialised countries; yet, in India's policy landscape, EPR still constitutes a relatively new element and it remains unclear how its potentials can be fully exploited. This paper aims to emphasise the importance of EPR for Plastic Waste Management in India and the way forward to implement EPR for plastics at a large scale in the country. The paper elaborates the current scenario of EPR in India and the world. It also dwells on substantive lessons derived from global implementation measures and India's own efforts to implement EPR for Plastics.

**Keywords**

*Plastic, Pollution, Extended Producer Responsibility.*

## 1. Introduction

Plastic is a discovery made by accident in the early 19th Century and has transformed the world since then. The subsequent process of its diversification in many forms of use and low-cost bulk production methods made this material viral across the world. World production of plastic expanded from about 2 million in 1950 to 335 million in 2016. It is expected that production will triple by 2050 (MoEFCC 2018).

Consequently, production of virgin plastics is inherently linked to climate change and generated $CO_2$-equivalent emissions of approximately 400 million tonne in 2012.

Provided that this trend continues, production of plastics could account for 20 per cent of global oil consumption and 15 per cent of global carbon emissions by 2050. The largest share of plastic consumption remained with packaging industry which accounted for around 35 per cent in 2013,

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followed by infrastructure (25 per cent), automotive industries (17 per cent), agriculture (8 per cent) and others (15 per cent, e.g. electronics, medical devices or else) (European Union 2018). India has also kept pace with the world in the production of plastics. Plastic industry in India started with making Polystyrene in 1957 with modest beginnings and a 2011 review of the industry showed that it is the fastest growing industry in the world (MoEFCC 2018). The production of plastic materials in India is done in more than 30,000 units across India (FICCI 2017). Approximately 85-90 per cent of these units are small scale enterprises (MoEFCC 2018), often producing low-grade plastics in unorganized and informal ways. Though the plastic industry in India is rapidly growing, per capita consumption of plastic in India remains lower than other developing and developed countries (FICCI 2017).

The flip side of consumption of plastics in huge volumes is the environmental pollution caused by its unchecked disposal. In the last 70 years, around 8.3 billion tonne of plastic have been produced and 6.3 billion tonne has been discarded. Unfortunately, most of the 6.3 billion tonne are still around in landfills, oceans, in animals and even humans (MoEFCC 2018). This situation is likely to deteriorate unless efforts are made to reduce, recycle and reuse. A Central Pollution Control Board study in 60 cities of India estimated that around 25,940 T/day of plastic waste is generated in India. As per the results of the study, out of total plastic waste, around 94 per cent waste comprises recyclable plastic and the remaining 6 per cent belongs to the family of non-recyclable plastics (CPCB 2017).

There is an urgent need to close the loop for linear utilisation of plastics, especially for packaging. One of the most effective policy principles to close this loop is Extended Producer Responsibility (EPR). Under EPR, producers are made responsible for the end-of-life phase of post-consumer products. This essentially means that the producer has a responsibility to take back the products from the market after they are discarded by the user. EPR seeks to induce changes in both upstream processes (e.g. eco-design) and downstream processes of a product's value chain (e.g. developing a waste management infrastructure). The high percentage of recyclable plastics in Indian plastic waste mix makes EPR a critical policy instrument that should be implemented at the national level for curbing environmental pollution from plastics and fulfil India's ambition to 'Beat Plastic Pollution'.

## 2. Objective

The implementation of EPR schemes globally has proven highly effective in fostering waste reduction, reuse and recycling across many industrialised countries. This paper aims to emphasise the importance of EPR for Plastic Waste Management in India and the way forward to implement EPR for plastics at a large scale in the country. The paper elaborates the current scenario of EPR in India and the world. It also dwells on substantive lessons derived from global implementation measures and India's own efforts to implement EPR for Plastics. India has achieved some success in implementing EPR, the paper documents a few of such case studies from across the country. There has also been a significant improvement in EPR policies at the national level; however, implementation remains far from completion. The paper also elaborates on the opportunities for improving EPR for plastic waste management implementation in India.

## 3. Evolution of EPR in Plastic Waste Management-Global and Indian perspectives

Application of the EPR principle has unlocked remarkable gains across many industrialised countries; yet, in India's policy landscape, EPR still constitutes a relatively new element and it remains unclear how its potential can be fully exploited. The EPR has gone through many developments in the past and has achieved global recognition as a central policy instrument to transition towards circular economy. On a global scale, cumulatively 384 EPR policies were implemented since 1990. To date, major applications of EPR schemes pertain to packaging waste are illustrated in Figure 1. Application of EPR in packaging was the third largest among all product types.

In Europe, EPR has become a cornerstone of effective waste management policies. Over almost 30 years, implementation has produced a magnitude of experience, with a wide range of success in the implementation of EPR. There is also precedence for plastic-generating corporations to establish Producer Responsibility Organisations (PRO) which come together to take back waste from the consumers. Table 1 provides an overview of the following:

- Start date of EPR scheme(s);
- Whether EPR is, in practice, implemented individually or collectively (i.e. through PROs) by producers;
- Number of collective schemes (PROs).

**Figure 1: Global Cumulative Application of EPR Schemes, (European Union 2018)**

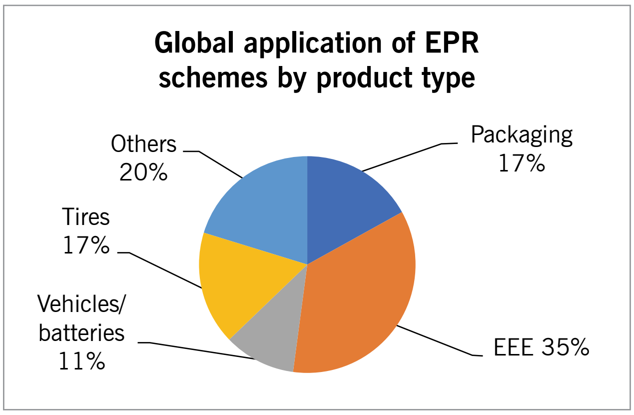


Figure 2 provides aggregation of EPR performance in EU member states. Recycling, recovery and reuse of plastics are used as an indicator to illustrate the extent of EPR implementation in EU member states to foster capture of the rising plastic waste.

With the renewal of the Plastic Waste Management Rules (PWMR) in 2016, the Indian Government also brought in an ambitious step forward to tackle the issue of plastic waste. The passing of the PWMR represent a landmark achievement and once again stressed the relevance of EPR to the Indian plastics industry by putting responsibility for waste management into the hands of producers,

**Figure 2: Recycling, recovery and re-use rate for packaging EPR systems in member states of EU (Monier *et al.* 2014). Note: Denmark's achievement of more than 100 per cent recycling, recovery and reuse rate indicates treatment of imported plastic waste**

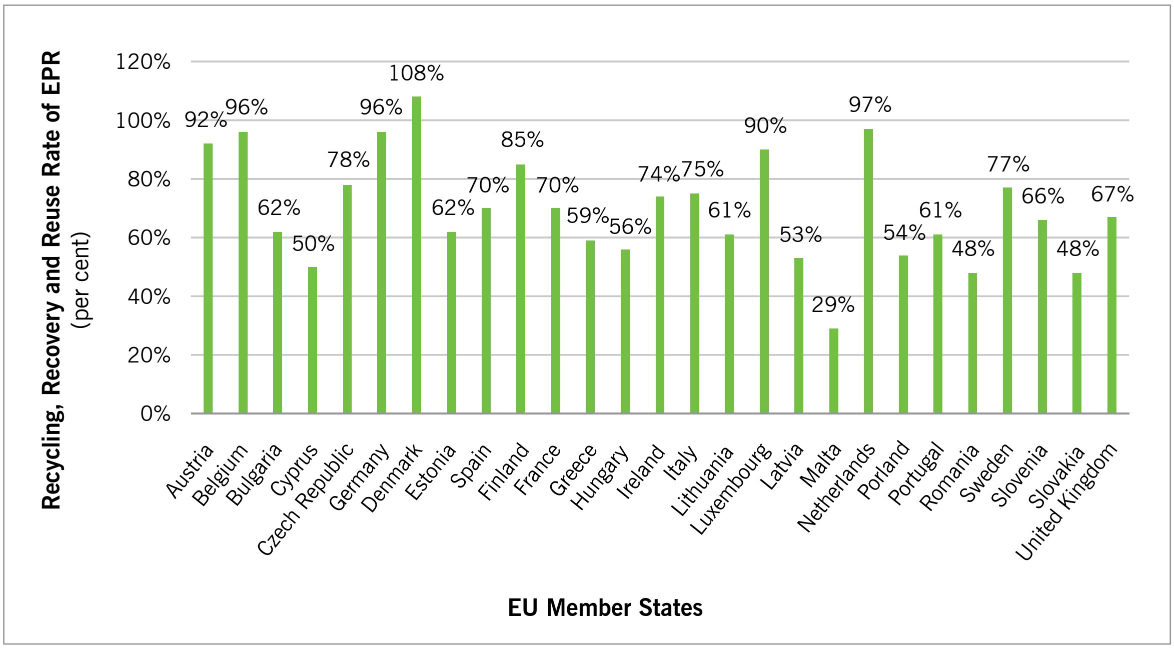

**Table 1: Overview of EPR schemes in the EU for packaging, (Monier *et al.* 2014)**

| Member State | Start date of the EPR scheme | Collective or Individual | If collective, number of Producer Responsibility Organisations (PROs) |
|---|---|---|---|
| Austria AT | 1993 | Both | 6 |
| Belgium BE | 1994 | Both | 2 |
| Bulgaria BG | 2004 | Both | 1 |
| Cyprus CY | 2006 | Both | 1 |
| Czech Republic CZ | 2002 | Both | 1 |
| Germany DE | 1990 | Both | 9 |
| Denmark DK | Government-led scheme | | |
| Estonia EE | 2004 | Both | 4 |
| Spain ES | 1996 | Both | 2 |
| Finland FI | 1997 | Both | N/A |
| France FR | 1992 | Both | 1 |
| Greece GR | 2001 | Both | N/A |
| Hungary HU | Government-led scheme | | |
| Croatia HR | 2006 | N/ A | N/A |
| Ireland IE | 1997 | Both | 1 |
| Italy IT | 1997 | Collective | 1 |
| Lithuania LT | 2002 | Both | 1 |
| Luxembourg LU | 1995 | Both | 1 |
| Latvia LV | 2000 | Both | N/A |
| Malta MT | 2005 | Both | 1 |
| Netherlands NL | 2013 | Both | 1 |
| Poland PL | 2000 | Both | 1 |
| Portugal PT | 1996 | Both | 1 |
| Romania RO | 2004 | Both | 7 |
| Sweden SE | 1994 | Collective deposit system; Collective and individual system for other packaging | 1+ several deposit systems |
| Slovenia SI | 2003 | Both | 4 |
| Slovakia SK | 2003 | Both | 11 |
| United Kingdom (UK) | 1997 | Both | 22 |

brand owners and distributors. In March 2018, the MoEFCC issued a notification announcing the Plastic Waste Management (Amendment) Rules 2018. It mainly clarifies terms like "energy recovery" and allows producers or brand owners to apply for registration with the Central Pollution Control Board (CPCB) when operating in more than two States or Union territories. Yet, not only producers have obligations, but also importers, brand owners, recyclers and processors must register with local bodies, operate in line with national standards. Also, producers, importers, brand owners, retailers and street vendors have to pay a user/plastic waste management fees to the local body to financially support the infrastructure behind the EPR schemes.

Moreover, the Guidelines for Disposal of Thermoset Plastics published in 2016 further promote EPR, especially for the disposal of Sheet Moulding Compound (SMC) and Fibre Reinforced Polymer (FRP) plastic waste. The non-recyclable plastics are primarily used in the automotive industry, for mass transport, electronics and the building and construction sector. In 2016, there was no system in place for the collection, segregation, storing or disposal of these products, but they are included in the PWMR. In detail, the following hierarchy for management and disposal is promoted by the guidelines:

1) Minimizing waste generation
2) Co-processing in cement kilns
3) Disposal in secure landfills

The guidelines state that the producers of thermoset plastics and major users like industries shall be working together with cement plants, in consultation with the local authority, to develop modalities for co-processing of such waste in cement kilns. This includes the establishment of shredding and feeding systems as well as the instalment safety measures (like online emission monitoring) to avoid negative effects on humans and the environment (European Union 2018).

***Gaps and challenges for EPR in plastic waste management in India***

With the renewal of Plastic Waste Management Rules in 2016, EPR has become a central tool within the Indian waste policy landscape. Yet, various implementation challenges remain which hamper its effectiveness. For one, monitoring and enforcement systems remain yet to be fully implemented so that policymakers can review the effectiveness of state-level implementation and allocate resources accordingly. Collection targets for plastic waste are non-existent, and hence reporting procedures also follow a different approach. There is no national framework under which EPR can be implemented in India. The rules also do not define clearly the incentives for private companies if EPR obligations are put upon them. There is no definition for EPR obligations of products like tetra pack which have paper as well as plastic. Hence, will they fall under new plastic waste rules is still unclear.

The PWM Rules also include gram panchayat as one of the prescribed authorities to manage plastic waste. There are however challenges to implement PWM rules in rural areas. This is due to the fact that villages are often remotely located and per capita waste generation in rural areas is also less. This makes it financially and logistically un-viable for most waste processing and recycling facilities to manage plastic waste in these areas.

## 4. Opportunities for India in improving EPR for Plastic Waste Management

The limited implementation of EPR can be overcome by making substantial changes in the existing policy framework for plastic waste management in India. Some of them are discussed below:

- **Setting targets:** Defining targets for take-back of plastic products should be the first step in the amendment of existing PWM Rules, 2016. If setting the target upfront is difficult then every producer should be mandated to give targets mandatorily within the stipulated time.

- **Output-based subsidy instead of capital subsidy:** Existing government schemes are built around capital subsidies and have several requirements on mechanical inputs that make projects unviable. Additionally, an upfront subsidy can lead to construction cost inflation and suboptimal use of technologies. Buyback arrangements of outputs after establishing clear quality standards will be a better model. These can be negotiated with O&G PSUs, private corporations in the petrochemical industry as well as large construction contractors. For low-value plastics that will not be viably picked up due to market dynamics, the government can institute bulk purchasing from collectors at fixed rates.

- **Leveraging EPRs and placing the burden on producers:** Through a combination of extended producer responsibility (EPR) levers (which can only be feasibly activated with large manufacturers), as well as strict monitoring of informal and unorganized producers of plastics, governments should place the burden of sourcing plastic waste for recycling in rural areas on the producers. States should fix proportionate targets for recycling to be executed by brands and producers within areas of their administration. This is likely to be extremely important in the face of increasing rural penetration of formally produced goods.

- **Defining product categories:** There should be a clear definition of all the products that should come under the EPR frame of existing PWM rules. This will make it easy for large companies and bulk producers to chalk out their EPR strategies at the company level.

- **Formalise and support informal workers in plastic waste management**: India has a strong network of informal workers which manages plastic waste. They are also an important part of existing EPR models of large companies. The informal sector needs to be formalised in an iterative process. In this context, the creation of formal-informal partnerships can link informal collectors to formal recyclers via designated interface agencies. In some cases, such partnerships can be designed as highly innovative business models which create additional value added at the bottom of the pyramid.

- **Promote Polluter Pays Principle:** Once the targets are set, producers of plastics should contribute towards the management of plastic waste based on the set target.

- **Support replication of Producer Responsibility Organisations (PROs):** PROs have worked very well in European countries in the implementation of EPR. Experienced PROs should be recognised in India and promoted to replication. There should be specific EPR targets of PROs and output-based incentives such as preferential procurement policies. There should also be fiscal incentives on loans and other infrastructural costs, e.g. land.

## 5. Good practices of EPR in plastic waste management-Global and Indian

There are many good cases in India and the rest of the world which strengthens the importance of EPR in plastic waste management. Some of them are discussed below.

A. **European Strategy for Plastics in a Circular Economy**

The European Strategy for Plastics in a Circular Economy was adopted in January 2018. Being the first EU Strategy of its kind, it seeks to transform the way plastic products are designed, produced, used and recycled across the EU. To this end, it lays out a vision for Europe's new plastics economy in 2030 and defines specific actions to achieve it.

***The vision for a circular plastics economy***

A smart, innovative and sustainable plastics industry, where design and production fully respect the needs of reuse, repair, and recycling, brings growth and jobs to Europe and helps cut EU's greenhouse gas emissions and dependence on imported fossil fuels.

In Europe, citizens, government and industry support more sustainable and safer consumption and production patterns for plastics. This provides a fertile ground for social innovation and entrepreneurship, creating a wealth of opportunities for all Europeans.

*Key actions*

a. Improving the economics and quality of plastics recycling; e.g. by supporting design innovation to make plastics easier to recycle, boosting demand for recycled materials and improving Europe's separate collection and sorting system.

b. Curbing plastic waste and littering; e.g. by promoting a stronger focus on waste prevention (including marine litter) through EPR schemes, establishing a clear regulatory framework for plastics with biodegradable properties and supporting research and prevention of microplastics.

c. Driving innovation and investment towards circular solutions; e.g. by promoting the use of alternative feedstocks, including bio-based feedstocks and gaseous effluents and using EPR as an instrument for promoting change in upstream processes of the plastics value chain.

d. Harnessing global action; e.g. by continuing to support international action, promote best practices worldwide and use external funding instruments to increase waste prevention and management.

B. **UK Packaging Waste programme**

The UK Packaging Waste programme is primarily based on the concept of tradable recycling credits, which provides incentives to the manufacturers for collection and recycling of waste Producer Responsibility Obligations (Packaging Waste) Regulations in 1997 and the Packaging (Essential Requirements) Regulations in 1998, require producers to recover and recycle a specific percentage of their packaging waste each year. The goal of the programme is to meet the European Union Packaging Waste requirements. Like the European Union (EU) targets, UK targets are also revised every five years. Usually, UK targets are slightly higher than the EU targets. Companies earning more than £2 million per year are allowed to participate in credit trading. Under this system, sellers share the highest responsibility (48 per cent) followed by packers/ fillers (37 per cent), converters (9 per cent) and manufacturers (6 per cent). The obligated companies can meet their recycling themselves either by contracting with a re-processor or by joining a 'compliance scheme', which is like a PRO that fulfils all the obligations on their behalf for a fixed fee. The system also allows for trading of the Packaging Waste Recovery Note (PRN) at the environment exchange among the re-processors, obligated companies and compliance scheme. There is an active spot market for this. For every 1 tonne of waste recycled 1 PRN is issued. Separate PRNs are issued for different packaging material. In the case of packaging waste exported for recycling, compliance is demonstrated by issuing of a Packaging Export Recovery Note (PERN), which is the equivalent to a PRN. This can be issued by accredited exporters only. The overall recovery rate increased by 68 per cent and material-specific recycling rates increased by 45 per cent to 137 per cent from 1998 to 2004. The programme resulted in a shift towards more recyclable packaging material compared with one-time use materials.

C. **Saahas programme**

Saahas Waste Management Private Limited, an Indian Not for Profit Organisation based in Bangalore has established MoUs with large producers of plastics like Britannia and Hindustan Unilever Limited. They collect post-consumer waste through aggregation centres and supply the collected scrap to either mechanical recycling centres or cement kilns for energy recovery.

D. **AARC initiative**

Leading corporations have joined hands to form the Action Alliance for Recycling Beverage Cartons (AARC) – a first-of-its-kind initiative to further strengthen the end-to-end waste management ecosystem by engaging with all stakeholders across the value chain. The alliance aims to increase recycling of used cartons from approximately 30 per cent today to 60 per cent by 2025. To begin with, 10 industry leaders in the field of juices, dairy, pharma, liquor and packaging have come together to kick start the alliance and many more are expected to join along the way.

## 6. Conclusion

EPR is a proven policy instrument that has worked well in the EU Member States. Indian environmental regulations have stepped up in upgrading existing PWM rules for a strengthened EPR in India for plastic waste. However, there is a long way to go till India reaps the real benefits of EPR in the long-term. There are clear lessons to be learned from various interventions done for strengthening EPR over time in other countries. The PWM rules though mention EPR in more detail than its predecessors, there is a need to make it suitable for implementation. There are other EPR regulations in India such as EPR for E-waste management rules which can be used as a guidance to strengthen EPR for plastic waste in India. Existing state actions on managing plastic waste are focused on the ban on plastic without realising its impacts on the informal sector. There is an urgent need to strengthen the informal sector to successfully implement EPR at the pan-India scale. At present, EPR obligations are largely being met under Corporate Social Responsibility (CSR) in a scattered fashion. Companies are establishing contracts with agencies and NGOs to fund the collection and storage of plastic waste from mostly urban areas. These partners then supply this plastic waste to recyclers or cement kilns, typically. For the systematic and sustainable implementation of EPR, there is a need to clarify the role of brands and producers and establish their liabilities. There is also an urgent need for establishing a national framework for EPR for plastics. The national commitment to beat plastic pollution till 2022 justifies the need for a guiding framework which can address EPR targets for large producers of plastics, informal sector strengthening, innovative mechanisms to trade plastic recycling, incentives for PRO replication, polluter pays principles etc.

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# Analysis of the current E-waste management in India and way forward

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**Abstract**

The electronics industry is one of the fastest growing industries in the world. E-waste has become the most rapidly growing segment of the formal municipal waste stream in the world and its disposal has become an emerging global environmental and public health issue. The world generated 44.7 million metric tonne of e-waste in 2016 of which only 20 per cent was recycled. India generates about 2 million tonne of e-waste annually. Of which only 1 per cent is recycled and 95 per cent of it is recycled by the informal sector which lies outside the ambit of law and regulation. Many informal workers expose themselves and their families to the dangerous toxins that emanate due to reprocessing of e-waste as they tend to work from homes. The policy response to the e-waste problem is crucial owing to not only increase in domestic e-waste but also the transboundary movement of e-waste from the developed world to the developing world. India announced the Guidelines for Environmentally Sound Management of E-waste in 2008. In 2011 the Government of India formulated the E-waste Management and Handling Rules (2011) which was revised in 2016. The E-Waste (Management) Amendment Rules 2018 allocates collection targets for producers starting with 10 per cent of total waste generated in the year 2017-18, going up to 70 per cent by 2023. The e-waste policy must address the livelihood opportunities of the informal sector and not only look at e-waste from the environmental perspective thereby rendering it ineffective. Circular economy models need to be adopted, encouraging the closing of loop materials.

**Keywords**

*E-waste, Hazardous, Pollutants, Management, Recycling, Policy.*

## 1. Introduction

The electronics industry is one of the fastest growing industry in the world. Electronic waste (e-waste) or Waste Electrical and Electronic Equipment (WEEE) comprises waste electronics/ electrical goods that are not fit for their originally intended use or have reached their end of life. Several conventions (like the EU WEEE Directive 2002[5], Basel Convention[6], OECD 2001[7], etc.) have

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[5] "Electrical or electronic equipment which is waste including all components, subassemblies & consumables, which are part of the product at the time of discarding." Directive 75/442/EEC, Article 1(a) defines "waste" as "any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force." EU WEEE Directive (EU, 2002a)

[6] "E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air-conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users." – Basel Convention Action Network (Puckett & Smith, 2002)

[7] "Any appliance using an electric power supply that has reached its end of life." – OECD (2001)

defined e-waste (UNEP 2009). Over 60 per cent of e-waste contains metals including iron, gold, silver, copper; 30 per cent is plastic and about 2.7 per cent is hazardous pollutants Raghupathy et. al 2010. In the modern world, advances in computing and communication have led to a surge in the consumption of electrical and electronic equipment (EEE). Increased use of appliances and devices has also contributed to increased productivity and economic growth. Hence, adoption of EEE is encouraged. Drop in prices and advancement in technology has led to the continuous launch of new gadgets with upgraded versions luring customers to buy new tech-devices and discard their old electronics in spite of being in a good working condition (Begum 2013). E-waste, provide services enhancing the quality of life, has become the most rapidly growing segment of the formal municipal waste stream in the world and its disposal has become an emerging global environmental and public health issue. E-waste is a significant burden in terms of disposal and management for formal sector in the developed world because of which 75 to 80 per cent of it is shipped to developing countries where it is managed through informal unsafe recycling channels. The amount of e-waste is expected to increase from 44.7 million metric tonne or an equivalent of 6.1 kilograms per inhabitant (kg/inhabitant) in 2016 to 52.2 million metric tonne, or 6.8 kg/inhabitant, by 2021 (Baldé *et al.* 2017).

The increase in the use of EEE in India has two impacts. One is that it is significantly contributing to better living standards and the second is the problem of e-waste generation, management and safe disposal. India generates about 2 million tonne of e-waste annually, improper management and unsafe disposal of which can lead to significant impacts on the natural environment and human health. As per 2014 estimates, per capita e-waste generation in India is 1.3 Kg. Only 1 per cent of this amount of e-waste generated in India is recycled and 95 per cent of it is recycled by the informal sector which lies outside the ambit of law and regulation. Recent studies by the UN has reported that e-waste from old discarded computers in India will jump by 500 per cent from 2007 levels by 2020 and that from mobile phones will be about 18 times for the same timeframe (Young 2010). This highlights the importance of e-waste management in India which is primarily done by the informal sector today. The policy response to the e-waste problem is crucial owing to not only increase in domestic e-waste but also the transboundary movement of e-waste from the developed world to the developing world due to lower environment and waste processing standards and cheaper labour. India announced the Guidelines for Environmentally Sound Management of E-waste more than a decade back in 2008. In 2011 the Government of India formulated the E-waste Management and Handling Rules (2011). The rules announced in 2011 was revised in 2016.

The objective of the paper is to review and present the e-waste management scenario in India, challenges and opportunities in the e-waste sector, the evolution of policy and legislation on e-waste management in India. The paper looks at the existing informal sector and their role in e-waste management in India and some successful case studies. The paper concludes with measures that could potentially be taken up for better management of e-waste in India.

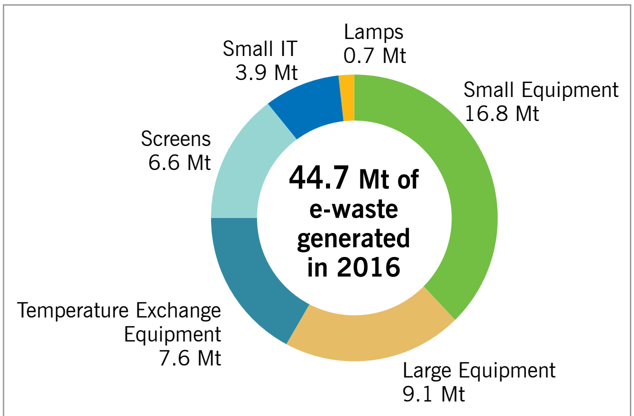
## 2. E-waste management challenges and opportunities

### 2.1 Data availability is both a challenge and an opportunity

As per the Global E-Waste Monitor 2017, the world generated 44.7 million metric tonne of e-waste in 2016 (See Figure. 1) of which only 20 per cent was recycled even though two-thirds of the world was covered by e-waste legislation. It reported that India generated 2 million tonne of e-waste in 2016, 82 per cent of which is personal devices. It has also been highlighted that there is a lack of country-level reliable e-waste data with exceptions of anecdotal information. Lack of reliable data on generation or import of e-waste in India is a challenge. Most of the studies conducted in the country are based on the model of obsolescence of electronic products which would need to be validated with field data.

In January 2017, the United Nations University (UNU), the International Telecommunication Union (ITU), and the International Solid Waste Association (ISWA) came together to launch the Global Partnership for E-Waste with the objective of helping countries to produce e-waste statistics and database which will help them track developments in this sector over time. Data availability will eventually help countries in minimising e-waste generation, assess their targets, inform policymakers and businesses, minimise e-waste related impacts both on health and environment, come up with policies and legislation that will promote recycling and economic growth by addressing employment and creating jobs. It will also help countries to contribute and report on Sustainable Development Goals (SDG) 11.6 and 12.5 by monitoring waste streams (Baldé *et al.* 2017).

**Figure. 1: Estimates of e-waste totals per category in 2016**




*Source: The Global E-Waste Monitor 2017*

## 2.2 Environmental and health challenges and opportunities

E-waste is composed of several components many of which are hazardous substances. Components of e-waste include metals including gold, silver, copper, platinum, iron, palladium; plastics and glass and over 50 toxic elements like Mercury, Arsenic, Lead, Chromium, etc. (Chaturvedi and Gaurav 2016). These hazardous and toxic substances are released into the environment due to improper handling, recycling and disposal processes practiced in countries like India. Toxic elements from the e-waste can lead to pollution of soil, air and water and long-term health issues. The informal sector is largely unaware of the environmental and health impacts of toxic components of e-waste. During the metal recovery process, the informal sector burns, dismantles, shreds e-waste releasing Polycyclic Aromatic Hydrocarbons (PAH) and brominated and chlorinated dioxins which pollute the air, soil and water. As only about 1 per cent of the e-waste generated in India is recycled, the remaining ends up in landfills which leads to producing contaminated leachates which pollutes the groundwater. Soil contamination occurs when acids and sludge obtained as a result of melting processes is disposed on the ground. Hence toxic heavy metals from e-waste enter the food chain through the 'soil-crop-food' pathway exposing humans to its harmful effects. The informal sector's recycling practices, lack of awareness and use of protective gears magnify the health risks (Gupta 2014). The toxic elements from the e-waste can cause long term health issues like neurological, endocrinal, respiratory disorders. Many of these elements are carcinogenic and can lead to cancer. De-soldering of one of the most valuable fractions of e-waste, Printed Circuit Boards (PCBs), by the informal sector to extract gold or other precious metals leads to potential inhalation of tin, lead, brominated dioxin, beryllium, cadmium and mercury by workers and residents in the vicinity.

However, there are some environmental opportunities in e-waste management as well. Improved e-waste management processes will lead to reducing emissions, ensuring reduced e-waste going to the landfill hence reduced soil and water pollution. Moreover, improved recovery, recycling and refurbishments will lead to reduced requirements of virgin metals and minerals and hence reduce the need for mining and associated economic and environmental damages.

**2.3 Social challenges and opportunities**

There is a lack of awareness regarding e-waste and its disposal in general in India. Even the private sector/IT companies provide little or no information on how the e-waste generated could be safely disposed of. Awareness campaigns by government agencies and NGOs have had limited success and outreach. One major social challenge is the integration of the informal sector which recycles more than 90 per cent of the e-waste recycled in India (Khattar *et al.* 2007). It has been reported that in India, about 4.5 lakh child labourers in the age group of 10-14 are observed to be engaged in various E-waste activities and that too without adequate protection and safeguards in various yards and recycling workshops. There is a need to bring out effective legislation to prevent entry of child labour into the E-waste market. Another challenge is the integration of the informal sector into the formal one. One of the studies has estimated that about 2.4 million people in India are employed in the informal e-waste sector earning about 3 USD per day (CSE 2015). Lack of alternative livelihood opportunities for those involved in the informal recycling of e-waste is also a huge challenge. Hence the legislation on e-waste management should also address the livelihoods of the informal sector in addition to the environmental focus.

When it comes to opportunities, it lies in raising awareness about e-waste and integration of the informal sector. Awareness can create pressure on businesses to take responsibility for the EEE produced and their safe disposal. The informal sector approaches on e-waste management though critiqued yet is mostly net positive in terms of impact whereas the formal sector operations have a net cost. However formal and safe disposal and recycling approaches have the potential to create a large number of jobs if significant investments are made.

**2.4 Economic challenges and opportunities**

The informal e-waste markets in developing countries seem to have some economic advantages over the formal markets due to their well-established networks, market intelligence and the fact that informal sector has cost advantages as it lies outside the ambit of laws and regulations thereby not subjected to taxation and environmental laws as compared to their formal counterparts. Despite the cost advantages that the informal sector is believed to have, which mostly is in the early stages of the value chain like collection, dismantling, and refurbishment, yet they also have significant economic disadvantages as the informality reduces their chances of accessing finance and hence their businesses do not expand beyond a certain size and limit. Also due to lower legislation compliance costs and ability to externalise environmental costs, the informal sector is capable of out competing for the formal recyclers in bidding for e-waste in India, which creates competition between the two, thereby leading to environmentally inferior outcomes due to the reduced financial feasibility of the formal sector.

It has been estimated that 44.7 million tonne of e-waste generated in 2016 was valued at 55 billion EUR. With 2 million tonne of e-waste being generated in India annually, and assuming a conservative value of INR 2000 per tonne, the sector can have a turnover of INR 4 billion. Recovery of precious metals and materials from EEE and the associated reduction in the mining of virgin material will result in cost saving and reduced environmental cost of production. It provides the opportunity of adopting circular economy models the encourages closing the loop of materials through better design, recycling, reuse, mitigating environmental pollution, etc. and offers employment and economic opportunities which might be valued at much more than the estimated

INR 4 billion. Also, refurbishment of reusable parts makes the appliances cheaper and more affordable for low-income consumers in developing countries (Lines *et al.* 2016)

## 3. E-waste policy evolution in India

National level e-waste policies and regulations set standards and controls for governing the actions of various stakeholders involved in the production, management and disposal of e-waste in the country. They are also important as they set up sustainable and properly functional economic models that cover collection sites, other logistics and physical recycling. Existing of legislation does not imply successful enforcement. These policies and legislation should lead to awareness creation and compliance of stakeholders with obligations. Environmentally sound management of e-waste is a significant challenge in India as India does not only have to manage its ever-increasing domestic waste but also deal with the large amounts imported from the US and Europe.

Indian e-waste policy landscape has evolved over the last one and a half decade (Refer to Table 1). Policymakers in India became aware of e-waste as an environmental issue in 2002. At that point in time, there were no e-waste laws in the country. The Environmental Protection Act of 1986 mandated CPCB to implement rules for managing municipal solid waste, bio-medical waste, plastic waste and hazardous waste. The Municipal Solid Wastes (Management and Handling) Rules 2000 had provisions for managing electronic waste by household collection and proper disposal. However, the Municipal Wastes (Management and Disposal) Rules, 1989, was amended in 2002 as The Hazardous Wastes (Management and Disposal) Rules, 2003, which incorporated e-waste into its fold (Chaturvedi *et al.* 2007a), while the Batteries (Management and Handling) Rules, 2001, took care of used batteries. In 2008 the old HWM Rules, 2003 was replaced with the Hazardous Wastes (Management, Handling, Transboundary Movement) Rules 2008 which incorporated issues of transboundary movement of e-waste in order to align the national framework with the Basel Convention. The HWM Rules require companies and individuals to first obtain permission from the relevant State Pollution Control Boards (SPCBs) to receive, treat, transport and store hazardous waste. It also stipulated the banning of imported hazardous waste for disposal and dumping. The SPCB was criticised for granting the same authorization to the collectors, dismantlers, recyclers without assessing their capability to treat e-waste in an environmentally sound manner (Skinner *et al.* 2010). A new framework for dealing with the end-of-life electronic gadgets called the Guidelines of Environmentally Sound Management of E-waste, 2008 was established. It classified the E-waste according to its various components and compositions and mainly emphasised on the management and treatment practices of E-waste. The guideline incorporated concepts such as 'Extended Producer Responsibility (EPR)'. This was then developed into the Draft E-waste (Management and Handling) Rules 2010 which included all the stakeholder's involved in e-waste handling with a focus on producers, dealers, refurbishers, collection centres, consumers, dismantlers and recyclers. It was also based on the EPR and IPR principles as well as the Reduction of Hazardous Substances (RoHS) provisions.

As a result of advocacy efforts of the civil societies and international organisations, the Government of India announced the E-waste (Management and Handling) Rules in 2011 which came into effect from 1 May 2012. With further amendments, the current E-Waste (Management) Rules, 2016, is in operation. A study by Toxics Link in 2014 puts the onus on both the producers as well as the SPCBs and found that of the 50 major EEE brands, 34 per cent have taken no action in response to the E-waste Rules of 2011, 30 per cent had taken a few steps only to comply with the e-waste rules while most have not set up any physical take-back system.

Table 1: Evolution of E-waste legislation in India

| Year | Policy landscape |
|---|---|
| 2002 | E- waste was identified as an environmental issue |
| 2003 | Amendments to the Hazardous Waste (Management and Handling) Rules, 2003, incorporated e-waste into its fold |
| 2005 | The E-waste (Handling and Disposal) Bill, 2005, was introduced in the Rajya Sabha. The Bill lapsed in 2010. |
| 2008 | New Amendments in the Hazardous Wastes (Management, Handling & Transboundary movements) Rules 2008, aligned the rule with Basel Convention |
| 2008 | Guidelines for e-waste management established<br>Two formal recyclers in India |
| 2010 | Draft E-waste (Management and Handling) Rules, 2010 |
| 2012 | E-waste (Management and Handling) Rules come into effect<br>Nearly 100 dismantlers and recyclers in India |
| 2016 | E-waste law revised - E-waste Management Rule 2016<br>More than 140 dismantlers and recyclers in India |
| 2018 | E-Waste (Management) Amendment Rules, 2018. |

Further, State Pollution Control Boards (SPCBs) and Committees, responsible for inventorisation of e-waste, grant and renewal of authorisation, recycler registration, monitoring compliance and action against violations of these rules, were also found inadequately equipped (Chaturvedi 2015).

The Government of India introduced the E-waste Management Rules 2016 which came into force from 1 October 2016. These rules shall apply to every manufacturer, producer, consumer, bulk consumer, collection centres, dealers, e-retailers, refurbishers, dismantlers and recyclers involved in manufacture, sale, transfer, purchase, collection, storage and processing of e-waste or electrical and electronic equipment including their components, consumables, parts and spares which make the product operational. It has also fixed the responsibilities of all stakeholders involved. The main feature of this rule is EPR. The amended rule has provisions for Producer Responsibility Organisations (PROs) and Deposit Refund Scheme under EPR.

The E-Waste (Management) Amendment Rules 2018 allocates collection targets for producers starting with 10 per cent of total waste generated in the year 2017-18, going up to 70 per cent by 2023. Although the rules have been in place for six years, enforcement is tricky. As of now, the rules do not provide details of the business model for the collection of e-waste from consumers and the consumers have no financial incentive for returning their e-waste through formal channels. These rules also need to address the issue of importing e-waste into India. Capital investments into the recycling infrastructure is abysmally low. Institutional capacity development is needed to accelerate implementation.

## 4. Informal sector scenario in India

The informal sector in India manages more than 90 per cent of the e-waste generated in India (UNU 2017; Ganguly 2016 and GTZ-MAIT 2007). The formal e-waste recycling sector in India is being developed in major cities. More than 2 million people, with low literacy levels and little awareness of the dangers of the operations, in India, are informally involved in recycling operations (Borthakur and Singh 2012). The unorganised sector consists of small and informal businesses not governed by any legislation or regulation. The informal workers face dangerous working conditions as they may be without protection like gloves or masks. It has been reported that the efficiency of metal recovery is around 28 per cent to 30 per cent which is way lower than those reported by smelting companies in developed countries (Chaturvedi *et al.* 2007b). The e-waste trade chain in India comprises of aggregators who purchase scrap from households and businesses, followed by segregators who dismantle the components manually and sell off to recyclers who process the waste further for extraction of precious metals (Ganguly 2016).

Many informal workers expose themselves and their families to the dangerous toxins that emanate due to reprocessing of e-waste as they tend to work from homes. For example, to extract metals from circuit boards, gas torches are used to heat a board just enough to melt the solder, which separates the metal parts from the boards (Rajya Sabha Secretariat 2011). Metals are also extracted by soaking the circuit boards in the open acid bath followed by manual scrapping to extract copper and precious materials next to open drains. In this sector, the dismantlers extract metals on their own or work with a big trader, earning about INR 100 per day. Two motherboards usually weighing one-kilogram cost INR 230. A profit of 10 per cent is made after selling the metals (Rajya Sabha Secretariat 2011).

## 5. Case Studies of successful e-waste management practices in India

### 5.1 HRA E-waste Private Limited, 2010, Delhi

HRA E-waste is a unique operational model, unprecedented in India which provides a crucial link between the informal sector and the formal recycling markets. The organisation works on a cooperative model engaging 250 waste collectors and collect, segregate and store waste from these collectors and then auction it to formal recyclers every month. The earnings from these sales go back to the informal sector after deducting a fee for the company. HRA E-Waste was the first company in Delhi to receive permission under the 2012 rules to collect and dismantle e-waste on site. HRA E-waste not only works to integrate the formal and informal sectors but is also involved in shaping policies that aim to achieve the same goal. In this case, the authorisation took two years and the owner, Mr. Shashi Pandit, had to pay rent for one full year without being able to do business legally. This he said is a deterrent for informal operators to become formal. Other deterrents are lack of regulatory enforcement. The process of formalising is often long and uncertain. Moreover, most of the informal waste workers do not have access to capital, technical knowledge or connections with NGOs to help them through this arduous procedure. Therefore, they chose to remain within the informal economy despite its many pitfalls.

### 5.2 Indo-German Swiss E-Waste Initiative, 2004, Bengaluru

The Indo-German Swiss E-Waste Initiative, a partnership between the German Society for Technical Cooperation (GTZ – now GIZ), the Swiss Federal Laboratories for Material Science and Technology (EMPA) and the Indian Ministry of Environment and Forests (now MoEFCC), was launched in 2004 as a solution to the growing problem of electronic waste in Bengaluru a city which was fast becoming the IT hub of the country and was unable to keep up with the pace of disposal of electronics. In the absence of a formal system to handle this waste, an informal economy began to grow around the city. Informal waste workers collected electronic waste from companies and then dismantled or melted them to extract precious metals and other recyclable components. It introduced the concept of a 'clean e-waste channel' (CEWC) to Bengaluru. As per the guidelines, companies were asked to separate e-waste from other waste right at the outset and then work with authorised e-waste handlers. This meant that the informal waste workers who were not registered with the CEWC were excluded from the system. It was essential that the clean channel operated under strict regulation in the formal sector. Collectors and dismantlers operating in the CEWC were required to formally register as legal entities and be licensed by the state pollution control board. The initiative was deemed successful by development experts in establishing a clean e-waste channel in Bengaluru.

Pilots to replicate it began in 2010 in Delhi, Kolkata and Pune under the WEEE Recycle initiative, after incorporating the learnings from the problems faced in Bengaluru (Manasi 2016).

### 5.3 Chintan Environmental Research and Action Group, New Delhi

Chintan Environmental Research and Action Group, founded in 1999, has been working with waste-pickers, trying to integrate them into the formal economy. Their approach is two-pronged: one, they train waste pickers on how to collect, sort and dismantle electronic waste in a sustainable manner as per E-waste Management Rules 2016; Two, they advocate for policy implementation and more representation of informal workers in the formal economy. Chintan is one of the first organisations to be authorised by the Delhi Pollution Control Committee (DPCC) as an 'e-waste collector' in Delhi. They now have dedicated collection centres in residential colonies, schools and organisations. To make the programme more effective Chintan partnered with Safai Sena, which is an association of waste pickers and waste recyclers. The formal processing of electronic waste that Chintan follows involves dismantling the equipment into various parts (metal frames, power supplies, circuit boards, plastics), often by hand, but increasingly by automated shredding equipment. It is then shredded to separate constituent metal and plastic fractions, which are sold to plastics recyclers. Some of the emissions are caught by scrubbers and screens. Magnets, eddy currents[8] are employed to separate glass, plastic, and non-ferrous metals, which can then be further separated at a smelter. Hazardous smoke and gases are captured, contained and treated to mitigate the environmental threat.

Working with the informal community, Chintan has welcomed the new rules and has high expectations that they will be enforced especially with regard to the extended producer responsibility, which means that producers will be responsible for the disposal of their products once they are unusable.

## 6. Conclusion

India traditionally supports the idea of reusing, repairing, and refurbishing and discourages wasteful consumption. This culture needs to be encouraged to address the growing menace of E-waste and the success of the implementation of the e-waste policy will depend on the economic incentive to clean it up. Recycling of e-waste is a billion-dollar opportunity for India. The e-waste policy must address the livelihood opportunities of the informal sector and not only look at e-waste from the environmental perspective thereby rendering it ineffective. Circular economy models, which to keep the value in products for as long as possible and eliminate waste, need to be adopted, encouraging closing of loop materials which includes better design of components, recycling, reusing among others while mitigating harmful effects of environmental pollution. India needs robust investment in institutions, infrastructure, capacity development for better management of e-waste and enforcement of the legislation on e-waste in the country.

