Disaster Resilience and Green Growth
Series Editors: Anil Kumar Gupta · SVRK Prabhakar · Akhilesh Surjan

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Hydro-Meteorological Extremes and Disasters

Springer

Disaster Resilience and Green Growth

Series Editors

Over the years, the relationship between environment and disasters has received significant attention. This is largely due to the emerging recognition that environmental changes - climate change, land-use and natural resource degradation make communities more vulnerable to disaster impacts. There is a need to break this nexus through environment based and sustainability inclusive interventions. Science – technology and economic measures for disaster risk management, hence, need to adapt more integrated approaches for infrastructure and social resilience. Environmental and anthropogenic factors are key contributors to hazard, risk, and vulnerability and, therefore, should be an important part of determining risk-management solutions.

Green growth approaches have been developed by emphasizing sustainability inclusion and utilizing the benefits of science-technology interventions along policy-practice linkages with circular economy and resource efficiency. Such approaches recognize the perils of traditional material-oriented economy growth models that tend to exploit natural resources, contribute to climate change, and exacerbate disaster vulnerabilities, Green growth integrated approaches are rapidly becoming as preferred investment avenue for mitigating climate change and disaster risks and for enhancing resilience. This includes ecosystem-based and nature-based solutions with potential to contribute to the resilience of infrastructure, urban, rural and peri-urban systems, livelihoods, water, and health. They can lead to food security and can further promote people-centric approaches.

Some of the synergistic outcomes of green growth approaches include disaster risk reduction, climate change mitigation and adaptation, resilient livelihoods, cities, businesses and industry. The disaster risk reduction and resilience outcome of green growth approaches deserve special attention, both for the academic and policy communities. Scholars and professionals across the domains of DRR, CCA, and green growth are in need of publications that fulfill their knowledge needs concerning the disaster resilience outcomes of green growth approaches. Keeping the above background in view, the book series offers comprehensive coverage combining the domains of environment, natural resources, engineering, management and policy studies for addressing disaster risk and resilience in the green growth context in an integrated and holistic manner. The book series covers a range of themes that highlight the synergistic outcomes of green growth approaches.

The book series aims to bring out the latest research, approaches, and perspectives for disaster risk reduction along with highlighting the outcomes of green growth approaches and including Science-technology-research-policy-practice interface, from both developed and developing parts of the world under one umbrella. The series aims to involve renowned experts and academicians as volume-editors and authors from all the regions of the world. It is curated and developed by authoritative institutions and experts to serve global readership on this theme.

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Hydro-Meteorological Extremes and Disasters

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Foreword

Extreme events such as droughts, heatwaves, heavy rain, and violent storms are now part of our daily news. Disasters due to extreme climatic events have been reported across the globe causing huge loss of property and lives. It is expected that these losses and casualties may multiply in future. Climate change is one of the biggest environmental threats faced by the world, which can potentially impact food production and security, sustained water supply, biodiversity of forests and other natural ecosystems, human health, and settlements. Climate variability and change could result in increased number of extreme events which can cause profound damage to human well-being. Simultaneous occurrence of extreme events not only multiplies the risk but also complicates the process of disaster risk mitigation and management. Hence, it is crucial to understand the occurrence, distribution, and mechanism of extreme events and their role in augmenting disaster risk. This book is a welcome step in that direction. Additionally, it provides an excellent introduction to the field to non-specialist readers.

This book, *Hydro-Meteorological Extremes and Disasters*, is a perfect compendium of recent issues, problems, and their possible solutions in the area of hydro-meteorological and extreme events disaster risk management. It covers wide-range contributions such as reviews, output of research studies, case studies, and reports on technological developments, presenting latest findings and raising awareness about climate change and hydro-meteorological and extreme events. The authors of the book are well-known experts in their respective fields, thereby providing the readers a studied and encapsulated version of the recent issues, challenges, and developments. The content is presented in a well-written and engaging form.

I compliment the editors of the book, Prof. Manish Kumar Goyal, IIT Indore, and Prof. Anil Kumar Gupta, NIDM, New Delhi, along with eminent scientist on the subject Dr. Akhilesh Gupta, Senior Advisor, DST-Govt. of India, for conceptualizing and taking this timely initiative. I congratulate the contributing authors for the time spent to prepare detailed methods and also for offering practical hints and tips that are often essential to obtain a new working protocol. I am sure this book would be a significant contribution in the area of hydro-meteorological and extreme events disaster risk management.

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Introduction

With the changing climate, extreme weather events have become more frequent and severe across the globe in the past decades. Several disasters such as flash flood in Indonesia and China (2020), Cyclone Amphan in India and Bangladesh (2020), and summer heat waves (2019), among others, disrupt socio-technical systems and cause huge social, economic, and environment losses. Such events expose the underlying vulnerability and resilience of the system towards disasters. And, as climate change is going to adversely impact the socio-economic systems, it is of paramount importance to understand the disaster risk and resilience from a multidisciplinary perspective. Therefore, the book is focused upon an integrated approach to assess associated risks and resilience, and further facilitating remediation strategies based upon the principle of sustainability. It offers a unique examination of different perspectives on disaster exposure, risk, resilience, and vulnerability, along with corresponding remedial strategies. It provides a compendium of case studies on risk and vulnerability assessment of floods, droughts, landslides, etc., along with a concise review on recent scientific approaches for disaster risk management. The book concludes with role of sustainable strategies in enhancing disaster resilience in different sectors such as environment, forestry, business, corporate, and transport.

Increasing exposure to hazards and increasing social and economic vulnerability are raising the specter of catastrophic disaster around the globe. Such events have adverse impact upon lives and economies; therefore, scientists\researchers\practitioners across the globe are focused on the most sustainable and efficient way to deal with these situations. Therefore, an integrated risk assessment approach incorporating social, economic, and environment dimensions would be helpful in formulating efficient climate adaptation and mitigation strategies. Despite the availability of a large number of studies/books on disaster management, only a handful of literature exists which focuses upon an integrated approach to assess risk/resilience, and recommend remedial strategies aligning with social, economic, and environmental systems simultaneously. The proposed book is formulated in order to bridge this gap. The book will contain chapters from a broad spectrum of topics from experts, thereby encapsulating research from different fields to further pave a path towards facilitating sustainable remedial strategies. The book is designed to cater to a wide audience, that is, along with research community (disaster risk, response and recovery, climate science, environment management and policy and others), it will also be beneficial for students, professionals, and policy makers.

The book is a unique work and brings global coverage and wider perspectives on hydro-meteorological extremes and disasters, with aim to support future studies and management of hydro-meteorological disasters. The book is presented in three parts, wherein Part I reviews the overview and strategies of hydro-meteorological and extreme events disaster risk management. Part II describes the tools and techniques required for evaluation of different climatic extreme events and their management. Finally, Part III of the book aims at case studies related to different climate disasters and their implications on water resources and others. Authors are drawn from across the developed and developing world, encompassing varied experience of dealing with hydro-meteorological and extreme events.

Contents

About the Editors

Manish Kumar Goyal is a Professor of Civil Engineering and Dean at the Indian Institute of Technology, Indore. Prof Goyal has 'i' index and 'h' index equal to 82 and 33, respectively, with total citations of 3324. He holds more than 100 refereed publications on different domains of GIS and remote sensing, water resources, climate change, hydrological and hydrodynamic modelling, soil carbon sequestration, anthropogenic changes, risk and resilience. He serves as an Associate Editor for several journals. His contribution fetched him Recipient of ASCE EWRI Visiting International Fellowship, Recipient of ASCE-Best Theoretical-Oriented Paper Award, Indo-US WARI Fellowship Award, DST–SERB Young Scientist-fast track grant, Inspire Faculty award, Erasmus Mundus Interweave Award, JSPS fellowship award and Canadian Commonwealth Scholarship Award.

Anil Kumar Gupta is a sustainability risk management strategist working in the area of disaster management, environment and climate resilience for more than 25 years with national, sub-national and business administrations. He is currently a full Professor and Head of India's National Institute of Disaster Management (NIDM) Division of Environment and Disaster Risk Management. He is Programme Director of the Centre for Excellence on Climate Resilience and implementing projects, viz. CAP-RES (with DST, under National Knowledge Mission on Climate Change), National Agriculture Disaster Management Plan (with Ministry of Agriculture & Farmer's Welfare). He was a recipient of Excellence Award by the Society of Environmental & Occupational Health, and bestowed with IDRC Canada's Thank Tank Initiative Senior Fellowship 2011 for policy research.

Akhilesh Gupta is presently Secretary of the Science and Engineering Research Board (SERB). Also, Dr. Gupta currently heads the Policy Coordination and Programme Management Division (PCPM) division and is the overall in charge of five National Missions at DST – National Mission on Interdisciplinary Cyber Physical System, National Mission on Quantum Technology and Applications, National Super-computing Mission, National Mission on Strategic Knowledge for

Climate Change and National Mission for Sustaining the Himalayan Ecosystem. A distinguished atmospheric scientist, Dr Gupta has to his credit over 200 research articles in national and international journals as well as proceedings. He is editor of 5 books and author of over 350 articles and nearly 1000 reports. He is a Fellow of Indian National Academy of Engineering (FNAE), Indian Meteorological Society (FIMS) and Association of Agro-meteorologists (FAAM).

Part I
Overview and Strategies

Chapter 1
Hydro-meteorological Extremes and Disasters: Integrated Risk, Remediation and Sustainability

Fatima Amin, Anil Kumar Gupta, and Syed Towseef Ahmad

Abstract Floods, landslides, and climate change hazards, to name a few, are all common natural hazards that have significant economic and social consequences in India. Tornadoes and floods have aided in the slowing down of progress toward the accomplishment of sustainable development goals. Recent observations of extreme weather events in different countries, as well as a growing understanding of their threat and increased risk of flooding, should compel authorities to act. This work focuses on Integrated Disaster Management strategies, Extreme events and the main causal factors. It was discovered that these events have rather complex components, which are reflected in the combined climatological characteristics, geological substrate properties, and human activity, all of which played a role in the rapid change.

In addition, present study aims key findings, conclusions and recommendations arising from the policy space. Floods, landslides, drought etc. are usually regarded as dreadful dangers that pose a severe threat to societal growth and economic development at diverse spatial and temporal scales an important aspect in developing community resilience to hydro metrological disasters is establishing policies and actions to strengthen early warning systems.

Results from this study suggest some of the mitigation strategies at national as well as on regional levels, the provision of knowledge to enhance the prevention of hazards and the development of appropriate response plans.

Keywords Integrated disasters · Disaster models · Sustainable approach · Preparedness · Gap areas · Resilient cities

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1.1 Introduction

Disasters are the result of combination of hazard and vulnerability. Disaster Risk management minimizes the vulnerability in order to safeguard people and property; it's all about saving lives and livelihoods. As a result, the Sendai Framework's international certification targets and goals of disaster risk reduction, including the 2030 Paris Agreement on Climate Change, included an integrated approach to risk management. The approach proposed by UNESCO is to "integrate economic, political, and social dimensions, as well as ethical considerations and human rights issues."

Natural and technical catastrophes, these two categories of hazards are outlined in the UN International Strategy for Disaster Reduction (UNISDR 2002). There are three types of natural disasters: (1) Natural disasters caused by hydro-meteorological events such as Floods, storm surges, droughts, cyclones, and related disasters (such as forest/scrub fires and high temperatures), and the occurrences like avalanches and landslides. (2) Earthquakes, tsunamis, and volcanic eruptions are examples of geophysical disasters. (3) Natural calamities, such as epidemics and pest infestations. The technological disasters are categorized into three parts: (i) Chemical spills and building collapses are examples of industrial accidents. (ii) Transportation mishaps. Traveling by air, rail, road, or water is an option. (iii) Unusual and unexpected events Household/non-industrial structures collapsing; explosions; fires Natural disasters, whether meteorological (cyclones, floods, tornadoes, and droughts) or geological (volcanoes, earthquakes, and volcanic eruptions) (earthquakes and volcanoes), are well-known for wreaking havoc on human life, the economy, and the environment. Developing countries are extremely susceptible to such catastrophes due to unstable landformsand essential tropical climate, as well as high illiteracy, poverty, lack of sustainable development, and population density. A total of almost 4 billion individuals were affected by disasters, which took around 1.23 million lives on average every year, and disasters led to economic damages caused by natural and techno disasters approximately US$ 2.97 trillion worldwide (UNISDR 2002; Pandey et al. 2021). The terms disaster management and emergency management are often used interchangeably. It entails the adoption of plans, organizations, and agreements to engage the routine endeavor of authorities, volunteer, and commercial entities in a comprehensive and coordinated manner to respond to a wide variety of emergency situations. When a calamity strikes, such operations must be carried out as early as possible.

1.2 Integrated Disaster Management: Concept and Scope

Proactive and reactive strategies are included in the integrated approach. The proactive strategy involves risk identification, mitigation, preparedness, and partial response actions that are based on the identified risk in the phases of prediction and warning. Since these activities are mostly based on the identified risk so, risk prediction and assessment are important and critical. Assessing impacts and their severity is part of the reactive approach. Response and recovery measures for the warning, rehabilitation, emergency relief, and reconstruction stages of disaster management can be carried out depending on the severity of hazard events. As a result, the impact assessment is important to the success of disaster-related public project management.

The most essential concern in disaster management is hazard identification and assessment (Uitto 1998). Its assessment, accuracy, and information quality are critical elements in effectively mitigating the negative effects of disasters. A risk assessment involves examining not only the physical, economic, physical, and social aspects of vulnerability, but also the technical features of hazards, such as their intensity, frequency, location, and probability. Vulnerability refers to the areas impacted by economic, social, physical, and environmental variables or processes that make a community more susceptible to injury of a disaster (UNISDR 2002). The major actors at the national, regional, district, sub-district, and village levels are typically the responsibility of risk identification and assessment. The government unit, particularly the Department of Mitigation and Preparedness Center, is the primary critical stakeholder in disaster management (DMPC). Impact levels must be assessed because they can be used for rehabilitation and restoration. The main aims are to assess the extent of damage caused by disasters in terms of economic, environmental assessments, and social, for prioritizing the rehabilitation and reconstruction of affected communities, as well as planning and designing the reconstruction process.

Using an integrated approach to disaster management can yield significant benefits. First, adopting a proactive approach allows for vulnerability reduction, preparedness, and warning before they occur. The onset period of hazards is generally used to categorize them. Some have a gradual onset and give you time to take precautionary measures. Droughts, floods, and volcanic eruptions are examples of slow-onset hazards. Recently, drought and their impacts are widely investigated (Kumar et al. 2021; Poonia et al. 2021a, b).

Other hazards, such as flash floods, tsunamis, and cyclones, have little or no warning time. A sufficient lead time raises the chances of sustaining lives, livestock, property, and livelihoods in a vulnerable population. When a proactive strategy is implemented, these potentials can be fulfilled as gains.

The integrated strategy includes both proactive and reactive disaster administration policies for during, before, and after disasters. As the severity and frequency of natural disasters rise, more and more lessons have been learned on how to improve resilience to catastrophic occurrences using insurance and other risk transfer instruments to better protect people from further natural disasters. There are five steps for managing any disaster (Fig. 1.1):

1. **Prevention**: A risk analysis is the first step in preventing major damage; it involves identifying hazards in a specific area and determining the vulnerability of agricultural areas, infrastructure, and businesses. In the next stages, this analysis will indicate what can be done to avert damage and feed into risk transfer

Fig. 1.1 Disaster management cycle

instruments and early warning systems. We can fortify infrastructure with robust materials to make it more resistant to meteorological hazards, and communities can work together to plant trees, build a wall to protect farm land and infrastructure from heavy rain, or clean drainage systems to prevent flooding. Land use regulations can be implemented and enforced by the government to ensure that people should not build in flood-prone areas.

2. **Addressing residual risk:** However, even if all preventative steps are taken, some hazards remain. This is where ex-ante finance, or financing before a hazard occurs, might be beneficial. Individuals can get a micro insurance policy in the event that their property is harmed. Weather Index insurance, which pays out when there is too much or too little rain during the year, could be a useful alternative for farmers in the community. Governments can also protect communities by providing pre-disaster finance through contingency facilities, which ensure that funds are accessible immediately after a disaster strikes to give humanitarian relief and support reconstruction. Different prevention strategies will dramatically reduce the overall risk exposure, reducing the price of these types of insurance and financial instruments.
3. **Preparing:** Community can prepare by stockpiling food and water in case of an emergency and ensuring that they have a safe place to go. Individuals can be trained in rescue and emergency services, early warning systems can be developed, and contingency plans can be developed to emphasize important what to do in the event of an emergency. Adaptation investments can also be are made to assist countries in adapting to climate change.
4. **Responding:** When a natural disaster strikes, the community and the government go into response mode. To avoid further loss of life or damage to property, it is critical to act swiftly. They can do so by assisting in the search and rescue effort, giving temporary shelter and food, and rebuilding the most critical infrastructure

as rapidly as possible. Ex-anti-financing will play a significant part in enabling this speedy response.

5. **Recovery:** The recovery process begins now that the community has responded to the disaster's first effects. Examining the regions and restoring things in a smarter approach that avoids these problems from happening again is necessary for a better recovery. All of these processes are interconnected, and they operate best when countries, governments, communities, and individuals engage. The repercussions will be considerably less severe if everyone learns what to do in the event of a natural disaster. All of these processes will make communities more resilient, ensuring that natural threats do not become disasters.

Many developing countries, which are more prone to disasters, lack proactive early warning, mitigation, and preparedness measures. Without a preventative approach, massive damages and devastation occur when calamity strikes. Previous disasters, which killed many people and destroyed natural and personal property, have always served as a reminder of people's negligent disaster risk management failures. Many lives can be saved by using an integrated approach.

1.3 Disaster Management Models

Most models are built on basis of historical data and observations, with the presuppositionthat the past is a good prognosticatorof the present and future. The vertiginousnumber of people on the planet, a changing climate, and the dynamic inter-connectivity of the biological and physical worlds all pose obstacle, forcing us to reconsider our assumptions about the relationship between past and future danger. Researchers and agencies have developed a variety of disaster management methods. Despite their effectiveness in some areas, disasters continue to be a major impediment to long-term development.

Some categories of disaster management models used for integration strategies are mentioned below:

The first category model is logical model. The key incident and acts that make up a disaster are accentuated in logical models, which provide a abbreviated definition of disaster stages. One of the well known and most extensively used disaster management logic models is the traditional model. The typical disaster management approach has three phases in this model: before, during, and after the incident. The first phase comprehend efforts such as prevention, mitigation, and readiness, while the second phase contains reaction and response activities, and the third phase includes recovery, reconstruction, and development activities (ADPC 2000) Integrated models are the second type of model. An integrated model of disaster management is a technique for arranging the actions involved in disaster management in order to ensure efficient and effective accomplishment, and it has four components: hazard evaluation, risk management, mitigation, and preparedness.

One of the most well-known integrated models is the Manitoba model. Strategic plan, hazard assessment, risk management, mitigation, preparedness, and monitoring and evaluation are the six autonomous elements of this concept. Each element has its own set of activities and procedures, as well as its own set of boundaries. The benefit of this strategy is that it strikes a balance between readiness and flexibility, allowing crises to be responded to quickly. This approach establishes a relationship between disaster-related activities and events, which can be either tight or loose.

Cause models are the third type of model. The concept of specify stages in a disaster is not applied to the cause category. This category suggests some of the disaster's fundamental causes. One of them is the Crunch model, which gives a framework for understanding disaster causes (ADPC 2000; Bankoff 2001; Cannon 2004; Heijmans 2001). This model is based on the speculation that certain factors influence catastrophe vulnerability. These facet are referred to as components at risk in this approach, such as human life and property, the environment, and infrastructures. The extension of a community's susceptibility is disclosed, and the underlying factors that fail to meet people's requests are discovered. After that, the model calculates the dynamic pressure and threatening situations.

Combinatorial models, which combine the logical, integrated, and causal models to propose a model, are the fourth type. One of these models, the Cuny model, is constructed up of features from the other three groups (Cuny 1998).

Last, the fifth category refers to models that do not comprise any of the previously stated attribute. Models that fall into this category are miscellaneous and refer to those whose structure and template does not fall into one of the four categories. For example, Ibrahim et al. (2003) proposed a model to depict the stages leading up to technology disasters. Shaluf and Said (2003) have enquired about the model's specifics.

Eight phases are included in this model: the emergence of errors, the accumulation of errors, warnings, and failures of corrections, stages of impending disaster, triggering events, an emergency, and the disaster.

1.3.1 Integration in DRR

Climate change is increasing the risk of disaster – from single climatologically events, and also from sustained global warming, thus cascading risk from impacts on human systems in the short, medium and long terms. It is still difficult to predict how dangers – such as their intensity and frequency – would affect human activity. Current risk measurement and management methodologies are unable to handle the problems of hazard's multidimensional interconnection, exposure's scarcely known breadth, and vulnerability's profound intricacy; we must tackle this inadequacy if we are ever to accomplish more than treat the symptoms. Understanding and controlling risk is everyone's business, and it's critical to the success of all 2015 agendas: "Disaster risk reduction necessitates all-of-society engagement and partnership" and "Civil society, volunteers, community-based organizations, and organized voluntary work organizations promote resilient communities and all-of-society disaster risk management that strengthens communities, in conjunction with public institutions" (Paras. 19d and 36).

1.3.1.1 Challenges of Increasing Disasters

Disasters' nature and severity are influenced by exposure and vulnerability as well as extremes. Presently, anthropogenic climate change, natural climate variability, and socioeconomic development all have an impact on climate extremes, exposure, and vulnerability. Even when risks cannot be totally removed, disaster risk management and climate change adaptation seeks to minimize exposure and susceptibility, as well as strengthening resilience to the possible negative effects of climatic extremes. Vulnerability and Exposure are important factors in determining catastrophe risk and the consequences if the risk is fulfilled. A tropical cyclone, for example, might have quite diverse consequences depending on where and when it makes landfall. Severe and non-extreme weather or climatic events alter resilience, coping capability, and adaptation, making people more vulnerable to future extreme events. Specifically, the cumulative impact of disasters on local adaptation and disaster risk management measures in a changing environment to minimize and manage disaster risk. Extreme weather and climate events alter in frequency, intensity, spatial extent, duration, and timing as a result of climate change, and can result in unprecedented extremes.

1.3.1.2 Framework of Integrated Disaster Management Strategies

The efficiency of catastrophe risk management and climate change adaptation are hampered by the lack of a comprehensive conceptual framework that allows for a common multidisciplinary risk assessment. Several worldwide disaster risk reduction (DRR) frameworks have been created over the last few decades. Japan's "Hyogo Framework for Action 2005–2015" and its follow-up "Sendai Framework for Disaster Risk Reduction" provide general instructions for minimizing the risk of natural disasters. As previously said, current research focuses only on a few disaster management related aspects such as inter-organizational coordination, vital infrastructure, mitigation planning, and emergency aid. As previously said, current research focuses only on a few aspects of disaster management, such as mitigation planning, vital infrastructure, inter-organizational coordination, and emergency aid activities. While individual system and phenomenon analysis is crucial, understanding the intricate interactions among many systems and processes, as well as multiple phenomena, is critical to obtaining the desired outcomes. Without the need for an integrative approach, possible integration risks and coordination concerns may occur, affecting performance across the disaster management life cycle. Integrated systems and processes are essential in reality, a little-studied issue in disaster research. Lack of an integrative perspective hinders the ability to assess and build solid strategic and operational plans to cope with disaster consequences in complex disaster management systems and processes. DRR should be considered in all areas of infrastructure development, health, mountain agriculture, and land use planning, Risk-based planning will aid in the creation of new land uses and the strengthening of current ones.

1.4 Initiative Taken for Integrated Disaster Management in India and Globally

Natural disasters have caused a great deal of concern on a global scale. Despite significant scientific and technological advancements, disaster-related deaths and property losses have not lessened. The United Nations General Assembly recognized the decide 1990–2000 as the International Decade for Natural Disaster Reduction in1989, with the intention of minimizing mortally and property damage and mitigation socio-economic disruption through concerted international effort, particularly in developing nations. The Indian government has initiated a paradigm shift in disaster management over a decade. The new method is premised on the idea that development cannot be protracted unless disaster mitigation is integrated into the strategic planning. Another premise of the method is that mitigation has to be multidisciplinary, encompassing all aspects of sustainable development. The new approach is also based on the assumption that mitigation investments are more cost effective than relief and rehabilitation. The Central Government established a High-Powered Committee on Disaster Management in 1999 to develop India's holistic response to "natural" catastrophes, which was later expanded to include "man-made disasters."Institutional inertia and an inability to comprehend the given context within which disaster management building based at the local level have led in few dramatic shifts to DRR 'on the ground' as an outcome of policy modifications at the national level. The paradigm shift that is anticipated in India is a shift in focus toward integrating national-level management with a bottom-up, positivist paradigm to hazard management.

In Single Hazard approach subsystems are created with which we can model the threat "satisfactorily" and according to the availability of the data. The same procedure is used for the analysis of multiple hazard approach, where subsystems are created for each individual process and just combine and compare the results. However, as natural processes, hazards are part of the same general system; they influence each other and interact. Therefore, the multiple hazard risk contains emergent properties: it is not just the sum of the single hazard risks, as their relationships would not be taken into account and this would lead to unexpected effects. For analysis purposes, the relationships can be divided into changes in disposition and activation (cascades and associated activation). In the integrated development planning process, multiple hazard maps are an important tool. Planning for development fails to address all natural hazards and to make provisions for their mitigation would eventually result in the property damage, bodily injuries, loss of lives, the disruption of important economic operations, and key facility failures. The real impact of the hazard can be catastrophic and terrible, depending on the size of the event, its location, and its ramifications. Natural resources, energy, infrastructure, agriculture, industry, human settlements, and social services are all prioritized in the integrated development planning process (OAS 1984). It places a premium on gathering and analyzing data on natural hazards in order to mitigate their negative influence on development. Natural disasters are thought to be avoidable or significantly reduced if hazards are recognized and appropriate mitigation measures are introduced into each level of the integrated development planning process.

1.5 Suggestions for Integrated Disaster Management Strategies

Insufficient and ineffective conception of the issues India confronts in developing its approach to disaster risk reduction is viewing the gap between policy and action for disaster risk reduction in India in terms of a few functional challenges. Instead, our findings show that India's DRR policy framework struggles to achieve its objectives because policy discourse has been de-contextualized, and there have been no shifts in perceptions of disasters as being driven by societal issues. Instead, attaining these objectives will demand a focus on (a) understanding how disasters are perceived and experienced at the local level, and (b) understanding institutional opposition to introducing a conceptual framework.

1.5.1 Proposed Approach of Integration for City Resilience

The global human population is projected to increase from 7.32 to 9.55 billion between 2015 and 2050 and at the same period the population of cities will increase from 3.96 to 6.34 billion (Koop et al. 2017). This rate of population growth will have substantial impacts on food and water supply, nature and built-up environment including Air, Water and Soil (Grant et al. 2015; Hoekstra and Wiedman 2014). Climate change, more particular in the urban regions has been observed globally and had a disastrous impact on its human population as well as on the natural biodiversity (Shaw et al. 2010). Cities are complex and dynamic systems that get evolved from the interaction between different elements like urban, social, and economic and policy factors (Vona et al. 2016). These factors continuously interact with each other and make the governance very complex function, more significantly in case of risk management. The functioning of these complex infrastructural systems determines the post disaster resilience of urban areas (Schwab et al. 1998). Therefore, rigorous efforts are needed to be taken in order to make cities and other urban regions more Disaster Resilient (Mileti 1999; Burby et al. 1999; Albrito 2012).

Scholars from diverse fields have extensively carried out research on climate resilient cities. The concept of 'resilience' in the contemporary times has carved its place in different fields (Vale 2014). Cutter et al. 2014 aid the emphasis upon the importance of culture creation of resilience and it was observed that the community resilience should be integrated approach based. Significant progress has been made to investigate, understand and improve the frame work and methodology for better community resilience (Ainuddin and Routray 2012; Zobel 2011; Olwig 2012).

In the last 20 years, disasters have affected billions of people, caused trillions of dollars in damage and killed millions. People in developing countries, particularly the most vulnerable communities, have been affected by natural disasters. Urban dangers are continuing to rise, particularly in the context of rising urbanization. Cities are becoming more vulnerable to disasters, owing to the poor living in high-risk metropolitan locations. However, disasters such as earthquakes, hydro-meteorological hazards, and others are not taken into account in urban planning and development. As a result of this fact, countries must focus on making the globe a safer place for urban dwellers and adopting novel techniques to strengthening resilience (Fig. 1.2).

Fig. 1.2 Essentials for making Resilient Cities. (Source: UNISDR 2017)

Fig. 1.3 Measures and Interventions for Resilience of Cities

The need for urban resilience is growing and local governments in the regions have shown some progress in building disaster resilience at the local level. Despite its importance, the poor financial situation and the inconsistency of resources are the most prominent problems. Cities should take improvement initiatives by incorporating identified disaster risk reduction measures into appropriate plans and taking proactive steps to implement DRR measures to ensure resilience and therefore reduce losses caused by disasters. Responding to the problems of achieving urban resilience and the Sustainable Development Goals will take significant work all over the world (Fig. 1.3).

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Chapter 2
Public Policy in Environment and Sustainability Strategies: Global & National Scenario

Sweta Baidya and Anil Kumar Gupta

Abstract Policies are the way of bringing change in the system and regulating the behaviour of the allied stakeholders. The idea of policies dates back to the ancient ages of Harappa Civilization 4500 years back. Since then numerous policies have been prepared for saving the nature and environment. United Nations (UN) has taken important roles in environment and climate change related policy intervention, starting from creating awareness to implementing strict laws within the countries. In India, keeping pace with Paris Agreement, several environmental policies have been prepared and implemented, but being a developing country, India is facing challenges in implementing the Nationally Determined Contributions due to economic shortfall. Mobilization of International finance is in need to implement many of India's targeted Green Policies. India has numerous policies and guidelines to safeguard the natural setting and the environment but proper implementation is needed.

Keywords Environmental policies · Sustainability strategy · Climate conference · Climate change adaptation · Disaster risk reduction

2.1 Introduction

Policies are rules those are followed at country level (Sertyesilisik 2019). Policies are guidelines, methods or systematic principles which are implemented or adopted as procedure or protocol by governing body to help in decision making and achieve rational outcomes (Kalu 2021; Alzadjali 2019). Policies are "Defined guideline used to direct and support decisions and actions" (Mayes 2015, www.igi-global.com). Policies can also be termed as "The science and art of employing, a careful plan or method, the art of devising or employing plans or stratagems toward a goal, an adaptation or complex of adaptations (as of behaviour, metabolism, or structure) that

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serves or appears to serve an important function in achieving evolutionary success" (Baporikar 2018, www.igi-global.com).

Policies play an important role in citizens' life and livelihood. As a common practice lawmakers are employed by Government, to set policies to be followed by government workers and all citizens of the country (Point Park University Online 2021). Sometimes the policies can be made in international level by coalitions of Governments of various countries to achieve some common goals and those policies are implemented worldwide, like for example, climate policies and policies on green growth. The cycle of policy making starts with the setting of the agenda. At this very first stage normally the public problems or challenges those are impacting the livelihood or associated things like environment etc. are identified and on the basis of this agenda is set. Agenda could be of four different types viz., Systemic agenda, Institutional agenda, Discretionary agenda and Decision agenda. In systemic agenda, all public issues are considered for addressing whereas in Institutional agenda, policymakers pick few of the challenges for working on When lawmakers themselves prepare the agenda is known as Discretionary agenda and the ultimate list of issues which the policy makers are going to address are known as the Decision Agenda. The next step of the policy cycle is Policy formation, involves the development of policy options and debate on the justification and possibilities of the proposed policies. Then comes the decision making stage, where the course of action is decided by the government for benefiting maximum people. After that the implementation of policies come, which is the most important step, where the government puts the chosen policy into effect either for some particular region or entire country. The last step of one policy cycle is policy evaluation where the impact of a particular policy is scrutinized to understand whether the policy is able to achieve the intended goal (Point Park University Online 2021; Benson and Jordan 2015).

2.2 Policy Implementation

There are various approaches for policy implementation. Research shows that the enactment of the legislation happens successfully if "Making it happen", – strategy is taken up (Fig. 2.1). "Making it happen"-strategy is proposed by Dean L. Fixsen, which aims towards enabling with the help of systematic training, supervision and follow up. Implementation through capacity building is another way where adequate capacity building within the organization is taken care of. Implementation of any new policy means change in the already existing procedures and practices which requires individual and organizational capacity building. In the word of Pekka Sundman (Director of the City Development Group, the City of Turku, Finland), "Implementation is about enabling-instead of liner implementation. The key is changing attitudes". irrespective of the quality or intention of the policy, it normally faces resistance. Figure 2.2 explains various types of resistance faced by the policies.

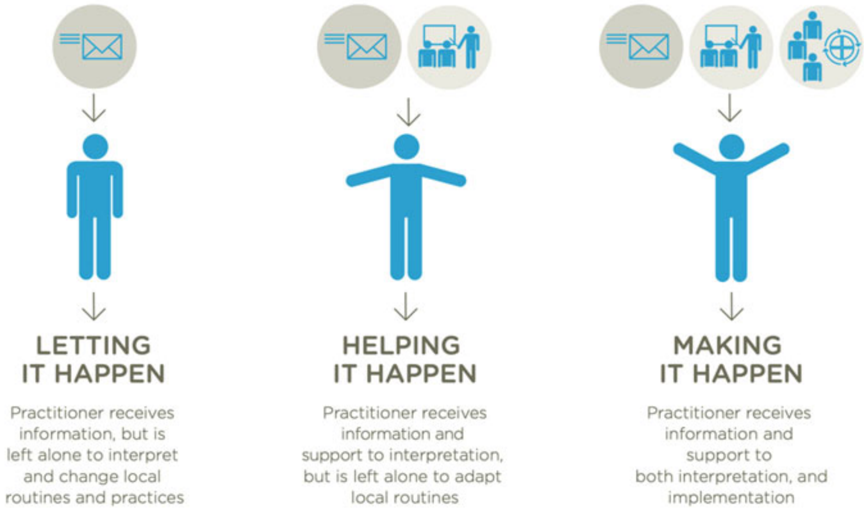

Fig. 2.1 Making it happen strategy for policy implementation. (Source: Figure adopted from Ejler et al. 2016)

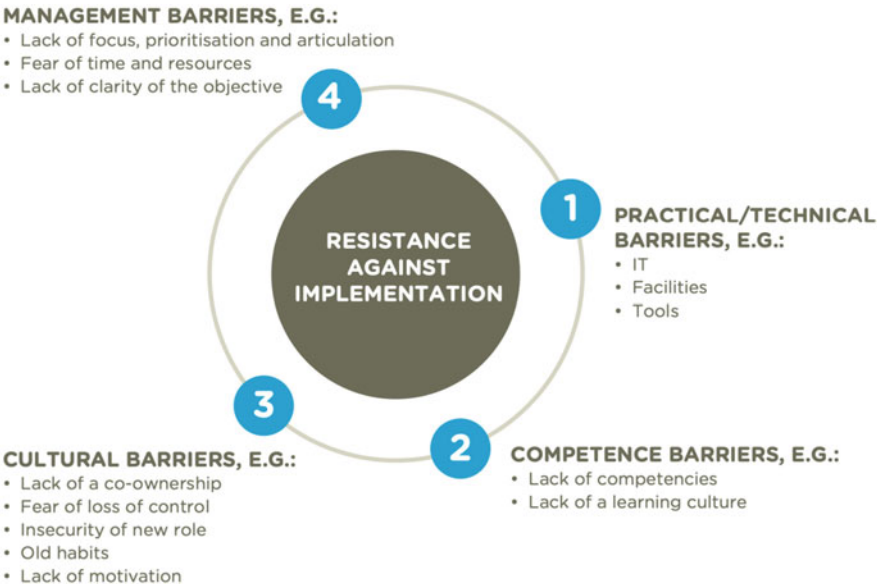

Fig. 2.2 The resistance against the implementation of policies. (Source: Figure adopted from Ejler et al. 2016)

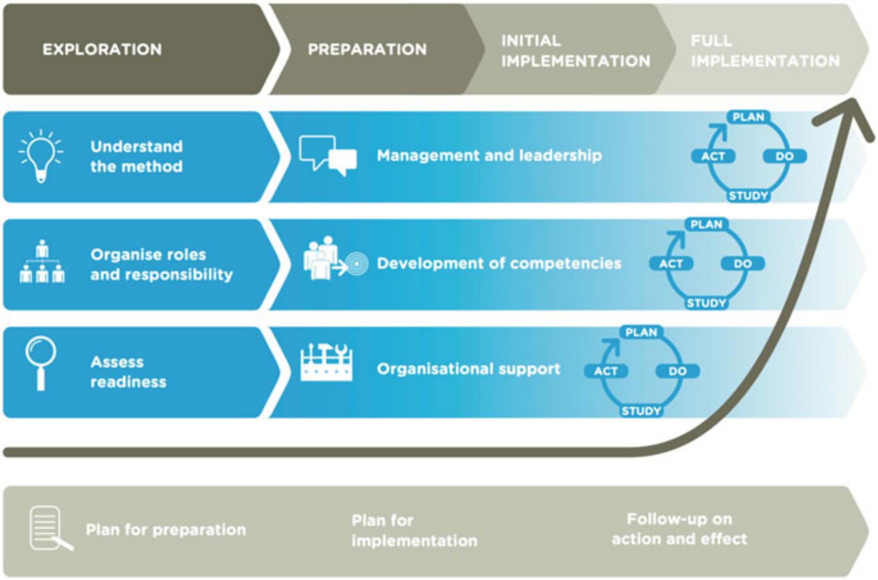

Fig. 2.3 The four stages of policy implementation. (Source: Figure adopted from Ejler et al. 2016)

Normally, there are four phases of policy implementation, viz. Exploration, Preparation, Initial Implementation and Full implementation. These four stages of policy implementation is explained in Fig. 2.3. During the exploration phase it is analysed whether the new policy is going to fit in the existing competencies or workflows. In the preparation phase organizations slowly modifies themselves to fit in the new policy environment. The initial implementation is the most demanding phase, where new batches of approaches, structures and practices are introduced in place of former well-accustomed practices. In the final phase, i.e., the full implementation phase, implemented policies start reaching its goals (Ejler et al. 2016).

2.3 History of the International Environment Policy

Any measure taken by Government or other organization towards reducing the human impact on the environment, is known as the environmental policy. Most of the organizational decision making does not consider the environment into account. Environmental resources are always underrated as nature is considered as the infinite source of resources. American Ecologist Garret Hardin in 1968 brought in the idea of “the tragedy of commons” where natural resources are the commons being used by people. Environmental public policies dates back to 4500 years, when the sewerage system were constructed in *Indus Valley Civilization* at *Mohenjodaro*. This was followed by similar steps taken in *Roman Civilization* 2700 years ago. Laws for

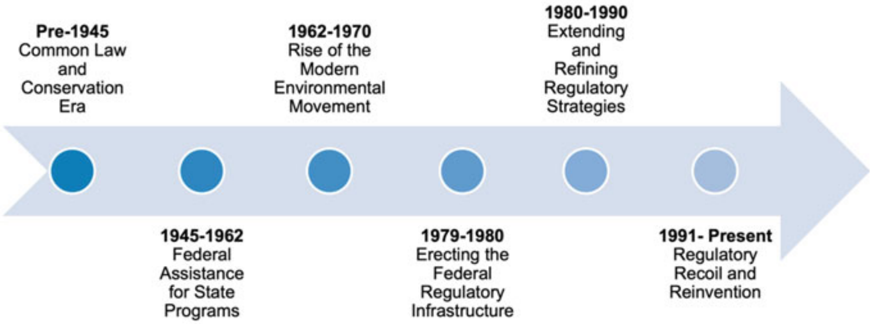

Fig. 2.4 Six Stages in the history of US Environmental Law. (Source: Figure adopted from Myers 2013)

governing the forest harvest were implemented in ancient Greece 2300 years ago. The emergence of *Minamata Disease* in 1956, caused by the mercury discharge of a closed by the chemical company and the publication of "*Silent Spring*" by Rachel Carson in 1962 drove in public awareness regarding the environmental issues (Surak 2018). In 1970, *National Environmental Policy Act* (NEPA) was signed (Kepner 2016). From late 1980s, the idea of sustainable development became the most important idea in the filed Standardization (ISO) issued its first standard protocol. Environmental Impact Assessment & *Ecolabeling* are other important steps towards saving the nature (Sharma and Goyal 2018; Shivam and Sarma 2017). The United Nations (UN) has provided platform, for all kinds of International Negotiations and agreement on the environmental issues and policy making. The *Stockholm Conference* is the first such conference to discuss environmental challenges. In 1992, The *United Nations Conference on Environment and Development* (UNCED) in Rio de Janeiro and in 2002 at Johanesburg are other notable global summits for discussing environmental issues. Similar kind of conferences on climate change were also organized in 1996 in *Kyoto* and in 2009 in *Copenhagen*. The Rio conference agreement was a soft law for environmental protection but the Kyoto Protocol was a hard law with distinct targets of Green House gas emission reduction target (Surak 2018). Significant International Environmental Legislations are listed in Figs. 2.4 and 2.5. In 1997, The *Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation* (BIMSTEC) was constituted including seven member states viz. Bangladesh, Bhutan, India, Nepal, Sri Lanka, Myanmar and Thailand. BIMSTEC was created to bridge the gap between SAARC and ASEAN Countries. This alliance aims towards shared and accelerated growth in several sectors like agriculture, counter-terrorism, climate change, culture, environment, trade, technology, energy, fisheries, transport, tourism, public health, poverty alleviation and people to people contact (https://bimstec.org).

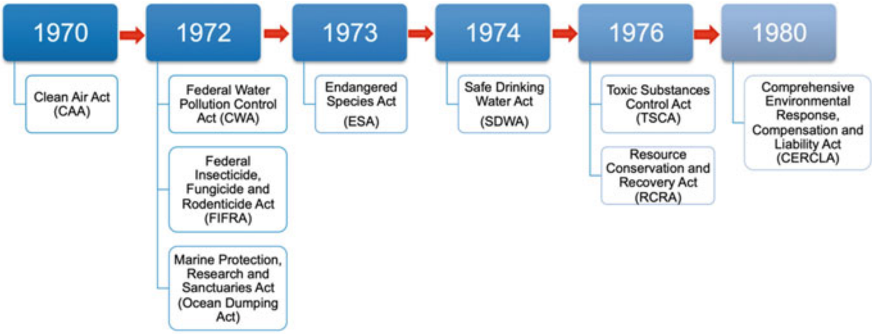

Fig. 2.5 Significant Environmental Legislations during 1970–1980. (Source: Figure adopted from Myers 2013)

2.4 Policy Initiatives by The Government of India

Government of India has adopted a holistic approach and launched various schemes towards achieving the *Sustainable Development Goals* (SDGs) by 2030. The economic survey 2018–2019 states that India will maintain its targeted economic growth by the means of various policies related to air pollution, climate change, resource efficiency and sustainable development. India's SDG Index score ranges between 42 and 69 for the states and 57 and 68 for Union Territories. Kerala and Himachal are the highest ranker among the States with the score of 69 and Chandigarh (68) among the UTs (Press Information Bureau Report 2019).

Government of India has taken many initiatives for the sustainable futures, which includes *Beti Bachao Beti Padhao, Deen Dayal Upadhyay Gram Jyoti Yojana, Pradhan Mantri Awas Yojana, Pradhan Mantri Jan Dhan Yojana, Pradhan Mantri Ujjwala Yojana, Swachh Bharat Mission, Smart Cities, Doubling Farmers Income, Ease of Living, Five Trillion Economy and Global Power House by 2024–25, Ten Trillion Economy by 2030* etc. The *Namami Gange Mission* is a key policy initiative to achieve SDG 6 which ensures access to water and sanitation for all. The *Namami Gange Mission* includes ecosystem conservation and Clean Ganga Fund, sewerage project management, urban and rural sanitation, tackling industrial pollution, water use efficiency and quality improvement etc. To fight India's air pollution problem, a comprehensive action plan called *National Clean Air Programme* was launched in 2019. To increase the optimum use of resources *National Policy on Resource Efficiency* has been proposed (Press Information Bureau Report 2019).

There are few National Flagship Programmes taken up by The Government of India to increase sustainability like *Per Drop More Crop*, which is a part of the *Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). Per Drop More Crop* promotes the water efficiency in agriculture through sprinkler and drip irrigation, the lesser use of fertilizers, etc. PMKSY also provides a Micro Irrigation Fund for resource mobilization and micro irrigation (https://pmksy.gov.in).

2.4.1 Indian Policies Towards Environmental Protection

In India, a few important policy initiative regarding safeguarding the environment and checking the air pollution includes *The Indian Forest Act, 1927, Wildlife (Protection) Act, 1972, Water Prevention and Control of Pollution Act, 1974, Water (Prevention and Control of Pollution) Cess Act, 1977, Forest Conservation Act, 1980, Air Prevention and Control of Pollution Act, 1981, Environmental Protection Act, 1986* (www.coursehero.com), *National Forest Policy, 1988, The Public Liability Insurance Act, 1991, The National Environment Tribunal Act, 1995, The National Environment Appellate Authority Act, 1997, 2002 and Biological Diversity Act 2002* (Fig. 2.6) which provides a strong legal framework for natural and environmental protection. Similarly, many notifications were issued time to time for establishing a rule for towards environmental protection. Some of the notifications (Fig. 2.7) are *Doon Valley Notification 1989, Revdanda Creek Notification*

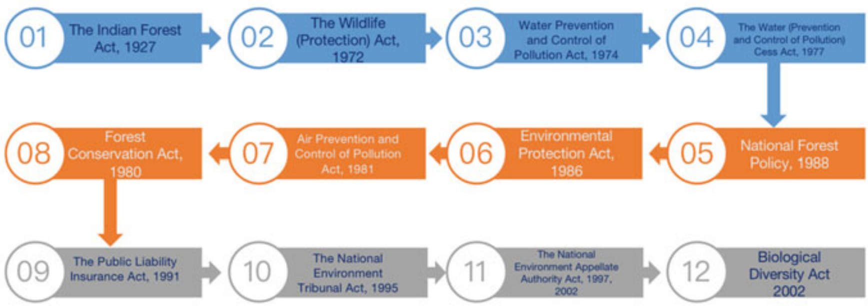

Fig. 2.6 Indian Acts for safeguarding the natural set up and environment

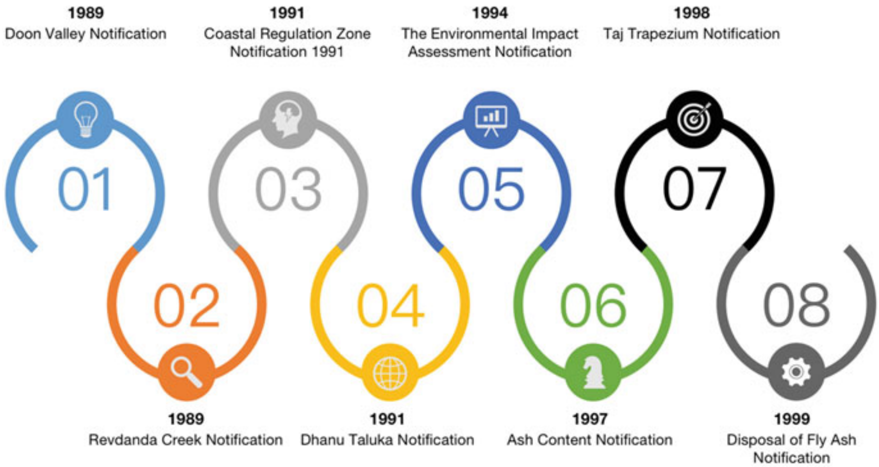

Fig. 2.7 Regulatory Notifications issued by Indian Government

1989, Coastal Regulation Zone Notification 1991, Dhanu Taluka Notification 1991(nidm.gov.in)*, The Environmental Impact Assessment Notification 1994, Ash Content Notification 1997, Taj Trapezium Notification 1998, Disposal of Fly Ash Notification 1999* (Gupta et al. unpublished data, www.ukessays.com) (Andrew 2015).

