Environmental Science

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Sangeeta Baksi *Editors*

Socio-economic and Eco-biological Dimensions in Resource use and Conservation

Strategies for Sustainability

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Foreword

In the context of global climate change scenario, conservation and rational use of ecological and biological resources needs to be prioritized for sustaining the environment. The *United Nations Framework Convention on Climate Change* (UNFCCC) states that “Adverse effects of climate change” means changes in the physical environment or biota resulting from climate change, which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.

The knowledge of ecological, biological and social dimensions of climate change from a sustainable and equitable development perspective is plausible, if interdependent approach adopted within a unified framework. Evidence influences the anthropogenic warming at a global scale resulting in a cause and effect relationship of resource use. These necessitate for undertaking fundamental and basic research at micro-level for understanding the dynamics of environmental changes in the society.

The present edited volume by distinguished experts with a blending from the discipline of natural, biological and social sciences is very unique and timely contribution in the field of climate change and its effect in the society. All the 26 chapters in the volume depicted the emerging and typical issues concerning the climate change and eco-biological and social contexts. Most of the chapters relate to the studies which are conducted with case studies and particular experiment. These studies have thrown new light on the possibilities and potentials of adaptability to climate change vulnerability which can be utilized for the benefit of the society at large. I am sure the present volume will be a landmark publication in the domain of socio-economic and eco-biological dimensions of climate change and its vulnerability.

I convey my congratulations to the editors of the book and writers of the chapters. I wish the editors all the best in their productive endeavours in the field of climate change issues.

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Contents

Socio-Economic and Eco-Biological Dimensions in Resource Use and Conservation: Prologue

Niranjan Roy, Shubhadeep Roychoudhury, Sunil Nautiyal, Sunil K. Agarwal and Sangeeta Baksi

Abstract Overexploitation of natural resources coupled with anthropogenic climatic variations has put the ecosystem services under enormous pressure not only at macro levels but also at micro levels thereby presenting challenges in social, economic, ecological and biological fronts. Sustainable use of natural resources and their conservation strategies require interdisciplinary and transdisciplinary thinking. The threat is especially severe in regions where people's livelihoods depend largely on natural resources. The objective of this book is to translate the body of scientific knowledge for proper conservation of natural resources and biodiversity in India's sensitive eco-regions and use them sustainably in the interest of our future generations. It may contribute effectively to suggest possible roadmap as well as strategies to address livelihood issues locally and globally while ensuring inclusive growth and social inclusion at large.

Keywords Ecosystem services · Fragile ecosystems · Marginalized communities · Rapid population growth · Landuse changes · Natural disasters

Overexploitation of natural resources coupled with anthropogenic climatic variations has put the ecosystem services under enormous pressure not only at macro levels but

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also at micro levels (MA 2005). The pace and pattern of the changing climate is not only resulting in degraded ecosystems but also threatening to severely test mankind's ability to adapt to them thereby presenting challenges in social, economic, ecological as well as biological fronts (IPCC 2014). Ability of marginalized communities living in susceptible areas to cope up depends on the internal structure of their social systems (Raju et al. 2017). Differential vulnerabilities of individuals, groups and societies vary according to the characteristics of the area which may be understood better in terms of the socio-economic engagements (agriculture, industry, tourism, transport, consumption, lifestyle), eco-biological (evolution of flora and fauna, living condition of populations, territory) and cultural (values and perceptions of trends on conservation and sustainability) indicators acting as a catalyst for the development of holistic and comprehensive plans for adaptation to climatic changes for sustainable use and conservation of natural resources (Lopez and Pardo 2018).

Factors such as land use changes and anthropogenic emissions of green house gases over the last two hundred years are new causes for concern (IPCC 2007). Surface temperature of earth is projected to rise over the 21st century with a higher frequency and longer duration of heat waves as well as occasional cold winter extremes. The ocean will continue to warm and acidify, and global mean sea level will rise. This unprecedented scale of climatic variation poses a great threat to natural resources globally making the environmental, human and financial cost unbearable (UN 2014). It has the potential to manifest at multiple levels impacting multiple sectors not only by intensifying existing risks but also by generating additional risks for natural and human systems (IPCC 2014). At the regional level, rise in temperatures in the Arctic increases the wildfires causing loss of tree cover in Arctic and sub-Arctic forests, whereas at more moderate latitudes shifting rainfall patterns affect land use, water and food security. Arid and semiarid conditions also expand northward making agriculture more difficult at low latitudes. At local levels, changing weather and precipitation patterns can increase large scale flooding and possibly droughts and storms (Emanuel 2005), affect agricultural potential posing a challenge to food and water security (Milly et al. 2002), influence household practices and vector borne diseases, including secondary affect such as desertification, famine and conflicts (Gupta et al. 2007; IPCC 2007; Harris 2018).