Monitoring mechanisms for e-waste management need to be strengthened in India. The capacities of SPCBs and Central Pollution Control Board in terms of expertise and manpower need to be enhanced for effective monitoring and managing of e-waste in the country. The informal sector in the country is widely networked and experienced and it needs to be mainstreamed into waste management. Experiences from the projects by NGOs and bilateral organisations should be utilised to identify ways of mainstreaming the informal sector. There is a need for across the board collaboration of

[8] Eddy currents are a manifestation of electromagnetic induction occurring when a magnetic field is applied to a conductor. (For more information: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/eddy-current-separation )

various actors for large scale transformation in existing consumption and production patterns. As the policy evolves, there need to be significant investments for capacity development of various stakeholders. The focus in India should be on creating a knowledge base, development of appropriate infrastructure, raising awareness and building capacities on e-waste management and inter-ministerial collaboration for developing more effective policies and programmes on e-waste. Proper management and handling of e-waste will also help India in meeting its SDGs like SDGs 3, 6, 11, 14.

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# Converting indigenous waste carbon sources to useful products

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## Abstract

India is importing close to 200 MMT each of petroleum and coal as well as 15 MMT of natural gas every year to fulfill its energy requirements, which amounts to a net import of approximately 330 MMT of carbon every year. On one hand India is importing carbon while on the other hand India has a wide abundance of untapped domestic carbon in the form of agricultural and forest residue, municipal solid waste, biogas and used cooking oil, which has the potential to supply more than 500 MMT of carbon every year. To utilize these sources, CSIR-Indian Institute of Petroleum has endeavored to convert this carbon into a usable form and has developed processes that can convert these into fuel like gasoline, diesel, LPG/CNG, biojet and biodiesel. Adoption of these technologies coupled with a firmed supply chain of feedstock has the potential to completely eliminate the requirement to import petroleum, coal or natural gas.



## Keywords

*Petroleum, Natural Gas, Biomass, MSW, Used Cooking Oil, Energy Security, Domestic Carbon.*


## Introduction

The primary energy needs of much of the world are being fulfilled predominantly by fossil fuels, which are all carbon-based materials. It has been estimated that worldwide in 2015, 87 per cent of the global primary energy requirement was met by coal, petroleum and natural gas with hydroelectricity, nuclear and renewables accounting for the balance. (Statistical Review of World Energy 2016). According to the same source, about 93 per cent of India's energy requirements are being fulfilled by fossil fuel and for this every year India is importing more than 200 MMT of petroleum and 15 MMT of natural gas (Indian Petroleum and Natural Gas Statistics 2018) as well as approximately 200 MMT of coal (Ministry of Coal 2018). This amounts to a net import of approximately 330 MMT of carbon every year (Table 1).

A key policy direction of the Government of India is to reduce the import of fossil fuels to enhance energy security and reduce precious foreign exchange outflow. This can be achieved in four ways – reducing demand-side requirements either through non-carbon energy sources like solar and wind, or through improved energy efficiency, or augmenting the supply side by strengthening domestic fossil fuel production, and by maximizing use of indigenous carbon sources, which have hitherto largely remained untapped except for informal use of biomass in domestic heating and cooking.

Carbon sources are available in plenty within our country in different forms like agricultural residue, forest residue, biogas, used cooking oil

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and municipal solid waste. These can potentially provide more than 500 MMT of carbon every year (Table 2) (Kumar *et al.* 2015; Rupnar *et al.* 2018; Gupta *et al.* 2015) which is significantly greater than the amount of carbon we are importing. However, these sources can only be tapped if this carbon is converted to usable form like liquid fuel (gasoline, diesel, ATF, CNG/PNG etc.) meeting standard specifications. CSIR-Indian Institute of Petroleum, Dehradun has been continuously striving to develop technologies for facilitating utilization of such domestic carbon sources and has been successful in demonstrating processes for converting waste plastics and used cooking oil to gasoline, diesel and bio-jet fuel meeting standard specifications, which could then be used as drop-in fuels in unmodified engines.

## Plastics to fuels

In India, the consumption of plastics is increasing by leaps and bounds, and it is expected that the consumption could increase to 20 MMTPA by 2020 from the present 16.5 MMTPA. (Report plastic infrastructure 2017). A significant amount of plastic wastes are generated every day and generally, end up as part of Municipal Solid Waste (MSW). In India, about 80 per cent of total plastic consumption is discarded as waste and at least 40 per cent of this waste remains uncollected. The Central Pollution Control Board (CPCB) has estimated that approximately 25,900 tons of waste plastics were generated every day in 2015-16. Considering these facts, as well as the adverse environmental impact of waste plastics, CSIR-Indian Institute of Petroleum (CSIR-IIP), in collaboration with GAIL (India) Ltd, commenced efforts to develop a process for converting waste plastics from different sources into value-added products. This has led to a novel process by which polyolefinic wastes like polyethylene and polypropylene, which account for about 70 per cent of the total waste plastics, can be converted exclusively into any one of the products, *viz.* Gasoline or diesel or aromatics, along with simultaneous production of by-product propane and butane which are the main constituents of liquefied petroleum gas (LPG). The GAIL-IIP process comprises of a pyrolysis unit operation followed by a catalytic conversion and subsequent condensation and fractionation to get the desired liquid hydrocarbons.1 Kg of clean polyolefin waste can produce up to either 550-600 ml gasoline or 750-800 ml diesel or 450-500 ml aromatics. The gasoline and diesel conform to the BS IV/VI norms. These have also been tested on vehicles and the emissions are at par with the refinery produced gasoline and diesel. Presently, a 1 metric ton per day pilot plant is being set up at Dehradun for converting waste plastics to diesel, which is likely to be commissioned in February 2019. Post the pilot studies on this plant to optimize operating conditions, the technology would be available for commercial application.

## Used cooking oil to biofuels

Just as for plastics, a very significant amount of used cooking oil (UCO) is being generated in India, which consumes over 25 MMT edible oils annually (fssai.gov.in/ruco/background-note). The collectable UCO, which otherwise either goes down the drain or is re-used informally even when unfit for human consumption, causing a grave public health risk, is potential of the order of 5 MMT. CSIR-Indian Institute of Petroleum has also developed a novel single-step catalytic process for conversion of plant and animal derived non-edible / waste, low-cost oils to produce drop-in biofuel specifically for air-transport purposes. Oils (soya, jatropha, karanj, algal, palm, animal fats, microbial oils or waste cooking oil) are deoxygenated, selectively cracked and isomerized over a single catalyst to produce aviation fuel meeting desired ASTM specifications required for aviation fuel (ASTM D1655 and ASTM D7566). The fuel has been tested and certified by leading oil companies (IOCL and HPCL) to meet Jet A1 specifications, and it has also been tested and found comparable to or better than conventional Jet fuel by aircraft engine manufacturer Pratt & Whitney of Canada. In addition to bio-jet fuel, a renewable drop-in high cetane diesel is also produced as a by-

**Table 1: Indian carbon imports (Approximate values)**

| Commodity | Import, MMT/yr | per cent, C | Imported C, MMT/yr |
|---|---|---|---|
| Crude Oil | 200 | 85 | 170 |
| Coal | 200 | 75 | 150 |
| Natural Gas | 15 | 77 | 11.6 |
| **Total** | | | **331.6** |

**Table 2: Domestic carbon sources (Estimated values)**

| Commodity | Scope, MMT/yr | per cent, C | Potential C, MMT /yr |
|---|---|---|---|
| Agri-residue (surplus) | 200 | 40 | 80 |
| Forest residue | 150 | 42 | 63 |
| Bio-gas, excl landfill | 800 | 45 | 360 |
| MSW | 50 | 25 | 12 |
| UCO | 5 | 85 | 4 |
| **Total** | | | **519** |

product in the process which can be added directly in the diesel vehicles without any modifications as a cetane improver.

Presently CSIR-IIP is producing 10-15 litres/day of Bio-jet fuel in a pilot plant and has already processed 2500-3000 litres of feedstock to produce Bio-jet fuel. Recently, on 27 August 2018, SpiceJet successfully operated the 1st Biofuel flight in India (between Dehradun and Delhi) on a Bombardier Q400 aircraft equipped with Pratt and Whitney engines, using 500 litres of Bio-jet fuel produced at CSIR-IIP. Spicejet aims to operate regular commercial flights on Bio-jet fuel blended with commercial ATF when an adequate supply chain of Bio-jet fuel becomes available. The Indian Air Force also plans to blend 10 per cent of Biojet fuel with conventional jet fuel for flying its fleet.

Used cooking oil (UCO) and cold-expelled seed oils, such as *shorea robusta* (sal), *madhuca longifolia* (mahua) and *pongamia pinnata* (karanj), which are found extensively in India's villages can also be converted to conventional biodiesel (fatty acid methyl ester) at the village, community or commercial establishment level using CSIR-IIP room temperature biodiesel technology. In this, the UCO or seed oil is simply treated with methanol, a catalyst and a proprietary solvent and allowed to stand for half an hour or more under ambient conditions, after that the biodiesel is formed and can be easily separated. This enables the use of local non-edible oil resources for fully or partially replacing diesel with biodiesel in generator sets, agricultural pumps, tractors, mobile telecom towers etc.

## Discussions

CSIR-Indian Institute of Petroleum has pioneered the utilization of waste domestic carbon for utilization as fuel by developing technologies that utilize the domestic carbon present in the form of waste plastics and used cooking oil for production of diesel and jet fuel. Presently these are obtained from refineries, which are processing mainly imported crude oil. Hence the adoption of these technologies along with streamlining the sourcing of feedstock would go a long way in reducing import of petroleum and producing wealth from the waste domestic carbon sources.

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# Policy framework for fostering Resource Efficiency in India

Ajay Mathur[1] and Souvik Bhattacharjya[2]

**Abstract**

India has emerged as the second largest consumer of materials. With the increasing economic growth, rapid urbanization and rising human aspiration the per capita consumption will tend to rise, thereby accelerating the future demand for resources. Augmenting resources would be a challenge in the future as the increasing imports of critical materials are exposed to volatile international prices, depreciating Indian currency and limited diversification of sources of imports. Further, there are environmental and social implications of augmenting virgin resources within India. Improving use of resource, through adoption of a Resource Efficiency strategy, will be key to ensuring India's sustained high growth and enhanced wellbeing. Resource Efficiency encompasses a wide variety of technology, process, policy and institutional interventions along the product and service life cycle stages that typically include mining, design, manufacturing, consumption, and end–of–life. An absence of life-cycle thinking at the policy level often impedes exploring inter-linkages that can make India utilise resources more efficiently and unlock the associated benefits. An integrated policy on Resource Efficiency will help in establishing the right public thinking thereby reflecting the government's even more commitment to facilitate the transition. Creating platforms for multi-stakeholder collaboration will result in the exchange of ideas and putting them into practice eventually generating new business models, resource efficient products, and demonstrating success. Simultaneously standards for new products will be very crucial that will enhance consumer acceptability and demand. Increased demand and consumer acceptance will provide economies of scale thereby reducing prices and facilitate the desired transition. Further, setting up of mandatory targets for recycled content and having an effective monitoring network will help to achieve the desired level of performance within set timelines.

**Keywords**

*Resource Efficiency, Circular Economy, Economic Growth, Life Cycle Thinking, Economic Instruments, 6 R Principles.*

## 1. Changing socioeconomic landscape

Economic growth and development in India over the last two decades have brought about a decline in poverty rates, increased urbanization, and has driven demand for goods and services. In a recent assessment by United Nations Development Programme (UNDP), between 2005 and 2015, the incidence of multidimensional poverty[3] has come

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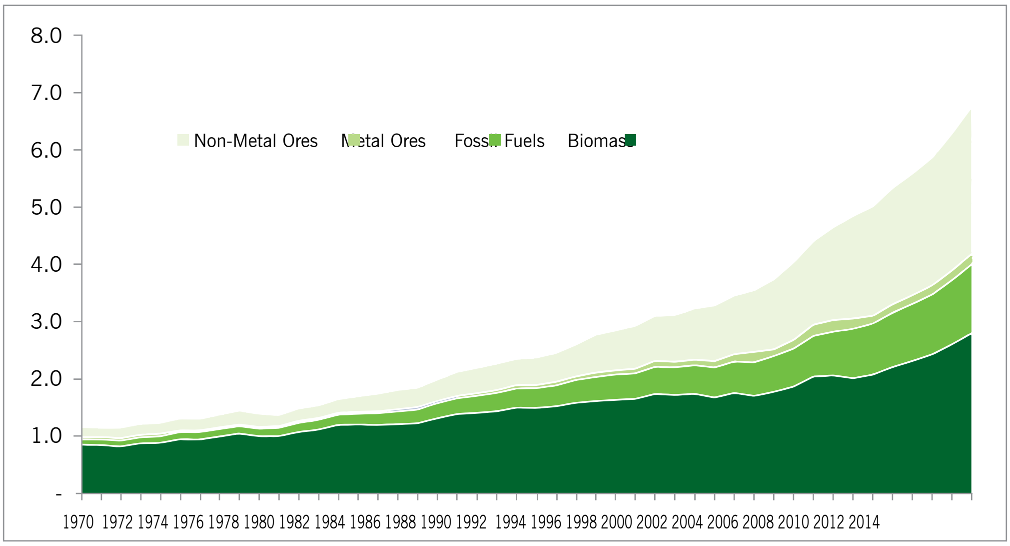
[3] Oxford Policy & Human Development Initiative defines multidimensional poverty as poverty made up of several factors that constitute poor people's experience of deprivation – such as poor health, lack of education, inadequate living standard, lack of income (as one of several factors considered), disempowerment, poor quality of work and threat from violence.

**Figure 1: India's trend in Material Consumption (billion tonne)**




*Source: http://www.materialflows.net/visualisation-centre/*

down to 27.5 per cent from 54.7 per cent. During the same period per capita GDP grew from INR 38,750 to INR 88,746. Between 2005 and 2012, the middle-income class population increased from 300 million to 600 million and is expected to increase by more than 1.5 times by 2025[2]. There has been a rapid increase in penetration of several consumer durables over the past decade. The penetration of refrigerators in the country has roughly doubled over the past decade to reach 30 per cent in 2015-16 (Ministry of Health and Family Welfare, 2016). Further, the share of households owning a television has increased 20 percentage points over the past decade to reach 66 per cent, while 20 per cent own an air conditioner or cooler (IBID). Urbanization is expected to rise to 50 per cent from its current level of 34 per cent by 2030 (Ministry of Housing and Urban Affairs 2018). India is likely to be the largest populated country in the world in a decade, with the share of youth expected to reach as high as 35 per cent by 2020 from 20 per cent estimated in 2011 (Ministry of Statistics and Programme Implementation 2017). Construction, infrastructure and transport are sectors that are expected to experience phenomenal growth. For example, demand for personal mobility is expected to triple by 2030 which eventually can make India the third largest market in the world by 2030 after China and US (Ministry of Statistics and Programme Implementation 2017). India's construction sector is projected to grow at a rate of 7-8 per cent over the next ten years and likely to become the world's third largest by the middle of the next decade. It is estimated that almost 70 per cent of buildings supposed to exist by 2030 are yet to be built.[4]

Meeting the demand for products and services require sustainable supply of various natural resources. The recent upsurge in consumerism has driven demand for various natural resources, thus exerting pressures on the environment and raising sustainability concerns. India is estimated to consume nearly 7 per cent of globally extracted raw materials per annum supporting around 18 per cent of the world population. India's resource extraction of 1580 tonne/acre is much higher than the world average of 450 tonne/acre (GIZ-TERI-DA-IFEU (2015). Material consumption in India has increased by more six times from 1.18 billion tonne in 1970 to more than 7 billion tonne in 2017. The trend in material

[4] https://economictimes.indiatimes.com/realty-trends/nearly-70-of-building-stock-that-will-be-there-in-2030-is-yet-to-be-built-in-india/articleshow/14732400.cms

consumption is presented in Figure 1.

The compound annual growth rate (CAGR) in domestic material consumption has increased at a modest rate of 3 per cent between 1970 and 2000. However since the beginning of this millennium the estimated CAGR has nearly doubled making India the second largest consumer of materials (at 7.42 billion tonne) after China (35.19 billion tonne). This is presented in Table 1.

Despite high aggregate consumption levels, per capita consumption in India remains lower than the world average although it has increased from 2.1 tonne per capita in 1970 to 5.67 tonne per capita in 2017 – less than half the world average (of 12.44 tonne) and can increase with income and aspiration. India's material productivity is low than the global average. India's resource productivity during 1970 and 2015 may have improved however it was less than the rates achieved by Japan (301 per cent) and China (311 per cent). Less productive utilization of resources has consequences in increased demand for virgin resources, high environmental burden, increased costs of production, etc. India's average material cost in total production cost is estimated at more than 70 per cent vis-à-vis 40 to 50 per cent in developed economies (NITI 2017). The rate of recycling in India is also low (20-25 per cent) when compared to the other developing and developed countries where the rate of recycling is over 70 per cent. Further the current process of augmenting secondary materials in production chains is highly inefficient largely because they are handled in the informal sector. Limited technology knowhow, access to finance and technology has factors that impede improved productivity in the informal sector.

With an estimated growth assumption of 8 per cent until 2030, the material consumption can increase to nearly 15 billion tonne. This will consist of 2.7 billion tonne of biomass, 6.5 billion tonne of minerals, 4.2 billion tonne of fossil fuels, and 0.8 billion tonne of metals in 2030; while the estimated per capita consumption would reach around 9.6 tonne which is current approximate global average.

Meeting the growing demand for materials is a daunting challenge. These challenges include growing costs, shrinking geological availability and risk of material exhaustion/uncertainty with regard to long-term abundance and finally social license to operate that arise from equity and distributional challenges and the associated uneven and unfair access to natural resources. India is already a net importer of resources, dominated by fossil fuel imports and critical materials. Import dependence increases the vulnerability of the economy to global geopolitical and economic risks apart from adversely affecting the trade balance.

## 2. Resource Efficiency as a strategy for promoting sustainable consumption and production

Enhancing Resource Efficiency and promoting the use of secondary raw materials (SRM) has emerged as a strategy for ensuring that the potential trade-off between growth and environmental well-being can be minimized. This strategy has the potential to stabilize raw material supply for industry, reduce

**Table 1: Material consumption and productivity in selected countries**

| | China | Germany | India | Japan | United States of America | World |
|---|---|---|---|---|---|---|
| Total Material Consumption (Bn Tonne) | 35.19 | 1.21 | 7.42 | 1.14 | 6.58 | 91.88 |
| Per capita Consumption (Tonne/Capita) | 25.19 | 14.75 | 5.67 | 8.92 | 20.58 | 12.44 |
| Material Productivity (% improvement from 1970) | 311 | 287 | 256 | 301 | 276 | 115 |

*Source: http://www.materialflows.net/visualisation-centre/*

pressures on the ecosystem and create many green jobs. Moreover, efficient use of resources has substantial economic benefits created through reduced costs linked to less extraction of virgin raw material and the reduced use of energy and process materials. European Commission (2011) defines Resource Efficiency as using the *'Earth's limited resources in a sustainable manner while minimising impacts on the environment'*. UNEP (2009) defines Resource Efficiency *'as reducing the total environmental impact of the production and consumption of goods and services, from raw material extraction to final use and disposal'*. From these definitions, it is evident that environmental protection is a key element and objective of adopting Resource Efficiency and signifies the relevance of life cycle thinking in addressing the Resource Efficiency agenda.

Interestingly the aspect of Resource Efficiency can be assessed either using an output-to-input relationship or input-to-output relationship. Resource Efficiency can be increased either by minimizing input or maximizing output by keeping the other variables constant. It is the former i.e. output to input relationship that is used as a broad way of presenting Resource Efficiency. If the same benefit (numerator) is generated by a decreased input of natural resources (denominator), resource efficiency is achieved. Hence it is more of a relative concept than an absolute statement. The United Nations Development Agenda of 2030 too recognizes the importance of efficient use of natural resources through SDG-12, i.e. promotion of sustainable consumption and production (SCP). Among various targets, SCP mentions that by 2030, countries should substantially reduce waste generation through prevention, reduction, reuse, and recycling. Essentially SCP, among other things, seeks to adopt the 6R principles along the various stages of the product life cycle right from mineral extraction to end of life stage. Other goals under SDGs like Goal 2, Goal 6, Goal 7, Goal 9, Goal 11 too have strong Resource Efficiency linkages.

## 3. Policy as an enabler to facilitate RE transition

Countries are increasingly introducing legislative frameworks to guide their economies towards resource efficient trajectories. Initiatives in China, Japan and South Korea in the Asia Pacific region are worth mentioning. China, for example, has enacted the Circular Economy Promotion Law (2009) and Circular Economy Development Strategy and Immediate Plan of Action (2013) enabling its transition to resource efficient development. In 2013 China also introduced the circular economy Development Strategy and Immediate Plan of Action and identified sector-specific development targets. Japan established the Fundamental Law for Establishing a Sound Material-Cycle Society (2000) to overcome the challenges with growing waste generations and resources scarcity. South Korea has adopted various policy instruments to transform a linear economy into a circular one. Related policy actions are the Resource Efficiency Programme (REP), Energy Recovery Programme (ERP) and Recycling Technology Programme (RTP). Europe, Austria, Denmark, Finland, Germany and Netherland, have dedicated national strategies for material Resource Efficiency. France announced circular economy Roadmap in 2018 which is to be put before Parliament in 2019. Belgium and the United Kingdom have regional Resource Efficiency strategies. Most countries incorporated material use and Resource Efficiency in a wide variety of their strategies and policies, including in waste and energy, industrial development and reform programmes, or national environmental strategies.

The aspect of waste minimization and enhancing resource productivity has gained salience in India, as reflected through certain policies and programs across various life cycle stages of typical product/ services. This is reflected through various policies like Sustainable Development Framework for Mining Sector in India, 2011, Minerals and Mining Development Regulatory Act (MMDR), 2016, Bureau of Indian Standards Act, 2016, National Manufacturing Competitiveness Program, 2014, Financial Support to MSMEs in ZED Certification Scheme, 2017, Solid Waste Management Rules, 2016, Construction and Demolition Waste Management Rules, 2016, E-Waste Management Rules (2016) and Amendment 2018. Yet an overarching strategy is the need of the hour.

An absence of life-cycle thinking of various products and services at the policy level often impedes exploring inter-linkages that can make India utilise resources more efficiently and unlock the associated benefits. For achieving economy-wide benefits of Resource Efficiency and Secondary Resource Management, it is crucial that policies across life cycle stages consider the waste hierarchy principles. Although existing policies of India have many aspects of the promotion of SRM, yet there also exist opportunities and options to include additional RE & SRM measures in various sectors.

## 4. Essential elements of an integrated policy framework

To deepen and make full use of the Resource Efficiency potential, a life cycle thinking is highly warranted, while, ensuring that 6R principles[5] are adopted at every stage of a product life cycle. Further, the prioritization of sectors/materials for bringing about resource efficiency improvements is equally essential in bringing the desired transition in the economy. Prioritization can be based on sectoral contribution to income, relative dependence on critical raw materials, environmental impact due to extraction and production of resources, supply risks of materials, recycling opportunities as offered by existing policies, processes and technologies, etc.

It is often said that 'What cannot be measured cannot be managed'. This calls for having indicators for measuring Resource Efficiency in the economy. While there can be a lead indicator, however, parallel indicators can also be developed for monitoring and tracking progress. For example, Roadmap to a Resource Efficient Europe (2011) refers to introducing lead indicator ('Resource Productivity') as well as series of complementary indicators on key natural resources such as water, land, materials and carbon that will take account of the exploitation/use of these resources. A target-based approach is warranted which will require introducing productivity benchmarks for the selected sectors/materials at various stages of the life cycle based on a realistic timeline acceptable to stakeholders. Over time their coverage needs to be expanded across sectors and product life cycles. New business models on Resource Efficiency will offer attractive opportunities for businesses and financial institutions, thereby creating avenues of employment growth and greater growth diversity. However, facilitating such processes through enabling regulatory framework and innovative policy instruments will attract interest from different industries and geographies.

Policies (and more particularly economic instruments) can strengthen facilitation of the Resource Efficiency transition and reduce transition cost. For example, Sweden, introduced a tax on natural gravel with an objective to promote the use of crushed rock and recycled materials, such as concrete, and thereby address the shortage / limited supply of supply of natural gravel in parts of the country. The tax encouraged substitution with other materials. Between 1996 and 2010 the same was doubled primarily to increase the incentive effects. Policies can have an impact on all stages of the life cycle and to a vast array of different materials and sectors. These would include promotion of zero-waste mining, designing products that use sustainable materials, promotion of R&D and innovation in and together with enterprises, the creation of public awareness for resource conservation, facilitating engagement

[5] Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture

for managing post-consumer wastes/ materials etc. Setting up of mandatory targets for recycled content and having an effective monitoring network will help to achieve the desired level of performance within desired timelines.

Finally, Resource Efficiency is a cross-cutting issue involving several domains and policy levels. In such a political set-up, an institutional mechanism is extremely important that will facilitate, monitor and review the implementation of various policies and programs across sectors and product life cycles and periodically propose necessary course correction measures. Their functions can include developing Resource Efficiency measures across the life cycle to avoid burden shifting across stages, sectors and resources (including biotic resources) keeping in mind ease of implementation and minimizing transition costs. Functions can include assessment of Resource Efficiency measures for their effectiveness and potential negative impacts along with providing regular feedback, serving as a repository of best practices and business models, and maintain a database of indicators for helping and tracking Resource Efficiency progress in India.

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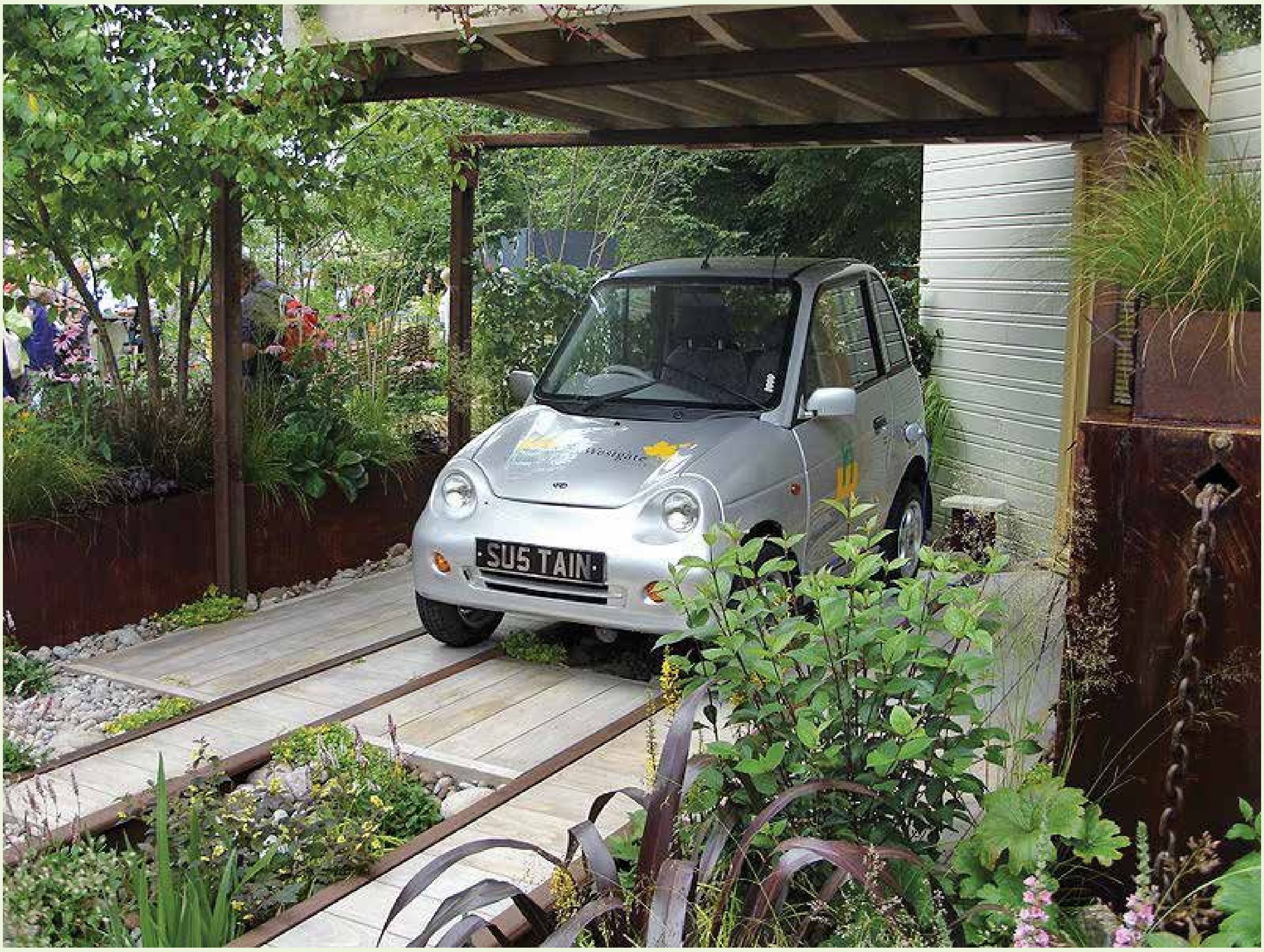
SECTION THREE

# Pollution Abatement



SECTION THREE

# Pollution Abatement

In a comman man's parlance, pollution may be defined as any undesirable alteration in the composition of land, air or water. India is facing an unprecedented challenge of land, water, air and noise pollution.

While India has around 18 per cent of the world's population, it only has 4 per cent of the freshwater resources. Water pollution is a significant challenge threatening access to water for most citizens. In addition, it is projected that national supply may fall 50 per cent below demand by 2030 due to several factors. During 2015, the estimated sewage generation in the country was around 61,754 Million Litres Per Day (MLD) against the sewage treatment capacity of 22,963 MLD. Out of which about 38,791 MLD of sewage (62%) was untreated. However, around 13,468 MLD of wastewater is generated by industries of which only 60 per cent is treated. In the case of small-scale industries that may not be able to afford the cost of a wastewater treatment plant, Common Effluent Treatment Plants (CETPs) have been set-up based on a cluster approach. Namami Gange Programme is an Integrated Conservation Mission, approved as 'Flagship Programme' by the Union Government in June 2014 with a budget outlay of INR 20,000 crore to accomplish the twin objectives of effective abatement of pollution, conservation and rejuvenation of river Ganga. Installation of online (24x7) monitoring devices and adoption of water conservation practices, besides notification of standards with respect to effluent discharge, are other steps by the government. A significant level of additional investment is required to ensure the treatment of sewage and wastewater generated in India.

Soil pollution is also an area of concern in urban areas due to landfilling of Municipal Solid Waste (MSW) that contaminates 1240 hectare per year, and in rural areas due to excessive use of fertilizers, around 65 per cent of land in villages is exposed to residual pesticides risk. To address these challenges, managing MSW and reducing the use of pesticides is critical. Industrial hazardous waste if dumped without treatment can also lead to soil pollution and there is a need for strict monitoring on these issues.

Air pollution is another significant problem in India. According to a study, the highest PM 2.5 exposure level is reported in Delhi, followed by the other North Indian states of Uttar Pradesh, Bihar and Haryana. Government has taken several steps to address air pollution which include *inter alia,* notification of Graded Response Action Plan, National Ambient Air Quality Standards, setting up of monitoring network for assessment of ambient air quality, launch of National Air Quality Index, universalization of BS-IV from 2017, leapfrogging from BS-IV to BS-VI fuel standards from 1st April 2018 in Delhi and from 1st April 2020 in rest of the country, promotion of public transport network, streamlining the issuance of Pollution Under Control Certificate, and launch of National Clean Air Programme.

This section contains five papers covering contemporary themes on various aspects of pollution abatement including short-lived climate pollutants and e-Governance for statutory clearances.

**Guest Editor**

# Issues and initiatives in controlling environment pollution

Prashant Gargava[1] and B. V. Babu[2]


## Abstract

Various facets of pollution and Mitigative measures have been discussed in the backdrop of legal and policy framework in India. This paper presents initiatives taken by the Central Pollution Control Board (CPCB) to deal with various components of the environmental pollution.



## Keywords

*Environment Pollution, Central Pollution Control Board, Circular Economy, Resource Efficiency.*


## Introduction

Environment pollution is one of the greatest challenges that the country is facing today. Urbanisation and industrialization significantly contributed to the release of pollutants in the environment and besides putting burden on natural resources. Today, mutlidimensional approach is being adopted by the government to conserve and protect the environment including control of pollution from industrial & non-industrial sources of pollution with special emphasis on Principal of reduce, reuse, recycle and recovery of waste.

To tackle growing environmental challenges, Government of India has laid down regulatory framework under the Air (Prevention and Control of Pollution) Act, 1981; Water (Prevention and Control of Pollution) Act, 1974 and the Environment (Protection) Act, 1986. Various rules have been notified under Environment (Protection) Act from time to time. The management of wastes generated from various industrial operations and urban areas is governed through various Rules notified under the Environment (Protection) Act, 1986, such as.

a. Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016
b. Solid Waste Management Rules, 2016
c. E-Waste Management Rules, 2016
d. Plastic Waste Management Rules, 2016
e. Construction and Demolition Waste Management Rules, 2016.
f. Bio-medical Waste Management Rules, 2016

Initiatives taken by subsequent sections discuss (CPCB) on various broad area of environment management are given below:

## 1.0 Air Quality Management

With an aim to preserve quality of air & control are pollution, National Ambient Air Quality Standards have been notified for 12 air pollutants (PM10, PM2.5) sulphur dioxide, nitrogen dioxide, carbon monoxide, ammonia, ozone, arsenic, nickel, lead, benzene, and benzo (a) pyrene.

The monitoring of ambient air quality is conducted under National Air Quality Monitoring

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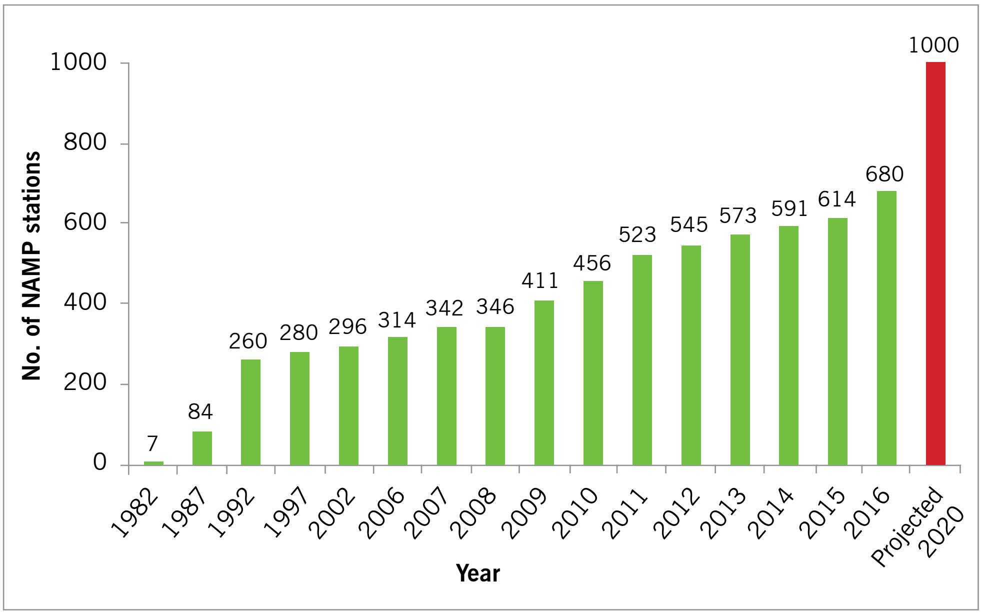
**Figure 1: Growth of NAMP operational stations**




Programme (NAMP) through a network of stations to determine ambient air quality level and identify non-attainment cities. It consists 731 stations covering 312 cities/towns in 29 States and 06 Union Territories. In addition, 167 real-time monitoring stations have been installed in 102 cities.

Efforts are being made expand the existing network to 1000 manual stations and 200 real time stations, by 2020.

Further, for effective communication and easy understanding of general public, CPCB has developed "Air Quality Index" as a tool to transform complex air quality data into a single number (index value), nomenclature and colour, informing prevailing air quality in simple linguistic term.

It has six categories, namely Good, Satisfactory, Moderately polluted, Poor, Very Poor, and Severe. Each of these categories is decided based on ambient concentration values of air pollutants and their likely health impacts (known as health breakpoints). AQ sub-index and health breakpoints are evolved for eight pollutants (PM 10, PM 2.5, $NO_2$, $SO_2$, CO, $O_3$, $NH_3$, and Pb) for which short-term (upto 24-hours) National Ambient Air Quality Standards are prescribed.

A web-based portal currently provides real-time AQI, air quality status and information on likely health impacts associated with AQI values for 103 cities. Air quality bulletin is issued on daily basis on CPCB website. Typical layout of the portal is shown in Figure 2.

The critical air quality in Delhi NCR is of utmost concern and various multilevel actions have been taken to improve the same.

## 1.1 Graded Response Action Plan

A Graded Response Action Plan (GRAP) has been developed for implementation in Delhi and NCR under air quality scenarios for different AQI categories. It lists out actions along with responsible agencies in accordance with the air pollution levels to prevent and deal with critical air pollution situations and emergencies. Ministry of Environment, Forest and Climate Change notified its implementation through Environment Pollution (Prevention and Control) Authority for the National Capital Region on January 12, 2017. Further, a GRAP Task Force headed by Member Secretary, CPCB has been constituted to review air quality status and suggest additional measures for implementation during critical periods to EPCA.

**Figure 2: Layout of the web-based portal proving real-time AQI**


## 1.2 Sameer Application

A mobile phone-based 'Sameer App' has been developed to provide the status of ambient air quality generated by Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in the country. This App facilitates lodging of public complaints on air pollution for immediate actions by implementing agencies to resolve the complaints.

## 1.3 Other major initiatives

i. An early warning system has been implemented from October 2018 by India Meteorological Department (IMD) to issue timely alerts to implementing agencies for facilitating them to take pre-emptive actions during critical episodes

ii. Use of petcoke and furnace oil is prohibited in industrial processes in Delhi, Haryana, Uttar Pradesh and Rajasthan

iii. Bharat Stage VI compliant petrol and diesel with 10 ppm sulphur has been introduced in Delhi since April 2018

iv. Directions have been issued for conversion of brick kilns to zig-zag technology

v. List of approved fuels permissible for use within the borders of the NCT of Delhi has been notified

vi. Operationalization of Eastern and Western Peripheral Expressways to ease congestion and diversion of traffic from Delhi

vii. Financial incentive by the Central Government for in-situ crop residue management in States of Haryana and Punjab

viii. Hourly tracking of PM 10 and PM 2.5 concentration levels by CPCB and generating alerts for public agencies in case of emergency.

ix. Various studies have been initiated in collaboration with IITs, such as,

   a. Bi-Weekly Action Plan for effective and efficient management of PM 2.5 concentration in Delhi City and thus devise other potential strategies to reduce PM 2.5, and

   b. Hotspots Management Plan and use of satellite-based data (Aerosol Optical Depth) for PM 2.5 monitoring to bring maximum areas under the ambit of current monitoring network.

## 1.4 Challenges

a. Need for larger monitoring network to assess air quality across the country and understand the air quality to which the population is exposed as per their geographical location

b. Particulate Matter (PM 2.5 and PM 10) is of major concern especially in Indo-Gangetic plain. Prominent identified sources of air pollution are construction activities, road dust, vehicles, garbage burning, industrial emissions, use of biomass for cooking etc. Based on the past trends winter season (October 15 – February 15) is considered as a critical season for northern region

c. The burning of agricultural residue is one of the major reason of seasonal degradation in air quality in NCR and Punjab
d. Based on air quality data from 2011 to 2015, CPCB has identified 102 non-attainment cities, where national air quality standards have been exceeded cautiously for which dedicated specific action plans are in different stages of development.

## 1.5 Way forward

A National Clean Air Programme (NCAP) was launched by MoEFCC on 10-1-2019 for ensure participation of all stakeholders to achieve better air quality levels within a stipulated timeframe.

## 2.0 Water Quality Management

The Government of India enacted the Water (Prevention and Control of Pollution) Act 1974 to provide for the preventions & control of water pollution, and for maintaining or restoring wholesomeness of water. The act prescribes various functions for CPCB at the apex level and State Pollution Control Boards (SPCBs) at the state level. The Main functions of CPCB are as follows:

a. To advise the Central Government on any matter concerning restoration and maintaining the wholesomeness of aquatic resources and the prevention, control and abatement of water pollution
b. To plan and cause to be executed a nation-wide programme for the prevention, control and abatement of water pollution
c. To provide technical assistance and guidance to the SPCB
d. To carry out and sponsor investigations and research related to prevention, control and abatement of water pollution
e. To collect, compile and publish technical and statistical data related to water pollution
f. To lay down standards for the quality of water in streams and wells.

Main functions of SPCBs are:

a. To plan a comprehensive programme for prevention, control and abatement of water pollution and to secure the execution thereof
b. To advise the State Government on any matter concerning prevention, control and abatement of water pollution
c. To collect and disseminate information related to water pollution
e. To collaborate with the CPCB in a programme related to prevention, control and abatement of water pollution
f. To inspect sewage or trade effluent and plant for their treatment, assess the quality of water and to take steps for prevention, control and abatement of water pollution in such areas

To perform the above functions, CPCB conducts continuous monitoring of water quality of water bodies in the country. For this a network of water quality monitoring stations has been established.

Quality of water resources is deterioraty to polluting sources *viz.* discharge of untreated domestic sewage, industrial effluents, run-off/seepage from contaminated wastes and soils, disposal of solid waste, use of chemical, the presence of pesticides and fertilizers in run-off from agricultural fields etc.

Water quality management involves establishing a water quality monitoring network, identifying critically polluted resources, and strategizing a management plan to restore the quality of surface and groundwater resources to acceptable levels. This involves effective control of industrial and domestic wastewater pollution, remediation of contaminated areas, etc. apart from regulation on water consumption and practising water conservation methods.

## 2.1 Water Quality Monitoring Network

Following are objectives of Water Quality Monitoring:

a. Rational planning of pollution control strategies and their prioritisation;
b. To assess the nature and extent of pollution control needed in different water bodies or their part;
c. To evaluate the effectiveness of pollution control measures already in existence;
d. To evaluate water quality trend over time.

CPCB in collaboration with SPCBs has established a Water Quality Monitoring Network spreading across 3500 locations in 29 States and 6 Union Territories of the country.

Under the National Water Quality Monitoring Program (NWMP), water samples are analysed for 28 parameters consisting 9 core parameters, 19 physio-chemical and bacteriological parameters apart from the field observations. Besides, nine trace metals and 15 pesticides are also analysed in selected samples. Biomonitoring is also carried out in specific locations.

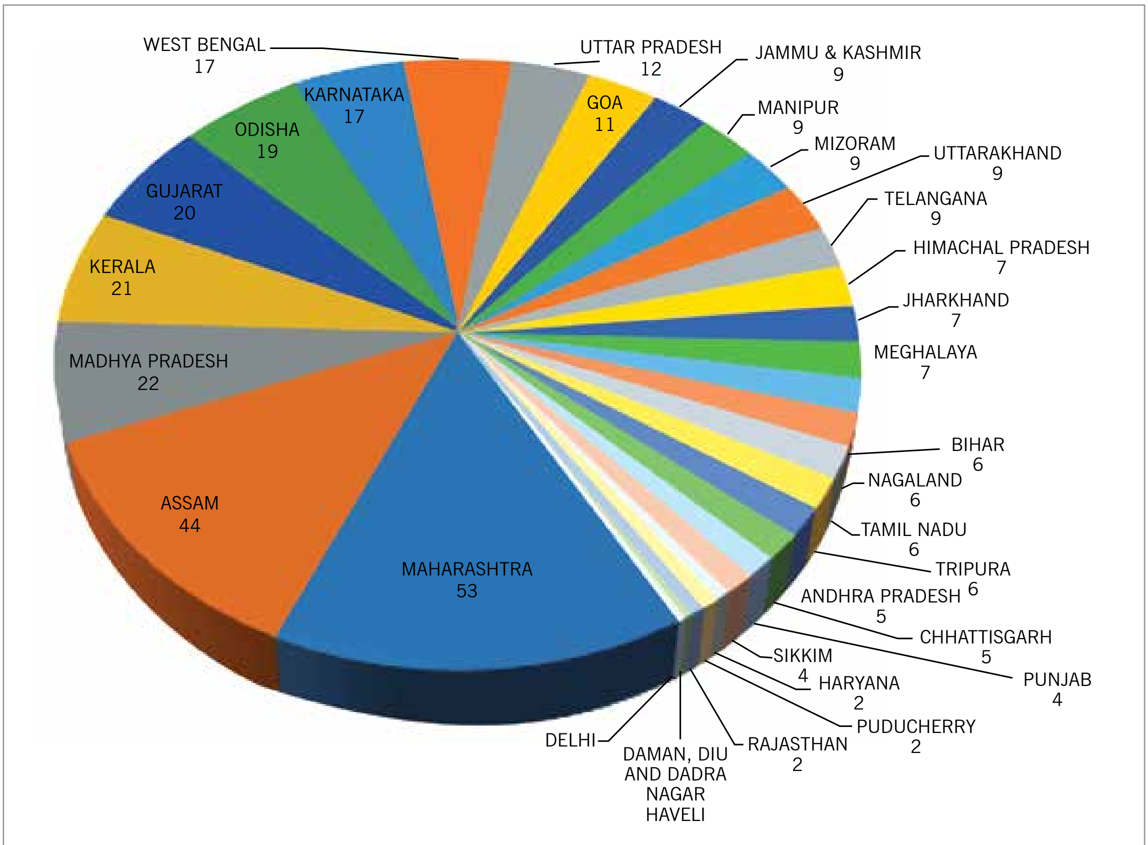
The water quality data being monitored under the network is evaluated against the water quality criteria and the monitoring locations in exceedance with respect to one or more parameters are identified as polluted, requiring action for restoration of water quality.