2.5 Indian Policies Towards Disaster Management

India was one of the significant signatories of the International Policy Frameworks like the *Sustainable Development Goals*, *Paris Climate agreement on Climate Change* and *Sendai Framework for Disaster Risk Reduction 2015–2030*. the importance of these international agreements lies in the fact that these not only provides the opportunity for refurbishing the existing policies and plans to create a coherence among the climate change issues with Disaster Risk Reduction (Lovell and Mitchell 2015), Environmental policies and developmental policies, but also helps in achieving the already-set goals for DRR through addressing the basic problems like poverty, hunger, sanitation pollution etc. Sendai Framework also highlights the role of sub-national and local governments in reducing disaster risks at their level (https://cdkn.org) (Carabine and Jones 2015). In 2015, Government of India also started implementing three crucial International agreements viz. in March *Sendai Framework for Disaster Risk Reduction* (SFDRR), in September, *Sustainable Development Goals* (SDGs) and in December, at the 21st *Conference of Parties* (COP 21), under the *United Nations Framework for Convention on Climate Change*, *Paris Agreement on Climate Change*. Towards disaster management, the Government of India had prepared a National Disaster Management Plan in 2016 and a revised plan in 2019. The international agreements cannot be implemented in isolated manner. Therefore, the revised plan has advised towards interconnecting these three agreements along with the Ten Point Agenda on DRR which was established by the Honorable Prime Minister at Asian Ministerial Conference on DRR (AMCDRR) in November 2016 in New Delhi (National Disaster Management Plan, 2018). Scenarios of India and International conventions ate listed in Tables 2.1a and 2.1b.

2.5.1 Hydro-meteorological Domains and Public Policy

In 2018, the Government of India has formulated *Hydro-meteorological Data Dissemination Policy* in 2018 which is to be implemented by *Central Warehousing Corporation* (CWC) and *Central Ground Water Board* (CGWB), the Ministry of Jal Shakti (Sharma and Goyal 2018). This policy supersedes previous related orders or guidelines of the Ministry of Water Resources, River Development and Ganga

Table 2.1a Scenario of Indian and international conventions

Convention	Effective	Year signed and enforced
International Convention for the prevention of Pollution of the Sea by Oil (1954)	1974	1974
The Antarctic Treaty (Washington, 1959)	1998	1983
Convention on Wetlands of International Importance, Especially as Waterfowl Habitat (Ramsar, 1971)	1982	1 October 1981 (ac)
Convention Concerning the Protection of the World Cultural and Natural Heritage (Paris, 1972)	1978	1977
Convention on International Trade in Endangered Species of Wild Fauna and Flora (Washington, 1973)	1976	1974
Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1979)	1982	1979
Convention on Early Notification of a Nuclear Accident (1986)	1988	1986
United Nations Convention on the Law of the Sea (Montego Bay, 1982)	1995	1982
Protocol on Substances that Deplete the Ozone Layer (Montreal, 1987)	1992	19 June 1992 (AC)
Convention on the Control of Trans Boundary Movements of Hazardous Wastes and Their Disposal (Basel, 1989)	24 June 1992	5 March 1990
Amendments to the Montreal Protocol on Substances that Deplete the Ozone Layer (London, 1990)	1992	19 June 1992 (ac)
Protocol on Environmental protection to the Antarctica Treaty (Madrid, 1991)	1998	1992, 1996
United Nations Framework Convention on Climate Change (Rio de Janerio, 1992)	1994	1 November 1993

Source: Gupta et al. (2013)

Rejuvenation. As per this policy all data collected by CWC and CGWB will be publicly available through the online portal.

2.5.2 *Climate Finance and India's Nationally Determined Contribution*

Paris agreement has highlighted the importance of Climate Finance in fortifying the global response towards climate change. Nationally Determined Contributions are the integral part of the Paris Agreement which helps the countries in determining and communicating post 2020 climate actions and this will ultimately help in achieving the long term goals of Paris Agreement. Consorted global efforts are needed to build resilience towards climate challenges (Goyal and Ojha 2011; Goyal et al. 2012). India needs sizable investments to implement India's Nationally determined contributions which indicates that over and above domestic budgets, mobilization of International Public Finance and Private Sector Resources are needed. India has

Table 2.1b Scenario of Indian and international conventions

Convention	Effective	Year signed and enforced
Convention on Biological Diversity (Rio de Janerio, 1992)	18 Feb. 1994	5 June 1992
Convention to Combat Desertification in those Countries Experiencing Serious drought and/or Desertification, Particularly in Africa (Paris, 1994)	17 Dec. 1996	14 October 1994
International Tropical Timber Agreement (Geneva, 1994)	1997	17 October 1996
Rotterdam Convention on the Prior informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, (1998)	2004	2005
Protocol to the United Nations Convention on Climate Change (Kyoto, 1997)	2005	1997
Cartagena Protocol on Biosafety (Nairobi, 2000)	23 January 2001	17 January 2003
Stockholm Convention on Persistent Organic Pollutants (2001)	2004	2006

Source: Handbook on International Environment Agreements: An Indian Perspective. Accessed at http://awsassets.wwfindia.org/downloads/mea_handbook_cel.pdf

taken great steps towards Sustainable Finance initiatives which has resulted in India's rank in the 11th Position in global country ranking, also India accounts for 33% of the *Certified Climate Bonds* (Press Information Bureau Report 2019).

2.5.3 One Health Approach

As per definition given by *One Health Initiative Task Force* (OHITF), the concept of *One Health* is "the collaborative efforts of multiple disciplines working locally, nationally, and globally, to attain optimal health for people, animals and our environment". One health approach emphasizes on the fact that the human health depends on the health of surrounding environment and animals (Fig. 2.8).

With the growing population pressure more and more people are living in close contact with animal which is mostly domestic but also wild animals in some cases. People come in contact with the animal for food, fiber, livelihoods, travel, sport, education or companionship etc. Close human contact with animals increases the chances of zoonotic diseases, which includes Anthrax, Brucellosis, Ebola, Lyme disease, Rabies, Ringworm, Salmonella infection, West Nile virus infection, Q Fever, etc. Susceptibility to some of the diseases and natural disasters are shared both by humans and animals. Therefore, sometimes animals can act as the early warning system for upcoming health or natural hazards. Through One health approach, inter-disciplinary experts monitor and control public health issues and do research on the pathways of spreading the diseases among the environment, animal and Human. It will be helpful if the community, law enforcement policy

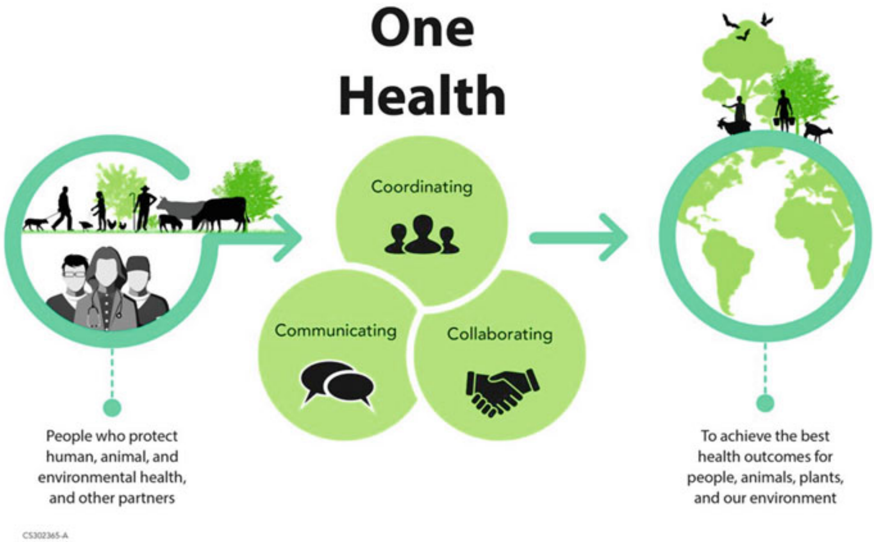

Fig. 2.8 One Health Approach. (Source: Figure adopted from Centers for Disease Control and Prevention)

makers and other stake holders are also included in One health approach (Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases 2018).

2.5.4 Corporate Sustainability Policy

Corporate sustainability is known as "a business approach that creates long-term consumer and employee value by creating a 'green' strategy aimed toward the natural environment and taking into consideration every dimension of how a business operates in the social, cultural, and economic environment" (Ashrafi et al. 2019; Purkayastha 2019; https://www.greerwalker.com/project/white-paper-companys-sustainability-policy/). Corporate Sustainability Policies include, *Corporate Waste Policy, Corporate Water Policy, Corporate Energy Policy, Environmental Purchasing Policy, Stakeholder Policy, Supply Chain Policy,* etc. These policies as a whole helps in reducing the carbon foot print of industries and businesses and promotes a sustainable development (https://www.greenbuoyconsulting.com/blog/do-you-have-these-corporate-sustainability-policies).

Table 2.2 The differences in objectives and approaches in EIA, SEA and Post-Crisis Integrated SEA

EIA	SEA	Post-Crisis Integrated SEA
Applied for specific projects	Applied for strategic decisions such as policies, plans and programs	Applied for strategic decisions in a post-crisis context
Aims to do things right	Aims to do the right things	Aims to prevent conflicts and disasters and build resilience
Mostly a technical instrument	Mostly a political instrument	Mostly a political instrument
Identifies specific environmental and social impacts	Addresses issues of sustainable development	Special attention to disaster risk reduction and climate change adaptation
Limited review of cumulative effects	Early warning of cumulative effects	Cumulative effects of multiple reconstruction projects
Emphasis on mitigating and minimizing impacts	Emphasis on preventing impacts	Emphasis on preventing new disasters and conflicts
Linear and stepwise process	Flexible and iterative process	Flexible and iterative process

Source: United Nations Environment Programme (2018)
Credit: R. Verheem, Netherlands Commission for Environmental Assessment (NCEA) and Sudmeier-Rieux, UN Environment

2.5.5 Policy Instruments in Environment Concerns

Incorporation of Disaster Risk Reduction Strategies in the *Environmental Impact Assessment* (EIA) and *Strategic Environmental Assessment* (SEA) an important step to reduce the future risks (Gupta and Nair 2012, 2013). Another crucial way out is *Post-Crisis Integrated Strategic Environmental Assessment (Integrated Strategic Environmental Assessments in Post-Crisis Countries, United Nations Environment Programme 2018). The following Table 2.2 depicts the differences in objectives and approaches in EIA, SEA and Post-Crisis Integrated SEA.*

2.5.6 Present Policy Scenarios in India

Proper implementation and synergies among the policies, are the key to the success to the sustainable development of the society and the sustainable future also depends on the implemented green strategies and policies at present. Synergies among the national plans and the state level plans are of utmost importance. Many of the state Disaster Management Plans have clarity on sectoral and departmental responsibilities but need to determine the instruments and pathways of mainstreaming DRR (Table 2.3). It is also important that the state level disaster management plans are prepared in concurrence with the International guidelines like Sendai Framework

Table 2.3 The synergies among the State Disaster Management Plan and the Annual Development Plan

State	Disaster contingency plan for various departments	
	State Disaster Management Plans	Annual Development Plans (ADP) and State Level Plans
Assam	Assam's SDMP has explicitly identified specific disaster management roles and responsibilities (like developing contingency plans etc.) the guidelines provided in the plan is generic and does not include time specific commitments (Assam State Disaster Management Authority 2013).	Assam's annual development plan does not explicitly explain disaster management in its sectoral and expenditure plan for 2014–2015.
Bihar	Bihar has emphasized on mainstreaming of DM into the development plans. Bihar leads in disaster contingency planning as it has prepared disaster management plans for all government offices. It has also identified hazard specific detailed response plans with special emergency functions.	ADP of Bihar has also included disaster management, along with mass awareness, capacity building, early warning mechanisms and emergency operation centres,
Gujarat	Gujrat has prepared disaster response and relief plans for each hazards and has identified responsibilities and timelines for line department(s). The plan also provides preparedness guidelines for relevant line departments.	Gujarat's annual development plan also includes 'community-based disaster preparedness Programme,' 'National Cyclone Risk-management Project', regional emergency response centres, and disaster preparedness training
Odisha	Each department of Odisha State Government has detailed and prescriptive response plans, which includes timeline for report submission other specific activities. But the SDMP does not include specific guidelines for mainstreaming cross sectoral management activities.	The annual development plan is available for few cities like Bhubaneshwar and few villages. Only annual activities Report for 2013–2014 is there, which does not include disaster risk activities.
Uttarakhand	Uttarakhand's SDMP highlights mainstreaming of DRR through various project implementation and departmental schemes. It is mandatory for all the projects to go through vulnerability and risk assessments before approval.	Uttarakhand has district and state level development plan. The state also have a 'sectoral outlay and expenditure plan', the 'district disaster mitigation fund', and the 'district disaster management fund'.

Source: Adopted from Bahadur et al. (2016), reliefweb.int

(Table 2.4). Therefore, to achieve the goal of all climate related National and International agreements and policies, synergies at the top and the local level is the need of the hour.

Table 2.4 Synergies among the State Disaster Management Plans and Sendai Framework

Priority for action	Alignment
Understanding the DRR	State disaster management plans highlights disaster risks for specific regions but lacks socioeconomic vulnerabilities. More scientific and socioeconomic data should be used for giving a composite analysis about the interaction of hazard exposure and vulnerability, to better understand the disaster risk.
Fortifying disaster risk governance to achieve DRR	India has a great structure for supporting disaster risk governance and highlight roles and responsibilities for different stakeholders across the country. As per the Disaster Management Act 2005, the state Disaster Management Plans should include a 'Complete Disaster Management Cycle' into the disaster risk governance structures and activities. This will help the Sectoral Development Plans to include disaster risk reduction for effective disaster risk management
Investment for DRR	Funds and investments for disaster risk management and DRR are limited. Due to lack of understanding resilience should be included in investment planning. Mainstreaming of disaster risk reduction among development policy and planning can be achieved through inter-sectoral engagement, investment in various ministries and stakeholders and public–private partnerships
Increasing disaster preparedness for effective response recovery, reconstruction and rehabilitation	SDMPs include disaster response, but need to include recovery, rehabilitation and reconstruction options Disaster preparedness and risk mitigation should be clearly mentioned within the SDMPs to make DRR approaches more holistic across different scales and sectors.

Source: Adopted from Bahadur et al. (2016), reliefweb.int

2.5.7 *Way Forward*

In India, the basic problem with the environmental laws are implementation issues. India, ranks 141st among 180 countries in terms of environmental governance as per *Environmental Protection Index* (EPI) 2016. Central Pollution Control Board and State Pollution Control Board are two authorities for pollution control in India, which do not have enough power to effectively penalize the creator of water or air pollution as per report 21 of Comptroller and Auditor General (CAG) of India on '*Performance Audit of Water Pollution in India*' (2011–2012). The polluter pays principle is not followed in India as the penalty cost is cheaper than the compliance cost. An independent Environmental Regulatory Body is needed to step up the penalty and liability mechanism and effectively implement the water and air Pollution Control Act. Not only the independent regulator but also a legal framework for environmental law is needed for risk regulation (Prasad 2017).

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Chapter 3
Climate Finance at International and National Level: Needs, Drivers and Sources

Niranjan Padhan, Michael Islary, and Anil Kumar Gupta

Abstract The top risks in the world are climate induced states the World Economic Forum report. Climate Finance (CF) plays an imperative role in reducing and altering on the impacts of climate resilience in developing countries. This chapter on CF is based on review of secondary sources such as journal articles, policy documents and reports, among others. International summits like the Kyoto Convention (1997) and the Paris Agreement (2015) have paved the way for a global fight against climate change; wherein, the developed countries have contributed funds to mitigate the effects of climate change and adopt a climate resilient development themselves. Bulk of India's climate finance comes from public budget. To meet India's NDC targets and keep within 1.5 °C temperature, the private sectors of this country must do their fair share by contributing or generating funds. Climate insurance as an instrument of climate financing needs to be explored but with caution.

Keywords Climate finance · Climate change · Climate adaptation

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3.1 Introduction

The top five risks confronting the globe today, according to the World Economic Forum (WEF) report (2020), are primarily climate-related, including extreme weather, climate action failure, natural disasters, biodiversity loss, and man-made environmental disasters, among others. Climate change is a global negative externality caused primarily by the accumulation of greenhouse gas emissions in the atmosphere (Harris 2006). The Rio-conference and the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 resulted in the emergence of a multilateral climate change regime, which has adopted a number of agreements and decisions to enhance the global response to climate change. The magnitude and the diverse impact of climate change seem to be disastrous because these are potential to disturb current growth and exacerbate poverty.

In this scenario, climate finance plays a vital role in addressing climate change that requires a large investment to significantly reduce GHGs. Climate financing, on the other hand, is critical for adaptation as it allows society and economies to adapt adverse effects and reduce the impacts of climate change. Therefore, it has become an integral component of international deliberations and negotiations on climate change. Although, the actual term of 'climate finance' is often associated with the international climate change negotiations but different countries have developed their own policies and institutional systems for accessing and using climate finance. Hitherto, Mandal (2019) states, "there is no wide or accepted definition of what constitutes climate finance. However, to estimate of financial flow towards mitigation and adaptation activities are available". Climate finance, according to the UNFCCC, refers to local, national, or transnational money derived from public, private, and alternative sources in order to support mitigation and adaptation actions that will address the climate change impact. Simply, it is the transfer of funding from developed to developing countries to assist them in reducing emissions and adapting to the effects of climate change.

3.2 An Overview of Climate Finance at Global Level

To address climate change impacts, the Kyoto protocol that emerged out of Kyoto convention (1997) and the Paris Agreement (2015) calls for financial assistance from developed countries to less endowed and more vulnerable countries to standardize to prevent climate change impacts. It also recognises the countries contribution towards climate change and their capacity to prevent and cope with the consequences which vary enormously. Both, the Kyoto protocol (1997) and the Paris Agreement (2015) are based on the principle of common but differentiated responsibilities, keeping in mind the socio-economic development of the concerned countries and the polluter pay principle.

The Paris Climate summit is a landmark mileage in the global fight against climate change which has been ratified by 118 countries, including the USA. The combined emissions of those 118 countries accounting for 80.05% of global emissions. The Paris Agreement is guided by the aim of the UNFCCC, i.e., making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development. One of the primary objectives of the Paris Agreement is to keep the global average temperature well below 2 °C, which is well above the pre-industrial level. To mitigate the risk and impact of climate change, Article 2 of the Paris Agreement calls for a further limit on the world average temperature of 1.5 °C. To meet the first goal, carbon dioxide emissions need to be reduced to zero between 2060 and 2075, and overall greenhouse gas emissions need to be reduced to zero between 2080 and 1990. The comparable years to keep warming below 1.5 °C are 2045–2050 and 2060–2080, respectively. To achieve the target, the agreement has invited voluntary contributions from other parties, such as stockholders and private parties.

Certainly, the Paris agreement emphasises on transparency and enhances predictability of financial support. To facilitate climate change finance, the agreement that has been decided to establish two important financial mechanisms, i.e., the Green Climate Fund (GCF) and the Global Environmental Facility (GEF) to mobilise the financial resources for developing countries. To enhance the transparency and predictability of financial support, the COP 21st in Paris agreement decided to establish two special mechanisms under GEF namely the Special Climate Change Fund (SCCF) and the Least Developed Countries Fund (LDCF) and in 2001 the Adaptation Fund (AF) was established under the Kyoto Protocol.

The GCF is one of the most important multilateral sources of adaptation finance, and the developed countries are pleased to provide a sum of USD 100 billion to developing countries annually, as agreed in Copenhagen in 2009, which will continue beyond 2020. According to the Panwar et al. (2022) study, the World Economic Forum (WEF) projected a $5 trillion annual investment in green infrastructure, which is significantly higher than the current commitment of USD 100 billion by developed countries. Such a commitment of financial assistance from developed countries to developing countries is seen as the “bedrock” of the entire international climate finance system (Table 3.1).

3.3 Allocation of Climate Finance

Figure 3.1 shows that an average climate finance flows between 2017–2018 and 2018–2019 reached to USD 574 billion of which the total climate finance flows of USD 608 billion in 2017 and USD 540 billion in 2018 (Global landscape 2019). Climate funding flows in 2017/2018 are approximately 24% higher than the average expenditure in 2015/2016. The trend line of above figure shows that the average climate finance at global level has increased steadily from 2012–2013 to 2019–2020. The estimated climate funding flow for 2019 is between USD 608 billion and USD

Table 3.1 Sources of global climate funds

Sl. No	Sources of climate finance	Year of establishment	Objective	Fund allocated
1.	Global environmental facility (GEF)	1992 in Rio earth summit	It funds projects relating to climate change, biodiversity conservation, the ozone layer, and other issues in emerging and transition economies. GCF also encourages local communities around the world to develop sustainable livelihoods.	This multilateral financial mechanism has provided $21.1 billion in grants and leveraged an additional $114 billion for over 5000 projects in 170 countries since its establishment.
2.	Special climate change fund (SCCF)	2001 under the UNFCCC	Funds are allotted to address the specific needs of developing nations in adapting to the effects of climate change and building resilience. SCCF's key priorities are climate change adaptation and capacity building activities.	As of November 2020, developed countries had pledged USD 375 million to the Fund for developing countries.
3.	The least developed countries fund (LDCF)	2001, in seventh conference of the parties in (COP7)	Its goal is to boost resilience capacities by implementing concrete adaptation initiatives and programmes that minimize the negative effects of climate change.	Through this fund, as of November 2020, developed countries have committed to providing a total of USD 1.6 billion to developing countries.
4.	The adaptation fund (AF)	2001, established under the Kyoto protocol	To assist developing countries in adapting to the negative effects of climate change.	Since 2010, the Adaptation Fund has directed $532 million to 80 specific adaptation projects in developing countries to fight against climate impacts.
5.	Green climate fund (GCF)	2010, under, the United Nations framework convention on climate change (UNFCCC).	Generating funds for low-emission and climate-resilient development paths for poor nations in limiting or reducing greenhouse gas emissions and responding to the effects of climate change	To assist climate finance of $100 billion per year for developing nations by 2020.

Source: Introduction to Climate Finance, UNFCCC (https://unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance)

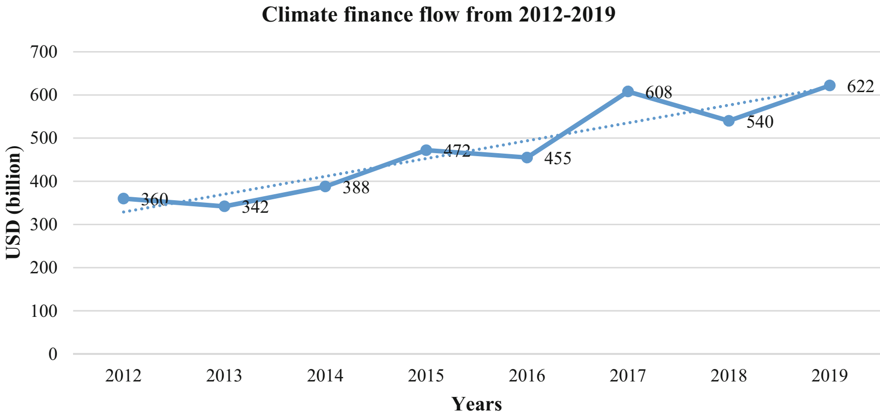

Fig. 3.1 Flow of climate finance at global level. (Source: Climate Policy Initiative 2013)

622 billion. This shows that the global economy recognizes the seriousness of climate change and is making significant efforts to mitigate its future impact.

From the above figure, it is noticed that, during 2017/2018, an average annual public climate finance was USD 253 billion representing 44% of total commitments in Paris agreement. According to CPI report (2013), transport spending has surpassed renewable energy to become the greatest recipient of public funds, accounting for USD 94 billion, or 37% of the total finance. The public sector's investment is mostly focused on adaptation and resilience, energy efficiency, land use, and cross-sectoral projects. Compared to other actors of public climate finance, domestic, bilateral and multilateral development financial institutions (DFIs) continue to account a major share of public finance and increase average commitments in 2017–2018. However, due to the global slowdown in economic growth and a shift in domestic policies toward deleveraging and financial risk management, some major players reduced their investment in 2018. National DFIs, on the other hand, remain the largest contributors to climate finance among the other DFIs, but their commitment in 2017/2018 remained unchanged from the previous year, at USD 132 billion on an annual average. It is also to be noted that climate finance from governments and their agencies doubled to USD 37 billion in 2017–2018.

The private sector continues to account for the majority of climate funding, with an average contribution of USD 326 billion each year in 2017/2018, as indicated by Fig. 3.2. Renewable energy, on the other hand, received 85% of total private finance, followed by low-carbon transportation (14%), while all other sub-sectors received less than 1% (CPI 2013). Despite the fact that corporations continue to account for the majority of private investment, commercial banking institutions have grown in importance, with funding increasing by 51% between 2015/2016 and 2017/2018. Institutional investors increased their contribution fourfold from 2015 to 2016. Households increased their climate-related consumption to USD 55 billion, a 32% increase over 2015/2016, implying increased awareness and widespread availability of sustainable energy and transportation alternatives.

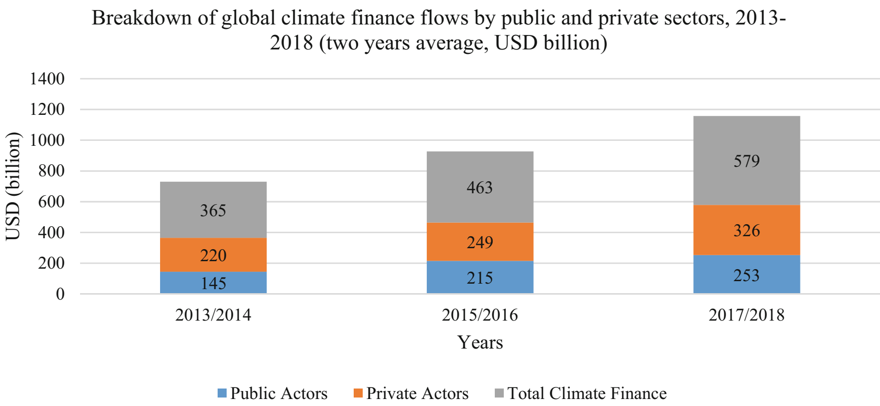

Fig. 3.2 Flow of climate finance by sectors. (Source: Global Climate Change Landscape Report 2019)

3.4 Climate Finance in India

IPCC (2014) states that the developing countries are the ones to suffer more from the impacts of climate change as compared to the developed countries. To achieve the long term emission reduction target at global level, apart from the leading role of developing countries, the agreement also encourages developing countries to enhance their mitigation and adaptation efforts to counter the climate change impact. The 22nd COP of the UNFCCC adopted the Marrakech Action Proclamation, which confirmed countries' commitment to implement the Paris Agreement in order to fulfil the Paris Agreement's goals. India's contribution in this regard is critical. This is because, despite its gross emissions being among the highest in the world, it is a country with very low per capita emissions as well as high levels of poverty and deprivation. India is one of the fastest growing economies in the world and has determined to overcome its developmental deficits.

3.4.1 Importance of Climate Finance in India

Being a developing country, India's climate variability and climate change poses huge risks to human life and threaten the sustainability of the country's socio-economic growth (Sheereen 2012; Mishra 2014; Karmakar and Mukhopadhyay 2014). According to a report released by an international environmental think-tank Garmanwatch[1] (2020), India is the fifth most vulnerable country to climate change in

[1] Germanwatch is an independent development and environmental organisation which work for sustainable global development. It is based in Bonn and Berlin (Germany). https://timesofindia.

the world in 2018 and it was ranked as 14th during 2017. The top most worst affected countries to climate change in 2018 were Japan, Philippines, Germany and Madagascar. According to this research, India experienced the largest number of fatalities and the second highest monetary loss as a result of climate change in 2018. The high rank of the country is due to severe rainfalls, followed by tyrant flooding particularly in the coastal belt and landslides that killed over 1000 people in the same year.

Further, according to the World Risk Index (2020), among the South Asian countries, India is the fourth most-at-risk country after Bangladesh, Afghanistan, and Pakistan respectively (Saini 2020). As per the World Risk Index (2020), India lost US$ 37 billion due to climate events such as cyclones battering the east coast and flooding and landslides in Kerala where about a quarter million people were displaced and more than 20,000 houses and 80 dams were destroyed. From 1998 to 2017, these losses added up to US$ 79.5 billion (Eckstein et al. 2019). On the other hand, India faced drought conditions worsening the farm crisis (Kumar et al. 2021; Poonia et al. 2021b, c). Chennai's record-breaking 272 mm rainfall in 12 h (2015) affected over 10 thousand MSMEs and reportedly caused US$ 250 million in damage (Idicheria et al. 2016). The country has faced at least one climate extreme event every year in the last two decades.

India's high ranking in the Global Climate Risk Index is attributable to the country's longest coastline (7500 km-long coastline) which is prone to cyclone, salinity, ingress and sea- level rise, among others. Further, significant use of fossil fuels in energy systems and high reliance on agriculture for rural livelihoods which heavily reliant on seasonal monsoon rains makes India more vulnerable (emphasis added) (Eckstein et al. 2019; CPI 2013). Climate change, according to the World Bank, will reduce India's GDP by roughly 3% and negatively affect the agricultural productivity (Das et al. 2020; Poonia et al. 2021a) living standards of half of its population by 2050 (Mani et al. 2018). Singh's (2017) study reveals a stark reality of the Indian economy that losses due to extreme weather drastically increased by USD 45 billion between 2008 and 2017, which was around USD 20 billion in 1988–2007. Moreover, the ILO (2019) report predicted that an increase in temperature and extreme climatic conditions in India will lead to a loss of 34 million full-time jobs, primarily among farmers by 2030. On the other hand, according to the Economic Survey report of 2017–2018, the farmers' income could drop by 15%–18% due to climate change impacts. Being an agrarian country, where both of its primary and secondary sector are hugely dependent on climate-sensitive natural resources; climate change, is projected to worsen the situation requiring huge investments in not just disaster preparedness and restoration but also to address social and economic impacts of loss and damage.

The National Action Plan on Climate Change (NAPCC) which is India's umbrella policy on climate change was framed by the Prime Ministers Council on

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indiatimes.com/home/environment/global-warming/india-ranks-5th-in-global-climate-risk-index/articleshow/72367505.cms

Climate Change in 2008 to address the need of rapid economic growth by highlighting the potential risk of climate change. The NAPCC encompasses twelve national missions (eight created in 2008 and four added in 2014) with a focus on climate sensitive sectors and the creation of climate knowledge. All the Missions integrate both mitigation and adaptation into India's development plans and each Mission's responsibilities are entrusted to subject-specific ministries and departments. To achieve the objectives of NAPCC, the central government highlighted the role of the states at sub-national level in formulating and implementation of climate action plans and policies. Initially, the Government of India instigated the eight major states to prepare the State Action Plan on Climate Change (SAPCC) through the Ministry of Environment, Forest and Climate Change (MoEFCC) with a vision of making it one of the largest efforts of state-level climate planning globally.

It is considered as an important milestone for the developing decentralized domestic policies on climate change in India. The important sectors like agriculture, forestry, fishery, health and disaster play a crucial role in achieving the objectives of the National Action Plan for climate change. For this, SAPCCs has recommended to identify the necessary adaptation and mitigation strategies/activities among the above mentioned sectors which will help to reduce the vulnerability to climate change at the state level in short, medium and long run. Among all other states of India, Odisha is the first state to formulate the SAPCC (2010–2015) at the sub-national level to increase the resilience capacity and decrease the vulnerability in the state. All the SAPCCs have been formulated on the lines of NAPCC with a higher focus on adaptation and afforestation than on mitigation (Kapoor and Malviya 2021) (Fig. 3.3).

It is observed from the above figure that climate finance in India comes from multiple sources from both international as well as national sources. At the national and sub-national level, these funds are made available either through the governmental budgets or by the government departments and different agencies. Besides that, the climate finance fund comes in the form of direct project funding by the private players and non-governmental organizations at the project level. The funds are in the form of budgetary allocations, taxes, subsidies, generation based incentives, private equity, loans, soft-loans and grants. Despite the presence of numerous sources of climate finance in India, public finance represents the greatest source of climate expenditure in the country, coming from both the national and subnational levels. However, the bulk of this budgetary support goes towards funding programme relevant to climate change adaptation. Although, both the international and private climate financing sources are yet to play a substantial role in the present context of climate finance in the country, they are likely to play an important role in the future. However, India requires significant financial assistance to achieve the twin goals of NAPCC, i.e., to manage the trade-offs between economic growth (required for poverty alleviation and employment generation) and the reduction of greenhouse gas emissions (required to curb climate change). To meet, the 1.5 °C temperature target, energy efficiency and low-carbon energy technology must be increased by six-fold by 2050 compared to 2015 (IPCC 2019).

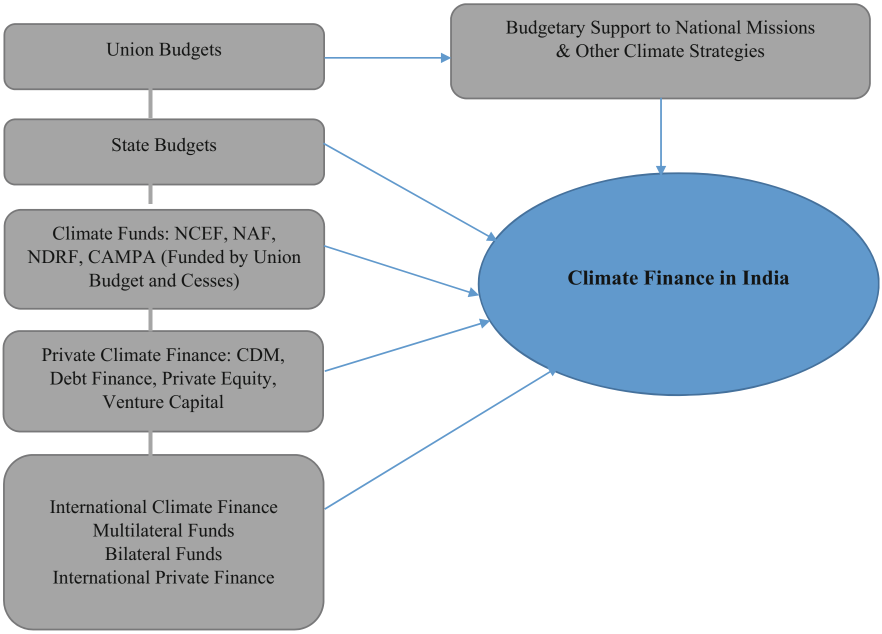

Fig. 3.3 Climate finance architecture in India. (Source: Singh 2007)

In addition, to reach its Nationally Determined Contribution (NDC) goals, India will need to increase its yearly investment ninefold from 2018 (CPI 2013). India's NDC aims to reduce the emission intensity of its GDP by 33–35% below 200 levels by 2030, achieve 40% of cumulative electric power installed capacity from no fossil fuel sources by 2030, and increase forest and tree cover to create additional carbon sinks equivalent to 2.5 to 3 billion tonnes of CO2 by 2030 (Economic Survey, 2020–2021).

According to the Mandal (2019) study, the total cost of low-carbon policies to the Indian economy over a 20-year period from 2011 to 2030 is anticipated to be US $834 billion (in constant 2011), which is a measure of the economic opportunity cost of following a low-carbon growth path. The Economic Survey of India (2015) has argued that at least US $2.5 trillion would be required to meet India's climate change targets between 2015 and 2030, and international climate finance is necessary to meet the difference between what can be made available from domestic sources. Steinbach et al. (2014) view that India, unlike China and Latin American countries, is not attracting enough climate finance to meet its future adaptation and mitigation needs. However, the country got approval for over US $1 billion from climate funds, which is much more than any other country in the world. India would have received much more funds from international climate finance as compared to its peer countries (i.e. China, South Africa, Brazil, Indonesia, and Thailand), if multilateral and bilateral sources were included in this mix (Mandal 2019).

3.5 Climate Insurance

Another, vital source of climate financing is climate insurance which could play a significant role in mitigating the impacts of climate induced disasters and extreme weather events. However, it is a less explored option to tackle the impacts of disasters even in developed countries. Although, developed countries insure the impacts of disaster but even in these countries less than a third of disaster losses are insured (Linnerooth-Bayer et al. 2009). The situation is far worse in developing countries.

Providing insurance cover to the low-income households, farmers and business on the events of disasters in developing countries can lessen the financial burden left by disasters and speed up the path to recovery. Climate insurance can also do away with the delays and an unpredictable nature of fundings are from donor agencies. But, experts call to exercise caution given the challenges of limited financial literacy, weak financial infrastructure and lack of data risks, among others (Surminski et al. 2016).

3.6 Way Forward

To address climate change and reduce the GHGs, a large investment of funds are required that's where the role of climate finance comes into play. It not helps in adapting to the adverse effects of climate change but also in reducing the impacts from it. developed countries need to provide financial assistance to developing countries as they are the worst sufferers from the impacts of climate change but have less capacity and means to overcome it. India ranks amongst the most vulnerable countries to climate change. India has adopted the Decentralised Domestic Policies on climate change in India in the form of NAPCC AND SAPCC, respectively. At present, the bulk of India's climate finance comes from public budget both at the central and state level. To meet India's NDC targets and keep within 1.5 °C temperature, the private sectors of the country must do their fair share by contributing or generating funds. Climate insurance as an instrument of climate financing needs to be explored but with caution.

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Chapter 4
Economic Impacts of Hydroclimatic Extremes and Disasters in India

Amarnath Tripathi and Sucheta Sardar

Abstract This study attempted to reexamine the relationship between hydroclimate extreme and economic growth in India. Using primary and secondary information, this exploration was carried out at three levels - macro, meso, and micro. The study confirmed the negative impact of hydroclimatic extreme events on economic growth, highlighting different impact pathways.

Keywords Hydroclimatic events · Economic growth · Livelihood · Agriculture

4.1 Background

The occurrence of hydroclimatic extremes is very likely to increase due to abrupt changes in climate (IPCC 2021; Sharma and Goyal 2018). These events have severe impacts on both society and the economy (Jahn 2015). India is no exception here weather-related disasters have increased significantly over the past 50 years (Ray et al. 2021). Between 1970 and 2019, total Hydroclimatic extremes experienced in India were 7063, which has caused about 141,308 deaths in the country. Some recent significant events endorse the seriousness of the situation in the country. For example, Kerala state saw its worst flooding since 1924 in August 2018. This devastating flood and associated landslides affected 5.4 million people, displaced 1.4 million people, and claimed over 400 lives. The total economic loss was estimated to be over Rs. 26 thousand crores. Similarly, Chennai received record excess rainfall during November and December 2015, causing heavy floods in the city. This flooding killed over 500 people and damaged about US$ 3 billion. In another incident, Odisha and West Bengal faced Cyclone Amphan in May 2020, which displaced 2.4 million people and caused economic losses of approximately US$ 14 billion. These losses have serious implications for economic growth. However, the relationship between Hydroclimatic extremes and economic growth is ambiguous. It depends on multiple situations. For example, developing economies

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experience much more impact from Hydroclimatic extremes than developed counties. Noy (2009) explained the reasons for the above distributional impacts. Counties with higher literacy rates, better institutions, higher per capita incomes, better fiscal position, larger governments, and a higher degree of openness to trade are better able to cope with adverse effects of Hydroclimatic extremes. Not only that, such countries are capable of preventing adverse effects spilling deeper into the economy. Panwar and Sen (2019) also found stronger growth effects in developing countries compared to developed countries. Loayza (2012) supported Noy (2009) and observed a similar observation that developing nations are much more susceptible to Hydroclimatic extremes than industrialized countries. It is mainly because developing nations have much lower adapting capacity than developed counties (Smit and Wandel 2006). Adaptive capacity depends on five capitals: natural capital (*e.g.,* natural resources and dependency on natural resources), physical capital (*e.g.,* infrastructure), financial capital (*e.g.,* income, diversification of economic activities), human capital (*e.g.,* education, health), and social capital (*e.g.,* institutions, socials norms).

Hydroclimatic extremes have direct and indirect impacts on society and the economy. Direct losses include damages to assets, crop losses, human and animal deaths, and health risks. On the other hand, indirect losses incorporate disruptions in the supply chain, and a fall in demand, loss in household savings and income. Noy and duPont (2016) has categorized indirect impacts of Hydroclimatic extremes into the first-order and the higher-order impacts. Therefore, the above impacts are counted as the first-order impacts. Higher-order impacts include loss of production due to shifts in resources from usual production activities to reconstruction and rehabilitation activities.

Direct impacts are immediate shocks, triggering indirect impacts, and hence, the economy gets disrupted. This disruption in the economy may be longstanding. Nevertheless, it depends on the severity of the damages, post-disaster response, rehabilitation and reconstruction, and technological change (Panwar and Sen 2019). In some cases, it has been observed that Hydroclimatic extremes increase economic growth in the long run. This could be possible due to rehabilitation and reconstruction as such efforts help increase economic activity and productivity. Nevertheless, this is also true that ability to take initiatives in rehabilitation and reconstruction works lies with developed countries. Therefore, the possible long-term positive effects of Hydroclimatic extremes appear to be limited to higher-income countries or regions (Goyal et al. 2012).

The growth effects of Hydroclimatic extremes vary from disaster to disaster (Panwar and Sen 2019). For example, floods positively impact and increase economic growth through increases agriculture production. Though flood damage crops grown during its occurrence, it helps increase in both ground and surface water, which further help irrigate crops in the following seasons and reduce irrigation costs (Goyal and Ojha 2011). However, the growth effects of floods are found to be more profound in the countries where the agriculture sector plays a predominant role in the economy. On the other hand, droughts have negative impacts (Shivam and Sarma 2017). Likewise, different sectors respond differently to Hydroclimatic extremes

(Panwar and Sen 2019). Since agriculture is a biological product and is highly dependent on nature, the agriculture sector appears to be more vulnerable to Hydroclimatic extremes than the other sectors (service and manufacturing).

Some recent studies (Parida et al. 2021; Parida 2020; Parida and Dash 2020; Panwar and Sen 2019; and Amarasinghe et al. 2020) have confirmed that negative impacts of Hydroclimatic extremes are more intense at the sub-national level than the national level. Parida et al. (2021) endorse that states in India experience lower economic growth due to higher food impacts. Parida (2020) estimated the average flood impact in 19 Indian states and confirmed that some states with a low level of economic development are more vulnerable compared to other states in terms of flood fatalities. Parida and Dash (2020) discussed different channels through which floods affect economic growth adversely. These channels are damage to physical and human capital, higher dependency on the agriculture sector, which is highly vulnerable to Hydroclimatic extremes, employment losses and fall in wages, and fiscal burden due to the adoption of flood prevention and mitigation measures. Parida and Dash (2020) and Panwar and Sen (2019) highlighted that states with a higher level of financial and human development show more resilient to floods and droughts compared to other states that are poor in terms of both financial and human development.

4.1.1 Objective of the Present Study

Considering the above ambiguity of relation between hydroclimatic extremes and economic growth, this paper made a reattempt to explore the above relationship. To accomplish this objective, the impacts of Hydroclimatic extremes on Indian economy were studied at the macro, meso, and micro levels. First, the relationship between the occurrence of Hydroclimatic extremes and economic growth at the aggregate country level is examined using time series data for a period from 1970 to 2019–2020, and then, the same relationship is assessed at the state level using a balanced panel of 28 States for the period from 1997–1998 to 2015–2016. Further, impacts of Hydroclimatic extremes are studied in detail at the micro-level using household information collected from 16 villages in two districts (Khagaria and Saharsa) of Bihar state.

4.2 Observations at National and Sub-National Levels

To evaluate economic impacts of Hydroclimatic extremes, the study conducted both time series and panel data analysis at national and sub-national levels. Gross Domestic Products (GDP) and Value of agricultural output are considered here in order to examine the economic impacts of Hydroclimatic extremes. At the country-level, time series analysis is estimated, while at the state level, panel data analysis is used. Data on GDP and agricultural output value are collected from the Economic Survey of India. In order to understand the behaviour of Hydroclimatic extremes, rainfall data are taken. Information on rainfall were collected from the India Meteorological Department. The period considered for analysis is from 1970 to 2019 for national-level analysis, while the period from 1997 to 2016 is considered for state-level analysis. This is because the Directorate of Economics and Statistics provides data for the agricultural value of output from 1997 onwards and the IMD provides rainfall data till 2016. To make a balanced panel, only 21 states could be taken due to the availability of rainfall data for these states. State-specific dummies are generated for these 21 states for the panel and time trend for 19 years creating 420 observations. The natural hazards are further calculated from the amount of rainfall in a particular year based on rainfall deviation from a 30-year average. A 10% rise and fall from the mean deviation of the mean are denoted as surplus/flood and deficit/drought, respectively. These occurrences of natural hazards are then denoted by dummies and the average of these events in a particular year are denoted as extreme events.

The study examined the effects of floods and droughts on the growth rate of real GDP and agricultural output at the country level using Ordinary least square, whereas the fixed effect model was used at the state level. Results are presented in Tables 4.1 and 4.2.

Results suggest adverse effects of hydroclimate events on economic growth at both national (Table 4.1) and sub-national levels (Table 4.2). Extreme events such as floods, droughts, etc. damage human and physical capitals, and these shocks disrupt the production process. Hence, the GDP gets affected adversely by Hydroclimate extremes. Such adverse effects may either cause a permanent departure in the economic growth of an economy from its normal path (Panwar and Sen 2019) or create a new normal and lower growth path for an economy (Cavallo et al. 2013). However, both the realization of the above cascading effects and recovery depend on the intensity of shocks, the fiscal strength of an economy, and an effective disaster risk reduction plan. In a recent study, Panwar and Sen (2019) observed that the GDP might take up to five years following a flood event to achieve its normal growth trajectory. We further compared outcome variables (GDP and agricultural output value) between two types of states. One is highly vulnerable, and the other is lowlily vulnerable to hydroclimatic events. Bihar, Assam, West Bengal, Jharkhand, Rajasthan, Maharashtra, Madhya Pradesh, Odisha, Tamil Nadu, and Andhra Pradesh are found to be highly vulnerable to hydroclimatic events as these states are highly prone to any of these natural disasters - flood, drought, and cyclone. We found that states with high vulnerability to hydroclimatic events are mainly dependent on the agricultural sector. Since the agriculture sector is highly dependent on weather, any occurrence of hydroclimatic events harms these economies severely. This is further strengthened by the fact that the gross domestic product of such states are much lower than the other group of states (Fig. 4.1).