Population growth has a direct influence on depletion of natural resources. Due to environmental variability, natural resources are compromised and are already shrinking. Rapid population rise has a negative impact on human development, provision of essential services and poverty alleviation. It also causes a significant increase in demand often leading to mismanagement of key resources (Stephenson et al. 2010). In fact, the scale of the human footprint has grown to the extent that human economic activity has the power to influence major planetary systems. An expected rise in global population by more than 2 billion people between 2010 and 2050 will put additional pressure on the natural resources that are finite. Rapid population growth also generates vast quantities of non-biodegradable waste, drives deforestation and produces massive amounts of CO_2 thereby putting enormous pressure on key natural resources, such as clean air, water, fuel, soil fertility, weather, and myriad ecosystem services. Increased rate of consumption tend to use the resources quicker than their rate of regeneration (Stephenson et al. 2010; Krauss and Kastning 2016). The impacts will be magnified because the increased population will be located primarily in cities, often in low-lying areas sensitive to storm surges and floods, in vulnerable agricultural areas, and in vulnerable eco-regions. Furthermore, current patterns of energy and natural resource use, agricultural practices, and urbanization appear to be largely unsustainable and may lead to increased economic, social, and environmental costs and decreased productivity (Steer 2014).

Very often, global environmental change has been linked to high consumption in developed countries, while its estimated impact is greatest on people in the developing world. The poorest people in vulnerable regions of the world are at severe risk (Stephenson et al. 2010; Feulner 2015), thereby necessitating safeguarding of rural livelihoods and ensuring sustainable development (Agarwal et al. 2019). Such people may be forced to migrate to areas that are environmentally marginal thus leaving them more vulnerable and more likely to exploit new resources in an unsustainable way. This, in turn, may lead to a vicious cycle of poverty and degradation weakening the capacity of poor communities to adapt (Stephenson et al. 2010). In essence, previous and future variations in climate predispose a huge portion of global population in the developing nations to major threats (Feulner 2015).

Research is urgently needed at micro level to come up with adequate strategies for sustainable conservation of key resources and biodiversity without depleting the natural resource base. Issues such as the contribution of population growth, migration, urbanization, and household composition need proper understanding and clarification. Important questions that deserve scientific investigation include proper recording and detailed examination of adaptation approaches of people, investigation of the mechanism of impact of demographic factors (e.g. growth rates, composition, spatial distribution and education levels) on their coping ability, analysis of the influence of fast growth of population and rapid industrialization in sensitive eco-regions (e.g. population structure, water availability, food and shelter requirements and labour markets). Mapping characteristics of migrant flows, including seasonal patterns, duration and destination to aid adaptation strategies, mapping availability of water according to spatially vulnerable groups over time form important aspects in order to identify adaptation strategies, and contribute effectively to UN-Sustainable Development Goals by 2030 (SDG 2015). Study of the impact of population pressure on equity and distribution of water and agriculture is imperative for developing strong measures of vulnerability (Stephenson et al. 2010; Kattumuri 2018).

India is a mega-diverse country in terms of both biodiversity and people. The mountainous region covers an area close to 100 million hectares, arid and semi-arid zones are spread over 30 million hectares and the coastline is about 8000 km long (MoEFCC 2009). It represents 2 'realms' (the Himalayan region represented by Palearctic realm and the rest of the sub-continent represented by Malayan realm), 5 biomes (tropical humid forests; tropical dry deciduous forests, including monsoon forests; warm deserts and semi-deserts; coniferous forests; alpine meadows), 10 biogeographic zones and 27 biogeographic provinces. With only 2.4% of the global land area, India is home to 7–8% of all species recorded, including plants (over 45,000 species) and animals (over 91,000 species) (IUCN 2019). Although

India ranks 10 among the countries with the largest forest cover (FAO 2010), forest distribution remains highly variable, with most located in the central and north eastern states (FSI 2011). Of the 34 globally identified biodiversity hotspots, India harbours four hotspots—Himalayas (entire Indian Himalayan region and that falling in Pakistan, Tibet, Nepal, Bhutan, China and Myanmar), Indo-Burma (entire north east India except Assam, and that of Myanmar, Thailand, Vietnam, Laos, Cambodia and southern China), Western Ghats and Sri Lanka (entire Western Ghats of India and Sri Lanka), and Sundaland (Nicobar group of islands plus Indonesia, Malaysia, Singapore, Brunei and Philippines) (BSI 2016). Over 130,000 species of plants and animals have already been documented from India. The richness of the biodiversity is largely due to the occurrence of species, genetic and ecological variabilities in different bio-geographically and bio-climatically defined zones formed by a wide range of ecosystems and habitats such as forests, grasslands, wetlands, coastal and marine ecosystems, and deserts owing to the varied edaphic, climatic and topographic conditions (Khandekar and Srivastava 2014).