Most of the surface water bodies in the country are contaminated to some extent due to organic pollutants and bacteriological contamination. Unregulated discharge of sewage from towns & cities and effluent from industries have resulted in 351 polluted river stretches on 323 rivers across the country. Details are shown in Figure 3.

## 2.2 Sewage management and issues

It is estimated that 62,000 million litres per day (MLD) of domestic sewage is generated from

**Figure 3: State-wise number of polluted river stretches**



urban areas in India. Sewage treatment capacity developed till recently is about 23,277 MLD from 816 STPs of which 522 plants are operating under capacity, due to several constraints, limiting treatment to around 18,883 MLD. In addition to these limitations, there are issues with regard to the regular operation of these STPs and compliance to discharge standards.

Limitation in managing the treatment of domestic wastewater is attributed to,

a. Lack of sewerage systems for collection and conveyance of sewage (open storm water drains carry sewage in many cities)
b. Non-availability of STPs and inappropriate technology and capacity of STPs
c. Non-prioritization of wastewater treatment (focus has been on the supply of drinking water rather than waste water treatment)
d. Limited revenue source to meet the management cost of sewage collection, conveyance and treatment
e. Limitation of skilled manpower, technical know-how on the operation and maintenance
f. Non-sustainable approach for sewage management projects
g. Multiple agencies are responsible for meeting the objectives.

## 2.3 Action plan for critically polluted river stretches

Based on long term water quality assessment, polluted stretches of rivers were identified. A workshop for Stakeholder organizations such as SPCBs, and State Water Resources dept. was organized during January 2018, and a document about "Restoration of Polluted River Stretches – Concept and Plan" was shared. Subsequently, it was also suggested to constitute State Level Committees for Sewage and Industrial Waste Management. Further, in September 2018, Hon'ble NGT passed orders in the matter of news item published in 'THE HINDU' regarding critically polluted stretches identified by CPCB, wherein respective State Governments and Union Territory Administrations were directed to prepare action plans and submit to CPCB for approval.

## 2.4 Action plan for Ganga water quality management

The Central Government vide notification dated 20.2.2009 has set up 'National Ganga River Basin Authority' (NGRBA) with the objective to ensure effective abatement of pollution and conservation of the river Ganga by adopting a holistic approach towards sustainable development needs. In this regard, CPCB has prepared a segmental action plan for restoration of water quality of river Ganga. The rejuvenation plan aims to stop the discharge of untreated sewage and industrial wastewater from 118 towns along the river Ganga. Real-time monitoring has been initiated at thirty six locations on river Ganga.

## 3.0 Industrial pollution control

CPCB has published Comprehensive Industry Documents providing information on pollution potential of different categories of industries, available technologies and techno-economically feasible standards.

Environmental standards have been notified for different industrial sectors (such as cement, sugar, distilleries, iron and steel, thermal power plants, tannery, etc.) to regulate industrial emissions and effluent discharges and ensure compliance to the industry-specific standards notified under Environment (Protection) Act 1986.

## 3.1 Industrial emissions and discharges

Main challenges in control of industrial emissions and discharges is to ensure proper operation of pollution control devices, compliance to stipulated standards, viability of small scale industry to treat effluent and emissions in a cost-effective manner. The failure of common facilities in complying with standards limited manpower, skilled staff and limited infrastructure at SPCBs are main factors affecting proper implementation of the regulations.

With rapid industrialization, it is becoming necessary to ensure compliance in industries with minimal inspections. Therefore, efforts have been made to discipline the industries and exercising self-monitoring. One such mechanism is implementation of online emission and effluent monitoring systems and uplinking data to regulatory authorities (SPCBs/PCCs/CPCB, other government agencies).

With this approach, CPCB initiated implementation of online monitoring mechanism during 2014 and issued directions under Section 18(1) of the Water and Air Acts to the SPCBs and Pollution Control Committees (PCCs) to ensure installation of online effluent quality and emission monitoring systems in 17 categories of highly polluting industries (such as Pulp and Paper, Distillery, Sugar, Tanneries, Power Plants, Iron and Steel, Cement, Oil Refineries, Fertilizer, Chloral Alkali Plants, Dye and Dye Intermediate Units, Pesticides, Zinc, Copper, Aluminium, Petrochemicals and Pharma Sector, etc.), as well as for Common Effluent Treatment Plants (CETP), Sewage Treatment Plants (STPs), Common Bio-Medical Waste and Common Hazardous Waste Incinerators.

At present, about 4500 industries are connected with a central web portal developed by CPCB, wherein real-time online emission and effluent data is received from 17 categories of highly polluting industry categories. In case of exceedance to norms, SMS alerts are generated, based on which industries are identified for inspection and appropriate action.

### 3.2 Severely Polluted Areas (SPAs)

CPCB has also developed Comprehensive Environmental Pollution Index (CEPI) to characterise the quality of the environment in the prominent industrial clusters. It is a rational number to characterize the environmental quality at a given location following the algorithm of the source, pathway and receptor.

In 2009, 88 prominent industrial clusters were identified in consultation with MoEFCC for detailed analysis. Out of these, 43 industrial clusters in 17 States having CEPI score of 70 were identified as Critically Polluted Areas (CPAs). Further, 32 industrial clusters with CEPI scores between 60 and below 70 were categorized as Severely Polluted Areas (SPAs).

To assess the environmental quality in the Polluted Industrial Areas (PIAs), monitoring is carried out periodically by CPCB through recognized environmental laboratory and CEPI score is re-assessed based on the recorded monitoring data. The evaluated CEPI reflects the environmental quality of the industrial areas and also serves as a yardstick to assess the progress achieved in implementation of action plans. So far, three rounds of monitoring have been conducted during 2009, 2011 & 2013.

### 3.3 Categorization of industries

The concept of categorization of industries as 'Red', 'Orange' and 'Green' was introduced to facilitate decisions related to a location of industries, Consent management and formulation of norms related to surveillance/inspection of industries.

This criteria of categorization of industrial sectors have been developed based on the Pollution Index which is a function of the emissions (air pollutants), effluents (water pollutants), hazardous wastes generated and consumption of resources. The Pollution Index (PI) of any industrial sector is a number from 0 to 100. Higher value of PI denotes the increasing degree of pollution load from the industrial sector.

a. Industrial Sectors having Pollution Index score of 60 and above – Red category
b. Industrial Sectors having Pollution Index score of 41 to 59 –Orange category

c. Industrial Sectors having Pollution Index score of 21 to 40 –Green category
d. Industrial Sectors having Pollution Index score including and upto 20 -White category.

The purpose of categorization is to ensure that the industry is established in a manner which is consistent with the environmental objectives. This criterion will guide industrial sectors to willing adopt cleaner technologies.

### 3.4 Corporate Responsibility for Environmental Protection

A Charter on "Corporate Responsibility for Environmental Protection (CREP)" was launched in March 2003 with the purpose to go beyond the compliance of regulatory norms for prevention and control of pollution through various measures including waste minimization, in-plant process control and adoption of clean technologies. The Charter has set targets concerning conservation of water, energy, recovery of chemicals, reduction in pollution, elimination of toxic pollutants, process and management of residues that are be disposed off in an environmentally sound manner. It also enlists the action points for pollution control for various categories of highly polluting industries which includes tanneries, pulp and paper etc.

## 4.0 Waste Management: Issues and initiatives

Waste management has become a major environmental concern. Waste management efforts so far have not yielded the desired results. There have been isolated examples of success, the situation so far, by and large, is not satisfactory. While there was some improvement in the management of wastes of industrial origin and healthcare facilities, management of household solid waste, E-waste, Construction and Demolition waste and plastic wastes remains a challenge.

### 4.1 Management of solid waste

Solid waste management is becoming a major environmental concern. Urban Local Bodies, vested with the responsibility of sanitation and waste management have been lagging on account of growing population, inadequate civic infrastructure and weak financial support system.

This is evident from the fact that out of about 1,40,000 metric tonne per day of municipal solid waste generated in Class-I and Class-II cities during 2015-16, only 27 per cent was processed and 3 per cent was disposed off in scientifically designed landfills, while remaining 70 per cent of the waste is dumped in unscientific manner. Similarly, out of about 26,000 metric tonne per day of plastic waste generated about 7 per cent ends up in solid waste dumps.

Segregation at the source, collection, conversion of organic waste to compost or biogas, recovery of material for recycling, resource or energy recovery and sanitary land filling are the key requirements of scientific management of solid waste.

Possible reasons for the state of affairs are lack of environmental awareness, lack of involvement of stakeholders, poor coordination, lack of financial and human resource with urban local bodies, inadequate attention to the issue and lack of understanding of implication on the health of people. It is in this background Government of India revised Waste management Rules in 2016 to minimize practical difficulties in implementation as well as to achieve scientific and sustainable waste management at par with best global practices.

Some of the salient points of revised rules on municipal solid waste management are as presented below,

i. Local bodies to facilitate door-to-door collection of household waste.
ii. Responsibilities have been given to bulk waste generators for segregation of wastes and for setting up on-site compost facilities.
iii. Time limits are given for compliance of various

activities such as establishing door-to-door collection system for segregated wastes, composting or biogas facility for wet wastes, setting up material recovery facilities or secondary storage facilities, construction of sanitary landfill and production of RDF or Waste to Energy from non-recyclable wastes within a period of 2 to 3 years. Five years have been given for closing down the old dumpsites and for its remediation.

iv. Local bodies to establish waste deposition centres for domestic hazardous wastes.

v. The "polluter pays principle" is envisaged, whereby households and commercial establishments are liable to pay user fee as may be decided by local bodies, which are mandated to make by-laws for implementing provisions of Solid Waste, Plastic Waste and Construction and Demolition Waste Management Rules.

vi. State policies and strategies should recognise the role played by the informal sector by including waste pickers and waste collectors in the waste management system;

vii. Responsibilities to other key stakeholders such as the Ministry of Housing and Urban Affairs for providing technical guidelines and project finance to States, UTs and local bodies;

viii. 'Extended Producer Responsibility' (EPR) has been brought in as an environmental protection strategy to achieve the minimal environmental impact of a product in its life-cycle. It makes the manufacturer or Producer of the product to take-up responsibility for life-cycle of the product including retrieval, recycling and final disposal. As a part of EPR responsibility, manufacturers or brand owners of disposable products such as packaging material, sanitary napkins, multi-layered plastics, etc. have to provide necessary financial assistance to local authorities for the establishment of the waste management system.

CPCB has prepared a 'National Action Plan for Municipal Solid Waste Management' that gives a broad framework in accordance with the Solid Waste Management Rules, 2016 to provide guidance on tools, equipment and indicative technological options. It also provides an outline of a suggestive/indicative strategy that states and UTs may refer for similar State Action Plan.

## 4.2 Management of plastic waste

Followings are main features of plastic waste nuisance,

a. Littering of plastic waste makes land infertile, choke the drains, ingestion by cattle causes death and asthetic nuisance.

b. Lack of a proper collection, segregation and disposal facility.

c. Accumulation of non-recyclable plastic waste such as multilayered laminated packaging, thermoset plastic including Sheet Moulding Compound, Fiber Reinforced Plastic etc. are threats to the environment.

d. Open burning of plastic waste, especially chlorinated plastic waste is a major health and environmental issue.

e. Leaching of harmful contents in soil and underground water as it contains metals and phthalates.

f. Running of unregistered plastic manufacturing and recycling industries in residential areas.

As per the study conducted by CPCB in 60 cities, it was observed that around 4059 MT/day of plastic waste is generated. The fraction of plastic waste in total Municipal Solid Waste (MSW) varies from 3.10 per cent (Chandigarh) to 12.47 per cent (Surat). Average plastic waste generation is around 6.92 per cent of total MSW. It is estimated that around 25,940 MT/day of plastic waste is generated in India. As per the results of the study, 94 per cent waste comprises thermoplastic content, which is recyclable such as PET, LDPE, HDPE, PVC etc. and remaining 6 per cent is thermoset and other categories of plastics such as sheet moulding compound (SMC), fibre reinforced plastic (FRP), multi-layered, thermocol etc., which is non-recyclable.

The concerned Local Bodies and Gram Panchayats are responsible for the collection, storage, segregation, transportation and disposal of waste in their jurisdiction. For effective management of plastic waste generated the recommended action plan for implementation by local authorities is as below:

a. A local authority may engage their staff or an authorized waste picker for segregation of all category of plastic waste at Material Recovery Facility or from other sources of generation.
b. A local authority shall involve producers for the collection of used multi-layered plastic sachet or pouches or packaging who introduce the products in the market, to establish a system for collecting back the plastic waste generated due to their products.
c. Collection of littered/dumped plastic waste in public places like market areas, bus stands, railway stations, cinema halls, parks, community centres, roadside etc. should be collected by engaging their own staff or authorized waste pickers/ agencies.
d. The waste collected by the authorized agency should be segregated at collection yard and the same should be shredded/baled as per requirement prior to transfer to recyclers/ utilizers.
e. The following options should be envisaged for utilization or recycling of plastic waste:
   - Use of shredded plastic waste in the construction of a bituminous road through hot mix plant (IRC Code SP 98:2013).
   - Conversion of plastic waste into liquid fuel (as per CPCB guidelines).
   - Transporting stored plastic waste in nearest cement kilns for co-processing (as per CPCB guideline).
   - Transfer to a plastic waste recycler for recycling into other plastic products.
   - Setting up of Material Recovery Facility for dry waste.
f. Following options are envisaged for utilization of non-recyclable plastic and the rejects/ residues (having high calorific value) generated from recycling units:
   - Transfer for co-processing to nearest cement kilns for energy recovery
   - May remain in a combustible fraction of solid waste for production of RDF or as feed to work to energy plant
g. The following options should be envisaged for the disposal of plastic waste where the option of recycling and utilization are not feasible:
   - Destruction by plasma pyrolysis process
   - Disposal by incineration unit complying with emission standards stipulated under Solid Waste Management Rules, 2016 (part C of schedule II)
   - The residues/rejects generated during recycling/processing of plastic waste should be disposed off in sanitary landfills as per the provisions under Solid Waste Management Rules, 2016.

### 4.3 Management of biomedical waste

The Biomedical Waste Management Rules, 2016 have been notified under the Environment (Protection) Act, 1986 by the Ministry of Environment Forest and Climate Change in March 2016 in supersession of earlier Biomedical Waste (Management and Handling) Rules, 1998 to improve collection, segregation, processing, treatment and disposal of the biomedical waste in an environmentally sound manner and thereby reducing possible environment and health impacts.

#### 4.3.1 Legal framework

Biomedical Waste Management Rules, 2016 stipulates some time-bound actions on which adequate measure are required to be taken by the SPCBs/PCCs in respect of the following:

(i) Grant of authorization to all the Healthcare Facilities (HCFs) irrespective of the quantity of waste generated;

(ii) Phasing out of chlorinated plastic bags and gloves excluding blood bags by March 2019;

(iii) Pre-treatment of highly infectious waste at the hospital;

(iv) Bar code system and GPS to be established, by March 2019, by the occupier or Operator of CBWTFs;

(v) In cities where terminal Sewage Treatment Plant does not exist all bedded HCFs which have less than 10 beds shall install Effluent Treatment Plants by December 2019;

(vi) Installation of Common Biomedical Waste Treatment Facilities (CBWTFs) in all States to facilitate centralised disposal of biomedical waste. As BMWM Rules, 2016 discourage captive treatment and disposal facilities;

(vii) Up-gradation of existing incinerators to comply with stringent emission standards as stipulated under BMWM Rules, 2016 which include two seconds residence time also;

(viii) Constitution of 'State Level Advisory Committee (SLAC)' and 'District Level Monitoring Committee (DLMC)'.

### 4.3.2 Biomedical waste management scenario

As per information received from SPCBs as on 2017, there are 2,38,170 no. of Health Care Facilities (HCFs) in the country out of which a total of 87,269 number of HCFs are bedded and 1,51,208 HCFs are non-bedded. The generation of bio-medical waste is about 557 tonne per day. 198 no. of CBWTFs are in operation (additionally 24 under construction) and 9,830 no. of HCFs have captive bio-medical waste treatment and disposal facilities, which are involved in treatment and disposal of 518 tonne per day of bio-medical waste. The bio-medical waste management scenario in the Country is given in Table 1.

### 4.3.3 Issues in the implementation of BMWM Rules, 2016

a. **Segregation of biomedical waste**: Segregation of biomedical waste is not carried out by HCFs as per the colour coded system given under BMWM Rules, 2016.

b. **Inventory of occupiers:** Inventory of non-bedded Occupiers such as clinics, pathological laboratories, research institute etc. is required to be conducted by SPCBs as per BMWM Rules, 2016.

c. **Authorization of healthcare facilities:** All HCFs including non-bedded HCFs like clinics etc. should obtain authorization under BMWM Rules, 2016 and also become a member of CBWTF for ensuring treatment and disposal of generated biomedical waste as per BMWM Rules, 2016.

d. **Up-gradation of Common biomedical waste incinerators:** Biomedical waste incinerators needs to be upgraded so as to achieve two second residence time in the secondary combustion chamber and to comply with new emission norms as required under BMWM Rules, 2016.

e. **Installation of Online Continuous Emission Monitoring System (OCEMS) by CBWTF operator:** As required under BMWM Rules, 2016 biomedical waste incinerators should install OCEMS and have connectivity with CPCB and SPCB servers for online transmission of data to CPCB and SPCBs.

f. **Biomedical waste management in veterinary hospitals:** Veterinary Hospitals are also required to take authorization under BMWM Rules, 2016 to ensure proper segregation, collection, storage, treatment and disposal of as per BMWM Rules, 2016

g. **States/UTs which are yet to develop CBWTFs in the respective State/UT:** No CBWTF is available in States/UTs like Arunachal Pradesh, Goa, Manipur, Mizoram, Nagaland, Sikkim, Andaman and Nicobar Islands and Lakshadweep to treat and dispose of biomedical waste as per BMWM Rules, 2016.

h. **Deep burials for disposal of biomedical waste:** BMWM Rules, 2016 restrict the practice of deep burial for disposal of biomedical waste however deep burial is allowed in rural or remote areas where there is no access to CBWTF. States like Assam, Bihar, Chhattisgarh, Himachal Pradesh, Jharkhand, Jammu and Kashmir, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh and West Bengal are practising deep burials for the disposal of biomedical waste despite having CBWTF.

### 4.4 Management of hazardous waste

Hazardous waste is mostly generated from industrial activities and, if not handled and managed in a safe manner, may cause a threat to human health and the environment. For safe storage, packaging, transportation, recycling, utilization, treatment, disposal, etc. of hazardous waste in an environmentally sound manner, Ministry of Environment, Forest and Climate Change, Govt. of India has notified Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (HOWM Rule, 2016) in supersession of earlier Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2008, under the Environment (Protection) Act, 1986. The HOWM Rules, 2016, lays down provisions w.r.t generation, packaging, storage, transportation, recycling/reprocessing, utilization, treatment, disposal, etc. of hazardous waste and obtaining authorization from the concerned SPCB/ Pollution Control Committee (PCC) for the same.

The SPCB/PCC has been envisaged with the responsibility of granting the said authorization on being satisfied that the applicant for the authorization possesses appropriate facilities for collection, storage, packaging, transportation, treatment, processing, use, destruction, recycling, recovery, pre-processing, co-processing, utilization, offering for sale, transfer or disposal of the hazardous and other waste, as the case may be, and after ensuring technical capabilities and equipment through site inspection.

The HOWM Rules, 2016, also lays down the responsibility of occupier of the hazardous waste for their safe and environmentally sound management following the waste management hierarchy viz. prevention, minimization, reuse, recycle, recovery, utilization and lastly safe disposal. The hazardous waste can be disposed at a captive treatment facility installed by the individual waste generator or at Common Hazardous Waste Treatment, Storage and Disposal Facilities (TSDFs). The common disposal facilities may have only secured landfill (SLF) or incinerator or combination of the both.

**Table 1: Bio-medical waste management scenario in India**

| | |
|---|---|
| **No. of HCFs** | 2,38,170 |
| **No. of bedded HCFs** | 87,269 |
| **No. of non-bedded HCFs** | 1,51,208 |
| **No. of beds** | 20,94654 |
| **No. of CBWTFs** | 198* + 24** |
| **No. of HCFs granted authorization** | 84,800 |
| **No. of HCFs having Captive Treatment Facilities** | 9,830 |
| **No. of Captive Incinerators Operated by HCFs** | 225 |
| **Quantity of bio-medical waste generated in tonne/day** | 557 |
| **Quantity of bio-medical waste treated in tonne/day** | 518 |

*Note: * - CBWTFs in operation ** - CBWTFs under installation*

The recycling and utilization as resource or energy recovery of hazardous waste are preferentialoptions over disposal of hazardous waste since it conserves resources and leads to a reduction of the carbon footprint. Utilization of hazardous waste by co-processing in cement Kiln has proven a sustainable option because there is a dual benefit in terms of utilizing the waste as supplementary fuel as well as alternative raw material. The HOWM Rules, 2016, has stipulated provisions about such utilization of hazardous waste as resource or energy recovery and emission standards for co-processing of wastes in Cement Kiln have been notified on 10.5.2016 under the Environment (Protection) Act, 1986.CPCB has published Guidelines for Pre-Processing and Co-Processing of Hazardous and Other Wastes in Cement Plant as per HOWM Rules, 2016". Further, CPCB has also prepared guidelines for environmentally sound recycling of commonly recyclable hazardous wastes such as Used Oil, Waste Oil, non-ferrous metals, etc. listed under Schedule IV of the under HOWM Rules, 2016. Besides these, CPCB has prepared Standard Operating Procedures (SOPs) for utilization of 40 different categories of hazardous waste as a resource or energy recovery.

The HOWM Rules, 2016, stipulates provisions for maintaining records and filing annual returns pertaining to hazardous waste generation and their management. As per Rule 20(2) of the HOWM Rules, 2016, the occupier handling hazardous waste and operator of the disposal facility is required to submit an annual return in the prescribed form to the SPCB/PCC by 30th June of every financial year about hazardous wastes generation, storage, recycling, utilization, disposal, etc. Based on which, as per Rule 20(3) of the HOWM Rules, 2016, the SPCBs/PCCs are required to prepare annual inventory of the waste generated, recycled, utilized, disposed, etc. for the respective State/UT and submit to CPCB by 30th September of every year. As per Rule 20(4) of the HOWM Rules, 2016, CPCB is required to prepare a consolidated report on the management of hazardous wastes and submit the same to the Ministry of Environment, Forest and Climate Change before 30th December every year.

As par 2016-2017 inventory compiled waste on information from CPCBs/PCC, there are 56,350 hazardous waste generating industries in the country authorized to generate and manage hazardous wastes as per provision of HOWM Rules, 2016. As per the annual return submitted by the occupiers, about 7.17 Million MT of hazardous waste have been generated during April 2016-March, 2017. The details of the management of hazardous waste during the said period is given in Table 2.

**Table 2: Details of management of hazardous waste (April 2016-March 2017)**

| | | |
|---|---|---|
| 1. | Quantity of HW disposed | 2.84 Million MT (39.61 per cent) |
| | (i) Common SLF | 1.68 Million MT |
| | (ii) Captive SLF | 0.89 Million MT |
| | (iii) Common Incinerator | 0.23 Million MT |
| | (iv) Captive Incinerator | 0.05 Million MT |
| 2. | Quantity of HW Recycled/ Utilized | 3.68 Million MT (51.30 per cent) |
| 3. | Stored Within premises | 0.9 Million MT |

Gujarat (39.20 per cent), Rajasthan (10.10 per cent), Odisha (8.30 per cent), Jharkhand (8.07 per cent), Tamil Nadu (5.34 per cent), Maharashtra (5.32 per cent), Karnataka (4.70 per cent), Andhra Pradesh (3.94 per cent), Telangana (3.86 per cent) and Uttar Pradesh (2.60 per cent) are the top 10 hazardous wastes generating states, which together contribute about 91 per cent of total hazardous waste generated in the country.

There are 1,733 authorized recyclers for recycling of commonly recyclable hazardous wastes (used oil/waste oil/non-ferrous scraps/etc.) listed under Schedule-IV of HOWM, Rules, 2016, having authorized capacity of 6.99 Million MT. About 0.99 Million MT of hazardous wastes has been recycled during 2016-17, of which 75 per cent has been recycled in Gujarat, Tamilnadu, Telangana, Karnataka and Andhra Pradesh.

Around 65 cement plants are utilizing hazardous waste in the country by co-processing the same having authorized capacity of 7.22 Million MT. Gujarat, Karnataka, Tamil Nadu, Telangana and Rajasthan together contribute more than 85 per cent of total hazardous waste co-processed in cement plant in the country and Gujarat leads with about 53 per cent.

There are 42 Common Hazardous Waste Treatment, Storage and Disposal Facilities (TSDFs) in 18 States/UT. Of which 18 are integrated TSDFs having both Secured Landfills and Incinerators; 10 have only common incinerators, and; 14 have only Secured Landfills. State/UT-wise availability of the same is given in Table 3.

### 4.5 Resource Efficiency (RE)

It is well understood that the increased consumption patterns deplete the available resources that will pose economic, social, political and environmental consequences. As per UNEP report (2010), material consumption levels in India have been growing since the year 1990 and stands at 3rd position globally owing to the size of the economy. However per capita consumption in India remains lower than the world average. UNEP assessment (for the year 2016) demonstrates that per capita consumption of material has increased from 2.1 tonne in 1970 to 4.2 tonne per capita in 2010 – still less than half of the world average at 10 tonne per capita.

National Environment Policy (2006) states that "Sustainable development concerns in the sense of enhancement of human wellbeing are broadly conceived, in India's development philosophy".

Coordinated and collaborative efforts are required to ensure availability as well as conservation of natural resources. While the developed countries have to demonstrate how they can maintain their living standard with considerable lower use of resources, the developing countries need to achieve necessary growth with the most efficient use of natural resources. Notwithstanding the fact that we are low in per capita consumption, there are concerns about increasing waste generation, non-recycling of waste, dumping of waste thereby losing natural resources and associated environmental impacts.

#### 4.5.1 Contribution of Waste Management Rules in RE

Waste Management Rules (2016) are built on the principles of resource conservation and recycling. The Rules stipulate the hierarchy of prevention; minimization; reuse, recycling and recovery – utilisation including co-processing of wastes prior to safe disposal.

a. These Rules provides for scope of resource recovery and conservation of primary resources in the management of Solid Waste, Plastic Waste, Hazardous and other wastes, E-waste, Construction and Demolition Wastes and Biomedical Wastes. Effective implementation of these rules facilitates the use of secondary resource material, which in turn provides an opportunity for achieving resource efficiency.
b. Despite having regulations in place, the ground situation in cities and towns indicates that there is a great need for improving the existing ecosystem. The key factors are awareness, investments, capacity building and institutional strengthening, in the priority areas for waste management.

#### 4.5.2 Approach for RE

While promoting waste recycling we have to also move towards a comprehensive strategy on resource consumption and resource efficiency including

**Table 3: List of common hazardous waste treatment, storage and disposal facilities**

| S. No. | Name of the State/UT | Integrated TSDFs (with both SLF and Incinerator) | TSDFs with Only Common Incinerators | TSDFs with only Common Secured Landfills |
|---|---|---|---|---|
| 1 | Andhra Pradesh | 1 | - | - |
| 2 | Gujarat | 4 | 2 | 3 |
| 3 | Haryana | 1 | - | - |
| 4 | Himachal Pradesh | - | - | 1 |
| 5 | Jharkhand | 1 | - | - |
| 6 | Karnataka | - | 6 | 2 |
| 7 | Kerala | - | - | 1 |
| 8 | Madhya Pradesh | 1 | - | - |
| 9 | Maharashtra | 3 | - | 1 |
| 10 | Odisha | - | - | 1 |
| 11 | Punjab | - | - | 1 |
| 12 | Rajasthan | - | 1 | 2 |
| 13 | Tamil Nadu | 1 | - | 1 |
| 14 | Telangana | 1 | - | - |
| 15 | UP | 2 | 1 | 1 |
| 16 | Uttarakhand | 1 | - | - |
| 17 | West Bengal | 1 | - | - |
| 18 | Daman, Diu, Dadra and Nagar Haveli | 1 | - | - |
| | TOTAL | 18 | 10 | 14 |

utilisation of secondary resources, which are key to India's sustainable development;

a. There is a need to adopt best global practices in managing the secondary resource material and to engage with institutions.

b. The concept of Extended Producers Responsibility with a primary objective of channelizing the end of life products for environmentally sound recycling has been introduced in our legislation for recycling of wastes such as used lead-acid batteries, plastic waste, Solid waste and E-Waste. However, there is a need to evolve a credible implementation mechanism to ensure success of implementation.

c. To start with, we may focus on resource efficiency programs in sectors where there is high consumption of natural resources such as construction and transportation. In the medium to long term, the focus of the Resource Efficiency Strategy may be broadened to include a spectrum of other resources.

d. Some degree of resource conservation can also be achieved through Pollution control enforcement – while regulating sectors like Sugar, Textile, Distilleries and Tanneries CPCB has stipulated standards for specific consumption of water, re-use of treated wastewater and implementation of Zero-Liquid Waste discharge; these measures have resulted in a reduction in water consumption and qualitative improvement in receiving water bodies.
e. India has a large scale informal recycling system. However, the main challenge is to convert this sector into the formal chain by creating linkages with responsible stakeholders. There is also a need to provide sustainable and low-cost viable technologies to the informal sector to achieve environmental and, health and social benefits. Efforts are being made in some centres to convert the informal recycling into formal or through mainstream industry.
f. At the local level, there is a need to implement a unified waste management framework to bring different sources of secondary raw materials for effective closed-loop recycling. Segregation of waste at the place of generation is, therefore, an important factor towards ensuring the quality of secondary material recovery.

### 4.5.3 Efforts made in achieving RE

The impetus to waste management has started showing results in the country. Success stories are emerging in the country where waste management following the principles of segregation, recycling and environmentally sound disposal has been implemented in sustainable and cost-effective manner.

About 50 Standard Operating Procedures have been prepared by the CPCB to facilitate utilization of 36 different categories of hazardous wastes. About 50 per cent of the Hazardous waste generated in the country is recycled for resource recovery. Co-processing of wastes in Cement Kilns has been implemented successfully in Indian Cement Industry since the year 2005. There is a need for setting up goals for resource utilization from wastes.

CPCB has issued guidelines for environmentally sound recycling of commonly recyclable hazardous and other wastes such as used lubrication oils, waste oils, batteries waste, metal dross, scrap metals, spent catalysts, used tyres, etc.

Construction and Demolition Waste Management Rules, 2016 provides for the production and use of secondary material such as aggregate and manufactured sand produced by recycling of construction or demolition wastes.

### 4.6 Circular economy

The linear practice of manufacture, use and disposal of material through landfills or incinerators would ultimately result in depletion of finite resources. A circular economy replaces the concept of managing end-of-life material with restoration or regeneration; in this concept, the value of products, materials and resources is maintained in the economy for a long period, and the generation of waste is minimised. Circular economy advocates use of renewable energy, eliminates the constraints in reuse or recycle, reduces use of toxic material and aims for the elimination of waste by adopting the superior design of materials, products, systems and business models.

Principles of the circular economy are ingrained in Indian habits; we see that material are utilised for extended periods by refurbishment and second-hand re-use. Material such as electrical and electronics equipment, furniture, vehicles are used after refurbishment or re-sale for extended periods of time.

Recycling activity in the country is mostly operated by the informal sector, which is the source of income or livelihood for a large number of poor population in the country. There is a scope for integrating existing informal practices into a developmental strategy wherein the core objective of the circular economy can be achieved.

### 4.7 Extended Producers Responsibility (EPR)

Extended Producers Responsibility has been brought in as an environmental protection strategy to achieve the minimal environmental impact of a product in its life-cycle. It makes the manufacturer or producer of the product to take-up responsibility for life-cycle of the product including retrieval, recycling and final disposal.

As part of EPR responsibility, producers/brand owners/ or importers of notified electrical and electronic equipment (EEE), are required to support a system of collection, storage, transportation, dismantling and recycling for their products.

EPR would help in achieving a sustainable waste management system, where segregated collection and environmentally sound recycling can be achieved. EPR will also minimise the quantity of disposable material, thereby reducing the burden on waste management.

EPR will help in increasing organised waste collection. For example, the formal collection of E-Waste in our country is a mere 2-6 per cent against the generation of about 1.7 million tonne.

Targets given under EPR may compel the producers to approach informal recyclers for waste collected by them. This may result in bringing this them as part of organised waste management. It may improve working conditions of poor people engaged by an informal chain.

EPR component would help in supporting efforts being made by local bodies, where the availability of adequate funds for waste management is a major concern.

#### 4.7.1 EPR in waste regulation

India has started implementing the provision of Extended Produces Responsibility through Waste Management Rules. At present EPR provisions are applicable for Producers or Importers or Brand-owners for collection and channelization of;

a. E-Waste [for 21 types of electrical and electronic equipment]
b. Plastic [for bags or multi-layered packaging or plastic sheets used for packaging or wrapping the commodities]
c. Packaging products [such as plastic, tin, glass and corrugated boxes, etc.]
d. Sanitary napkins
e. Lead acid batteries

We may see that type of responsibility under EPR varies from waste type is given in Table 4.

#### 4.7.2 Implementation of EPR

Producer's Responsible Organisations (PROs) can play a vital role in our country by helping Producers in achieving their EPR targets as well as requirements. PROs are required to have a clear understanding of the sources of waste, waste infrastructure for waste management and provision under the Waste Management Rule to collect sufficient volumes of waste using cost-effective arrangements, and to maintain uninterrupted collection, treatment, and recycling services.

In case of EPR provisions under Solid Waste and Plastic Waste Management Rules 2016, it would be difficult for producers to individually meet the EPR scope/targets. In this regard, producer or a consortium of producers can engage PRO to do the task in a dedicated manner.

CPCB is mandated to grant EPR-authorizations

**Table 4: Different types of responsibility under EPR**

| | Type of Waste | Regulatory provision | Who is responsible | Scope of EPR | Prescribed Authority |
|---|---|---|---|---|---|
| 1 | E-Waste | E-Waste (M) Rules, 2016 | Producers, Brand Owners, Importers | Collection Targets assigned depending upon quantity placed on market | CPCB and SPCBs |
| 2 | Solid Waste (packaging products including sanitary napkins/ diapers) | Solid Waste (M) Rules, 2016 | Manufacturers and brand owners | Broader scope, no targets.<br>Provide financial assistance to local authorities<br>Provide awareness to public | Local Authorities |
| 3 | Plastic Waste<br><br>(from Carry bags or multi-layered packaging or plastic sheets used for packaging/ wrapping) | Plastic Waste (M) Rules, 2016 | Producers, Importers, Brand Owners | Establish a system for collecting back the plastic waste generated due to their products.<br>No specific targets.<br>Multiple modals can be applied for waste management;<br>• Involve UDD<br>• individually or collectively<br>• Through Local Body<br>• Own distribution channel | Producers to seek registration from SPCBs if placed in up to 2 States<br><br>CPCB if placed in more than 2 States<br><br>[Read with Rule 13 (2)] |
| 4 | Used Batteries | Batteries (M and H) Rules, 2001 | Manufacturers/ Assemblers/ Re-conditioners | The term 'EPR' not specified but Manufacturers responsible to set up collection centres to channelize all used batteries to Recycling facilities. | SPCB |

under E-Waste Rules to producers of Electrical and Electronic Equipment. Scrutiny of 345 EPR Authorisation granted by CPCB to the Producers indicates that majority of the producers have engaged Recyclers to meet their EPR, while only a few producers have opted for Producer Responsibility Organisations (PROs) for managing their EPR. In the case where recycler is providing dual services as both PRO and recycler, there should be a clear demarcation of activities without conflict of interest.

In case of used batteries, Batteries Rules, 2001 does not outline a mechanism to monitor the implementation of EPR for collecting and channelizing used Batteries. However, manufacturers are given the responsibility of setting up collection centres and to ensure recycling of their used batteries.

In most of the EPR plans submitted by EEE producers, it has been observed that producers are planning to buy e-waste from consumers, which may not be sustainable in the long run. Producers have to motivate consumers by providing attractive schemes so that consumers can return their e-waste.

To start with, producers responsible under Solid Waste and Plastic Waste Management Rules 2016 may demonstrate their commitment by carrying out case studies in selected cities. In one such EPR initiative, CPCB provided technical guidance to collect and dispose about 650 MT of Multilayer Packaging (MLP) for energy recovery over 3 months. This has proved to be a successful model which could encourage many more such initiatives in future.

# Green startups in India: Challenges and opportunities

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**Abstract**

The Government of India is focusing on promoting startups to support innovation, employment generation and other benefits. Stakeholders including entrepreneurs, venture funds, accelerators, banks etc. have also been promptly engaged leading to the creation of a healthy ecosystem. Green startups are a category of startups which develop and implement products or services that contribute to the goals of a green economy (reducing greenhouse gas emissions, improving energy efficiency, adopting a circular economy approach etc.). It is possible to promote green startups to meet the environmental goals of the government of India, but it needs additional supportive policies and programs. This paper based on a review of publicly available information highlights the challenges and opportunities for green startups in India. An analysis of the green startups ecosystem in India using the ecosystem diagnostic tool developed by Dutch Good Growth Fund (DGGF) and Aspen Network of Development Entrepreneurs (ANDE) in 2015 has been provided. Based on the description of some of the key sub-sectors like biogas, clean cookstoves, electric vehicles, energy efficiency etc. it can be concluded that there is tremendous potential but only if supportive policies and programs are initiated. Recommendations including increasing access to financing, reducing policy risks, addressing regulatory risks, increasing access to infrastructure, developing human resource, improving access to markets, providing business support, supporting business model innovations, carbon markets supporting green startups have been explained.

**Keywords**

*Startup, Green, Economy, Policies, Financing, Innovation, Business Models, Risk, Resources.*

## Introduction

The role of start-ups in India's economic development and their potential in creating employment opportunities have been recognized by the Government of India with the launch of the "Startup India Initiative". 14,036 enterprises have been recognised as Startups by Department of Industrial Policy and Promotion (DIPP) till November 2018 with various support including tax exemption of up to 7 years, establishment of 'fund of funds' of INR 10,000 crore till 2025, establishment of Atal Innovation Mission (AIM) etc. (MCI 2018). The ecosystem is developing with a number of startups, new venture funds and angel investors, evolving technology, incubators

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and accelerators, etc. Indian startups raised USD 38 billion in 2018 that highlights the potential of startups to reach scale (ToI 2018). Arguably despite the challenges entrepreneurs can act as powerful agents of change reducing inefficiencies, creating jobs, and boosting economic development (World Bank 2017). However, IBM has estimated that around 90 per cent of Indian startups fail within the first five years for reasons including launching products or services that market does not want or need, inferior or inappropriate product despite good idea, inadequate cash flow, human resource etc. (Mirza 2018). Other challenges faced include limited availability of domestic risk capital, constraints of conventional bank finance, information asymmetry and lack of hand-holding support (The Hindu Business Line 2018).

Startups serve as a source of technological innovation across sectors including in the development and market introduction of radical sustainable innovation, while incremental innovation tends more to be the turf of established companies (Fichter and Wei 2013). Therefore, "green startups" could be termed as a category of startups which develop and implement products or services that contribute to the goals of a green economy (reducing greenhouse gas emissions, improving energy efficiency, adopting a circular economy approach etc.). Further, within green startups, there is a wide diversity of products and services. Markets and institutional or regulatory environments influencing the green startups determine the challenges and opportunities experienced by these (Bergset and Fichter 2015). Further due to the presence of several not-for-profit or NGO led initiatives in the environmental sector there is a need for a distinction to made for defining sustainable entrepreneurship as it takes place in a business context that needs to be financially self-sustaining in the middle to long-term (Shepherd and Patzelt 2011; Thompson *et al.* 2011). This distinction between for-profit and not-for-profit enterprise is critical to attracting mainstream financing expecting a return on investment which is significantly larger compared to impact financing expecting lower returns or no return on investment if economical, social and environmental impacts are positive. Impact investing has emerged in India as a key source of financing for green startups along with sectors like health, microfinance, education etc. attracting over 50 active impact investors, who, along with mainstream investors, provided around the USD 5.2 billion (Pandit and Tamhane 2017).

Existing research has highlighted that cleantech companies have high financing requirement, for example, renewable energy technologies like solar, biomass etc. (Caprotti 2011) and this is true for most green startups as well. The potential conflict between short-term profits and a triple bottom line of economic, environmental, and social value creation leads to a situation where financing green start-ups may be substantially more challenging compared to startups from other sectors (Shepherd and Patzelt 2011).

This paper based on a review of publicly available information highlights the challenges and opportunities for green startups in India. First, the paper provides a broad overview of the opportunities considering the key global commitments of the Government of India. In the second section, the paper presents an analysis of the green startups ecosystem in India using the ecosystem diagnostic tool developed by Dutch Good Growth Fund (DGGF) and Aspen Network of Development Entrepreneurs (ANDE) in 2015. The ecosystem analysis section also includes a description of some of the key sub-sectors where green startups are active. Recommendations for improving the startup ecosystem are provided with a discussion of the key challenges followed by a conclusion.

## Opportunities for green startups in India

The Nationally Determined Contribution (NDC) target of India aims to reduce the emissions intensity of GDP by 33 to 35 per cent by 2030 from 2005 level, achieve 40 per cent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 and creating an additional carbon sink of 2.5 to 3 billion tonne of $CO_2$ equivalent. To achieve the mitigation goals financing of USD 834 billion till 2030 would be required while adaptation needs USD 206 billion in this period (MoEFCC 2015). There is a need for a significant level of domestic innovation and market development to deploy the technologies required for achieving India's climate change mitigation targets. Already several start-ups in energy efficiency, waste management, organic farming etc. have been recognized for their potential to contribute to climate change mitigation and adaptation along with addressing other environmental and social issues.

Particularly for the new and renewable energy technology related enterprises, there are several schemes offered for example the Loan for rooftop solar PV power projects and National Clean Energy Fund Refinance, both of which are headed by the Indian Renewable Energy Development Agency (Inc42, 2017a). The former provides a 70-75 per cent project cost loan, while the latter is a re-financing instrument for scheduled commercial banks and financial institutions.

According to the Ellen Mac Arthur Foundation report a circular economy path to development could create benefits of around ₹40 lakh crore (USD 624 billion) in 2050 compared with the current development path. These benefits would occur due to sectors including cities and construction, food and agriculture, mobility and vehicle manufacturing. Further report highlights that circular economy will reduce negative externalities like greenhouse gas emissions around 44 per cent lower in 2050 compared to the current business as usual scenario and other externalities like congestion and pollution would fall significantly providing health and economic benefits (Ellen Mac Arthur Foundation 2016). There are several green startups like those providing electric taxi or ride-sharing service, providing technologies for improving water and fertilizer use efficiency, etc. that can contribute to circular economy development in India. Air pollution due to vehicular, industrial and domestic activities have also created a market opportunity for green mobility, air pollution control equipment etc. Water pollution is another significant challenge where green startups can play a critical role.