Table 4.1 Estimates of regression analysis at national levels

Variables	Log of agricultural GDP	t-stats	Log of GDP	t-stats
Parameters				
One year lag of GDP			1.038	31.25
One year lag of agricultural GDP	0.65	7.10		
Extreme event	−0.04	−3.61	−0.03	−2.25
Time trend	0.00	3.67	−0.00	−0.53
Intercept	4.31	3.72	−0.44	−1.09
Model summary				
Number of obs	66		66	
R-squared	0.99		0.99	
Adj R-squared	0.99		0.99	
Durbin	3.76		1.14	

Note: Time trend is included as explanatory variable in regression analysis to control the effect of technologial change and other progress on output variables

Table 4.2 Estimates of regression analysis at sub-national levels

Variables	Log of agricultural GDP	Z	Log of GDP	Z
Parameters				
One year lag of GDP			0.72	17.09
One year lag of agricultural GDP	0.68	10.5		
Extreme event	−0.01	−5.1	−0.02	−3.51
Time trend	0.01	5.29	0.01	7.28
Intercept	3.06	4.79	2.85	6.6
Model summary				
Number of obs	378		378	
Number of groups	21		21	
Number of instruments	174		174	
Wald chi2(3)	867.97		15683.17	
Prob > chi2	0		0	

Note: Time trend is included as explanatory variable in regression analysis to control the effect of technologial change and other progress on output variables

4.3 Evidence from Vulnerable Households

To understand disaster impacts at household level, 240 households, including landed cultivators, landless farmers, agriculture labours, and non-farm workers, were chosen from two districts of Bihar – Khagaria, and Saharsa. These districts see floods almost every year. Floods data were analyzed for these two districts for years from 2001 and 2010. It observed that people in Saharsa encountered floods in all ten years and those of Khagaria suffered from floods in all years except for 2006. As per data released by the Government of Bihar, six administrative blocks in Khagaria and five blocks in Saharsa are identified as the most frequently flood-affected as these blocks

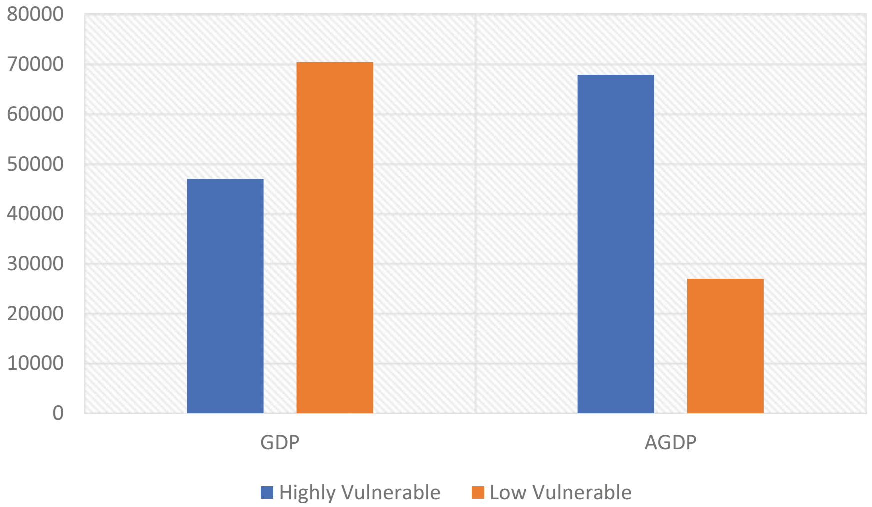

Fig. 4.1 Comparison of GDP and value of agriculture output between highly and low vulnerable states. (*Source:* Authors' own calculation using information collected from Ministry of Statistics and Programme Implementation, Government of India, New Delhi)

have faced floods more than 16 times in the last 27 years. These districts are in the northern part of Bihar, which is highly vulnerable to floods. The Kosi river and its tributaries flow through this region and are mainly responsible for the frequent flooding in the region. In additon, frequent flooding in the region caused severe problems such as prolonged water logging and siltation. The Kosi river and its tributaries transport high sediment loads eroded from mountains upstream, and these transported sediments are finally deposited in North Bihar.

Sample households were chosen randomly following a multi-stage sampling procedure. Khagaria district is divided into seven administrative blocks, and Saharsa in ten blocks. Four blocks were chosen from each sample district based on proximity to the Kosi river, and two villages were selected from each chosen block. Village selection was also made on the basis of proximity to the river. The equal number of households were chosen for the survey from both the chosen districts. 25% of sample households in Saharsa and 9% in Khagaria are headed by female. 55% and 78% of sample households in Saharsa and Khagaria respectively belong to other backward caste. 14% of chosen households in Saharsa and 6% in Khagaria come from scheduled caste communities. Structured questionnaire was used to collect information from sample households, and information were collected on different aspects of social and economic development. Key observations are discussed in the following sub-heads.

4.3.1 Poor Infrastructure Development

Each chosen village in both the above districts had the facilities of primary schools, anganwadis (Rural Child Care Centre in India), and government Ration shops. In seven chosen villages, middle-level school was also found. Except for a few cases, sample villages lack public health facilities. Electricity and Telephone (Mobile) was available not to all households nor for 24 h. Hand pumps were the most common source of drinking water. However, the quality of water was not always good. Limited sample households have a gas (LPG) connection. Cow dung and crop residue were found in all sample villages as the main sources of cooking fuel. Barring a few villages, most sample villages are not accessible to paved roads.

4.3.2 Agriculture Is the Main Occupation

Cultivation was found to be the main source of occupation in all sample villages. Working population in the sample households were found engaged in agriculture either as cultivator or as agriculture labour. However, the proportion of agriculture labour was observed significantly higher than that of the cultivators. Despite the country’s lofty land reforms programmes, agriculture in these villages was noted suffering from skewed landownership. Few farmers have large sized holding varying from 50 Bigha to 100 Bigha (1 Bigha = 0.25 ha) while a large number of farmers have very small sized, even less than one Bigha, of land holding.

A significant number of sharecroppers were observed to be operative in the villages we visited indicating that the majority of landlords owning the farm lands in these villages do not want to do cultivation on their own. Such a situation is known to create poor incentive to increase productivity. Those who own the land and have the capacity to invest are little interested in doing so while those who have considerable interest in investing in agriculture lack in rights, security and capacity. This skewed landownership is one of the most important reasons of low productivity in agriculture in the Koshi river basin apart from extreme climate events. Thus, numerical dominance of farm labour, the skewed land distribution and the tenurial practices all suggest inequalities and the lack of access to land that discourage agricultural progress. The yield rates of the leading crops (i.e. Rice, Wheat, and, Rapeseed & Mustard) is lower in this region in relation to other parts of the country, even while the soil quality is much better in this region compared to many other regions (see Fig. 4.2). Land reform has been a great challenge for the government in entire Bihar state, not only in the Kosi river basin. Political influence of landlords is mainly responsible for poor implementation of land reform policy in the state. Even, the present state government headed by Mr. Nitish Kumar constituted a committee on land reform in 2006 which has submitted its report on April 2008 with some recommendations. But, the state government has not taken any action, till today after

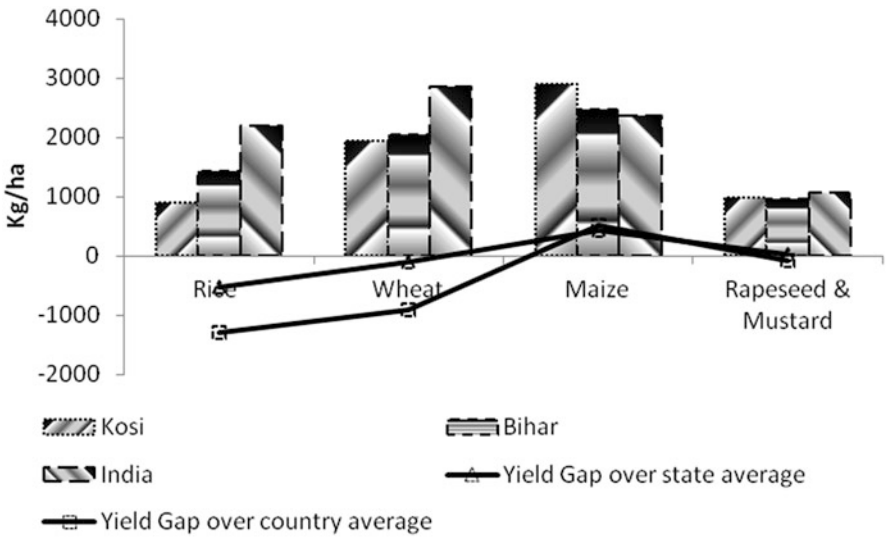

Fig. 4.2 Yield and yield gap of selected crops. (*Source*: Authors' own calculation using information collected from Department of Agriculture and Cooperation. Ministry of Agriculture and Farmers' Welfare, Government of India, New Delhi)

12 years. Even for a government that claims itself as development oriented the lack of political will in this matter is implicit.

Cropping pattern in the sample villages was found mainly dominated by food crops – rice, wheat and maize. However, these crops except for maize were found highly vulnerable to flood. Mostly, flood occurred during the Kharif season and damaged Kharif rice. Farmers in sample villages clearly showed their reluctance to grow rice or other crops in the kharif season for fear of flood. We also learnt that poor drainage leading to water-logging owing to monsoon rains prevented sowing of rabi crops in some of sample villages.

4.3.3 Disaster-Induced Migration

Migration is seen as a sign of distress when there is a natural calamity. It is also considered as adaptation strategy to cope with adverse effects of Hydroclimatic extremes. Several existing studies (Gray 2009; Mueller et al. 2014; Dallmann and Millock 2017 and many more) reported increase in outmigration due to hydroclimatic extremes. In each of the sample villages, outmigration was found highly prevalent in sample households. 52% of the households in Saharsa and 62% in Khagaria experienced outmigration in their family. As is discussed in the previous sub-section, the majority of people residing in sample villages engaged in farming activities for their livelihood. These activities are highly dependent on weather;

hence any change in weather or occurrence of extreme hydroclimate events affect agriculture production directly, causing to household livelihood loss. Therefore, people living in these locations tend to migrate to other places to minimize the above loss. This pattern was found prevalent in the study region too. Most of the migrants were migrated for work to earn and their share is about 85% in sample chosen for the purpose of the current study. Many migrant workers went to work outside the state. Inter-state migrant workers who went to other states make up 86% of the total number of migrant workers in Saharsa and 80% in Khagaria. The situation appeared to be depressed when we came to know that the majority of migrants were working as migrant labour. This clearly confirms that push factors (*e.g.* natural disaster, poverty, unemployment etc.) are responsible for outmigration in sample districts.

4.3.4 Loss in Cropped Land

Sample households in all chosen villages reported a significant loss in the cropped land due to waterlogging and siltation problems. In both sample districts, loss in the cropland was estimated at 0.76 ha per household in Saharsa and 0.47 ha in Khagaria. Waterlogging and siltation are very common in the chosen districts, caused by the frequent flooding in the districts. Flood is considered as a major problem in the Koshi river basin due to the dynamic nature of the river. The Koshi River frequently changes its course and transports high sediment loads eroded from mountains upstream. All transported sediments are finally deposited in the plains, which partially lie in Terai Nepal and partially in North Bihar in India. The downstream part, therefore, faces a significant issue of siltation with intense implications for agriculture. This silt is a mixture of both sand and clay. The villagers also pointed out that silt deposition in farmlands significantly reduces crop productivity. The extent of the decline in crop productivity depends on the thickness of deposition. In order to calibrate the perception-based implication, we further interviewed a soil scientist working in Krishi Vigyan Kendra, Madhepura district. According to him, the deposition of silt initially has an adverse effect on crop productivity by undermining the balance in the soil's organic content and by reducing the water-retaining (holding) capacity of soil. But, in the longer run, this adverse impact turns to positive. The long-run waiting period may be five to ten years, depending on the location of the farm and the thickness of silt deposition.

4.4 Conclusions and Policy Implications

This study revisited the relationship between Hydroclimatic extremes and economic growth. Focussing on the Indian economy, the above relationship has been explored across different levels- national, sub-national, and local, to see if there is a difference in the above relationship across these three levels. This study reported a negative impact of hydroclimatic events on economic growth, and this observation was found consistent across the above three levels. The study further confirmed that the above negative relationship was observed through different channels. *One,* hydroclimatic extremes damage both human and physical capitals adversely, and these damages disrupt economic growth by harming the production process. *Two,* the agriculture sector provides livelihood supports to most citizens residing in vulnerable regions. On the other hand, it is highly dependent on the weather. Hence hydroclimatic extremes increase livelihood insecurity and outmigration particularly in males, leaving women and children behind. These further increases the deficit in skilled labour and thus harms production activities performed in vulnerable regions, calling for immediate actions from the government.

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Part II
Tools and Techniques

Chapter 5
Remote Sensing Applications in Drought Monitoring and Prediction

Ashutosh Sharma, Vijaykumar Bejagam, and Manish Kumar Goyal

Abstract Drought is a frequently occurring hydrometeorological event, which is defined as a reduction in water availability in different hydrologic elements. Over the last century, the hydrologists around the world have put substantial efforts to improve the monitoring and prediction of droughts through the development of new drought indices and prediction models. However, the scarcity of site-based observations has constrained these efforts to date. Remote sensing has emerged as an alternative to supplement these observations and has enabled the progress in drought studies in data-scarce parts of the world. This chapter describes the applicability of remote sensing in evaluation and assessment of drought (i.e., meteorological, agricultural, and hydrological). We also discuss the limitations associated with remote sensing applications (resolution, continuity, and uncertainty) and future perspectives. Further, a case study on remote sensing application in assessment of drought impact on Net Primary Production (NPP) in India is also presented, which highlights the importance of remote sensing in providing information of ecohydrological variables that are difficult to monitor on ground.

Keywords Droughts · GIS · Net primary production · Remote sensing

5.1 Introduction

Droughts are undoubtedly one of the most catastrophic hydroclimatic events that occur around the globe every year. In general, drought is defined as an event of lesser availability of water resources to meet the environment, human or industrial demands over a significantly extended period, such as months, seasons, or longer

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(Wilhite 2000). There is general perception that droughts occur only in the regions of low precipitation (i.e., arid climate); however, aridity (long term dryness) and droughts (short term dryness) are two different phenomena. Former is a permanent climatic characteristic of a place having less long-term rainfall, whereas the latter is a temporary condition of significantly low rainfall compared to normal. Therefore, droughts are not limited to arid climates but occur in all climates, including low and high rainfall receiving regions of the world. Drought modeling and prediction is highly sophisticated as the drought occurrence and propagation depends on many natural and human factors.

Droughts have a profound impact on different human-natural systems such as fresh water ecosystems, agriculture, ecosystem services, ecology, hydropower, and food production (Carrão et al. 2016). Multiple drought occurrences in recent decades have underlined the exposure and vulnerability of all communities to this natural disaster. Drought has an economic, environmental, and social impact on human-natural systems. The growth of population and increase in need for resources have led to exponential growth of agricultural, energy and industrial sectors. These sectors have become the primary consumers of freshwater causing the issue of water scarcity. Due to the long-lasting socioeconomic impacts of droughts, these extreme events are believed as one of the most destructive natural disasters (NCDC 2015; Wilhite et al. 2014). Every year, extreme drought events occur in different parts of the world causing different regional issues. The developed nations generally suffer from economic and ecological disruptions, whereas in developing nations, droughts have profound impact on food availability. The drought management approach adopted by most of the countries is still reactive, i.e., to address the issue after it has already impacted (Carrão et al. 2016; Wilhite et al. 2014). However, it is seen that this method is not very efficient in preventing the losses due to these events. The socioeconomic impacts of droughts have significantly increased in the recent years. For example, on an average, a droughts event in United States causes about $6–8 billion loss (NCDC 2015). India has experienced 12 major famines between 1765 and 1947 resulting in death of millions (Mishra et al. 2019). Failure of summer monsoon rainfall remains the primary cause of most of the events, which caused extreme dry conditions resulting in widespread crop failure. Mishra and Singh (2010) also reported that India has experienced a drought event at least once in every 3 years in the last five decades. In addition, there is a substantial evidence on global climate change influence in the dynamics of droughts (Cook et al. 2018; Trenberth et al. 2014). For example, Trenberth et al. (2014) reported that the rise in temperature due to global warming had led to alteration in characteristics of droughts such as frequency and intensity of droughts. Similarly, based on the projections of climate models, Dai (2011) reported increase in aridity in various regions of the world over the twenty-first century. Likewise, an ample amount of literature is available indicating the exacerbating climate change impact on droughts.

Considering detrimental impacts of drought on human-natural systems, it is critical to understand and predict the drought dynamics (Mishra and Singh 2011). Mishra and Singh (2011) reviewed the various aspects of drought modeling from simple statistical techniques to complex models. In the recent decades, development of new drought indices has made significant progress, enhancing modeling capability, and improving resolutions. Remote sensing has emerged as a great tool for Earth Observation (EO) and data acquisition (Goyal et al. 2020). Due to its capability of continuous monitoring of larger regions, it has been widely used for management of natural environment and resources. EO has progressed dramatically with expansion in number of satellites and headways in the innovation. Multi-temporal remote sensing can be adequately used to examine and quantify the drought conditions (Tucker and Choudhury 1987). In contrast to other climatic disturbances, droughts have larger spatial extent, which is challenging to monitor using traditional approaches (such as site-based observations), especially in developing countries with inadequate monitoring stations. In such cases, satellite data are helpful in providing fairly accurate drought monitoring and detection (Kogan 1995).

The role of remote sensing in drought monitoring and prediction is discussed in this chapter. The first section gives an outline of the remote sensing and the drought concept. The second section talks about different drought monitoring and prediction methods. The third section discusses the utilization of remote sensing in drought modelling.

5.1.1 Remote Sensing

As per United States Geological Survey (USGS), remote sensing is defined as "the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft)". The satellites or aircraft carries a sensor that measures the energy (electromagnetic waves) that is reflected or emitted from Earth. The characteristics of incoming energy (such as wavelet, intensity) enables the distinction between different features on the surface of Earth. The variation of reflectance or emittance of a surface with respect to wavelengths is called spectral signature, which is an indicative measure of composition of the surface. Differences among spectral signatures is the key to classify different features (such as water, vegetation types, land use, geology) on Earth surface. The major advantage of remote sensing over traditional site-base measurement is that it does not require ground-based stations to monitor an area, which enables a large spatial coverage including the regions without any measuring stations. Further, the repetitive coverage of area by satellites provides information of land surface dynamics. Remote sensing technologies have witnessed phenomenal advancement with a large network of EO satellites, state-of-the-art sensors, and advanced processing tools (Prakash 2000). At present, the remotely sensed information is used in many fields, such as hydrology, geography, agriculture, atmospheric science, geology, and natural resources management (Chebud et al. 2012).

5.1.2 Drought Concept

Drought is a slow on-set phenomenon caused by a lack of rainfall, in general classified as: meteorological, agricultural, hydrological, and socioeconomic (Wilhite and Glantz 1985). First three classes of droughts are linked to the physical natural process associated with precipitation, whereas socioeconomic drought links the supply and demand of water for human use. Meteorological drought is characterized based on measure of precipitation, and it represents the period of lesser precipitation compared to long-term average (normal) precipitation at a place or region. Hydrological drought alludes to the decrease in the surface or subsurface water storages/ supply (e.g., streamflow, groundwater, or reservoir water levels). Agriculture drought is the condition of reduced moisture in the top layers of soil to the level that it is not sufficient to support the crops (Kumar et al. 2021; Poonia et al. 2021a, b). Socioeconomic droughts are related with the lack of supply of some economic goods like flood, water, fish, and hydroelectric power to fulfill demands. Socioeconomic droughts largely depend on the demand of the economic goods whose production depends on the water availability. In the recent years, researchers have defined other classes of droughts such as ecological drought, groundwater drought or anthropogenic drought (AghaKouchak et al. 2015b). The ecological drought is characterized by the water stress across the ecosystems due to widespread water deficit. The groundwater drought is the period of fallen groundwater levels such that the fall in level causes substantial water availability issues. Each type of drought start off with a persistent precipitation deficit and the responses of different elements of hydrologic cycles leads to propagation of droughts from one class to another. Figure 5.1 summaries the interaction between different hydrological variables as drought propagates from one class to another. The climate variability results in a period of precipitation deficit, which is generally driven by the natural climate cycles. If the precipitation deficit sustains for some time (over a scale of weeks/ months depending on the climate), it leads to reduction in soil water content, streamflow, and reservoir storages. The water availability is also influence by other climatic variables such as temperature and evapotranspiration. The reduced surface water and soil water adversely affects the food production, hydropower generation and industrial activities leading to socioeconomic droughts. The interactions between these variables in highly complicated because of the intricacies in land surface processes and human influences.

5.2 Drought Monitoring and Prediction

Drought monitoring and prediction is extremely important for drought preparedness, mitigation, and risk management but is challenging due to the complex nature of associated processes and variability at different spatiotemporal scales (Hao et al. 2018).

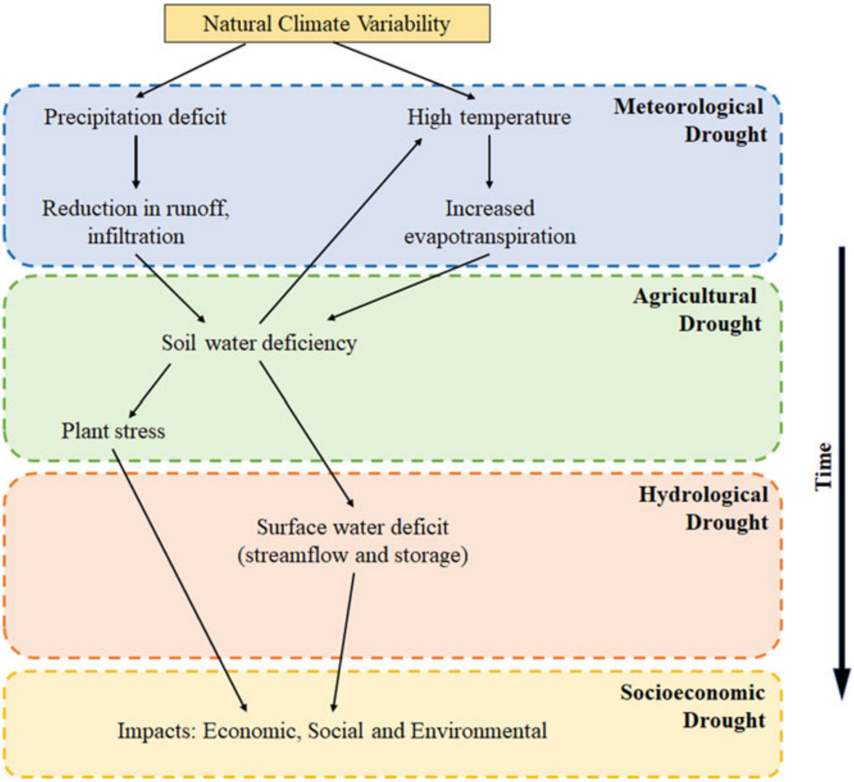

Fig. 5.1 The propagation of drought through the interaction of different hydrologic variables. (Derived from NDMC, University of Nebraska-Lincoln, U.S.A., https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx)

Traditionally, drought monitoring relied on the site-based observations of precipitation and other hydrologic variables such as streamflow, soil moisture, atmospheric evaporative demand and atmospheric water vapor. Drought indices were computed based on these observations to monitor the drought events. However, this approach was limited by the scarcity of observation sites and inconsistencies in the measurements. Secondly, drought assessment requires a long-term time series of hydrological variables (at least precipitation), but in many regions, sufficient observations are not available. During twentieth century, hydrological and climate models were utilized to simulate and predict the hydrological processes resulting in development of gridded products through interpolation of available observations. In the recent decades, the wide availability of remote sensing and earth observation technologies has expanded the drought monitoring capabilities. Remote sensing-based observations of climate and earth's surface have overcome the inadequacy of site measurements.

5.2.1 Drought Prediction Approaches

Generally, three types of approaches are applied for drought prediction: statistical, dynamical, and hybrid approaches (Mishra and Singh 2011).

5.2.1.1 Statistical Approach

The statistical approach establishes an empirical relationship between influencing factors (predictors) and drought conditions (precipitation or drought indices) using the historical records. The predictors include hydroclimatological variables (land, atmosphere, and ocean components) or large-scale climate indices such as Southern Oscillation Index (SOI), Sea Surface Temperature (SST), and El Nino-Southern Oscillation (ENSO). Statistical methods (or data driven methods) such as regression models, time series models, probability models or machine learnings techniques are widely used to build the spatiotemporal relationship between predictors and drought variables.

5.2.1.2 Dynamical Approach

The dynamical approach utilizes the physically based hydrological and/or climate models to simulate the different hydrological process and their relations with atmospheric and ocean processes. These models are generally computationally expensive; however, recent advances in computing has benefitted the research community in utilizing these models. Though there are multiple ways the dynamic approach can be used for drought prediction, a standard way is to calibrate/train a hydrological model using historical observed records of forcings (climate inputs) and target (streamflow or soil moisture), and then run the trained model with climate forecasts obtained from climate models (General Circulation Models, GCMs). The outputs of GCMs generally have coarse resolution and have large uncertainty associated. These issues are handled with pre- or post-processing methods such as downscaling, ensemble generation, etc. If the dynamical climate predictions are not available, there is another way of making dynamical predictions. Hydrological model can be initiated based on real-time observed Initial Hydrological Conditions (IHC) and driven with historical meteorological data.

5.2.1.3 Hybrid Approach

The hybrid approach (statistical-dynamical) combines both statistical and dynamical methods. This approach generally uses the large-scale climate information from GCMs as predictors (dynamic approach) and establishes statistical relationships between these predictors and drought indices (statistical approach).

Hybrid approach has many advantages such as:

1. These are highly computationally efficient.
2. These can integrate a wide range of inputs (e.g., GCM outputs, large scale climate indices, climate teleconnections, etc.)
3. These utilize the state-of-art statistical and machine learning tools.

5.3 Remote Sensing in Drought Monitoring and Prediction

The evolutions in remote sensing have presented a variety of tools and datasets for estimation of climate parameters (e.g., precipitation and atmospheric water), surface water, and vegetation parameters, which have revolutionized the drought monitoring capabilities (Dahdouh-Guebas 2002). The critical drought-related information is now available at higher temporal and spatial resolutions around the globe, which has enabled the accurate prediction of drought events even in the 'data-poor regions', especially in the developing world (West et al. 2019). At present, satellite- based remote sensing has been extensively applied to observe the drought related climate variables and to quantity the impact on different natural systems such as terrestrial ecosystems. The multispectral, thermal infrared, or microwave information available from satellites has been utilized to estimate the hydrologic variables. These variables are then transformed into drought indices that enable the comparison of real-time information with long-term normal conditions to quantify the drought severity.

The satellite-based monitoring of droughts offers multiple advantages:

- The global coverage of the satellites provides information on data-scarce regions.
- Higher spatial resolution of satellites drives climate information compared to site-based measurements.
- Near-real time information is available from satellites.
- The satellite observation of consistent over the globe, whereas the site-based observations suffer for inconsistencies.
- Availability of large amount of data from remote sensing on multiple parameters has enable the development of new drought indicators.

In the next sections, the application of remote sensing in observation of hydroclimatic variables is discussed.

5.3.1 Precipitation

Precipitation is the most important hydrologic input for any drought assessment as all types of drought begins with sustained deficit of precipitation. Meteorological drought is defined based a long-term significant negative deviation from normal precipitation at a place. These conditions usually occur over a short timescale such as days/weeks, and sometimes may elongate to months/seasons. Ground based

Table 5.1 Widely used satellited-based precipitation products

Product name	Product description	Reference
TRMM – TMPA	Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA)	Huffman et al. (2007)
CMORPH	Climate Prediction Center (CPC) Morphing technique	Joyce et al. (2004, 2010)
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station	Funk et al. (2015)
PERSIANN-CDR	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record	Ashouri et al. (2015)
MSWEP	Multi Source Weighted Ensemble Precipitation	Beck et al. (2017)

measurements of precipitation have been employed to calculate the drought indices, but the satellite-based precipitation products have provided continuous records over larger regions (Thiemig et al. 2012). In the recent decades, several quantitative precipitation estimate products (QPEs) were released that provided global/sub-global daily/sub-daily estimates of precipitation. Some of the remotely sensed satellite-based precipitation products that are mostly used are listed in Table 5.1. TRMM has been extensively utilized to assess the global precipitation and drought patterns (Levina et al. 2016; Naumann et al. 2012; Sahoo et al. 2015; Yaduvanshi et al. 2015; Zhong et al. 2019). Multiple investigations were performed in different areas of the world to assess the accuracy of TRMM and GPM precipitation products (Behrangi et al. 2011; Meng et al. 2014; Sahoo et al. 2015; Thiemig et al. 2012; Ward et al. 2011; Zhang et al. 2019).

The standard approach is to use the satellite-based remote sensed precipitation to compute precipitation anomalies or drought indices. Among many other indices available in the literature, SPI is extensively used and it is suggested by World Meteorological Organization (WMO) (Mckee et al. 1993). Only precipitation data is required for computing SPI, which makes it highly efficient in the 'data-scarce' regions also. SPI can be used to study different drought classes by selecting different timescales (e.g., 1, 3, or 6 months). In addition, satellite precipitation has also been used in different types of modelling-based drought assessment studies (Anderson et al. 2007; Damberg and AghaKouchak 2014; Naumann et al. 2012; Sheffield et al. 2012; Yaduvanshi et al. 2015). For example, Aghakouchak and Nakhjiri (2012) developed a long-term climate dataset of droughts by combining the high spatial resolution satellite-based precipitation with low-resolution gauge-adjusted data. Zhou et al. (2014) assessed the consistency of TMPA-RT and TMPA-RP datasets for drought nowcasting and reported that both products were consistent over 75% of land cells. Sahoo et al. (2015) analyzed the TRMM precipitation products for large-scale meteorological drought analysis using SPI drought indicator and concluded that these products are reliable in detecting the spatiotemporal characteristics of most of the major drought events. Zhong et al. (2019) compared two long-term remotely sensed precipitation products (CHIRPS and PERSIANN-CDR) and one short-term

(TMPA) remotely sensed precipitation product using SPI and PDSI over China. The performance of all three products was satisfactory in densely gaged eastern parts, whereas their performances could not be determined in sparsely gaged western parts.

5.3.2 *Soil Moisture*

Another important variables in drought monitoring is soil moisture, which is widely used to determine the agricultural drought conditions (also known as soil moisture drought) (D'Odorico et al. 2007; Narasimhan and Srinivasan 2005; Western et al. 2002). Persistent meteorological drought conditions over a long-time scale result in the reduction of water in the top layers of soil, which further affects the crop yield. Like precipitation-based drought indices, several soil moisture-based indicators have been developed for consistent quantification of soil moisture deficit. These indices include soil moisture percentile (Sheffield et al. 2004), Evapotranspiration Deficit Index (ETDI) (Narasimhan and Srinivasan 2005), Soil Water Deficit Index (SWDI), Standardized Soil Moisture Index (SSI) (Hao and Aghakouchak 2014) and Soil Moisture Drought Index (SODI) (Sohrabi et al. 2015). The computation of these indices required a record of soil moisture, which could either be site-based observations or estimates from satellite products or land surface model simulations.

The satellite-based observation of soil moisture is achieved through microwave active (radar) and passive (radiometers) remote sensing (Njoku and Entekhabi 1996; Wang and Qu 2009). Historically, the optical and thermal infrared radiation were also utilized for remotely sensing the amount of moisture present in soil based on the soil reflection and surface temperature, but these techniques were not efficient due to their limited surface penetration and large atmospheric noise. The microwave radiation with larger wavelength can penetrate the top layer of soil to sense the amount of moisture with less atmospheric noise; however, these generally have coarse resolutions. It should be noted that these sensors directly does not measure the soil moisture, it measures by relying on relationship between measured signal and soil moisture (Wang and Qu 2009). The recent developments have shown that both active and passive microwave remote sensing are highly efficient in monitoring the soil moisture variations. Wang and Qu (2009) and Kim et al. (2019) have presented a comprehensive review of different techniques of monitoring and predicting soil moisture using remote sensing. The microwave remote sensing based soil moisture started with scanning Multichannel Microwave Radiometer (SMMR). Over last few decades, many products were developed including Multi-frequency Scanning Microwave Radiometer (MSMR) (since 1999), Advanced Microwave Scanning Radiometer (AMSR-E) (since 2002), Microwave Radiation Imager (MWRI) (since 2008), Advanced Scatterometer (ASCAT) (since 2007) Soil Moisture and Ocean Salinity (SMOS) (since 2009), European Space Agency-Climate Change Initiative (ESA-CCI) (since 2012) and, Soil Moisture Active Passive (SMAP) (since 2015). Bolten et al. (2010) evaluated the soil moisture retrieved from AMSR-E by integrating it with USDA modified Palmer soil moisture model to monitor the agricultural droughts. Their study concluded that the soil moisture data from AMSR-E provided near real time root-zone soil water values in data scarce regions for drought applications. Martínez-Fernández et al. (2016) calculated SWDI using the SMOS L2 soil moisture data in network of *in-situ* soil moisture stations (REMEDHUS) in Spain and compared with *in situ* data. Their comparison suggested that the SWDI derived from SMOS represents well the dynamics of soil water balance and could be used for monitoring the agricultural droughts. Ford and Quiring (2019) performed drought monitoring using *in situ data*, model-based and remote sensing-based (ESA-CCI, SMAP, SMOS) soil moisture. The study found that SMAP-L3 product was able to identify the *in-situ* ground-based soil moisture variation and could effectively detect the drought conditions.

5.3.3 Evapotranspiration

Generally, drought is defined in terms of precipitation; however, evapotranspiration (ET) plays a major role in drought evolution. It is often assumed that as the soil dries during the drought conditions, the ET also decreases with reduction in soil moisture. However, studies have shown that ET is not much influenced by soil moisture, rather by atmospheric conditions, during the most of available soil moisture range (Teuling et al. 2013). Teuling et al. (2013) pointed out that ET played an important role in amplifying the European summer drought. Increasing ET is the crucial factor in meteorological and agricultural droughts. Considering the importance of ET in drought, several drought indices were developed using ET as an input including Crop Water Stress Index (CWSI) (Idso et al. 1981; Jackson et al. 1981, 1988), Evaporative Drought Index (EDI) (Yao et al. 2010), Water Deficit Index (WDI) (Moran et al. 2004), Reconnaissance Drought Index (RDI) (Tsakiris et al. 2007; Tsakiris and Vangelis 2005), and Evaporative Stress Index (ESI) (Anderson et al. 2011a, b).

Like other hydrologic variables, site observations of ET are also scarce. Empirical and conceptual models are generally used to estimate the ET, which requires many inputs on vegetation types, soil conditions and climate. In the recent decades, Inputs that are required in ET models are estimated and prepared using remote sensing products. For example, the Moderate Resolution Imaging Spectroradiometer (MODIS) Global Evapotranspiration Project (MOD16) estimates the global terrestrial evapotranspiration from earth land surface using Penman-Monteith equation (Mu et al. 2007, 2011). Different inputs to MOD16 model, such as land use, albedo, fraction of photosynthetically active radiation (FPAR), radiation and temperature, are obtained from MODIS satellite. Global Land Evaporation Amsterdam Model (GLEAM) is another widely used terrestrial evaporation and soil moisture product that has gone a few revisions (Martens et al. 2017; Miralles et al. 2011, 2014). GLEAM is the only global scale evaporation product that derives ET based on remote sensing data only. It uses climate and land information from different sensors using MODIS. For further details, Zhang et al. (2016) have presented a comprehensive review on estimation of ET using remote sensing.

5.3.4 Surface Water

The hydrological drought is quantified based on availability of surface water sources such as streamflow, water storage in lakes and reservoirs, etc. Remote sensing can be used to map these water resources (e.g., lakes, reservoirs, rivers, and wetlands) using the spectral signals. Lakes and reservoir are the predominant factors in regional water balance (Gleason and Smith 2014; Wood et al. 2011). The water area changes, and water level dynamics of these water bodies can be monitored from space. In the last decade, many advanced sensors were launched to monitor the surface water, including the Gaofen satellite series from China High-resolution Earth Observation System (CHEOS), Joint Polar Satellite System (JPSS), Copernicus sentinel mission program, and Cubesat Constellations of Planet Labs.[1] The Surface Water and Ocean Topography (SWOT) mission (Durand et al. 2010a), planned to be launched in 2021, works on Ka-band radar interferometer (KaRIN) and plans to deliver a key improvement in the availability of information on spatial extent and storage change of surface water bodies such as rivers, reservoirs, lakes, and wetlands, globally. Durand et al. (2010b) evaluated the river discharge estimates that would be obtained from SWOT mission over the Ohio river. Their evaluation found a fair agreement between SWOT-derived discharge and measured discharge. Gao et al. (2012) estimated the surface water storage of 34 global reservoirs using MODIS vegetation product. Their study found that the storage estimates agreed with the observations. The accurate estimation of streamflow or surface water storage can be used for monitoring the hydrologic droughts in ungagged catchments.

5.3.5 Ground Water

Groundwater is an important element of hydrologic cycle. It acts as an alternative source of water during the period of surface-water drought (or hydrological drought). The groundwater level may decrease during the drought period or due to the excessive pumping of groundwater. Changes in groundwater level can affect the water quality and may result in land subsidence in some cases. Therefore, from hydrologic perspective, it is essential to monitor the groundwater levels. Traditionally, groundwater is measured via network of wells, which are used to observe the depth of water table. Groundwater drought conditions can be identified or monitored by comparing the well observations with long-term historical records. Like other

[1] https://eos.org/editors-vox/seeing-surface-water-from-space

hydrologic variables, the problem in monitoring groundwater levels is the scarcity of well and inconsistencies in well observations.

Launched in 2002, Gravity Recovery and Climate Experiment (GRACE) mission provided a remote sensing-based estimates of groundwater and Terrestrial Water Storage (TWS) (Rodell and Famiglietti 2002; Tapley et al. 2004). It was first remote sensing satellite capable of providing the estimates of variations in TWS (i.e., sum of snow, surface water, groundwater, and soil moisture). The fundamental principle use in GRACE is to estimate the effect of varying gravity fields (due to different weights of saturated and dry ground) on a pair of satellites. Interannual changes in ground water storage around the world were effectively estimated using GRACE data (Frappart and Ramillien 2018). GRACE was used to examine the drought conditions during 2011 Texas drought (Long et al. 2013), in California (Thomas et al. 2017), in India (Shah and Mishra 2020; Sinha et al. 2017), 2005 drought in Amazon river (Chen et al. 2009), in Southeast Australia (Leblanc et al. 2009), and in China (Cao et al. 2015; Sun et al. 2018).

5.3.6 Vegetation

Drought-induced soil moisture deficit result in decline in vegetation productivity (Chen et al. 2013; Xu et al. 2019). This gives an opportunity to monitor the drought by observing the vegetation growth, vigour, and health. Several vegetation indices have been developed to analyse the response of vegetation to droughts, including Ratio Vegetation Index (RVI) (Jordan 1969), Difference Vegetation Index (DVI) (Richardson and Wiegand 1977), Perpendicular Vegetation Index (PVI), Normalized Difference Vegetation Index (NDVI) (Hasegawa 1976), Atmospherically Resistant Vegetation Index (ARVI) (Kaufman and Tanré 1992), and Enhanced Vegetation Index (EVI) (Liu and Huete 1995). A comprehensive review of different vegetation indices is presented in (Mulla 2013; Xue and Su 2017).

Most of these indices are calculated using the remote sensing-based information on reflectance from vegetation in different wavelength regions of spectrum. For example, NDVI, the most widely used vegetation index, is calculated based on the reflectance in near-infrared (NIR) and red (R) wavelengths of the electromagnetic spectrum (Tucker 1979). It is computed as:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \tag{5.1}$$

where NIR and R denotes the reflectance in near-infrared and red bands, respectively. NDVI can differentiates vegetation and other land cover and can also provide information in the vegetation health. There are multiple indices derived from NDVI such as Standardized Vegetation Index (SVI) that are used for drought monitoring (Peters et al. 2002). SVI is a standardized index (like SPI) that quantifies the deviation in vegetation health from long-term "normal". Advanced Very

High-Resolution Radiometer (AVHRR), launched in 1979, provided the first satellite-based global scale mapping of vegetation through NDVI (Tucker et al. 1985). AVHRR- based NDVI products were popularly used to monitor the terrestrial vegetation dynamics and droughts around the world (Bala et al. 2013; Pinzon and Tucker 2014; Singh et al. 2019; Wang et al. 2005). After AVHRR, different high resolution and hyperspectral sensors have been used to compute NDVI or other vegetation indices. For example, MODIS based NDVI and EVI data are available from NASA (Huete et al. 1994).

In addition to these vegetation indices, primary productivity of terrestrial ecosystems can also computed using remote sensing satellite data (Running 1990). AVHRR and MODIS have been popularly used to estimate the Gross/Net Primary Production (GPP/NPP) (Turner et al. 2006; Wang et al. 2018; Zhao et al. 2005). The MOD17 algorithm, which is based on radiation use efficiency method, is used to estimated GPP/NPP (Monteith 1972). It is assumed that the well-watered and fertilized vegetation's productivity has a linear relation with the APAR (Absorbed Photosynthetically Active Radiation) and the actual productivity is estimated using a conversion efficiency parameter (ε), which is a function of climate and vegetation types. The user guide describes the details of MOD17 algorithm. Drought events affect the terrestrial primary productivity. From remote sensing based dataset, it was found that a large-scale drought during 2000–2009 resulted in the reduction in NPP (Zhao and Running 2010). Rainfall deficit and extreme summer heat in Europe in 2003 resulted into reduction in GPP (Ciais et al. 2005). Likewise, several studies were carried out to assess impact of droughts through remote sensing based estimates of NPP/GPP (Cao and Woodward 1998; Sharma and Goyal 2018a, b).

5.4 Challenges and Future Perspectives

As discussed in the above parts of this chapter, remote sensing has provided several tools for drought assessment and prediction. The remote sensing products are improving every year with the launch of new satellites and sensors and development of new methods. In spite of these vast technological advancements, there are numerous challenges with the applications of these tools for drought assessment such as:

- *Data continuity:* The drought assessment is generally carried out with respect to a long-term baseline, which requires considerable time series of observations. However, most satellite products are not for short durations (less than a decade).
- *Data consistency:* To perform a long-term study, it is inevitable to use data from multiple satellites. Different satellites generally carry different sensors and therefore their observations could be biased.
- *Uncertainly:* Using data from multiple sources (sensors or products) brings significant uncertainty in the drought monitoring. Therefore, it is essential to evaluate the uncertainty incorporated with remotely sensed satellite-based production before using these for any applications.

- *Resolutions:* The remote sensing datasets have fixed resolution (spatial, spectral, and temporal). For example, the active and passive remote sensing-based products have lower spatial resolutions, which limits their applications in fields like agriculture. There always a trade-off between the spectral and spatial resolutions of satellite products.

The advancements in sensor technology is ongoing with the launch of new sensors/ satellites that provide greater insight into the hydrological process and their connections to carbon cycle. These new technologies provide opportunity to hydrologists to develop tools (such as new drought indices) for efficient monitoring of droughts. AghaKouchak et al. (2015a) pointed out that most of the current drought indicators are designed to effectivity assess the connection between droughts and carbon (and nitrogen) cycles. These cycles are closely linked to droughts and the affects the functioning of natural vegetations and ecosystems. Several present satellite products (such as MODIS) provides the opportunity to study these connections to improve drought monitoring through the consideration of ecosystem changes.

There are multiple missions planned in next decade that will provide new information on presence and changes of water resources on Earth. For example, ESA Surface Water Ocean Topography (SWOT),[2] launch was planned in 2021, will acquire valuable information on freshwater on land surface. It will be possible to monitor the variations in surface water (in lakes, reservoir, rivers, and wetlands). Presently, free stream gage data is available for only few rivers in the world. This mission will be highly beneficial in monitoring the streamflow in river (width $>$ 100 m) and lakes, which will help in understanding the water cycle, dynamics of flood plains and wetlands, and water resources availability. For further information on different aspects of remote sensing in drought assessment, reader may also refer to detailed reviews by AghaKouchak et al. (2015a) and West et al. (2019).

5.5 Case Study

In this section, we present an application of remote sensing in monitoring the impacts of droughts on terrestrial ecosystems.

5.5.1 Background

Terrestrial ecosystems have an essential role in both global carbon and water cycles by regulating the carbon exchange through photosynthesis and respiration processes

[2] https://swot.jpl.nasa.gov/

and water release to atmosphere through transpiration (Meir et al. 2006; Schimel 1995). These water and carbon exchanges between terrestrial ecosystems and atmosphere has played a crucial role in Earth's past and present. These processes largely depend on the climate and therefore are greatly affected by the variability of climate. Among different hydroclimatic disturbances (such as floods, droughts and heatwaves), droughts have most severe threat on the primary production of terrestrial ecosystems (Du et al. 2018). The primary production is synthesis of chemical energy (in the form of biomass) by the plants through the process of photosynthesis. In this case study, we utilized remote sensing-based estimates of net primary production (NPP) to analyze the impact of droughts. It is extremely difficult or impossible, to measure the NPP on ground over such a large geographical region. Remote sensing and EO have revolutionized the monitoring of terrestrial ecosystems and other components of Earth system. This case study shows how remote sensing enables us in examining the impact of droughts in the absence of ground-based observations.

5.5.2 *Study Area*

This study was carried out over India considering whole geographic region of the country excluding the islands of Andaman and Nicobar, and Lakshadweep. India has a diverse patterns of terrestrial ecosystems due to the occurrence of different climates, land covers, and seasonality of vegetation phenology (Nayak et al. 2015). The average annual precipitation of India is about 119 cm; however, there is substantial spatial variation in the distribution of rainfall (Fig. 5.2). The amount of rainfall varies from heavy in the northeast and the Western Ghats to scanty in western India. About 80% of the annual rainfall happens during the monsoon period (June to Sep). In addition, there is a large variation in land cover types in India.

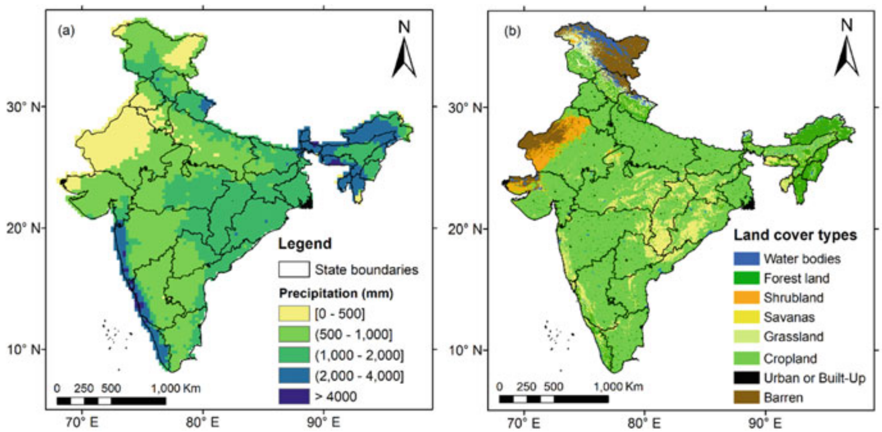

Fig. 5.2 Spatial pattern of (**a**) annual rainfall and (**b**) land cover types in India

Cropland is the dominant land cover, which spreads over 50% of geographic area. The diversity in these controlling factors lead to heterogeneity in the terrestrial ecosystems' response to drought in different parts of the country.

5.5.3 Data Used

A gridded precipitation data (product name: IMD4) was acquired from the Indian Meteorological Department (IMD), Pune. IMD4 dataset has been used in many recent studies (Das et al. 2020; Poonia et al. 2021a, b, c). The daily gridded precipitation product was prepared using the 6955 gauge-stations with $0.25° \times 0.25°$ spatial resolution (Pai et al. 2014). MOD17A3 product was used for NPP estimates, which used the MOD17 algorithm (Running et al. 2004). This product has been extensively used and validated at global and regional scales (Huang et al. 2017; Tang et al. 2016; Turner et al. 2006; Xue et al. 2015; Zhao et al. 2005, 2006). NPP data with 1 km spatial resolution was used for the period 2000–2014.

5.5.4 Methodology

Figure 5.3 describes the methodology used for this case study. The methodology includes following steps:

- The first step was to identify the drought period at each grid point of IMD gridded precipitation dataset. Drought period was identified using SPI (Mckee et al. 1993), a drought index which is widely used and recommended by WMO. Though the IMD data was available from 1901 to 2015, but this analysis was performed for 2000–2014 due to the availability of MOD17A3 data. At each grid point, the driest year between 2000 and 2014 was identified based on the value of SPI.
- The MODIS based NPP dataset has higher spatial resolution, therefore, NPP dataset was resampled to the resolution of IMD dataset (i.e., $0.25° \times 0.25°$) using bilinear interpolation.
- The impact of drought on NPP was assessed in terms of deviation in NPP. The identification of drought and computation of deviation was carried out separately at each grid. The deviation was computed as:

$$Deviation = \frac{NPP_d - \overline{NPP}}{\overline{NPP}} \tag{5.2}$$

where $\overline{NPP}$ is the mean annual NPP and NPP_d is the NPP during the dry period.