Owing to the location in the eastern Himalayan periphery, India's north east, endowed with rich natural resources has been identified as sensitive to water-induced disasters, fragile geo-environmental settings and underdevelopment in terms of economy. The region's powerful hydrological and monsoon regime, particularly the Brahmaputra and the Barak river systems serve as a resource as well as a source of vulnerability. In comparison to other Indian states with similarity in terms of average per-capita income, India's north east has registered higher incidence of poverty. Environmental sustainability of this region is also affected by growing population and declining productivity of land coupled with comparatively greater dependence on forests and other natural resources (Das 2009; INCCA 2010). Land use change is also considered as an important driver of change in tropical regions either singly or in combination with others (McNeely et al. 1990). About 51.09% of India's land are cultivated, 21.81% forested and 3.92% under pasture, where as 12.34% is occupied by built up areas and uncultivated land, and 5.17% is uncultivated waste. The rest comprises of other types of land (IWP 2009). Large-scale alteration of the landscapes for economical, industrial and infrastructure development and consequent habitat degradation, fragmentation and depletion are considered to be the prime causes of biodiversity loss in tropics. In India's north east, clearance of forests for cultivation including agriculture, tea, coffee, rubber as well as the slash and burn mode of '*jhum*' cultivation wherein the cycle is ever reducing, modification of main natural habitat for industrial and developmental activities (oil and natural gas, coal mining, construction of roads etc.), forest fire and other anthropogenic activities have been significant drivers of change. In the absence of effective land use policy, as large as 2 million hectares of land in India's north east has been affected by '*jhum*' cultivation (Tripathi et al. 2016). Hence, vulnerability of fragile forest ecosystems of north eastern India is perceived to pose a variety of stress on sustainability of livelihood system of the poor inhabitants through stresses on ecosystem function (Bujarbarua and Baruah 2009). The eastern Himalayas is also likely to expect major transformations in biodiversity across all systems (terrestrial, freshwater) and all levels (genetic, species, ecosystem), which is triggered by the speedy erosion of the ecological balance in the flow of material and energy (ICIMOD 2010). A recent study has ranked the north eastern state of Assam to be the most vulnerable, followed by Mizoram, Manipur, Meghalaya, West Bengal, Nagaland, Tripura, Arunachal Pradesh and Sikkim (NMSHE and SDC 2019).

In India, more than 57% people are dependent on agriculture and forestry sectors for their livelihood. In 2017, a parliamentary committee in its report submitted to India's Agriculture Ministry noted that extreme weather events are costing the country annually USD 9–10 billion, and is likely to impact agricultural productivity with increasing severity from 2020 to the end of the century (Mohan 2017). According to a 2018 UN report, India suffered a massive loss of USD 79.5 billion due to extreme weather events in the past 20 years (The Hindu 2018). A World Bank report published in 2018 warned that with possible 1–2% rise in annual average temperature, the living standards of nearly half of India's population will be lowered by 2050 costing up to 2.8% of the country's GDP (World Bank 2018). According to last year's IPCC report, the impact of climatic variations could be distressing for India both socially and politically particularly because of its large population and magnitude of inequality and poverty. The estimated rise in global temperatures could affect the underprivileged and vulnerable populations through food insecurity, income loss, adverse health impacts, population displacements etc. (Awasthi 2018). A recently published Stanford study reported that between 1961 and 2010 global warming has caused the Indian economy to be 31% smaller than it would otherwise have been, and the shrinkage in wealth per person in the world's poorest countries has been 17–30% (Economic Times 2019). A 2019 report by the International Labour Organization projected India to incur a loss of 5.8% working hours in 2030 due to global warming, particularly affecting agriculture and construction sectors, which is equivalent to a productivity loss of 34 million full-time jobs (The Hindu 2019).

There is a probable link between increased variability in Indian monsoon rains and natural disasters. Uneven increase in temperature has been associated with driving more energy into local, regional and sub-continental climate systems thereby amplifying climate alterations and frequency as well as severity of extreme weather events. Human encroachment and heavy siltation in river beds and other water bodies have exacerbated the flood risks (Mishra 2014). Studies suggest noted rise in frequency and extent of landslides in India, particularly in the Himalayas and the Nilgiris (Sati et al. 2011; Ganapathy and Hada 2012). During June 2013, thousands of people were drowned, dozens of bridges tore apart, miles of paved roads swept away and herds of livestock carried off in one of the most disastrous floods in recent memory in the Himalayan settlement of Kedarnath. Researchers believe that melting of glaciers and shifting of storm tracks have played major roles behind this calamity apart from commonly reported causes, such as poorly built homes, and unregulated development along the river (Grossman 2015). During November–December 2015, an extreme pluvial flooding, following a heavy and unusual rainfall, occurred in Chennai and its surroundings and caused severe damages to the properties, infrastructure, livelihood, health and environment besides taking away hundreds of precious lives. Researchers found a relation between the onset of the atmospheric weather change and the swarms of 8th to 9th November 2015 in the Indian Ocean region and associated thermal radiation, and indicated that the great pluvial flood disaster in Chennai and its surroundings was a resultant of the swarms in the north Sumatra oceanic region (Akilan et al. 2017). Again in July–August 2018, 42% more rain than expected during the monsoon months of July and August caused a shift in the behaviour of Periyar river and its basin in Kerala state of India which the landscape could not adjust causing the worst flooding in nearly a century. Hundreds of people died, and at least a million had to be evacuated whereas thousands of cattle, calves, buffaloes, goats, dogs also lost lives (NDMA 2018; Vijayan 2018). As per the records of India's Ministry of Environment, Forest and Climate Change, extreme weather events have taken away as many as 2405 human lives in the year 2018 alone (The Weather Company 2019). As such, climate variations has been recognized as a risk multiplier that disproportionately burdens the poorest and most vulnerable as evident from some of the natural disasters cited as above. Therefore, possible aversion, adaptation and mitigation of extreme natural events necessitate the immediate understanding of the footprints of climate change over natural disaster profile (Sami et al. 2016).