The rich biodiversity in India and several national parks and sanctuaries with government programs focusing on conservation of biodiversity offers opportunities for products and services to manage these resources better. Startup linking communities living around forests with people interested in supporting afforestation or reforestation activities can have significant potential.

Green sectors, such as renewable energy, energy efficiency, waste management, sustainable agriculture etc. are some of the most important sectors for meeting the Sustainable Development Goals (SDGs) including SDG 6, 7, 11, 12, 13, 14 and 15 (UNDP 2015).

The green startups ecosystem in India has been analysed using the ecosystem diagnostic tool developed by DGGF and ANDE.

### Business support

Major India focused funds for green startups include, Infuse Ventures that has included 30 companies in the accelerator program and invested in 10 enterprises. Some of the key successful companies include Fourth Partner a leading Renewable Energy Services Company (RESCO); Ecolibrium provides an energy management platform used for increasing energy efficiency, TESSOL uses thermal energy storage technology to provide transportation as well as stationary storage solutions using the cold plates technology (Infuse Ventures 2018). The Green India Venture Fund that has invested in Regent Energy

Limited focusing on small hydro, KVM Energy Pvt Limited with biomass and hydro projects, Ganesh Ecosphere Limited focusing on recycling of polyethylene terephthalate (PET) bottles for textile production, Shakti Pumps involved in manufacturing of efficient water pumps (Green India Venture Fund 2019). The sectors in which these firms are invested include waste management, telecom, technology, renewable energy, resource efficiency and emissions reduction. In June 2018, the founder of a payment company Paytm based in India launched a USD 150 million environment protection fund (The Economic Times 2018). Paytm's stage agnostic fund is looking to make as many as 18-20 investments and will fund startups working on green cities, clean food, carbon mitigation, reduction of plastic pollution, clean energy and forest restoration. Incubators like Sangam AIC (Sangam 2019), Climate Collective (Climate Collective 2018) etc. are supporting green startups as well. However, the support ecosystem is much smaller compared to other sectors and almost non-existent in smaller cities.

In India, technology business incubation efforts have grown over the last two decades. However, it is only over the last few years that the number of incubators in India has increased significantly. There are over 120 TBIs in India that are promoted by the DST, Ministry of Information and Communication Technology, and other private companies, institutions, banks and government departments (DST 2016).

Incubators are intended to assist start-ups in taking their ideas and business plans to the market place. A study of the start-up environment of the country reveals that a significant percentage of start-ups fail to succeed in their initial phase. Therefore, the primary goal of an incubator is to nurture start-ups during their crucial nascent period.

Start-ups typically spend two years with an incubator (Menon and Mallik 2016). During this period, start-ups get insights/advisory services from experts and may receive office space and other basic infrastructure. This infrastructure could be in any form pertaining to operational requirements of start-ups, such as using research laboratories and technical support. Villgro, the Centre for Innovation Incubation and Entrepreneurship (CIIE) and the Society for Innovation and Entrepreneurship (SINE) are some examples of incubators that are supporting start-ups/social enterprises in India and are receiving CSR funds from Mahindra & Mahindra Financial Services, SAP, Tata Motors and Bajaj Electricals, Castrol, etc (Villgro 2019).

## Policy

India ranks 77 globally in the ease of doing business ranking (World Bank 2019). The policy scenario for green businesses including green startups is supportive as far as legislation is concerned. However, a lot is desirable to increase the competitiveness of the sector compared to the conventional sector through tax breaks, preferential access to finance, infrastructure etc. which is non-existent. While there are several policies for supporting startups, in general, there is a need for a specific policy for green startups.

## Markets

The markets for green startups are very challenging due to limited awareness, lack of strict enforcement of legislation related to pollution control, and because environmental issues are not considered as a priority by the citizens. However, the situation is changing with awareness creation campaigns by the government, specific spending and better enforcement of regulations.

## Human capital

The National Youth Policy (NYP-2014) launched in February 2014 proposes a holistic 'vision' for the youth of India, which is "To empower the youth of the country to achieve their full potential, and through them enable India to find its rightful place in the community of nations". The NYP-2014 has defined 'youth' as persons in the age group of 15-29 years. As per India's Census, the total youth population increased from 168 million in 1971 to 422 million in 2011 (MoSPI 2017). It is a cause of concern that the skill level of recent graduate engineers in India is not enough to meet industry requirements. This creates challenges for green startups or all startups with an inadequately skilled workforce as a key constraint. The availability of skilled professionals in the middle and senior level management is also limited increasing cost of the human resource. The number of universities focusing on skills for the green sector is another concern. However, the Skill Council for Green Jobs (SCGJ) is a recently launched initiatives of the Government of India aligned to the National Skill Development Mission with focus on renewables, green construction, green transport, carbon sinks, solid waste management, water management and e-waste management (Ministry of Skill Development and Entrepreneurship 2018).

### Infrastructure

Challenges related to supply of electricity, roads connectivity, water supply, industrial parks etc. increase cost and constrain business. India's infrastructure gap is significant with an investment need of USD 1.5 trillion over the next ten years. However, due to several reasons, it is challenging to mobilize the required financing (Pandey 2017). It is, therefore, necessary that green startups are provided with the necessary infrastructure to the best possible extent.

### Innovation and Research & Development (R&D)

India spends 0.6-0.7 per cent of GDP on R&D which is much less compared to other countries (PTI 2018). There are incentives available for the private sector to invest in R&D, but it is challenging for green startups to invest in R&D as they lack access to finance in general. There are few dedicated universities and departments in large institutions that undertake research related to green technologies, but significantly more resources are required for meeting the desired goals.

### Entrepreneurial culture

The entrepreneurial culture in India is developing at a fast pace with a greater number of universities and private institutions setting up incubators and accelerators. An increasing number of graduates are willing to explore entrepreneurial opportunities and social acceptance for entrepreneurship as a career option has increased. Still compared to the size of the economy and considering the demographics it is critical that further support is provided to the development of the entrepreneurial culture in India.

### Performance and impact

There are several green startups operating in India with significant potential for scale-up. While the exact impact is difficult to determine this section provides a description of some key sub-sectors that highlight the performance and impact:

**Rural household level biogas plants:** National Biogas and Manure Management Programme (NBMMP) was first launched in 1981 and renamed in 2003, it offers Central Financial Assistance (CFA) for family-type biogas plants. As of 2014, around 5,400,000 biogas plants at the household level have been installed in India (Mittal *et al.* 2018). According to the Ministry of New and Renewable Energy (MNRE), the total potential for biogas plant installations is around 11,400,000 million (MNRE 2017). The limited adoption of biogas is due to several barriers including the high capital cost for rural households, challenges in maintenance, limited financing available for enterprises working in the sector etc. but with additional support it is possible to meet the targets.

**Clean cookstoves:** Unnat Chulha Abhiyan (Improved Cookstove Mission) was launched in 2014 by MNRE with the aim of deploying 2.4 million household-level and 350,000 community-level improved cookstoves (ICS) by March 2017. It is estimated that over 235 million households in India need improved cookstoves (ICS). Based on historical data, this need is estimated to grow at an average rate of 1.6 per cent per year. The Global Alliance for Clean Cookstoves (GACC) continues to be the biggest financial contributor, bringing in more than USD 100 million into the ICS sector it aims to raise a total of USD 250 million by 2025 to achieve its goal of supporting the adoption of 100 million improved cookstoves. GACC invests in the ICS ecosystem at different stages through its various initiatives like Spark fund that provides unproven startups with grants up to USD 500,000. Catalytic small grant fund by GACC provides proven startups with grants up to USD 100,000 and Pilot innovation fund by GACC provides capital to pilot new approaches within established ICS enterprises, Capacity building facility funds capacity building initiatives to get enterprises scale-ready etc. (GACC 2018). Globally, some of the most successful ICS enterprises like Envirofit have helped more than 5 million families across Africa, Asia and Latin America adopt improved cookstoves.

In India, Acumen has made the largest ICS investment of USD 2.5 million into a Mumbai based ICS startup called Greenway Grameen (Knowstartup 2016). In addition to this, among others, impact funds like Aavishkar and Villgro have also invested undisclosed amounts into clean cookstove startups. While the government of India has initiated the Ujjwala Yojana which is providing one LPG cylinder and stove free of cost to low-income rural households there is still a significant need for clean cookstoves that is being fulfilled by green startups and established organizations in this sector.

**Grid-connected biomass power:** The estimated potential for biomass based power generation from grid-connected biomass/bagasse co-generation in India is 25,860 MW (Lok Sabha Secretariat 2018). As per MNRE's Annual Report 2016-2017, more than 530 biomass power plants and co-generation initiatives have yielded close to 8,000 MW installed capacity for grid power. The biomass sector faces challenges due to unorganized supply system and inadequate infrastructures (and, therefore, high costs) for collection, processing, storage and transportation. Given the range and variety of biomass materials used for power generation - bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, and groundnut shells, saw dust etc (MNRE undated), there exists immense potential for innovation and efficiency forged by start-ups and social enterprises to tackle these challenges, creating impactful economic growth while also promoting environmental responsibility and inclusive, enhanced access to power generation. However high initial investment needs and high transport costs continue to be a major barrier for startups related to biomass utilization. As an alternate scenario, in India, there are successful companies like Husk power systems that have pioneered the decentralized off-grid models of converting biomass to energy and selling it to under-served segments on a pay-as-you-go model (Husk Power Systems 2019).

**Electric vehicles:** To reduce Greenhouse Gas (GHG) emissions and local air pollution challenges electric vehicles can prove to be an effective solution. It is estimated that by 2030, electric two-wheeler sales will rise to a total of 26,514,000, three-wheelers to 4,072,000 and four-wheelers to 15,911,000. This is a total of 46,497,000 electric vehicles (RMI 2017). The global electric vehicle market is driven by government support in the form of subsidies, grants, and tax rebates. Improving charging infrastructure, increasing vehicle range, and reducing the cost of batteries have fuelled the demand for EVs across the globe. Chinese Original Equipment Manufacturer (OEMs) produced more than 43 per cent of all EVs built worldwide and now also has the largest fleet of EVs on the road (Mckinsey 2017). The Indian government's ambitious National Electric Mobility Mission Plan 2020 envisages achieving 6-7 million sales of hybrid and electric vehicles by 2020 (DHI 2017). While Mahindra Electric continues to be India's only electric passenger vehicle maker, competitors like Maruti Suzuki, for example, has announced that it will invest USD 600 million into a new EV factory at Gujarat (Inc42 2017b). These developments are on track to paving the path for green startups to enter this sector for either manufacturing or providing the services.

**Energy efficiency in buildings:** The major areas of energy consumption in buildings are heating, ventilation, and air conditioning; lighting, major appliances (water heating, refrigerators and freezers, dryers); and a significant fraction remaining in miscellaneous areas including electronics. In each case, there are opportunities both for improving the performance of system components and improving the way they are controlled as a part of integrated building systems. The need for commercial space is increasing with 5.5 million square meters of office space added annually in the top seven Indian cities, with the total commercial space rising to more than 28 million square meters (CBRE 2011). Compliance with the Energy Conservation Building Code has the potential to reduce average energy consumption by 30- 40 per cent in new commercial buildings across all five climatic zones within India (BEE 2018).

The energy efficiency potential in residential buildings is also significant. From 2019 – 2030, the number of urban households will likely grow from 117 million to 171 million (based on UN population and household size projections). Correspondingly, the total MWh per year usage will increase from 96,390,803 to 243,189,875. Under the business-as-usual scenario, the annual electricity use per household is predicted to increase from 650 kWh in 2012 to 2750 kWh by 2050. Using a very aggressive policy strategy, the increase in household electricity consumption could be cut to 1170 kWh per household in 2050. Examples of startups in the energy efficiency sector include (Minion Labs 2019) and Flamingo Industries (Flamingo Industries 2019).

**Renewable energy powered micro and mini-grids:** According to the National Policy for Renewable Energy based Micro and Mini-Grids published by Ministry of New and Renewable Energy (MNRE) there is a target to achieve deployment of at least 10,000 RE based micro and mini-grid projects across the country with a minimum installed RE capacity of 500 MW in next 5 years (taking average size as 50 kW). Through the draft policy, the MNRE has set a target of deploying at least 10,000 RE-based micro- and mini-grid projects across the country over a five-year period, with a minimum installed capacity of 500 MW. Startups related to solar lighting, solar pumps and home lighting systems have been very active in raising financing and deploying several thousand systems across the country. Examples of green startups in the decentralized renewable energy supply sector are (Mera Gao Power 2019 and Boond Engineering and Development (Boond Engineering & Development 2019).

**Solar rooftop:** *Accelerating India's Clean Energy Transition*, a November 2017 report published by Bloomberg New Energy Finance, suggests India's solar rooftop PV sector offers a 23 billion dollar investment opportunity. The Ministry of New and Renewable Energy has set a target of 40GW total installed capacity of rooftop solar PV by 2022 and is providing incentives to the sector for enabling this transformation. Given this vast market opportunity and scope for deep impact in rooftop solar PV, start-ups are strong contenders in this sector for lucrative investment potential. With declining costs of inputs, the increasing cost-effectiveness of solar PV when compared to fossil fuel-based energy sources and India's landmass offering peak solar radiation, start-ups are ripe for massive influence in this space (World Bank 2017).

**Waste management:** In 2015, India generated 144,000 tonne of MSW per day out of which only around 22 per cent was processed (CPCB 2016). Most of the MSW is disposed of in landfills or unmanaged dumpsites causing GHG emissions and other environmental, social and economic problems. There is a significant opportunity for green startups to engage in the management of MSW. There are three main categories of MSW the first being biodegradables like food waste and a certain percentage of garden waste that can be treated through aerobic or anaerobic composting or biomethanation leading to the production of compost and biogas. There are several green startups managing MSW in India including Saahas Zero Waste (Saahas Zero Waste PRO 2019), GPS Renewables (GPS Renewables 2019) etc.

## Recommendations to address the challenges facing green startups

According to the Startup India Action Plan 2016, one of the major challenges is the failure of most start-ups during the initial five years due to lack of either funds or management skills (DIPP 2016). Therefore, developing a conducive environment becomes crucial to support start-ups during their initial years of operations.

## Addressing risks to green startups

**Increasing access to financing:** There are currently very few funds investing in green startups. Creating dedicated funds combining both public and private sector funding could prove to be transformational for the sector. In the case of debts, there is the risk of losing the principal amount, therefore, creating instruments like Risk Sharing Mechanisms can enable banks to finance green startups. Alternate financing structures like enhanced credit facility, blended debt fund with flexible repayment terms, impact bonds, guarantee and asset-backed securitisation and asset lease financing etc. can be explored. Donors and CSR funds can be asked to allocate certain funding necessarily for supporting startups. Tax-breaks for investors even individuals to enable them to invest in green startups could be effective in mobilizing a significant level of funding.

**Reducing policy risks:** There are several policies supporting sustainable development, pollution control and addressing climate change. However, there is a risk of policy changing or not being implemented as proposed leading to risks for green startups. For example, sudden policy changes in tariffs, subsidies etc. can change the business potential of the sector. To address this risk change of policies should be applicable to enterprises from the date of new policies, all enterprises requesting access to benefits under the previous policy should continue to gain the benefit as earlier to avoid disruptions of existing business models. For instance change in feed-in-tariff for rooftops from INR 5 per kWh to INR 3 per kWh should not lead to renegotiation of tariff for a project approved and financed considering INR 5 per kWh.

**Addressing regulatory risks:** There are several clearances, approvals and certifications required with processing time periods ranging from few days to months that limit the growth of startups. The regulations surrounding startups should be such that it does not limit implementation while ensuring that adverse environmental and social impacts are addressed.

**Increasing access to infrastructure:** Industrial parks may have dedicated areas for green enterprises with a preference for startups with access to electricity, transport and other services at affordable costs.

**Developing human resource:** Skills related to green enterprises should be developed so that startups and other enterprises do not find it challenging to recruit.

**Improving access to markets:** Startups should be provided with better access to markets through policies like green public procurement, mandatory green standards for certain products and services. Incentives to companies adopting green procurement or procuring from startups could help open new markets.

**Providing business support:** Availability and accessibility to incubators, accelerators, networks and platforms that help build capacities of green startups and enable them to scale-up would be very helpful. There are several examples of such support under the Atal Innovation Mission. Further, there is a need for support to develop and refine products and bringing prototypes to market.

**Supporting business model innovations:** There is a need for developing and supporting innovative business models. For example, the pay-as-you-go (PAYG) model is one such business model innovation that has been a game changer for the distributed energy sector.

**Carbon markets supporting green startups:** A significant number of companies in India use global standards to report their GHG footprint. In addition, several projects from India adopt any of the Voluntary Emission Reduction standards like Verified Carbon Standard (VCS) now VERRA (VERRA 2018) and Gold Standard (Gold Standard 2017) to participate in voluntary carbon markets. Development of Indian voluntary carbon market with special incentives for green startups can help improve their revenue and assist in scaleup. A mechanism to quantify and monitor adaptation impacts can enable CSR funding for organizations implementing climate change adaptation activities to support green startups focusing on adaptation.

## Conclusion

If India must achieve its SDGs, meet the commitments as part of the Paris Agreement and provide a clean environment for all citizens it needs to promote green enterprises including green startups. There is enough evidence that with limited support from the government and that need not to be government grants only the green startups can create significant impact while providing a decent return on investment. For example, there are dedicated funds already in India like Infuse Ventures and the Green India Venture Fund that have invested in successful companies. However, considering the size of the Indian economy and the potential of Green Startups in India, there is a need for significant scaling up of the sector. With dedicated funding, incentives for investing in green startups and with risk sharing mechanisms, a significant level of financing can be mobilized for the green startup's sector. Therefore, there is a need for a dedicated Green Startups Programme or Mission that focuses on achieving the potential of startups across the country. Green startups can also introduce very innovative technologies that could help reduce the cost of meeting the environmental goals of the country. Therefore, adequate support should be provided to educational and research institutions to collaborate with green startups or incubate them for transformational change.

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# Emissions of short-lived climate pollutants from India: An analysis of sectoral mitigation potential

Chandra Venkataraman[1]

**Abstract**

The Paris Agreement on Climate Change strengthens the global response to the threat of climate change by aiming to bring global temperature rise below 2°C. Current climate action under this Agreement suggests that global warming is expected to surpass 1.5°C even a strong ambitious mitigation after 2030. This leads to a strong need to expand the focus of climate action from a GHG-only perspective to incorporating warming short-lived climate pollutants (SLCPs). India ratified the Paris Agreement on climate change, signalling its commitment to the "global cause of environmental protection and climate justice." India's NDC proposes an ambitious eight-point action plan aimed at addressing greenhouse gas emissions and mentions both air pollution and waste management, however, does not specifically address SLCPs. Here we attempt to evaluate sectors which offer significant SLCP mitigation potential and interventions which can effectively exploit this potential. An emission inventory was developed for the year 2015 using technology-linked energy-emissions modelling to estimate multi-pollutant emissions including those of GHGs and SLCPs. Global Warming Potential (GWP) was used to calculate net $CO_2$-eq emissions from each pollutant while keeping a link to the sector of emission. It is found that significant mitigation potential for warming SLCPs from India arises from transformations in sectors including residential, brick production and agricultural residue burning.

**Keywords**

*SLCPs, Mitigation Potential, Emission Inventory, GWP.*

## Introduction

The Paris Agreement on Climate Change, which came into force in November, 2016, following ratification by over fifty world nations, aims for a global response to limit global mean temperature increases above pre-industrial levels to well below 2°C, while pursuing efforts to further limit the increase to below 1.5°C (UNFCCC 2015). This ambitious long-term temperature target is firmly positioned in the framework of "sustainable development and efforts to eradicate poverty," thus placing great priority on the path taken to achieve the target, particularly in terms of climate justice for those who bear a large share in the burden of the impacts of climate change. Current climate action under the Paris Agreement is embodied in Nationally Determined Contributions (NDCs), or

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national pledges to reduce emissions and undertake climate adaptation actions, given each country's unique circumstances. However, recent evidence suggests that under emissions consistent with current NDC pledges, global warming is expected to surpass 1.5°C, even if they are supplemented with significantly ambitious mitigation after 2030, towards achieving net zero $CO_2$ emissions in less than 15 years (IPCC 2018). In this context, there is a significant need to expand the focus of climate action, from a GHG-only lens to one that includes warming short-lived climate pollutants (SLCPs).

SLCPs can impact climate for about 10-20 years, following emission, through radiative forcing exerted during their typical lifetimes of days to a week. SLCPs include warming agents like black carbon (BC) and tropospheric ozone ($O_3$), formed from reactions of carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and nitrogen oxides (NOx), and cooling agents like sulfur dioxide ($SO_2$), which forms particulate sulphate, and organic carbon (OC). It is estimated that SLCP mitigation has the potential to avoid up to 0.6°C of warming by mid-century (for example Hu *et al.* 2013; Shindell *et al.* 2012), but also offset long-term global mean temperatures. It is shown that sustained emission changes of SLCPs can be usefully compared with pulse emission changes of long-lived GHGs (Allen *et al.* 2016). Existing air quality and $CO_2$ mitigation policies which reduce emissions of sulphur and nitrogen oxides will drive up warming in the near term (despite improving air quality). Both the UNEP Emissions Gap Report (UNEP 2017) and the IPCC Special Report on Global Warming of 1.5 C (IPCC 2018), identify emission pathways which emphasize strong reductions in SLCPs, concomitantly with those in GHGs. In addition to modulation of future global temperature trajectories, the mitigation of SLCPs would contribute to reducing other climate change impacts (for example, sea-level rise, and glacier and ice-sheet melting) (Hu *et al.* 2013, WB/ICCI 2013), and reducing the likelihood of large positive feedbacks or crossing irreversible thresholds. SLCP reductions also improve air quality, with benefits for human health, agricultural yields, rainfall stability and other environmental and social policy goals.

In early October 2016, India ratified the Paris Agreement on climate change, signalling its commitment to the "global cause of environmental protection and climate justice." India's NDC (India's NDC 2015) proposes an ambitious eight-point action plan aimed at addressing greenhouse gas emissions, including clean energy production, industrial energy efficiency, waste to energy conversion and sustainable transport. India's NDC does not specifically address SLCPs; however, it refers to actions for abatement of air pollution and municipal solid waste management. Here, we ask two questions. For India, in which sectors does SLCP mitigation potential lie? What actions or interventions can effectively exploit this potential? To attempt to answer these questions, we examine sectoral emissions of GHGs, cooling SLCPs and warming SLCPs from India, for the base year 2015, in terms of $CO_2$-eq emissions, to evaluate sectors which offer the largest mitigation potential, and possible interventions which effectively target this potential.

## Methods

An emission inventory was developed for India, for the year 2015, based on an "engineering model approach" using technology-linked energy-emissions modelling adapted from previous work (Pandey *et al.* 2014; Pandey and Venkataraman 2014; Sadavarte and Venkataraman 2014), to estimate multi-pollutant emissions including those of GHGs ($CO_2$ and $N_2O$), cooling SLCPs ($SO_2$ and OC) and warming SLCPs (BC, pyrogenic $CH_4$, NMVOCs, CO and NOx). We do not include $CH_4$ emissions from agricultural practices in this analysis since methodologies for such emissions are not included in the emission inventory used. An engineering model approach goes beyond fuel divisions and uses technology parameters for process and emissions control technologies, including technology type, efficiency or specific fuel consumption, and technology-linked emission factors (g of pollutant/ kg of fuel), to estimate emissions.

The inventory disaggregates emissions from technologies and activities, in all major sectors. Plant-level data (installed capacity, plant load factor, and annual production) are used for 830 individual large point sources, in heavy industry and power generation sectors, while light industry activity statistics (energy consumption, industrial products, solvent use, etc.) are from sub-state (or district) level (CEA 2010; CMA 2007a,b, 2012; MoC 2007; FAI 2010; CMIE 2010; MoPNG 2012; MoWR 2007). Technology-linked emission factors and current levels of deployment of air pollution control technologies are used. Vehicular ten emissions include consideration of vehicle technologies, vehicle age distributions, and super-emitters among on-road vehicles (Pandey and Venkataraman 2014). Residential sector activities comprise of cooking and water heating, largely with traditional biomass stoves; lighting, using kerosene lamps; and warming of homes and humans, with biomass fuels. Seasonality included water heating and home warming. The "informal industries" sector includes brick production (in traditional kiln technologies like the Bull's trench kilns and clamp kilns, using both coal and biomass fuels) and food and agricultural product 15 processing operations (like drying and cooking operations related to sugarcane juice, milk, food-grain, jute, silk, tea, and coffee). Also, monthly mean data on agricultural residue burning in fields, a spatiotemporally discontinuous source of significant emissions, were calculated using a bottom-up methodology (Pandey *et al.* 2014). Uncertainties in the activity rates, calculated analytically using methods described more fully in previous publications (Pandey and Venkataraman 2014; Pandey *et al.* 2014; Sadavarte and Venkataraman 2014).

To put all SLCPs on a common scale, Global Warming Potentials (GWP) (Table 1) was used to calculate net $CO_2$-eq emissions from each pollutant, while keeping a link to the sector emission. GWP is the ratio of radiative forcing of pulse emission of any pollutant integrated over a certain time period to the radiative forcing exerted by pulse emissions of $CO_2$ during the same period (Fuglestvedt *et al.* 2010). Typically, a time horizon of 20, 50 or 100 years is used to estimate GWPs, the choice of which is typically dictated by policy choice. A time horizon of 20 years represents an upper bound on the time scale of climate effects from a pulse emission of SLCPs. It also resembles the maximum lifetime of regulatory actions or technologies, aimed at changing levels of SLCP emissions. Typically, policies have a lifespan of 5 to 10 years, rather than longer time horizons like 100 years, thus making it more pertinent to choose a GWP equivalent estimated over a 20-year timescale (GWP-20) from a policy perspective. The GWP-20 values used in this study are adopted from the IPCC's fifth assessment report (Myhre *et al.* 2013). More recently, a new definition of GWP for SLCPs was proposed (Allen *et al.* 2016) to obtain equivalence in sustained emission changes of SLCPs, to pulse emission changes of long-lived GHGs. We do not apply this formulation here since it applies to future scenarios wherein emission levels change over a period of time. The GWP-20 metric is used here simply to evaluate the significance of emitting sectors, not to evaluate SLCPs against GHGs, whose control is central to curbing long-term climate change.

## Results and discussion

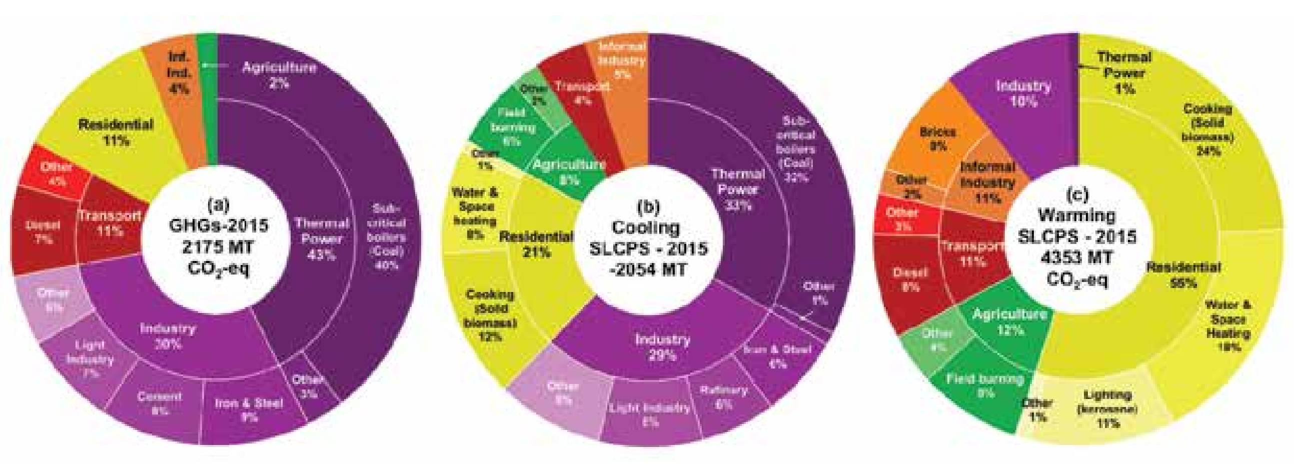
A sectoral analysis of Indian emissions in the base year 2015 (Figure 1), identifies emitting sectors. The total emissions of GHGs are found to be 2175 MT $CO_2$-eq and a net positive $CO_2$-eq from emissions of SLCPs with 4353 MT $CO_2$-eq of warming SLCPs and -2054 MT $CO_2$-eq of cooling SLCPs. It is to be noted that the estimated SLCP emission magnitudes are a strong function of the chosen GWP time horizon, and would decrease by factors

**Table 1. Global warming potentials (GWP-20) for different pollutants**

| $CO_2$ | $N_2O$ | $SO_2$ | NOx | OC | BC | $CH_4$ | VOC | CO |
|---|---|---|---|---|---|---|---|---|
| 1 | 263.7 | -141.1 | -40.7 | -244.1 | 2421.1 | 83.9 | 27.8 | 5.9 |

*Source: Myhre et al. 2013*

**Figure 1. Emissions of MT $CO_2$-eq of (a) GHGs, (b) Cooling SLCPs (OC, $SO_2$ and $NO_X$) and (c) Warming SLCPs (BC, $CH_4$, NMVOCs and CO) from India in 2015, by sectors and technologies, calculated using GWP-20.**




of 3-4 for GWP over a longer time horizon of 100 y. However, the sectoral distribution of SLCPs would remain unaltered, regardless of the metric is used, with similar overall conclusions. Emissions of GHGs and cooling SLCPs, arise largely from (i) thermal power generation, which contributed nearly 43 per cent and 33 per cent respectively and (ii) heavy industry sectors with nearly equal contributions of 30 per cent for GHGs and SLCPs. This is in diametric contrast to emissions of warming SLCPs, which arise from three main sectors: (i) residential cooking, heating and lighting contributing the largest (55 per cent) followed by (ii) open burning of agricultural residues for field clearing (12 per cent) and (iii) informal industry (including brick production) (11 per cent). The transport sector is a moderate contributor to both GHG and warming SLCP emissions emitting 11 per cent of total emissions respectively with a meagre contribution of 4 per cent to emissions of cooling SLCPs.

Specific pollutants among warming SLCP emissions include BC (1.3 Mt/yr), NMVOCs (33.4 Mt/yr), which arose primarily from traditional biomass technologies in the residential sector (for cooking and heating), the informal industry sector (for brick production and for food and agricultural produce processes), as well as from agricultural residue burning. Specific pollutants among cooling SLCPs include $SO_2$ (8.1 Mt/yr) and NOx (9.5 Mt/yr), which arose largely from coal boilers in industry and power sectors and vehicles in the transport sector.

Emissions of GHGs and those of warming SLCPs arise from strongly unrelated sectors and economic activities. Thus, we note that, for India, climate actions which centre on $CO_2$ mitigation cannot automatically cut warming SLCP emissions. Also, to improve regional air quality the proposed air pollution regulations targeting emissions of $SO_2$ from the power and industrial sectors (MoEFCC 2015) will benefit air quality, but unmask GHG warming, through reductions in cooling sulphate aerosols. Thus, climate policy targeting only GHGs as well as recent emission regulations for power plants and industrial sector would leave warming

SLCP emissions unaltered, thereby leaving unaddressed concerns about their more immediate regional climate impacts from temperature response to unmasked GHG warming. Further, there is a general agreement across 1.5°C-consistent pathways that reductions in radiative forcing from 2010 to 2030 are lower from warming SLCPs than net cooling aerosol effects, with an overall warming effect (IPCC 2018). This underlines the importance of identifying measures at national and global levels to effectively mitigate warming SLCPs.

The UNEP Emissions Gap Report (UNEP 2017) defines the emission gap for SLCPs as "the difference between emission levels that are consistent with emission trajectories resulting from NDC implementation, and the lowest emission levels achievable using current mitigation technologies and policies". Mitigation potential of warming SLCPs is linked to transport legislation in the European Union and the United States, transformation in the coke sector in China, and solid waste separation and treatment across all regions (UNEP 2017). Here, we find that the largest mitigation potential for warming SLCPs in India lies in transformations in the residential sector, brick production and agricultural field burning.

When considering opportunities to reduce the emissions gap, it is also important to consider how the measures and strategies adopted to cover the temperature gap will affect societies, human well-being and health, as well as ecosystems. In this context, near-term mitigation of warming SLCPs is perhaps even more important. Targeting warming SLCPs provides India with an emissions reduction opportunity that is aligned with important and immediate local concerns. Clear policy actions to reduce SLCPs include enabling substitutions from biomass cookstoves to cleaner gasifier stoves or liquefied petroleum gas or natural gas (LPG/PNG), from kerosene wick lamps to solar lanterns, from current low efficiency brick kilns to cleaner brick production technologies, and from field burning to agricultural practices using deep-sowing and mulching technologies (Venkataraman *et al.* 2016). Such actions have the potential to cut over 70 per cent of present-day SLCP emissions.

## Conclusions

Emissions of GHGs over India arise largely from power plants and industrial sector which is in contrast to the major emitters of warming SLCPs such as residential, brick production and agricultural residue burning thus having significant mitigation potential for emissions of warming SLCPs. The substitution of traditional technologies with cleaner technologies improves energy efficiency, yielding direct cost-effectiveness. Further, such interventions targeting warming SLCPs provide an emissions reduction opportunity that is aligned with important and immediate local concerns of improved air-quality and sustainable development, related to the provision of residential clean energy, which forms part of India's core development agenda.

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# Addressing air pollution with development policy

*How mainstreaming air quality in India's existing policies beyond environment can help address air pollution*

Prarthana Borah[1]

## Abstract

This paper outlines the need for intersectoral collaboration between government departments and academic and a scientific organisation for effective air quality management. It highlights the need to engage multiple government departments in air pollution action by emphasizing co-benefits of smart policies that address the country's energy, urban waste management and urban development needs, leading to a unique approach beyond just monitoring and research for air quality and defining solutions for action to reduce air pollution. The need for integration of air quality management in sectoral strategies has been emphasized as well as how a number of sectors will need to be aligned for solutions of better air quality.

## Keywords

*Environmental Issues, Air Pollution, Air Quality Management, Waste Management, Transport Sector.*

## Introduction

With the air quality index in Delhi ranging between poor and very poor revealing unhealthy, very unhealthy and hazardous trends the government is often forced to issue directives for taking drastic action like banning private cars and putting a complete halt to construction. While emergency measures are what a city may need at a time when it is unsafe to go out and everyone seems to be complaining of throat problems, wheezing and cough, air quality cannot be addressed with short term solutions and requires long term strategic interventions. Ban, masks, purifiers are all adaptation measures. Mitigating air pollution needs a systematic Air Quality Management Strategy that is embedded in national policy. It also needs a country to realise that air is not something that can be dealt with in isolation within the Ministry of Environment, Forest and Climate Change but requires strong policies from other Ministries like transport, waste, energy and urban development. Many of our existing policies do contribute in some way or other to the better air quality movement but the impact of this correlation is never accounted for and this is where the country needs to devise its strategic communication.

## Methodology

This paper analyses existing policies of the Indian government to identify areas of intervention that can be linked with air quality. It is based on Clean

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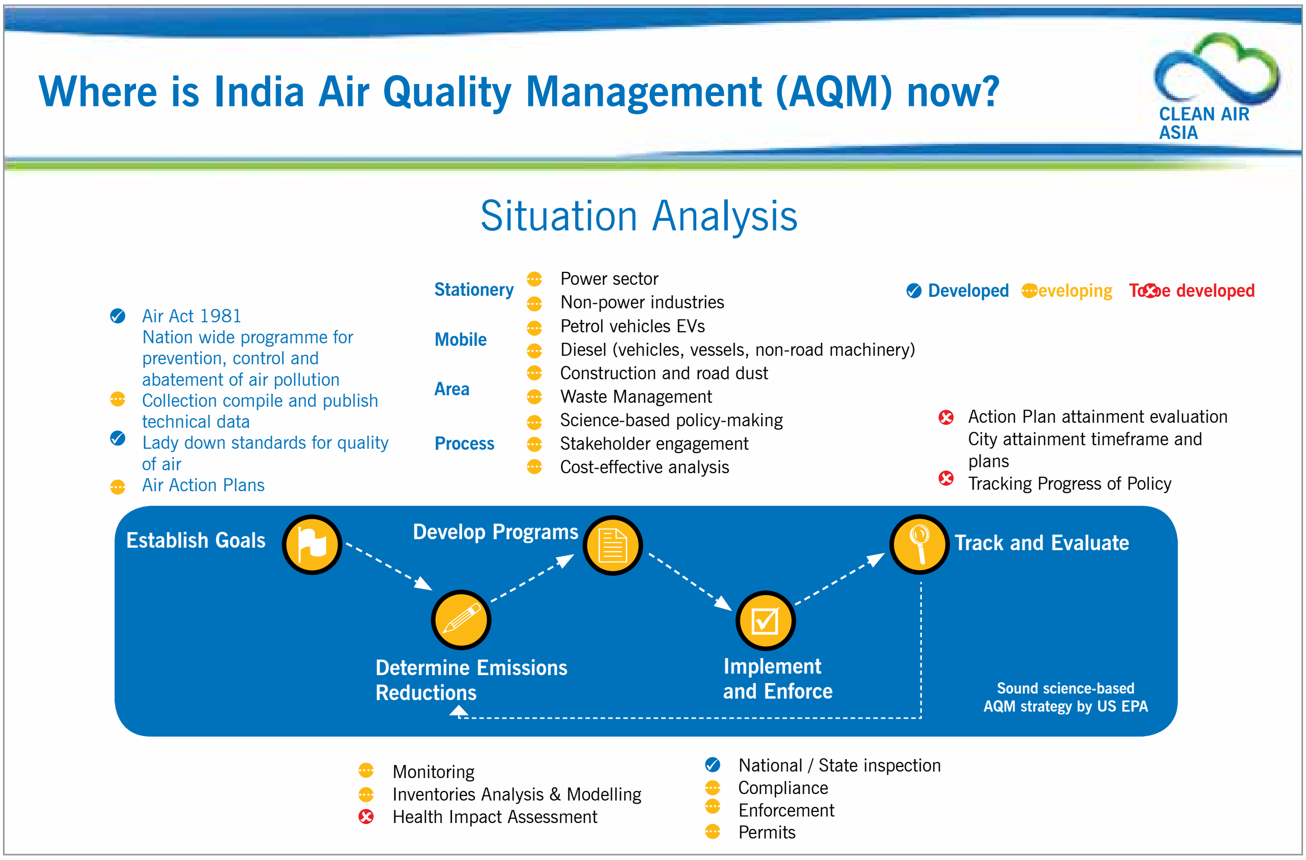
**Figure 1: Air Quality Management: Policy status for India**[2]




Air Asia's direct intervention and capacity building experience with cities in India. Clean Air Asia has been working in India to identify air quality management needs of cities and in the last 6 months supporting the SPCB, local municipalities and smart city missions to integrate air quality management in sectoral work and policies (Clean Air Asia 2016). Clean Air Asia's research on 30 cities air quality management profiles reveals a strong need for a cross-sectoral approach as well as strengthening capacity about the need for integrating air quality in different departments. The study was conducted throughout one and a half years through desk research using Clean Air Asia, Clean Air Scorecard Tool and consultations at the city level (Clean Air Asia 2018). The data on government agencies that need to be involved in Air Quality Management has been extracted and analysed from this report and presented here.

## What is Air Quality Management?

The USEPA defines air quality management as activities that a regulatory body implements to support the protection of human health and the overall environment from the harmful effects of air pollution. It is for government institutions to establish goals for better air quality by understanding the state of the air, using source apportionment, emissions inventories, air quality monitoring and modelling and other assessment tools. This is followed by developing control strategies by applying pollution prevention and emission control techniques. The process involves all levels of government – political leaders, national agencies, regulated industry groups, scientists, environmental groups, and the public.

## Policies for AQM in India

Clean Air Asia over the past one and half years assessed the air quality management capacity of

[2] Adapted from Situation Analysis Model by CAA China

cities including Delhi. Because Delhi compared to other cities in India has a robust monitoring system, has conducted source apportionment studies as well as emissions inventories and there is adequate public awareness on the issue of bad air, in the assessment it received a very high score in terms of its management capacity. There were other cities which in the absence of continuous monitoring, do not have adequate information on the hourly quality of air let alone addressing the issue. In the absence of the hourly average and adequate research on pollution hot- spots, sources of air pollution, cities remain oblivious to the issue of air quality as the information is not passed on to the general public.

Figure 1 shows a Clean Air Asia assessment of the air quality management principles defined by the USEPA. This diagrammatic representation was developed by Clean Air Asia's China office and contextualised for India to relate the USEPA guideline to India's policies. It shows air quality management strategies that are evolving and others where the country has not made an impact. As can be seen in the diagram the blue square shows the USEPA guidelines for air quality management. The diagram is an attempt to align Indian policies in the context of this framework and put the status in terms of developed, developing and to be developed. For instance, in the setting of goals, India has been quite advanced with having established the Air Act in 1981, setting down national AQM standards and defining the need for air action plans. Correspondingly the country has also several policies and programme that can contribute to better air quality like the electric vehicle policy and these policies do not necessarily fall under the purview of the MoEFCC or are directly related/ reviewed in terms of their impact on air pollution. The challenge is in creating a system of aligning the various policies of different departments and analysing its contribution to better air quality. In addition, as we see in Figure 1 enforcement mechanisms are where we need a solid working strategy as we do in tracking progress. It is impossible to assess the effectiveness of these policies in the context of AQM since there are no indicators or processes to gauge the progress. In order to create a baseline, there is a need to bring together different departments and define PM 2.5, NOx, SOx and PM 10 levels that cities hope to reach in a period of 3,5,10 years and then correlate it to policy interventions that are being planned. This will not only help in defining the baseline but also analyse policy in terms of its contribution to reducing air pollution and define how effective strategies can be scaled.

## Need for mainstreaming air quality

Mainstreaming air quality involves the active promotion of better air as a component while identifying, planning, designing and implementing development strategies and policies. Mainstreaming in this context refers to addressing air quality issues strategically as a cross-cutting aspect of development and goes beyond just air pollution mitigation to a more holistic and strategic approach to achieving sustainable development.

Mainstreaming requires considering the impact of air quality in the earliest stages of the decision-making process, when development challenges and proposed implementation plans are being designed. Taking into consideration air quality as an integral part of development planning- especially in the context of our cities can play a major part in achieving broader development objectives (World Health Organization 2014). It can also define how initiatives outside the conventional environment sector can be designed to support environmentally sustainable development.

Mainstreaming air quality means identifying interventions that create long-term economic development benefits and take better air quality into account. While the benefits of mainstreaming air quality exist, some basic considerations need to be understood for its practical and effective application. Attention to a problem such as air is typically understood in the development community as an exercise in recognizing and mitigating adverse environmental impacts of projects. This traditional understanding is the result of the emphasis placed on the implementation of policies designed to reduce adverse environmental impacts by development agencies. The protectionist approach focuses on compliance with certain procedural standards. However, we must go beyond this traditional approach to a conservation perspective and think about benefits. Instead of emphasizing cleaning up of air, we must therefore talk about clean approaches that take externalities into account and highlight economic benefits. The integration of air quality requires consideration of air at the earliest stages of the decision-making cycle in the context of development challenges and proposed interventions. Mainstreaming requires us to consider how interventions aimed at improving air quality can play an integral role in achieving environmental standards as a condition for achieving other objectives. It therefore requires a focus on proactive investment in policies and projects promoting air integration into development strategies.