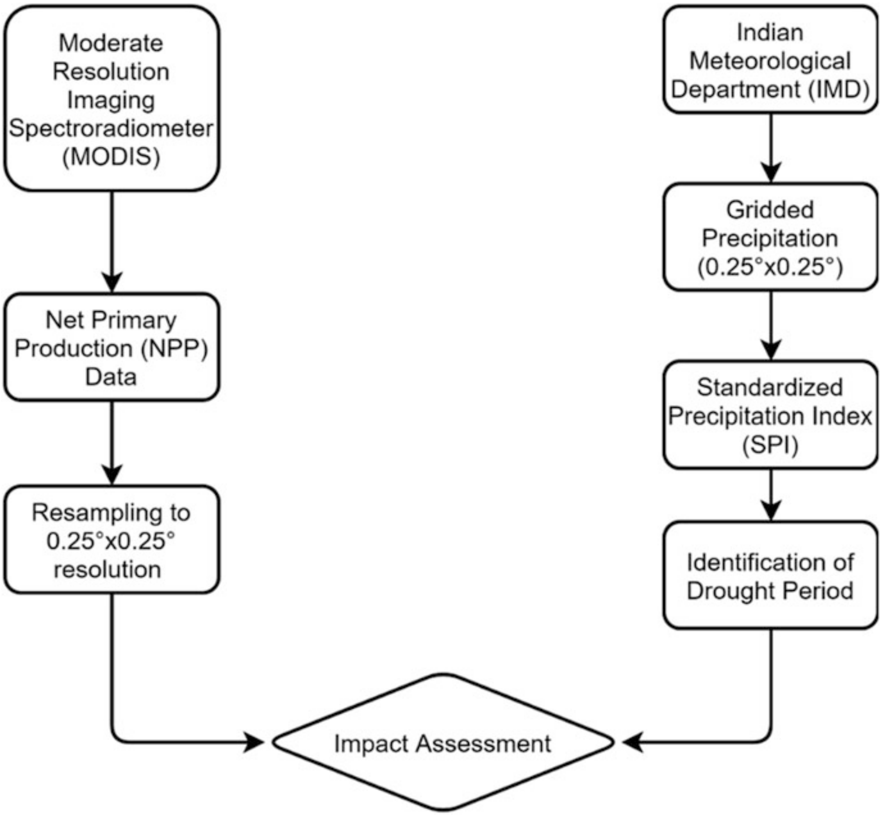

Fig. 5.3 Methodology for drought impact assessment

5.5.5 Results and Discussion

Due to substantial ecohydrological diversity in India, NPP has a large spatial variation. Figure 5.4 shows the spatial variation and interannual variability in NPP in India. Higher NPP (>1500 gC m^{-2}) was found for the forest dominated north-eastern and Western Ghats regions, whereas the arid northwestern areas had the least NPP. Indo-Gangetic plains had moderate NPP (500–1500 gC m^{-2}). The interannual variations (presented in the form of the coefficient of variation, CV) in NPP was very high for the northwestern arid zones compared to other parts of India. The vegetation productivity in these regions is controlled by water availability or precipitation, which has very erratic behaviour. In this region, the standard deviation in annual NPP is much higher compared to lower values of mean annual NPP, resulting in a higher CV. However, CV was less for regions with higher NPP (i.e., for the Western Ghats and northeast India). Figure 5.5 shows the temporal variation on the country average NPP over the period 2000–2014. The country-average NPP in India is

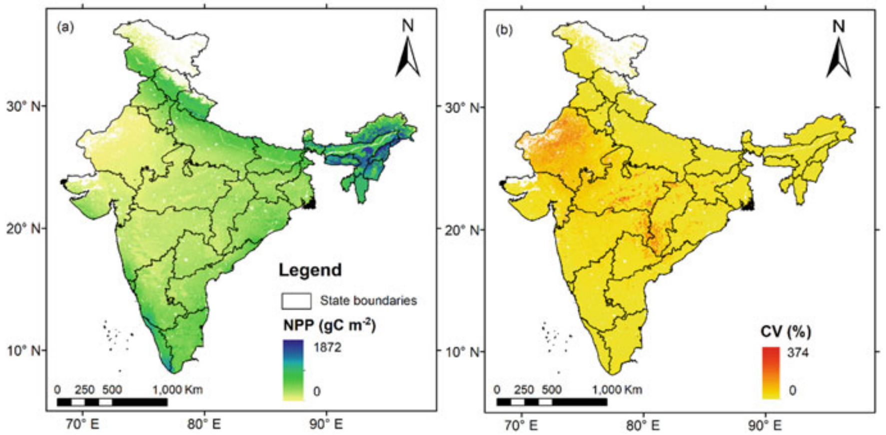

Fig. 5.4 Spatial variation in net primary production (NPP) in India. (**a**) The mean annual values of NPP over the period 2000–2014. (**b**) Coefficient of Variation (CV) in the pixel values of NPP to highlight the temporal variability

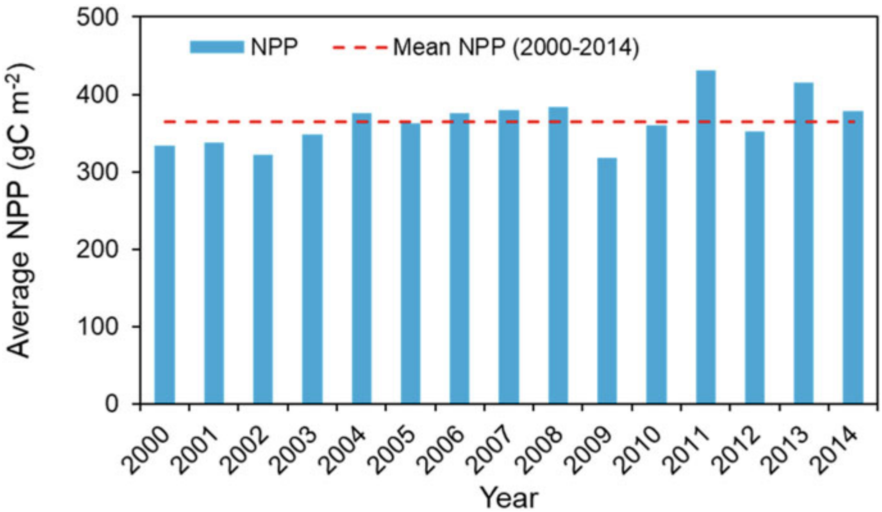

Fig. 5.5 Temporal variation in country-average NPP in India from 2000 to 2014

365 gC m^{-2}, which varied between 318 gC m^{-2} in 2009 and 430 gC m^{-2} in 2014. The country average NPP has significant interannual variability with CV of 8.7%. The spatial variation in NPP over India was consistent with the distribution of different land covers (shown in Fig. 5.2). Forest dominated regions of Western Ghats and northeast India has higher NPP compared to other regions.

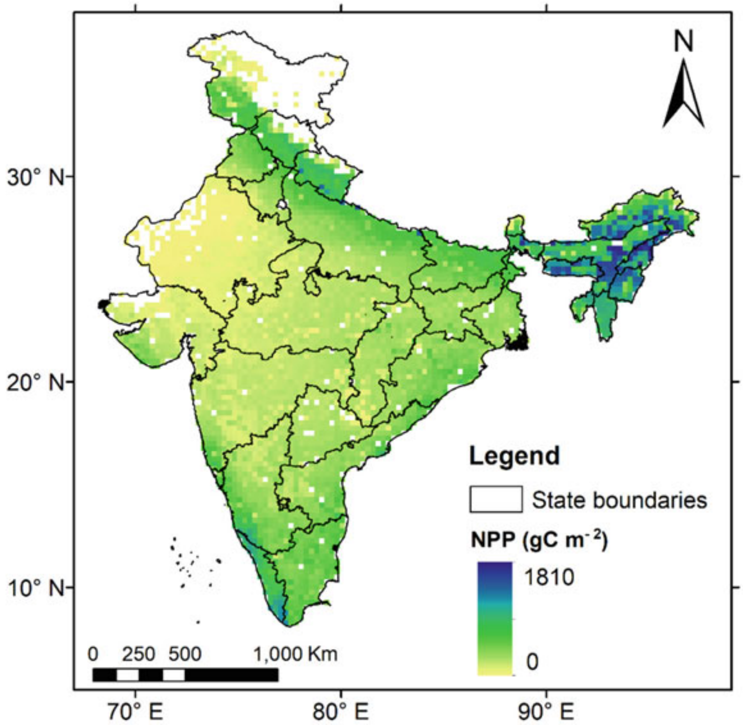

Fig. 5.6 Resampled (regridded) NPP raster. The high-resolution NPP (1 km) was resampled to IMD precipitation data resolution (0.25° × 0.25°) using Bilinear resampling method

The MODIS NPP data was not consistent with the resolution of IMD data, therefore, NPP raster were resampled to 0.25° × 0.25° using Bilinear resampling method. Figure 5.6 shows the resampled NPP raster. The resampled NPP has similar spatial variation compared to MODIS NPP. There is a slight decrease in upper range of NPP, which could be due to the averaging of pixel values during resampling process.

The impact of drought on NPP was quantified using deviation from normal NPP of region. This analysis was performed at pixel scale (of resampled raster). First, the drought year was identified separately for each pixel using SPI. SPI was computed using long-term precipitation (1901–2014) but was used only for 2000–2014. The deviation in NPP for every pixel during drought period was computed as per Eq. 5.2.

Figure 5.7 shows the deviation values for all pixels over India. Deviation map indicates that a large part of the country experienced reduction in NPP under dry conditions. It should be noted that in this study we used SPI of 6-month scale to examine the dry conditions. 6-month scale SPI considers accumulated precipitation of a 6 month period to compute the index value. This enables to study hydrological or soil moisture droughts, which occur after an extended reduction in precipitation.

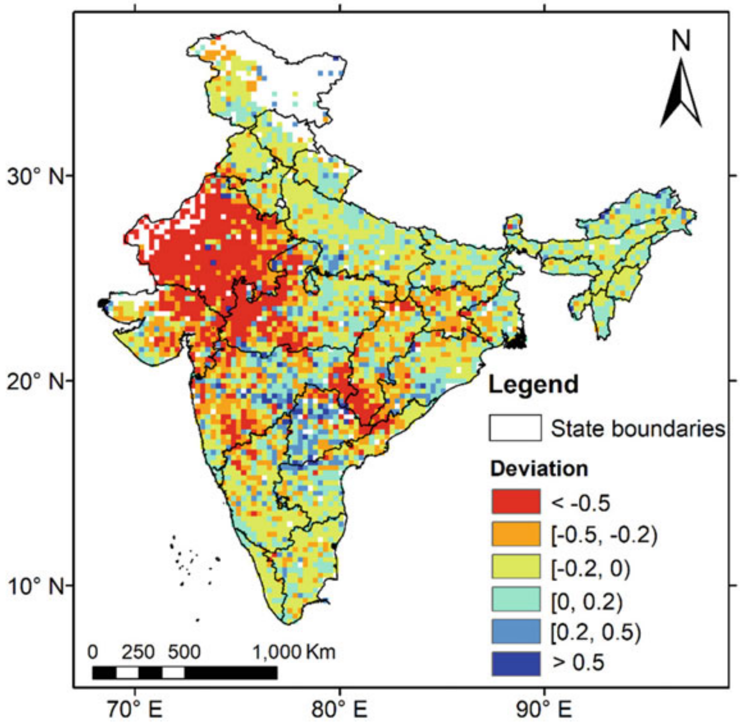

Fig. 5.7 Deviation in NPP under drought conditions in India

About 27% area in the country experienced significant reduction in NPP (deviation < -0.2) under the dry conditions. The value of deviation was least (higher reduction) in western and central regions of the country. These results are consistent with ecosystem resilience analysis of Sharma and Goyal (2018a). Some pixels in central and southern parts of country indicated increase in NPP under dry conditions; however, the number of such pixel was less ($<10\%$). Such results could be due to the inconsistency of satellite data used on this study (i.e. MODIS products) and thus highlights the uncertainty associated remote sensing products. Due to the lack of observation of NPP, this study could not validate the MODIS NPP dataset in India. The comparison of MODIS NPP with Carnegie Ames Stanford Approach (CASA) model simulated NPP (e.g., Nayak et al. 2010, 2013) indicates that the MODIS NPP underestimated the average annual NPP ($\approx$365 gC m^{-2}) compared to their estimates ($\approx$520 gC m^{-2}). Nonetheless, the deviation map identifies the ecological hotspots ecosystem monitoring and management. Future investigation into the ecosystem functioning will unravel the dynamics and controls of terrestrial ecosystem productivity.

5.6 Summary

Droughts monitoring and prediction has been a challenge for hydrologists for decades. Traditionally, the site-based observations of precipitation and surface water were utilized for monitoring droughts, which was limited by the scarcity of gauge stations. Satellite remote sensing-based observations have overcome this limitation by providing hydrologic observations (of climate, soil, and terrestrial water) at larger spatial scale and finer temporal resolutions. In addition of hydrologic observation, the dataset on vegetation and ecosystem has enabled the assessment of drought impacts. With the use of remotely sensed information different drought indices were developed, which are being utilized for drought detection and monitoring. Despite these developments, the application of remote sensing in drought assessment is still limited by issues like continuity and consistency of observations, spatial and spectral resolutions, and uncertainty in estimates. Lack of ground observation of influential variables such as soil moisture and ET affect the calibration of sensors and induces uncertainty/errors in products. Further, the improvements and developments of remote sensing products and tools will widen the applicability in this field. In this chapter, we have discussed the relevance of remote sensing in drought monitoring and prediction. We highlighted the advantages of remote sensing in monitoring different hydrological variables that directly reflect the drought conditions/impacts. We also discussed the challenges and future perspectives of remote sensing application in drought monitoring applications. Further, we presented a case study on drought impact on terrestrial ecosystems in India, which utilized remote sensing-based observation of NPP. This case study reveals how remote sensing has enabled us in examining drought impact in the absence of ground-based observation of key variables such as NPP.

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Chapter 6
Disaster Early Warning Communication Systems

Preeti Banzal

Abstract Worldwide frequency of natural hazards, and associated economic losses are perpetually increasing. Human interaction with the nature is continuously and unsustainably exploiting natural resources and causing harm to the eco-system at an unprecedented rate. The developmental gains are overriding over environmental degradations. The recent IPCC report raises a red flag that delaying climate action is no longer an option for the world. Climate change impacts are affecting agriculture, endangering food security, increasing extreme weather events, species extinction, and the spread of vector-borne diseases. Disaster risk reduction is a necessity to save developmental gains against disaster induced socio-economic losses. Disaster Early warnings (EW) are very important component for Disaster Risk Reduction. EW facilitates risk predictions and risk communication and plays major role in prevention, mitigation, and preparedness for Disasters. Accurate and timely communication with community at risk, and all-important stake holders saves lives and property, and speeds up recovery process.

The chapter describe about importance of technology driven disaster early warning communication systems. It defines systemic, process oriented approach for an effective early warning system. The chapter highlights about present technologies and briefly summarises about new age disruptive technologies and communication protocols, being employed internationally, for EW and communication systems.

Keywords Automatic weather stations · Common management committee · Disaster management · Disaster risk reduction · Internet of Things (IoT) · Radio frequency identification

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6.1 Introduction

Humans are undeniably responsible for the current state of the environment through their excessive exploitation of nature in pursuit of economic growth. The repercussions to these actions are finally catching us. Worldwide trends suggest that the frequency of occurrence and ferocity of natural disasters due to climate change have increased at an alarming rate. Recently, Brihanmumbai Municipal Corporation (BMC) has disclosed that as per the recent city's vulnerability assessment Mumbai's temperature is perpetually increasing which is causing substantial increase in extreme rainfall. Natural catastrophes namely Earthquakes, Cyclones, Floods, Droughts, Tsunami, landslides etc. cause natural disasters and those caused by chemical, industrial, accidents, mass flocking, and other security-related threats including chemical, biological, and nuclear attacks are classified as human-induced or anthropogenic disasters.

Recently, the first part of its "Sixth Assessment Report (AR6)" titled "Climate Change 2021" was brough out by the "Intergovernmental Panel on Climate Change (IPCC)". The IPCC report raises a red flag on rising global temperatures and demands for urgent climate actions for the world. The report raises many questions and alarms including, among others, expected faster rise in Sea Temperature in areas of the Indian Ocean, Arabian Sea and Bay of Bengal. According to the report, the sea surface temperature over the Indian Ocean may increase by 1–2 °C and there is close likelihood of 1.5–2 °C increase in average global temperature. It would certainly translate to more cyclones, increasingly extreme heatwaves, droughts and flooding and many more unexpected repercussions in the form of climate change induced natural catastrophic events or natural disasters.

Worldwide, natural, and manmade disasters are causing significant impact on vulnerable communities, livestock, physical infrastructure services, natural resources, water bodies, soil, agriculture, horticulture, and forest and other livelihood mechanisms and overall geo-socio-economic fabrics of risk areas. Such impacts are not the same for everyone and could easily be correlated with risk and vulnerability factors and with the coping capacity of the community at risk. In developing countries, vulnerability to all kinds of hazardous events is already high due to unplanned growth and settlement of large population in primarily unplanned and unsafe areas. Poor socio-economic and environmental conditions further exacerbate problems and have a direct impact on a country's ability to coping capacity and therefore enhance potential risk and vulnerabilities. Therefore, advocacy for strong disaster risk governance in developing countries have become a focal point in all international organizations.

Globally, holistic Disasters Management (DM), based on a multi-pronged approach towards disaster risk reduction is being adopted. These new age DM methodologies have a focus on per-disaster prediction, preparedness, capacity building and mitigation and therefore have significantly changed and improved the overall DM Paradigm. As an indication of changing paradigm, the current globally adopted Sendai Framework for DRR necessarily advocate for "*enhancing disaster* *risk governance, disaster risk reduction and management, vulnerability reduction and resilience enhancement as key priorities for holistic disaster management*".· As a result, recently, all countries across the world have started using Science and Technology to manage disaster risks. Technology is shaping and equipping preparedness, Mitigation, response, and recovery mechanisms and helping for changing situational awareness of local communities, who inevitably are the first responders.

6.2 Disaster Management Scenario in India

After facing multiple disasters such as Uttarkashi earthquake in the year 1991, Latur earthquake in the year 1993, Bhuj earthquake in January 2001, harsh floods of Assam (1998), super cyclone in Orissa (1999) and Indian Ocean tsunami (2004) Disaster Management Act of India was enacted in 2005. (DM Act 2005). The DM Act legally established a paradigm shift from hitherto response and relief centric approach to a more holistic way of disaster management quintessentially having focus on "prevention-preparedness-mitigation" in pre-disaster and planned response and recovery management after the disastrous event take place. India also participated in Kobe world conference on disaster reduction and subsequently adopted HFA, the Hyogo Framework for Action (2005–15) as a prime rule for its disaster management related interventions.

The DM Act 2005 has facilitated institutional capacity building in a form of the "National Disaster Management Authority (NDMA)", "State Disaster Management and District Disaster Management Authorities (SDMA/DDMA)", "National Disaster Response Force", "State Disaster Response Forces (NDRF/SDRF)" and a "National level Institute for capacity building on Disaster Management (NIDM)". India has its "National Disaster Management Policy" and "Sectoral Guidelines" and Standard Operating Procedures (SOP). The Government of India has created dedicated National/State Disaster Response funds. In addition, several finance commissions are taking note of disaster management requirements and keeping budgetary allocations for capacity building to manage pre, during and post disaster phases in India. Overall, India as a country is witnessing changes in disaster management regime.

6.3 Early Warnings for Disaster Risk Reduction

Early warnings are, increasingly, being mainstreamed in disaster preparedness with broad-based multi stakeholder involvement. Time and again, it is being proven that timely communication of warning information can save several lives. Developed nations rely on effective early warning systems to significantly achieve reduction in disaster stimulated losses. UN General Assembly resolutions has also identified importance of early warning as a vital tool for disaster risk reduction and mitigation.

"International Strategy for Disaster Reduction (ISDR) (2000)" assigned paramount importance to people-centered approach of early warning systems. Apart from ISDR all major international agendas such as the "Yokohama Strategy", "Rio Declaration on Environment and Development,Agenda 21", "Barbados Plan of Action for Small Island Developing States", the "G8 Summit in Gleneagles" the "UN Framework Convention on Climate Change and the Convention to Combat Desertification" etc. have all assigned utmost importance to early warning systems for attaining resilience against disasters.

In a world conference on Disaster Reduction, held in Hyogo, Kobe Japan, about 168 Governments agreed to adopt a 10 year action plan as HFA, the Hyogo Framework for Action (2005–2015). The HFA aimed for making nations and communities disaster resilient. HFA identified 5 important priority actions to fulfill its mandate:

- *"Priority Action 1: To Ensure that disaster risk reduction is assigned national and a local priority with strong institutional building for implementation".*
- *"Priority Action 2: To Identify, assess and monitor disaster risks and enhance early warning".*
- *"Priority Action 3: To Use knowledge, innovation and education to build a culture of safety and resilience at all levels".*
- *"Priority Action 4: To Reduce the underlying risk factors".*
- *"Priority Action 5: To Strengthen disaster preparedness for effective response at all level"s.*

HFA, in its Priority Action −2, laid stress to adopt early warning as one of the imperative and key enablers for DRR. The HFA acknowledged early warnings as technological tool which could save lives and reduce disaster induced losses and enhance coping capacity to respond to natural hazards. Similarly, the Sendai Framework on Disaster Risk Reduction (SFDRR) (2015–2030) has identified its Targets number 7 as to "*significantly enhance the availability of and access to disaster early warning systems and disaster risk related information to people in potential risk areas by 2030".*

6.4 Early Warning Communication Procedures and Systems

As per the standard definition, Early warning (EW)[1] is *timely provisioning of useful information, by predefined institutions, that help individuals exposed to potential hazard, take necessary actions to reduce their risks and prepare them for effectively acting and responding to the situation.*

[1]Early Warning Systems: State-of-Art Analysis and Future Directions by Veronica F. Grasso Ashbindu Singh United Nations Environment Programme (UNEP).

The emergency and risk communication are a field wherein the focus is to provide the information about an expected outcome and potential consequence. Therefore, in an emergency risk communication, time urgency to provide information to allow all stakeholders, and entire community at risk to make the best possible decisions about their safety and welfare within limited timeframe is very critical. In case of disaster warnings, it is a timely communication about likelihood of an expected undesirable outcome.

Broadly Early Warning Systems (EWS) may consist of set of equipment, sensors, simulators, dissemination protocols, communication satellite and wireline and wireless terrestrial communication systems & communication links, a wide range of ICT tools, simulators, and prediction models, firmware, technical human resources and standard operating procedures and guidelines. An effective EWS follows a standard set of procedures and processes. As per "International Strategy for Disaster Reduction (ISDR), 2006" Early Warnings as an outcome-oriented process can be divided in following important aspects:

1. Risk Knowledge: A good understanding of risk and its fair assessment provide important information and is helpful for risk profiling. The risk profile of the vulnerable area is helpful for designing effective prevention, preparedness and mitigation strategies and associated early warning systems.
2. Prediction: Early Warning Systems, post data collection through sensors and other data collection and aggregation and monitoring mechanisms, employ its predicting capacities for giving timely information of the potential risk which communities, economies and overall environmental eco-system could face.
3. Disseminating Information: Telecommunication media and support systems are required for dissemination of warning messages to the possibly affected community, local governmental agencies, and other actors. The messages need to be simple, unambiguous, consistent, systematic, integrated, concise, clear and straightforward to be understood by authorities and the masses. It requires a lot of social and cultural understanding to spread appropriate message.
4. Response: Based on the gravity of the situations, the message is to be suitably communicated to all non- government stakeholders, response agencies, volunteers, civil society organizations, industry, and all other resource providers.

For making warnings effective, it is important that above-mentioned all four steps are followed. Lacunae at any step may cause overall failure of complete warning system. Coordination among all stakeholders, pre-defined and populated Standard Operating Procedures, effective local and regional governance, and appropriate action plans are key requirements for an efficacious early warning system. Likewise, access to information, education and understanding of the potential risk are critical aspects to ensure that timely warnings are followed by disaster appropriate actions by the potentially affected community.

6.5 Technological Tools for EWS

All developed and technologically advanced economies have established state of the art early warning prediction and forecasts systems based on various sensing and data modelling mechanisms. These systems are essentially based on data acquisition through monitoring, data mining, data analytics, and state-of-the art climate simulations and prediction models. Climatologists analyses the observations, data based simulation and prediction modelling to predict climate variances well in advance. However, in ever-changing weather conditions, continual monitoring and prediction modeling is the way to enhance reliability of the forecasting.

Wireline and Wireless Communications Initial telecommunication technology started with voice communication via wireline telephones followed by written communication through telex and fax. Originally early warning agencies were extensively using faxes to communicate official warning messages to local administrative offices.

Wireless networks do not use any form of cable. The transmissions of data/ information take place over radio waves· In wireless network access to and connectivity of the user device with the core network is not connected with physical cable/ wire/fiber. Therefore, susceptibility to physical disconnection, which leads to interruption of communication, is not a problem in wireless communication. With the worldwide spread of mobile phones, mobile communication technology has become an important medium to disseminate early warnings and also a medium for collaborating and coordinating preparation activities. Short Message Service or SMS, alerts are widely used for mass dissemination of warning messages. SMS is available in all generations of digital mobile technologies 2G/2.5G/3G/4G/5G and beyond and is supported by every single mobile device today. Short message service (SMS) permits the sending of short messages between mobile phones, other handheld devices and even landline telephones. There have been situations, during disasters, when due to non-availability of voice channels residents of disaster affected areas are not able to call but could easily communicate through SMS with help givers. This is because SMS mostly and particularly in old generation mobile phones (2G), works on a different information channel and can be sent or received even when voice channels are not available due to network congestion. However, during some disasters such as earthquake, cyclone, cloudburst there is a probability that telecom towers and terrestrial telecom infrastructure get affected and may result in non-availability of this service.

With advancement in wireless broadband connectivity/evolution of mobile technology to support high bandwidth data, it is possible to avail real-time information and early warnings on mobile. Besides mobile technology evolution to 4G/5G and now 6G utilization of mobiles as multimedia communication tools for disaster reporting is hugely enhanced. MMS is an acronym for "Multimedia Message Service" and is most popularly used to send pictures or images through mobile phones. With the advent of newer and powerful social media messaging tools and applications messaging has got widespread usage across all types of early warnings.

6.6 Geo-spatial Information Systems

Geospatial data is time and space-based data that is related to a specific location on the surface of the Earth. There have been immense technological developments, over the years, for capturing geospatial data. The "ground-based survey techniques", "photogrammetry using manned/unmanned aerial vehicles (UAV or drones)", terrestrial vehicle mounted "Mobile Mapping Systems", "LIDAR" "LADAR", "RADAR Interferometry", "satellite-based observations for remote sensing", mobile phone "Global Positioning Systems (GPS)" "Global Navigation Satellite System (GNSS)" etc are some notable technologies used for geo-spatial data acquisition.

Remote sensing and GIS applications, using geo-spatial data, contribute significantly in early warning systems. Timely location based, spatial-temporal information on development of disasters captured in a dynamic digital map is crucial towards effective disaster prediction, mitigation, and response. Geographic Information System (GIS) is digitally integrated with the real-time space-based imageries of the hazards with the corresponding ground information and provides a complete information solution with Global Positioning System (GPS).

"Mobile Mapping System (MMS)" is a technique used to acquire complete 3D (three-dimensional) data of on surface components. In this technique, a series of sensors, scanners, cameras, and systems such as "Global Navigation Satellite System (GNSS)", 3D laser scanner, panorama camera, etc., are installed on a vehicle. Through a combination of sensors and vehicle mobility the area of is surveyed and geo-spatial data is collected and recorded.

Recently the Government of India, via, Department of Science and Technology (DST) has released an open geo-spatial data policy. Through this policy, huge arena of geo-spatial data acquisition and utilization have been made open for innovators, researchers, technology developers and solution providers to use the data for larger benefit of the society and in turn adding to the economic development.

There are multiple climate models available, which use geo-spatial data and historic data of past disasters data to create simulation and prediction models by using classic regression models or Machine Learning and Artificial Intelligence (ML/AI).

6.7 Satellites for Remote Sensing and Earth Observation and EW Communication

Satellites, based on design, purpose of utilization, adopted technology, power utilization etc. are launched to three types of orbits. “Geostationary Orbit (GEO)”, “Low Earth Orbit (LEO)” and “Medium Earth Orbit (MEO)”. A geostationary satellite orbit is located at around 35,800 km (22,300 miles) directly over the equator and revolves in the similar direction in which the earth rotates so that it appears stationary from a point on the earth surface. Satellites are a very good source of remote sensing and geo-spatial data collection. All new digital maps are sourced through such data. Depending upon the height of the satellite orbit, Geostationary (GEO)/Low Earth Orbit (LEO)/Medium Earth Orbit (MEO), technologies adopted, and camera technology employed, on ground and higher altitude resolution of the sensing data changes.

Satellite imageries are key inputs for all types of simulation model development of early warning systems for meteorological, hydrological predictions. Indian forecasting institutions such as IMD, CWC, INCOIS, GSI etc. are dependent upon these satellite observations, images and data shared by multiple Indian and international remote sensing satellites. Communication satellites regularly transmit this data to ground stations almost on a real time basis. Such data, when compared with standards and analysed, lead to timely warnings. Improved data analytic technologies and state of art simulation models have extensively enhanced credibility of warning predictions. The Figs. 6.1 and 6.2 shows satellite-based navigation and early warning system and disaster management systems of Indian Space Research Organisation (ISRO).

Satellite based early warning communication networks, to a large extent; use Very Small Aperture Terminals (VSATs) based communication network to meet requirements of varied users caters to various telecommunications applications such as Business to Business (B2B) Corporate networks, industrial Wide Area Networks (WAN), Rural Telecommunications, Distance Learning, Telemedicine, video conferencing, defense operations, defense establishments, stock exchanges, manufacturing & FMCG companies Disaster Recovery, Ship – Board –coast communications, and for early warning systems.

Recently, the Department of Space (DoS) has come out with new open space remote sensing policy and guidelines. The policy is facilitating Indian entities to manufacture/hire and launch a satellite to acquire; use and share remote sensing earth observation data of Indian Territory. With the opening of space, a paradigm shift would take place for climate change and disaster prediction and early warnings.

Internet/Intranet/Virtual Private Network Technologies The Internet as a concept started in the decade of 1960s. During that time the computing machines were large and so were the information storage systems such as magnetic tapes for movement of information from one machine to the other. Subsequently U.S. defense department formed the ARPANET (Advanced Research Projects Agency Network),

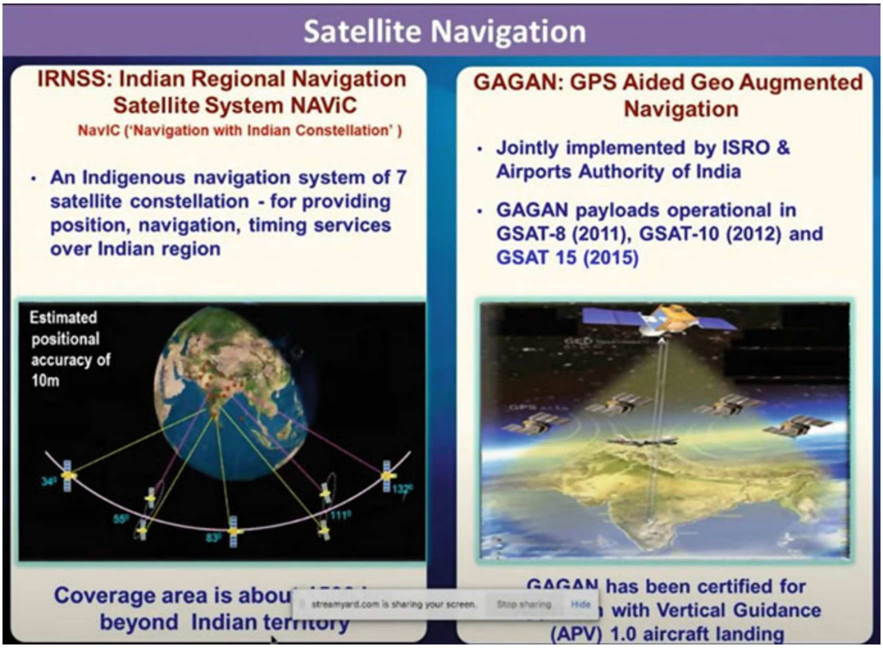

Fig. 6.1 Satellite-based navigation system. (Source: IRSS Dehradun, ISRO)

which subsequently evolved into the Internet. However, the Internet got prominence and gained huge user base after adoption of Transfer Control Protocol/Internetwork Protocol (TCP/IP) as a standard protocol for information sharing among different machines and networks. Now the Internet is a global network of many large medium and small networks enabling computers/mobiles/processing devices, institutes and almost everything to remain connected and to directly, safely, securely communicate, for all purposes, all across the world.

Intranet is again a network of connected devices for sharing information, collaboration tools, and operational systems, within an organization. Devices could be connected within a building or to different sites. The connecting links could be wired (cable, Ethernet, Optical Fiber Cable) or wireless, satellite (VSAT) based. The information is intended to be shared primarily in a secure manner within the organization. For sending information out of the Organisation, help from the Internet is taken. Intranet could be used for risk communication within the organization. Virtual Private Networks are again private networks like Intranet, but in virtual space. Actual physical network setup is not laid out. VPN could be virtually created using public internet/WAN to get benefit of existing infrastructure, and security policies could be laid out for desired performance of secure communication.

The internet provides fast, economic, and reliable means of making national, regional and international disaster warning communications. Due to the internet, real -time information and communication is now available from a variety of sources at

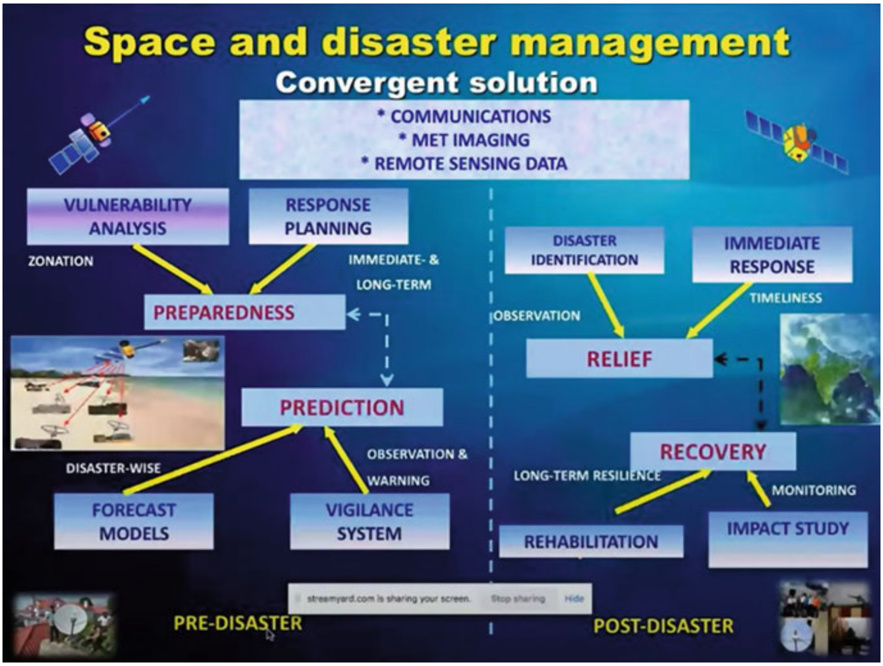

Fig. 6.2 Space-based convergent solution for disaster management. (Source: IRSS Dehradun, ISRO)

global, regional and local levels. The Internet is the fastest way of warning dissemination. With ever expanding technological capabilities and availability of undersea optical fibers cables, internet bandwidth has been increased manifolds. The Internet is facilitating the global distribution of disaster data and information at all levels and is considered to be a backbone of national and global meteorological early warning and forecasting networks.

Crisis Mapping and Crowdsourcing Tools With ever expanding use devices like smartphones, iPads, small hand held digital cameras and smart and internet connected devices, huge amounts of data, video & audio are being generated and shared over all kinds of social media network. Social media has increasingly become a very important tool for community connection. Wide spread of the internet and mobile has made facebook, twitter, instagram, whatsapp etc. important tools of mass communication. The use of ‘crowd sourced’ data, before or during a hazardous event is gaining momentum with increasing wireless broadband internet connectivity. “Self-organizing & managed decentralized social networking tools with FOSS, free and open-source platforms are good in meeting this requirement. “Ushahidi, developed by Kenyan bloggers in the aftermath of the 2008 Kenyan elections is a platform, which uses SMS, Twitter and Google Maps to crowd source crisis information and is now widely used in disaster response and relief operations”. “Ushahidi has now also developed tools for rapid verification system of crowd sourced information by cross checking tagged information from different sources to ensure reliability and authenticity of the information".[2]

Google Crisis Response, crisis mapping are also designed to leverage crowdsourcing of real-time information on an upcoming or already existing crisis situation. New age mobile applications may also be having capability to analyse real time data and can feed to such systems which are immensely helpful for dissemination of early warnings.

6.8 Disruptive Technologies

With new age distributive technologies like Internet of Things (IoT), Machine to Machine communication popularly known as M2M communication, Big Data Analytics, Machine Learning (ML) Artificial Intelligence (AI), Augmented and Virtual Reality (AR&VR) are envisioned to play major role in general for all phases of disaster management continuum. These technologies are significantly contributing to early warnings.

Broadly, Machine to machine (M2M) means technologies that enables communication between wireless and wired systems and other devices/machines of similar capabilities. M2M communications normally use sensors/meters/actuators to capture an event/interaction/transaction which is communicated over a telecommunication network to an application that translates the captured event/transaction/interaction into meaningful information and actions. In a common man's language M2M may be described as machines connected to the Internet, using a variety communication network, and communicating with each other and with the wider world.

The term Internet of Things (IoT) and M2M are frequently used interchangeably with various other terms - Internet of Everything (IoE), Smart systems (Homes, Cities, Meters, Grids etc.), Industry 4.0 applications etc. However, M2M is only a subset of IoT. IoT is a wider term which refers to addition of communications and sensing capabilities to a wide range of physical objects. It includes Human to Machine (H2M), "Radio Frequency Identification (RFID)", "Location Based services (LBS)", "Robotics", "Telematics", smart watches, e-health sensors and wearable smart devices and smart appliances etc. In the coming decade it is expected that millions of IoT devices will be deployed in electric meters, parking meters, thermostats, car components, roads, traffic signals & cameras, Industrial devices, automated transport etc. IoT devices will send data directly using protocols such as Wi-Fi, Wi-Max, Bluetooth, narrow band IoT, Sigfox, LoRA, 5G and other specialized networks and over the global network.

Advancement in M2M technology will add entirely a new dimension to disaster early warnings. Technologically empowered sensors, gauges, meters will take

[2] www.ushahidi.com

measurements, viz. hydrological measurements will talk to their respective devices at the back end which in turn will provide feeding data for prediction models and more accurate forecast/nowcast/early warnings will be generated. These machine trails would be extended to provide necessary triggers to mitigation and risk aversion mechanical models and actuating data and signals to digital devices as well.

Machine Learning (ML) and Artificial Intelligence are no longer technologies of the future. They have very much arrived and have become part of our daily lives in the form of personal assistants like Siri and Alexa or advising on purchase decisions, health benefits and exercise requirements to self-driven Tesla cars. AI and ML are being considered as panacea of all problems. They are extensively being used for disaster management as well. Large sets of past events i.e. historical data for various disasters, extant maps and geo-spatial data, real time observations and images and ground data are helping machine learning algorithms to be trained and become artificially wiser day by day. All new age prediction warning models are based on AI and ML. With facilities like natural language translation, with the help of AI, warnings can be disseminated in vernacular language. All standardization bodies and UN organizations are extensively exploring the potential of AI by employing them in climate change actions and disaster management related technological interventions.

Digital Twin Technologies are progressively becoming new age tools for disaster prediction and warning models. In Digital Twin technologies, a digital replica creation of real-life situation, geographic location is created and using augmented reality, AI and ML prediction models are formed. These models could also be used for Mitigation planning, response, and relief operation design etc.

Public Protection and Disaster Response and Relief (PPDR) operations can obtain considerable benefits by having access to a wide variety of information, databases, access to instant messaging, high-quality images and video, location and digital map services, remote control of robots, and other applications. In future, large deployments and proliferation of drones (UAV), robotics, Machine-2-Machine (M2M) communication, Internet of Things (IoT) will have a significant impact on PPDR operations and emergency search rescue (SAR) operations.

6.9 Early Warning and Forecasting Networks in India

Nodal agencies for monitoring and early warning of major disasters in India are:

- IMD (Cyclones, Floods, Drought, Earthquakes), Ministry of Earth Sciences
- Central Water Commission under Ministry of Jalshakti (Floods)
- Geological Survey of India (Landslides), Ministry of Mines
- National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences (Tsunami)

"IMD, The India Meteorological Department" was established in 1875. Presently it is working under the Ministry of Earth Sciences and is considered as National Meteorological Service of the country and the principal government agency in all matters relating to meteorology, seismology and allied subjects and its mandate and current operations, among others, include:[3]

- *Meteorological observations and forecasts for weather related activities for example agriculture, irrigation, shipping, aviation, offshore oil explorations, etc.*
- *Warnings for tropical cyclones, norwesters, dust storms, heavy rains and snow, cold and heat waves, and other extreme weather events*
- *Data collection, analysis and data provisioning providing advisories*

"CWC, Central Water Commission" is entrusted with the general responsibilities, *interalia,* coordinating and undertaking water resource management related policy programs and project implementation. Their work streams involve water conservation, Flood Control, Irrigation, Navigation, Drinking Water Supply and Waterpower Development. CWC's flood forecasting network sites spread across many river basins and states. CWC through its twenty systems and flood forecasting divisions issues forecasts through Fax, Email, SMS, Website, and portal-based advisories etc. to the various user agencies higher order offices, cabinet secretariat and central ministries.[4]

GSI, **Geological Survey of India**, is an attached office to the Ministry of Mines.[5] GSI is the nodal agency for monitoring landslide activity and its mitigation and also provides terrestrial data on landslides and impending warnings. The GSI is entrusted with responsibility of Landslide Hazard Zonation (LHZ).

Apart from GSI, as a nodal agency, there are multiple government departments and organizations such as Central Road Research Institute (CRRI), Central Building Research Institute (CBRI), Indian Institute of Technology, Roorkee (IIT-R), Wadia Institute of Himalayan Geology (WIHG), Department of Space (DoS), National Remote Sensing Centre (NRSC), Defense Terrain Research Laboratory (DTLR), Bureau of Indian Standards (BIS), some academic institutions, and individual experts are also working to study landslide hazard and its management in the country. In addition, Department of Science and Technology (DST) and Department of Scientific and Industrial Research (DSIR) also fund Research and Development (R&D) activities that include different types of landslide investigations.

"INCOIS, Centre for Ocean Information Services" Hyderabad, is working under Ministry of Earth Sciences (MoES).[6] After great Sumatra earthquake of 26th December, 2004, the Ministry has set up an Indian Tsunami Early Warning System (ITEWS), in INCOIS, with a mandate to provide advance warnings on Tsunamis likely to affect the coastal areas of the country and the region. INCOIS

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[3] http://www.imd.gov.in/doc/mandate.htm

[4] http://www.cwc.gov.in

[5] https://www.gsi.gov.in/

[6] http://www.incois.gov.in/Incois/tsunamicontents

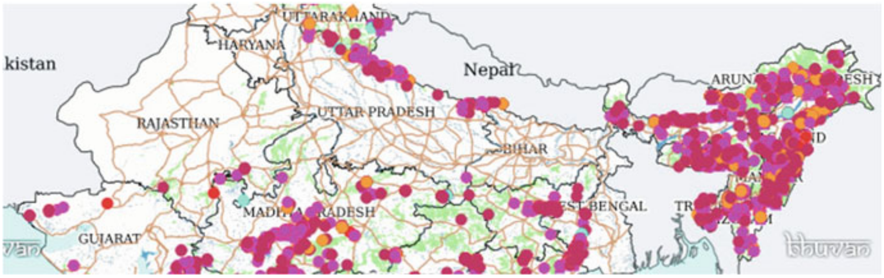

Fig. 6.3 ISRO's forest fire rating system – Map

acts as one of the Regional Tsunami Advisory Service Providers for the Indian Ocean Region along with Australia & Indonesia.

Other than aforementioned prime institutions multiple organizations such as "Defence Geoinformatics Research Establishment (DGRE) or earstwhile Snow and Avalanche Study Establishment (SASE)" and "Defence Terrain Research Laboratory (DTLR)", under the Ministry of Defence, "National Remote Sensing Centre (NRSC) under Department of Space (DoS), Ministry of Health and Family Welfare, Ministry of Railways, Ministry of Environment Forest and Climate Change, are monitoring, sharing data, and issuing warnings for many other hazards such as, snow avalanches, extreme weather events, epidemics, oil leakage, forest fire, chemical and industrial disasters (Fig. 6.3).

6.10 Early Warning Communication

Early warnings are aimed to initiate suitable actions at multiple levels with varied roles and responsibilities as effectiveness of early warning systems for disaster risk reduction largely depends on early follow-up action. Warnings should be effectively conveyed, and sufficiently acted upon, with sufficient awareness of the nature, frequency, positions, situations and intensity of hazardous situation and related vulnerability of the habitants. There need to be scientific and technical capabilities of sensing and predefined systems and mechanisms in place to act upon such warnings.

Reliability: The uncertainty intrinsic to warning information could be one of the reasons of inaction. Thus, the message communicating the level of uncertainty and probability of potential threat may help people decide on urgency and nature of the action. The warning messages need to be necessarily simple, contextual and location specific. For enhancing effectiveness, early warnings need to be concise,simple and in clear and preferably in vernacular language to be properly understood. It is also important to work with the media persons so as to ensure that to accurate, and proper information is covered in the local media.

Prioritization: When a warning is issued, it may not help a recipient to make a decision on prioritizing impending risk over his/her routine higher priorities Therefore proper prior awareness of the local community about risks and vulnerabilities of the area along with capacity building in terms of dissemination of information on Dos and Don'ts, their quick response to warnings, preparation of safety kits and family safety plans, having micro insurance against disaster induced losses, etc. may be helpful.

Coordination: Cooperation, coordination and collaboration between all stakeholders is a systemic backbone to an effective early action because organizations who release warnings are generally scientific organizations and are normally different from those who have to act upon warnings, and to respond at ground. There should be proper coordination between such agencies. For major disasters which have effects across more than one country/region, such as Tsunami information sharing becomes more important. Better communication channels and proper pacts/memorandum of understandings/policy for regional cooperation may help to address this.

Technology Agnostic Protocol: For communicating early warnings, standard technology protocols play fundamental and important role. For effective transmission of messages, it is important to select a protocol which may offer efficiency and flexibility to interwork across different types of communication channels and mediums. The "Common Alerting Protocol (CAP)" is an example of such standard data sharing and exchange protocol. The advantage of standard format alerts is that they are technology agnostic and are therefore compatible with all types of warning systems, mediums, and most importantly, with most of the new technologies. CAP may be designed to define a prototype standard message format for all kinds of disasters, and which could activate multiple warning systems at the same time and with a single information source.

6.11 Conclusion

Human interaction with the nature is continuously and unsustainably exploiting natural resources and causing harm to the eco-system at an unprecedented rate. The recent IPCC report raises a red flag that delaying climate action is no longer an option for the world. Climate change impacts are affecting agriculture, endangering food security, increasing extreme weather events, species extinction, and the spread of vector-borne diseases. Disaster risk reduction is a necessity to save developmental gains against disaster induced socio-economic losses. Early warnings (EW) are a very important component for Disaster Risk Reduction. EW facilitates risk predictions and risk communication and plays major role in prevention, mitigation, and prepared for Disasters. Accurate and timely communication with community at risk, and all-important stake holders saves lives and property, and speeds up recovery process.