For instance, various climate models used to predict the macro- and meso-level scenarios have not been validated at local level in order to understand their practical implementation (Nautiyal 2011). In comparison to macro level studies, there is considerable gap in data so far as micro level studies are concerned. Very strong and dynamic case studies are also lacking at micro level. But, for effective and informed planning at the macro-level, a better understanding of micro-level perception is imperative (Singh et al. 2018). But, several models predicting national and regional level scenarios do not usually consider micro variables such as environmental resources, socio-economic factors and policy aspects, including land availability, local climatic conditions, labour and capital, subsidies, nature conservation strategies etc. This micro-macro paradox indicates that even if affirmative action works and achieves direct impact, yet the changes might seem unstoppable (van der Berg 2011). This is the case for the historical loss of biodiversity that is now increasingly seen as a human caused mass extinction, and for the increasing pollution of our environment with chemical substances, which endanger human health and the health of our habitat (van den Berg and Cando-Noordhuizen 2017). In particular, micro level research needs to be undertaken in relation to biodiversity, health, natural resource management, land use and land cover development, adaptation and the development of socio-ecological systems for facilitating holistic adaptation and mitigation activities (Nautiyal 2011). In this process, it becomes imperative to connect knowledge institutions with field based developmental agencies to address such challenges with local institutional arrangements by empowerment and imparting skills to local communities with appropriate and scalable technological interventions and strong social engineering component (Agarwal 2013).

Sustainable use of natural resources and their conservation strategies require interdisciplinary and transdisciplinary thinking (IPCC 2014; Feulner 2015). In this endeavor and to address the above issues and challenges, contributions were invited for present knowledge product from stakeholders, scholars, policy makers, academia and students cutting across the disciplines to portray a large variety of theoretical and actual research on resource use, conservation and related developmental issues in sensitive and vulnerable eco-regions of India. The threat is especially severe in regions where people's livelihoods depend largely on natural resources. The objective of this book is to translate the body of scientific knowledge for proper conservation of natural resources and biodiversity and use them sustainably in the interest of our future generations. Thus, it may contribute effectively to suggest possible roadmap as well as strategies to address not only conservation and livelihood issues locally and globally, but also to ensure inclusive growth and social inclusion at large.

The volume is the outcome of the national workshop on "Agrobiodiversity Conservation and Ecosystem Management" during 4–5 April, 2017 followed by the international conference on "Scientific and Indigenous Bio-cultural Knowledge in Understanding Climate Change in Biodiversity Hotspots to Develop Strategies for Socio-ecological Development: Data Availability, Requirement and Gaps" during 27–28 July, 2017 held in Assam University, Silchar (AUS). These events were organized jointly by the Centre for Ecological Economics and Natural Resources (CEENR) of the Institute for Social and Economic Change (ISEC), Bengaluru, and Assam University's Department of Economics and Department of Life Science & Bioinformatics. For these events, financial support was received from various funding agencies, such as (i) Indian Council of Social Science Research (ICSSR), Govt. of India, (ii) Technology Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology, Govt. of India, (iii) Ministry of Development of North Eastern Region, Govt. of India, and (iv) Science and Engineering Research Board, (SERB), DST, Govt. of India. Hon'ble Vice Chancellor of Assam University Prof. Dilip Chandra Nath inaugurated the events and scholars from academic institutions in India and abroad have participated and presented papers in these events. We take this opportunity to express deep, sincere and whole-hearted thanks and gratitude to the funding agencies for giving us the privilege to organize the events in Assam University, Silchar in association with CEENR, ISEC, Bengaluru, India which culminated into this volume. Since the topic of this volume is highly interdisciplinary therefore, scholars from Indian Institute of Technology Kanpur (IIT) Kanpur; G.B. Pant National Institute of Himalayan Environment & Sustainable Development (GBPNIHESD), Almora; Gujarat Institute of Development Research (GIDR), Ahmedabad; Institute for Social and Economic Change (ISEC), Bengaluru; CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur; Central University of Jharkhand, Ranchi; Pondicherry University, Puducherry; Department of Science and Technology, New Delhi were invited to contribute chapters on their grounded research work for publication in this volume. We extend our sincere thanks to all the paper contributors who made presentations during the academic events held in Silchar and authors from invited papers for their contribution for publication in this volume.