China's Air Action Plan released in September 2013, may have been China's most influential environmental policy of the past five years. It helped China to make significant improvements to air quality by setting PM 2.5 targets for key regions, requiring significant reductions between 2013 and 2017 – of 15 per cent in the Pearl River Delta, and of 33 per cent in Beijing. This involved reducing PM 2.5 levels from 89.5µg/m³ down to 60. Beijing took very strict measures and closed its coal-fired power plants and prohibited people from burning coal for heat. This measure required strict deadlines and a strong connection to clean energy. It was

**Table 1: Ministries directly involved in Air Quality Management Framework**

| Ministry | Scope |
|---|---|
| Ministry of Environment, Forest and Climate Change | The Ministry implements policies and programmes relating to conservation of the country's natural resources including prevention and abatement of pollution. |
| Ministry of Earth Sciences | The Ministry promotes scientific research in the country in the field of air quality monitoring, source, air quality modelling studies and emission characterisation studies related to various pollutants. |
| Ministry of Science and Technology | The Ministry promotes research which facilitates greater understanding about ambient air quality and its implications on the environment, human beings, crops, animals, etc. |
| Ministry of Petroleum and Natural Gas | The Ministry is an active participant in efforts to reduce vehicular emissions from incomplete combustion and inappropriate usage of fuel. The ministry is also a participant in various inter-ministerial committees, which form policy framework for the air quality management in, the country, specifically related to automobile fuel policy. |
| Ministry of Health and Family Welfare | The Ministry undertakes various research activities on studying the impact of both 'Indoor Air Pollution' and 'Outdoor Air Pollution' air pollution on human health. |
| Ministry of Power | The Ministry emphasize the supply of clean power in the country by mandating conventional power generation to comply with the pollution control norms. |
| Ministry of Road, Transport and Highways | The Ministry is involved in the formulation of regulations relating to Emissions. Fuels and Alternative Fuel vehicles. |

also followed by other cities and provinces with a proactive involvement by the relevant stakeholders to mainstream air quality (2013-2017 Beijing Clean Air Action Plan).

In India, there are seven ministries that need to be directly engaged in air pollution action. Major air pollution policies and programmes for prevention and abatement of air pollution are conceptualised in the Ministry of Environment, Forest and Climate Change while scientific research in this area is within the purview of the Ministry of Earth Sciences. Vehicular emissions are highly debated and often the easiest target to attribute air pollution too. But it requires interventions related to clean fuel that needs active engagement of the Ministry of Petroleum and Gas and emissions control that requires inputs from the Ministry of Road, Transport and Highways otherwise achieving fuel efficiency standards would remain as a line item in the air action plan (Narain and Krupnick 2007).

Similarly closing down coal-fired power plants requires the direct intervention of the Ministry of Power and a shift in the country's overall energy policy. While clean energy, clean transport is common terminology in the sustainable development debate, its correlation to air, especially in India, is not clearly mentioned. Energy policy, as well as transport policy, needs to highlight the contribution to better air as well as define clear indicators for tracking the progress of air quality *vis-a-vis* policies implemented (Government of NCT of Delhi 2016).

## Why mainstreaming is a complex agenda

The Table 1 shows the Ministries that need to be directly involved in air pollution reduction in the country. India's electric mobility vision is technically a vision that can be achieved by policies from the Ministry of Road, Transport and Highways but the outcome of such a policy can be immediately correlated to better air quality, which is an environment domain. Similarly considering that inappropriate garbage burning is another contributory factor to air pollution in India cities

**Table 2: Ministries indirectly involved in Air Quality Management Framework**

| Ministry | Scope |
|---|---|
| Ministry of New and Renewable Energy | MNRE is actively working towards addressing problems related to Indoor Air pollution and Black Carbon. |
| Ministry of Coal | MoC indicated that industries now run the risk of even having their coal linkage cancelled if the transporters engaged by them are found flouting norms that lead to pollution due to spillage of coal particles that rise in the air. |
| Ministry of Corporate Affairs | The Ministry had mandated Corporate Social Responsibility activities for PSUs (Public Sector Undertaking) and given voluntary guidelines to corporate entities. These activities can eventually lead to air pollution control. |
| Ministry of Housing and Urban Affairs | The ministry has come up with various policies which are intended to reduce pollution, prioritizing the use of public transport and using clean technologies. |
| Ministry of Heavy Industries and Public Enterprises | The ministry has various projects aiming at industrial pollution control technologies with respect to air, water and solid waste to avoid unintended side effects of economic growth. |
| Ministry of Commerce and Industry | The Ministry recognizes the importance of environmental clearances in its 'Industrial Policy.' |

and India has a strict set of waste management at the city level there is a need to engage with local authorities since urban waste management falls under the purview of the urban local bodies.

Table 2 shows the Ministries that are indirectly related but do have a significant role in air pollution reduction. The Ministry of Housing and Urban Development is responsible for the Smart Cities Mission. Under the Mission, the liveability index mentions monitoring of key criteria pollutants for better air quality for citizens. If this is implemented with support from scientific organisations, it could create a system for an alternative air pollution monitoring strategy that engages public as well as links action taken within the smart cities mission-clean energy, waste management and improvement in public transportation with action for better air quality.

While the Central Pollution Control Board is responsible for setting standards for AQ and monitoring air pollution with the help of states, for policies like setting up vehicular emissions standards and as well implementing air action, other scientific institutions and government agencies have a significant role to play (CPCB 2013). Table 1 and Table 2 show the Ministries of the Government of India that can have an impact on air pollution-related research and interventions.

## How to mainstream air quality in development policy

The birth of the environmental sector makes compliance with the environment a component of development projects. However, a separate environmental sector and the perception that environmental issues are the sole responsibility of environmental departments have led to a sectoral approach to addressing challenges such as improved air quality Other departments other than the environment are not responsible for the fact that environmental protection is not an integral part of their policies and projects. Rarely do these departments have the procedures or capacity to hold them accountable. Moreover, sectoral development approaches conflict with mainstreaming of the environment by preventing synergies between sectors. For example, the benefits of improving urban air quality are not highlighted in the transport or energy sectors were necessary reforms are required to reduce emissions and must be implemented. Why else would India's enormous electric mobility and solar targets fail to measure its impact on air quality if it is successfully implemented? Therefore, mainstreaming requires revisions to institutional planning processes to ensure that air is integrated early and systematically into standard decision-making procedures and issues such as air. In addition, the possibilities for mainstreaming are limited by short-term planning and geographical objectives for projects and policies. For instance, many of the smart cities action focus on moving toward sustainable transportation be it non – motorised transport, infrastructure changes for creating walking and biking facilities and improved public transportation. Clean Air Asia is using a sensor based methodology to track the progress of this work in cities and assess the benefits to air quality if any.

Environmental sustainability can be achieved by assessing development programs and policies taking into account the ecosystem, which is not limited by political and geographical boundaries. For example, air integration would require consideration of consequences outside the region and the measurement of transboundary impacts. Finally, prescriptive planning and flexibility requirements can not achieve the mainstreaming agenda. For example, developers of agricultural or industrial projects can achieve compliance with environmental air quality policies by selecting technologies that result in emissions of pollution in accordance with relevant standards, or support farmers by promoting proper agriculture waste methods. This if we relate to the present situation in Delhi where very poor air quality is being attributed to stubble burning in Haryana and Punjab, cannot be solved in October but would need to be a well thought out process of development planning.

There are however, no pre-determined answers. The essence of addressing air pollution in India may be mainstreaming. It is, therefore, best approached by asking the right questions, involving stakeholders and creating a consultative decision-making that promotes innovative strategies and is inclusive, rather than making the issues political or religious in October-November.

### Need for mainstreaming: The classic case of Delhi

A disadvantaged geographic location and regional meteorology with windy and dusty conditions during summer contribute greatly to Delhi's air pollution. This is particularly worsened by low relative humidity that increases particle resuspension. In addition, there are episodic dust transport events from surrounding areas. As a land-locked megacity, there are limited avenues for the polluted air to be flushed out of Delhi. Nor is Delhi in the advantageous position of enjoying the replacement of air from relatively unpolluted marine regions. This means that atmospheric transport from all directions, adds to pollution in the city. Air, as we know, has no boundaries and when air is a transboundary problem, it requires a regional approach. Delhi's air pollution being a regional problem, there is very little that Delhi can do about it on its own. Unless the governments of Haryana, Punjab and Delhi work together to address the issue and look at collectively controlling the pollution from neighbouring power plants and biomass burning, residents of landlocked Delhi will continue to bear the brunt of bad air quality.

There are thirteen coal-fired power stations that operate in 300-kilometre radius of Delhi. Smoke from post-harvest burning in Haryana and Punjab reach Delhi in winter. A study conducted by the National Environmental Engineering Research Institute (NEERI) in Nagpur and the International Institute for Applied Systems Analysis (IIASA) showed that about 60 per cent of the PM 2.5 burden in Delhi is due to transboundary sources. If it does not adopt a regional approach and the cities collaborate, no policy is likely to work. Delhi's pollution must therefore be treated as a regional problem, if not national, and the efforts of interagencies must be monitored and coordinated by one agency.

Emissions sources are a challenge for Delhi. In the last decade, 15 source allocation studies have been carried out, 10 of which were based on a direct sampling method. Five are based on secondary information. There are many sources of air pollution in Delhi: About three million trucks and cars, many of which run on diesel, as well as about five million two-wheelers and a large number of trucks, many of which use the city for transit, building and road dust, industrial and power plants, and garbage burning and burning paddy stubbles in Haryana and Punjab. A large proportion of air pollution in Delhi is attributed as a source to road dust. This is a source that is particularly difficult to control.

### Conclusion

The solution lies in addressing air quality as a development- not an environmental problem and this calls for mainstreaming air quality, so we do not just discuss it when the air turns severe and hazardous in October in Delhi but right in the beginning when we look at our economic policy for the entire country. So, before every city becomes a Delhi let's look at a holistic approach that strengthens air quality management, not just in Delhi but all our cities. China has managed to reach targets not by publishing data or because of public demand but because the national government has included air quality management in the national planning process. India needs to strengthen the air quality linkage in policies like the Smart Cities Mission, Skill Development and Start-

Up India, Electric Mobility Policy, Fuel Efficiency Policy, Municipal Solid Wastes (Management & Handling) Rules, Construction and Demolition Waste Management Rules. At the implementation level coordination is required to assess policies with clear indicators for air pollution management so that the country can define the challenge of air pollution better and position itself strongly as strategic air pollution reducing country.

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# e-Governance for statutory clearances: PARIVESH

Hardik Shah[1]


## Abstract

In last five years, the Government of India has successfully promoted the use of Information and Communications Technology (ICT) to ensure development within the framework of transparency, accessibility and accountability with an objective to achieve good governance. PARIVESH (ProActive and Responsive facilitation by Interactive and Virtuous Environmental Single-window Hub) is one such example introduced by the Government in 2018 to bring more transparency and accountability in the environment, forest, wildlife and coastal regulation zone clearance processes.



## Keywords

*PARIVESH, e-governance, Ease of Doing Business, Environmental Clearance, Forest Clearance, Coastal Regulation Zone Clearance.*


## Introduction

The Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal agency in administrative structure of the Central Government for planning, promotion, co-ordination and overseeing the implementation of India's environment, forest and wildlife policies and programmes. The Ministry has a challenging task of achieving sustainable development by facilitating economic growth for poverty eradication, but at the same time, ensuring clean air, water and green environment for all. Unlike other areas, environment is a cross-cutting and multi-disciplinary subject requiring cooperation and collaboration with line ministries, states, local bodies and various stakeholders. Apart from its policy planning and legislating role, the Ministry administers various clearances under different environment, forest and wildlife statutes. Over the years, the Ministry had issued norms, standards and streamlined processes to expedite development and to ensure ease of doing responsible business without impacting the environment. It has also taken a number of steps to improve transparency, particularly in the last five years.

## Environment Impact Assessment in India

Environment Impact Assessment (EIA) is an important planning tool for ensuring optimal use of natural resources to achieve sustainable development. A beginning in this direction was made in our country with the impact assessment of river valley projects in 1978-79 and the scope has subsequently been enhanced to cover other important developmental sectors such as industries, thermal power projects, mining projects etc. for projects requiring clearance. To facilitate the collection of environmental data and preparation of management plans, guidelines have been evolved

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over a period of time in the last three decades.

Ministry, vide S. O. 60 (E) dated 27th January 1994, mandated prior environmental clearance for new/expansion/modernization of any activity pertaining to 20 sectors listed in the schedule to the notification. The Ministry has re-engineered the entire process of environmental clearance specified in EIA notification, 1994 and issued EIA notification, 2006 and its amendment from time to time under the provisions of the Environment (Protection) Act, 1986, to obtain prior environmental clearance either from MoEFCC for 'Category A' projects or the State Level Environment Impact Assessment Authority (SEIAA) for 'Category B' projects before commencing any activity. The prior clearances are also needed for carrying out any activities within the forest areas and the wildlife protected areas under the provisions of the Forest (Conservation) Act, 1980 and the Wildlife (Protection) Act, 1972 (MoEF 1972), respectively. Similarly, for the projects falling in the Coastal Regulation Zones, prior clearance under the Coastal Regulation Zone (CRZ) Notification, 2011/2019 issued under the provisions of the Environment (Protection) Act, 1986 is mandatory. Many a time, the large-scale projects planned in and around the protected areas and coastal zones would necessitate prior clearances under all these regulations, which prescribe the different procedure to be adopted for clearance although the document requirements would be same by and large barring certain specific conditions related to the subject.

## Issues and challenges

Due to strong regulatory framework, multiplicity of permits requirements and comprehensive clearance processes, the Ministry has been perceived as a roadblock in the development process. The MoEFCC, therefore, like other regulatory bodies, is also criticized for empire building, red-tapism, buck-passing and legacy of command and control. Further, due to non-integration of these clearances under various environmental and forestry regulations, the regulatory authorities find it difficult and complex to comprehend the overall impacts which further delays the appraisal process resulting into the anguish of project proponents.

On the other side, it is imperative to protect the fragile ecosystems and biodiversity not only for the present but also for the future generation, which are compromised to a great extent due to ill-conceived notions for appraisal of projects, lack of information and inadequate and inefficient monitoring mechanism. This also resulted in several litigations putting the regulatory authorities on receiving hands.

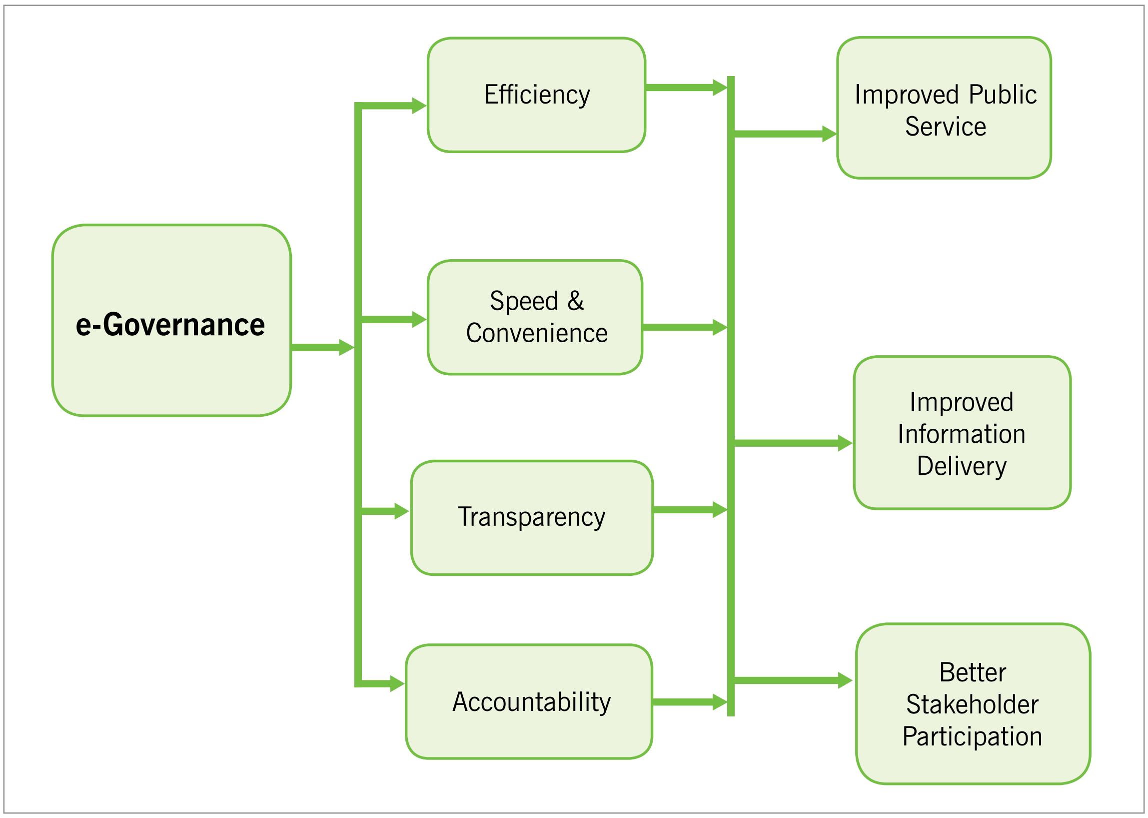
## e-Governance in environment sector

e-Governance is the application of information and communication technology (ICT) for delivering the public services, exchange of information, communication transactions, integration of various stand-alone systems and services between Government-to-Citizen (G2C), Government-to-Government (G2G), Government-to-Businesses (G2B) as well as back office processes and interactions within the entire government framework (DAR&PG 2008). As shown in the Figure 1, the implementation of e-Governance aims at efficient, speedy and transparent delivery of public services.

The process of e-Governance implementation in environment sector started almost two decades back but rather at an extremely lower speed than that is expected to meet the objectives of better delivery of public services as well as integration and exchange of information between various stakeholders.

There were several efforts made by the MoEFCC and various State Governments and State Pollution Control Boards (SPCBs) to introduce ICT in environment and forestry management, but could not achieve desired success, until the success of eXtended Green Node (XGN) (Shah and Advani

**Figure 1: Benefits of e-Governance**




2014) introduced by the Gujarat Pollution Control Board with technical support from National Informatics Centre (NIC), Gandhinagar for management of permissions/consents under the pollution control laws. XGN was later replicated in six SPCBs and fetched several national awards and recognitions.

With increased awareness about the need for ICT implementation in environment sector, the MoEFCC with the help of NIC-Delhi took a lead and developed a software named Online Consent Management and Monitoring System (OCMMS) for SPCBs, which is today implemented in about the 20 States for meeting their basic needs of consent management system under the pollution control laws administered by the SPCBs.

Further, in mid-2014, the MoEFCC launched a portal for online application for the prior environment and forest clearances and thus began the real era of e-Governance in India in environment and forestry sectors. Though this portal had many basic features like online submission of applications, generating and replying queries, uploading of minutes of the meetings of the Appraisal Committees and uploading of final clearance letters, the software didn't have logic to process the application. Though it was more of an e-Communication than e-Governance, as many people say, it paved the path for country's environmental governance through the use of ICT and implementation of e-Governance and also facilitated a two-way communication in green clearances which enhanced the speed of clearances. Further, few more initiatives have also been taken by the MoEFCC for online monitoring of ambient environmental quality and emission/ discharge qualities as well as hazardous waste tracking system, though, it lacked an integrated approach and was implemented in a compartmental manner.

## Need for an integrated approach for e-Governance implementation

India is developing rapidly now, but the delay in implementation of projects due to slow regulatory permit system has been identified as a major hurdle in the process. To meet with the general aspirations of development and providing employment, the slow regulatory process is a bottleneck. However, it is also important to have a robust mechanism to ensure environmental compliance for leading to the path of sustainable development. It was, therefore, imperative to work out a better strategy of implementing the regulatory mechanism that could not only result in ease of doing business but also help improve environmental compliance. A need was therefore felt for an integrated approach in managing these green clearances by having a more robust and comprehensive software.

## PARIVESH and Ease of Doing Business

After successful implementation of Phase I of e-Governance, the MoEFCC took a decision in February 2017 to prepare plan for Phase II for real implementation of e-Governance in environment sector with an objective to have good Governance through e-Governance. The need for integration of all these clearance processes, real-time tracking system, alerts at all stages of processing, online processing of application at all stages paved the path for the architecture of the software named “ProActive and Responsive facilitation by Interactive, Virtuous and Environmental Singlewindow Hub” – PARIVESH. While designing the Phase II architecture, the planning for next phases was also kept in mind for integration with GIS database of other Ministries in Central Government and that of the State Governments as well as those furnished in the EIA reports by the project proponents.

Aligning itself with Government of India’s vision of making India go digital and easy governance, the launch of ‘PARIVESH’ is a great propeller for ensuring central, state and district level environment, forestry, wildlife and coastal regulation zone clearances by re-engineering of business processes with the objective of having highly efficient, transparent, accountable and virtuous governance to help the business moving towards ease of doing responsible business by focusing more towards sound decision-making and enhanced compliance. It is a revolutionary step to open doors to new businesses with ease and transparency, mitigating red-tapeism and unnecessary delays. With this system in place doing responsible business in India with ease will get the necessary impetus in terms of mandatory clearances that were otherwise an arduous and labyrinth task.

## PARIVESH architecture

PARIVESH automates the entire processing of proposals which includes online submissions of the new proposal, editing/updating the details of proposals and displays status of the proposals at each stage of the workflow which is presented in detail in Figure 2, 3 and 4 below.

PARIVESH system is based on web architecture, using IIS as an application server, Net as a framework and SQL server as a database server. The technical details of the software are as follows:

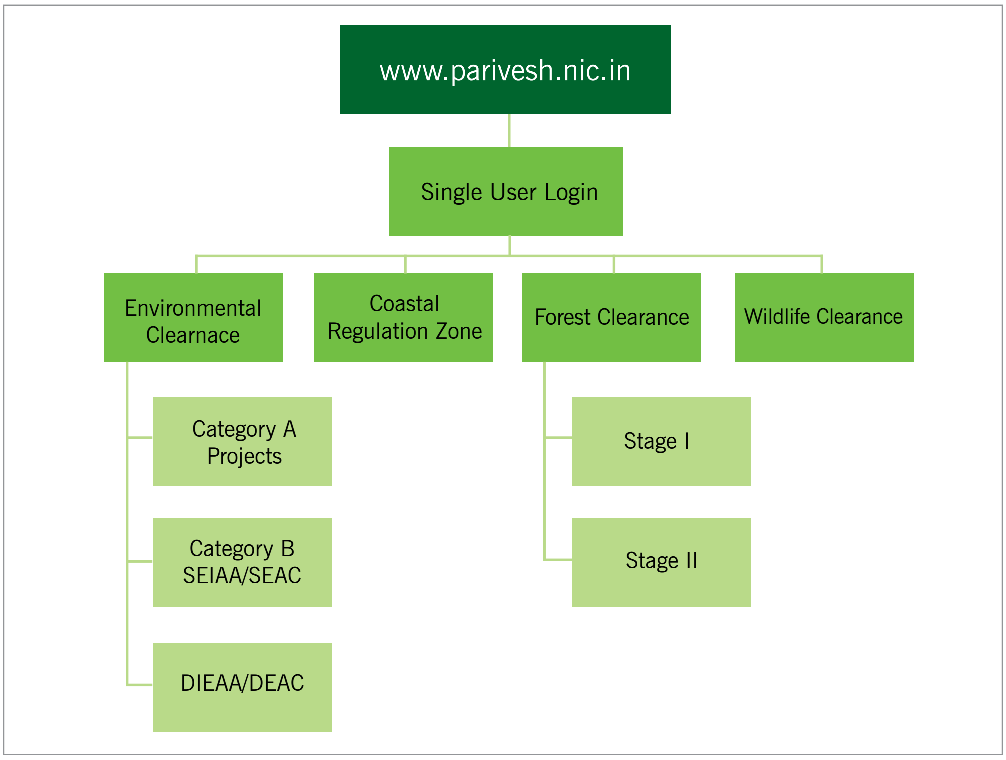
<u>Application Server</u>

| | | |
|---|---|---|
| Hosted at | : | NIC Cloud, NDC,<br>Shastri Park, New Delhi |
| Configuration :- | | |
| Storage | : | 60 GB |
| RAM | : | 32 GB |
| vCPU | : | 8 |
| Operating System | : | Windows Server 2012 |
| Web Serverz | : | IIS 8 |

<u>Database Server</u>

| | | |
|---|---|---|
| Hosted at | : | NIC Cloud, NDC,<br>Shastri Park, New Delhi |
| Configuration :- | | |
| Storage | : | 600 GB |
| RAM | : | 32 GB |
| vCPU | : | 8 |
| Operating System | : | Windows Server 2012 |
| DB Server | : | MS-SQL- 2012 |

**Figure 2: Workflow of PARIVESH**

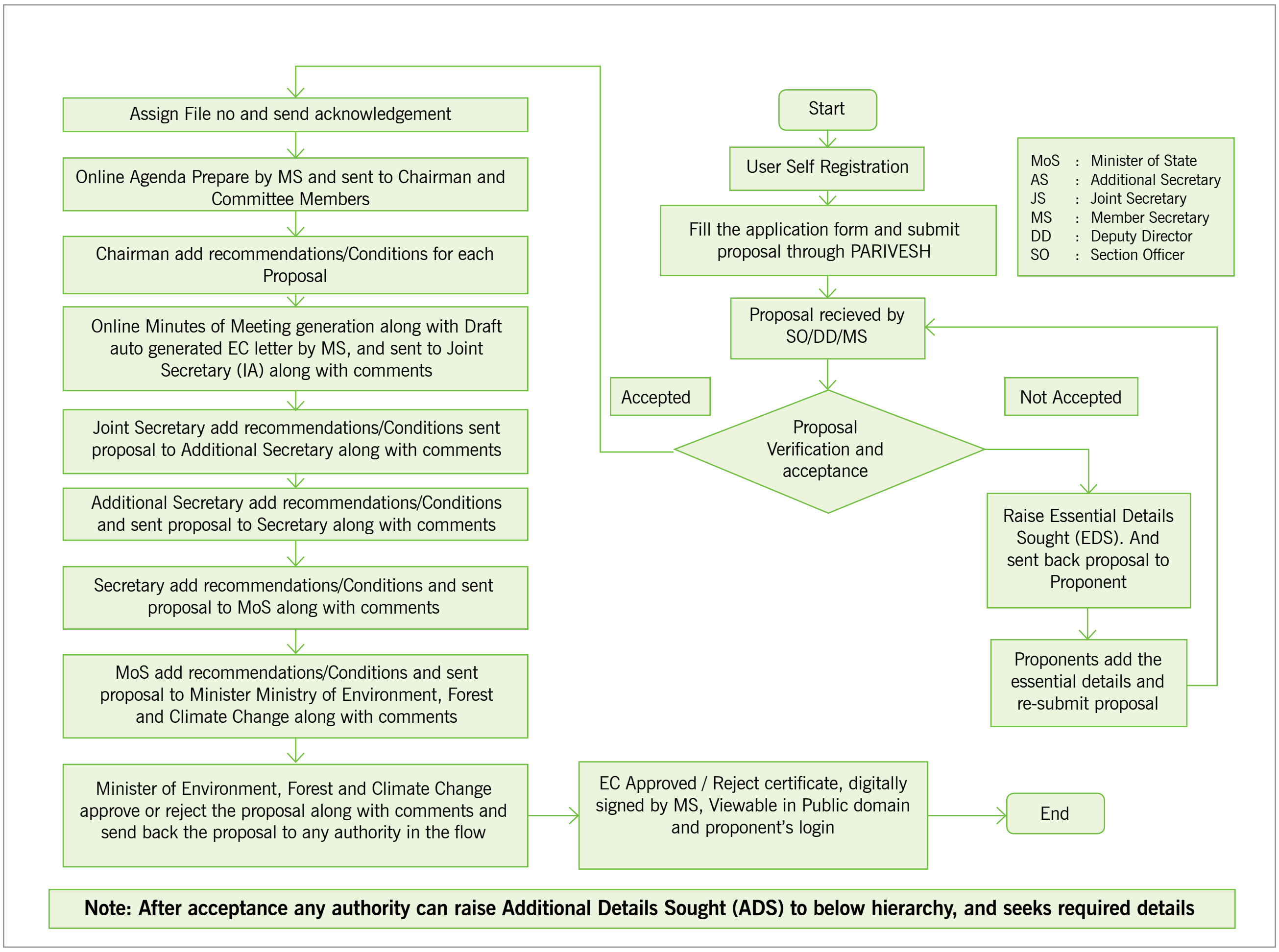



## Salient features and benefits of PARIVESH

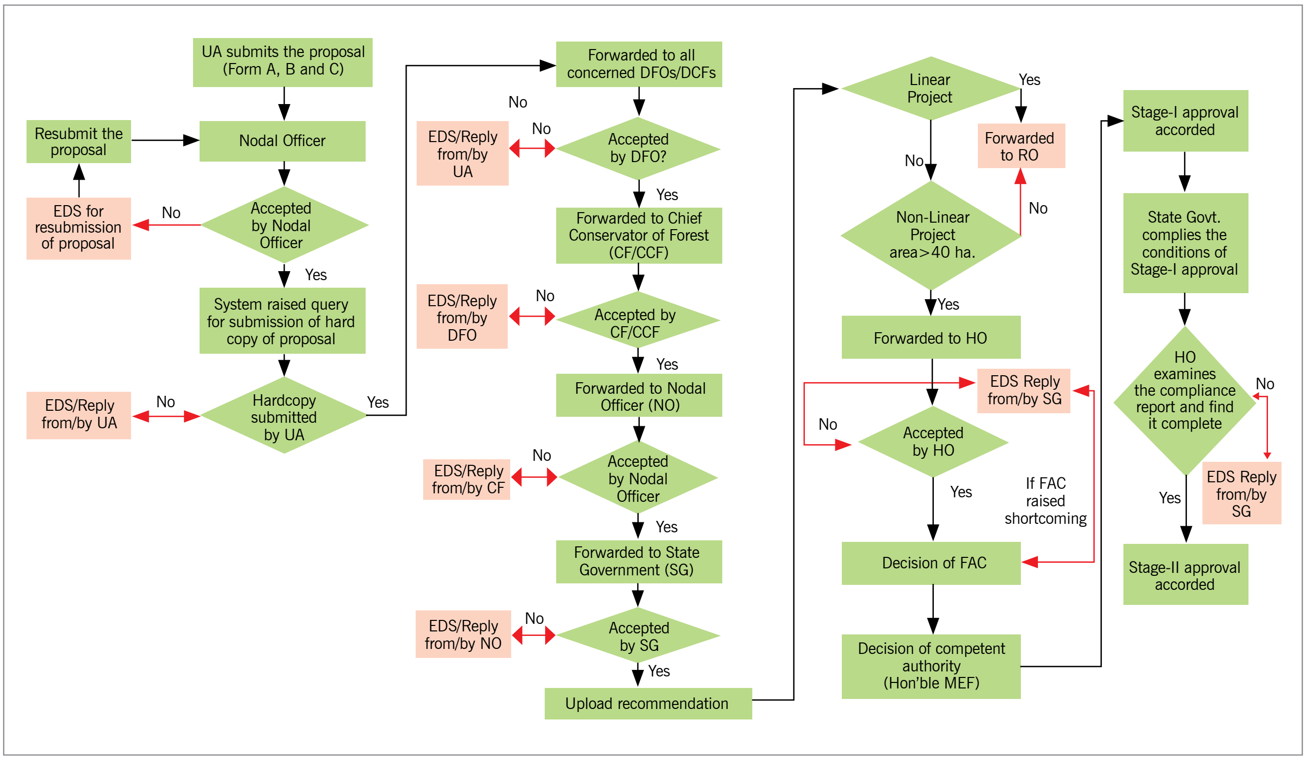
**Project proponents perspective:**

a. Online Registration of Proponents and Projects
b. Unique ID for all types of clearances required for a particular project
c. Single Window interface – the proponent to submit an application through single ID for getting all types of clearances (i.e. Environment, Forest, Wildlife and CRZ clearances)
d. The smooth transition to the digital world helps the user to apply, view, track, interact and respond to the process whenever he wants and wherever he is
e. Quick resolving of queries through an e-talk facility provided to the proponent
f. The system eliminates physical interaction with the Ministry
g. Supplemented by a Mobile App to match the vision of Hon'ble Prime Minister for mobile governance and governance on the palm of people to make them feel real fruits of democracy. The status of the application, agenda and minutes of meetings of appraisal committees can also be viewed anytime on a mobile phone through the PARIVESH App
h. SMS and Email module will notify the project proponent about all correspondences starting from submission of application, acceptance of application once fully complete with requisite documents, queries if any, agenda and minutes finalized, all important decisions upto decision-making stage in the clearance
i. Automatic SMS/Email alerts to proponent if compliance report is not submitted within the defined timeline – will help improve the environmental compliances
j. One Click dashboard for the entire workflow is also available on the portal from desk officer to the highest-level officers and even reaching the pinnacle of the structure with Hon'ble Minister himself being able to track applications and bringing transparency into the entire system
k. The project proponent will also get a bar chart for a number of days taken at each desk concerning their application
l. Hassle free clearance processes for ease of doing responsible business with a transparent system

### Figure 3: Environmental clearance workflow in PARIVESH




### Figure 4: Forest clearance workflow in PARIVESH



on the web. Made entire application process completely user-friendly – Ministry shifting the focus of being a facilitator to improve the compliance then merely a regulator for enhancing environmental compliances

m. Linkage of the software with Green Skill Development Program (GSDP) webpage and other similar programs would help easily identify the requisite skilled manpower needed by the project proponents – project proponents would be able to contact the skilled personnel trained under the GSDP based on skill profile or geographical distribution using various filters. This will further be linked to the Skill India Mission database at a later stage to facilitate the businesses/project proponents to identify the requisite manpower in other skill pools too.

**Ministry's perspective:**

a. With the launch of this portal, Ministry of Environment, Forest and Climate Change has become first of its kind in regulatory ministries to strive towards highly transparent, efficient and accountable e-governance system in dealing with its stakeholders

b. Through further improved efficiency, transparency and accountability in the Ministry's functioning, there will be great image building from that of merely a regulator to more of a facilitator driving the pace towards sustainable development through ease of responsible business while improving environmental compliances

c. Will achieve standardization in clearance processes across the states – will help eliminate subjectivity to a great level by informed and improved decision-making

d. A single software application for the district, state and central level clearances – bring in uniformity across the country

e. Workflow based Government-to-Government (G2G) and Government to Citizen (G2C) application

f. Integration of PARIVESH (through web services) with various state applications adopted by their SPCBs for their clearances

g. Auto-generation of agenda, minutes of the meetings and approval letters by the system. This will reduce the manual work of the Ministry helping enhanced efficiency and making them focus more on compliance improvement for cleaner and greener India

h. Geographic Information System (GIS) interface is available for the Appraisal Committee, thereby enabling them to view the geographical information, which will help in analyzing the proposal efficiently and more accurately while eliminating the subjectivity

i. Geo-tagged images of the project site can be uploaded at the time of site visit by officials through the mobile application resulting in enhanced compliance monitoring

j. Automatic Alerts (via SMS and email) at all important stages to the concerned officers, Committee members and proponent. Alerts are sent to higher authorities via SMS and mailers in case of delays beyond the requisite timeline This would help better review process and further reduce the delays, if any, in processing.

k. The workflow monitoring by the senior most level officer and Ministers, which would further enhance the accountability and transparency in the whole system

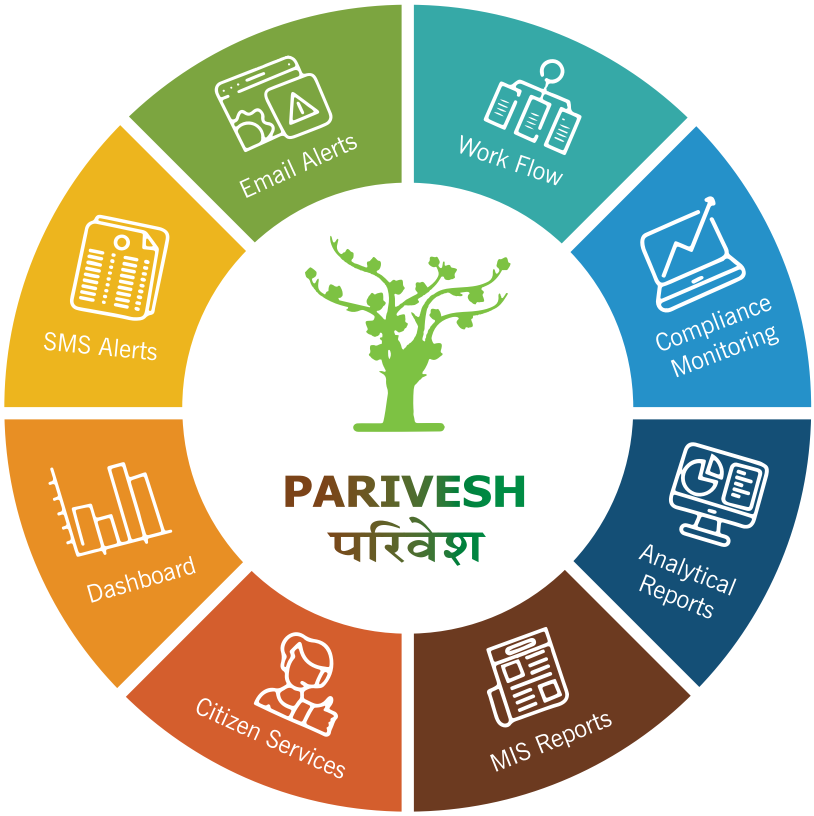
l. Dashboard based dynamic graphical analysis for decision support. Various analytical reports which will help in improving the performance and efficiency of the whole appraisal process

m. Most of the details related to projects are available in the public domain which will further enhance the credibility of the decision-making process and also reduce RTI queries

n. Structural changes have also been ushered in, to make the entire process paperless with online queries and SMS alerts resulting in considerable reduction of exchange of letters to gradually shift towards complete e-processing of files to support the aim of Digital India

o. The database created through this

**Figure 5: PARIVESH: Some important features**




re-engineered version of the clearance process would pave the path for the next phase of GIS-based environmental, biological, geophysical and socio-economic database. This will help identify the hotspots for better planning and policy-making process as well as a lead towards self-decision making by the project proponents in next phase eliminating the conflicts at a later stage in project planning and execution.

### Citizens and society perspective:

a. Easy access to information and services – will enhance the ease and convenience of citizens
b. All important information to be in the public domain – will build the confidence of citizens while improve relationship between Government, citizens and businesses
c. Improved environmental quality due to enhanced compliances
d. Availability of details of each project in the public domain gives a clear picture of the clearances accorded to the projects and their likely impact on the environment as well as mitigations proposed
e. Timeline for each stage is available in the public domain which will bring transparency in the system
f. Better management of socio-economic aspects through the compliance module – protection of their equitable rights through the transparent system for enhanced compliances
g. Increased opportunity for employment by easy access to information about the needs of the project proponent about the skilled and unskilled manpower through the vacancy of employment module to be provided for the project proponents.

### Conclusion

PARIVESH demonstrates that a good justice delivery mechanism and an entrepreneur-friendly environment is possible, even with a small and less intrusive government. The enhanced efficiency in environmental governance has successfully balanced national security concerns with developmental imperatives while ensuring environmental protection and sustainable development.

Good governance is the cornerstone of sustainable development. The ICT initiatives of Ministry is in line with the principle of 'Minimum Government, Maximum Governance', to make lives of common man easy while ensuring inclusive, sustainable development. The focus is on nation building while meeting the basic, developmental and aspirational needs of more than 1.3 billion Indians by accelerating economic growth which is environment-friendly. The smart and extensive use of ICT with the launch of 'Digital India', has created a platform enabling seamless delivery of services and has transformed the way of life and way of Governance in India. Transparency, Accountability and Ease as well as Speed of doing responsible business has improved significantly in the last five years.

In last few years, things have significantly improved as the Ministry reviewed, revised, simplified and streamlined the norms, standards and processes for pollution control as well as enhanced transparency related to environment and forest approvals. The information has been made online and simple enough for easy public access and consumption (MoEFCC 2018). Some of the major achievements due to e-governance initiatives undertaken by the Ministry are as follows:

- The process for environmental clearances, coastal regulation zone clearances and forest clearances have been streamlined with the minimal public interface
- The number of days taken in granting Environmental Clearances (EC) has come down substantially from 600 days in 2014 to 140 days in 2018
- CRZ clearances are now granted within a period of 60 days at MoEFFC
- Integration of the EC/CRZ applications with that of the Forest Clearances/Wildlife applications
- e-governance has also been extended to different states of the country (SPCBs) for streamlining their "Consent Management System", State Level Environment Impact Assessment Authorities (SEIAAs) for expediting environmental clearances and the State Forest Departments for forest and wildlife clearances to bring in transparency and accountability.

To conclude, these initiatives have improved efficiency, transparency, accountability and also global ranking of our country towards, ease of doing business while practically demonstrating to the world the way of living and developing harmoniously with nature.

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SECTION FOUR

# Climate change

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# Climate change

For solutions to global environmental issues, India believes and pursues multilateralism, while bilateral environmental matters are to be resolved through mutual efforts and bilateral approaches. As a responsible nation, India is proactively addressing and fulfilling its obligations under various Multilateral Environmental Agreements.

Climate change is a global problem where developed countries had promised the world at the 1992 Earth Summit to take a lead in addressing it and also partnering with developing countries to enable their preparedness by providing new and additional financial and technological resources. Developing countries agreed to follow a greener, cleaner path of development and not the conventional path dominated by fossil fuel dependance.

The United Nations Framework Convention on Climate Change notes that the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and developmental needs.

The problem of climate change remains to be tackled largely owing to inaction and apathy of developed nations. Continued wasteful consumption and production by rich countries is the root cause of this problem which is slowly but surely taking Earth towards a path of ruination. The Intergovernmental Panel on Climate Change's Special Report on 1.5°C, scientifically informs us in no uncertain terms that the beginning of the end is here unless we reinvent our convectional fossil fuel based system. As still most of the world's population has no or limited access to energy, there is a need for rich countries to become sustainable and vacate the carbon space for the poor to live. Fading interest in multilateralism, growing inequity and disrespect for climate justice is a challenge impacting climate debate. There are no easy solutions.

India is a developing country with limited financial resources. The country is striving to provide basic facilities to its growing population while meeting their developmental aspirations. Climate change further adds to our already growing developmental challenges. Majority of the country's economic sectors are vulnerable to the impact of climate variability. Transition to a low carbon ecosystem is cost-intensive even for developed countries. The poorer sections of the society are worst affected. Mainstreaming and integrating climate imperatives into developmental sectors require technological support, skill and capacity development and upgradation, and substantial financial investments. India's Nationally Determined Contributions (NDCs) submitted to the UNFCCC in 2015 is a combination of the country's traditional values (in the form of sustainable lifestyles) and present-day aspirations. Implementing measures to promote adaptation of our varied ecosystems and rural populace are key priorities of India.

India through optimally deploying its domestic resources has achieved a reduction in its emission intensity of GDP by 21 per cent over the period 2005-2014. The country is well on track to meet its

Copenhagen commitments of achieving reduction of the emission intensity of its GDP by 20-25 per cent from 2005 levels until 2020. There are several actions afoot at national and sub-national jurisdictions to combat climate change. However, to meet its Paris commitments and implement NDCs, India requires new and additional financial, technological and capacity support, which is yet to be realised.

At the level of United Nations, there is a tendency to segregate environmental issues such as climate change, biodiversity loss, land degradation and ozone hole which are albeit all linked in one way or the other among themselves. However, there are separate conventions, treaties and agreements catering to each of these issues. For a vast developing country like India, these problems knock at our door collectively presenting a formidable challenge, and coax us to address each of them. This distracts our scarce resources, manpower and attention from immediate, basic and developmental needs of 1.21 billion Indians.

This section contains four papers covering contemporary themes on various aspects of climate change including observed impacts of climate change, implementation of NDCs, geoengineering research activities in India and on using energy models to inform policy.

**Guest Editor**

# Observed impacts of Climate Change in India

Lokesh Chandra Dube[1]

**Abstract**

Due to its varying physical features, diverse socio-economic profile and a wide range of climatic conditions India is vulnerable to the impacts of climate change. A significant temperature increasing trend of 0.66°C per hundred years has been observed in India. The impacts of climate change get aggravated by increasing severity and in the frequency of extreme weather events. This article draws examples from latest scientific evidence of the observed impacts of climate change in India on the sectors such as Himalayas and Glaciers, Water Resources, Forests and Biodiversity, Agriculture, Coastal and Marine Ecosystems. The article also draws attention to the latest efforts being undertaken to conduct systematic observation and understanding of the impacts of climate change in India through initiatives such as long term ecological observatories programme. The article concludes with a suggested framework for systematic and coordinated research in this direction.

**Keywords**

*Climate Change, India, Impacts.*

## Introduction

India is a developing country with limited financial resources. The country is striving to provide basic amenities to its growing population. Climate change, a global problem, further adds to its already growing developmental challenges. Majority of the country's production/economic sectors are vulnerable to the impacts of climate variability and change.