The new age EW systems are progressively becoming data driven. Such systems are intelligent and accurate. Integration of all stakeholders and systems is very crucial for better data integration and data organization. Clean technology research and innovation and development of clean-tech start-up eco-system is a need of the time. In addition, participatory approach to early warnings by including local community as first responders and enhancing coping capacity and capability of local populations would help them play pro-active role in ensuring the security of their families and livelihoods.

Further Readings

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Chapter 7
Spatial Data Infrastructure for Suitable Land Identification for Government Projects

Nikhil B. Khandare, Valmik B. Nikam, Biplab Banerjee, and Arvind Kiwelekar

Abstract Locating a piece of land for upcoming government project or choosing a correct piece of land for shifting an existing government project is indeed a difficult task. This task is difficult as the wrong decision in this regard may lead to increased financial stress and in worst case lead to project failure. To facilitate this decision making, spatial data infrastructure is used in this research, data model is also given for decision making. Here three map layers are created namely land use land cover map, temperature map and rainfall map. Detailed procedure to generate map is given for each map layer and final map is generated using weighted sum to find out most suitable location for upcoming project by using land use land cover along with meteorological data. Verification is done by using actual ground control points for above three parameters. Accuracy calculation is also done in order to find out accuracy of LULC classification. Finally, significance of this research to government agencies for effective decision making is given.

Keywords Spatial data infrastructure (SDI) · Geographic information system (GIS) · Spatial data analysis · Satellite images · Topo-sheets · Land use land cover (LULC) · Rainfall map, and temperature map · Data model

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7.1 Introduction

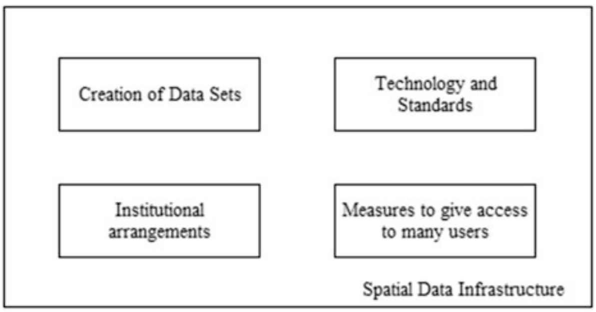
Term spatial data infrastructure was brought by United States national research council in 1993 and today geographic information system, especially spatial data infrastructure has become integral part of national and economic development with effective decision making (Esri 2010). GIS is computer system for storing, displaying, processing and querying geographical data (Chang 2016), GIS is helping people in various ways every day and making life of an individual easier. Among various uses of GIS few are government institutions for planning and development, economic development. GIS can also be used for finding shortest path for LPG, water pipeline and landline telephone lines. Problem of finding railway, road and air route can be solved by GIS. Locating a good place for starting a shop can also be found using GIS. Natural resources location and rate of depletion can also be done using GIS, other information like climate change and desertification can also be obtained by GIS. Along with above uses of GIS few more can be finding exact location for school, college or university and safety and security of individual can also be addressed by GIS by tracking patients infected by disease (Masser 2005).

GIS technology is computer system for spatial data and many times this data is shared, however, in the exchange of geographical data some standards need to be followed. Here spatial data infrastructure come into picture, spatial data infrastructure is like any other infrastructure, and SDI ensures the easy exchange of geospatial data. Key components of spatial data infrastructure are creation of data sets, institutional arrangements, technology and standards, measures to give access to users. Figure 7.1 depicts important components of SDI (Masser 2005).

In order to find the piece of land for any purpose, land use and land cover detailing map is needed, if such map is available mentioning whether land is buildup area or forest or agriculture land or barren land then problem addressed here can be solved by sitting at one place. Again how to create this map is a challenge which will be discussed in Sect. 7.3.2. And accuracy of this classification will be discussed in Sect. 7.4.2. Land use land cover map will have attribute data mentioning ownership, area etc.

Along with this land use information, if temperature and rainfall map is also given then finding a location as per the requirement of user becomes a very easy task.

Fig. 7.1 Basic components of SDI



Similar to LULC, creating these maps (rainfall and temperature) is a challenge which will be discussed in Sects. 7.3.4 and 7.3.5.

Finding a place with given meteorological information, decision needs to be taken by using all the three maps collectively. How this decision will be taken using spatial data infrastructure and three map layers will be discussed in Sect. 7.3.6.

This chapter is organized as follows, Sect. 7.2 discusses the work related to this research, Sect. 7.3 discusses proposed idea of finding a location of land for government project using spatial data infrastructure, this section mainly includes SDI architecture for given problem, data model for given problem, creating different layers required and decision making. Section 7.4 discussed about accuracy and verification. Section 7.5 concludes chapter.

7.2 Related Work

Work done in land use and land cover detailing, meteorological detailing and spatial data infrastructure is presented here, Study of economic benefit of spatial data infrastructure was made in northern Italy in Lombardy 2 surveys were carried out one survey focused on environment impact analysis using spatial data infrastructure and found that regional SDI helps in economical and policy benefit. Second survey focused on planning and design where use of SDI was analyzed (Campagna and Craglia 2012). With advancement in technology and everyone is having GPS enabled handheld device, location of the user can be captured and data is stored on his device or on location service providers cloud, which can be easily downloaded. Idea of sharing this data in spatial data infrastructure was highlighted in (Coleman 2010), what opportunities and risks are involved with this idea were also studied. Spatial data infrastructure for social science in Germany was proposed in (Schweers et al. 2016), role of librarians, architects was explored for designing SDI, considering privacy constraints of country, idea of merging survey data and spatial data was given. Idea of developing SDI for archeological and heritage site was given in (McKeague et al. 2012), and what area should be kept private and what site should be kept public taking into consideration the bigger historical group worldwide was given. Case studies from other countries was also discussed, developing geoportal, web services and applications were also given. Spatial data infrastructures formal model has been defined in which one component is data sources (creation and maintenance), SDI has shared data and idea of adding volunteered geographic data to SDI was given in (Cooper et al. 2011).

Use of SDI for finding environment noise in European countries with INSPIRE was proposed in (Abramic et al. 2017), wherein actions taken by government to reduce noise are shared with public, citizens can do e-reporting of noise and various parameters can be monitored line air quality, biodiversity, health, population to name few. Land use land cover analysis was done in tropical regions and various things were uncovered including increase in buildup are, change in agricultural land, change in forest area to name few, it was claimed that if current change in land use is known then future change of land use and land cover can be predicted (Lambin et al. 2003). A research was carried out to figure out myths about causes of land use land cover changes, it was supported by case studies in (Lambin et al. 2001), this research has claimed that neither poverty nor population is changing land use across the globe, however people's perception about the economic opportunities is changing the land use land cover world-wide, Federal markets and other opportunities are the driving factors to change land use land cover. Amount of carbon going inside or outside of an area under consideration of land use and land cover change is calculated in (Houghton et al. 2012), total is called net flux which is measured approximately as $1.14* 10^{15}$ gram carbon per year. Mean and standard deviation were calculated, errors in this calculation were also given. Review of multi agent system for LULC problem was done in (Parker et al. 2003), where various advantages and issues of multi agent system were discussed, it was found that this technique is useful for complex spatial analysis, various challenges and new question which needs attention in this field were also highlighted in this review.

To find the soil erosion caused by rainfall in Brazil, research was done in (da Silva and Marco 2004) to find out how much soil is lost every year, soil erosion was measured as erosivity (R) using nationally accepted equation of soil loss, GIS was used and spatial interpolation technique was used to create erosion map for states of Brazil, it was found that northwestern states have high erosion whereas northeastern have low erosion. Rainfall was calculated at measuring station in Kruger national park and averaging was done based on given rainfall data and rainfall map was created for entire region in (Gertenbach 1980), based on this data change in rainfall can be determined and amount of rainfall in future can be predicted. Rainfall averaging and prediction using geostatistical techniques was done in (Goovaerts 2000), three different techniques were used namely simple kriging, kriging with external drift and collocated kriging, it was found that simple kriging techniques gives more accurate rainfall prediction, in this research data was collected from 36 climatic stations.

Ground temperature map of the ground which remains completely frozen was calculated using remote sensing, mean annual ground temperature was calculated using statistical technique (Westermann et al. 2015). Koppens climate classification map was created for Brazil in (Alvares et al. 2013), the map include temperature and rainfall, monthly data was collected from 2950 stations, geographic coordinates and altitude was used and map of 100 m resolution was created for Brazil, results were given in the form of maps, chart, table, graph to people in order to predict climate types in Brazil. Permafrost map for Norway, Sweden and Finland was created in (Gisnås et al. 2017), cryogrid1 model was implemented and map of 1 km resolution was obtained, map has given the data that total permafrost are is $23.4*10^{3}$ square km from 1980 to 2010.

Many other authors have worked on regional, national level SDI, also various works were undertaken in past on rainfall map, temperature map and land use land cover independently. However, little or no attention (to the best of author's knowledge) has been paid to locate a piece of land using SDI for government project. Locating this piece of land also takes meteorological data into consideration for best fit. Rest of the chapter is organized as follows, Sect. 7.3 discusses the idea of locating a piece of land and Sect. 7.4 discussed accuracy and verifies the classification done in Sect. 7.3. Section 7.5 concludes the chapter.

7.3 Spatial Data Infrastructure (SDI) for Land, Rainfall and Temperature Detailing

To find the piece of land as per the given requirement of area, land type and meteorological parameters like rainfall and temperature is a challenge (Goyal et al. 2012; Goyal and Ojha 2011; Sharma and Goyal 2018; Shivam and Sarma 2017). Having a good regional spatial data infrastructure can help in decision making and locating piece of land easier. Detailed solution to this problem is presented in this section. This section deals with creation of land use land cover map, creation temperature map and creation of rainfall map. Here LULC map can be created using either satellite images or digitizing topo-sheets from survey of India, however latter solution to create LULC map is better as data is more up to date.

7.3.1 Spatial Data Infrastructure Architecture for Land, Rainfall and Temperature Detailing

Architecture of SDI for LULC and other meteorological detailing is shown in Fig. 7.2, it mainly shows user, geoportal, services and database. User wants to access the temperature, rainfall and LULC maps from the spatial database. Geo-portal is used by user to interact with SDI, user can access data by giving place-name, kml file or lat-long details. User can upload, download and modify the maps in spatial database. Various services are used in SDI for accessing the data from spatial data bases which mainly include web base mapping service (WMS), web based file service (WFS) and web based catalog service (WCS). In this scenario user wants to access maps from spatial database this WMS service will be called and maps in database can be accessed. Spatial metadata will give other information about who has created data, why the data was created, when data was created, what was intention behind creating data etc. Data (required map) will be accessed from spatial database and will be given to user, user can view the data and he can download the data. Thus user can download or view three maps, namely temperature map, rainfall map and land use land cover map. These maps can be viewed in the geoportal as layers or user can download these maps and can view in GIS software like arcMap or QGIS or similar software as layers. These software have large number of tools to do spatial analyst tool, 3D analyst tool, interpolation tool, hydrogeology tool to name few.

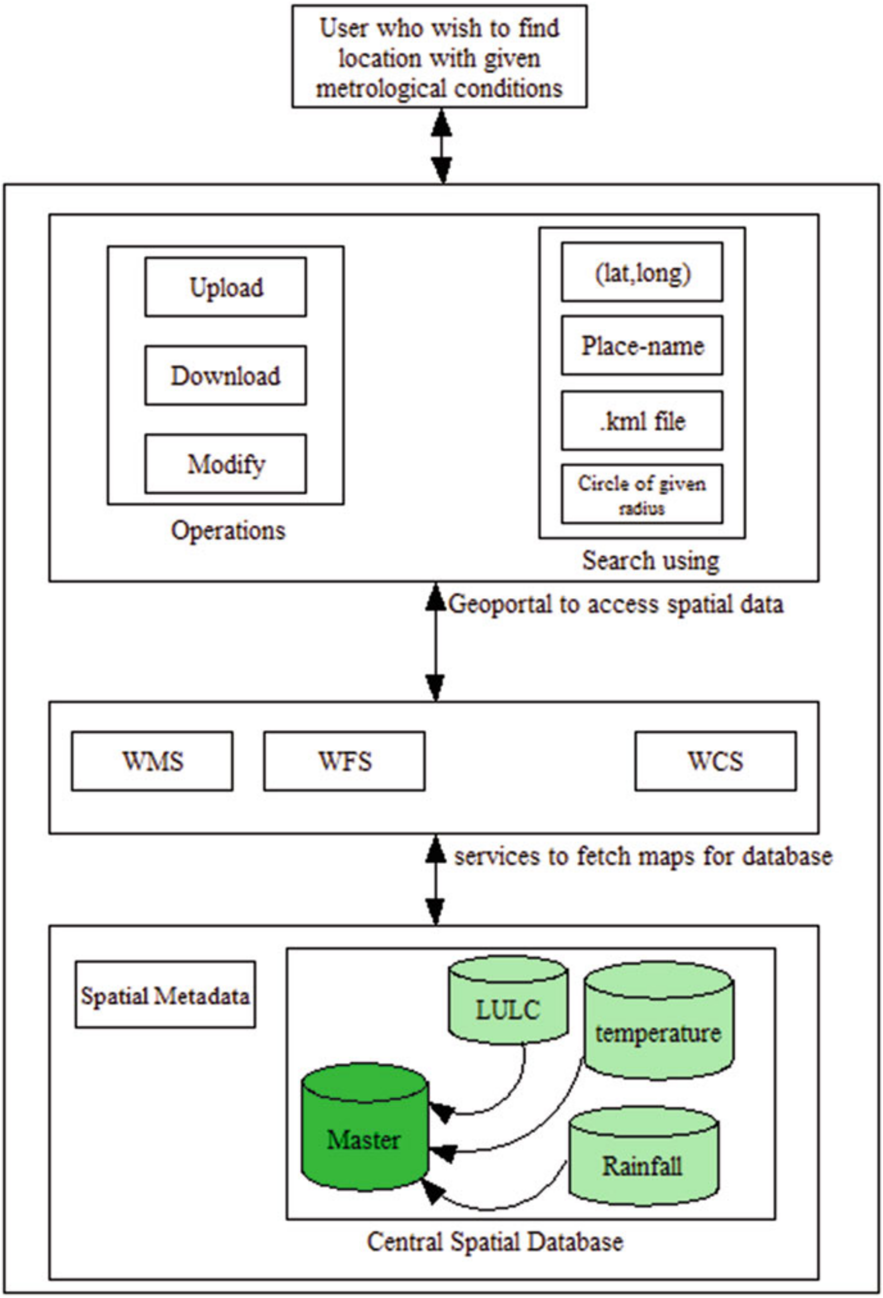


Fig. 7.2 Spatial data infrastructure architecture for LULC along with meteorological detailing

Once the maps are downloaded user can view them in GIS software and can do weighted sum operation, user can also perform overlay operation and create a composite colored map for easy identification of location or area. Now the question which arises is how spatial data infrastructure is getting all this temperature, rainfall and LULC maps? Answer to this question is given in Sects. 7.3.2, 7.3.4, and 7.3.5 respectively. Idea is people, researchers, academicians and industries are creating such maps and are uploaded to SDI. One of the aim of SDI is easy sharing of geographical data and thus people can gets the required maps easily. Standards and policies of SDI ensured that all the data that is uploaded to database as per regulation given. How exactly these maps (temperature, rainfall and LULC) are created is discussed in detail in Sects. 7.3.2, 7.3.4, and 7.3.5 below.

Generalized data model for maps (rainfall, temperature and LULC), sometimes called as service (which should not be confused with WMS, WFS, WCS) is given below,

Generalized data model with Class diagram representation is given in Fig. 7.3, main components of SDI (which form the important classes in data model) which are, User, Geoportal, Services, Network, Metadata, Database. User can has attributes as username, password, aadhar card and address and can perform the functionalities like logging in to the system, view the geoportal and add details to the geoportal. User can be admin user, who has super user privileges. Superuser can update metadata, change the structure of database, and check whether policies and standards are followed. User can also be a general user who can access services.

Geo-portal has web address and can be implemented in any language, but it should comply with standards and policies. Geoportal will have server name, throughput and name of geoportal. Using geoportal user can upload data, download data, modify data, login to SDI, and connect to service server. Geoportal also has to comply with standards and policies.

There can be various services in SDI, there will be separate server for handling services, user can choose any type of service which is available in SDI (here services will be rainfall, temperature and LULC). These will be service provider who will provide the service. User can choose service, input locations, view service, update service data, report if there is any error in service, add and remove any service. This service portal has to comply with standards and policies.

Network is the integral part of spatial data infrastructure, access network should have good bandwidth, and there should be network name and ID, network service provider and network admin name. Access network in SDI should be able to connect all components with high speed, transfer data fast, should be able to do inter server communication, there should be auto update of metadata, auto update of database through network. Access network should also comply with policies and standards.

Spatial metadata is the information about the data (data about data). Metadata gives information like location of data, location of service, database indexing. Metadata should store location of data, search into data, should be able to search a service (for its presence). And should also be able to search analyzed maps. More

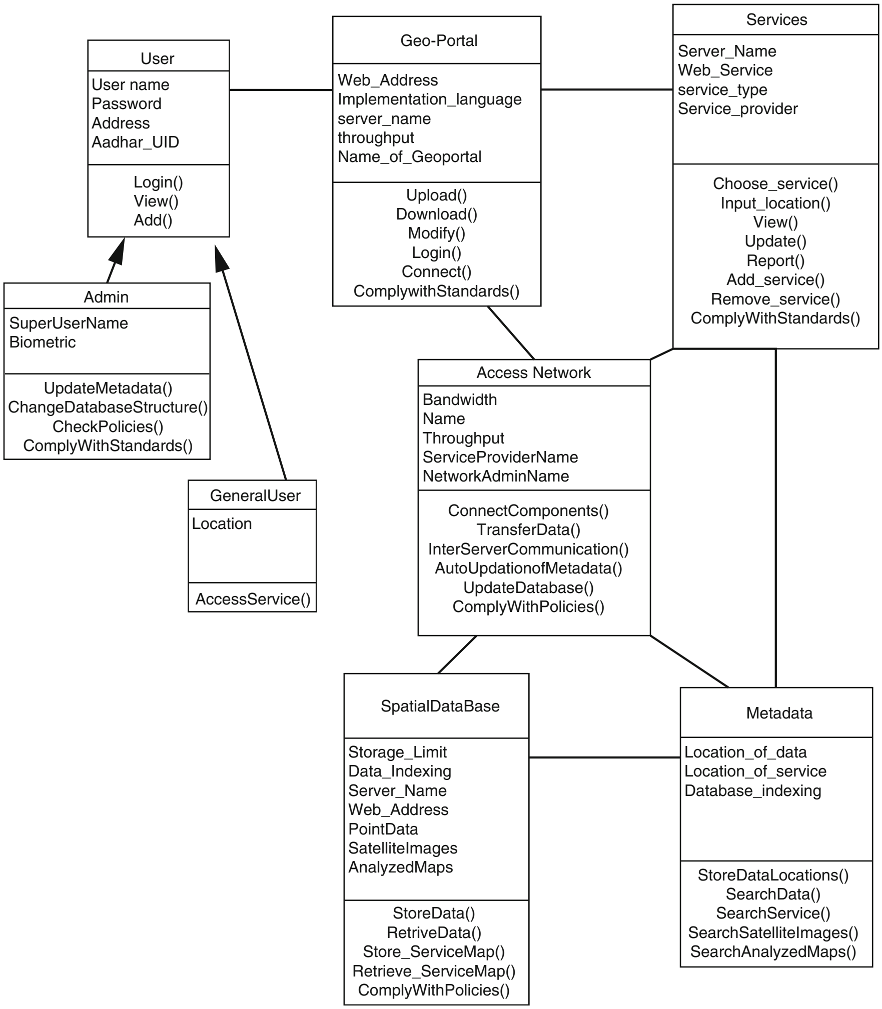


Fig. 7.3 Generalized Data Model for SDI having rainfall, temperature and LULC. (Class Diagram)

information like who created data? What was the purpose of creation of data? Where data was created? Is answered by metadata.

Spatial database will store all spatial data, it will have some limit to store thus there spatial data warehouse will come into picture. There should be data indexing, server name and web address. It should be able to store point data, satellite images, Maps etc. Important features of database like storing, retrieving data, storing service maps and retrieve service maps. This spatial database should comply with policies and standards.

7.3.2 LULC Detailing by Using Satellite Images (Landsat)

Coming back to the question which was opened in Sect. 7.3.1, How SDI gets all these layers, answer is people, organizations will create maps and upload in SDI in order to facilitate data sharing. Law says that any data created in government (federal or provincial) or government funded organization is property of government. How exactly Land use land cover map is created is discussed in this section. User can download satellite images from earth explorer and then user can open these images in GIS software.

User will perform digitization or downloaded satellite image wherein user will identify the following or classify the piece of land as Urban or buildup and which can be further classified as residential, industrial, commercial, transportation etc. It can also be classified as agricultural land, further classified as cropland, grazing, and tree plantation. Other classification include forest land further classified as mangrove forest, disturbed forest. Land can be classified as wetland, which can be further classified as forested freshwater swamp and non-forested freshwater swamp. Waterbodies can also be identified and further classified as oceans, river, lake and ponds. Classification is shown in Table 7.1 below.

Once this digitization is finished user can get LULC map of the specified area and this can be shared with other researchers, academicians and industries for planning, development and research by uploading to spatial data infrastructure.

7.3.3 LULC Detailing by Using Topo-Sheets from Survey of India (SoI)

Land use land cover map can also be obtained by digitizing the topo sheets downloaded from survey of India website. Before digitization topo sheets need to be georeferenced, this is not the case with satellite images which are already georeferenced. Firstly required topo sheets need to be downloaded from survey of India website. These topo sheets need to be georeferenced then digitized and during digitization land can be classified as per classification done in Sect. 7.3.2 or Table 7.1. How to measure the accuracy of this classification is discussed in Sect. 7.4. More detailed is the digitization process more services will be offered by SDI.

Table 7.1 Land use land cover classification

LULC Classification	Further classification
Buildup	Residential, Industrial, commercial
Agricultural Land	Cropland, grazing, tree plantation
Forest	Mangrove forest, distributed forest
Wetland	Forested freshwater swamp, non-forested freshwater swamp

7.3.4 Rainfall Detailing by Using Indian Meteorological Department Data

Rainfall data can be obtained from Indian meteorological department in excel format which include latitude longitude and amount of rainfall. Sample rainfall data is of the form as shown in table below, this data is downloaded from Indian meteorological department website (Table 7.2).

This data downloaded from IMD website is converted into excel file, of some other parameters like altitude are given then those can be kept or removed as per requirement. Once this rainfall data is converted into excel file then this excel file can be imported into GIS software like arcMap or QGIS. This excel file will form points on given latitude longitude with attribute data as average rainfall. Now rainfall at particular points on the map are available but we don't have rainfall at all locations on the map. Thus some mathematical operation like averaging is needed, this operation is available in spatial interpolation tool to get rainfall map. Thus complete rainfall map can be formed even if rainfall data at particular point is available using interpolation tool of GIS software. Now this map can be shared with people by uploading on spatial data infrastructure through its geoportal.

7.3.5 Temperature Detailing by Using Indian Meteorological Department Data

Temperature at particular station can be obtained from Indian meteorological department (IMD) website. Measurement stations measures temperature and other meteorological information, in order to create temperature map, data is typically required in this format (Table 7.3).

This data is converted into excel file, if there are other parameters in the given data then those parameters are removed. This excel file is imported to GIS software for example arcMap and them map will have points with attribute data as average temperature. Now data at spatially distributed point is available, however rainfall data at all points on map is needed thus a good tool for averaging is needed. Interpolation tool under spatial analysis can be used to create temperature map at all points on the map.

Table 7.2 Sample rainfall data downloaded from IMD website

Rainfall Station	Long	Lat	Average rainfall
Kondapur	81.59	21.43	1404.564375
Pindraon	81.52	21.4	1147.52448
Kanki	81.59	21.23	1231.59514814815
Arang	81.59	21.12	1352.85915789474
Mahasamund	82.06	21.06	1327.10440677966
Kusurungi	82	21.21	1320.79409302326

Table 7.3 Temperature data downloaded from IMD website

Temperature Station	Long	Lat	Average temperature
Akola	77.002777	20.705540	29.307
Amaravati	77.758133	20.929720	30.945
Wardha	78.606499	20.742001	28.124
Nashik	73.789803	19.997454	22.12
Jalgaon	75.562607	21.007658	24.678
Pune	73.856743	18.520430	25.537
Latur	76.560387	18.408792	24.543

Table 7.4 Assigning weights to layers

Raster/Layer name	Weights
LULC	9 (Value between 1 to 10 based on what is project)
Temperature	4 (Value between 1 to 10 based on what is project)
Rainfall	7 (Value between 1 to 10 based on what is project)

7.3.6 Weighted Sum Overlay for Decision Making or Selection of Piece of Land

Now when all the layers are created in Sects. 7.3.2, 7.3.3, 7.3.4 and 7.3.5 now decision has to be taken using GIS which location to choose for upcoming government project which can be done by the procedure which is given in this section. Open all the layers temperature, rainfall and LULC layer in GIS software. In GIS software like arcMap various tools are available for spatial analysis, weighted sum overlay tool needs to be chosen to make composite map. After opening all layers one by one and add weights to those layers. Weights from 1 to 10 are assigned as follows (Table 7.4),

If the project does not need high temperature, like cold storage project by government then assign low values to temperature map, if project need very low rainfall for example purchase ground for agriculture products the assign very low values for rainfall. Land use land cover will give free space, meteorological information and composite map by weighted sum will help to identify the best suitable free space for upcoming government project.

7.4 Verification, Accuracy and Use of this Research

In land use and land cover classification land has been classified as per table no 1, however there should be some mechanism to verify that that classification made is correct i.e. land which is classified as buildup and further classified as residential is actually a residential land. Similar verification needs to be done for rainfall and temperature map, rainfall and temperature information at the points where data was not obtained from IMD was calculated using interpolation. Thus there is need of verification of rainfall and temperature data. How this verification can be done is discussed in Sects. 7.4.1 and 7.4.2 discusses the accuracy of land use and land cover classification, Sect. 7.4.3 discusses significance of research to government agencies.

7.4.1 Verification Using Actual Ground Control Points

Verification can be done using actual ground control points for land use land cover map, temperature map and rainfall map. Few points should be reserved as ground control points in the area under consideration. Minimum number of ground control points should be kept, however increase in ground control points lead to more accuracy in all the three map layers. Map layer creator will actually visit the location with particular latitude longitude and find (temp, rainfall, LULC) at that location and which will be compared with (temp, rainfall, LULC) in map. Verification is necessary due to many reasons, some of them are errors in spatial analysis, manual error in digitization, low resolution satellite images, and outdated topo-sheets to name few.

7.4.2 LULC Accuracy Calculation (How Accurate Is Our Classification)

Following calculations must be done in order to find the accuracy of land use and land cover classification done by user. This accuracy calculation must be done to make sure that sites are correctly classified and errors (if any) are minimized. These accuracy calculation are done based on error matrix, in order to understand LULC accuracy calculation (using error matrix) an example shown in Table 7.5. In this example dummy data is taken to calculate accuracy.

Table 7.5 (this error matrix) is read as out of total 25 buildup reference sites, 18 were correctly classified as buildup, however, 3 were classified as agriculture and 4 were classified as forest.

Table 7.5 Error matrix for accuracy calculation

Error matrix for accuracy calculation		Reference data			
		Buildup	Agriculture	Forest	Total
Classified data	Buildup	**18**	4	1	23
	Agriculture	3	**28**	2	33
	Forest	4	1	**20**	25
	Total	25	33	23	**81**

7.4.2.1 Overall Accuracy

Overall accuracy is the easiest term which tells how many sites out of total number of sites classified correctly. This is usually expressed as percentage, formula for overall accuracy is given below,

Overall accuracy= (Correctly classified sites / Total No of reference sites).
In the example given in Table 7.5, overall accuracy is ((18 + 28 + 20)/80) *100 = 82.5%.

7.4.2.2 Errors of Omission

Omission error tells how many sites were omitted from the correct classification, error of omission can be calculated using the formula given below,

Errors of Omission = (Incorrectly classified reference sites/ Total No of reference sites). Thus in example given in Table 7.5 omission error is calculated as

Omission error for Buildup = ((3 + 4)/25)*100 = 28%
Omission error for Agriculture = ((4 + 1)/33) *100 = 15.15%
Omission error for Forest = ((2 + 1)/23) *100 = 13.04%

7.4.2.3 Commission Error

Commission error is in classified data, it shows how many slides are incorrectly classified as reference sites (which were omitted from its correct class). Commission error is calculated by using the formula given below,

Commission Error = incorrectly classified sites / Total No of classified sites).

For the example given in Table 7.5, commission error is calculated as below,

Commission error for Buildup = ((4 + 1)/23)*100 = 21.73%
Commission error for Agriculture = ((3 + 2)/33) *100 = 15.15%
Commission error for Forest = ((4 + 1)/25) *100 = 20%

7.4.2.4 Producer's Accuracy

Producer accuracy is defined as accuracy from the point of view of person who has created map layer. It is also called complemented omission error. Producer accuracy is given by formula given below,

Producer's Accuracy = (Correctly classified reference sites/ Total No of reference sites). Thus for example in Table 7.5 producer accuracy is,

Producer accuracy for buildup = (18/25)*100 = 72%
Producer accuracy for agriculture = (28/33)*100 = 84.84%
Producer accuracy for forest = (20/23)*100 = 86.95%

7.4.2.5 User's Accuracy

Accuracy is from the point of view of user, it tells how accurately area in the classification will be reflected on the ground. User accuracy is calculated using the formula given below,

User's Accuracy = (Correctly classified sites / Total No of classified sites).

Thus for example in Table 7.5, user accuracy is calculated as,

User accuracy for buildup = (18/23)*100 = 78.26%
User accuracy for agriculture = (28/33)*100 = 84.84%
User accuracy for forest = (20/25)*100 = 80%

7.4.2.6 Kappa Coefficient

Kappa coefficient is calculated based on statistical test, this coefficient tell how better is the classification as compared to random classification, value of kappa coefficient as zero means that classification is as good as random classification and value 1 indicates that classification is very accurate classification, It is good practice to calculate kappa coefficient for the given classification.

7.4.3 Significance of This Research to Federal and Regional Government Agencies

Consider a situation wherein government want to setup a new COVID care hospital in the region or province, these hospitals will be temporary and will be removed once the pandemic is over. For this project, government want free spaces in the heart of big cities, also it is believed that rainfall may increase the number of COVID patients in the province as microorganisms grow during rainy season and it is also believed that high temperature tend to decrease the impact of this disease as high temperature will kill most of disease causing microorganism. Considering this scenario and requirement of government, this research work can be used wherein temperature, rainfall and LULC map will be obtained from spatial data infrastructure. LULC map will give free spaces in the province and composite map can be created by overlay weighted sum, where high temperature and low rainfall is preferred. Higher weights will be given to high temperature and higher weights to low rainfall (or lower weights to high rainfall).

Similarly other examples of government projects can be setting up new school, setting up server farm, setting up cold storage, setting up IT Hubs, building Airports, National highways, performing green space analysis, setting up guest house, setting up skill development centers and starting new ocean university to name few.

7.5 Summary

Geographic information system and spatial data infrastructure is now integral part of decision making. SDI has been instrumental in economic, social and overall development of organizations, province and nation at large. Countries and continents having NSDI are using it in infinite ways for their benefit. Here the problem of finding a piece of land for government project with given temperature and rainfall requirement is discussed. Spatial data infrastructure architecture for finding land was given and data model for creating a service or map was given. Creation of map layers like LULC map using satellite images and topo-sheets was discussed, also process of creation of temperature and rainfall map was discussed. Overlay weighted sum was used to find the area of interest on map. Verification of map layers using ground control points was discussed and accuracy calculation of LULC was also discussed. Finally significance of this research to provincial and federal government agencies was discussed.

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Chapter 8
Role of Stable Isotopes in Climate Studies – A Multi-archive Approach Focusing on Holocene to Anthropocene Records

Shweta Singh and Praveen K. Mishra

Abstract In the recent years, the growing concern to understand the impact of climate variability on various aspects of human civilizations have led to developing an understanding of proxy response according to change in the environmental conditions. Among various climate-sensitive proxies (e.g., geochemistry, pollens, biomarkers, grain size, etc.), the stable isotopes are the crucial component that not only helps us to understand the climate variability in the past, but also provides a detailed understanding of past meteorological variables such as temperature and precipitation, and vegetation response with changing hydrological conditions.

The present study is focusing on the application of stable isotopes ($\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$ and δD) in order to understand the climate variability since Pleistocene to present day conditions and provide a significant insight towards understanding the role of external (solar forcings), and internal forcing factors (teleconnections, such as El-Niño Southern Oscillation – ENSO, North Atlantic Oscillation – NAO) influencing the centennial to millennial-scale climate variability. Further, using case studies from the south Asian region, we have highlighted several challenges such as the impact of post-depositional changes and moisture pathways associated with the isotopic studies. This understanding will further provide better insights of isotope behaviour in natural archives in spatially varied terrains which is essential to decipher the temporal evolution of climate.

Keywords Isotopes · ENSO · Climate variability · Paleoclimatic

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Author "Shweta Singh" was deceased on 10th May 2021.

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8.1 Introduction

The stable isotope of carbon, hydrogen, oxygen and nitrogen are considered as the most reliable proxy to understand (a) climatic variables such as temperature and precipitation, and (b) vegetation response with changing hydrological conditions (Talbot 1990; Meyers 1997; Leng and Marshall 2004; Tiwari et al. 2011; Mishra et al. 2015b; Shivam et al. 2017; Sharma and Goyal 2018; Holtvoeth et al. 2019; Kämpf et al. 2020). Also, along with other proxies, such as, geochemical and sedimentological approaches, these stable isotopes can be utilized to understand the climate variability, which in turn influence the rise and fall of civilizations (Giosan et al. 2012; Ponton et al. 2012; Sarkar et al. 2016). In the present-day condition, the increasing frequency and intensity of extreme events (flood events, heat waves, and droughts) and their impact on agriculture and health sectors have severe implications on the country's economy (Goyal and Ojha 2011; Goyal et al. 2012; Roxy et al. 2017; Shashikanth et al. 2018; Hrudya 2020). The observational data based on the instrumental records have pointed out the significant role of forcing factors (such as solar insolation and Inter-Tropical convergence zone, i.e., ITCZ[1]) as the causal mechanism for these extreme events (Goswami et al. 2006; Roxy et al. 2017). However, these instrumental records are associated with several uncertainties. Therefore, the paleoclimatic investigation came into the picture, which provides a broader understanding of the temporal evolution of climatic condition on different timescales.

In the present study, we have reviewed several case studies from south Asian region dominantly controlled by Indian and East Asian summer monsoon, focusing on applications of stable isotopes in climate reconstruction from the latest Pleistocene to Anthropocene (Fig. 8.1). In addition, we have also highlighted several challenges, such as the impact of post-depositional changes and moisture pathways on stable isotopes and their applications in climate study. The present study will provide a significant insight towards understanding the role of external (solar forcings), and internal forcing factors (teleconnections, such as El-Niño Southern Oscillation – ENSO, North Atlantic Oscillation – NAO[2]) influencing the centennial to millennial-scale climate variability from latest Pleistocene to Anthropocene.

The present chapter is divided into four sections: Sect. 8.2 discusses the basic concept of isotopes and their responses in various natural archives; Sect. 8.3 provides a detailed understanding of various climatic events since latest Pleistocene, and their causal mechanisms; and finally, Sect. 8.4 addresses the challenges associated with the application of stable isotopes in paleoclimatic studies.

[1] ITCZ is a band of low-pressure region near equator, which determines the onset and intensity of precipitation in the Indian sub-continent (Fleitmann et al. 2003).

[2] NAO is large scale weather phenomenon observed in the North Atlantic Ocean, and characterised by the pressure difference between Icelandic low and Azores high (McManus et al. 2004).

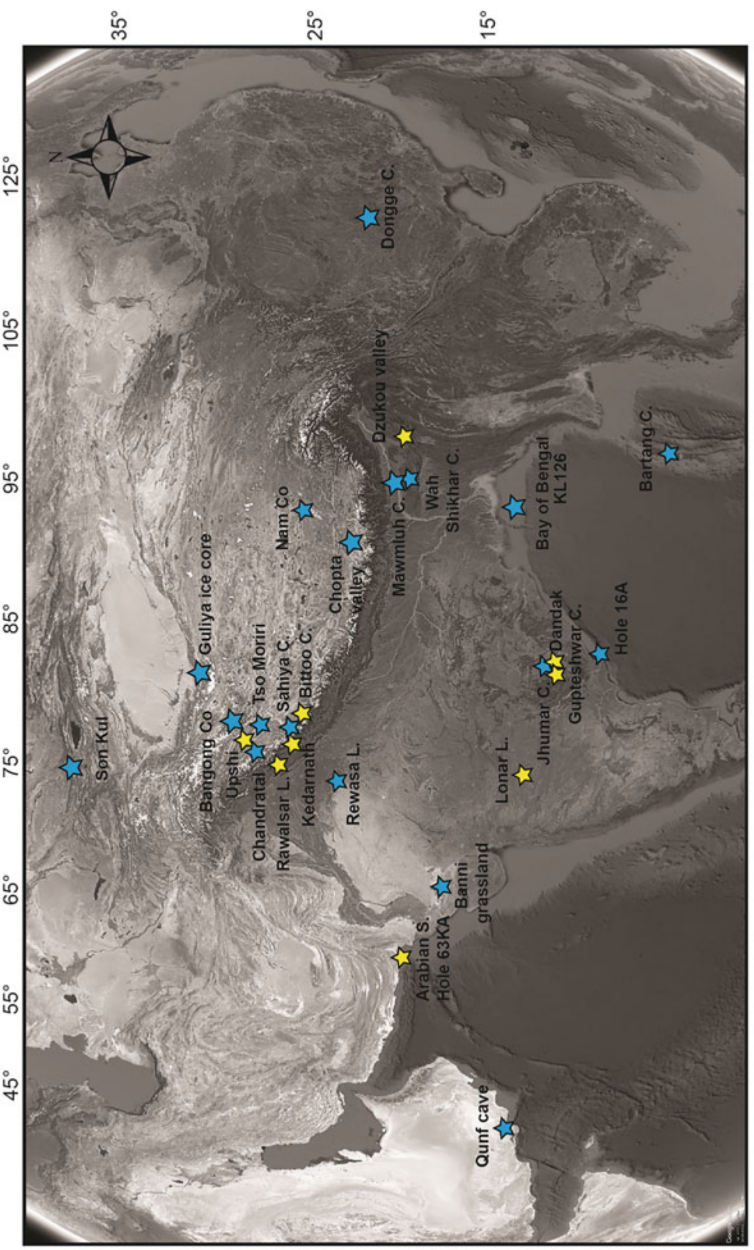

Fig. 8.1 Location map for the isotope records used in the present study. Blue star indicates, records used for climate reconstruction (please refer Figs. 8.2 and 8.3); and yellow star indicates other records discussed in the text

8.2 Basics of Isotopes

Isotopes are the variant of any element with the same number of protons but the different number of neutrons (White 2013). Fundamentally, isotopes are divided into two main groups which includes, radioactive isotope (unstable isotope) and stable isotopes. The radioactive isotopes are characterized by unstable nuclei, which consequently decays and dissipate excess energy in the form of alpha (α), beta (β) and gamma (γ) rays (Dickin 2005; White 2013). Each radioactive elements have characteristics half-life,[3] which is being used to establish the geological age of various objects or climatic events. Dating plays a crucial role in determining the past climate as it establishes the synchronicity between climatic events and depositional sedimentary sequences (Ramsey 2008; Blaauw and Christeny 2011; Törnqvist et al. 2015). For example, for the older sedimentary sequences, U-Th ($U_{half\text{-}life}$ = 245250 years; $Th_{half\text{-}life}$ = 75690 years), and ^{14}C (half-life = 5320 years) have been commonly used radioisotopes for the dating, whereas ^{210}Pb (half-life = 22 years), and ^{137}Cs (half-life = 30 years), are being used for relatively recent sediments (goes up to century-old record) (Turekian et al. 1983; Bard et al. 1990; Cheng et al. 2000; Robison et al. 2003). In addition, several other radioisotopes (e.g., ^{39}Ar; half-life 269 years, ^{40}K; half-life 1.28*109 years) can also be used to develop an age-depth model of sedimentary sequences (Muse and Safter 1982; Ebser et al. 2018). However, it is difficult to discuss this in details, as it is beyond the scope of this chapter.

Further, the stable isotopes are non-radioactive and are characterized by stable nuclei (White 2013). During the natural processes (e.g., evaporation, condensation, phase change, photosynthesis) the mass-dependent fractionation of stable isotopes ($\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$ and δD) provides a detailed understanding of variable climatic parameters and change in the hydrological conditions (Talbot 1990; Meyers and Lallier-Vergès 1999; Altabet 2006; Günther et al. 2015; Prasad et al. 2016). In paleoclimate studies, the application of these environmental isotopes in range of natural archives such as lake and marine sediments, peat sequences, ice cores and speleothems demonstrated their robustness for climate reconstruction (Yao et al. 1997; Tiwari et al. 2003; Yadava and Ramesh 2005; Staubwasser and Weiss 2006; Mishra et al. 2015a; Rawat et al. 2015). In isotopic studies, the isotopic composition of a compound is represented with reference to standards (Table 8.1), depending upon the isotopes (see Eq. 8.1). For example, in the case of carbon isotopes, the relation is represented as (Eq. 8.1).

[3] Half-life is the time taken by the radioactive nuclei to decay and reduce to half of its original values (White 2013).

$$\delta^{13}C = \left(\frac{\left({}^{13}C/{}^{12}C \right)_{sample}}{\left({}^{13}C/{}^{12}C \right)_{standard}} - 1 \right) * 1000\backslash \text{fontencoding}\{U\}\backslash \text{fontfamily}\{\delta\ \text{wasy}\}\backslash\ \text{char } 104 \quad (8.1)$$

For the purpose of climate reconstruction, the most frequently used stable isotopes are $\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$ and δD (Table 8.1). In this section we briefly discussed the key points of stable isotopes and their applications in paleoclimate studies using various archives.

8.2.1 Stable Isotopes of Carbon ($\delta^{13}C$), Oxygen ($\delta^{18}O$), Nitrogen ($\delta^{15}N$) and Hydrogen (δD)

The stable isotope of oxygen, carbon and hydrogen are commonly used to understand the paleo-temperature and precipitation history in the region (Yao et al. 1997; Meyers and Lallier-Vergès 1999; Günther et al. 2015; Mishra et al. 2015b; Ali et al. 2018). These isotopes are frequently used in ice cores, speleothems, microfossils (e.g., foraminifera, gastropod shells), marine and lake sediments (Thompson 2000; Staubwasser and Weiss 2006; Lachniet 2009; Mishra et al. 2015a; Sinha et al. 2015; Dutt et al. 2018; Misra et al. 2020).

The variability in $\delta^{18}O$ is primarily controlled by the evaporation, moisture sources and temperature fluctuation at the time of carbonate mineral precipitation (Talbot 1990; Yu et al. 2009; Dixit et al. 2014a; Dutt et al. 2020). However, the $\delta^{13}C$ in bulk carbonate is mainly governed by dissolved inorganic carbon, CO_2 exchange between the atmosphere and residual water and, aquatic productivity (Meyers and Lallier-Vergès 1999; Leng et al. 2010; Saini et al. 2017). In speleothems, $\delta^{18}O$ value is dependent on drip water composition and cave temperature (Lachniet 2009), whereas in marine settings, sea surface temperature at which carbonate mineral precipitates; and the isotopic composition of residual water are the dominant factors controlling $\delta^{18}O$ composition (Maslin and Swann 2005). However, other parameters such as moisture source, the latitudinal difference in $\delta^{18}O$ composition, local precipitation, input from river or glacial discharge, and evaporation may complicate the interpretation of $\delta^{18}O$ in both the marine and speleothem (Clark and Fritz 1997). In the case of speleothems, the enriched values for $\delta^{18}O$ are inferred as low precipitation condition where else the depleted values for $\delta^{18}O$ suggest the high precipitation condition in the region (Bar-Matthews et al. 2003) (Figs. 8.2a–c and 8.3a–e).

Further, in marine sediments, the $\delta^{13}C$ and $\delta^{18}O$ of bulk carbonate is mostly being used to reconstruct past climatic condition in terms of atmospheric precipitation, thermohaline circulation patterns, sea surface temperature, aridity, and upwelling intensity (Kudrass et al. 2001; Maslin and Swann 2005; Staubwasser and Weiss 2006; Govil and Naidu 2010). In the tropical region, the $\delta^{18}O$ is related to the sea surface temperature. For example, the higher $\delta^{18}O$ is related to colder/drier climatic

Table 8.1 Isotopes used in climate studies

S. No.	Isotopes	Sampling material	Extracted information	Standards used
1.	$\delta^{18}O$	Marine and Lacustrine sediments Ice core, Cave deposits, Groundwater, Rain water	Temperature and precipitation reconstruction, Moisture sources identification	NBS 18, NBS 19, IAEA-CO8
2.	$\delta^{13}C$	Marine and Lacustrine sediments Cave deposits, leaf wax,	Source of organic matter, Temperature and precipitation reconstruction Carbon cycle	IAEA- CH_3, USGS-40
3.	$\delta^{15}N$	Marine and Lacustrine sediments	Source of organic matter, Anthropogenic traces Nitrogen cycle	KNO_3, USGS-40
4.	δD	Groundwater, Rain water, Ice Cores, leaf wax	Moisture source identification, Precipitation reconstruction	RM 8535, RM 8537

condition, whereas, depleted $\delta^{18}O$ demonstrated warmer condition (Fig. 8.2e) (Kudrass et al. 2001; Prabhu et al. 2004). However, this condition is complicated over the polar region, where the depleted $\delta^{18}O$ is related to the colder environment, and enriched values points out the warmer condition (Andersen et al. 2004). This is due to relative fractionation between ^{18}O and ^{16}O. During the colder environment (ice ages), due to relatively low temperature at the tropical region, the water vapour condenses easily resulting in enriched ^{18}O in the ocean water, and depleted value in residual water vapour. Further, the residual water vapour containing depleted $\delta^{18}O$ precipitates in the polar region, and gets locked in ice sheets. Thus, the depleted $\delta^{18}O$ composition of ice sheets (or ice cores) demonstrated low atmospheric temperature in the region (Fig. 8.2f) (Thompson 1997). In contrast, as the warming increases, the ice melts, resulting in a contribution of depleted $\delta^{18}O$ in the ocean water (Alley 2000).

In the lake basin, the behaviour of $\delta^{13}C$ and $\delta^{18}O$ is largely dependent on the relation between inflow versus evaporation processes. In a closed lake basin, as the evaporation increases, both $\delta^{13}C$ and $\delta^{18}O$ shows enriched values representing negative water balance (Mishra et al. 2015b; Talbot 1990). However, certain other parameters, such as lake alkalinity, carbon cycling, factors influencing $\delta^{18}O$, lake level stabilization may also affect the relation between $\delta^{13}C$ and $\delta^{18}O$ (Hillman et al. 2020).