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Climate Change Impacts and Implications: An Indian Perspective

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Abstract Climate change is one of the most complex global environmental problems, impacting the physical and biological systems of aquatic, terrestrial and marine environments. India is among one of the most vulnerable countries that has already been experiencing changes in climate and the impacts of climate change. Various sectors such as agriculture, forestry, health, socio-economy, etc. have found to be severely affected by the implications of climate change in the country. Significant impacts over the forest ecosystems, global biodiversity and ecosystem integrity have also been observed in recent days. Apart from reduction in forest productivity, a shift in the forest type boundaries along altitudinal and rainfall gradients have been found. Loss of sea ice, rapid warming, and higher organic inputs affect marine and lake productivity, while combined impacts of wildfire and insect outbreaks decrease forest productivity. All these emerging uncertainties due to climate change have found to aggravate the problems of future food security within the country. Despite putting numerous efforts to mitigate the effects of climate change, India has failed in responding sufficiently in dealing the issue of climate change. Thus, it is imperative to come up with more effective adaptation and mitigation strategies in order to combat the effects of climate change.

Keywords Climate change · Implications · Adaptation · Mitigation

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Abbreviations

TRMM	Tropical Rainfall Measuring Mission
AVHRR	Advanced Very High Resolution Radiometer
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
ERS	European Remote Sensing
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
MODIS	Moderate Resolution Imaging Spectroradiometer
SMOS	Soil Moisture and Ocean Salinity
SPOT	Satellite Pour l'Observation de la Terre, "Satellite for observation of Earth"
SARAL	Satellite with ARgos and ALtiKa
ALOS PALSAR	Advanced Land Observation Satellite Phased Array type L-band Synthetic Aperture Radar
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
NISAR	NASA-ISRO Synthetic Aperture Radar
JERS	Japanese Earth Resources Satellite
RISAT	Radar Imaging Satellite
ENVISAT	Environmental Satellite
IRS	Indian Remote Sensing
UNFCC	United Nations Framework Convention on Climate Change

1 Background

Climate change is the prime issue in global warming and global environment due to its associated vulnerability and biodiversity loss (IPCC 2007). UNFCCC (1992) has defined climate change as *the change that can be attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*. India is among one of the countries that has been predicted to be impacted severely due to climate change in the near future because of its diverse physiographic conditions and exploitation of natural resources at rapid pace (Puthucherril 2012; Saha and Talwar 2010). Climate change has profound impacts on the physical and biological systems of aquatic, terrestrial and marine environments (Lolaksha and Anand 2017). The effect may be direct on crop yield due to a change in temperature and increased pest populations or indirect such as damage to agricultural crops caused by the increased frequency of coastal flooding due to sea-level rise (IPCC 2007). Climate change stands to alter ecosystem structure and function through numerous and diverse pathways (Post 2013).Changing the water availability, CO_2 concentration, tropical storm activity, accelerated sea-level rise, increasing sea surface and atmospheric temperature, variability in the timing and quantity of precipitation and littoral erosion are the critical factors affecting the ecological integrity of coastal ecosystems as well as important societal activities (Day et al. 2013; Yañez-Arancibia 2015). Climate change is expected to alter the behavior and life history characteristics of organisms which could lead to dramatic changes in inter and intra-specific competition, predation, mutualisms, species distributions, biodiversity patterns, and the provisioning of ecosystem services (Tylianakis et al. 2008). In the long-term, climate change will most likely alter the littoral zone, the species composition and biodiversity of coastal areas, and important ecosystem services such as nutrient cycling, primary and secondary productivity (Walther et al. 2002; Day et al. 2013). Climate change along with habitat fragmentation is one of the major threats to biodiversity and these changes have adverse and irreversible impacts on various ecosystems services which are ultimately going to affect the social, cultural and economic conditions of the human society (Bharali and Khan 2011). Most of the climate change research have tended to examine climate effects on biotic components by focusing on single species while treating the larger community as background variation (Jamieson et al. 2012) and by typically focusing on a single climate variable at a time (Todgham and Stillman 2013). The present study discussed the impacts and consequences of climate change over various sectors including agriculture, biodiversity, mangroves, coastal and forests ecosystems.

2 Impacts of Climate Change

Climate change is one of the most critical environmental issues that have grabbed the attention of the whole world. India is facing an alarming environmental and socio-economic challenge in its effort to protect its fast depleting natural resources (Lolaksha and Anand 2017). Coastal ecosystems, biodiversity, water, human health, energy, transportation, forests, and agricultural productivity are some other important sectors that will be subjected to the maximum exposure to climate change (UNFCCC 2006; National Research Council 2013). Climate change will have a profound impact on human and ecosystems during the coming decades through variations in global mean temperature and precipitation pattern. The main culprit behind the changes in the climatic conditions is believed to be the effects of human interference (Santer et al. 2013).