This article presents an overview of the recent evidence of the impacts of climate change in India. The article starts with a general discussion on climate change including observations and projections cited in recent IPCC reports and national reports. Thereafter the discussion moves on to the observed impacts in the identified key sectors of national significance namely, Himalayas and Glaciers, Water resources, Agriculture, Forests, Marine and Coastal ecosystems. These sectors reasonably represent the major sectors that face the impacts of climate change due to inherent vulnerability. Figure 1 shows the relationship of these climate-sensitive sectors and the 'worst-hit' groups. These groups have high exposure to the worst impacts of changing climate as they are dependent on the climate-sensitive sectors for their livelihood, food and shelter. These groups also have the low adaptive capacity that makes them vulnerable to the risks posed.

## Climate change and its impacts

A greenhouse maintains temperature conditions

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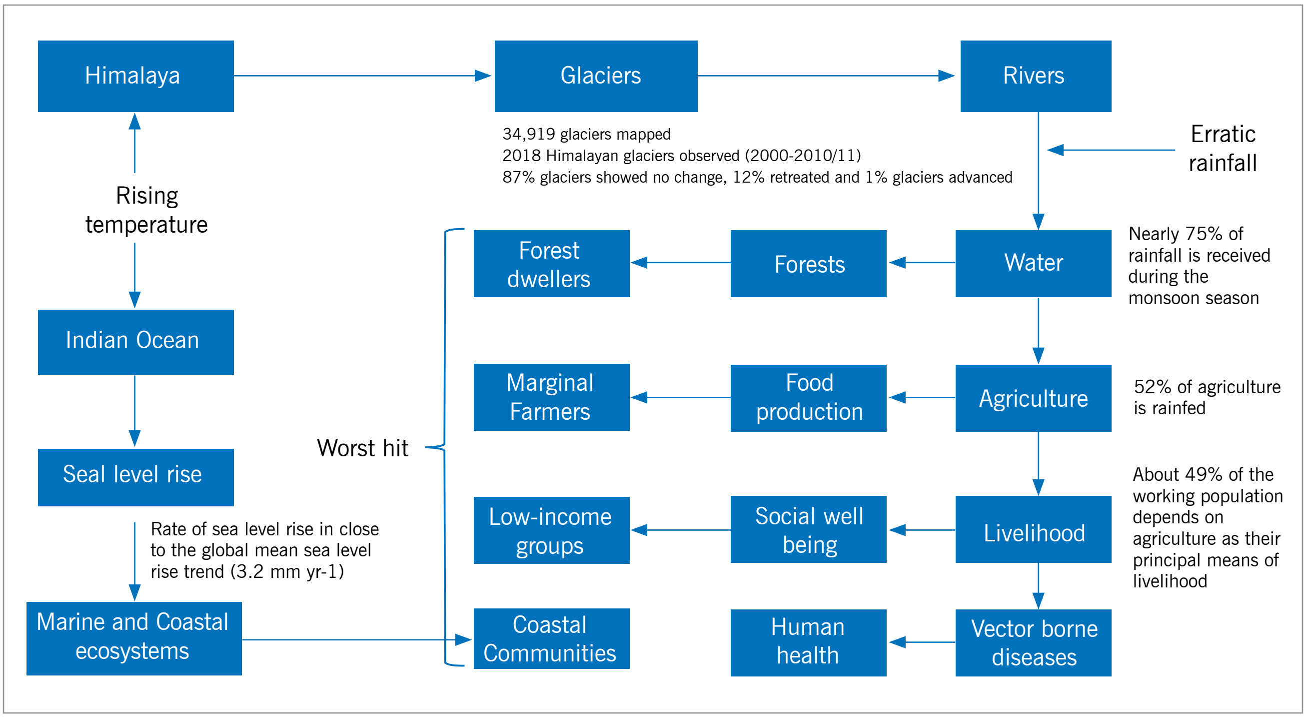
**Figure 1: Climate Sensitive sectors and worst hit groups**




optimum for the growth of plants. Similarly, the planet earth also has a natural greenhouse cover made of certain gases known as Greenhouse gases (such as $CO_2$, $CH_4$, $N_2O$, $H_2O$) which maintain temperature conditions optimum for the sustenance of life on earth. Continued and overwhelming emission of greenhouse gases due to human activities causes additional warming and long-term changes in the components of the climate system, increasing the possibility of severe, widespread and irrevocable impacts on society and ecosystems (IPCC 2014).

United Nations Framework Convention on Climate Change (UNFCCC) defines Climate Change as "*Change in Climate attributed directly or indirectly to human activity that alters the composition of global atmosphere and is in addition to natural climate variability over comparable time periods.*" (United Nations Framework Convention on Climate Change, 1992)

To assess scientific, technical and socio-economic information concerning climate change, its potential effects and options for adaptation and mitigation, World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC assesses research on climate change and synthesizes it into 'assessment reports' every 5–7 years. The latest in the series of such reports are the volumes of the Fifth Assessment Report (AR5) of IPCC released in 2013 and 2014. The Special Report on 'the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty', is the first publication in the Sixth Assessment Report (AR6) cycle of IPCC. Key highlights from IPCC SR 1.5 (IPCC 2018) are given in the following bullets:

a. Average global temperature has increased by about 1.0°C as compared to pre-industrial levels due to anthropogenic actions. Extreme weather events have increased, both in severity and in occurrence

b. The effects of temperature rise on people and ecosystems at 1.5°C are much greater than previous scientific reports originally expected

c. The overall impact at 2°C is well above 1.5°C and will be disastrous for the developing countries

d. The Paris Agreement's objective of limiting temperature increase to 2°C needs to be reviewed. The target now needs to be strongly set at 1.5°C for a safer world

d. To remain under 1.5°C temperature rise, the world will have to reduce $CO_2$ emissions by 45 per cent from 2010 levels by 2030 and attain net zero emissions by 2050

e. Even with a warming of 1.2°C, which is slightly higher than the annual global average, India is severely impacted. The impact at 1.5°C would increase significantly and be devastating for farmers and coastal communities at 2°C

f. The report highlights a number of climate change impacts that could be avoided by limiting global warming to 1.5°C compared to 2°C, or more. For instance, by 2100, global sea level rise would be 10 cm lower with global warming of 1.5°C compared with 2°C. The likelihood of an Arctic Ocean free of sea ice in summer would be once per century with global warming of 1.5°C, compared with at least once per decade with 2°C. Coral reefs would decline by 70-90 per cent with global warming of 1.5°C, whereas virtually all (> 99 per cent) would be lost with 2°C

g. The report finds that restricting an unnatural weather change to 1.5°C would require "quick and expansive" advances in land, vitality, industry, structures, transport, and urban communities. Worldwide net human-caused emanations of carbon dioxide ($CO_2$) would need to fall by around 45 per cent from 2010 dimensions by 2030, achieving 'net zero' around 2050. This implies any residual outflows should be adjusted by expelling $CO_2$ from the air.

## How impacts are placed in negotiations

The Convention sets an ultimate objective of stabilizing atmospheric concentrations of greenhouse gases at a level that prevents dangerous anthropogenic interference with the climate system. Such levels, which the Convention does not quantify, should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed sustainably. To achieve this objective, all countries have a general commitment to address climate change, adapt to its effects, and report on the action they are taking to implement the Convention.

As per Article 3.1 of the Convention: "The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof."

## Warsaw International Mechanism (WIM) on Loss and Damage

The mechanism was established at the COP19 in Warsaw, Poland. It addresses losses and damages associated with the impacts of climate change, including extreme events and slow onset events in developing countries that are particularly vulnerable to the adverse effects of climate change. Article 8 of the Paris Agreement addresses the issue of Loss and Damage. The Article calls for the WIM to be subjected to authority and guidance of the Conference of Parties serving as Meeting of Parties to the Agreement (CMA) and the latter shall collaborate with other bodies to enhance understanding, action and support in areas such as early warning systems, emergency preparedness, and risk insurance facilities. Although paragraph 51 of the decision 1/CP.21 states that Loss and damage under the Paris Agreement will not 'involve or provide a basis for any liability or compensation', it nonetheless, does not rule out the financial support for other elements of Loss and damage.

Finance has always been one of the focal issues in the negotiating process of UNFCCC. It is closely linked to mitigation, adaptation, technology transfer and capacity building. It is an important criterion to judge whether developed countries have effectively assumed the historical responsibility or not, and hence a core concern of developing countries.

Paris Agreement states that "developed country achieve the goal of jointly providing USD 100 billion annually by 2020, and set a new collective quantified goal from a floor of USD 100 billion per year prior to 2025" (UNFCCC 2015). However, the Agreement does not specify how developed countries share the financing responsibility in the future, nor it plans a clear road-map to realize the annual financing goal of USD 100 billion per year by 2020.

## India's vulnerability

Because of its enormously diverse socio-economic profile; a topography that includes some of the world's highest glaciated peaks and a long coastline; and a climate ranging from cold to hot tropical, India is especially vulnerable to climate change. The unique geo-climatic circumstances also make the country vulnerable of floods, droughts, cyclones, urban flooding, landslides, avalanches and forest fire. Out of India's 36 States and Union Territories in the country, 27 are disaster prone. Around 12 per cent land is prone to flood and river erosion, of the around 7,500 km coastline, 5,700 km is prone to cyclones; 68 per cent of the cultivable land is vulnerable to drought; hilly areas are at risk from landslides and avalanches; and 15 per cent of the landmass is prone to landslides (MoEFCC 2018). Climate change risks in India are further compounded by changing demographics and socio-economic conditions, unplanned urbanization, development within high-risk zones, environmental degradation, natural disasters, geological hazards, epidemics and pandemics.

India has a long coastline of around 7,500 km and the coastal region comprises 78 districts in the nine maritime states. There are around 1,238 large and small islands in India which are vulnerable to the impact of climate change. The coastal populations and their livelihoods are vulnerable to sea level rise. The rate of sea level rise in India is comparable to the global mean sea level rise trend (3.2 mm $yr^{-1}$). The sea level along the Indian coast increases from 0.33 to 5.16 mm per year and the pattern is projected to continue.

As an emerging economy, India has a strong global focus on mitigation and adaptation. India needs to meet its growing demand for energy in the backdrop of increasing greenhouse gas emissions. Though 16 states have achieved 100 per cent household electrification (MoP 2018), a sizable population in remaining states remains without access to electricity.

HSBC Global Research report (Paun *et al*. 2018) ranks 67 developed, emerging and frontier market countries for their vulnerability to climate change risks. Overall vulnerability of countries were assessed by assigning equal weights (25 per cent) to each of four indicators: (1) physical impacts; (2) sensitivity to extreme weather events; (3) energy transition risks; and (4) a country's potential to respond to climate change, covering financial resources and national governance indicators. Based on the assessment, India was found to be the most vulnerable to climate change. Germanwatch, a German non-governmental organization published Global Climate Risk Index 2019 (Eckstein *et al*. 2018) which analyses the extent to which countries and regions have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.). The most recent data available — for 2017 and from 1998 to 2017 — were taken into account. According to the report, India ranked 14th in the list of 181 countries for the climate risk index. According to the report, India lost 13,789.86 million USD of its GDP (PPP) in 2017 due to extreme weather events. Average annual loss for the period of 1998-2017 was 12,822.71 million USD which was third largest after the USA and China.

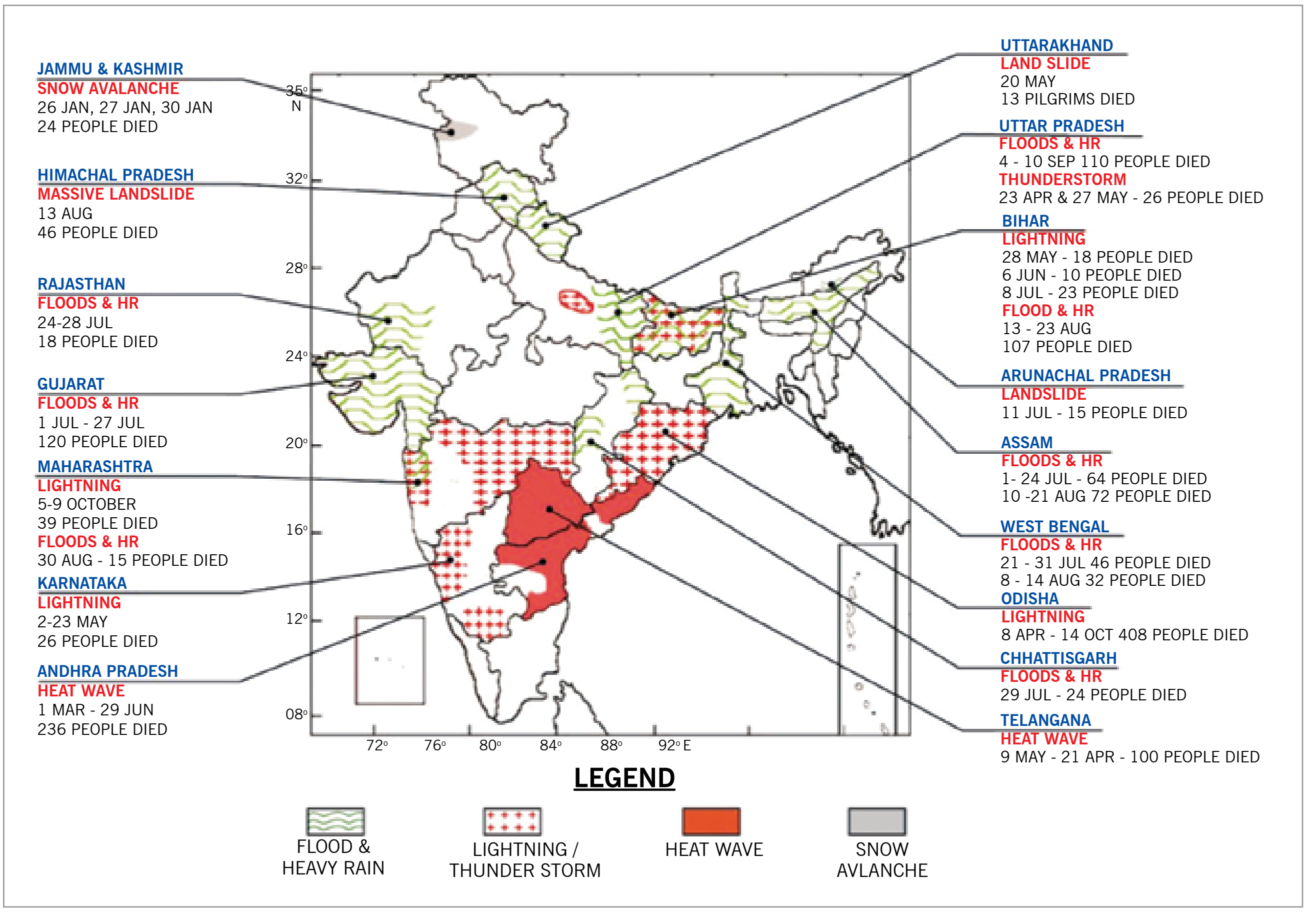
## Extreme weather events

India is experiencing extreme weather events resulting in enhanced exposure to multi-hazard vulnerability with adverse impact on ecosystems, natural resources, agriculture and socio-economic profile. Nearly two-thirds of India's agriculture – the mainstay of its economy – depends on the monsoon. The erraticism of monsoon rains is increasing, with more frequent and intense extreme events such as drought and floods. Minimum temperatures are changing across India, far above changes attributed to natural climate variability.

In line with the increasing trend witnessed in global surface temperatures, the average yearly temperature over India for the period 1901-2017 also showed a significantly rising trend of 0.66°C over 100 years. Extreme events like heat waves have risen in the last 30 years (MoEFCC 2017).

India's vulnerability to natural hazards can be gauged from the fact that it experienced 431 major natural disasters during the period 1980-2010, resulting in huge loss of human lives, property and resources. India suffered an absolute loss of USD 79.5 billion during 1998-2017 (CRED and UNISDR 2018). There have also been 19 major earthquakes of 6.5-9.2 magnitude on the Richter scale during the period 1819- 2016 (MoEFCC 2018) which further increases the vulnerability in the phase of climate change. Figure 2 gives a national map of significant weather events during 2017.

**Figure 2: Significant weather events during 2017 (IMD n.d.)**



Increasing frequency and intensity of disasters related to climate change impacts on weather systems, ecological dynamics and natural resources, reflect the need to adopt measures for disaster management and climate change adaptation. Climate change is known to increase people's vulnerability by intensifying underlying factors, besides aggravating frequency and intensity of hazards.

The action plans to combat climate change and natural hazards should have dual objectives of Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR). For both CCA and DRR, the major shared objectives include protecting developmental goals through effective planning, managing risks and uncertainties. Early warning of extreme weather events is one of the critical components of DRR. For this purpose, the country has developed modern meteorological observation systems (Satellites, Doppler Weather Radars, GPS Radiosonde, AWS/ARG, Wind Profiler Radar).

The Earth System Science Organization-India Meteorological Department (ESSO-IMD) and the Indian National Centre for Ocean Information Services (ESSO-INCOIS) are responsible for monitoring, detecting and forecasting severe weather events and for issuing flood warnings to India's rivers.

## Projected impacts

The Government of India had conducted a scientific study to assess the impact of climate change and a report entitled "Climate Change and India: A 4X4 Assessment - A Sectoral and Regional Analysis for the 2030s" was published in 2010 (MoEFCC 2010). This is the most recent report of the Government of India dedicated to the projection of impacts. Based on literature review, modelling, projections and evidence-based research, the study has assessed impacts of climate change on four key sectors of Indian economy namely, Agriculture, Water, Natural Ecosystems and Biodiversity and Health in four climate-sensitive regions of India namely, the Himalayan region, the Western Ghats, the Coastal Areas and the North-East Region. The report projects climate parameters and related impacts on the mentioned sectors. The report projected changes in agriculture production including losses in some crops, change in the composition of the forests and Net Primary Productivity and spread of Malaria in new areas. Other projections include:

### 1. Climate projections

Climate change scenarios in the 2030s show an increase in temperatures in all the regions concerned. The net annual temperature increase in the 2030s varies from 1.7°C to 2.2°C compared to the 1970s, with extreme temperatures rising by 1-4°C and a maximum increase in coastal areas.

### 2. Sea Level Rise and extreme events

Extreme rainfall events, average and extreme precipitation during monsoon will increase. The sea level along the Indian coast has increased at a rate of 1.3 mm per year (20 years average) and is likely to rise in future as the global sea level increases. For the east coast, extreme events are expected to be more catastrophic.

### 3. Projected impacts on Agriculture

Irrigated rice is likely to gain slightly in yields due to changes in temperature compared to rainfed rice, as irrigated rice tends to benefit from the $CO_2$ fertilization effect. Wheat yields in Indo-Gangetic Plains will be reduced. Maize and sorghum are projected to reduce yields in all regions. Monsoon sorghum yield will reduce by 2 to 14 per cent by 2020, with worsening yields by 2050 and 2080. The western coastal coconut productivity is projected to increase and decrease in the eastern coastal area. Observations show a reduction in the production of apples in the Himalayan region, which is likely to continue in the future. Evidence also suggests shifting of apple belts from lower to higher altitudes.

Some species gain in yields in the case of marine fishing, as the warming trend favours their productivity, such as sardines. Some species, such as Indian mackerel, probably move up to the higher latitudes to maintain their production rates. Species like Threadfin breams can change their breeding seasons to the season that support spawning temperatures adequately. Thermal humidity index is projected to increase in all the regions, especially in the months of May and June, leading to stress to the livestock and hence a reduction in milk production. The agricultural loss is estimated to be more than USD 7 billion (INR 49 billion) in 2030; severely affect the income of 10 per cent population.

### 4. Projected impacts on water resources

Water yields depend on rainfall, total surface area, evapotranspiration as well as soil properties. In Himalayan region the water yields are expected to rise by 5-20 per cent in the 2030s. In the 2030s, moderate to extreme drought severity in the Himalayan region is forecasted in comparison with the other regions. All regions are likely to face floods that exceed existing magnitude by 10- 30 per cent.

### 5. Projected impacts on forest productivity

Over one-third of the areas under forest will witness change mostly from one forest type to another by 2100. A 23 per cent increase in net primary productivity in the Western Ghats, 20 per cent increase in the north-eastern region, 57 per cent increase in the Himalayas and 31 per cent rise in the coastal region are expected in the 2030s.

## Evidence of observed climate change from India

Changes in surface air temperature in India between 1956 and 2005 are attributed to anthropogenic forcing mainly by greenhouse gas emissions and counterbalanced by other human-induced forcings, such as aerosols and land use, land cover change (Dileepkumar *et al*. 2018).

### Himalayas and Glaciers

There are a few regions in the world where climate change might be as rapid as found in case of a Himalayan region, and even very low where the penalty of climate change is likely to be as severe for biodiversity, ecosystems services and human well-being (Chaudhary and Bawa 2011).

Himalayan Cryosphere plays an important role as a sensitive indicator of climate change and as a major source of water for northwest to northeast Indian region. Himalayan snow cover monitoring for 33 sub-basins of Indian region is being carried out since 2004 (from October to June) using AWiFS data of Resourcesat-2 satellite at every five-day interval. The analysis of the snow cover products shows no significant increase or decrease in snow cover during the 2004-2016 timeframe. The glacier inventory carried out on 1:50,000 scale using Resourcesat-1 AWiFS and LISS III satellite data shows 34,919 glaciers covering 75,779 sq km area in Indus, Ganga and Brahmaputra basins of Himalayan–Karakoram region. Changes in 2018 glaciers of Himalayan region have been observed for the timeframe between 2000 and 2010/2011 using multi-date satellite data. The analysis depicted that 87 per cent of the glaciers showed no change, 12 per cent retreated and 1 per cent glaciers have advanced.

In addition, six hundred and seven (607) glaciers of the Karakoram region were also monitored using satellite data of 1977-2013. Around 341 glaciers exhibited no change throughout the 36 years of the study. In remaining glaciers, fluctuations have been seen, however no sustained pattern of retreat or advance was observed.

The Indian Himalayan Region has many glaciers that are directly affected by climate change. Over the course of 14 years (1999–2013), the Chandra basin has lost 5.01 ± 2.48 Gt of ice mass, providing a clear indication of the impact of climate change on the Himachal Pradesh district of Lahaul–Spiti, India, and how climate change could cause glacier health imbalance (Ramsankaran *et al.* 2019). (Chevuturi *et al.* 2016) found that the Leh's climate shows a warming trend with lower precipitation.

## Water resources

Streamflow in most river basins in the Indian subcontinent is more susceptible to changes in precipitation during the monsoon season than air temperature (Mishra and Lilhare 2016).

Climate change can substantially affect water availability in India (Immerzeel *et al.* 2010). Climate change projections of the monsoon season precipitation are largely uncertain (Turner and Annamalai 2012), (Asharaf and Ahrens 2015). The severity of droughts is projected to increase in many parts of India under climate change (Mishra and Liu 2014).

## Agriculture

Due to an increase in the minimum temperature of upstream waters of the Ganges river by 1.5 °C over a 30-year period, the Indian Major Carps suffered a breeding decline (Vass *et al.* 2009).

Increase in temperature and decrease in precipitation have influenced apple cultivation in Himachal Pradesh. The decrease in chill units in the normal apple growing zone (1200- 1800 amsl) has led to a reduction in area under apple orchards. Rising temperatures and changes in weather conditions are affecting apple production and is a matter of serious concern in Himachal Pradesh thus apple farmers have shifted to crops like kiwi and pomegranate (Singh *et al.* 2016).

The climate for rice, tobacco and groundnut significantly affects crop yields. Crops grown in Rabi are more susceptible to climate change than in Kharif, while drought crops such as jowar are better off than others (Padakandla 2016).

During 1966–2002, drought and extreme rainfall negatively affected rice yield in predominantly rainfed areas. Yield would have been higher if monsoon characteristics, especially drought frequency and other meteorological changes (warmer nights and lower rainfall at the end of the growing season) had not occurred during this period (Auffhammer *et al.* 2012).

Wheat yield in the northern parts of the country is affected by the temperature extremes coinciding with flowering and grain filling period (Duncan *et al.* 2015).

## Forests

Monsoon precipitation and land surface temperature over the Indian sub-continent landmass have a significant impact on the distribution of vegetation (Sarkar and Kafatos 2004). In Sikkim, many endemic plant species have migrated to higher elevation in two alpine valleys between the mid-$19^{th}$ century and the present (Telwala *et al.* 2013).

Mundra forest on the western coast of Gujarat state is famous for its unique mangrove biodiversity. An analysis of the meteorological variables indicates high pressure and changes in mangrove density during the period of 1994 to 2010. Mundra mangroves are at high risk of climate change-induced habitat loss (Srivastava *et al.* 2015).

The decline of subalpine forests and treeline elevation was coincident with weakening monsoonal influence and increasing anthropogenic interferences (Schickhoff *et al.* 2016). Altitudinal movement of temperature sensitive plant species is being observed in the state of Jammu and Kashmir (Ishtiyak *et al*. 2016).

## Coastal areas and Marine ecosystems

Based on the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the mean sea level rise in the global ocean was estimated to be about 1.7 [1.5 to 1.9] mm per year between 1901 and 2010, and it increased to 3.2 [2.8 to 3.6] mm per year between 1993 and 2010. Long-term sea level estimates using tide gauge records show a rate of sea level rise of about 1.06-1.75 mm per year in the Indian Ocean during 1878-2004 (Unnikrishnan and Shankar 2007). However, altimeter data analysis over 1993–2012 period reveals that the rate of sea level rise is rather spatially homogeneous over most of the north Indian Ocean, reaching values close to global mean sea level rise trend (3.2 mm per year) (Unnikrishnan *et al*. 2015). This indicates that the rate of sea level rise has accelerated. It is reinforced by Swapna *et al*. (2017) study which mentions that the sea level rise in the North Indian Ocean has accelerated to 2.3 ± 0.09 mm per year during 1993–2015. Analyses of long-term climate data sets and ocean model sensitivity experiments indicated that significant increase in North Indian Ocean sea level during last three to four decades is accompanied by a weakening of summer monsoon circulation (Swapna *et al*. 2017).

The increase in sea surface water temperature (up to 34°C) in the summer of 2010 resulted in bleaching of about 74 per cent to 77 per cent of corals in the South Andaman. Several coral species such as *Acropora cerealis, A. humilis, Montiporasp., Favia pallida, Diploastrea sp., Goniopora sp., Gardineroseries sp., Porites sp.,* were severely affected. The recovery of coral cover observed after bleaching was 21.1 per cent at Port Blair and 13.29 per cent at Havelock Island. The mortality rate of coral cover at Port Blair Bay and Havelock Island was estimated at 2.05 per cent and 9.82 per cent respectively (Marimuthu *et al*. 2013). Coral bleaching Due to Thermal Stress was also reported in summer months of 2016 along the Andaman coast (Mohanty *et al*. 2017).

The Government has prepared adaptation-oriented missions under the National Action Plan on Climate Change, recognizing the potential threats of climate change to hydrological systems, ecosystems, sea levels, crop production and other related processes.

## Progress on the evidence-based research on systematic observations of impacts

India is a vast country endowed with great variations in climate and vegetation, showing a wide variety of ecosystem types. It is high time to initiate long-term ecological observations in different ecosystems in India to record the long-term large-scale response of ecosystems in the changing environment scenario in the 21st century. Recognizing the need explained above, the science initiatives are planned by the Ministry as part of the Climate Change Action Programme (CCAP). Long Term Ecological Observatories (LTEO) programme is funded and operated through the Climate Change Division at the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. As the programme is complex and spread over a large geographical area, the network of scientists involved in the programme would inevitably come from scientific institutions and research groups across the country (Sharma and Dube 2018); (MoEFCC and IISc 2015).

## Long Term Ecological Observatories

Long Term Ecological Observatories (LTEO) for climate change studies are one of the components under the 'Climate Change Action Programme' with an outlay of INR 40 crore in the 12th Five Year Plan Period. A Science Plan of LTEO was released during the 21st Conference of Parties to the UNFCCC at Paris in December 2015. The first phase of the LTEO Programme includes creating a network of field sites to assess the health of eight different biomes of the country namely; Western

Himalaya, Eastern Himalaya, North-Western Arid Zone, Central Indian Forests, Western Ghats, Andaman & Nicobar Islands, Jammu & Kashmir and Sundarbans.

India's LTEO programme, through a network of scientific institutions, aims to understand the biophysical and anthropogenic drivers of ecosystem change in selected biomes and their impact on social-ecological responses. Activities include experimental work to assess the change of structure and function in the natural ecosystems, identification of patterns and drivers of change in the natural ecosystems by monitoring populations of freshwater fish, birds, mammals, herbivores and carnivores, animal movements, soil processes in forests and grasslands, biophysical climatic variables, etc.

There are examples of countries participating in long term ecological research. National Science Foundation of United States has initiated establishing Long Term Ecological Research (LTER) station network since 1980 from 5 sites to collect detailed information on various ecological patterns, processes and phenomena that vary over a long-term and on a large scale to acquire knowledge and predictive understanding that is necessary for the proper management of ecosystems and their services. In 1993, the establishment of International LTER (ILTER) stations was initiated to cover a greater range of ecosystem types over the world and it has become the 'network of networks' by joining a total of 39 countries (each having number of LTER stations). About half of the existing networks are located in the European countries having relatively similar climatic conditions and degrees of anthropogenic stress and the remaining half are distributed in North America, South America, Australia, Africa and quite a few in Asian countries like China, Japan, Thailand and Philippines. The ILTER Coordinating Committee, the governing body of the ILTER Network, convenes annually at a meeting hosted by one of the Member Networks.

**Indian Network for Climate Change Assessment (INCCA)**

To increase capacity at the institutional level for conducting research into Climate Change science and making necessary assessments, MoEFCC has set up an evolving and dynamic network, namely the Indian Network for Climate Change Assessment (INCCA) comprising of 127 research institutions tasked with undertaking research on the science of Climate Change and its impacts on different sectors of economy across various regions of India. INCCA has helped the Ministry put together its Greenhouse Gas (GHG) Emissions Inventories and in carrying out other scientific assessments at more frequent intervals. Efforts need to be made to make INCCA a part of ILTER. This will help to strengthen Indo-US and other international cooperation on climate change. Most ILTER members are national or regional networks of scientists engaged in long-term, site-based ecological and socio-economic research (known as LTER or LTSER). The data gathered from the above-mentioned network can be suitably linked / exchanged with the ongoing ILTER programme. The expansion of LTER network in countries like India would make it possible to represent a greater range of ecosystem types that are being influenced by changes in climate, biogeochemistry and biodiversity.

**Coordinated Studies on Climate Change for North East region (CSCCNE)**

Another effort in the direction of evidence-based research on Climate Change in India, being steered at the government's level is the CSCCNE programme under CCAP. The North-eastern region can be physiographically categorised into the Eastern Himalayas, Northeast Hills (Patkai-Naga Hills and Lushai Hills) and the Brahmaputra and the Barak Valley Plains. The North-eastern region of India is characterized by diverse climate regimes. The region is highly dependent on the southwest monsoon (June–September), with over 60 per cent of the crop area is under rain-fed agriculture, and so is in areas highly vulnerable to climate variability and climate change. The region has two main river basins (the Brahmaputra and Barak), a large dependence of the population on natural resources, and poor infrastructure development. The powerful hydrological and monsoon regime of the region, especially the Brahmaputra and the Barak (Meghna) river system are both a resource and source of vulnerability.

Jhum cultivation, a traditional agricultural system, is often cited as a reason for the loss of the region's forest cover. This primary agricultural economic activity carried out by local tribes reflects the use of 35 crop varieties. The area is rich in medicinal plants and many rare and endangered taxa. Its high endemism in both higher plants, vertebrates and avian diversity has qualified it as a 'hotspot' for biodiversity. In 1995, the International Union for Conservation of Nature identified Namdapha in Arunachal Pradesh as a centre of plant diversity.

The following figures highlight the significance of the region:

a. Fifty-one forest types are found in the region broadly classified into six major types — tropical moist deciduous forests, tropical semi-evergreen forests, tropical wet evergreen forests, subtropical forests, temperate forests and alpine forests
b. Out of the nine important vegetation types of India, six are found in the North Eastern region
c. These forests harbour 8,000 out of 15,000 species of flowering plants. In floral species richness, the highest diversity is reported from the states of Arunachal Pradesh (5000 species) and Sikkim (4500 species) amongst the North Eastern States
d. According to the Indian Red data book published by the Botanical Survey of India, 10 per cent of the flowering plants in the country are endangered. Of the 1500 endangered floral species, 800 are reported from North East India
e. Most of the North Eastern states have more than 60 per cent of their area under forest cover; a minimum suggested coverage for the hill states in the country
f. North East India is a part of Indo-Burma 'hotspot'. The hotspot is the world's second largest, next only to the Mediterranean basin with an area 2.2 million sq km. among the 25 identified
g. The Eastern Himalaya and the Assam plains have been identified as an Endemic Bird Area by the Royal Society for Protection of Birds.

The INCCA 4x4 assessment report has made assessments in the national and regional level regarding climate projections and vulnerability. Some of the north-east specific results as extracted from the report are as follows:

a. The trend in precipitation in the north-eastern region exhibits considerable spatial variability with respect to the predictions for the 2030s. The northern part shows a reduction in precipitation varying from 3 per cent in the north-western portion to about 12 per cent in the north-eastern portion. In the remaining part of the north-east, there is an increase in precipitation varying up to 25 per cent for the central portion of the north-east. The majority of the north-eastern region, but for some parts of Mizoram, Tripura, Manipur and Assam, shows an increase in evapotranspiration during the 2030s scenario. It is interesting to note that even those parts of Arunachal Pradesh that were showing a decrease in precipitation show an increase in evapotranspiration The trend in water yield in the north-eastern region is similar to the precipitation trend. The areas that have shown less increase in precipitation show a correspondingly low water yield. The reduction in water yield in Arunachal Pradesh is up to about 20 per cent. An increase in water yield is seen in Assam and Manipur and the magnitude is up to about 40 per cent

b. The projected increase of night-time temperature may lead to a decrease in the production of rice and hence affect the nutritional health of the population

c. Soil erosion due to an increase in the intensity of precipitation events may lead to an increase in the occurrence of landslides, affecting agriculture activities, including tea plantations. This might lead to morbidity among the workforce dependent on this

d. Also, there is a likelihood that the windows of transmission of malaria may increasingly remain open for at least for 7–9 and may even remain open for a larger number of months (10–12 months) in a year.

## National Mission on Sustaining the Himalayan Ecosystem

There is a serious lack of systematic studies and empirical observations about species-level impacts of climate change in the Himalayas (Gautam *et al*. 2013). The main goal of NMSHE is to assess scientifically the vulnerability of the Himalayan region to climate change in physical, biological and socio-cultural context. Major initiatives include the establishment of a Centre for Himalayan Glaciology at the Wadia Institute of Himalayan Geology, Dehradun. Under the mission, State Climate Change Cells (SCCC) in the Himalayan States have been set up. These cells provide support for vulnerability and risk assessment studies at district and sub-district levels as well as for institutional and capacity building. At the state level, a training institute or a university has been designated for conducting the capacity building programmes. A training manual has also been developed following a consultative process. The manual provides information on climate change impacts and risk mitigation and adaptation measures in the Indian Himalayan region.

## National Mission on Strategic Knowledge for Climate Change

One of the NAPCC's mission is on 'Strategic Knowledge for Climate Change' which is being coordinated by the Department of Science and Technology, Government of India (GoI 2018). The main objectives of this mission are as follows:

a. Formation of knowledge networks among the existing knowledge institutions engaged in research and development relating to climate science, and facilitate data sharing and exchange through a suitable policy framework and institutional support

b. Establishment of global technology watch groups with institutional capacities to carry out research on risk minimized technology selection for developmental choices

c. Development of national capacity for modelling the regional impact of climate change on different ecological zones within the country for different seasons and living standards

d. Establishing research networks and encouraging research in the areas of climate change impacts on important socio-economic sectors like agriculture, health, natural ecosystem, biodiversity, coastal zones, etc

e. Providing an improved understanding and awareness of the key climate processes and the resultant climate risks and associated consequences

f. Building alliances and partnerships through global collaboration in research & technology development on climate change under international and bilateral S and T cooperation arrangements.

Two National Knowledge Networks *viz.,* a Network on Climate Change, Human Health and Climate Modelling have been set up. Two more networks are being launched shortly: Network on Climate Change and Agriculture and a Network on Coastal Vulnerability. Three new National Knowledge

Network Programmes were launched in areas including climate modelling, climate change and human health, and climate change and coastal vulnerability.

## Alpine Treeline Ecotone

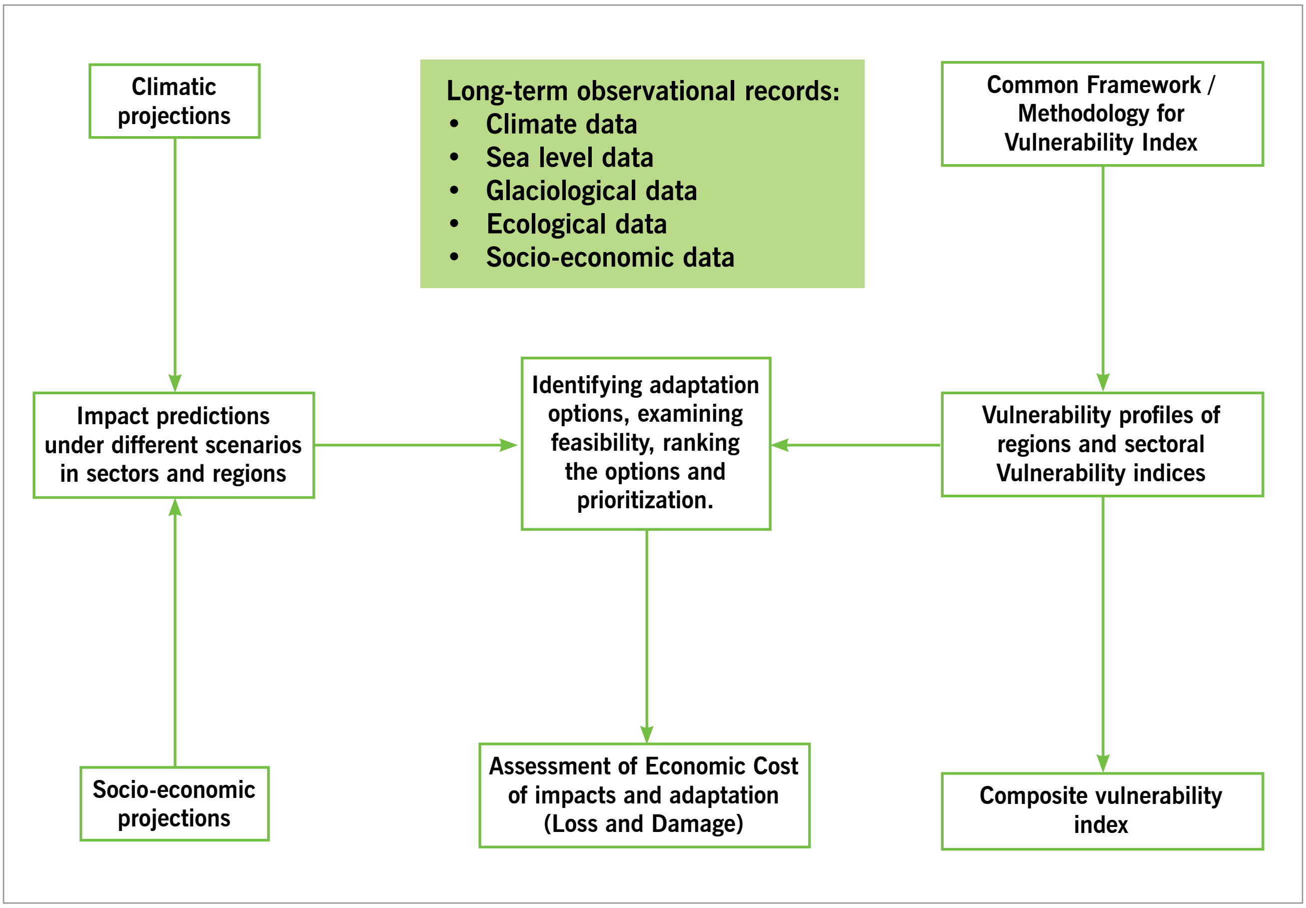
a. ISRO has also established a multi-summit approach based on long-term ecological record sites, known as a network of "HIMADRI" (Himalayan Alpine Dynamics Research Initiative) in partnership with subject expert institutions to study changes in the Alpine treeline ecotone due to climate change. This will map species level migration. The archived satellite data (from 1976 to 2014) show that the alpine ecosystem is definitely undergoing changes and alpine treeline has shifted upward with the positive greening trend observed at the alpine treeline ecotone

b. The satellite information thus collected will contribute to strengthening the country's scientific response towards addressing the impacts of climate change.

## The way forward

The Earth system is complex and long-term policy direction can only be based on long-term observations and comprehensive assessments of the best available science. The UNFCCC calls on Parties to promote and cooperate in research and systematic observation of the climate system, including through exchange of information and supporting international programmes, networks and organizations. Parties are also called upon to cooperate in improving the capacities of developing countries so that they can participate in research and systematic observation activities (Articles 4.1(g,h) and 5). Parties regularly report on their national and cooperative research activities

**Figure 3: Framework for integrated assessment in climate change area**



and their contributions to climate science, as well as emerging research needs and priorities through their National Communications. Under the National Communication periodically submitted by the Parties to the UNFCCC, information on National Inventories, Climate Change Vulnerability and adaptation, Mitigation Actions, Research and Systematic Observation and other details are provided. India has already submitted Initial and Second National Communications in 2004 and 2012 respectively. There are certain gaps identified in both the reports in existing knowledge which need to bridge with a better understanding of issues related to climate change. This will require long-term ecological monitoring and research through monitoring stations and/or observatories through a network of institutions. A combination of long-term observation and anticipatory investigations would be helpful in the context of climate change.

A schematic diagram of the broad framework discussed in this section is given in Figure 3.

India's climate variability trends need to be compiled followed by climatic projections using multiple models and impact assessment in different sectors in different climate scenarios. Model ensembles such as CORDEX and CMIP5 may be used for projections. These sectors and regions should be subjected to quantitative assessment of vulnerability by constructing a 'vulnerability index' for each sector. The vulnerability index is a key indicator for measuring the vulnerability of a sector/ region. This index may be based on several sets of indicators that assess vulnerability of a region/sector. Vulnerability indices may be developed for different sectors such as water vulnerability index, agriculture vulnerability index and forest vulnerability index. Vulnerability indices developed at the sub-regional level for different sectors and sub-sectors may be ranked on an ordinal scale. Based on vulnerability indices, GIS-integrated spatial vulnerability profiles and maps need to be prepared. A composite vulnerability index could be developed after integrating all sectoral indices in a scientific manner. It will serve as a single number, which can be used to compare different regions. Adaptation strategies will be developed based on the identified vulnerability profiles and maps. Vulnerability indices will be calculated in each core sector and a composite index will be estimated for states and for the country as a whole.

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# Implementation of India's Nationally Determined Contribution

Apurba Mitra[1]

**Abstract**

This paper analyses the progress India has been making towards achieving it's climate change mitigation goals, especially the quantitative goals that are part of it's Nationally Determined Contribution (NDC). A discussion on the key enabling policies, schemes and programmes that are contributing towards meeting these goals is also presented. As a special focus, the paper also reflects upon India's solar journey so far and the significant milestones achieved.

**Keywords**

*India, Nationally Determined Contribution (NDC), Climate Change, Emissions Intensity, Renewable Energy.*

## Introduction

Over the past decade, India has developed a range of policies, plans, and targets to address climate change while supporting the country's long-term development agenda.

Given that India is a developing country which is confronting poverty and deprivation with minimal emissions per capita so far, ensuring energy access and economic development are still the primary challenges (and priorities) for the country. Notwithstanding competing priorities, over the years, significant emphasis has been placed on decoupling economic growth from growth in carbon emissions, placing sustainable development and low-carbon growth as key priorities in development planning.