The stable isotope of carbon and nitrogen in bulk organic sediments are commonly used to understand the source and fate of organic matter which in turn is related to both climatic and anthropogenic inputs (Kohn 2010; Prasad et al. 2016; Ali et al. 2018; Sharma et al. 2020; Singh et al. 2020). In case of $\delta^{13}C$, the isotopic composition of the organic sediments are dependent on the photosynthetic pathways (C3, C4, or CAM) and dissolved inorganic carbon (DIC) composition in water (O'Leary 1981 1988; White 2013). The $\delta^{13}C$ ratios in terrestrial vegetation vary between –34‰ to –24‰ and –16‰ to –10‰, for C_3 and C_4 type plants,

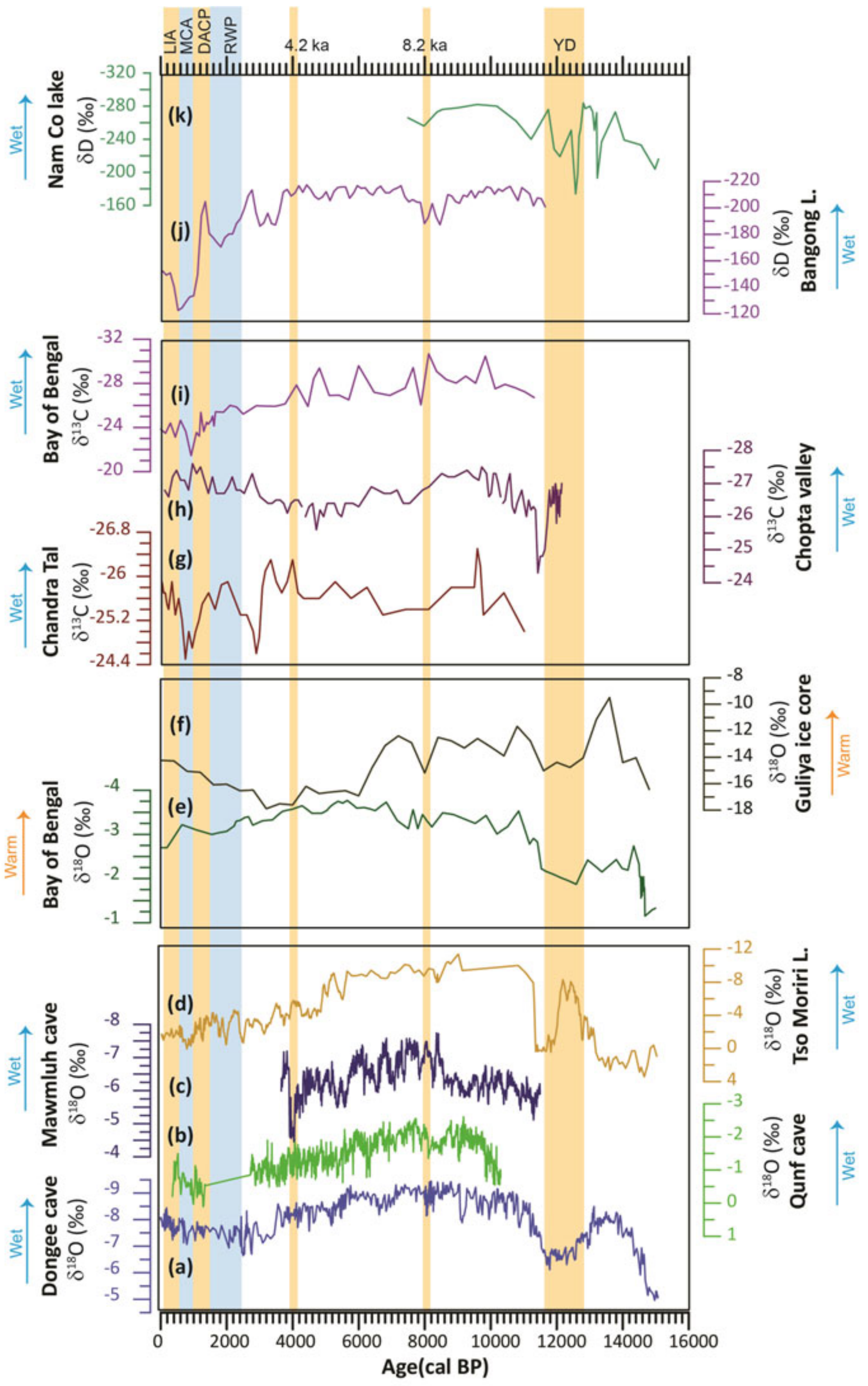

Fig. 8.2 Climate records from South Asian region based on different isotopes from ~ 16000 cal year BP to present (bottom to top): (**a**) $\delta^{18}O$ of speleothem from Dongge cave, SE China (Dykoski

respectively, whereas, plants from the arid regions (Crassulacean Acid Metabolism plants, i.e., CAM) have typical values ranging between –20‰ and –10‰ (Meyers and Ishiwatari 1993). In addition, in lake sediments and peat sequences, the $\delta^{13}C$ variability may also directly related to rainfall condition in the region (Kohn 2010) (Fig. 8.2g–i). Further, the nitrogen isotopic composition of organic sediments provides a detailed understanding of lacustrine productivity, human-induced changes, and trophic status in the basin (Altabet 2006; Menzel et al. 2014). The terrestrial plants assimilate nitrogen from the atmosphere with their $\delta^{15}N$ ratio varies from –1‰ to 1‰, whereas in lakes, phytoplankton $\delta^{15}N$ ratio ranges between 3‰ and 8‰ depending on lake productivity, dissolved inorganic nitrogen content, nitrification and anthropogenic activity in the catchment (Talbot and Johannessen 1992; Altabet 2006).

In recent decades, the application of hydrogen isotope (δD) has increased significantly, as it has an advantage over the conventional proxies because of its inherent property to represent the isotopic signal of source water (Günther et al. 2015; Saini et al. 2017; Holtvoeth et al. 2019). Depending upon the vegetation source, the variation in δD values represents ambient moisture source (in case of terrestrial vegetation), whereas for aquatic vegetation, it corresponds to physico-chemical condition of the lake water (Günther et al. 2015). The higher δD deciphers high leaf/soil evapotranspiration and thus relatively drier climatic condition, whereas, during the wet condition, δD shows depleted values (Lauterbach et al. 2014) (Figs. 8.2j–k and 3h). However, as similar to $\delta^{18}O$, the δD of meteoric water is also influenced by temperature, latitudinal and altitudinal difference from source to sink, amount of precipitation and evapotranspiration (Günther et al. 2015; Holtvoeth et al. 2019). Therefore, in such cases, the compound specific isotopic analysis (CSIA) of bulk organic sediments from the lake or marine settings or the vegetation samples, provides a detailed understanding of past hydrological condition.

Fig. 8.2 (continued) et al. 2005); (**b**) $\delta^{18}O$ of speleothem from Qunf cave, Oman (Fleitmann et al. 2003); (**c**) $\delta^{18}O$ of speleothem from Mawmluh cave, NE Himalaya (Berkelhammer et al. 2012); (**d**) $\delta^{18}O$ of lake sediments from Tso Moriri lake, NW Himalaya (Mishra et al. 2015b), (**e**) $\delta^{18}O$ of Globigerina ruber from Hole KL126 from Bay of Bengal (Kudrass et al. 2001); (**f**) $\delta^{18}O$ of Guliya ice core, Tibetan plateau (Thompson 1997), (**g**) $\delta^{13}C$ of bulk organic sediments from Chandra Tal, NW Himalaya (Rawat et al. 2015); (**h**) $\delta^{13}C$ of sedimentary sequence from Chopta valley, NE Himalaya (Ali et al. 2019); (**i**) $\delta^{13}C_{n\text{-}C29}$ of marine core sediment (Hole 16A; from Bay of Bengal) (Ponton et al. 2012), (**j**) δD of leaf wax from Bangong lake, NW Himalaya (Hou et al. 2017); (**k**) δD of core sediment from Nam Co lake, Tibetan plateau (Günther et al. 2015). (*LIA:* Little Ice Age, *MCA:* Medieval Climate Anomaly, *DACP:* Dark Age Cold Period, *RWP:* Roman Warm Period, 4.2 ka: 4.2 ka cold event; 8.2 ka: 8.2 ka cold event, *YD:* Younger Dryas)

8.3 Climate Extremities from Latest Pleistocene to Present

The time period from latest Pleistocene (~16000 cal year BP) to present-day condition carries great importance in climate study owing to its impact on Earth's climate and their significant effects on the ecosystem and human civilizations (Menounos et al. 2009). In recent decades, the paleoclimatic study based on marine and lake sediments, ice cores and speleothems, focusing on the latest Pleistocene and Holocene climate variability has pointed out several short term, millennial to centennial-scale climate variability. However, the timing of these events in different archives are not always synchronous due to the interaction of multiple factors such as proxy and archive response, sample resolution, dating uncertainty and moisture regimes (Wang et al. 2010; Mishra et al. 2015a). Further, the impact of these short-term climatic events, on various civilization and societies around the world has provided significant insight to our understanding of culture-climate link. In this section, we have discussed the application of stable isotopes in understanding various small scale climate incursion during the latest Pleistocene to present.

8.3.1 Younger Dryas (YD)

The period after last glacial maxima is marked by the shift from glacial to the interglacial period (Platt et al. 2017). This interglacial era (initiating from ~14500 cal year BP) witnessed a phase of cold climate conditions termed as Younger Dryas (~12900–11700 cal year BP) (Fig. 8.2). The period was named after flower growing in colder climate condition *Dryas octopetala* (Peteet 1995). The YD was characterized by the anomalously low atmospheric temperature all over the globe. For example, during YD, in Greenland, the temperature decreased ~10 °C, whereas in Cariaco basin (Venezuela) it goes below 3 °C (Alley 2000; Lea et al. 2003). Further, this abrupt global event witnessed sudden cooling and drier climatic condition over the northern hemisphere (Rein et al. 2005; Kramer et al. 2010; Mishra et al. 2015a; Yan et al. 2018; Ali et al. 2019) (Fig. 8.2d, h). This event is caused due to sudden influx of melt-water into North Atlantic from the rapidly melting Laurentide ice sheets resulting in the weakening of thermohaline circulation (McManus et al. 2004; Lynch-Stieglitz et al. 2011). Further, this is also supported by the study from Antarctica (Dome C), based on δD illustrating the "*bipolar seesaw*" condition in Atlantics during the Younger Dryas (Augustin et al. 2004). In the Indian sub-continent, this climatic event is well documented in several archives. For example, withing the dating uncertainities, the speleothem records from Mawmluh (northeastern India) and Dongge cave (SE China), show enriched $\delta^{18}O$ values during the YD cold interval (Dutt et al. 2015; Dykoski et al. 2005) (Fig. 8.2a, c). The increased $\delta^{18}O$ in speleothems demonstrated relatively drier and low rainfall condition corresponding to YD. Similarly, the enriched $\delta^{18}O$ from marine (Bay of Bengal), and lake (Tso Moriri, NW Himalaya) sediments pointed out the dominance of aridity during YD (Kudrass et al. 2001; Mishra et al. 2015b) (Fig. 8.2d, e). In contrast, the depleted $\delta^{18}O$ values from the ice core (Guliya) record suggested a decrease in temperature during this period (Thompson 1997) (Fig. 8.2f). The YD event also mirrors with the phase of desert expansion in northwestern India and the migration of people towards the southern and southeastern part of India (Fuller 2015).

8.3.2 8.2 ka Cold Event

The global cooling event observed in several records marks the end of the Early Holocene period at around 8.2 ka (Fig. 8.2). This cold event lasted for ~150 years and is well correlated with Bond event[4] 5 (Thomas et al. 2007; Kobashi et al. 2007). The record is well studied using archives like speleothem, marine and lake sediments showing a sharp decrease in temperature over the northern hemisphere (Hughen et al. 2000; Lachniet et al. 2004; Gupta et al. 2005; Cheng et al. 2009; Liu et al. 2013; Dixit et al. 2014b). Over the Indian subcontinent, the colder climate condition of this period corroborates well with the record based on enriched $\delta^{13}C$ ratio in peat section from Chandra Tal (Northwest Himalaya) (Rawat et al. 2015) (Fig. 8.2g), and enriched $\delta^{18}O$ ratio from Mawmluh (Berkelhammer et al. 2012; Dutt et al. 2015) and Qunf cave (Fleitmann et al. 2003) (Fig. 8.2b–c). Additionally, the temperature record from the Guliya ice core (Tibetan Plateau) based on $\delta^{18}O$ ratio suggested a decrease in temperature during this period (Thompson 1997) (Fig. 8.2f). Further, the study from Riwasa lake (Dixit et al. 2014b) based on $\delta^{18}O$ indicated the abrupt decline in summer monsoon precipitation, which corroborates with $\delta^{18}O$ records from Dongge cave (China) (Dykoski et al. 2005), and $\delta^{13}C$ of leaf wax from marine sediment (Bay of Bengal) (Ponton et al. 2012), and δD from Bangong (Hou et al. 2017) and Nam Co (Günther et al. 2015) Lake (Fig. 8.2a, i–k). This cold and dry period reflects large flux of melt-water into the north Atlantics due to the draining of glacial lakes Agassiz and Ojibway which are fed by the remains of the Laurentide Ice sheets which in turns modulated the thermohaline circulation (Ellison et al. 2006).

8.3.3 4.2 ka Cold Event

The period during the end of mid-Holocene is characterized by extreme cold, and the most severe arid climatic condition is known as 4.2 ka event. This period marks the initiation of the Meghalayan age (also known as the period of "Holocene Turnover"

[4] Bond events are colder millennial scale event characterised by ice-rafted debris in North Atlantic Ocean (Bond et al. 1997). Total Eight such cold event have been observed (11.1, 10.3, 9.4, 8.1, 5.9, 4.2, 2.8, 1.4 ka) during the Holocene epoch.

owing to the significant change in the climatic condition) (Walker et al. 2018). The cold event corresponds to Bond event-3, which lasted for ~300 years (Bond et al. 2001). Over the Indian subcontinent, 4.2 ka cold event is one of the most intense cold phases and also linked to the collapse of the Harappan civilization (Dixit et al. 2014a; Mishra et al. 2020). This cold event is well documented in Tso Kar Lake and Chandra Tal from NW Himalaya (Wünnemann et al. 2010; Rawat et al. 2015). The records based on $\delta^{18}O$ from Mawmluh cave, Kotla Dahar, Son Kul Lake and Guliya ice core indicated towards the cold and dry period during this interval (Thompson 1997; Berkelhammer et al. 2012; Lauterbach et al. 2014; Dixit et al. 2014a) (Figs. 8.2b, f and 8.3f, h). The abrupt drought condition during this period was caused due to sudden North Atlantic cooling (Bond et al. 2001). In the Indian sub-continent, study from the Arabian sea (Staubwasser and Weiss 2006) and lake records (Prasad et al. 2014) have pointed out the crucial role of increased El-Niño[5] events, which prevented the further northward propagation of ITCZ due to increased northward cross-equatorial energy fluxes (Haug et al. 2001; Rein et al. 2005; Bischoff and Schneider 2014).

8.3.4 Roman Warm Period (RWP)

The RWP period, ranges between 2550 and 1550 cal year BP (~600 BC–400 AD), is the warmest period since 2000 years (Ljungqvist 2010; Singh et al. 2020). A recent study from the Mediterranean Sea by Margaritelli et al. (2020) suggested that during RWP, the sea surface temperature was relatively higher (~2 °C) as compared to the present-day condition. In the historical point of view, this period was considered as the most favourable phase for growth and development of various civilization in Roman and Indian history (McCrindle 1877). Due to the increase in trade and agricultural activity during this phase, the period is also known as the "Golden age of India" (McCrindle 1877; Singh et al. 2020). In the Indian subcontinent, based on the depleted $\delta^{18}O$, several paleorecords (Sahiya and Borar cave speleothems, Kotla Dahar paleolake, and Banni Grassland in western India) show enhanced monsoonal precipitation during this phase (Dixit et al. 2014a, b; Kathayat et al. 2017; Pillai et al. 2017; Singh 2018) (Figs. 8.3a–b, f–g). Further, based on $\delta^{18}O$ ratio, the temperature reconstruction from Guliya ice core and marine sediments from the Bay of Bengal suggested increased sea surface temperature during this climate event (Thompson 1997; Kudrass et al. 2001) (Fig. 8.2e–f). The period is described as the manifestation of increasing solar activity which is turn triggered the warming of North Atlantics and the latitudinal shift of ITCZ (Haug et al. 2001; Solanki et al. 2004; Martín-Puertas et al. 2009).

[5] El-Niño is the warm phase of El-Niño Southern Oscillation (ENSO), characterised with warmer ocean in central and east-central equatorial Pacific. The El-Niño events are negatively correlated with the Indian summer monsoon precipitation (Goswami 2006).

8.3.5 Dark Age Cold Period (DACP)

The period from ~1550 to 1000 cal year BP is characterized by the extreme cold conditions and marks the transition from late Antiquity to the early Middle age in Europe and corresponds to Bond event 1 (Bond et al. 2001; Wanner et al. 2011). The period is also known as "migration period" in Europe because of mass migration and invasion of Germanic tribe into the Roman Empire (Helama et al. 2017). Over the Indian subcontinent, this phase of weak monsoon precipitation has subsequently led to the decline in Gupta dynasty (McCrindle 1877). The weak monsoonal condition during DACP is well corroborated with several paleoclimate records from the Indian subcontinent. For example, $\delta^{13}C$ record from Kedarnath, Ladakh and Chandra peat bog (Rawat et al. 2015; Srivastava et al. 2017; Sharma et al. 2020) along with the record from Rewalsar Lake (Singh et al. 2020) suggested weak precipitation condition in the NW Himalaya. The result is well corroborated with enriched $\delta^{18}O$ from Arabian Sea sediments, Sahiya and Bartang cave (Staubwasser and Weiss 2006; Laskar et al. 2013; Kathayat et al. 2017) (Fig. 8.3b, e). This phase of cold climate is considered as the reflection of the negative phase of North Atlantic Oscillation (NAO) which linked with the decreased solar activity in the northern hemisphere (Gray et al. 2010; Singh et al. 2020).

8.3.6 Medieval Climate Anomaly (MCA)

During the period from ~1000 to 600 cal year BP (~950 AD–1400 AD), the warm climate conditions prevailed in the northern hemisphere is described as MCA or the medieval warm epoch (Crowley and Lowery 2000). The climate anomaly is well documented in the records based on speleothems (Kathayat et al. 2017; Sinha et al. 2011), peat and sedimentary sequences from Himalaya (Rawat et al. 2015; Ali et al. 2019) and δD records from Son Kul (Lauterbach et al. 2014) (Figs. 8.2g, h and 8.3b–c, h). This period of warm and wet climate is also discussed in Sainji cave (Uttarakhand), as well as Borar cave (Himachal Pradesh) and marine sediments from the Bay of Bengal and Arabian sea sediments based on variability in $\delta^{18}O$ values (Kudrass et al. 2001; Kotlia et al. 2015; Singh 2018). In addition, the $\delta^{18}O$ ratio from the Greenland ice core (GISP2) suggested that the temperature during the MCA was warmer (~1 °C) than the modern-day temperature (Rasmussen et al. 2006). In addition, the temperature anomaly from northern hemisphere and Spannagel cave (central Europe) also directed towards the warmer conditions during this period, suggesting the global impact of MCA (Andersen et al. 2004; Mangini et al. 2005; Mann et al. 2008). The probable cause of this event is due to less volcanic activity and higher solar irradiance. In addition, the northward migration of ITCZ also caused the enhanced precipitation in the northern hemisphere (Bradley 2003; Zhou et al. 2011).

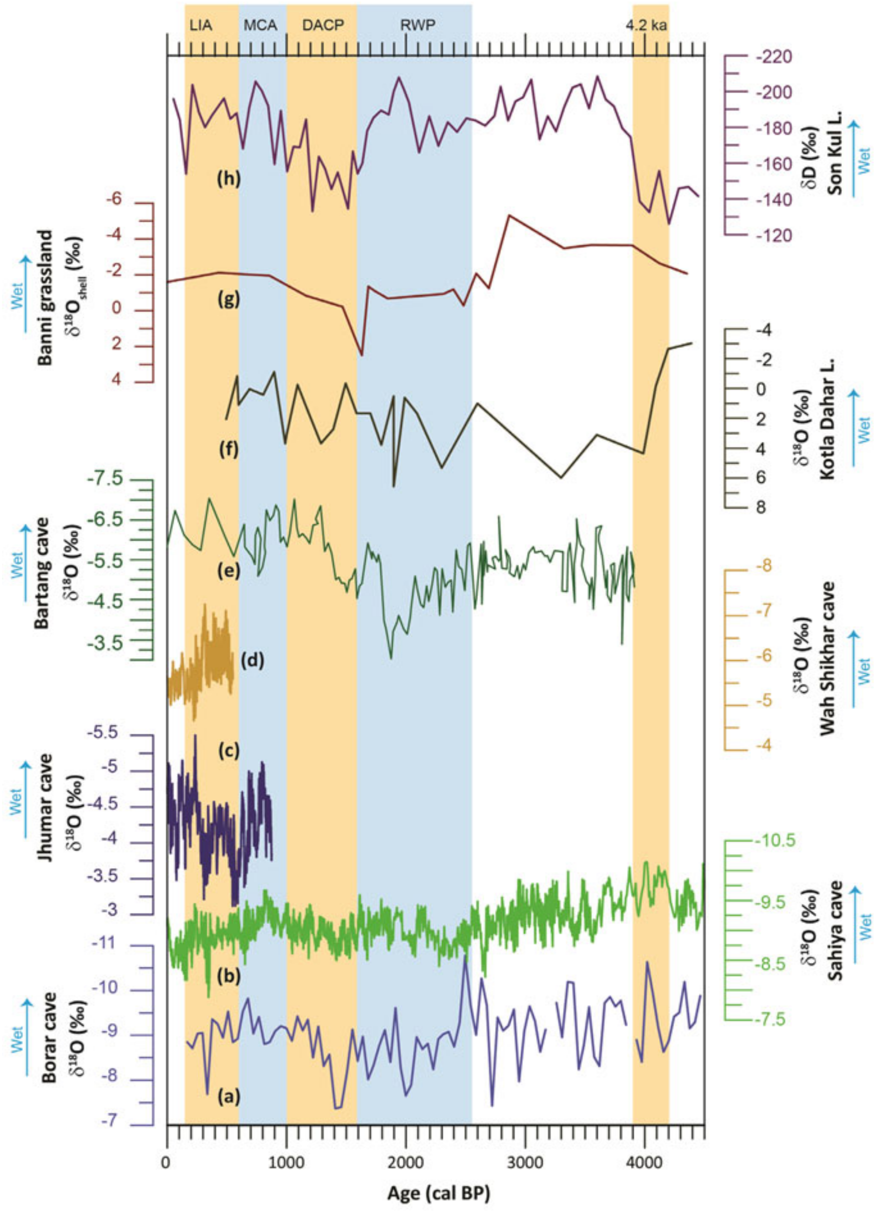

Fig. 8.3 Climate records from South Asian region based on different isotopes from ~4500 cal year BP to present (bottom to top): (**a**) $\delta^{18}O$ of speleothem from Borar cave, Kashmir (Singh 2018); (**b**) $\delta^{18}O$ of speleothem from Sahiya cave, NW Himalaya (Kathayat et al. 2017); (**c**) $\delta^{18}O$ of speleothem from Jhumar cave, Central India (Sinha et al. 2011); (**d**) $\delta^{18}O$ of speleothem from Wah Sikhar cave, NE Himalaya (Sinha et al. 2011); (**e**) $\delta^{18}O$ of speleothem from Bartang cave, Andaman region (Laskar et al. 2013); (**f**) $\delta^{18}O$ of Gastropod shells from Kotla Dahar, western India

8.3.7 Little Ice Age (LIA)

The period from ~600 to 150 cal year BP is considered as the one among the coldest interval in the northern hemisphere characterised with ~0.6 °C decrease in temperature relative to average temperature during past millennia (Bradley and Jonest 1993; Mann 2002). The cold event during this period is significantly marked in several high resolution speleothem records (such as, Jhumar, Sahiya, Bartang, and Wah Sikhar caves) from the Indian subcontinent (Sinha et al. 2011; Laskar et al. 2013; Kathayat et al. 2017) (Fig. 8.3c–e). Additionally, the record from Chandra Tal (Rawat et al. 2015), Tso Moriri lake (Dutt et al. 2018), Rewalsar Lake (Singh et al. 2020), Kedarnath and Ladakh peat bog (Srivastava et al. 2017; Sharma et al. 2020), sedimentary profile from Sikkim (Ali et al. 2019) also suggested cold and dry climate during this period (Fig. 8.2d, g–h). During this cold event, the increased volcanic activity, reduced solar insolation and southward shift of the ITCZ hastened the cold climate condition and weak monsoonal precipitation over Indian subcontinent (Haug et al. 2001; Solanki et al. 2004; Miller et al. 2012; Slawinska and Robock 2018).

8.4 Challenges and outlook

Stable isotopes are a powerful tool to understand past hydrological condition, vegetation changes, and atmospheric and ocean circulations. Several studies have focused on various isotopes ($\delta^{18}O$, δD, $\delta^{13}C$, $\delta^{15}N$), to decipher the past climatic condition and there controlling factors (Govil and Naidu 2010; Lauterbach et al. 2014; Kathayat et al. 2017; Ali et al. 2019). Although these proxies are frequently used for climate reconstruction, there are certain issues associated with the analysis and their interpretations.

The stable isotopes of bulk organic sediments provide useful insight to understand the fate and source of organic matter (Talbot and Johannessen 1992; Leng and Marshall 2004; Prasad et al. 2014; Holtvoeth et al. 2019). The isotopic composition of these organic sediments is largely influenced by vegetation type and photosynthetic pathways. However, during the early sedimentation bacterial degradation and diagenesis, can affect the isotopic composition of sediments, which leads to wrong interpretation of depositional environment (Ankit et al. 2017; Holtvoeth et al. 2019; Naafs et al. 2019). To overcome this issue, compound-specific isotopic analysis of particular extracted compound (e.g., alkanes) from the sediments can be performed

Fig. 8.3 (continued) (Dixit et al. 2014a, b); (**g**) $\delta^{18}O$ of Mollusc shells from Chachi core, Banni grassland, western India (Pillai et al. 2017); (**h**) $\delta D_{n\text{-}C29}$ from Son Kul lake, Kazakhstan (Lauterbach et al. 2014). (*LIA:* little Ice Age, *MCA:* Medieval Climate Anomaly, *DACP:* Dark Age Cold Period, *RWP:* Roman Warm Period, 4.2 ka: 4.2 ka cold event) to understand the past environmental condition and moisture changes in the region. The isotopic composition of the individual carbon chain length is dependent on fractionation due to the photosynthetic pathways, thus, the role of any other external factors such as salinity change, and the isotopic value of DIC or degradation is minimal (Holtvoeth et al. 2019).

The isotopic investigation of precipitation (δD and $\delta^{18}O$) contributes a detailed understanding of synoptic-scale atmospheric circulation, local and regional hydrological cycles, and contributing moisture sources in the region (Sarkar et al. 2016; Jeelani et al. 2017; Vuille 2018). However, the behaviour of these proxies is highly sensitive to temperature, moisture source, trajectory, mixing, and phase changes (Sengupta and Sarkar 2006; Guenther et al. 2013). Therefore, a detailed insight of these factors, along with the isotopic data of modern precipitation from meteorological stations (e.g., Global Network for Isotopes in Precipitation – GNIP) and validation with general circulation model (GCM) is crucial to advance our understanding of the hydrological cycle and the dominating factors controlling the isotopic composition of precipitation (Vuille 2018). However, the spatially heterogeneous distributed stations and lack of modern isotopic data hinders our understanding of modern precipitation condition, which further can be utilized for paleoclimatic studies. Therefore, it is important to spatially increase the number of stations and strengthen the isotopic network for better understanding of processes controlling the isotopic composition of precipitation (Panarello et al. 1998). In addition, the comparison of isotopic data with other multiproxy data may also reduce the uncertainty associated with these datasets, thus providing a better insight of the factors controlling climate variability in the past. Further, the implementation of these understanding on tropical archives (e.g., lake and marine sediments, ice cores, speleothems), facilitate the reconstruction of past environmental and hydrological conditions and discern the extreme climatic events and their causal mechanisms.

8.5 Conclusion

In the last few decades, the application of stable isotopes ($\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$ and δD) has increased manifold, in order to understand present and past climatic variability in both the terrestrial (e.g., lake sediments, peat sequence, speleothems, and ice cores) and marine archives. The sensitivity of these isotopes for various natural processes (e.g., evaporation, condensation, and phase change) makes them an ideal proxy to understand past and present climatic condition, temperature and precipitation changes, vegetation response with changing hydrological condition and physical, biological and chemical processes in the ocean. In this study, we have attempted to summarize the application of stable isotopes in understanding the climate extreme from latest Pleistocene to present. These centennial to millennial scale climate extremes, from all over the globe are dominantly controlled by solar insolation, thermohaline circulation, and coupled ocean-atmospheric phenomenon (e.g., ENSO, NAO). In addition, we have highlighted several issues (such as impact of post-depositional changes and moisture pathways) associated with isotopic studies, which lead to the modulation of isotopic values in various environmental conditions. Additionally, we consider this vital to have high resolution and easily accessible modern isotopic data for developing better understanding of isotopic behaviour in the climate at spatially varied terrains which is essential to decipher the temporal evolution of climate.

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Chapter 9
Integration of Climate Model & Hydrology Model-Tools, Bias-Correction, Downscaling, & Future Focus

Jew Das, Manish Kumar Goyal, and N. V. Umamahesh

Abstract The current chapter provides an overview of climate change impact assessments in water resources, as well as the techniques and procedures that underpin it. In addition, the generally utilised impact analysis process, such as the integration of climatic and hydrological models, is discussed. The authors have produced a case study over a river basin so that readers can understand and appreciate the effect analysis using a GCM and a hydrological model. It should be highlighted that, based on the outputs from the GCM, the investigation's findings are limited to the Wainganga river basin. Despite advances in technical elements, increased understanding, and computing capabilities, forecasting future variability demands considerable research initiatives in order to develop appropriate adaptation plans and policies. The multidisciplinary research will also assist in the creation of scientifically sound water and climate change policy. Most critically, for a climate resilient nation or planet, communication between researchers and policymakers should be strengthened, as climate change impacts are underutilised in decision and policy making.

Keywords Climate change · Downscaling · GCMs · Hydrological models

9.1 Introduction

Climate change, according to the Intergovernmental Panel on Climate Change (IPCC), is defined as variability in statistical parameters over time (decades or longer) due to natural or anthropogenic perturbations. The natural and anthropogenic

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climatic forcings exhibit internal variations in the different components of the earth's climate system. These variations give rise to different feedback mechanism that can either intensify (i.e., positive feedback) or diminish (i.e., negative feedback) the initial forcing. Moreover, the response time of various climate system components to the climatic forcing plays an important role in climate change. With increasing irrevocable evidences of global warming, climate change is widely acceptable as a real, crucial, and truly a global problem (Allison et al. 2009). Therefore, evaluation and investigation of significant impact of climate change on water resources are at utmost priority due to social and political implications of water (Babel et al. 2014). The significance of the climate change has increased in water resources because the change in global mean temperature is likely to alter the hydrological cycle and which in turn create difficulties in policy making. Moreover, climate change alters the availability of water, quality of freshwater resources, magnitude and frequency of the extreme events, irrigation water use (Simonovic 2017). These erratic temporal and spatial behaviour of the hydro-climatic variables is likely to reintroduce challenges in water security in the developing countries. According to World Bank (2013) report, the number of people who live under the water scarcity is likely to increase drastically from 1.6 billion to 2.8 billion by 2025. In addition, WHO (2013) reports that climate change along with non-climatic drivers viz. urbanization and population growth are expected to impact the progress of supporting the mankind with their basic rights such as drinking water and sanitation. WHO (2009) identified that repair and rehabilitation of water supply infrastructure in low-income countries, breakdown of sanitation facilities due to flooding, and water scarcity in groundwater dependent countries are some of the significant impacts of various climate change effects (floods and droughts).

As discussed earlier, the changing climate and its adverse consequence are likely to intensify and is expected to modify the occurrence of the extreme events like flood and drought (Poonia et al. 2021a, b). However, these extreme events can have both positive (recharge to the ecosystem, food production) and negative side (health, property, sanitation, etc.) as well (Simonovic 2017). Global warming significantly enhances the atmospheric capacity to hold more moisture according to the nonlinear Clausius–Clapeyron equation and this accelerates many hydrological processes, such as flood generating processes in the atmosphere (Kundzewicz et al. 2010). According to the IPCC (2012), flood events are more likely to increase under future climate scenarios; however, substantial uncertainty is associated with the evolvement of the processes (Simonovic and Li 2004). The consequences of extreme flood events are different in developed (large material damage) and developing (life, and economy) countries (Simonovic 2017). On the other hand, the erratic behaviour of rainfall, temperature, potential evapotranspiration and their combined consequences are inducing the manifestation and magnitude of drought (Das et al. 2021). According to the IPCC (2012), the properties of drought have become more persistent, widespread, and intense in the past three decades because of less precipitation over land and increase in temperature.

Hydrology is viewed as a multidisciplinary science and as an applied engineering subject which deals with the distribution and various manifestations of precipitation on the earth and below the earth. In this sense, hydrology leaves atmosphere to meteorology and climatology, oceans to oceanography, and deals only with rainfall, surface runoff, and groundwater. However, the climatological changes and the changes in ocean characteristics vis-a-vis temperature, pressure, and concentrations and their gradients substantially affect the hydrological characteristics. Hence, the global climate change has potential impacts on regional hydrology due to the inextricable link between the water resources and climate. As previously stated, increased surface air temperature is a result of increased greenhouse gas concentrations, and increased temperature causes changes in major components of hydrological cycles such as precipitation and evaporation (Simonovic 2017). Also, the projections indicate that there would be temporal and spatial changes in the precipitation characteristics such as variability, frequency of extremes, and magnitude of intensity. The enormous importance of water in both society and nature emphasises the requirement of foreseeing the water availability under climate change (Xu 1999). Therefore, assessment and quantification of the modification in hydrological processes and water resources systems have become indispensable in the prevailing climate change scenario. Certainly, Water availability and streamflow are very sensitive to the change in the precipitation and temperature and evaluating the changes with respect to the climate change scenarios over a river basin helps in proper planning and management of the water resources systems. Assessing the impact on hydrology includes the projection of variables having hydrological importance (e.g., humidity, geopotential height, sea level pressure, temperature etc.) based on the forcing scenarios, bring down the large-scale variables to the local scale using downscaling techniques, and quantifying the variability with respect to the observed climate. Global Climate Models (GCMs) are used as most credible tool to project the future projection of climatic variables at global scale. Then, based on the appropriate association between the climate and hydrologic variables the large-scale projections are downscaled to obtain the regional scale hydrologic projections. In addition to the GCM projection, the integration of the climate model and hydrologic model has been proven an effective combination to analyse the climate change projection on water resources components (Liuzzo et al. 2014). The commonly used conceptual hydrological models are characterized into lumped and distributed types according to the ability of the model to conceptualize the input and output variables with the catchment characteristics like land use land cover, soil type, slope, etc. Due to the better representation of physical process, the distributed models are considered as superior than others (Feyen et al. 2000).

To assess and analyse the potential impact of climate change IPCC has released different scenarios, which unfold the different possible images of future and are suitable tool to analyse the influence of driving forces on the future emission outcomes and to evaluate the associated uncertainties. In addition, they enable to model the climate change impact to take proper adaptation and mitigation strategies. At initial stage, IPCC in 1992 developed first global scenarios (IS92a to f) incorporating the complete suite of greenhouse gases. However, in 2000, IPCC proposed a new set of emission scenarios by re-evaluating the IS92 scenarios, which provides input to the Third and Fourth Assessment Report of IPCC during 2001 and 2007 respectively. This Special Report on Emission Scenarios (SRES) comprises of four different socio-economic “story-lines”, viz. A1, A2, B1, and B2. These scenarios mainly focus on the economic development, industrialisation, fossil fuel utilisation, population growth, and advancement in the technological applications enables to explore the human contribution to the future climate change.

However, Fifth Assessment Report (AR5) of IPCC focuses on the emission trajectory and radiactive forcings rather than the social-economic conditions. This approach was motivated by the varying information requirements of policy makers as well as the growing interest to minimize the risk that encompasses reductions in emissions and adaptation strategy to reduce climate change consequences. Radiactive forcings is used to categorise the different climate scenarios, defined as the extra energy taken up by the earth due to the increase in greenhouse gases. More precisely, it is the difference in the energy balance that enters and leaves the atmosphere as compared to the pre-industrial state. The unit of the radiactive forcing is expressed as watt per meter square (W/m^2). The developed scenarios known as Representative Concentration Pathways (RCPs) define the projected trajectories of concentrations of greenhouse gases, pollutants, dynamic vegetation due to the anthropogenic activities over the time and their radiactive forcing in 2100. In SRES scenarios the climate change evaluation is primarily based on the population growth, economic, and technology development. However, in RCP scenario the projections are mainly based on the radiactive forcing instead of any predefined assumption as in case of SRES scenario because different socio-economic storylines may produce same magnitude of radiactive forcing. RCP scenarios are categorised into four groups, viz. RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Based on the forcings, RCP2.6 and 8.5 are considered as low and high emission scenarios respectively with RCP4.5 and 6.0 as intermediate emission scenarios. The value indicates the magnitude of forcing in W/m^2.

Direct and indirect climate drivers have a substantial impact on water resources by impacting the system through their impacts on various hydro-climatic variables. There are several methods for assessing the climate change impact, and the suitability of the opted method depends on the availability of baseline data, morphological characteristics of the region, and level of required detail (e.g., detail required for global assessment is significantly different from a river-basin scale assessment). In terms of adaptation and sustainability, basin level or regional level approach is adopted as climate change impact on a regional scale can be varied substantially than a global scale. As mentioned earlier, to assess and evaluate the potential climate change impact GCMs are considered as most effective tools, and the integration of the outputs from the GCM and any hydrological model provide a robust assessment. In this sense, the present chapter focuses on different downscaling techniques to project large scale outputs from the climate model to a regional scale along with different post processing techniques to correct the inherent bias in the outputs. Moreover, the chapter also deals with the integration of climate model and hydrological model to assess the climate change impact over a region and the complete analysis is presented as a case study over a river basin.

9.2 Downscaling Techniques

In this section, evaluation and analysis of the impact of climate change on water resources using various downscaling methods are concisely presented. Specifically, characterisation of different downscaling techniques and their applications to model the climate change impact on hydro-meteorological variables are initially studied. The hydrological changeability due to climate change will affect the productivity of natural and agricultural systems, designing of hydrological structures, demand and supply for water, and aquatic ecosystem. Hence, projection and evaluation of climate change impact on water resources is of paramount importance under the scenario of changing climate. To evaluate the impact of climate change for better management and adaptation of water resources outputs from the GCMs are used (Goharian et al. 2016). Incorporating different climatic forcings, GCMs simulate historical and future projections of climatological variables at different horizontal and vertical directions (Dibike and Coulibaly 2005). The climate models have better performance in simulating climatological variables at courser resolution; however, the regional impact analysis requires the variables at the finer scale. The downsides of the GCM outputs, such as decreasing capability at finer temporal as well as spatial scales and inability to simulate the variables of hydrological importance, prevent direct involvement in hydrological studies (Xu 1999). In addition, the circulation pattern causing the extreme hydrological events are also not captured by the GCM (Christensen and Christensen 2007).

Therefore, to analyse the impact of climate change, large scale climatic outputs should link to the hydrologic variables at regional scale (e.g., precipitation, runoff) for better planning and management. The method of modelling the hydrologic variables at a finer scale based on coarser scale outputs from GCM is known as downscaling. Dynamic and statistical downscaling techniques are commonly accepted downscaling methodologies, in which the former projects the coarser resolution GCM outputs to a finer resolution by incorporating the physical laws, boundary conditions, and atmospheric processes (generally known as Regional Climate Model, RCM or Limited Area Model, LAM). The approaches to the dynamic downscaling are varied based on the boundary conditions and Rummukainen (1997) studied three different approaches such as: (1) coarser GCM output as geographical or spectral boundary conditions to run a regional LAM; (2) considering GCM outputs as initial (and partially also boundary) conditions and carrying out global scale experiments with high resolution atmosphere GCMs; (3) use of a variable resolution global model having highest resolution over the area of interest. There are numerous studies and reviews are carried out using dynamic downscaling but are not limited to (Giorgi and Mearns 1991; Wilby and Wigley 1997; Leung et al. 2003; Fowler et al. 2005; Rauscher et al. 2010; Shaaban et al. 2011; Kure et al. 2013; Jang and Kavvas 2015; Paul et al. 2016) and interested readers are advised to follow the above-said literature.

Statistical downscaling techniques establish statistical association between large scale GCMs variables and regional scale hydrological variables, project for the future scenarios and finally assess the significances with respect to the present climate. As stated by Ghosh and Mujumdar (2008) the three important assumptions in statistical downscaling are (i) statistical relationship holds good in future for causal and target variables; (ii) selected causal variables represent the variable climate signals completely; and (iii) spatial variation remains constant in different climate change forcings. Broadly, the statistical downscaling is categorised into three different groups: regression models, weather typing schemes, and weather generators (Fowler et al. 2007). In case of weather typing approach, the regional variables are grouped with respect to the different classes of atmospheric circulation. Then, the climate scenarios are obtained by generating sequences of weather classes using Monte Carlo simulation and resampling technique. Finally, the regional climate impacts are estimated based on the change in the frequency of weather classes. Similarly, weather generators reproduce the statistical attributes of local variables. These models represent the daily rainfall event through Markov chain approach by providing a conditional probability upon the state of previous day. However, the regression models are the most commonly used statistical downscaling technique. Regression models represent the linear and nonlinear relationships between the large-scale climate variables (predictors) and the climate variable having regional importance (predictand). Conceptually these models are very simple and commonly used in statistical downscaling. Based on the choice of predictors, mathematical transfer function, and statistical fitting approach there are varied statistical downscaling schemes that are reported in the literature. There are many studies, which show the applicability of statistical downscaling techniques in different parts of the world. These include, but are not limited to (Semenov and Barrow 1997; Wilks 1999; Qian et al. 2002; Wilby et al. 2002; Huth 2002; Kyselý and Dubrovský 2005; Ghosh and Mujumdar 2008; Raje and Mujumdar 2011; Jiang 2011; Tseng et al. 2012; Goyal et al. 2012; Jeong et al. 2012; Sharif et al. 2013; Khazaei et al. 2013; Hertig et al. 2014; Chen and Brissette 2015; Lee 2015; Das and Umamahesh 2016; Rahmani et al. 2016; Li et al. 2017; Lin et al. 2017).

9.3 Integration of GCM and Hydrological Model

Climate change has widened its domain significantly since pre-industrial periods as a result of anthropogenic and natural actions, endangering the sustainability of natural resources on a regional scale. The increase in greenhouse gas concentrations leads to an increase in surface temperature, which has an impact on the hydrological cycle's essential components. In general, hydrology impact studies use a two-step approach known as indirect downscaling (Joshi et al. 2013, 2016). The climatological variables (e.g., precipitation, temperature) are first scaled down from large-scale projections to the regional scale. The downscaled variables are then put into a hydrological model to assess hydrological variability due to climate change (Okkan and Fistikoglu 2014; Zhou et al. 2015; Kuo et al. 2017). In case of indirect downscaling, hydrological modelling links the climate change and different water balance components through simulation of hydrological processes at regional scale (e.g., river basin scale) and also requires meteorological data at regional scale (Xu et al. 2009). In addition, the outputs from the GCMs cannot be used directly to investigate the impact of climate change on hydrological cycle due to the coarser resolution and cannot capture the hydrological responses due to changing climate. Hence, to assess the changes in the regional hydrological regimes due to climate change, the outputs from the GCMs are integrated with hydrological models and are commonly used (Maurer 2007; Arnell and Gosling 2013). In this sense, during past years a great deal of work on integration of climate model and hydrological model has been done around the globe. Table 9.1 represents such applications from different investigators using different methodologies over different study areas.

Therefore, hydrological impact analysis due to climate change incorporates: (i) future projection of climate change with GCM simulation; (ii) bringing down large scale atmospheric variables to the finer scale using downscaling technique; (iii) simulating hydrologic predictions by giving downscaled variables as an input to the hydrologic models (Bae et al. 2011). Although there are number of methods have been developed to downscale (Xu 1999), up to now, the common applicability of these methods enable to capture the relationships between large scale atmospheric variables and regional weather. The quality of the input dataset is critical in hydrologic modelling since a tiny error might accumulate throughout the process and result in an incorrect output. Therefore, Studies show that post-processing (bias-correction) of GCM simulation has a better agreement with the observed data than the uncorrected GCM data and has a narrow uncertainty range (Teutschbein and Seibert 2012). To reduce the systematic and randomness model errors, bias-correction in necessary prior to the downscaling and hydrological impact analysis. In this sense, the next section provides a brief discussion about the bias correction techniques.

9.4 Bias-Correction in Climate Change Impact Analysis

From the above discussion, it is now clear that climate models are considered as major tool to understand the climate change. In hydrological climate change studies, high-resolution climate models show considerable deviations from observational data due to systematic and random model errors (Teutschbein and Seibert 2013). However, the bias-associated with the precipitation is more often causing difficulties in hydrological modelling (Argüeso et al. 2013). Furthermore, the failure of the weighted mean GCM to capture extreme rainfall events can be attributed to insufficient spatial resolution (Rauscher et al. 2010), which can be improved by improving certain circulation features such as tropical storm generation and evolution (Oouchi et al. 2006), monsoon circulation (Gao et al. 2006), and orographic precipitation (Iorio et al. 2004). Therefore, bias correction or bias adjustment is required in climate model data. Model Output Statistics (MOS) in numerical weather prediction

Table 9.1 A few case studies those integrate GCM outputs and hydrological model

Sl. No.	Study area	Methodology	Significant outcomes	Source
1	Upper Mississippi River	Coupled RCM with Soil and Water Assessment Tool (SWAT) hydrological model	50% increase of water yield	Jha et al. (2004)
2	Indian River	Coupled outputs from different scenarios with SWAT model	A general reduction in available runoff has been predicted	Gosain et al. (2006)
3	Adour-Garonne River	Coupled outputs from GCM with spatially distributed hydrological model named SAFRAN-ISBA-MODCOU (SIM)	11% decrease in the discharge during low flow period	Caballero et al. (2007)
4	Iran	Integrated Canadian Global Couple Model under different scenarios with SWAT model	Production of wheat is affected adversely	Abbaspour et al. (2009)
5	Shiyang River Basin	Coupled outputs from PRECIS regional climate model with SWAT model	Increase in mean monthly streamflow	Wang et al. (2012)
6	San Juan River Basin	integrated multiple hydrological models with the outputs from multimodel dataset under CMIP3 project	Decrease water availability under changing climate condition	Miller et al. (2012)
7	Tunga-Bhadra River Basin	SDSM was used for statistical downscaling of meteorological data which was forced into the HEC-HMS 3.4 hydrological model	Increase in rainfall and runoff with declining rate of actual evapotranspiration	Meenu et al. (2013)
8	River Basins in Central Canada	Outputs from CMIP3 project were coupled with SLURP hydrological model	Precipitation variations throughout the year has a substantial impact on runoff	Choi et al. (2014)
9	Upper Ganga Basin	CORDEX simulated meteorological variables were forced into the Variable Infiltration Capacity (VIC) hydrological model.	Streamflow sensitivity is higher in urban regions than in croping areas	Chawla and Mujumdar (2015)
10	ZayandehRud River Basin	IHACRES hydrological model is integrated with the statistically downscaled meteorological data from different GCMs	Increase in the drought severity level as compared to the historical period	Khajeh et al. (2017)
11	Himalayan catchment Teesta Basin	SWAT model is integrated with downscaled climatological variables	Increase in precipitation amount and water yield	Singh and Goyal (2017)

by Glahn and Lowry (1972) is the first step to bring the concept of bias correction, which is widely use in downscaling techniques. Due to the low computational demand, simplicity and with increasing climate model datasets at global as well as regional scale, there is widespread use of bias correction in climate impact research. Hence bias-correction enable to adjust the uncertain veracity for future projection and can be used for real world adaptation decisions. Moreover, the bias-correction is generally applied to the outputs obtained from the regional climate model (RCM). A detailed representation of different bias correction methods are discussed by Teutschbein and Seibert (2012) which includes (i) linear scaling; (ii) local intensity scaling; (iii) power transformation; (iv) variance scaling; (v) distribution transfer; and (vi) delta-change approach. In the present chapter, different methods and their review are presented in a tabular form under Table 9.2 for the brevity.