3 Impacts on Agriculture and Agricultural Productivity

The agricultural productivity is under direct influence of climate change and any change in the temperature, precipitation pattern and CO_2 concentration are certainly prospected to affect the crop productivity (Kumar and Gautam 2014). Climate change impacts agricultural productivity mainly in two ways: first, directly through changes in temperature, precipitation and CO_2 concentration and second, indirectly through changes in soil, distribution and frequency of infestation by pests, insects, diseases or weeds (Chatterjee 2003). The growth, development, water use efficiency and yield of crop are mainly dependent on weather during their growing seasons. Any deviation from the normal weather will ultimately affect the efficiency of applied inputs as well as impair the food production (Mall et al. 2007). With the changes in the climate, adjustments and adaptations are required to current practices in order to maintain the productivity, while in some cases the optimum type of farming changes (Gornall et al. 2010). The severity of climate change impacts on the agricultural productivity depends on the degree of adaptation at the farm level, farmers' investment decisions and policy choices (Kahil et al. 2015). Agriculture in India is hindered due to small landholdings, inadequate resources and lack of agro-technological information. The broad objective of sustainable agriculture is to balance the inherent land resources with crop requirements, paying special attention to optimization of resource use towards achievement of sustained productivity over a long period (Lal and Pierce 1991). The emerging uncertainties due to climate change are certainly going to aggravate the problems of future food security by exerting pressure on agriculture (Anand and Khetarpal 2015). Agricultural production is highly sensitive to monsoon variability (Chakrabarty 2016). In India, more than 60% of the crop area is mainly rain-fed and rain-fed agriculture is highly vulnerable to change in the precipitation pattern. With the change in the climate, major crops like rice, wheat, maize is going to be affected in India (Chatterjee 2003) and consequently, the food security is going to be adversely affected (Wheeler and Braun 2013; Chakrabarty 2016). Soil quality, water availability or drought stress and climate change are three biophysical factors which need to be addressed for food security in the face of climate change (Lal 2009). It has also been estimated that the *Kharif* crops are going to be affected more by rainfall variability, while *Rabi* crops by minimum temperature (Tesfaye et al. 2017). Agroforestry offers the potential to develop synergies between efforts to mitigate climate change and to help vulnerable populations to adapt to the negative consequences of climate change (Verchot et al. 2007).

4 Impacts on Forests and Forestry Sector

Climate is one of the determining factors of the distribution, structure and ecology of forests ecosystems (Kirschbaum et al. 1996). Climate change has significant impacts over the forest ecosystems, global biodiversity and ecosystem integrity (Ravindranath et al. 2005). In India, changes in the climatic conditions have affected the forests productivity and also a shift in the forest type boundaries along altitudinal and rainfall gradients (Kaushik and Khalid 2011). The shift has been indicated towards wetter forest types in the northeastern region while towards drier forest types in the northwestern region in the absence of human interventions (Ravindranath et al. 2005). The regions that have identified as more vulnerable to climate change include the upper Himalayas, northern and central parts of Western Ghats and parts of central India, while the northeastern forests have been identified as the more resilient ones (Chaturvedi et al. 2010). The major impacts of climate change that on the forests are the disruption of carbon-regulating services, prolonged droughts, more pest invasions and other environmental stresses that would eventually lead to their destruction and degradation (Seppälä 2009). Natural disturbances such as pest and disease outbreaks are going to be affected by climate change which in turn is going to impact the forestry (Alig et al. 2002). Not only the forest fires or insect damage but also a variation in the frequency of extreme events such as strong winds, winter storms, droughts, etc. can bring about a loss to commercial forestry (Kirilenko and Sedjo 2007). Many terrestrial biogeochemical processes, such as soil respiration, litter decomposition, nitrogen mineralization and nitrification, denitrification, methane emission, fine root dynamics, plant productivity and nutrient uptake will be impacted with temperature changes which in turn will alter forests and ecosystem dynamics (Norby et al. 2007). Changes in the structure and functioning of forest ecosystem are going to have negative impacts on the productivity of forest ecosystems which in turn will affect local economies (FAO 2005). The impacts of climate change on forestry include the increasing global timber supply and a slow increment in the demand for forest production (IPCC 2001). Climate change brings an irreversible damage to the forest ecosystems which certainly require the longest response time to adapt (Leemans and Eickhout 2004). With the change in the forest structure and composition, other dependent entities such as wildlife, human systems and economies will face a challenge to keep pace with the rate of change within the forest ecosystem.

5 Impacts on Biodiversity

India harbors a huge variety of biodiversity and, it is under the threat of climate change (Kumar and Chopra 2009; Soni and Ansari 2017). Climate change has been identified as one of the major drivers behind the adverse effects on biodiversity and its associated goods and services (MEA 2005). Climate is one of the most important factors that regulate the growth, abundance, survival and distribution of species (Travis 2003). Climate change has affected the global biodiversity resulting in the extinction of many species of flora and fauna from their natural habitat (Bharali and Khan 2011). The changes in the climatic conditions have found to exacerbate the effects of other anthropogenic factors that threaten the biodiversity (Moore et al. 1999; Forrest et al. 2012). Impacts of climate change over the biodiversity vary from region to region (Sarkar 2012). It is also a major determinant of distribution and abundance of species in both managed ecosystems (agriculture, production forests, cities and many coastal zones) and natural ecosystems (terrestrial and marine) (Perrings 2010). With the shift in the climatic conditions, species with small fragmented populations, or populations restricted to small areas are more vulnerable (Integrated solutions for biodiversity, climate change and poverty 2010). Also, the synergism between the rapid temperature rise and other factors of climate change could disrupt the linkage among the species resulting in reformulation of species communities, differential changes in species and in their extirpation or extinction (Root et al. 2003). Effects of climate change on the natural system may be diverse and range from change in the timing of phenological events of plants to changes in species abundance, distribution, timing of reproduction in animals and plants, animal and bird migration patterns, and frequency and severity of pest and disease outbreaks and shifts in habitat, etc. (Perrings 2010; Bharali and Khan 2011). Apart from these effects, the risk of extinction for already vulnerable species is likely to increase (Thomas et al. 2004) because many species require a particular time period to adapt themselves against the changing climatic conditions (Menéndez et al. 2006).