Since 1990, India's emissions intensity (GHG emissions per unit gross domestic product, or GDP) has fallen by more than 50 per cent. To put this achievement in context, when China had a similar GDP to India's 2014 GDP, it's emissions intensity was almost three times higher (World Bank 2018). With a per capita energy consumption of around 30 per cent of the world's average, and a low per capita GDP (about 1/30th of U.S. per capita GDP in 2017), India's per capita emissions remain low, at about 10 per cent of those for the highest emitting countries. In terms of historical responsibility, if India accounts for less than 2.5 per cent of the world's cumulative $CO_2$ emissions between 1850 and 2010, the US accounts for more than 25 per cent (WRI CAIT 2012). A comparison of some other relevant indicators, i.e. total GHG emissions, population and GDP-PPP is shown in the graph below for the top 10 emitters that produce around 70 per cent of global emissions

However, despite the progress made thus far, there are unique governance challenges to sustaining and strengthening mitigation progress in alignment with

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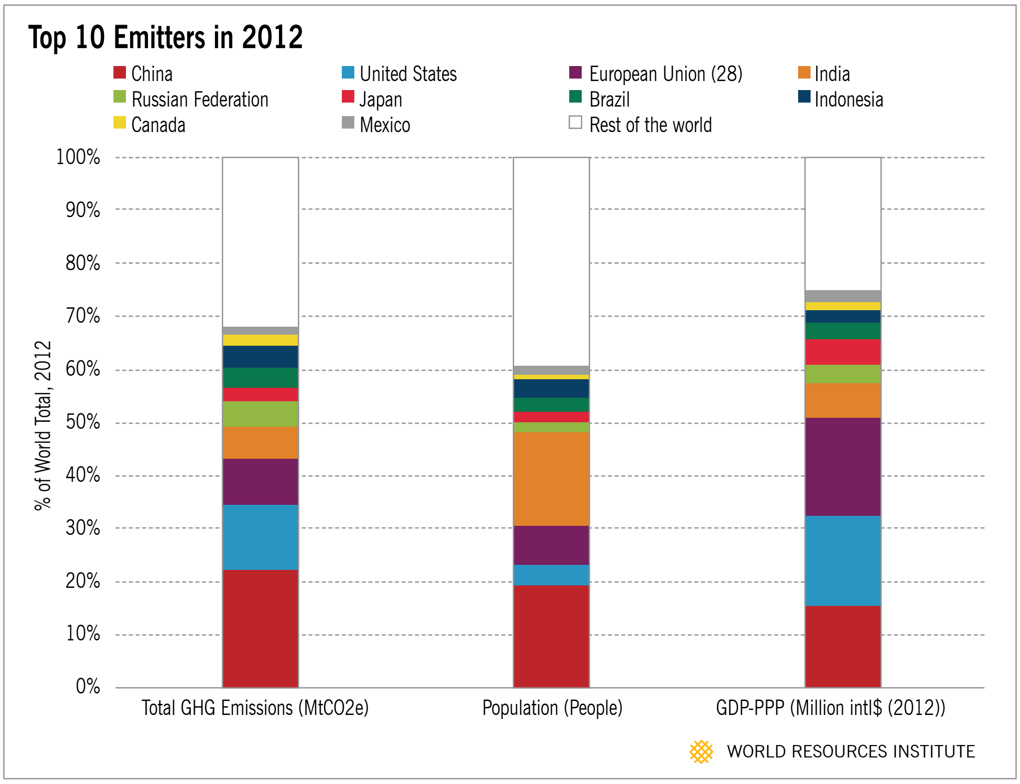



*Source: (WRI CAIT Climate Data Explorer 2016 )*

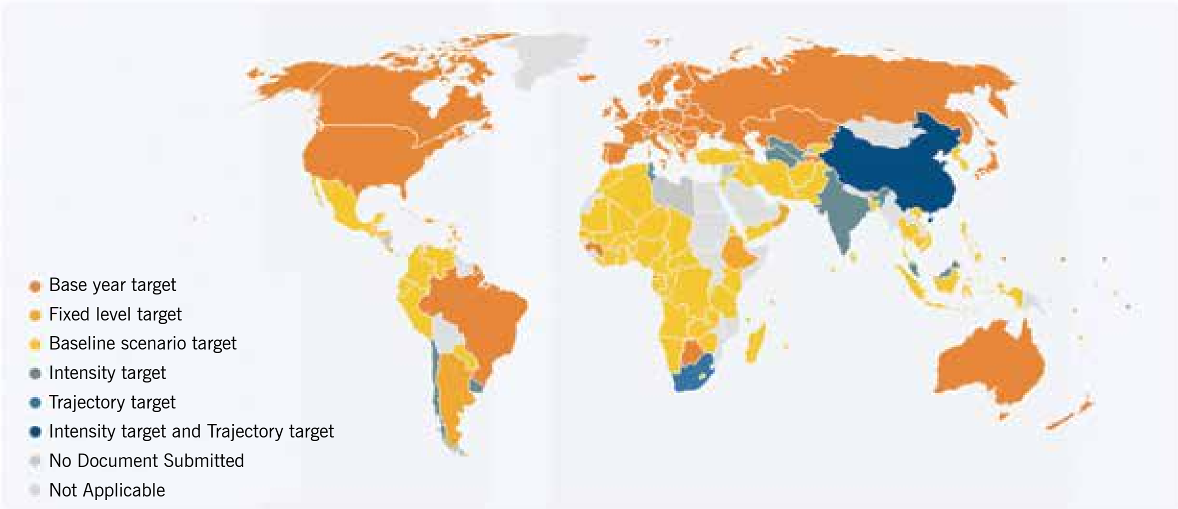
the country's aspirations and what climate science demands. Effective integration across multiple sectors ranging from energy, industry, transport, agriculture, waste, and forestry is crucial for planning and implementation of effective climate strategies. While the sectors may seem distinct, the delicate interlinkages make it vital to explore solutions and advancements in these areas jointly to be able to maximize the chances at achieving decarbonization cost-effectively and at the pace needed in line with climate science.

Another challenge is that of scale- truly effective decarbonisation efforts necessitate concerted action at both national and sub-national levels. Ensuring that the state, city and local level authorities take ownership for implementation of mitigation policies and decisions undertaken by the national government is a challenge for a number of climate-relevant policies in India. Furthermore, whether it's to fulfill international commitments or to decrease the risk of expensive lock-in of carbon-intensive infrastructure, the time planning for mitigation compels the country to look to 2030 and beyond, which typically goes beyond sectoral planning time horizons at the national and subnational levels. Undertaking the analytical work underpinning this long term planning is also a challenge, necessitating addressal of data needs, projections, uncertainties, and the choice of adequate models. For instance, a recent synthesis of scenario studies finds a wide range of possible carbon dioxide emission projections for India – ranging from 12 per cent to 169 per cent above 2012 levels by 2030 (Dubash *et al.* 2017).

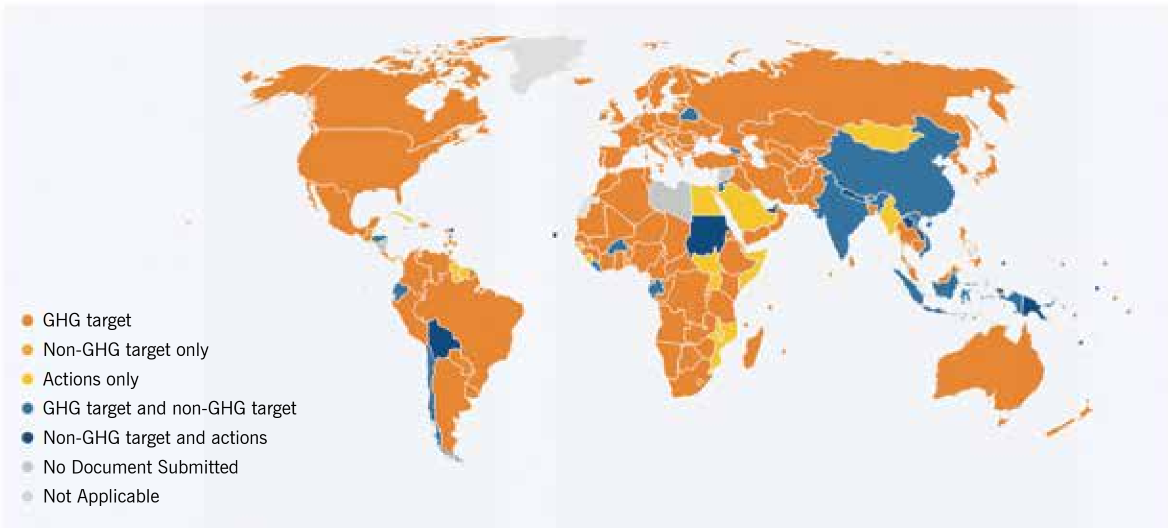
Various efforts are underway in the country towards addressing these governance challenges, with the Ministry of Environment, Forest and Climate Change (MoEFCC) which is the nodal ministry for climate under the Government of India, taking the lead in coordinating efforts across various line ministries. The MoEFCC plays a vital role by taking stock of the programmes and actions of various line ministries, coordinating strategies and planning as well as assessing the progress towards meeting India's climate goals (such as those outlined in India's NDC).

## BOX 1: Global comparison of NDCs

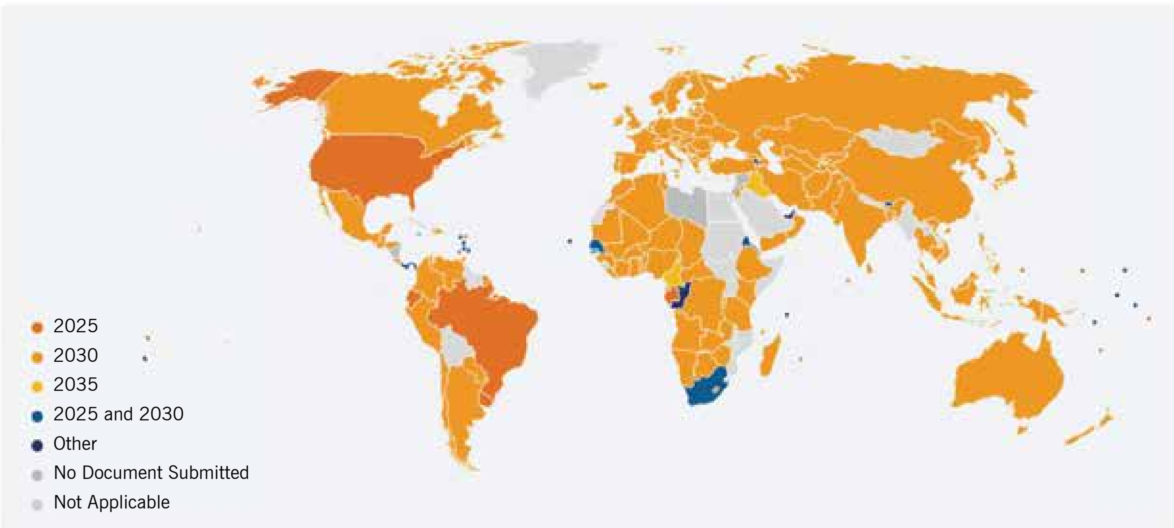
### By GHG target type




### By target year




### By mitigation contribution type




*Source: WRI Climate Watch*

**BOX 2:**
**India's Nationally Determined Contribution**

India communicated its NDC for the period 2021 to 2030:

1. "To put forward and further propagate a healthy and **sustainable way of living** based on traditions and **values of conservation and moderation**.
2. To adopt a **climate friendly and a cleaner path** than the one followed hitherto by others at corresponding level of economic development.
3. To **reduce the emissions intensity of its GDP** by **33 to 35 percent by 2030** from **2005 level**.
4. To achieve about **40 percent cumulative electric power installed capacity** from **non-fossil fuel based energy resources** by **2030** with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
5. To **create an additional carbon sink of 2.5 to 3 billion tonne** of **$CO_2$ equivalent** through additional forest and tree cover by **2030**.
6. To **better adapt** to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management.
7. To mobilize **domestic and new & additional funds** from developed countries to implement the above mitigation and adaptation actions in view of the resource required and the resource gap.
8. To **build capacities**, create domestic framework and international architecture for quick diffusion of cutting edge climate technology in India and for joint collaborative R&D for such future technologies."

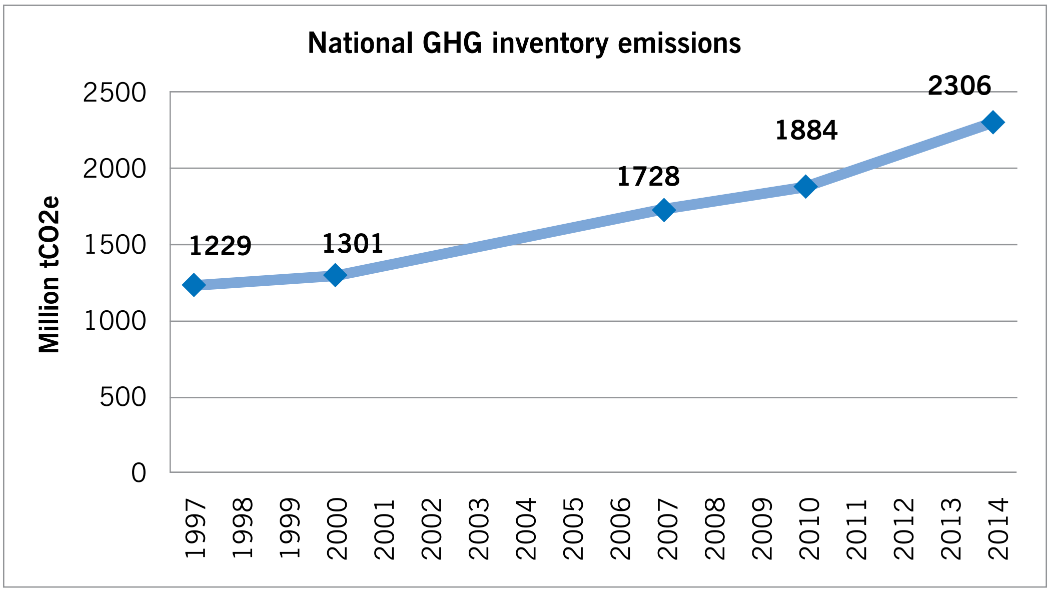
The first section of this paper identifies India's quantitative NDC targets and analyses the progress made so far. This is followed by a discussion on the mitigation enabling policies, schemes and programmes that are currently being implemented in pursuit of meeting these targets.

## India's NDC targets

Prior to the Conference of Parties (COP) 21 in Paris in December 2015, India submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), outlining the country's post-2020 climate actions. That year emerged as a pivotal year for the climate when the Parties at COP 21 reached an agreement to limit the average global temperature increase to well below 2°C above preindustrial levels and to pursue efforts to limit warming to 1.5°C. On April 22, 2016, Earth Day, 175 countries, including India, became signatories to the Paris Agreement. On October 2, 2016, India formally joined the agreement by depositing its instrument of ratification and that's when the word Intended was dropped, and it became a Nationally Determined Contribution (NDC). The Nationally determined contributions (NDCs) are central to the Paris Agreement and India's NDC embodies the efforts planned to be pursued by the country to reduce national emissions and adapt to the impacts of climate change.

India's NDC commits to reducing India's GHG emissions intensity per unit GDP by 33 to 35 per cent below 2005 levels by 2030, building upon its previous voluntary Copenhagen commitment of achieving 20 to 25 per cent reduction in emission intensity of GDP over 2005 levels by 2020. The NDC also commits to creating an additional carbon sink of 2.5 billion to 3 billion tonne of carbon dioxide through additional tree cover and sets a new clean energy target to increase the country's share of non-fossil-based installed electric capacity to 40 per cent by 2030 (with the help of international support). The plan also prioritizes efforts to build resilience to climate change impacts and provides a broad indication of the amount of financing necessary to reach India's goals. The Climate Action Tracker, a joint project of several research organizations, finds that given a fair distribution of global effort, India's pledge is compatible with limiting global warming to less than two degrees Celsius.

**Figure 1: India's National Greenhouse Gas Inventory, 1997–2014**




*Sources: India's Initial National Communication to the UNFCCC, India's Second National Communication to the UNFCCC, India: Greenhouse Gas Emissions 2007 prepared by MoEFCC; India's First Biennial Update Report to the UNFCCC; India's Second Biennial Update Report to the UNFCCC*

## NDC Emissions Intensity target

As per India's first Biennial Update Report (BUR), by 2010, the country had already achieved a reduction in emissions intensity of 12 per cent over 2005 levels. As evidenced by the second BUR, by 2014, the country had achieved a reduction in emission intensity of GDP by 21 per cent over 2005 levels, reaching its voluntary Copenhagen target well ahead of the scheduled target year (2020). Going by past trajectories and future predictions of emissions growth versus GDP growth, the emissions intensity of GDP is only expected to fall further by 2020. However, for the NDC timeframe, within the second BUR to the UNFCCC, India has firmly put forth the requirement for enhanced new, additional and climate specific financial, technological and capacity building support to be able to achieve the NDC goals by 2030.

Figure 1 charts India's official inventory estimates which are available for the years 1994, 2000, 2007, 2010, and 2014:

- In 2004, India submitted its initial national communication (INC) (for the 1994 emissions inventory)
- In 2010, India brought out a GHG emissions report prepared by the Indian Network of Climate Change Assessment to present updated inventory estimates (for the 2007 emissions inventory).
- In 2012, India submitted its second NATCOM (SNC) (for the 2000 emissions inventory).
- In 2016, India submitted its first BUR (for the 2010 emissions inventory).
- In 2018, India submitted its second BUR (for the 2014 emissions inventory).

As per India's BUR 2, in 2014, India's emissions were 2,607 MtCO2e without Land Use, Land-Use Change and Forestry (LULUCF), and considering emissions and removals from the LULUCF sector, net national emissions were 2,306 MtCO2e, which is an increase from 2010 levels of 2,136.8 MTCO2e (1,884.3 MtCO2e with Land Use, Land Use Change and Forestry (LULUCF).

## NDC Non-Fossil Fuel target

The share of renewable energy in the electricity mix has progressively been increasing. Starting in 2015, when India's solar capacity was just 2.9 GW, the country boosted its initial target of 20 GW of installed solar capacity to 100

GW by 2022, and the overall renewables capacity target was increased to 175 GW by 2022. Apart from 100 GW of solar, this target included installation of 60 GW wind, 10 GW biomass, and 5 GW small hydropower capacity by 2022.

As of October 2018, the total installed power capacity in the country stood at 347.38 GW, within which renewables contributed to 21.12 per cent with a total installed capacity of 73.35 GW. Of the 73.35 GW of renewable capacity, wind had a share of 34.98 GW, followed by solar at 24.33 GW, biopower at 9.54 GW and small hydropower at 4.5 GW. The share of non-fossil sources in installed capacity of electricity generation stood at around 36.2 per cent in October 2018 (Ministry of Power Government of India 2018).

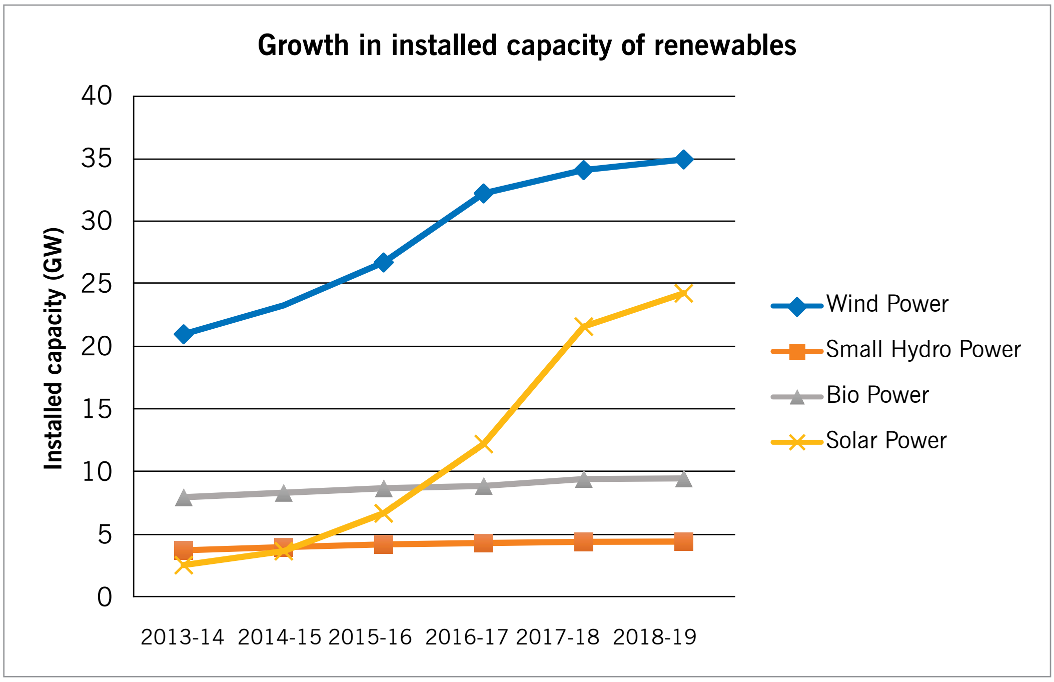
Owing to the phenomenal growth in renewables (attributable to policies described in a subsequent section), India is now the fifth largest solar market in the world in terms of installed capacity and ranks fourth in wind power installed capacity as of October 2018. It is now at the fifth position globally in terms of overall installed renewable

**Table 1: Renewable electricity generation capacity in India (as on October 2018)**

| | Target (GW) | Installed capacity (GW) as on 31.10.2018 | Under Implementation (GW) | Tendered (GW) | Total Installed/ Pipeline (GW) |
|---|---|---|---|---|---|
| Solar Power | 100 | 24.33 | 13.8 | 22.8 | 60.93 |
| Wind power | 60 | 34.98 | 7.02 | 2.4 | 44.4 |
| Bio Energy | 10 | 9.54 | 0 | 0 | 9.54 |
| Small Hydro | 5 | 4.5 | 0.73 | 0 | 5.23 |
| Total | **175** | **73.35** | **21.55** | **25.2** | **120.1** |

*Source: Ministry of New and Renewable Energy, Government of India*

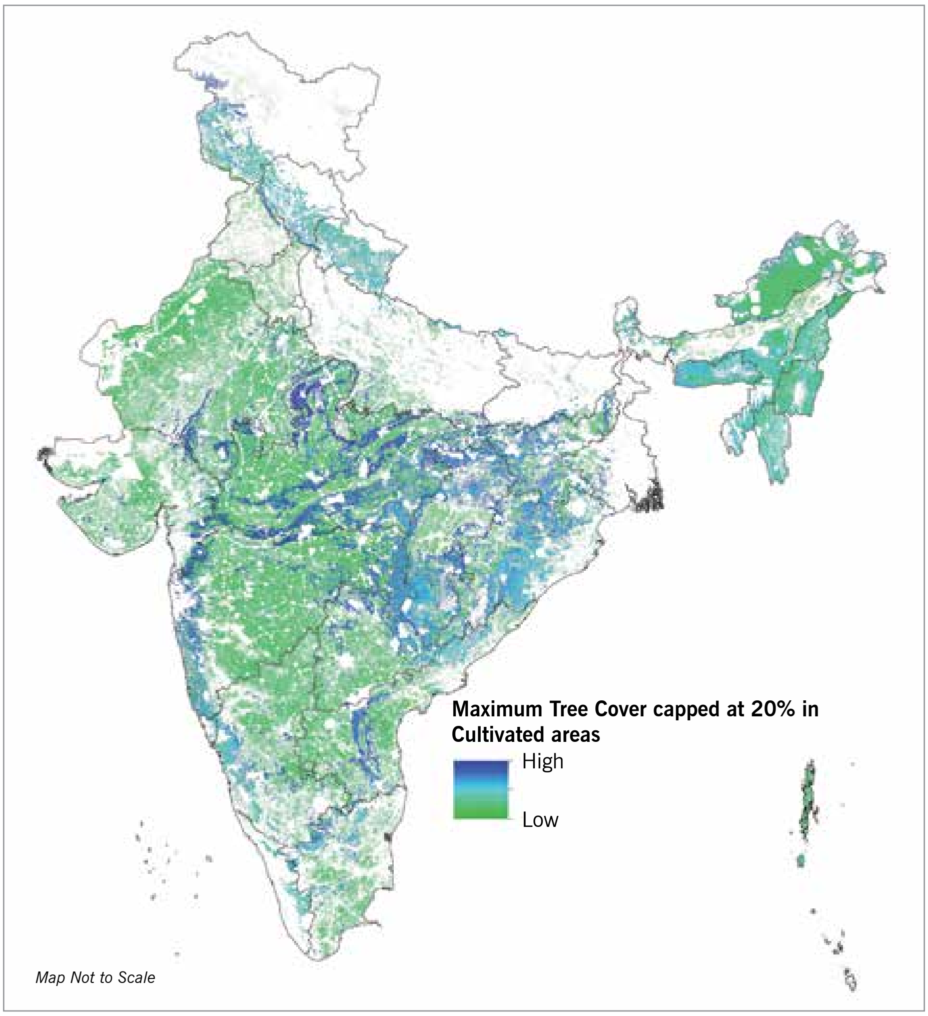
**Figure 2: Growth in Renewable electricity generation capacity**




*Notes: All years in the chart are financial years from 1 April to 31 March. The installed capacity shown for 2018-19 is only till 30th October 2018.*

*Source: Ministry of New and Renewable Energy (MNRE), Government of India*

**Figure 3: Carbon sequestration through landscape restoration**




*Source: WRI India Restoration Opportunities Atlas*

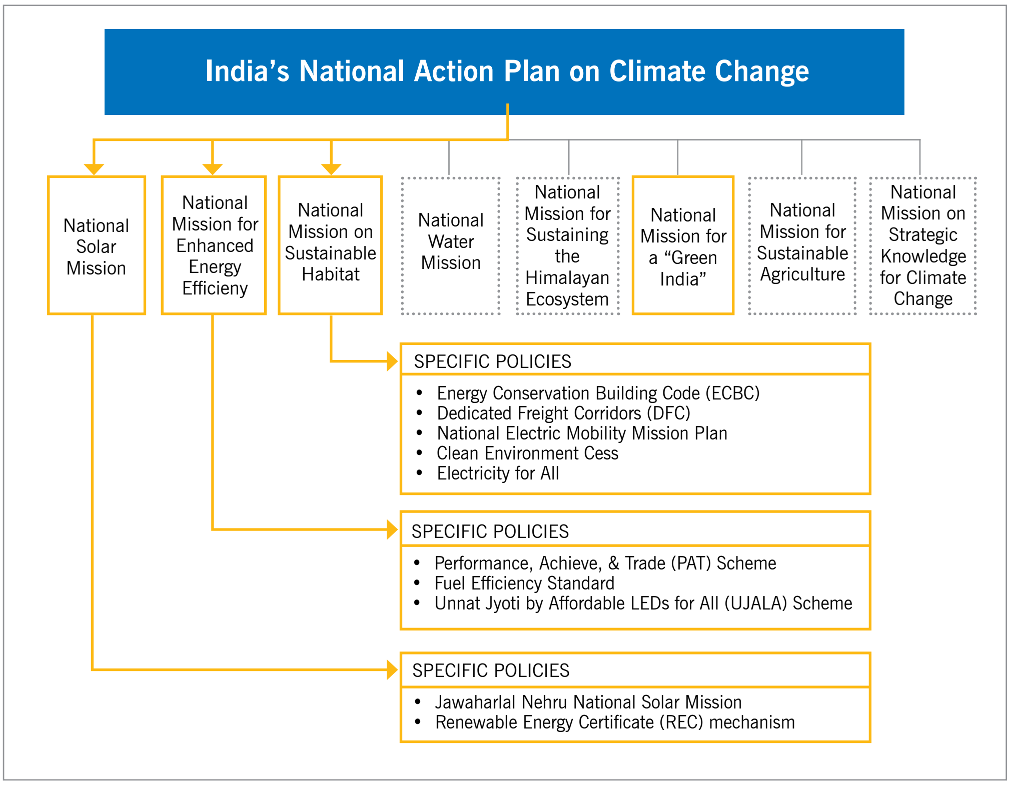
energy capacity. If current trends in increasing share of renewables in the grid electricity mix, and current trends in the growth of power demand are to continue, it is possible for India to achieve the BUR target of 40 per cent share of non-fossil-based installed electric capacity by 2030.

## NDC Forestry target

The NDC commits to sequestering an additional 2.5 to 3 billion tonne $CO_2e$ by 2030 through improved forest and tree cover. Official estimates suggest that achieving this target requires protecting and improving existing forest cover while also extending tree cover in more than 25 to 30 million hectares (MoEFCC 2017). India's second BUR quotes that Forest and tree cover increased from 24.01 per cent of the total geographical area as reported in India State of Forest Report (ISFR) 2013 to 24.39 per cent as reported in ISFR 2017.

So far, trends indicate that additional effort will be necessary to meet the forestry NDC target, with about 10 per cent of the target $CO_2e$ being sequestered annually today. WRI India has developed a Restoration Opportunities Atlas that brings together best available information relevant for India's NDC, and that also ties with the Bonn Challenge commitment under which the country will need to restore 21 million hectares of deforested and degraded land by 2030. The results from the Atlas show that India has nearly 140 Mha of potential for forest protection and landscape restoration, and can achieve the NDC and the Bonn Challenge through forest protection and landscape restoration activities (WRI Restoration Opportunities Atlas).

**Figure 4: National Action Plan on Climate Change**




*Source: (Mitra et al. 2017)*

With several initiatives being introduced by the Government in the forestry sector, the pace of progress is expected to pick up in the future. India's extensive and varied experience of initiatives for improving forest and tree cover provides a strong foundation for planning programmes and projects at scale. The Atlas shows that a variety of restoration interventions have been implemented across the country which includes natural regeneration, monoculture and mixed plantation, compensatory plantations, bamboo plantation, silvopasture development, planting trees on field boundaries and bunds, agri-horti-silviculture interventions including Wadi and farm forestry. Two programs, namely the Government of India's National Afforestation Program for strengthening the forest sector and the National Bank for Agriculture and Rural Development (NABARD) Wadi program for agroforestry linked livelihoods development of tribals, are spread across all states (WRI Overview of the Restoration Opportunities Atlas).

## Policy initiatives

In 2008, India launched the National Action Plan on Climate Change (NAPCC), which outlined eight national missions to promote sustainable development and simultaneously yield co-benefits for climate change. The government approved these missions between 2010 and 2014, under which, various policies, programs, and initiatives have encouraged sector-specific climate change actions in the country.

Given the fact that with development, India's energy demand has almost doubled since 2000 and still continues to grow at a rapid pace, the energy sector holds a special focus in the country's low carbon strategy. The government has established aggressive targets to increase electricity generation from renewable sources as well as encourage demand-side energy efficiency measures.

Given that coal will continue to account for a major share of India's installed capacity in the near future, coal beneficiation, as well as the use of advanced coal technologies like supercritical technology, was made mandatory for new plants. Renovation and modernization and life extension of existing old power stations is being undertaken in a phased manner. In December 2015, more stringent emission standards on particulate matter (PM), $SO_2$, $NO_x$ and mercury from coal-based thermal power plants were introduced.

Buildings in residential and commercial sectors consume over 35 per cent of India's electrical energy (Rawal *et al.* 2012). The Energy Conservation Building Code (ECBC) was introduced in 2007 to encourage more energy-efficient building construction and design, prescribing a minimum standard for energy use in new commercial buildings. ECBC Version 2 was launched in June 2017. So far, twelve states and one Union Territory have notified ECBC to make it operational for new construction (BUR 2). ECO Niwas Samhita 2018, an Energy Conservation Building Code for Residential Buildings (ECBC-R) was also launched in 2018. The Building Retrofitting Project was also initiated by Energy Efficiency Services Limited (EESL) in 2014. Another programme of the BEE, the Standards and Labelling programme, covers 22 appliances of which 10 appliances are now made mandatory. The BUR-2 reports that this scheme has led to energy savings of 121 billion units from 2011 to 2018.

For industry, the government has set up the domestic cap-and-trade mechanism called the Perform, Achieve and Trade (PAT) Scheme in order to incentivize energy-efficiency initiatives among the energy-intensive sectors of the economy. After extensive baseline data collection, benchmarking, and stakeholder consultations, the Ministry of Power in consultation with the BEE rolled out the scheme on March 31, 2012.

During the first cycle of PAT (2012-15), Bureau of Energy Efficiency (BEE) reported that energy savings of 8.67 Mtoe were achieved against the target of 6.686 Mtoe assigned for 478 designated consumers. The BEE reports that this translates to avoiding about 5,635 MW of energy demand and about 31 $MtCO_2e$ emissions. In PAT Cycle-II (2016-19) that was notified in the year 2016, 621 Designated Consumers (DCs) from 11 sectors have been given Specific Energy Consumption (SEC) targets, with an intended energy saving of 8.869 Mtoe. PAT Cycle-III commenced from 1 April 2017, to achieve an overall energy consumption reduction of 1.06 Mtoe and PAT Cycle-IV has commenced with effect from 1st April 2018 in which 109 DCs have been notified from the existing sectors and two new sectors, i.e., Petrochemicals and Commercial Buildings.

The '*Unnat Jyoti*' by Affordable LEDs for All UJALA Scheme, previously known as the Domestic Efficient Lighting Programme (DELP), is another demand-side measure promoted by the government that aims to replace all incandescent bulbs with energy-efficient LEDs by 2019. More than 318 million LED bulbs have been distributed till January 2019 under the UJALA programme. The UJALA dashboard reports that the replacement of incandescent and CFL bulbs by LED bulbs has resulted in energy saving of about 41 billion kWh and reduction of 33 $MtCO^2$ per year (as on January 2019). The distribution of energy efficient fans was also started in August 2016 and the BUR-2 reports that till October 2018, 2.06 million energy-efficient fans have been distributed under this scheme resulting in an estimated energy savings of 191.41 million kWh per year.

For the transportation sector, the government has introduced a range of interventions in the passenger as well as freight transportation segments. Fuel consumption standards have been developed to improve vehicle efficiency, and an infrastructure cess is being implemented to discourage the purchase of fossil fuel-based vehicles. The Faster Adoption and Manufacturing of (Hybrid) and Electric vehicles

(FAME) program, under the National Electric Mobility Mission Plan (NEMMP) 2020, aims to encourage adoption of electric and hybrid vehicles through demand-side incentives and technology development. Mass Rapid Transit Systems and Dedicated Freight Corridors (DFCs) are also under development in many cities to induce modal shift within the passenger and freight segments respectively.

With regards to the waste sector, In 2015, the government launched a major program called the Swachh Bharat Mission to eliminate open defecation, eradicate manual scavenging, practice modern and scientific solid waste management techniques, and bring about behavioral change in sanitation practices across rural and urban India. The Solid Waste Management Rules of 2016 have also been revised to tackle waste disposal issues.

**India's solar journey**

India's efforts in building its solar energy capacity are particularly inspiring. The Jawaharlal Nehru National Solar Mission (JNSSM) has played a key role in bolstering the diffusion of solar energy technologies across the country. The JNSSM Mission adopted a three-phase approach, with the first phase (2010-2013) designed to focus on capturing the low-hanging options in solar thermal, promoting off-grid systems to serve populations without access to commercial energy and modest capacity addition in grid-based systems. The second (2013-2017) and third (2017-2022) phases were designed to aggressively ramp up capacity to create conditions for scaled-up and competitive solar energy penetration in the country.

Overall, the JNNSM has made good progress, with early stages of the mission showing such promise that the Indian government increased its original target fivefold, to reach 100,000 MW of solar installed capacity by 2022. The revised target of 100 GW was divided into two major, segments—a) 60 GW of grid-connected ground-mounted solar power plants and b) 40 GW of rooftop solar power plants.

The mission's success so far can be attributed to several diverse policy instruments that were adopted to implement this mission, for example, Renewable Purchase Obligation, bundling schemes, reverse bidding mechanism, viability gap funding etc. Solar water heaters and rooftop systems have been promoted in certain commercial and residential areas through regulatory interventions and off-grid and rooftop solar applications have been promoted through the provision of subsidies from the central government. Finally, research and development was also being encouraged through approvals of R&D projects and the establishment of Centers of Excellence by the MNRE such as National Centre for Photovoltaic Research and Education (NCPRE) at IIT Bombay in 2010.

The decline in solar power prices in India exceeded the expectations of most analysts and assisted in the accelerated deployment of solar power through the mission. The minimum bid price for solar power began at INR 10.95/kWh (USD 0.17/kWh) during the bidding of Phase 1, Batch 1, in December 2010; and fell to as low as INR 2.44/kWh in 2017, which is lower than the average tariff of coal-based power. However, on average, the price of solar-based power generation is still higher than coal-based energy generation today due to additional costs arising from grid integration as well as land acquisition.

By the end of 2017, India had established 20 GW of operational solar power capacity which was its original target, four years ahead of the original timeline. Ground mounted solar energy capacity increased by about nine times from 2.63 GW in March 2014 to 23.23 GW in June 2018. In 2016-17, India added 5.5 GW of new grid interactive solar capacity in 2016-17, which was 50 per cent more than the amount installed the previous year, but less than half the 12 GW annual target. In the fiscal year 2017-18 however, India managed to achieve the target of 9 GW of grid-connected solar capacity set for the year. However, added capacity will have to significantly ramp up to reach the 2022 target.

The solar rooftop sector has seen slower progress, with only 1.33 GW of grid-interactive rooftop capacity installed till July 2018 against the 2022 target of 40 GW. However, the segment saw steady growth in 2017, driven by government incentives and subsidies, although it could not meet the downscaled target of 1 GW for FY 2017-18, with a grid interactive solar rooftop capacity increase of 353 MW in the year.

There still are considerable roadblocks to meeting the 100 GW solar target and keeping up the pace of growth, some of which include, scarce land, challenges in grid integration and balancing, high transmission losses, the need for more low-cost finance and domestic manufacturing capacity, as well as the lack of supporting infrastructure and skilled manpower. This is where international support, in terms of financial, technological and capacity building support, could serve as a crucial input to alleviating these barriers.

Internationally, one of India's noteworthy contributions is the formation of the International Solar Alliance (ISA). India and France jointly launched the ISA, which an alliance of 121 solar resource-rich countries on the side-lines CoP 21 in 2015. The ISA Framework Agreement was opened for signature on 15 November 2016 in Marrakech, Morocco, on the sidelines of CoP-22. In conformity with the ISA Framework Agreement, 30 days after ratification by the 15th country, in December 2017, ISA became the first full-fledged treaty-based international intergovernmental organization headquartered in India. Till date, out of 121 prospective member countries that lie either fully or partially between the Tropics of Cancer and Capricorn, 70 countries have signed the Framework Agreement of the ISA and 44 of these countries have ratified the ISA treaty.

## Conclusion

The sectoral coverage of India's climate policies is diverse and targets for climate action focus on specific areas that are essential for long-term, low-carbon growth. India has already made progress toward its NDC, with a decline in emissions intensity of around 21 per cent through 2014 from 2005 levels, against the target of 20 per cent to 25 per cent reduction by 2020, and 33 per cent to 35 per cent reduction by 2030. The aggressive promotion and bold targets in ramping up renewable energy are responsible for renewables contributing to more than 21 per cent of the installed power capacity in the country, with non-fossil-based power capacity rising to 36 per cent against the NDC target of 40 per cent by 2030. Although trends indicate that progress towards meeting the forestry NDC target has been considerably slow, the large potential for forest protection and landscape restoration, combined with the country's extensive and varied experience of implementing initiatives for improving forest and tree cover, indicate that it is possible to meet the target with concerted additional effort.

In light of IPCC's special report on $1.5^0$ C, we know now that rapid and deep emission cuts are needed at an unprecedented and disruptive scale to meet the 1.5°C temperature limit adopted in the Paris Agreement. Reinvigorated individual leadership, as well as global collaboration, are needed today to help us align with the global temperature targets, and India has firmly demonstrated intent for both. Despite competing developmental priorities, India's bold targets and investments in specific areas such as clean energy reflect its commitment to long-term low-carbon growth.

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# Geoengineering research activities in India

G. Bala[1], K.S Krishnamohan[1] and Akhilesh Gupta[2]

## Abstract

In recent years, solar geoengineering has been proposed as an option to ameliorate the detrimental impacts of climate change in case the required emission reductions do not take place rapidly or humanity encounters a "climate emergency" such as successive crop failures in the vulnerable developing world due to global warming. Hundreds of research papers have been published in the last decade by both natural and social scientists on the feasibility, effectiveness, cost, risks, and the ethical, moral, legal, social, political, and governance dimensions of geoengineering. Most of this research is conducted in the developed world and very little research or discussion has taken place in the developing world. In this article, a brief account of scientific research in India into solar geoengineering in the last decade is presented. Climate modeling constitutes the major component of this geoengineering-relevant climate science research. The recent funding initiative by the Department of Science and Technology, in support of geoengineering modeling research and its efforts to bring natural, social and political scientists together for an evaluation solar geoengineering at meetings are also discussed. Finally, the directions for future scientific research into geoengineering in India are also discussed.

## Keywords

*Solar Geoengineering, Climate Modeling, Climate Change, Gobal Warming.*

## Background

Our planet has warmed by about 1°C since the pre-industrial era. There is a scientific consensus that the current warming is attributable to mostly human activities such as fossil fuel burning and deforestation which have released vast amounts of $CO_2$ and other greenhouse gases such as methane and nitrous oxide into the atmosphere in the industrial era (IPCC 2013). Further, it is well established that this anthropogenic $CO_2$ is the main driver for global warming and the concentration of this well-mixed greenhouse gas has increased by over 40 per cent since 1850 (~280 to ~400 ppm).

In addition to the scientific basis for climate change, the likely impacts of climate change in the 21st century and beyond on important sectors such as water resources, agriculture, forestry, fishery, coastal zones, etc. have been assessed extensively by researchers around the world. Several scary scenarios such as dieback of forests, failure of crops, severe heat waves, floods and droughts, intense cyclones, breaking of Antarctic ice sheets and release of $CO_2$ and $CH_4$ from permafrost soils in high latitudes have been projected to occur in the

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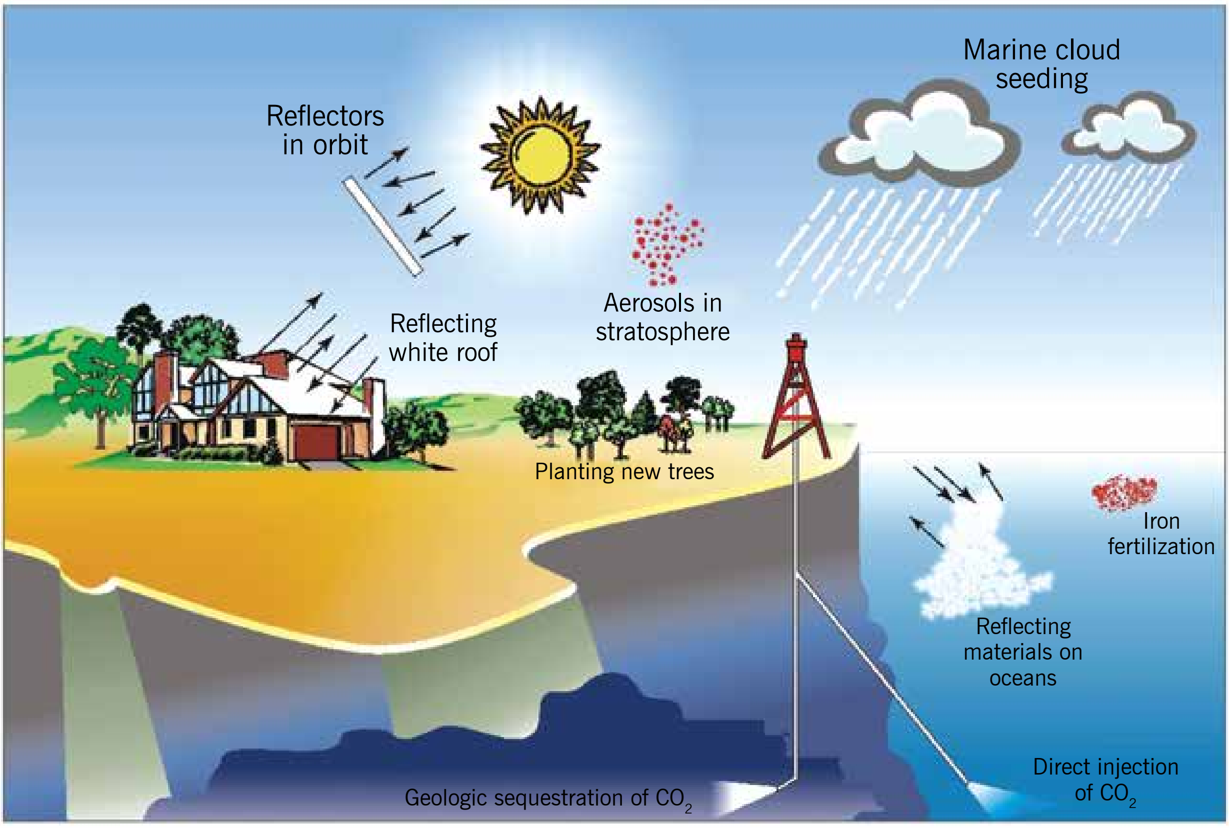
**Figure 1: A schematic diagram of some of the SRM and CDR geoengineering proposals (figure adopted from Bala 2009)**




future (Cox *et al.* 2000; Schuur *et al.* 2015; Church *et al.* 2013; IPCC 2018). In essence, one can conclude that the planet has already warmed, and some amount of additional warming is inevitable. What is uncertain is whether the impacts of climate change would be catastrophic. In such an uncertain situation, a suitable strategy would be to prepare for the worst.