Not only the bias but also the uncertainty plays a significant role in global climate change, including climate change science and impact studies. In particular with hydrology and water resources, it is indispensable to examine the uncertainties due to: (i) different scenarios; (ii) different GCMs and RCMs; (iii) different downscaling procedures; (iv) different bias-correction method; (v) input dataset; (vi) use of different hydrological models; (vii) different parameters of the hydrological models (Kundzewicz et al. 2018). Therefore, next section portrays a brief review of the uncertainty analysis in climate change impact studies.

9.5 Uncertainty Analysis in Climate Change Impact Assessment

At regional scale, the impact evaluation is burdened with uncertainties due to a variety of factors (Mujumdar and Ghosh 2008). Furthermore, because different climate models and scenarios are available, there is always the possibility of ambiguity in climate change impact analysis (Najafi and Hessami Kermani 2017). The findings of global and regional climate modelling cannot be utilised directly to propose different adaption options and decisions because to the uncertainty involved (Pielke and Wilby 2012). In the context of water management, addressing the impacts of climate change without first determining the uncertainty can mislead decision-makers (Bennett et al. 2012). Beven (2016) proposed taxonomy of uncertainty and stated that incomplete knowledge and information about the system dynamics, forcing and response data are categorised into epistemic uncertainty. Also, he recognized semantic/linguistic uncertainty (due to meaning of the term) and ontological uncertainty (due to different belief systems). Uncertainties resulting from downscaling procedures and scenarios are frequently seen as key causes of uncertainty (Chen et al. 2011a, b; Teng et al. 2012). Moreover, Wilby et al. (2014) used the Coupled Model Inter-comparison Project 5 (CMIP5) outputs to show the cascade of uncertainty caused by the choice of scenarios, GCM, and realisation of climate variability in precipitation change. They claimed that the ambiguity associated with scenarios will lead to even greater uncertainty in the impact of regional climate change. As a result, incorporating the assessment of uncertainties arising from the aforementioned sources is critical to achieving effective outcomes and

Table 9.2 Different bias-correction techniques

Sl. No.	Bias-correction	Description	Source
1	Linear Scaling	$P_{con}{}^{*}(d) = P_{con}(d).\left[\frac{mean_m(P_{obs}(d))}{mean_m(P_{con}(d))}\right]$ $P_{fut}{}^{*}(d) = P_{fut}(d).\left[\frac{mean_m(P_{obs}(d))}{mean_m(P_{con}(d))}\right]$ $T_{con}{}^{*}(d) = T_{con}(d) + mean_m(T_{obs}(d)) - mean_m(T_{con}(d))$ $T_{fut}{}^{*}(d) = T_{fut}(d) + mean_m(T_{obs}(d)) - mean_m(T_{con}(d))$ • It corrects the bias based on the monthly correction value. • Precipitation is corrected based on ratio term and temperature is corrected based on additive term	Lenderink et al. (2007) and Teutschbein and Seibert (2012)
2	Local Intensity Scaling	• It adjusts the wet-day frequencies and intensities along with mean. • Initially, a precipitation threshold ($P_{th,con}$)is calibrated from RCM simulated precipitation. So that precipitation less than threshold can be considered as dry days and vice versa. $P_{con}(d)\ and\ P_{fut}(d) = 0, if\ P_{con}(d) < P_{th,con}$ $P_{con}(d)\ and\ P_{fut}(d) = P_{con}(d)\ and\ P_{fut}(d), if\ otherwise$ $s = \frac{mean_m(P_{obs}(d)\vert P_{obs}(d) > 0\ mm)}{mean_m(P_{con}(d)\vert P_{con}(d) > P_{th,con}) - P_{th,con}}$ $P_{con}{}^{*}(d) = P_{con}(d).s$ $P_{fut}{}^{*}(d) = P_{fut}(d).s$	Schmidli et al. (2006)
3	Power Transformation	• Linear scaling adjusts the bias in mean only and does not correct the bias in the variance. • To adjust the variance statistics in the precipitation series, a non-linear correction in an exponential form is used i.e. a. P^b. Where a and b are parameters.	Leander and Buishand (2007) and Leander et al. (2008)

4	Variance Scaling	• The power transformation method is used to correct both mean and variance only in the precipitation series due to the use of power function. • Hence, variance scaling is used to correct the bias in mean and variance of the temperature profile. • The mean is adjusted based on the linear scaling method and standard deviation is scaled based on the ratio of standard deviation of observed and control run.	Chen et al. (2011a, b)
5	Distribution Transfer/ Mapping	• The goal of this strategy is to match the distribution of observed series to the probability distribution function of the model simulated series. • This procedure is referred as quantile mapping, probability mapping, or histogram equalisation. • In the case of precipitation and temperature profiles, gamma and gaussian distributions are typically used. • For the observed and model simulated results, correction factors are calculated for various cumulative distribution functions throughout the baseline period. $P_{con}{}^{*}(d) = F_{\gamma}^{-1}\left(F_{\gamma}\left(P_{con}(d)\vert\alpha_{con,m},\beta_{con,m}\right)\vert\alpha_{obs,m},\beta_{obs,m}\right)$ $P_{fut}{}^{*}(d) = F_{\gamma}^{-1}\left(F_{\gamma}\left(P_{fut}(d)\vert\alpha_{con,m},\beta_{con,m}\right)\vert\alpha_{obs,m},\beta_{obs,m}\right)$ $T_{con}{}^{*}(d) = F_{N}^{-1}\left(F_{N}\left(P_{con}(d)\vert\mu_{con,m},\sigma^{2}_{con,m}\right)\vert\mu_{obs,m},\sigma^{2}{}_{obs,m}\right)$ $T_{fut}{}^{*}(d) = F_{N}^{-1}\left(F_{N}\left(P_{fut}(d)\vert\mu_{con,m},\sigma^{2}_{con,m}\right)\vert\mu_{obs,m},\sigma^{2}{}_{obs,m}\right)$	Teutschbein and Seibert (2012)
6	Delta-Change Approach	• Generally, this method is used as one of the downscaling techniques. • The motive of the method is to incorporate the RCM simulated future changes as a perturbation to the baseline period rather than using it directly. • The anomalies are computed monthly basis between the scenario and control periods. • Multiplication and additive correction is used to adjust the precipitation and temperature respectively $P_{fut}{}^{*}(d) = P_{obs}(d).\left[\frac{mean_m\left(P_{fut}(d)\right)}{mean_m\left(P_{con}(d)\right)}\right]$ $T_{fut}{}^{*}(d) = T_{obs}(d) + mean_m\left(T_{fut}(d)\right) - mean_m\left(T_{con}(d)\right)$	Anandhi et al. (2011)

Different symbols and notation used in the table: *con* control period (RCM simulated under baseline period), *fut* future, *obs* observed, *(d)* daily, *m* monthly interval, *P* precipitation, *T* temperature, *s* scaling factor, *a*, *b* parameters; γ gamma distribution, *N* normal distribution, α and β shape and scale parameter of the Gamma distribution, μ and σ location and scale parameters of the Gaussian distribution, * denotes bias-corrected

Table 9.3 Framework to reduce uncertainty

Sl. No.	Reducible uncertainty	How to reduce
1.	Data and information	Finding more exact information Performing more measurements and observations Spreading the hydro-meteorological observation networks Providing unrestricted access to the available data Creating and maintaining the global datasets
2.	Climate Models	Improving the parameterization process in models Reducing scale mismatch by using both GCM and RCM at finer scale Impact analysis by incorporating ensemble of climate models Improving testing of climate models
3.	Hydrological Models	Understanding the processes involved in the models Complete evaluation of models at finer resolution Incorporating multimodel approach Proper calibration and validation of models including sensitivity analysis of parameters Integration of both climate and hydrological models

modelling performance (Lespinas et al. 2014). Multiple climate models and scenarios are studied by different researchers to forecast a variety of possible changes in the hydrologic variables to address the uncertainty associated with GCM and scenarios in climate change effect analysis (Mujumdar and Ghosh 2008; Das and Umamahesh 2017).

It is vital to understand the underlying reason of various uncertainties linked with various sources before measuring the uncertainty. The uncertainty in GCM forecasts stems from the ambiguity in future greenhouse emissions, as well as the GCM's reaction to atmospheric forcing, which is affected by parameterization, model structure, and geographic resolution (Teng et al. 2012). Furthermore, different climate models make different decisions, which increases model complexity and, as a result, model simulations (Clark et al. 2016). The scenario uncertainty, on the other hand, originates from the unpredictability and partial knowledge of the future climate that results from a lack of information and comprehension of the biophysical process (New and Hulme 2000). As a result, it is important to stress that the scenarios given are exploratory rather than predictive (Brown et al. 2015). Despite identical performance during the training period, when forced with GCM outputs, different downscaling strategies differ in future forecasts, resulting in uncertainty due to the multiple downscaling techniques as stated by Ghosh and Katkar (2012). Kundzewicz et al. (2016) stated that Uncertainties are introduced by transfer functions, such as from scenario emissions to climate change and subsequently to the repercussions on water resources, which are mostly based on extreme occurrences, as well as adaptation strategies. The hydrological models' structure and parameterization will contribute uncertainty to the effect study on water resources in the context of climate change. A summary of proposed framework to reduce uncertainty is discussed by Kundzewicz et al. (2018) and briefly presented in Table 9.3 in the present chapter.

However, in case of irreducible uncertainty two alternatives can be envisaged viz. precautionary principle and adaptive management (Kundzewicz et al. 2018). Precautionary principle is based on min-max concept, where approach is chosen to minimize the worst outcomes of significant importance. Adaptive management is based on the outputs obtained from different climate scenarios along with the multimodel ensemble. However, some adaptation measures perform well under any future projections; however, some can be accomplished under some future predictions.

Therefore, understanding the importance of water availability in future and to propose the proper adaptation strategies and resources management, it is crucial to evaluate the climate change impact analysis on water resources for the fraternity working the water resources and hydrology. In this context, authors are presenting an application of impact of climate change on water resources over a river basin so that readers would appreciate different tools and techniques involved in impact analysis. Therefore, next section deals with a case study over a river basin in India.

9.6 Case Study

9.6.1 Study Area

In this study, the largest sub-basin of the Godavari River, Wainganga (Fig. 9.1), is considered. Wainganga basin has 49695.40 km^2 and is located between 19°30′–22°50′ N latitude and 78°0′–81°0′ E longitude. The river is 635.40 km long. Agricultural and forestlands dominate most of the study region, according to the land use categories. The decadal land use classification's variability shows that land use patterns do not change significantly over time. As a result, the impact of dynamic vegetation on streamflow is ignored in this study (Das and Umamahesh 2018). The basin's agro-climatic zone is separated into three portions: (i) Central plateau and hills, (ii) Eastern plateau and hills, and (iii) Western plateau and hills. The basin is covered with mostly fine and medium texture soil, with moderate to severe soil erosivity. The basin's elevation ranges from a height of 1032 m to a minimum of 144 m (Fig. 9.1c). The meteorological data are obtained from India Meteorological Department (IMD) over all the grid points from 1978 to 2002 as shown in Fig. 9.1d. Moreover, the basin is divided into different reaches viz. lower, middle, and upper reaches according to the elevation and shown in Fig. 9.1d. High elevation regions are categorised under upper reach, medium range elevation regions are put under middle reach and the low elevation regions are fall under lower reach. The outlet of the basin is in lower reach and the streamflow data for the basin are downloaded from the Central Water Commission (CWC), Hyderabad.

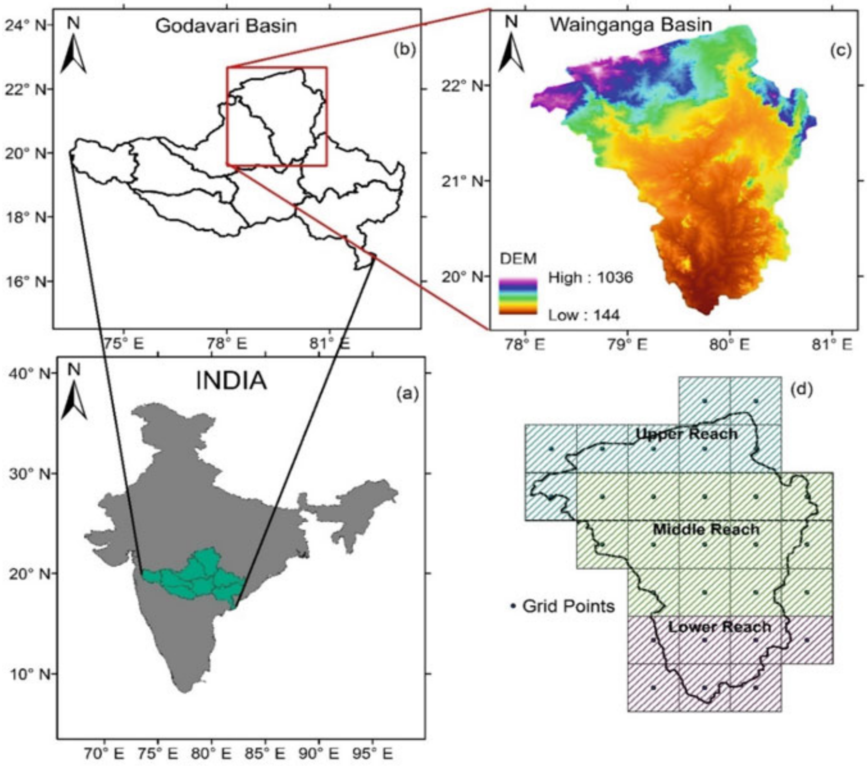

Fig. 9.1 (**a**) Godavari basin is superimposed over India map; (**b**) location map of the study area (Wainganga) superimposed over Godavari Basin; (**c**) digital elevation map of Wainganga basin; (**d**) study area is divided into different reaches based on the elevation

9.6.2 Climate and Rainfall

The yearly rainfall in the study area ranges from 900 to 1600 mm, with the monsoon season seeing the most rain. The current research area has a tropical climate, with maximum temperatures ranging from 39 to 47 °C in the summer and minimum temperatures ranging from 7 to 13 °C in the winter. The annual cycle is separated into four seasons: post-monsoon rabi (January to March), pre-monsoon (April to June), monsoon (July to September), and post-monsoon kharif (October to December).

9.6.3 Climate Model Data

The outputs from various GCMs are used in this work to project future changes in hydroclimatic variables. As a result, the GCM outputs are downloaded from the Indian Institute of Tropical Meteorology (IITM), Pune website under two alternative

Table 9.4 List of climate models

Experiment	Driving GCM	Institution
Commonwealth Australia Scientific and Industrial Research Organization, (CSIRO) Australia- CCAM	CCSM4 (0.5°*0.5°)	National Center for Atmospheric Research
	CNRM-CM5 (0.5°*0.5°)	Centre National de Recherches Météorologiques
	GFDL-CM3 (0.5°*0.5°)	Geophysical Fluid Dynamics Laboratory
	ACCESS1.0 (0.5°*0.5°)	CSIRO
	NorGCM1-M (0.5°*0.5°)	Norwegian Climate Centre
	MPI-GCM-LR (0.5°*0.5°)	Max Planck Institute for Meteorology (MPI-M)

future scenarios, namely Representative Concentration Pathways (RCPs) 4.5 and 8.5, from the Coordinated Regional Climate Downscaling Experiment (CORDEX) for South Asia. The list of the climate models is presented in Table 9.4. It is worth-mentioning that the outputs from the GCMs are already dynamically downscaled by CORDEX and hence no downscaling procedures are opted to bring down the coarser data to the finer resolution. Furthermore, because the GCM outputs fall on the same grid points as the observed data, regridding is not performed in this work. The meteorological variables that are selected are precipitation, minimum and maximum temperature, and wind velocity. All the variables are obtained over the grid points for the historical and future (2020–2094) as shown in Fig. 9.1d.

9.6.4 Methodology

The present study focuses to evaluate the climate change impact on water balance components of the study area by integration of climate model and hydrological model. Moreover, the uncertainty analysis and bias-correction in the climate models' outputs are performed. A flow chart is presented in Fig. 9.2, which depicts the graphical representation of the proposed study. Initially, the uncertainty associated with the multiple climate models are analysed and based on the analysis weights are assigned to the different climate models. The final weighted ensemble outputs are then examined for bias-correction using non-parametric method. The next step involves the calibration and validation of the hydrological model using historical observations of the climatological variables. The final step of the proposed methodology incorporates the integration of the calibrated hydrological model and bias-corrected outputs from the climate model to investigate the climate change impact on the water balance components over the study area.

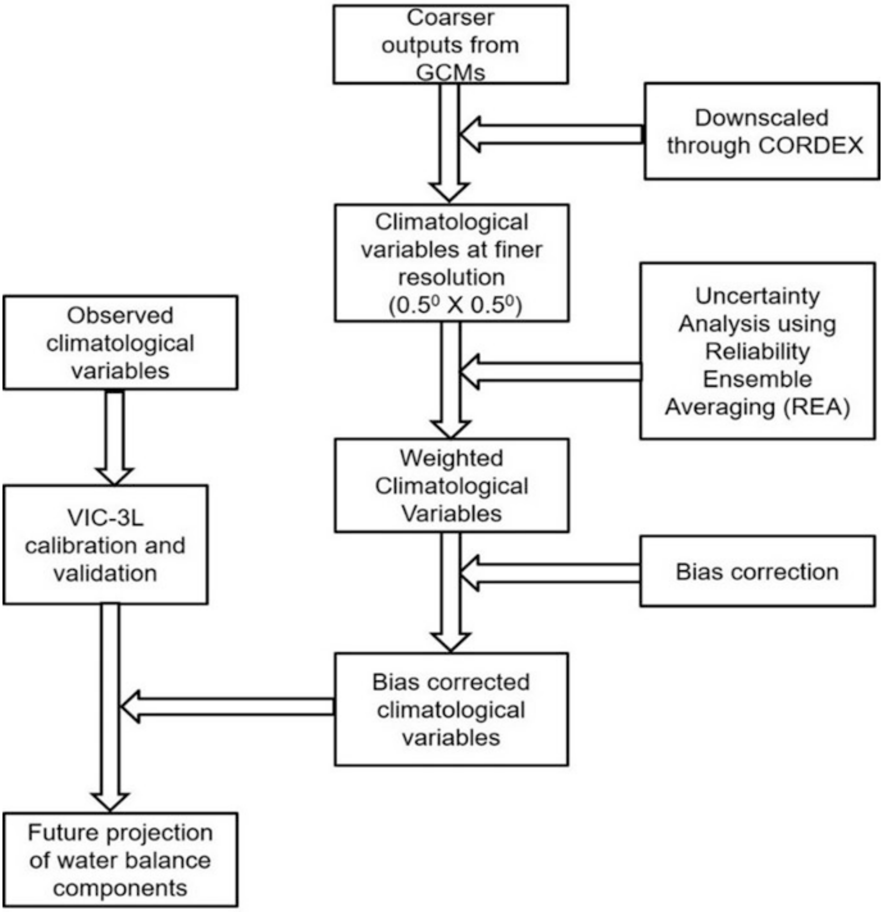

Fig. 9.2 Flow chart of the proposed methodology

9.6.5 Multimodel Uncertainty Analysis

As discussed earlier (Sect. 9.5), although the uncertainty associated with data coming from measurement errors or a lack of understanding of processes cannot be totally eliminated, uncertainty analysis can be used to quantify the uncertainty. Therefore, special attention should be given while using multi-model projections. One of the main components of GCMs uncertainty is that regional changes can be simulated quite differently even under the same radiactive forcing scenario (Whetton et al. 1996; Kittel et al. 1997) and it is very hard to determine which of the different models are more reliable. Therefore, an ensemble of the models for comprehensive study at a regional scale is suggested by Giorgi and Mearns (2002). The uncertainties in climate model outputs should be analysed using criteria based on model performance in the past (Wilby 2010). The current work uses a method called Reliability Ensemble Averaging (REA) to measure model uncertainty, and it is employed in the case of precipitation and temperature for modelling uncertainty deriving from the employment of many models (Giorgi and Mearns 2002; Ghosh and Mujumdar 2009). Before performing hydrological modelling, REA is performed to assess the multimodel uncertainty. The procedures to evaluate the multimodel uncertainty are as follow.

Performance Criteria
The Root Mean Square Error (RMSE) is evaluated based on the observed historical observation and GCM simulated for the historical period at different percentiles (0–1). Then summation of the inverse RMSE is calculated. Next, the inverse RMSE of each model is divided by the summation to compute the initial weight for that GCM. Likewise, initial weights for all the GCMs are computed.

Convergence Criteria
Based on the initial weights, weighted ensemble outputs are computed for future period for different percentiles. Then, the procedure is repeated as in case of performance criteria. The whole procedure is repeated until the obtained weight and the previous weight are same. The weights obtained in the final step are known as final weights. These weights are multiplied with future observations to obtain the weighted ensemble for precipitation, temperature and wind velocity.

It should be noted that the multimodel uncertainty is computed for all the grid points separately. Model convergence is calculated with respect to weighted mean CDF acquired from ensemble of GCM future simulations, whilst model performance is evaluated based on errors generated from the deviation of CDF between GCM simulated and original series. Furthermore, the convergence criterion assesses how well a model's future projections coincide with those of other models. In addition, Tebaldi et al. (2005) advocated that differential weighting of the members using REA is more appropriate than the equally weighted. A statistical interpretation of the REA method was carried out by Nychka and Tebaldi (2003) stated that this method is equivalent to the statistical procedure to compute the central tendency of the population in the presence of outliers and the weighted average obtained is in fact the median of the sample of model projections.

9.6.6 Bias-Correction

As discussed in Sect. 9.4, bias correction is a crucial step in climate change impact analysis as unbiased dataset has significant influence on the outcomes. Primarily, bias correction plays a significant role in hydrological modelling as precipitation is more sensitive to the bias as discussed in Sect. 9.4. However, the applicability of different bias correction methodologies varies considerably (Gudmundsson et al. 2012). Therefore, Gudmundsson et al. (2012) examined different bias correction

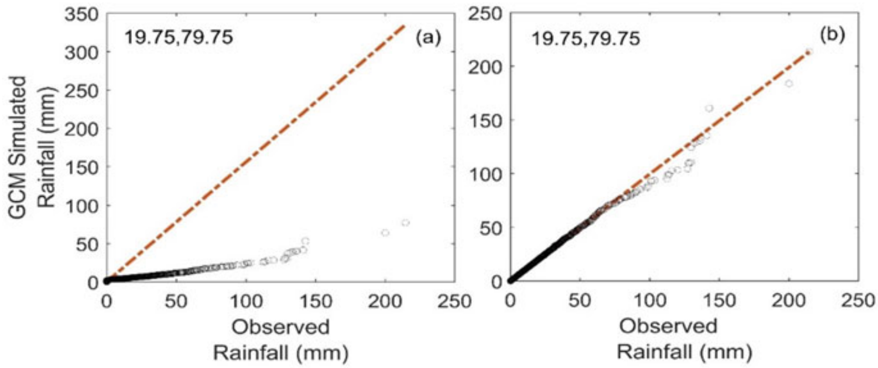

Fig. 9.3 (**a**) without bias correction; (**b**) with bias correction

methodologies based on the performance to correct the bias in precipitation and recommended non-parametric quantile mapping as this method does not require any information regarding prior distribution. Moreover, non-parametric quantile mapping has the better ability to correct the bias in precipitation series under entire range of distributions. Therefore, in the present study non-parametric quantile mapping is used to correct the bias. Prior to the bias-correction the weighted ensemble climatological variables obtained from the performance criteria of REA are compared with the observed variables and it is found that except precipitation series (mostly in extremes) all other variables are considerably matching well the observed series. Therefore, bias-correction is employed only on precipitation series under all the grid points. It should be noted that the correction factor obtained for the historical period is also applied to the future scenarios also. It is assumed that the bias will remain same in the future (stationary bias). For the brevity, here we are presenting the before and after bias-correction result for one grid point i.e. 19.75 (Lat), 79.75 (Long) in Fig. 9.3.

9.6.7 Hydrological Modelling

A semi-distributed, macro scale, grid-based model namely, 3-Layer Variable Infiltration Capacity (VIC-3L) is employed for hydrologic modelling in the current study. It takes into account the region's spatial variability and has been studied and implemented at a variety of spatial sizes, from large river basins (Abdulla et al. 1996; Wood et al. 1997; Zhu and Lettenmaier 2007) to continental and global dimensions (Nijssen et al. 2001; Shi et al. 2008), throughout the years (Liang et al. 1994; Liang et al. 1996). In addition, Hurkmans et al. (2010) clearly stated that (1) physically based evapotranspiration; (2) accumulation and melting process of snow; and (3) variations in the infiltration, land use, and elevation are the advantages of the VIC model. Thus VIC, as a process-based hydrologic model allowing for a more plausible extrapolation of hydrologic process into future climate regimes, is used in present study.

VIC has been used to examine the sensitivity of the reservoir system using the Parallel Climate Model (PCM) outputs (Christensen et al. 2004) and multiple GCMs (Christensen and Lettenmaier 2007) over the Colorado River basin. VIC has also been applied in several sectors of water resources coping with climate change impacts all around the world (Zhang et al. 2012; Lu et al. 2013; Yan et al. 2015). The principles of VIC model in simulating streamflow can be divided in two parts. The study area is divided into different grid points as shown in Fig. 9.1a. The climatological variables such as precipitation, maximum and minimum temperature, wind velocity and physical characteristic such as soil type and land use types are obtained for all grid points. In the first part of VIC model, water balance components are computed based on the climatological and physical characteristics of the basin. The second part of the model computes streamflow at the outlet of the basin incorporating the water balance components obtained from the first part. Moreover, the second part also includes the flow direction, flow fraction, and outlet location of the basin. In the present study the parameters of the VIC model are calibrated based on the trial and error method. The parameters of the hydrological model include soil depth, fraction of maximum soil moisture, fraction of maximum velocity of baseflow, maximum velocity of baseflow at each grid, and variable infiltration curve. The calibration and validation results are presented in Fig. 9.4. The model's performance is measured in terms of the statistical efficiency such as Nash-Sutcliffe Efficiency (NSE) and correlation coefficient (R). During calibration and validation periods the computed NSE values are 0.82 and 0.77 respectively. Similarly, the calculated R value for calibration and validation periods are 0.90 and 0.88 respectively.

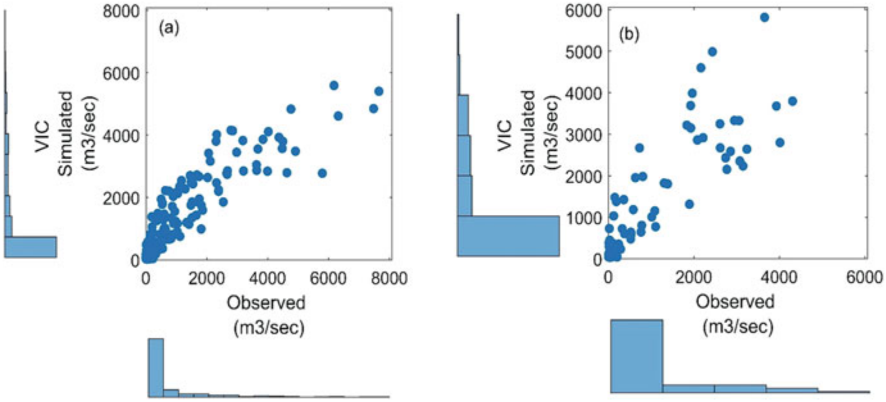

Fig. 9.4 (**a**) Calibration period (1978–2002); (**b**) Validation period (1971–1977 and 2003–2005)

9.6.8 Climate Change Impact Analysis

In the present study, we have analysed the climate change impact on hydrology of the study area. The change in the water balance components are analysed spatially over the river basin under different climate scenarios. Moreover, the percentage change is also computed with reference to the historical period. To evaluate the variability, water balance components are extracted from the calibrated VIC model for the historical and future periods. Figure 9.5 represents the spatial variability of precipitation, evapotranspiration, and runoff for the baseline period i.e. 1978–2002. It can be noted from the figure that most parts of the upper and middle reaches are getting less precipitation and evapotranspiration as compared to the lower reach at annual scale. However, there is no significant variation in runoff over the basin. The spatial distribution of the water balance components is possible because VIC hydrological model simulates variables at each grid point. It should be noted that the water balance components are extracted at annual scale and long term annual mean is computed. The range of each variable is fixed after comparing the variability in historical and future projections.

Climate change impact analysis at spatial scale enables the water manager for sustainable water resources management and adaptation policies. Moreover, at a river basin scale the spatial scale analysis is of paramount importance. In this sense, water balance components like precipitation, evapotranspiration, and runoff are analysed for different time periods i.e. near, mid, and far futures. Figure 9.6 depicts the mean annual spatial variability of precipitation under different scenarios. The spatial variability pattern of future projected precipitation in the upper reach is quite similar as the baseline period. Most of the parts in the upper reach is likely to get less precipitation amount. However, the middle and lower reaches are likely to receive more depth of precipitation in the both climate forcing scenarios. It can be noted from the figure that the annual mean depth of the precipitation increases from near future (2020–2044) to far future (2070–2094) under both RCP scenarios. Like the precipitation, evapotranspiration and runoff are also plotted and presented in Figs. 9.7 and 9.8 respectively. The mean annual evapotranspiration is likely to intensify over the future time period due to increase in temperature profile. It is

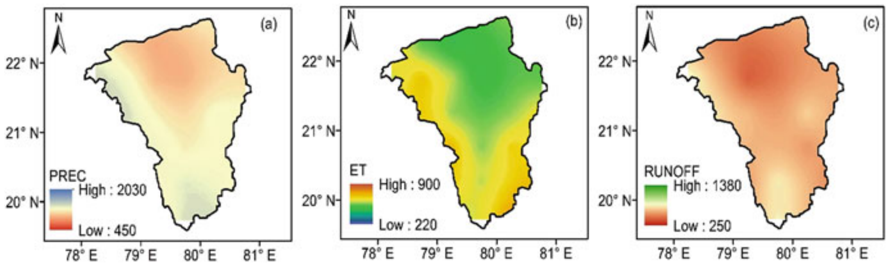

Fig. 9.5 Spatial distribution of water balance components during baseline period (**a**) Precipitation; (**b**) Evapotranspiration; (**c**) Runoff

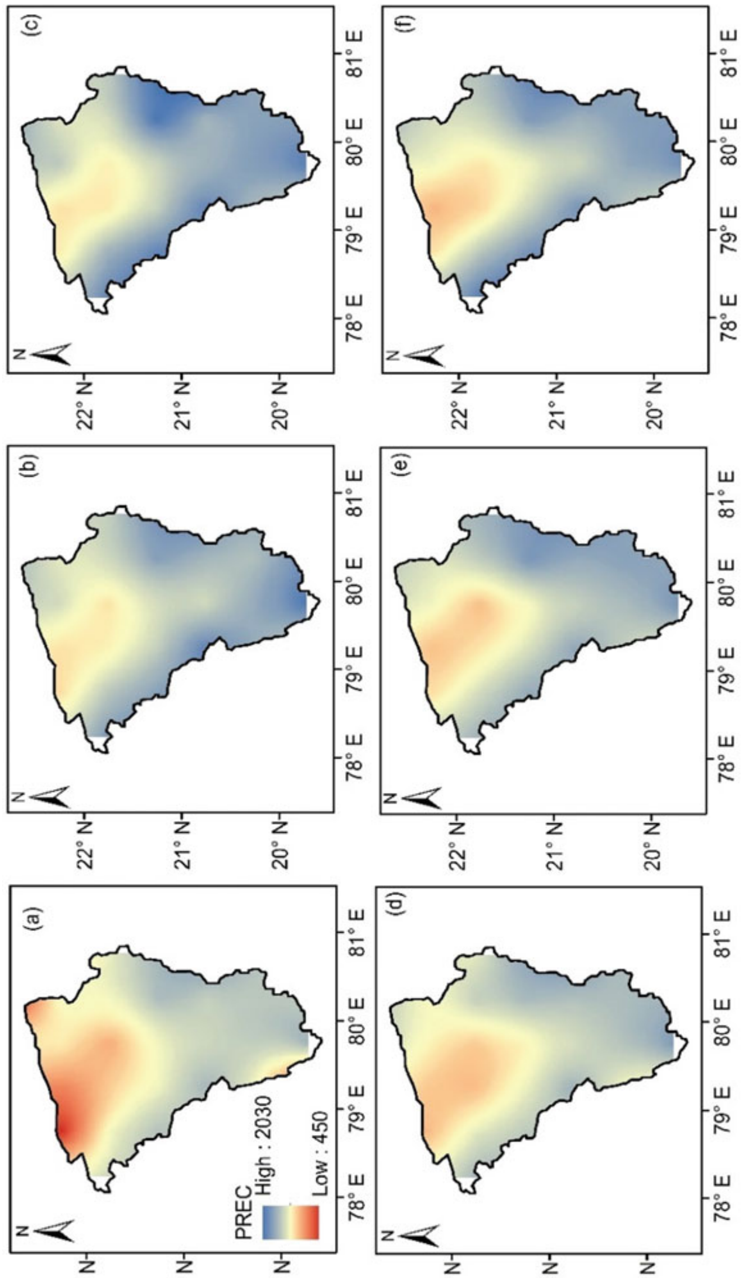

Fig. 9.6 Spatial distribution of precipitation during future projections; (**a**)–(**c**) RCP4.5 and (**d**)–(**e**) RCP8.5; (**a & d**) 2020–2044; (**b & e**) 2045–2069; (**c & f**) 2070–2094

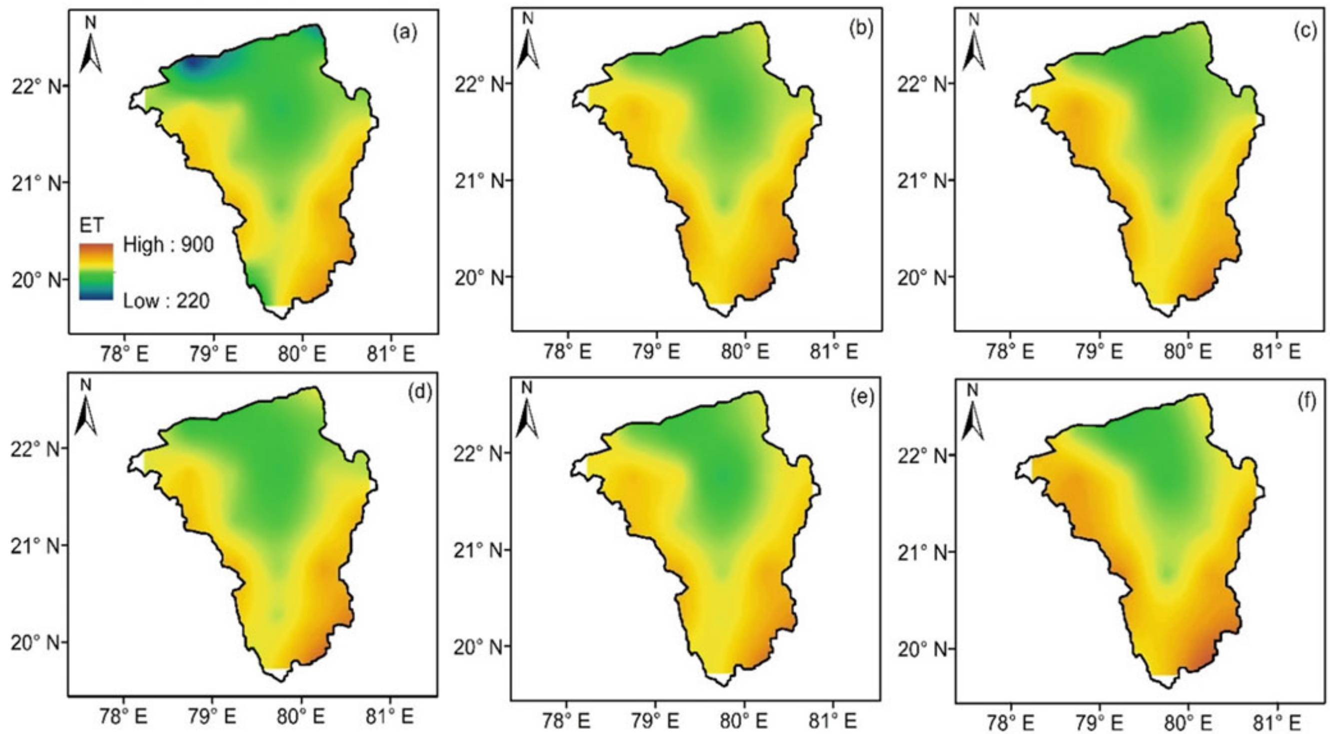

Fig. 9.7 Spatial distribution of evapotranspiration during future projections; (**a**)–(**c**) RCP4.5 and (**d**)–(**e**) RCP8.5; (**a** & **d**) 2020–2044; (**b** & **e**) 2045–2069; (**c** & **f**) 2070–2094

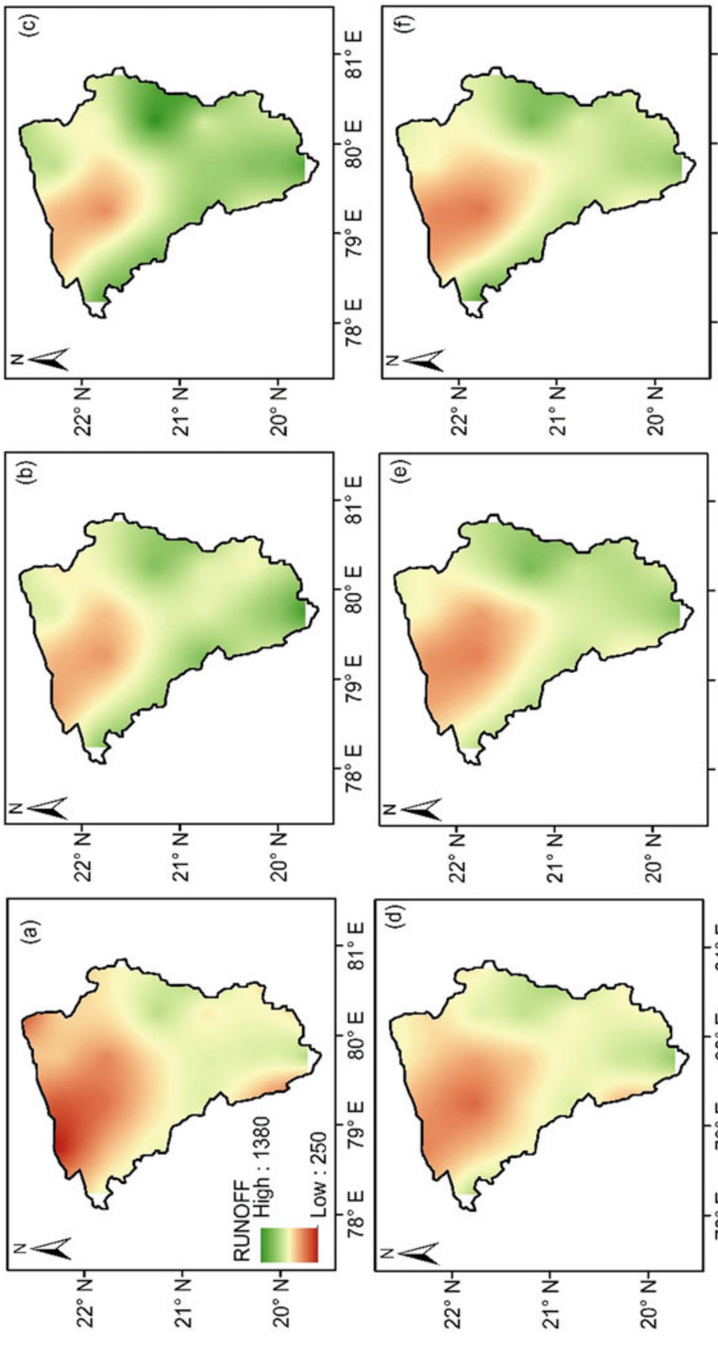

Fig. 9.8 Spatial distribution of runoff during future projections; (**a**)–(**c**) RCP4.5 and (**d**)–(**e**) RCP8.5; (**a** & **d**) 2020–2044; (**b** & **e**) 2045–2069; (**c** & **f**) 2070–2094

also observed that the reaches under the high precipitation amount are likely to experience high evapotranspiration and can be supported by the studies from Mishra and Lilhare (2016) and Yang et al. (2016). Likewise, the mean annual runoff depth is likely to increase with respect to the historical period in lower and middle reaches. The reason can be attributed to the nonlinear association of runoff and precipitation under climate change and runoff is more sensitive towards the precipitation than evapotranspiration (Wang et al. 2013).

Change in percentage of different water balance components over 2020–2094 is computed in comparison with baseline period over different reaches of the study area as shown in Fig. 9.9. The reaches are categorized based on the elevation of the study area. The percentage change is plotted in the form of boxplot and the star mark in the boxplot defines the mean value. The mean values are presented just below the boxplots. Figure 9.9 shows that the change in the mean is bigger in the RCP8.5 scenario than in the RCP4.5 scenario, owing to the 8.5 scenario's high temperature profile due to substantial climate forcings. It's also worth noting that the percentage change is calculated using annual values. Furthermore, runoff variability in the lower reaches is influenced by local variability as well as changes in the upper and middle reaches. Therefore, the hydrological variables over the study area are going to be intensified due to climate change.

The relative changes in the streamflow for three future time slices, relative to the reference time, are shown as probability density function (PDF) plots for different reaches in Figs. 9.10, 9.11, and 9.12 under RCP4.5 and 8.5 scenarios. To develop

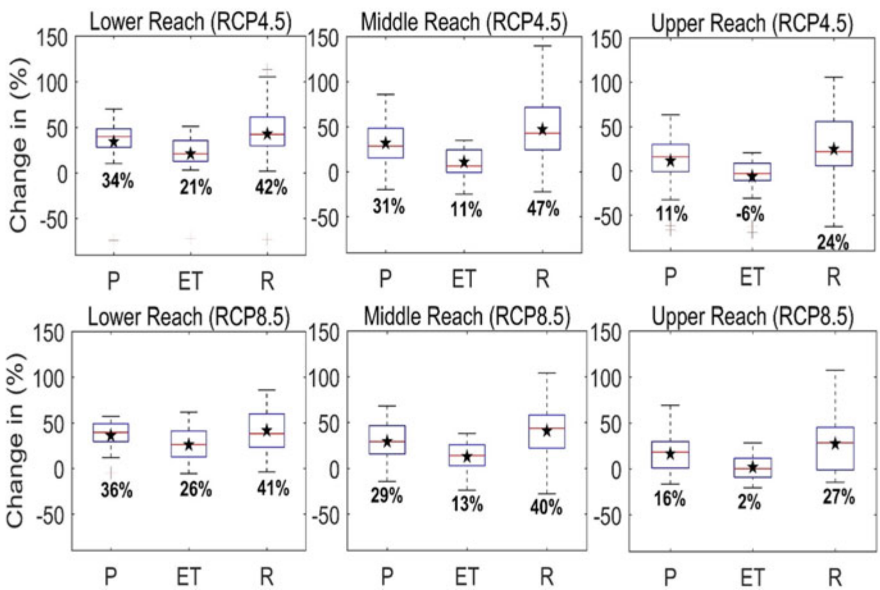

Fig. 9.9 Percentage change in P (Precipitation), ET (Evapotranspiration), and R (Runoff) with respect to the historical period. Percentage changes under RCP4.5 and 8.5 are presented in upper and lower panel respectively

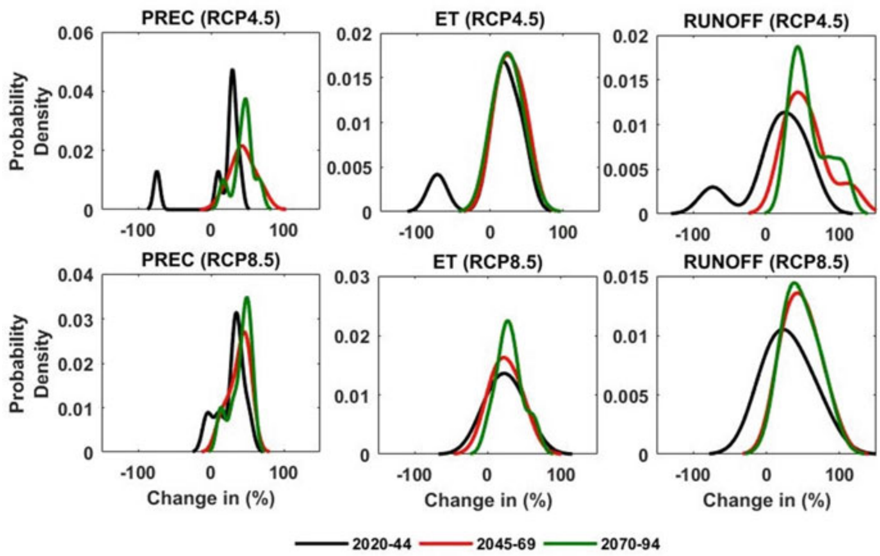

Fig. 9.10 PDF of P, ET, and R for Lower Reach under RCP4.5 and 8.5 scenarios

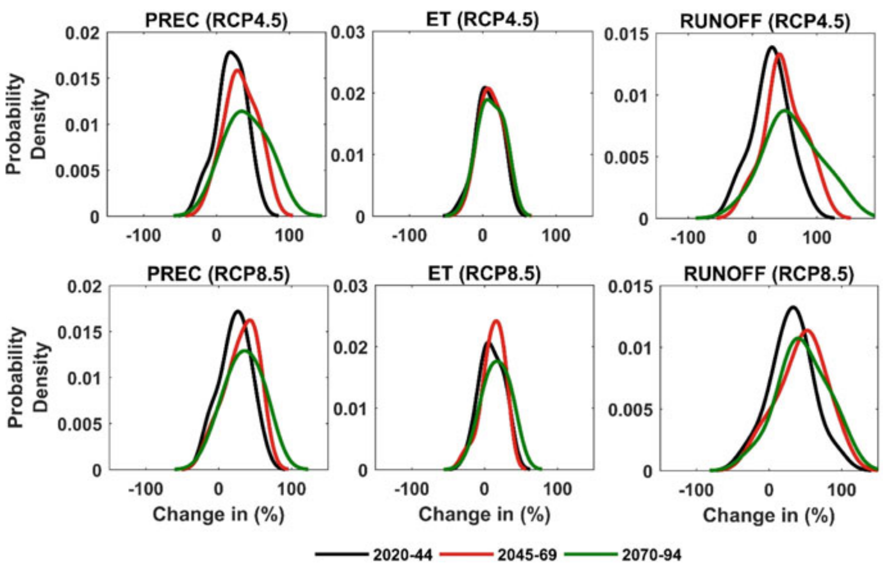

Fig. 9.11 PDF of P, ET, and R for Middle Reach under RCP4.5 and 8.5 scenarios

these figures, kernel density function is used. From Figs. 9.10, 9.11, and 9.12, it can be noted that larger variability is associated with the period from 2020 to 2044 in most of the cases. And these variabilities are more pronounced in upper and lower reaches under RCP4.5 scenario. Moreover, the percentage change in the runoff is

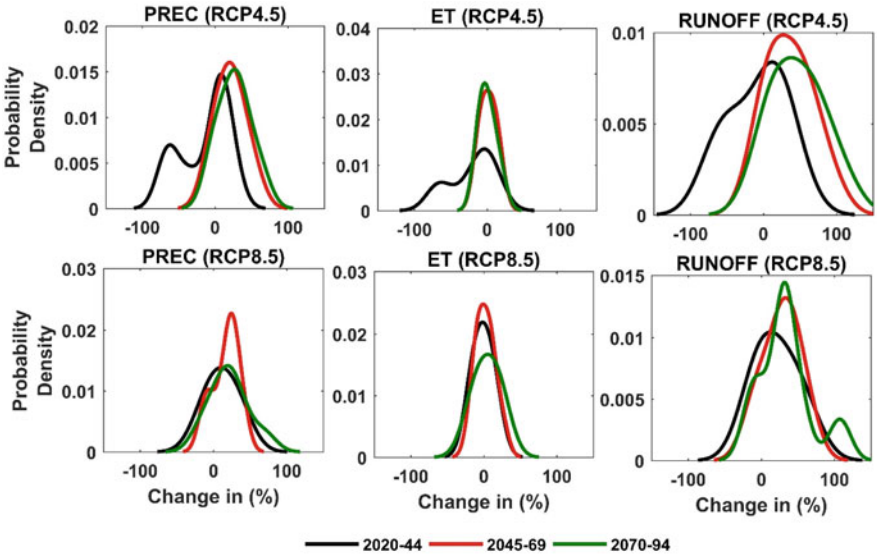

Fig. 9.12 PDF of P, ET, and R for Upper Reach under RCP4.5 and 8.5 scenarios

mostly associated with the percentage change in the precipitation rather than ET. A clear evidence can be observed in Fig. 9.11 under RCP4.5 scenario, where the percentage change in the ET is similar for all the time slices; however, the percentage change of the runoff follows the percentage change of the precipitation for different time slices. Mostly, larger differences in the PDFs are observed in case of precipitation and runoff under both the scenarios for all reaches.