6 Impacts on Coastal Ecosystems

Human pressure on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, installation of energy generation infrastructure in coastal and marine ecosystems, transportation networks and urbanization (Yáñez-Arancibia 2013, 2015). The analysis and implementation of coastal adaptation toward climate-resilient and sustainable coasts have progressed more significantly in developed countries than in developing countries (Wong et al. 2014). The use of combined approaches to coastal adaptation instead of a single strategy, such as the combination of ecology and engineering, allows for better preparation for a highly uncertain and dynamic coastal environment (Cheong et al. 2013).

The biggest climate change challenge faced by the coastal ecosystem is the rising sea level (McLeod and Salm 2006). The ongoing phenomenon of climate change has been predicted to pose a major threat to the Indian mangroves (Sandilyan 2015). Impacts of climate change on mangroves of coastal areas used to be influenced by various factors including sea level rise, changes in river flow due to changes in snowmelt and precipitation pattern in the catchment, changes in local temperature and in storm surges (Mckee et al. 2012). Sea level rise (SLR) of up to 1 m has been projected for the period 1990–2100 with substantial regional variation (IPCC 2007) and mangroves have been found to be vulnerable to SLR and even a 1 m rise would result in the complete submergence of the mangroves of Sunderbans (Chowdhury and Rob 2007). However, mangroves in low-island coastal regions where sedimentation loads are high and erosion processes low can adapt better. The mangrove forests along the arid coasts, in subsiding deltas, and on many islands have been predicted to decline in area, structural complexity and in functionality along with their continuous expansion towards poles (Alongi 2015).

Climate change has also impacted the coral reefs where the major observed effects include increased mass coral bleaching, declining calcification rates, and a range of other changes to subtle yet fundamentally important physiological and ecological processes (Guldberg 2011). Coral reefs are found to be sensitive and are vulnerable to rise in the sea surface temperature (SST) against their optimal temperature

(Sebastian and Kaaya 2018). Bleaching of coral reefs due to the increase in sea surface temperature (SST) of > 1 °C has been very well known (Kumagai and Yamano 2018). One of the most widespread coral bleaching worldwide, including in the Indian coral reefs, occurred during 1997–98 when SSTs increased by an average of 3 °C in the Indian Ocean in conjunction with a major El Nino event (Sum 2016). It was estimated that the 1997–98 El Niño event alone had caused the bleaching of 16% of the world's coral reefs (World Bank 2007). Enhanced SST during the 1997/98 El Niño event affected the marine ecosystems, including fishery and coral bleaching, while enhanced air temperature affected terrestrial ecosystems, public health and air quality due to the production of photochemical smog under strong sunlight (Sum 2016). Bleaching also sets the stage for other decline in reef health, such as increment in the coral diseases, breakdown of reef framework by bio eroders and the loss of critical habitat for the associated biota (Baker et al. 2008). Increased ocean acidification, via increased absorption of CO_2 by seawater has reduced the capacity of coral reefs to grow and maintain their structure and function (Spillman et al. 2011).

7 Impacts on Human Health

Climate change impacts on health is one of the important determinants for the assessment of total costs of climate change to enhance the understanding of weather and climate's effects on socio-economic sectors (Confalonieri et al. 2007). The health risks associated with climate change are on the rise worldwide (UN 2017) and thereby worsening the existing health threats and creating new public health challenges (NOAA 2016). Changes in the climatic conditions have been predicted to cause more heat stress, an increment in waterborne diseases, poor air quality, extreme weather events and a rise in the transmittance of diseases by insects and rodents (USGCRP 2016) which is ultimately going to impact the human health. Based on the present day sensitivity to heat, an increment of about thousands to tens of thousands in premature heat-related deaths in the summer and a decline in the premature cold-related deaths in the winter has been projected as a result of climate change by the end of the century (USGCRP 2016).

Climate change effects on human health in India are a broad topic, covering areas from extreme weather events to shifts in vector-borne diseases. Floods create conducive environments for numerous health consequences resulting from disease transmission. In South Asia, scientists predict an increased frequency of floods in mountainous regions in the coming days due to greater intensity of rainfall events and glacier lake outburst (Cruz et al. 2007). Floods resulting from monsoon rains killed more than 2000 persons and displaced more than 20 million people in Bangladesh, India, and Nepal during 2007 (Bajracharya et al. 2006). Rising sea-surface temperatures are expected to increase tropical cyclone intensity and the height of storm surges (Ali 1999). Although cyclones originating in the Bay of Bengal and the Arabian Sea have decreased in frequency since 1970, these have increased in intensity, causing significant damage in India and Bangladesh (Lal et al. 2001). Public health effects of cyclones include diseases and illnesses associated with the loss of clean water, hygiene, and sanitation, loss of shelter and belongings, population displacement, toxic exposures, hunger and malnutrition risk due to food scarcity (Keim 2006).