How should the global community respond and address the worst impacts of climate change? There are two broad categories of responses: adaptation and mitigation. Adaptation refers to adaptive responses such as building greener homes to keep living areas cooler, construction of sea walls to protect coastal communities against sea level rise and building storm shelters along the coasts in anticipation of intense cyclones. Mitigation refers to efforts to reduce the emission of greenhouse gases and steer the global energy system towards decarbonization, efficiency and conservation. Mitigation has been a preferred strategy as most people believe in "prevention is better than cure", and hence been the central theme for the climate negotiations over the last 3 decades (Gupta 2016).

In 2015, at the COP21 ($21^{st}$ Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change) in Paris, the global community signed the "Paris Agreement" wherein it was agreed to limit the global mean warming to 2°C and pursue efforts to limit the warming to 1.5°C. The threshold 2°C refers to the warming level above which experts agree that the impacts of climate change could be "dangerous" to human and biological systems, and the stricter limit of 1.5°C was mostly preferred by small island nations which could face severe risks from sea level rise. Breaching these thresholds are to be prevented through legally non-binding voluntary emission reduction pledges by signatories to the Paris Agreement. The recently concluded COP24 at Katowice (2-15 December 2018), Poland, laid out the roadmap for the implementation of the Paris Agreement (UNFCCC 2018).

In recent years, there have also been serious discussions on whether the current climate change could be arrested or reversed using the so-called "Geoengineering methods" (Caldeira *et al.* 2013; NRC 2015). Geoengineering is now recognized as the third option to address climate change. By definition, geoengineering refers to the intentional large-scale engineering solutions designed to ameliorate the detrimental impacts of climate change (Figure 1). Two broad categories of geoengineering are under discussion:

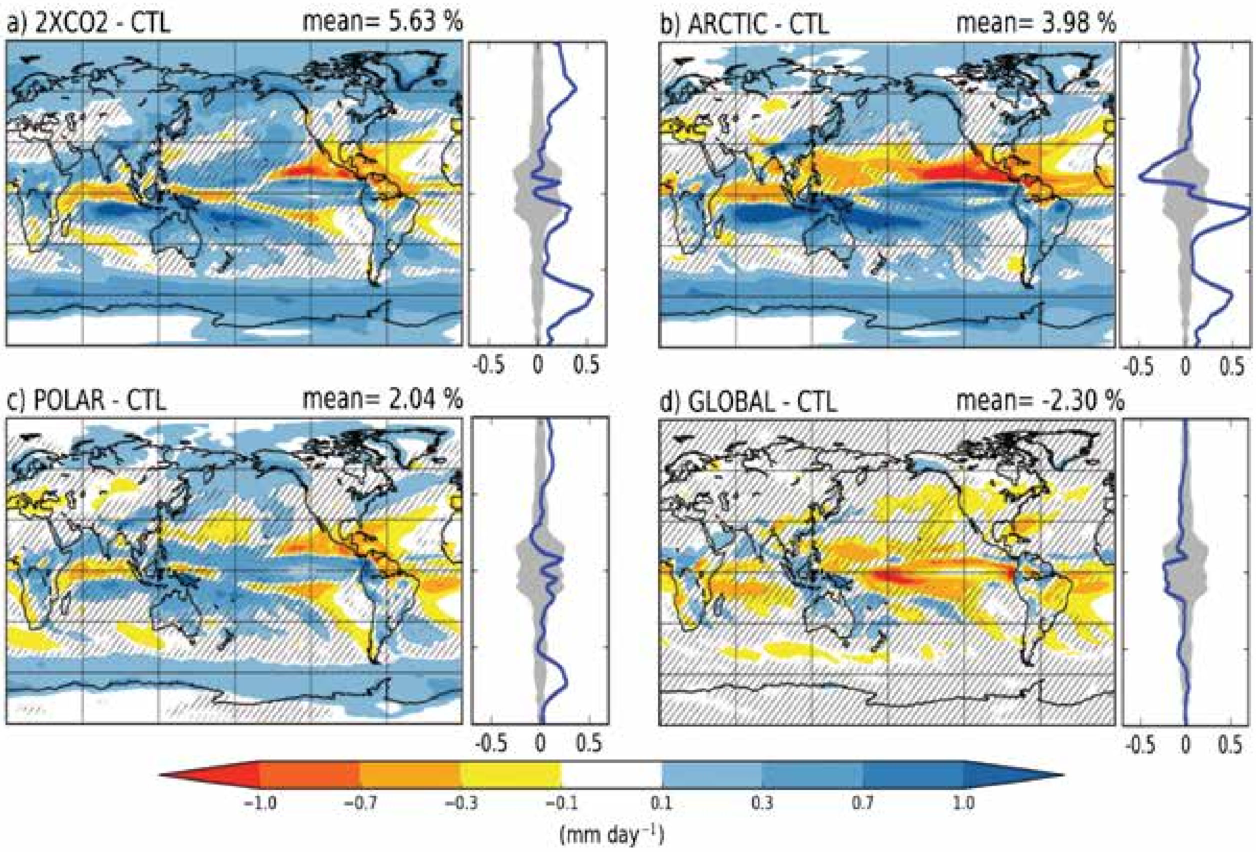
a. Solar geoengineering schemes and
b. Carbon Dioxide Removal (CDR) methods.

Solar geoengineering schemes would cool the planet by increasing the amount of solar radiation reflected by the planet. Solar geoengineering methods are also known as SRM (Solar Radiation Management), and in some instances, for brevity, the term "geoengineering" is simply used to refer to solar geoengineering. Mirrors in space, reflective aerosol particles in the stratosphere, and brighter marine clouds are some examples. By design, CDR methods would accelerate the removal of atmospheric $CO_2$ through either natural carbon cycle processes or artificial industrial means. Large-scale afforestation/reforestation, biochar, bioenergy and carbon capture and storage (BECCS), ocean iron fertilization, accelerated weathering of silicate and carbonate rocks and direct air capture of $CO_2$ are some of the proposed CDR methods. Hundreds of research papers have been published in the last decade on both SRM and CDR methods by both natural and social scientists on the feasibility, effectiveness, cost, risks, and the ethical, legal, social, political, and governance dimensions of these planetary-scale schemes (Caldeira and Bala 2017). There are some overlaps between the traditional mitigation techniques and CDR, particularly in the area of land-plants-based CDR approaches such as afforestation/reforestation and BECCS. We limit our discussion to only solar geoengineering below.

Since solar geoengineering can cool the planet rapidly within 4-5 years by any desired amount and is estimated to cost much less than conventional climate mitigation techniques, many scientific bodies are advocating research into solar geoengineering so that it can be deployed in case of a planetary emergency such as successive crop failure in vulnerable countries due to climate change or rapid break-up of Greenland and Antarctic ice sheets. The scientific societies that have advocated research include the American Meteorological Society, American Geophysical Union and the Royal Society of London. The prominent scheme among the solar geoengineering methods is the proposal to inject aerosol particles such as sulfates or calcium carbonate into the stratosphere and deflect about 1-2 per cent of the incoming solar radiation. Modeling studies have consistently confirmed that solar geoengineering can markedly diminish regional and seasonal climate change from anthropogenic $CO_2$ emissions. The residual changes are likely to be too small.

While solar geoengineering schemes such as sulfate aerosol injection are "supposedly" cheap and can rapidly cool down the climate system, they do come with some undesirable side effects such as weakening of the global water cycle when implemented on a larger scale (Bala *et al.* 2008). These schemes do not address "ocean acidification" which could be detrimental to marine life and also commit us to maintain them for decades to centuries until atmospheric $CO_2$ levels fall to sufficiently lower values. Further, the risk with such schemes, if they fail or are halted, is that the planet could be subjected to large warming within a very short period of time. This rate of warming could be many times that of the current warming. Thus, human and natural systems could be subjected to extreme stress following an abrupt termination, although a resilient system could be designed against all

**Figure 2:** Changes in annual mean rainfall (mm day[-1]), relative to pre-industrial simulation, in a) a simulation where $CO_2$ is doubled ($2xCO_2$), b) a geoengineering simulation where aerosols are prescribed only in the Arctic Stratosphere (ARCTIC), c) a geoengineering simulation where aerosols are prescribed in the Arctic and Antarctic Stratosphere (POLAR) and d) a geoengineering simulation where the aerosols are prescribed uniformly around the global stratosphere (GLOBAL). Hatched regions are not significant at the 5 per cent significance level estimated using student's t-test for 60 annual means and standard error corrected for autocorrelation. The zonal means are shown on the right of each panel and the width of the shading is equal to twice the standard deviation in the pre-industrial simulation. It can be seen that the rainfall in the northern hemisphere monsoon regions decreases in the ARCTIC (panel b) simulation (Figure adapted from Nalam *et al.* 2017).




but the most extreme catastrophes (Parker and Irvine 2018).

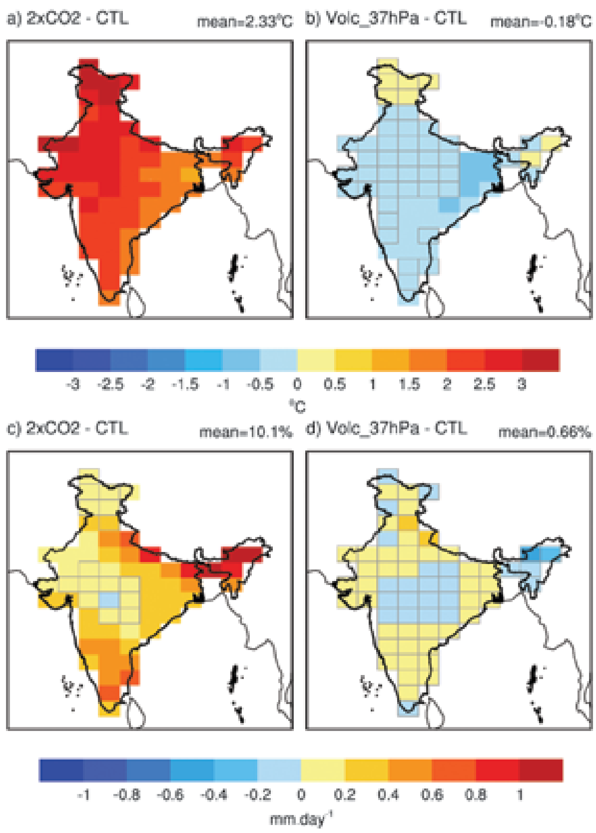
As the desired $CO_2$ emission reductions are not happening rapidly, and every new study into climate change suggests that we have less time and that the impacts are likely to be bigger and sooner than we previously thought, it is now argued that the ambitious target, set by the Paris Agreement, of limiting global warming to 1.5°C above the pre-industrial temperature level is difficult to achieve without the implementation of geoengineering as the planet has already warmed by 1.1°C (Parker and Geden 2016). It has also been rightly pointed out that the global south should have a central role in solar-geoengineering research, discussion, and evaluation for political and moral reasons (Rahman *et al.* 2018).

Most solar-geoengineering research is done in the European and North American research labs and universities. However, modest efforts have started in India too. The dialogue and research in geoengineering started in India almost ten years back (Bala 2009; Bala 2014). Climate modeling studies conducted in India have investigated the impacts of solar geoengineering on the global water cycle (Bala *et al.* 2010; Bala and Nag 2011; Modak and Bala 2014; Kalidindi *et al.* 2014), extreme events (Muthyala *et al.* 2018a, 2018b) and cyclones in the Bay of Bengal (Ghosh *et al.* 2016). Indian researchers have also been collaborating with foreign scientists in climate modeling to understand the climate processes related to the various methods of solar geoengineering (Bala *et al.* 2010; Cao *et al.* 2016; Cao *et al.* 2017; Duan *et al.* 2018) and in the assessment of the impacts of geoengineering on agricultural crops (Yang *et al.* 2016). The remote effects of Arctic Geoengineering on the Indian Monsoon rainfall have also been assessed recently (Figure 2; Nalam *et al.* 2017).

On the issue of governance, the Council on Energy, Environment, and Water (CEEW) which is based in New Delhi has organized regular international conferences (2011, 2014, 2016) to discuss the governance of solar geoengineering research and technologies. These discussions have attempted to identify the role of India in developing regional and global governance frameworks on solar geoengineering (for laboratory research, field experiments, and large-scale deployment).

The Indian government has also taken initiatives in geoengineering research. The Department of Science and Technology (DST) of India has been supporting an active climate modeling research programme in geoengineering since 2012 at the Indian Institute of Science, Bengaluru and the Indian Institute of Technology, New Delhi, under the umbrella of a broader climate change research programme. In 2017, DST launched a major Research & Development programme (MRDP) to understand the implications of geoengineering in developing countries like India. One of the major scientific objectives of the MRDP is to study the sensitivity of the tropical hydrological cycle (particularly in the South Asian Monsoon Region) to stratospheric sulphate geoengineering. The research will identify and work on geoengineering-relevant climate physics problems using climate models. Some preliminary climate modeling results from this project is shown in Figures 3, 4 and 5. These results clearly illustrate the effectiveness of solar geoengineering in offsetting the mean and extreme changes in temperature and precipitation associated with $CO_2$-induced climate change over India.

**Figure 3:** Changes in annual mean a) temperature (°C) and c) rainfall (mm $day^{-1}$) in a simulation where $CO_2$ is doubled (2xCO2) and a geoengineering simulation (panels b and d) where volcanic aerosols are prescribed at the 37 hPa pressure level (~ 22 km) in the stratosphere (Volc_37hPa) relative to a pre-industrial simulation. The boxes with grey border show the regions where the changes are not significant at the 5 per cent significance level. Significance level is estimated using Students t-test from 60 annual means of the experiments. Domain mean value changes are shown at the top left of each panel. It can be seen that the mean changes simulated in the 2xCO2 simulation are nearly offset in the geoengineering simulation.

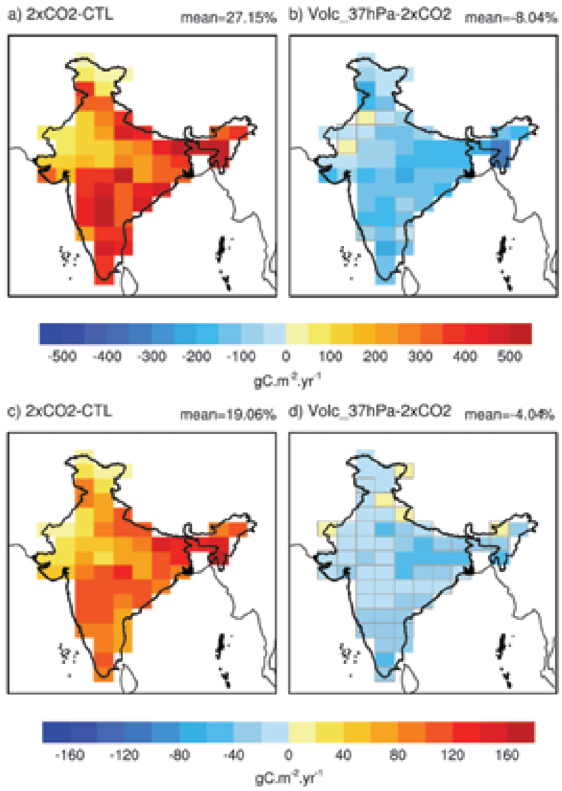


A roundtable discussion on Geoengineering funded by DST was also organized in New Delhi on 23 June 2017 to seek views of the Indian experts and policymakers on the issue of geoengineering and whether and how geoengineering is likely to impact India (Bala and Gupta 2017). The meeting was attended by about 35 attendees from 14 Institutions, and it brought the physical and social scientists together in India for an inclusive dialogue on geoengineering. The second "National Round-table discussion on geoengineering and India: Science and Policy" was organized on 26 July 2018 by the Centre for Atmospheric and Oceanic Sciences (CAOS), Indian Institute of Science (IISc), Bengaluru. The issues discussed at the meeting and the recommendations are listed in Table 1.

Other Institutions such as the Indian Institute of Technology-Delhi had also been supported by DST during 2012-2015 to understand the effects on geoengineering on the Indian Climate. These studies used multi-model data from the Geoengineering Model Intercomparison Project (GeoMIP) to assess the uncertainty in the model projections. Climate modeling studies at the Vellore Institute of Technology (VIT) has assessed the potential of marine cloud seeding to weaken cyclones in the Bay of Bengal before they make landfall (Ghosh *et al.* 2016).

In the area of CDR, one notable field experiment in which India was involved is the LOHAFEX (LOHA is a Hindi word for iron, FEX stands for Fertilization Experiment) ocean iron fertilization experiment conducted jointed by India and Germany in 2007, with the participation of scientists from Chile, France, Spain, and the UK. As expected the experiment led to the development of a phytoplankton bloom. However, the algal bloom also stimulated the growth of zooplankton that feeds on them. The zooplankton, in turn, could be consumed by higher organisms. Thus, it was found that artificial ocean iron fertilization could contribute to the carbon-fixing marine biomass of fish species fishing reduce the carbon sequestration potential of ocean iron fertilization.

**Figure 4:** Changes in annual mean a) gross primary production (GPP), and c) net primary production (NPP) in $gCm^{-2}yr^{-1}$ in a simulation where $CO_2$ is doubled (2xCO2) relative to a pre-industrial simulation. The changes in a geoengineering simulation where volcanic size aerosols are prescribed at the 37 hPa pressure level (~22km) in stratosphere (Volc_37hPa) relative to the 2xCO2 simulation from are shown in b) and d). The boxes with grey border show the regions where the changes are not significant at the 5 per cent significance level. Significance level is estimated using Students t-test from 60 annual means of the experiments. Domain mean changes (in per cent) are shown at the top left of each panel. It can be seen that the vegetation productivity is reduced in the geoengineering simulations because of a reduction in incoming sunlight.




Solar geoengineering is a highly controversial idea, and it may be societally and institutionally infeasible as it is riddled with moral, ethical, legal and insurmountable governance and political issues. It may be worthwhile to develop an improved scientific understanding of the processes involved

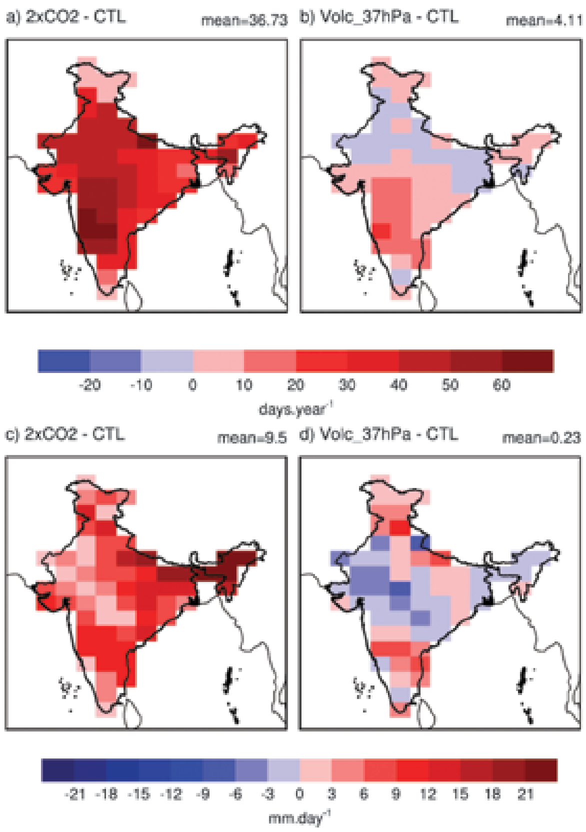
**Table 1: Recommendations from the 2nd National Roundtable Discussion on "Geoengineering and India: Science and Policy" organized at the Indian Institute of Science, Bengaluru on 26 July 2018.**

| S.No | Specific Geoengineering research issue discussed | Recommendation |
|---|---|---|
| 1 | What should be the major focus of geoengineering research in India? | For the moment modeling (SRM) should be the focus of GE research. However, ***efforts should be made to develop a way forward integrating SRM, CDR and other Mitigation initiatives.*** |
| 2 | Will geoengineering adversely impact India? If so, in what way? Will there be benefits for India? If yes, what are they? | Geoengineering (GE) research in India is at an early stage. These answers will emerge after a few years of thorough investigation and numerical experiments. ***There is a need to build institutional capacity to upscale GE research in the country.*** |
| 3 | Should India consider joining a "coalition" of countries that support geoengineering? | ***Efforts may be made to explore the possibility of bringing the research agenda at some of the regional groupings like BRICS, BIMSTEC, IORA, etc.*** |
| 4 | Can we develop a policy paper on GE research in India? | ***There is a need to develop an Approach paper on GE Research in India by setting up an Expert group comprising of experts/ professionals from government/ private institutions and NGOs.*** |
| 5. | What are the mechanisms needed to bring the physical and social scientists together in India for an inclusive dialogue on geoengineering? | ***Set up a "Google Email Discussion Forum" wherein all interested physical & social scientists and policymakers may participate in an academic discussion.*** Dr G. Bala, IISc may be designated as group admin to set up the above discussion forum. |
| 6 | What mechanisms are needed to increase the capacity of a national programme? | ***Dr G. Bala in consultation with other research groups may identify and prepare a list of individual scientists, groups and institutions in India working or interested to work on GE related research areas.***<br><br>***DST may consider initiating a National Network Programme on GE research on long-term.*** |
| 7. | Should India develop international joint research programmes with other countries, taking account of research capacities, funding mechanisms, liability rules, and intellectual property? | ***International joint research programme should be taken only after attaining some maturity in GE research in the country.*** The GE research in India is currently at the infancy stage. |

in geoengineering and its possible implications, globally as well as regionally.

In the coming years, an expansion in scientific capacity in geoengineering research in India is likely. Scientific research in India on geoengineering would focus on identifying if geoengineering would adversely impact the natural systems in India. The investigation into the robust response of monsoon and the Indian hydrology (represented by precipitation, evapotranspiration, and runoff) to solar geoengineering is likely the top priority areas in this direction. Field experiments that study monsoon clouds, aerosol-cloud interaction and intrusion of tropospheric aerosols into the stratosphere could provide crucial region-specific information on albedo modification. Indian climate scientists could use the earth system model that is currently developed by Indian Institute of Tropical Meteorology (Swapna *et al.* 2015) for performing solar geoengineering simulations to generate locally produced knowledge on the effects of geoengineering on the Indian climate.

**Figure 5:** Changes in annual mean a) summer days (days with daily maximum temperature greater than 25°C) and c) maximum one day precipitation (mm day$^{-1}$) in a simulation where $CO_2$ is doubled (2xCO2) relative to a pre-industrial simulation, and a geoengineering simulation (panels b and d) where volcanic size aerosols are prescribed at the 37 hPa pressure level (~22km) in the stratosphere (Volc_37hPa). Domain mean changes are shown at the top left of each panel. It can be seen that the increase in extreme temperature and precipitation are nearly offset in the geoengineering simulation.




One relevant issue of societal importance is to assess the ability of solar geoengineering to reduce the intensity of heat waves in the pre-monsoon season in India which causes thousands of deaths each year. Research should also assess if geoengineering would be beneficial to the regional forestry and agriculture sectors by reducing the heat stress and extreme rainfall events and to the coastal zones by preventing regional sea level rise in India. Research should also investigate if solar geoengineering would help to reduce the accelerating mass loss in the Himalayan glaciers and avert the looming water crisis in the Himalayan valleys where people heavily depend on the low altitude glaciers for their water resources. The robustness and uncertainty in impacts should be assessed by using data from multiple climate models that participate in climate model inter-comparison projects.

As discussed earlier, geoengineering is a controversial idea which, in addition to the numerous scientific and technological issues, involves societal, economic, moral, ethical, political, legal and governance issues. Therefore, the interaction between physical and social scientists should be facilitated: social scientists will and must have a central role in geoengineering discussions. Scientific research must, however, continue and the global south including India should be actively engaged in solar geoengineering research, evaluation and discussion. Ultimately, we may need a portfolio of several approaches that involve all three options – adaption, mitigation and geoengineering – to combat climate change.

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# Using energy models to inform policy in India: What more is needed?

Simi Thambi[1] and Anil Kumar Jain[2]

**Abstract**

Energy modeling is not a new phenomenon in India, but these activities are still to be fully integrated into the institutional set-up. This article discusses the status of energy modeling in the country and suggests ingredients for its strengthening. The views expressed are based on interactions with different stakeholders actively engaged in energy modeling in India. The article highlights that supportive institutional structure, reliable data and platforms conducive for exchange of ideas are important for using energy models more effectively for informing policy.

**Keywords**

*Energy Modeling, Institutions, Data, Inter-model Comparison.*

## Introduction

Energy models can be extremely useful tools to inform climate policy and Multinational Environmental Agreements. India is expected to be one of the fastest growing economies of the world. With the population anticipated to grow in the future and improvements in socioeconomic developments, energy demand is expected to rise consequently. Considerable progress has been made in improving energy access in the country in the past few years. Nevertheless, almost 27 million households (MOP 2018) still do not have access to electricity and 780 million people (IEA 2017) rely on biomass for cooking. The country faces the trilemma of achieving objectives of higher energy access alongside higher energy security and higher sustainability. While energy security and sustainability are mutually reinforcing as India's energy imports are predominantly fossil-based, the goal of accessibility will conflict with the goal of sustainability as long as fossil fuels are the cheapest source of energy (NITI Aayog 2017). To ensure that the country achieves a fine balance in attaining these objectives integrated energy planning is extremely important. Energy modeling can contribute immensely to integrated energy planning and policy analysis. Holistic energy planning for the entire energy sector is critical for informing important policy questions. The government needs the ability to understand trends and the implications of decisions in a complex but interconnected world.

Energy models can provide a platform to build energy systems which can be used to assess the competitiveness of different types of fuels across time for various demand sectors at global, regional, national or state level. Thus, providing a scientific basis for understanding tradeoffs in various policy choices, by creating scenarios to display alternative

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futures. This facilitates a deeper understanding of the interconnected dimensions of the energy sector.

India has been engaged in energy modeling activities for long, but they have been done in a largely un-systematic fashion, with work happening here and there, in some government ministries and research organizations. This fragmented approach to energy modeling has limitations. It is important that the Government of India supports creating an institution that undertakes energy modeling for different types of sectors collectively and integrates the various kinds of modeling initiatives within the country under one umbrella institution. It is also important to encourage in-house capabilities as this will help policymakers to fully appreciate and understand the challenges and opportunities, the simplicity or complexity of these models. To use the modeling results more proactively for policy making, the quality of energy data needs to improve gradually. It is suggested to use more than one model to analyze the same issue as this will make results more robust. By providing avenues for inter-model comparisons the strengths and weaknesses of different types of models can be leveraged productively.

In the following sections, we discuss some of these issues in greater detail to understand the status of energy modeling in the country and what more is needed to use it for informing policy.

## Supportive institutional structure

A dedicated institutional structure within the government is vital to make energy modeling an integral part of government functioning. Across the world, there are several countries which have government institutions who by their legal mandate are required to undertake modeling for the entire energy sector. United States has Energy Information Administration (EIA) which is an independent statistical agency of the US Department of Energy, the OECD countries have the International Energy Agency, China has the Energy Research Institute which comes under the National Development and Reform Commission (NDRC), European Commission has the Joint Research Centre (JRC). Through these organizations, modeling inputs feed into policy outputs from time to time.

In India, at present majority of energy modeling work is outsourced by the government to research organizations, academic institutions or private consultancies. Some organizations which are actively engaged in this work in India are Council for Energy Environment and Water (CEEW), The Energy and Resources Institute (TERI)), Center for Study of Science, Technology and Policy (CSTEP), Integrated Research and Action for Development (IRADe), Observer Research Foundation (ORF). Along with them, there are other organizations like ICF, Shakti Foundation, World Resources Institute (WRI), Energy Policy Institute at the University of Chicago (EPIC), Rocky Mountain Institute (RMI), Prayas Energy Group (PEG) and more recently The Celestial Earth (TCE). Also, there are consultancies like McKinsey, KPMG, PwC (PricewaterhouseCoopers) and academic institutions like the IITs Indian Institute of Technology) and the IIMs (Indian Institute of Management) to whom work is outsourced[3]. These are need-based collaborations for informing decisions in the Government.

There is no government body in India that is legally mandated to undertake modeling for the entire energy sector. Central Electricity Authority (CEA) and Petroleum Planning and Analysis Cell (PPAC) undertake modeling in-house only for their respective areas and on select policy issues concerning their sector. Because separate research divisions under each ministry undertake technical work in their respective area, there is a lack of integrated research in the domain of energy. And

[3] The names mentioned here are non-exhaustive.

experts have expressed that this has inadvertently led to situations where sometimes ministries end up promoting their fuel over the fuels of other ministries. For holistic planning for the entire energy sector, this fragmented approach to energy modeling needs to be overcome.

Energy modeling in the country has come a long way. To put the history of energy modeling within the government in perspective, a non-exhaustive chronological list of modeling related activities within the government are summarized below:

**1960s:**

- In 1963, Energy Survey Committee (ESC) was formed for surveying energy resources and forecasting energy demand. The report was prepared by Detroit Edison Company of the United States for the Indian Government.

**1970s:**

- In 1974, The Fuel Policy Committee (FPC) was published under the Chairmanship of S. Chakravarti, Member, Planning Commission with the modeling work undertaken by Gokhale Institute of Politics and Economics.

- In 1978, Report by the Working Group on Energy Policy (WGEP) was released, the work was led by N.B Prasad, Secretary, Ministry of Energy. This working group comprised a mix of civil servants and academicians, the modeling work was carried out by the academic institutions of the members in the working group.

**2000s:**

- In 2006, Integrated Energy Policy (IEP) came out under the Chairmanship of K. Parikh, Member Planning Commission. The modeling work for IEP was done by ORF (Observer Research Foundation; Planning Commission 2006).

- In 2009, the Ministry of Environment and Forests published a report on India's GHG Emissions Profile: Results of Five Modeling Studies. The studies were carried out by National Council of Applied Economic Research (NCAER), TERI (The Energy Resources Institute), IRADe (Integrated Research and Action for Development) and McKinsey (MoEF 2009).

- In 2014, the Planning Commission came out with report on Low Carbon Strategies for Inclusive Growth (LCIG), which was also the under the Chairmanship of K. Parikh, with modeling work done by IRADe (Planning Commission 2014).

- In 2015, NITI Aayog which replaced Planning Commission launched an interactive national-level energy calculator, IESS 2047 (India Energy Security Scenarios). The calculator provides a transparent web-based interface for users to develop energy security and emission scenarios for different levers of a national effort through demand and supply-side management. It also provides an easily downloadable excel sheet which provides detailed data on technical and cost parameters of various technologies. It was modeled like the DECC 2050 calculator of the United Kingdom. Several research organizations of India worked collectively alongside NITI Aayog to develop IESS 2047 (NITI Aayog 2015).

- With the successful launch of IESS 2047, steps were taken to encourage the creation of State Energy Calculators. Andhra Pradesh launched its state energy calculator in 2017 (APSEC 2050). As of 2018, few other states including Assam, Tamil Nadu, Gujarat, Karnataka, Maharashtra have shown interest in having similar state energy calculators. ICF and the Celestial Earth are actively engaged in setting up such calculators for different states in India.

- In 2017, NITI Aayog took steps to develop an energy optimization model in-house with technical support from IIASA (International Institute of Applied System Analysis) under the umbrella of Technology Information Forecasting and Assessment Council (TIFAC) membership in IIASA. The model built by NITI Aayog uses the MESSAGE$_{ix}$ optimization model of IIASA (Thambi *et al.* 2018).

One can see from the timeline above, India has moved away from completely outsourcing modeling to foreign agencies towards doing it within the country. However, there is scope for improvement. Still very little modeling work is carried out in-house within the government. Much of the work is also largely need-based and not continuous. This raises the pertinent question, should the government be engaged in in-house modeling at all when it can outsource such work to domestic organizations who specialize in doing this work on a day to day basis? Views on this issue diverge. While some are active proponents of building this capacity within the government as this could result in greater appreciation of modeling outputs, there are some who argue that technical work like modeling should be carried out outside the government as government officials are often tied up with day to day operational work.

In this article, we argue that it is important to encourage modeling within the government. This will benefit not only the government but also the wider modeling community. It benefits the government because it will prevent government officials from being taken for a ride with the outputs and costs of such technical projects. Moreover, when the government undertakes modeling, technical outputs have greater ability to seep into the planning system. It will benefit the modeling community because modelers sometimes face challenges in explaining the strengths and weakness of their technical outputs to government officials. If government officials are already aware of some technical features of these models, such situations can be minimized.

The government needs to create a mechanism to ensure that energy modeling activities for the entire energy sector are undertaken in a sustainable, periodic and timely manner as a part of the normal organizational functioning. This will result in the publication of reports based on results of modeling exercises that feed into the planning process from time to time. This will also facilitate free-flowing interaction between the models, modelers and the policymakers to encourage the development of models better suited to depict Indian realities. It will build capabilities within the government to refine existing models to answer new policy questions.

The suggestion to have a government-supported institution mandated to undertake integrated manner energy modeling was first recommended as a part of the Integrated Energy Policy (Planning Commission 2006). Several other scholars have supported the creation of such an agency. For instance, Chikkatur and Chakravarty (2008) suggest the institutional structure could take the form of either a single integrated unit or multiple distributed units. Rai *et al.* (2016) suggest the creation of a national Energy Information Agency – an IndianEIA or "indEIA in the likes of the Energy Information Agency (EIA) in the United States.

The Government of India must create a structure most suited to proactively use energy modeling for planning in the national context, after carefully evaluating the pros and cons of different types of institutional structures. It is important to legally mandate it to conduct modeling and analysis for the entire energy sector as well as other interconnected sectors for integrated nexus analysis, for instance, the nexus between land use in the power sector and agriculture or nexus of water use in agriculture and power sector. In the long run, these integrated assessment models will be extremely useful to frame India's position on Nationally Determined Contributions (NDCs) and develop its mid-century strategy in a more informed way.

## Reliable data pool

Data forms the backbone of energy models. Reliable datasets ensure that outputs of models are trusted by the policy makers. PEG (2014, 2015) and Rai *et al.* (2016) have already identified a lot of burning issues that need to be addressed to improve the status of energy data management in India. In this section, we present some of their concerns and suggestions on way forward.

Data management in India is currently done only for administrative purposes and not with the purpose of research or dissemination. PEG (2014) point out that several government institutions in India have enough legal authority to collect energy data and share it among different departments for administrative reasons. However, they have a limited mandate to disseminate this data to the general public. Apart from the Ministry of Statistics and Programme Implementation (MoSPI) which is responsible for disseminating statistics, only the Central Electricity Authority (CEA) has the mandate to disseminate electricity data.

There are also important data gaps in energy data. On the supply side, there is a paucity of data on new renewable energy technologies. For instance Rai *et al*. (2016) mentions there is a paucity of authenticated data on deployment of solar energy particularly, financial and technical state of this sector which explains the evolution of installed prices, technologies, market structure, and policies. Furthermore, there is little to no monitoring of off-grid systems, making it unclear as to how many of these are even functional (PEG 2014). There are far more gaps in energy demand-side data when compared to energy supply side data. For instance, even though biomass accounts for a major share in the total primary energy supply of the country, there is the unavailability of data regarding its non-commercial energy consumption (PEG 2014).

In addition to data gaps, there are also inconsistencies in energy data across sources. For instance, the United Nations Framework Convention on Climate Change has an internationally recognized method for classifying coal reserves. This classification was adopted by the Government of India in 2011 (Sreenivas and Bhosale 2013). However, all Indian coal reserves are still not classified using this methodology. This results in discrepancies in the volume of coal reserves across different sources. Another example of inconsistency is data for electrification. Household and village electrification rates vary across sources. For example, Census 2011 and NSSO expenditure survey of 2011-12 differs in household electrification rates, possibly due to differences in the nature of the surveys (PEG 2014).

Long gaps in data dissemination is another impediment to researchers in using the data for research and modeling. For instance, CEA General Review and CCO's coal directory are released 1.5 to 2 years after the reference year (PEG 2014). In general, for the entire energy sector, sometimes the data that is available is not readily accessible, often in pdf formats which increases the costs and time involved in the analysis of such data.

Several suggestions have been put forward to improve the status of energy data management in the country. One major suggestion that is common across all authors reviewed for this section, is the need for creating a single well-defined and staffed agency to collate, harmonize, reconcile and publish energy data from multiple sources. This agency should have staff that has expertise in data, statistics and their management, domain expertise related to energy and have the powers to suggest refinements to data. This agency should also be empowered to analyze the energy data that is collected.

To understand which kind of energy data

management model will be best suited for India, one could learn from the best practices of energy data management in other countries. Different countries have adopted different types of energy data management models with different degrees of centralization. To better understand this, U.S. Department of Energy and Prayas Energy Group on request of NITI Aayog conducted a review of, 'International Best Practices on Energy Data Management'. India's data management can be strengthened with lessons from these best practices.

In recent years, firm steps have been taken for better energy data management. NITI Aayog entered into a tripartite agreement (SOP) with the United States Energy Information Administration (EIA) and the United States Agency for International Development (USAID) in the area of energy data management (EDM). Planned areas of cooperation include: (a) adapting EIA best practices to the Indian context; (b) sharing methodological approaches towards improving the accuracy, availability and timeliness of energy data; (c) sharing analysis tools; and (d) compiling lessons learned in EDM institutional design, including structure, authority, budget, manpower requirements and other activities (Ram 2017).

For improving the regularity of data, NITI Aayog supported Prayas Energy Group to create a central energy information portal, India energy Portal[4]. This online portal collates the data already available with different ministries at one place, making energy statistics available to the public in visually interesting and easy to understand manner.

To address the issue of data gaps and inconsistencies, NITI Aayog formed two working groups on the demand and supply side of energy data management. The demand side comprises sub-working groups, transport, industry, agriculture and building. And the supply side comprises, coal, oil and gas, renewables and electricity sub-groups. These groups bring together officials from the government and research organizations to brainstorm on vital issues like what are the data gaps, what should be the frequency of collecting data, what is the source of this data collection and how to update it on a real-time basis. One of the aims of these working groups is to act towards automating energy data to the extent possible. Automated data collection can improve data collection to ensure accuracy and completeness. Recent initiatives like the National Statistical Commission and National Data Sharing and Accessibility Policy (NSDAP) are some attempts by the government to improve the status of data in general. These initiatives can benefit energy data management as well. These sub-group meetings have also recognized the importance of continuous training and strategic staff planning to maximize the effective use of staff at central and state levels. In that direction, NITI Aayog has already started coordinating with organizations like the International Energy Agency (IEA) to conduct training for Indian government officials on better energy data management.

### Encouraging inter-model comparison

A model helps in understanding future uncertainties in the energy landscape by creating alternate scenarios. If one tries to examine the same policy question by creating alternative future scenarios in different energy models, the results need not be the same. The divergence in results can be explained by the different characteristics of the models, their levels of details, different implicit assumptions. Hence, using more than one model to analyze the same issue could help in making the findings more robust. Prominent international reports like reports of the Intergovernmental Panel on Climate Change (IPCC) always base their policy implications on findings of a handful of comparable models. It is important that India too develops the expertise to develop multiple models that can throw light on the

[4] This portal can be accessed at http://indiaenergy.gov.in/edm/

same policy question in their different unique ways.

All models have their unique strengths and weakness depending on the way they are structured. Macro-economic models give a better representation of inter-industry energy demand and its linkage to national output while bottom-up models can model technical parameters of different types of technologies. Policy questions must be designed by understanding the inherent strengths and weakness of the model.

Harmonizing key assumptions used in different models is an important way to reduce uncertainty and better interpret the results of different types of energy models. Dubash *et al.* (2015) compared the results of 7 prominent modeling studies in India to find the results diverged even in the baseline scenario. They strongly suggested harmonizing important assumptions to improve the usability of modeling results for policy.

NITI Aayog took a commendable step in this direction by encouraging inter-model comparison exercise with common modelling protocols. Under the Sustainable Growth Working Group of Government of India, NITI Aayog for the first time provided a platform for inter-model comparison. Four Indian research institutions (CSTEP, CEEW, IRADe and TERI) and PNNL (Pacific Northwest National Laboratory) of the United States Department of Energy, coordinated to provide analysis on topics of national interest. They did studies on energy-food-water nexus and pathways for decarbonization in the transport sector. In both these studies, to facilitate interaction between the government and modelers, an Advisory Board with representatives from different ministries of the government, was formed. Through this platform, the teams could get government officials to review modeling assumptions and methodologies. Based on that, the teams harmonized key assumptions and scenarios by developing a common modeling protocol. This interactions between the modelers and advisory board members provided a critical link between analysis and policy development. The results of these two modelling exercises were published in top ranking journals, Energy Policy and Applied energy (Paladugula *et al.* 2018; Srinivasan *et al.* 2018).

With the upsurge of inter-model comparison exercises, the global modeling community has developed an Integrated Assessment Modeling Consortium (IAMC)[5] that facilitates a platform for standardization of results across the models of different organizations. As India builds its domestic modeling base, it would be useful to align to such common modelling protocols by developing common tabular and graphical formats, to ensure smooth comparison across different types of models. The government could facilitate this process.

### Inculcating scientific temperament

All models rely on a base year which is the starting point of every modeling study. Based on this baseline, scenarios are created for the future which are called alternate scenarios that model implications of different policies by making changes to baseline case using different assumptions. Inter-model comparison exercise must start with a credible starting point against which implications of alternative scenarios can be modeled. However, sometimes this task is not easy. Sometimes base year numbers cannot be harmonized because differences in base year data may reflect a legitimate source of uncertainty.

An area where baseline numbers are particularly difficult to harmonize is Indian transport demand. Based on an analysis of different sources

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including ministry publications and datasets of international organizations, studies find differences in aggregate estimates of energy consumption of the transportation sector to be around 23 per cent. This is due to differences in sources and interpretation of existing data. In addition, there are large differences in energy consumption by mode of transport, differences in energy consumed by passenger vehicles in total energy demand in the range of 38–68 per cent in 2010 (Paladugula *et al.* 2018). This kind of divergence in historical data of consumption has been observed in other developing countries as well, for instance, in China (Yin *et al.* 2015) and Russia (Kholod *et al.* 2016). Chaturvedi *et al.* (2016) point that differences in historical data across different data sources may not be because of poor craftsmanship of the modelers but rather due to legitimate reasons. Artificially forcing the model for harmonizing data points of a specified source would not be the right approach, as it will only end up giving a fake sense of uncertainty which is not present in the real world. Ministries could accept these issues with an open mind and debate on them with a scientific temperament.

## Platform for exchange

Nowadays, there are several modeling studies happening in different ministries as well as private institutions and NGOs in India. There should be a annual platform where people engaged in this field could share their findings and get ideas for future research. Policy makers from relevant ministries should also be invited to this forum. In this direction, NITI Aayog initiated the First Indian Energy Modeling Forum in March 2019. This Forum will enable both sides, modeling community and policymakers, to understand each other's needs and limitations. It will help in driving policies backed by scientific research of the modeling community. Planning Commission (2006) had also suggested the creation of a National Energy Fund which could support this kind of a modeling forum. There could also be a web-based knowledge management system that links all modeling related initiatives of the government as well as that of other organizations. This could be linked with information of donors of funds for projects. This kind of information management system will also help in moving towards the common tabular formats proposed as a part of the Biennial Transparency Report which India should submit to the United Nations Framework Convention on Climate Change (UNFCCC) by 2024.

## Conclusion

In this article, an attempt was made to highlight some areas of action to strengthen modeling activities in India. Undertaking energy modeling by the government for the government is important. It helps in skill building, generating awareness and leads to a greater appreciation of the modeling outputs. Energy data in India needs to significantly improve by overcoming inconsistencies, bringing timeliness and increasing usability. Platform for sharing of results, ideas and suggestions need to be facilitated for seamless interaction of modelers and policymakers.

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