8 Socio-Economic Consequences of Climate Change

The alleviation of poverty and food insecurity has been undermined in the present scenario of changing climatic conditions (Karfakis et al. 2012). Climatic conditions play a major role in influencing almost all aspects of life on earth and in shaping the physical, biological, and socioeconomic environment (Rogers 1994). The impacts of GHG emissions and the resulting climate change have found to influence the global economy significantly (Raman et al. 2012). Agriculture, fisheries and other economic sectors that depend on weather conditions are mostly affected by climate change either directly or indirectly (IPCC 2012). The events of climate change have raised a concern about the threats to current income and consumption patterns of households and individuals that are dependent on these sectors (Foresight 2011; IPCC 2012). Changes in frequency and intensity of extreme weather events may lead to devastating floods (Karl et al. 1996). These extreme climatic events can result in large economic losses through direct damage to infrastructure, property, and agricultural land (Waterton and Wynne 2004). The impacts of climate change can be measured in terms of economic cost particularly associated with the impacts that are linked to market transactions (Smith et al. 2001). The quantitative estimation of the economic damages of climate change is generally based on the aggregate relationships linking average temperature change to loss in gross domestic product (GDP) (Ciscar et al. 2011). Monetary measures of climate change impacts on human health and ecosystems are difficult to calculate (Smith et al. 2001). Prolonged climatic variations have contributed to the collapse of several well-established civilizations at certain times in the past (Weiss et al. 1993). The quantitative assessment of the economic impacts of climate change provides the justification for the strategies to control global warming and minimize detrimental consequences (Ciscar et al. 2011). With the changes in the climate, the impacts on agricultural production, income and health-related effects are expected to rise which ultimately impact the rural livelihood (Karfakis et al. 2012). Climate change adaptation and mitigation are likely to involve policy decisions and investments in infrastructure. The impact of climate change on the society is mainly dependent on the direct or indirect interplay between environment, on the one hand, and health and consumption on the other hand (Karfakis et al. 2012). A society can be benefited only by improving the understanding, assessment, prediction, and early detection of both natural variability and any possible anthropogenic changes that can help towards the insight of a stable climate system (NRC 1998).

9 Role of Geoinformation Science in Climate Change Research

Geoinformation science has provided a new dimension to global climate change research over the past few decades and has significantly been contributing in climate change monitoring through continuously observing remote sensing satellites by providing biological, physical, and chemical parameters on a global scale at varied resolutions (Justice et al. 2002; Gou et al. 2015). A climate change monitoring system is an amalgamation of satellite observations, ground-based data and forecast models to monitor and forecast changes in the weather and climate with reference to historical patterns shift due to frequent and repetitive coverage of earth's environment (Tucker and Sellers 1986). It is widely used to estimate various parameters in the domain of atmosphere, oceanic and terrestrial which has provided major advances in understanding earth system and its climate (Yang et al. 2013). The periodic monitoring of different climate variables is being done by specially designated earth science missions (Table 1). For example, sea surface temperatures (SST) is being monitored by NOAA satellite (Heirtzler et al. 2002), whereas glacier recession, which is the response to climate warming due to their sensitive reaction to even small climatic changes (Lemke et al. 2007), is being monitored by various optical satellite remote sensing satellites (Bishop et al. 2000). The sea surface topography over the open ocean and the study of the ocean circulation is being studied efficiently by powerful

Table 1 Major climatic variables (as per UNFCCC)

Domain	Parameter	Sensors
Atmosphere	Greenhouse gases, water vapour, pressure, precipitation, surface radiation budget, temperature, wind speed and direction, ozone and aerosols	TRMM, NOAA (AVHRR), GOME, GOMOS, ERS, ENVISAT, SCIAMACHY
Oceanic	Sea surface temperature, wind velocities, bathymetry, sea level, ocean colour, coastal processes, sea ice	Oceansat, TRMM, NOAA (AVHRR), Aqua/Terra (MODIS), INSAT (VHRR), SMOSS Aquarius, Jason, ERS, Topex/Poseidon, Landsat, SPOT, IKONOS, SARAL, Megha-Tropiques
Terrestrial	Land use/land cover, river morphometrics, ground water, snow cover, glacier studies, fraction of absorbed photosynthetically active radiation (fPAR), leaf area index (LAI), above-ground biomass (AGB), gross primary productivity, soil moisture, forest fire, desertification, terrestrial biodiversity, and habitat properties	Landsat, Sentinel, SPOT, IKONOS, Resourcesat, Quick Bird, RADARSAT, Aqua/Terra (MODIS), ALOS PALSAR, ENVISAT, TerraSAR-X, SMOS, AVIRIS, JERS, IRS, RISAT, Cartosat

Sources CEOS (2007), NRC (2008), Weng (2011)