9.7 Concluding Remarks and Future Focus

The present chapter portrays a review of climate change impact analysis in water resources and the underlying processes and procedures. Moreover, the commonly used impact analysis procedure such as integration of climate model and hydrological model is also presented. Authors have presented a case study over a river basin so that the readers would appreciate and get a clear picture regarding the impact analysis integrating GCM and hydrological model. It should be noted that the results obtained from the investigation are limited to the Wainganga river basin based on the outputs from the GCM. Despite advancements in technical elements, improved understanding, and computational capabilities, estimating probable variability in the near future necessitates significant research initiatives in order to establish effective adaptation plans and policies. Furthermore, the multidisciplinary study will aid in the development of scientifically sound water and climate change policies

(Goyal and Surampalli 2018). Below, authors concisely address future focus in climate change impact analysis, which will refine the research agenda.

- Attempts should be made to reduce the epistemic uncertainties and maximize the network of data assimilation so that research gaps in the context of understanding the impacts of extreme events and climate variability on agriculture, ecosystems can be minimized. In addition, the quantification of the impacts due to the variability and prevalence of adverse effects in terms of socio-economic aspects is likely to improve.
- Due to the erratic behaviour of the precipitation pattern, priority has been increased substantially for sustainable development in river basin scale. Therefore, multicriteria based management strategy incorporating the active involvement of institutional, economical, environmental, geospatial etc. perspectives to improve the water resources in a holistic manner is of paramount importance.
- There is an urgent need to improve the continuous monitoring system by integrating the satellite and land-based information at regional scale for better understanding, improving the quality of the dataset, and to provide an early warning system to minimize the consequences of the catastrophic climate events.
- In the changing climate scenario, the assumption of stationary approach among the causal and target variables are questionable in downscaling technique, which may lead to erroneous outputs and subsequently affect the adaptation strategies and policies. Hence, non-stationary based downscaling approach should be incorporated which will continuously update the relationship among the causal and target variables with respect to time and will provide a robust estimate.
- Most critically, for a climate resilient nation or planet, communication between researchers and policymakers should be strengthened, as climate change impacts are underutilised in decision and policy making. For example, the gap can be minimized by active involvement of both the scientists and policy makers in generating most feasible climate change scenarios for the foreseeable future.

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Chapter 10
Analysis of Precipitation Extremes at the Intra-seasonal Scale Using a Regional Climate Model

Nishtha Agrawal and Vivek Kumar Pandey

Abstract The agriculture and economic conditions of India are primarily dependent upon monsoon rainfall during the rainy season. The seasonal monsoon cycle embodies surplus and deficit precipitation conditions, which are often resulted in flood and drought like events in major parts of India. The variability of these events can be studied precisely with the help of Monsoon Intra-Seasonal Oscillation (MISO). The investigation of MISO requires the availability of higher resolution dataset as they incorporate the interaction of small scale processes associated with cumulus convection and boundary layer processes. This enhances the representation and predictability of active/break spells and monsoon depressions in hydrological modeling studies. The literature has illustrated about two major monsoon modes having high frequency (10–20 days) and low frequency (30–60 days) variability. Present study utilizes the outputs of Regional Climate Model v4.6 (RegCM v4.6), observed precipitation and reanalysis datasets to compute the dominant modes of variability using a band pass filter. Our analysis shows the importance of quasi-biweekly oscillations over 30–60 day variability in representation of active/break precipitation and progression of monsoon depressions for 24 years (1982-2005) of our study. We found that the higher frequency mode (10–20 day) of MISO is having a stronger correlation with the mean monsoon rainfall as compared to the Lower Frequency (LF) mode. The LF mode has weaker correlation with the mean monsoon rainfall and it is mainly associated with the northward propagation of Boreal Summer Intra-Seasonal Oscillation (BSISO). The implementation of BSISO indices in our analysis reveals that these indices have weaker correlation with the HF mode of MISO. The study emphasizes the need to refine the representation of high frequency mode in models and its role in improving monsoon predictability over India.

Keywords Hydrological modeling · Extreme precipitation · Indian monsoon · Flood and drought

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10.1 Introduction

The Indian summer monsoon is one of the strongest monsoons of the global monsoon systems. It affects the production of agriculture, conservation of water resources, and economic growth of India (Sharma and Goyal 2018). The monsoon precipitation over India varies at different spatio-temporal scales including the centennial, decadal, inter-annual and intra-seasonal scales (Shivam and Sarma 2017). Among them, the sub-seasonal variability of ISM has substantial impact on annual precipitation over India. The intra-seasonal fluctuations appear mainly in form of excess and deficit monsoon rainfall across major parts of the country. The cycles of heavy and weak rainfall are often responsible for flood and drought like situations in various regions and are affected by several factors (Goyal et al. 2012). The risks associated with flood and drought like situations have already been discussed by some recent studies (Poonia et al. 2021a, b). The oscillations in monsoon precipitation arise due to sub-seasonal variability of monsoon trough, which covers a large proportion of India during the days of active monsoon. It shifts northwards near the foothills of Himalayas during the break monsoon conditions. The sub-seasonal variability of monsoon is influenced by direct and indirect response of large scale meteorological phenomena (Goyal and Ojha 2011). The major responses appear from the Madden Julian Oscillation (MJO), the El-Nino Southern Oscillation (ENSO), and the Indian Ocean Dipole (IOD). Different studies have shown that the intra-seasonal variability of monsoon rainfall exhibits two major modes of variability, which is often observed at 30–60 days and 10–20 days time scales (Goswami 2005; Goswami and Mohan 2001). The variations in 30–60 days are accompanied by a slow northward propagating mode, whereas the 10–20 days fluctuations are caused by a westward propagating mode of the Intra-Seasonal Oscillation (ISO) (Krishnamurti and Bhalme 1976).

The occurrence of active and break spells is considered to be predominantly associated with the low frequency or northward propagating mode in most of the previous studies (Goswami 2005; Lau and Chan 1986; Mandke et al. 2013; Sikka and Gadgil 1980). The alternate wet and dry lobes of the northward propagating mode can trigger or retard the convective activity over major parts of India. The low frequency mode carries enormous amount of moisture and momentum towards the Indian subcontinent, and perturbs the mean state of northern Indian Ocean. It has an average propagation speed of 0.5°/day between 5° N to 25° N latitude range, and has eastward moving tendency with a speed of 9°E/day. The oscillation associated with high frequency mode appears to move westward and has comparatively weaker wind intensity. This mode is originated in tropics, and is associated to the equatorial Rossby wave of wavelength 6000 Km (Chatterjee and Goswami 2004). The scientific community has made tremendous efforts in simulating higher and low frequency modes using various state-of-the-art numerical models in the recent decade. Studies performed with various General Circulation Models (GCMs) have shown the inability of models in capturing accurate state of BSISO (Rajendran et al. 2002; Sabeerali et al. 2013; Xavier et al. 2008). In continuation with this, the importance of oceanic feedback was also realized by many studies (Klingaman et al. 2008; Rao et al. 2012; Sengupta et al. 2001). It was seen that Indian Ocean Sea Surface Temperature (SST) is important for modulating the convective activity over India. The SST and oceanic fluxes can modulate the moisture convergence, which alters the formation of clouds and precipitation over monsoon core region. Modeling studies concerning the Intra-Seasonal Oscillations (ISO) have shown that the coupled climate models have improved the simulation of low frequency mode as compared to the stand-alone simulations (Rajendran et al. 2012, Kemball-Cook and Wang 2001; Seo et al. 2007; Webster et al. 1998). For the ISO mode, the role of oceans in simulating the phase and intensity due to the modulation of MJO is also shown to be passive by many studies (Sperber 2004; Waliser et al. 1999). Apart from this, there also exists some speculation because the exact influence of air-sea coupling on the phase and intensity of the ISO is still not clear. For the Indian subcontinent, the portrayal and prediction of ISO is performed with the Climate Forecast System (CFS v2) model. It has robustly captured the strength and variability of monsoon over India. Over the intra-seasonal scale, it has shown several systematic biases in simulating the MISO. The CFS v2 exhibits dry bias over the Indian landmass region, and cold bias in SST (Abhilash et al. 2014). These have affected the accurate representation of monsoon, especially at the high frequency scale. Thus, the studies for improving its capability are still under progress.

The studies concerning 30–60 days mode have rapidly grown in the recent decade. It is linked with convectively coupled MJO, and northward propagating ISO. However, the importance of 10–20 days mode has not gained enough attention in literature, and very few studies have shown the inefficacy of GCMs in simulating the higher frequency mode. The structure and variability of high frequency mode is also missing in the past studies. Moreover, we are not completely familiar with the impact of ISO modes on the overall variability of monsoon circulation over India. Since the research elaborating the nature of high frequency mode is still in numbers, the present study attempts to shed light on the importance of high frequency mode on seasonal precipitation over India. The analysis shows the dominance of this mode over low frequency mode to represent seasonal precipitation over India. In this work, we have tried to quantify the proportionate influence of 30–60 days and 10–20 days mode on monsoon precipitation over India. The study is performed by analyzing the outputs of Regional Climate Model (RegCM v4.6), observations and reanalysis datasets to infer the predictability skill of monsoon precipitation during the period of active/break days and monsoon depressions. The analysis is expected to contribute towards better understanding of extreme rainfall events during the summer monsoon season. The outcomes of the study can be helpful for enhancing the extended range prediction of monsoon circulation over India. The paper is organized as follows; Sect. 10.2 describes the source and spatio-temporal scale of datasets being used. Section 10.3 demonstrates the results, and we have concluded our work in Sect. 10.4.

10.2 Data and Methodology

10.2.1 Model and Data Used

The present study uses the outputs from RegCMv4.6 to study the intra-seasonal variability of monsoon for 24 years of the study (1982–2005). RegCM is a hydrostatic model, which has been developed at the National Centre for Atmospheric Research (NCAR), and is currently maintained at the Earth System Physics (ESP) section of the International Centre for Theoretical Physics (ICTP). It was designed to dynamically downscale the GCM data at smaller grid scale by providing lateral boundary conditions to the governing primitive equations. The model is highly versatile for simulating various climatic processes due to the inclusion of latest schemes for multiple atmospheric processes. For our analysis, the model data is obtained at 25 Km horizontal resolution over the south Asian domain (50°E:110°E; 10°S:45°N) for the historical simulation period. The initial and lateral boundary conditions were taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim dataset. The details of model setup and the description of initial and boundary conditions are provided in Kumar et al. (2019). For analyzing and comparing our results, we further utilized gridded observed and pressure level reanalysis data fields. Apart from the model results, we also used observation and reanalysis data for the analysis and comparison of results. We have used daily gridded precipitation data at 0.25°× 0.25° horizontal resolution constructed from station observations and it was made available by the India Meteorological Department (IMD). The circulation variables are compared with the high resolution (0.25°× 0.25°) ERA5 reanalysis dataset. The precipitation and pressure-level data are used for the same spatio-temporal range as that of the model data. The record of monsoon depressions is obtained from the IMD's e-Atlas portal for the June-July-August-September (JJAS) months of the 24 years of this study.

10.2.2 Methodology

For analyzing our outputs, we have extracted the dates of wet and dry spells over the core monsoon zone. The location of monsoon core zone is shown in the Agrawal et al. (2021) study. The anomalous precipitation values are averaged over this region, and their values were analyzed. The durations of active (break) events were decided, if the precipitation anomalies were greater (less) than +1 (-1). This criteria is inspired from the Rajeevan et al. (2010) study, and has been popularly used in most of the studies concerning active-break days of monsoon. The analysis requires mean distribution of our datafields during the active and break period of monsoon. We further made the use of wavelet-coherence spectrum to evaluate the dominance of multiple modes present in the data. The wavelet-coherence analysis is analogous to the correlation analysis. It evaluates the relationship between two time series at multiple time and frequency scales. The model and IMD observation were used to check the co-movement of precipitation anomalies at difference frequency range. After quantifying the dominance of modes, we tried to filter our datasets at the required frequency range. For this purpose, we applied band-pass filter on our data between the low and high frequency range. A band-pass filter retains the data between the given frequency range and attenuates the unwanted outside signals. In this analysis, we have applied the filter between 10–20 days and 30–60 days. The frequencies outside this range were suppressed.

10.3 Results and Discussion

The subseasonal variability of monsoon incorporates high intensity rainfall that influences the environmental resources inevitably. Among the various monsoon modes, the intra-seasonal variability of monsoon is expected to influence seasonal monsoon rainfall over India at a large scale. The duration and strength of active/ break events determines the overall condition of monsoon during a year. However, it is still not know to what extent this influence can be seen. The present work focuses on extracting the major monsoon modes, and their influence on seasonal monsoon conditions over India. We analyze the impact of low and high frequency modes on the seasonal precipitation over India.

10.3.1 Intra-seasonal Variability of the Indian Summer Monsoon

The intra-seasonal oscillations comprise of excess and deficit monsoon rainfall conditions over major parts of the country. These are responsible for flood and drought like conditions over India. The situation of active and break monsoon appears due to oscillatory shift in the position of monsoon trough. For the analysis of intra-seasonal variability, we have firstly calculated the active and break phases of monsoon. The dates of active and break monsoon days are quantified using the precipitation data obtained from the RegCM model run and IMD data portal. We have averaged daily precipitation data over monsoon core region as shown in the Agrawal et al. (2021) study. This region is considered to be analogous to the monsoon trough region and is considered by most of the previous studies given in literature (Pai et al. 2014; Rajeevan et al. 2010). The declaration of active and break days is based upon the values of rainfall anomalies. If the anomalies are $> +1$ for 3 or more consecutive days, we called it an active spell, and if it is < -1 for 3 or more days again, the break period was declared. The length and duration of active and break periods calculated using the IMD data and that of the previous studies have shown similar results. However, on considering the RegCM outputs, we have found

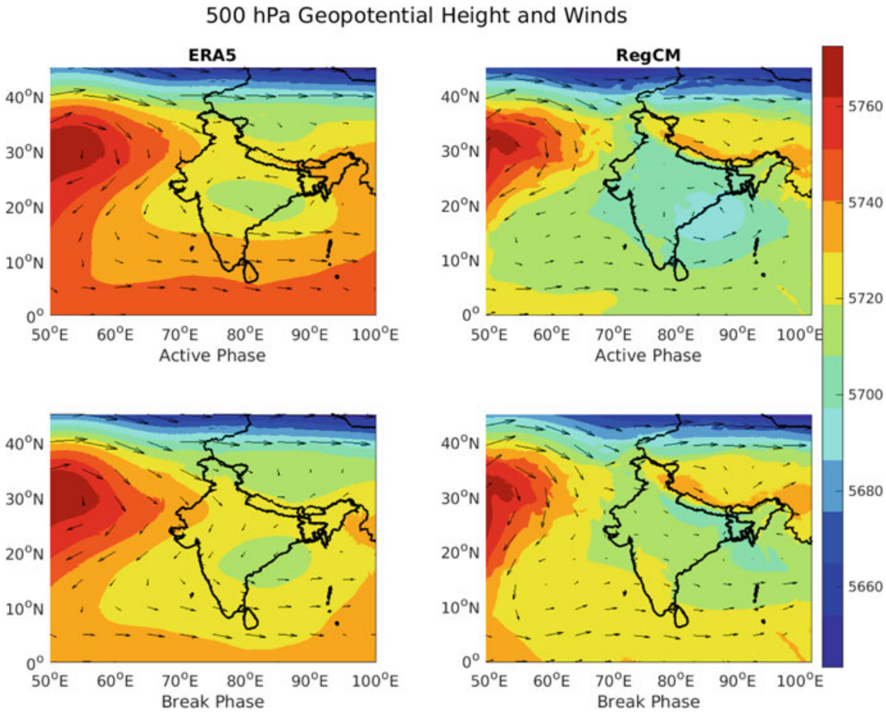

Fig. 10.1 Distribution of 500 hPa Geopotential Height and wind vectors during the active and break monsoon spells

certain discrepancies (Agrawal et al. 2021). We further examine the capability of the model in capturing realistic atmospheric conditions during active and break days of monsoon. Figure 10.1 shows the composites of 500 hPa height and wind vectors from the model and reanalysis (ERA5) datasets. It shows the position of monsoon low over the western coast of Bay of Bengal and subsequent high in western longitudes (between 50°E and 60°E) during the active and break days of monsoon.

The monsoon circulation is characterized by a notable presence of monsoon low over the western boundary of BoB, which provides necessary precipitation in eastern and central India. In Fig. 10.1, the monsoon low corresponding to the model data is of higher intensity as compared to the re-analysis data during the active and break phases of monsoon. The model captured low is elongated to a larger horizontal area especially during the break conditions. The notable differences are further evident over the Ocean and high topography areas (Indian Ocean and Himalaya regions).

The model calculated sub-tropical high is underestimated again over the northen IO during both the events. These differences appear due to inability of the model in providing up to date air-sea interaction and surface fluxes from the ocean and high topography areas. Overall, the characteristic large scale circulation and thermal structure of the atmosphere is still found to be similar in our model results.

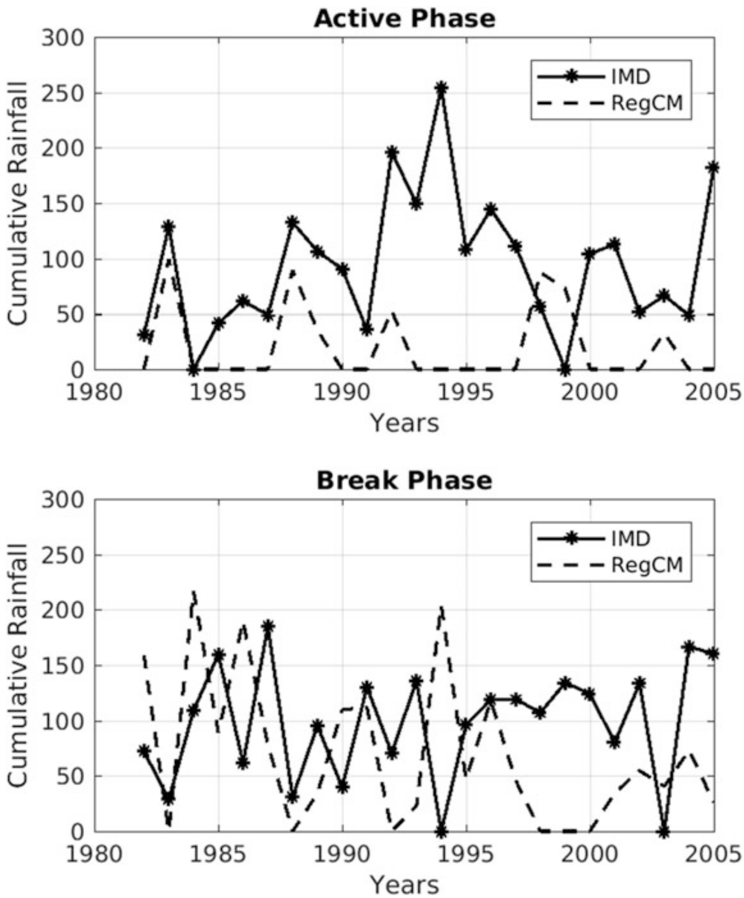

Fig. 10.2 Estimate of cumulative rainfall (in mm) during the active and break phases of monsoon from the model and observed data

The distribution of large scale circulation and temperature affects the precipitation rate, which is crucial for governing the atmospheric balance and local harvesting. We have further evaluated the cumulative precipitation of each year from the model and IMD datasets during the active and break phase of monsoon. Figure 10.2 shows cumulative precipitation (in mm/d) from both the datasets for 24 years of study. The figure shows the deficiency of the model in capturing intra-seasonal rainfall especially during the active monsoon events. The model has mostly shown dry bias in representing actual rainfall for almost all of the years. The large bias in rainfall arises due to evident cold temperature bias in the model which is shown in Agrawal et al. (2021). The situation is better during break monsoon events as the cumulative precipitation is closer to the observed data in early years and significantly deviates in later years. Thus, although the model evaluated low is

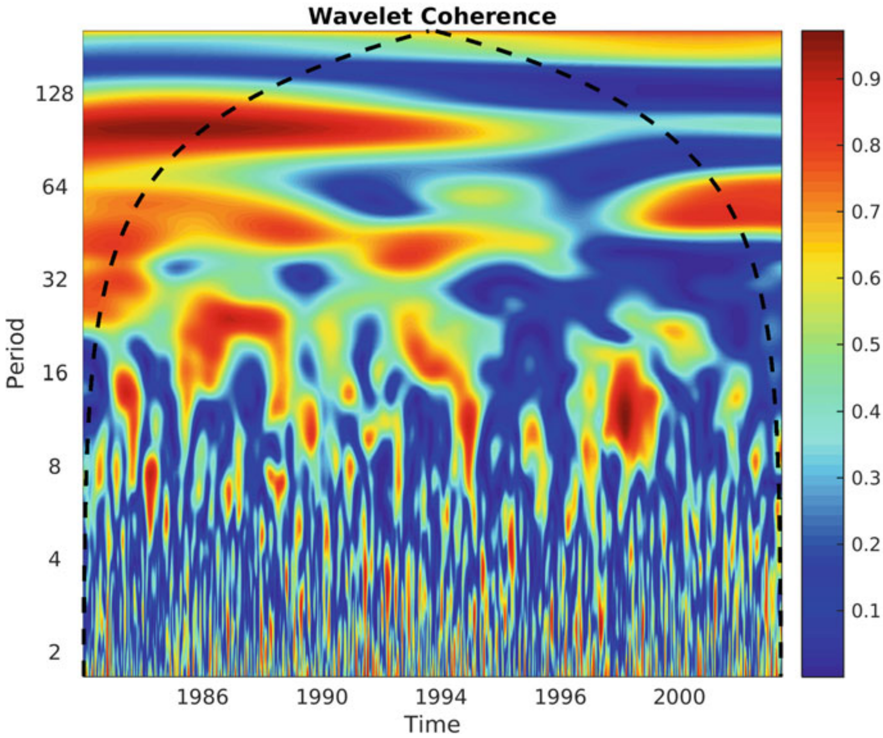

Fig. 10.3 Wavelet coherence spectrum between the model and IMD precipitation. Dashed line represents the cone of influence

comparatively of higher intensity, its precipitation strength is really low. The differences are appearing expectedly due to the lack of ocean coupling and irrelevant distribution of input topographic details fed in the model.

The inefficiency of the model in capturing realistic precipitation compels us to identify the gaps. We intend to find out which mode of ISO is causing huge discrepancy in the model. Therefore, we next find out the coherence between the model and observed precipitation datasets at multiple timescales within a monsoon season. Figure 10.3 shows the wavelet coherence spectrum between the model and IMD rainfall data averaged over the monsoon trough region (15–25°N; 70–80°E). It is showing similarity between daily precipitation time series at different frequencies. The black dashed lines represent the cone of influence, which is the area where the spectrum is expected to be slightly distorted due to the edge effects. The coherence spectrum depicted in Fig. 10.3 shows strong coherence at low frequencies (30–60 days) under the cone of influence.

There is no specific pattern at higher frequencies especially below the 10–20 days range. This shows that model has efficiently captured low frequency modes, but it has faced difficulties in capturing high frequency signals which are affecting the ISO variability and active/break monsoon precipitation in the model. The importance of high frequency modes will be discussed in further subsections.

10.3.2 Analysis of Low and High Frequency Modes

RegCM v4.6 has failed to represent MISO variability and associated precipitation during the active and break days. The large bias in the model is mainly arising due to the high frequency events. Since the objective of the present work is to quantify the dominance of high and low frequency events, the model results corresponding to high frequency events may turn out to be inappropriate. Therefore, we now proceed only with the re-analysis ERA5 data for the analysis of low and high frequency modes. We have applied 10–20 days and 30–60 days band-pass filter on IMD and ERA5 datasets to check the importance of high and low frequency modes for predicting seasonal precipitation during monsoon. The filtered and unfiltered time series for July–August (JA) months are obtained, and correlation of unfiltered series with lower and high frequency modes is computed. We have not selected the June and September months as they mark the onset and withdrawal of the monsoon, and a slight change in the dates can affect our results. The JA months are considered as the peak monsoon months. In our analysis, the correlation of unfiltered JA series is found to be ~0.4 and ~ 0.1 with high and low frequency modes, respectively.

The observed correlations are significantly ($p < 0.05$) captured using the IMD precipitation anomalies. This shows that rainfall during the seasonal monsoon has strong association with the high frequency modes as compared to the low frequency events. Since the high frequency modes can produce high magnitude precipitation, their dominating impact on seasonal precipitation can be convincingly true. The monsoon season is dominated by the northward propagating Boreal Summer Intra-Seasonal Oscillation (BSISO). It is characterized by northeastward propagating convective clouds from Indian Ocean to western Pacific ocean. The subseasonal prediction of monsoon requires the phase and amplitude of BSISO for the prediction of active and break spells. Therefore, we have further used the daily BSISO indices obtained from the National Centre for Environmental Prediction (NCEP) for the correlation analysis. We have obtained the correlation between the BSISO index and both the phases of monsoon at high significance level ($p < 0.05$). Our analysis reveals that the BSISO is mainly associated with the low frequency mode, whereas the high frequency mode remains significantly unaffected with it. This shows that a large proportion of monsoon variability is still unexplored.

The major components of monsoon variability are characterized by wet-dry spells, whose impact is reflected through the surface flux of heat. Therefore, it could be interesting to see which of the higher or low frequency modes have larger affect on them. To validate our findings, we have computed the composites of filtered anomalies of sensible heat fluxes during mean active/break day period in Fig. 10.4. They are useful for estimating the extent of precipitative cooling over the surface.

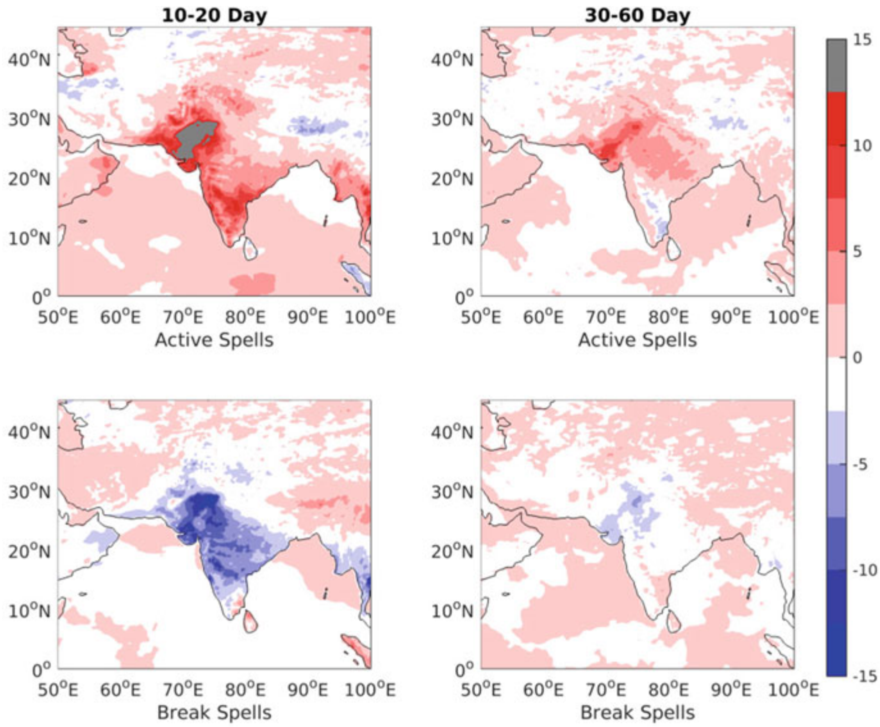

Fig. 10.4 Band-pass filtered anomalies of sensible heat fluxes (W/m^2) during active and break phases of monsoon

The fluxes are filtered over 10–20 days and 30–60 days time-band during the wet and dry monsoon spells. The composite fluxes during different phases of monsoon show the dominance of high frequency mode as compared to the 30–60 days mode over the core monsoon region. The fluxes have positive values over entire India during the active days under the high frequency mode. The break days are mainly dominated by negative fluxes, it has an higher intensity under the high frequency mode This shows that intense precipitation of shorter days is more effective than the variability during the larger time scale.

The impact of monsoon intra-seasonal variability is further associated to the genesis and propagation of monsoon depression (MD) over India. The monsoon season accompanies the presence of monsoon low over the western boundary of BoB, which is considered to be the birthplace of major monsoon depressions. Most of the depressions are formed within the monsoon trough region, and are a significant part of intra-seasonal variability of the monsoon. The genesis and westward propagation of MD further affects the seasonal variability of monsoon. The area surrounding MD are equipped with strong cyclonic vorticity which has tilted upward structure. To elucidate the dominance of high and low frequency modes on the formation of MD, we have taken out the composites of 500 hPa vorticity from the

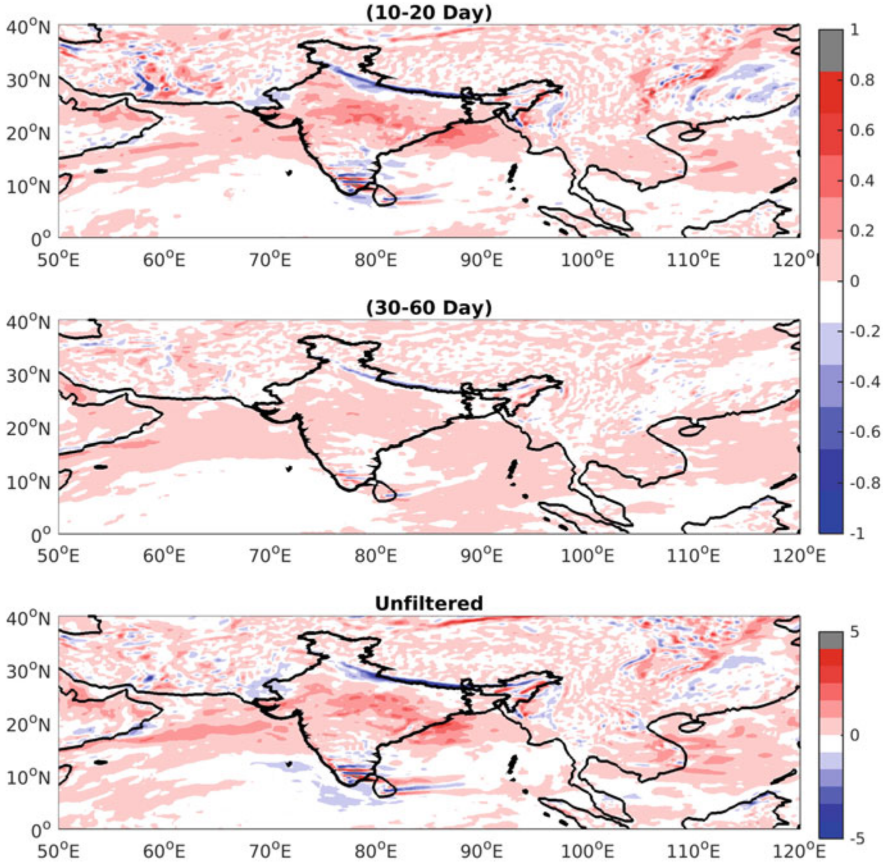

Fig. 10.5 Band-pass filtered anomalies of relative vorticity during the passage of monsoon depressions

filtered and unfiltered data during the passage of MD for 24 years of this study (1982–2005). The data of MD events is obtained from the cyclone e-Atlas website of the IMD. The composite relative vorticity in Fig. 10.5 exhibits a larger contribution of 10–20 days mode to the unfiltered vorticity as compared to the 30–60 days mode. The strong positive vorticity surround the monsoon core region. The strong cyclonic circulation in this region reinforces convection and precipitation during the active days. The break days are found with rare cases of MD. This shows that consideration of 10–20 days mode not only enhances the flood and drought related warnings, it also improves the predictability of tropical storms and coastal vulnerability over the Indian subcontinent.

10.4 Conclusion

The agriculture and economic conditions of India are strongly dependent upon the variability of summer monsoon. The hydrological resources and industrial productivity requires timely and optimum rainfall during the summer monsoon season. The variability of seasonal monsoon is strongly based upon the intra-seasonal precipitation which is dependent upon certain factors. The variability of ISM has two major intra-seasonal modes having the variability of 30–60 days and 10–20 days. The present study attempts to demonstrate the efficiency of RegCM v4.6 in simulating intra-seasonal variability of monsoon at different time scales. Our analysis reveals the consistency of the model in simulating large scale features during the active and break monsoon spells, when compared to the reanalysis data. The issues remain evident with model precipitation at higher frequency, which may arise due to several factors including the lower resolution of the model, lack of ocean coupling and erroneous topographic details. The analysis of high frequency mode demonstrated with observed and reanalysis data has shown its dominance for the representation of seasonal monsoon rainfall over India. The high frequency events are composed of wet and dry monsoon phases that incorporate monsoon depressions. The precipitation associated with 10–20 days mode is of higher magnitude and is affecting mean precipitation over India. It is also seen that the high frequency mode is not affected by BSISO, which is considered to be one of the major predictors of monsoon intra-seasonal variability. This shows that our understanding of analyzing monsoon variability is still very limited. The accurate representation of high frequency mode should be extremely helpful for predicting the monsoon fluctuations over India. The present state-of-the-art models are unable to capture its variability. It is still a challenge for the scientific community to enhance it in major numerical models.

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Chapter 11
Geospatial BigData and Its Applications

Nilkamal P. More, Manisha Galphade, V. B. Nikam, and Biplab Banerjee

Abstract In the modern world of developments in geospatial data capture techniques, the data handling of geospatial data as big data is pivotal. The most of real world data is available in an unstructured form. While some of this data is stored in databases, much of the data is unstructured and temporal in nature. In this book chapter, we survey different forms of geospatial big data their characteristics, tools and techniques. We present case studies which are related to hydrology and meteorology department. A flood management and wind power generation using geospatial big data is explained in this chapter as an application of geospatial data. We discuss ten different features of geospatial big data.

Keywords Geospatial big data · Big data · Hydrology · Flood detection · Raster data

11.1 Introduction

In this digital world lots of data is available at our fingertips. Because of advancement of geospatial technologies and availability of data, the applications can be developed. Though "big data" is the emerging term, most widely used definitions broadly refer to a circumstance in which it is part of the problem to cope with the nature of the data (Mike 2010). We initially highlight the set of features assigned to big order to better insight and focus on geospatial Big Data applications. We then focus on applications and case studies related to geospatial big data. The motivation of this book chapter is to study features of geospatial big data how it can be used for developing applications. With this purview, we want to analyze the strong points and

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applicability of each geospatial big data for various applications like Flood detection and Wind power prediction applications.

11.2 Geospatial Data as a Big Data

Geospatial big data has a wide scope of applicability. Geospatial applications ranges from simple land use land cover classification to more complex applications related to disasters. Geospatial data has the big data properties. We will discuss the properties of geospatial data in detail (Khan and Alsaqer 2018; More et al. 2018).

11.2.1 Features of BigData

There are ten different features of big data which are explained here in the table given below (Khan and Alsaqer 2018).

Volume: Data volume property of big data describes the amount of information available from different applications. If large volume of data is available then the data preprocessing, management and administration is necessary. Because of advancement in cloud computing technologies voluminous data is available for processing.

Value: Value of the data refers is helpful in taking decisions. Value plays an important role in businesses and in Big data world. Value of data may degrade with the time. Historical may also be useful for some applications.

Velocity: Velocity of the data is associated with the speed at which data is generated. This property is useful when the data is time intensive and faster processing of results is required. E.g. Apache Spark is preferably used for continuous and repetitive jobs. Hadoop is used to process data generated from traditional applications in a distributed manner.

Veracity: Veracity of data is defined with respect to the quality of the data as well as accuracy of data. Major decision making is based on veracity of the data. Veracity of data can be observed to classify it as inconsistent, incomplete, ambiguous or deceptive.

Viscosity: Viscosity of data comes in picture when data comes from heterogeneous sources. Viscosity of such data is unmanageable, complex and critical. Complexities of big data deals with the extent of dependence in big data in such a way that minute changes can have a very big effect on the performance of the system.

Variability: Variability in the data is introduced because of inconsistent or irregular flow of the data. Inconsistency makes data difficult to manage. This property is more observed because of more use of digital media. Like use of video conferencing applications like Zoom meet/google meet, social media websites like twitter, Facebook etc.

Volatility: Volume of big data, different forms of data, and speed at which data is generated; these three factors are useful to define volatility of big data. In the real world we need to check the validity of the data. Data which is useful today may become outdated tomorrow. Such data cannot be used for analysis as it may lead to an ambiguity. This is particularly useful in an environment where we have streaming data.

Viability: Big data ought to be dynamic and live perpetually and should be capable to give information when required. These properties of big data ensured with the help of viability. By using Big Data, we gather multidimensional information. Viability is an important feature of big data as it helps choosing precisely the attributes and factors that are well on the way to recognizing the outcomes that most concern organizations.

Validity: Validity is one of the properties of big data that is necessary in order to get the closeness inside enormous big data age sources of concealed associations among components. Validity of the data is related with the legitimacy of information. Validity of data is important in enterprises.

Variety: Variety of a data defines the level of data relationships. Structured data has high degree of association but unstructured data needs sufficient level of association. Weakly-formed and amorphous information therefore needs an established basis for planning, and traditional tools of administration are not in a position to cope with the massive density and variability of big data.

11.2.2 Gap Analysis of Geo-spatial Data

The large volume of geospatial data is available from several sources. But it cannot be used directly. Different challenges which are faced by scientist are listed over here.

(i) **Lack of number of experts:** Enough people are not available in this field to share concepts, opportunities and challenges. A lack of people working in the efficiency of geographic technology identified.

(ii) **Softwares/tools available**: The softwares which are available for use of GIS are not that user friendly. Training needs to be conducted for using these softwares. Proprietary softwares like ArcGIS and ERDAS are out of reach of common man because of cost. ELWIS, QGIS like softwares are available but training is not available.

(iii) **Software and hardware cost**: The softwares and hardware which are available for GIS are costly.

(iv) **Lack of supply of accurate preliminary information:** In order to ensure the availability to the private sector of a go, relevant and development preliminary information, there is an immediate need to access and make accessible all the data created by various agencies.

(v) **Systematic policy:** The vision document points out that there are a total of 17 national-level policies and regulations, with four in the prototype phase dealing with geospatial information, in as many as six committees.

(vi) **Data sharing standards:** Given the emergence of the 2012 National Data Sharing and Accessibility Policy, most geospatial data produced in India is in warehouses since there is unique platform which can be used to collect valuation of data by all departments.

(vii) **Standard inspection:** The judgement process is sluggish, with multiple age Data sharing standards: Given the emergence of the 2012 National Data Sharing and Accessibility Policy, most geospatial data produced in India is in warehouses since there is unique platform which can be used to collect valuation of data by all departments.

(viii) **Standard inspection:** The judgement process is sluggish, with multiple agencies controlling approvals and hypersensitivity correlated with satellite imagery. Agencies controlling approvals and hypersensitivity correlated with satellite imagery.

(ix) **Technology awareness:** Computers with specialised software, computers not capable of handling GIS data, little administrative help, lack of useful or accessible data, scarcity of high-resolution satellite imagery, variable ability set needed are the additional problems in GIS domain.

11.2.3 Categorization of Geospatial Big Data

Geospatial data is mainly available in two forms, vector and raster data. This section will explain the difference between raster and vector data and how it is useful for different types of applications.

11.2.3.1 Raster Data

One of the widely used forms for geospatial data is raster data. Geospatial data is created and delivered in this form. Raster data model is used to describe data as a grid of small cells. These cells are also called as pixels i.e. picture elements. Pixels are arranged in a row-column form. It is composed of single-band or multi bands. Each point in a raster data (More et al. 2020) occupies an area of fixed size.

Figure 11.1 shows the raster, vector data in real world. A satellite image is an example of a multidimensional image. With each pixel there is value which gives information about the different frequencies associated with it. The spectral resolution of the satellite image is associated with the number of spectral bands. The quality of the satellite image depends on the spatial resolution e.g. LANDAT 7 images are available at a spatial resolution of 30 m. But the CARTOSAT 2 images are available at a resolution of 1 m. CARTOSAT 2 images are of better quality than LANDASAT 7 images.

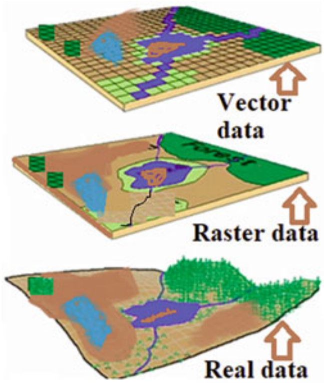

Fig. 11.1 Raster, vector and real data

Raster data is very useful (Davis 1996) to represent information of a contiguous area. For example if we want to mark the green space in a city then it is very difficult to represent through the vector data. Other applications which use raster data are listed below.

(i) Tree canopy assessment
(ii) Change detection after earth quake
(iii) Slum area detection
(iv) Covid prone areas detection.
(v) Malaria prone area detection
(vi) Rainfall prediction

11.2.3.2 Vector Data

Geospatial data can be available in terms of points, lines, multiline or polygons. The geospatial data which is available in this form is called as vector data. Vector data are composed of geometrical objects. It is based on mathematical expressions. It consists of one or more interlinked nodes to represent images in computer graphics domain. Any geo location can be represented with the help of two or three axis. The vector data can be a single point, a line, a polyline, a triangle or a polygon in two dimensional spaces. Trees, hotels, houses, colleges, schools, roads and rivers are all entities which can be represented. This information can be either in a text string or a numeric form. Vector data is highly suitable for representing Map data. For example building can be represented as points; roads can be represented in the form of polylines.

Various applications which can use vector data are listed (Davis 1996).

- Solid waste management application.
- Shortest route recommendation
- Recommending a location for a school/college
- Cab availability prediction in an area.

11.2.4 Pre-processing

Preprocessing of data is an important process in GIS domain. The preprocessing process removes ambiguity. The data obtained by geographical information systems are not quite often sufficient for analysis due to various distortions. Preprocessing involves those operations that are normally required prior to the data analysis and extraction of information.

11.2.4.1 Pre-processing Architecture

The architecture used for pre-processing of geographical information system is shown in Fig. 11.2.

Restructuring of data involves interfering in all parts of specifically chosen geographical elements to accommodate them for further processing, alternative practice of topological relationships, spatial classification of vector and raster representations, image segmentation, resolution adjustment, handling of attribute values.

- **Geometric transformation of representations** – Geometric transformation involves the process of converting geographic coordinates to rectangular plane coordinates which is called the analytic transformation and conversion of coordinates between rectangular plane coordinates, so called the numerical transformation. Transformation mechanisms are based on the transition of defining the position of the relevant reference ellipsoid. In case of raster data the part of the geometric transformation is the process of resampling. During resampling the position of the centre of each cell of new representation in the coordinate system of original representation is calculated by transformation equations. Consequently, by using different methods it is possible to assign or calculate the attribute value. We can use method of the nearest neighbour assignment, method of the cubic convolution.
- **Data conversion and image processing** – image processing is a process which is used primarily for raster systems and remote sensing. In GIS the use is limited; the following list of documents contains therefore only a fraction of the functions which this process involves. Functions of image processing include: filtering (edge detection, smoothing and sharpening borders), histogram modifications,

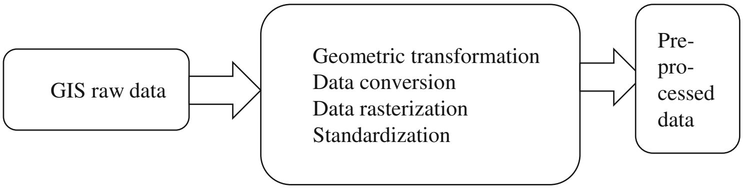

Fig. 11.2 Architecture of Satellite image preprocessing

change of brightness and contrast, classification, etc. Data conversion allows transition between vector and raster data formats.

- **Data rasterization** (conversion of vector to raster format) the vector layer is overlapped by raster grid of fixed size cells, to which the correct attribute is assigned. Problems with this conversion can occur when after the overlap one cell contains parts of more objects. The resulting situation is then solved by centroid method, dominant type method or the most important category method. Vectorization of points is quite simple. In the vector representation the location of the point which corresponds to the centre of the raster cell is identified. Similarly it is possible to proceed with the lines when the adjacent cells interconnect.
- **Standardization:** GIS environment is a process whose goal is to generalize the content of spatial database both for displaying maps and communication processes, and analytical processes. The first requirements for generalization are economic requirements, emphasizing that any modelling of reality require funds and at the same time it is also limited by technical development. Next in line are the requirements on reduction of the data volume which combine generalization with the need to filter out potential errors formed in the process of building GIS. The last reason for the generalization – the requirement of data visualization and perception – is based on the basic cartographic recommendations which suggest the rate of filling. The most common generalization techniques are:

  (i) Selection – selection of elements, elimination – removing of elements, simplification of elements,
  (ii) Aggregation – combination of smaller elements into larger ones, spatial reduction of elements,
  (iii) Typification – reduction of elements density,
  (iv) Exaggeration – highlighting of elements, reclassification and connection of elements, conflicts solution,
  (v) Refinement – smoothing of elements or peaks reduction.

11.2.5 Feature Extraction

Feature extraction is the process of extracting useful information from the given data. The important tasks which are involved in feature extraction are listed here.

11.2.5.1 Curse of Dimensionality

The remote sensed data used for analysis purpose are high dimensional in nature. Processing these high dimensional images is time and space consuming. So the

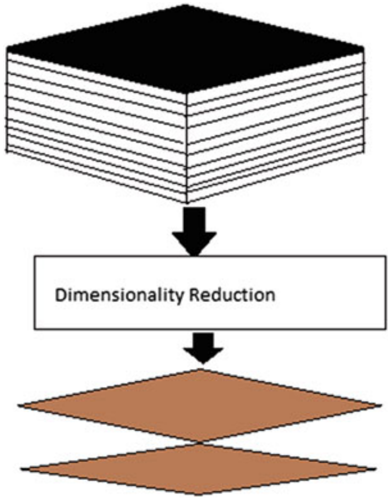

Fig. 11.3 Dimensionality reduction process

number of dimensions needs to be reduced. The process of reducing number of dimensions of a satellite images are covered under dimensionality reduction.

The issues with high dimensionality are

- The class parameters are estimated by statistics computed using training samples
- For high dimensional data the number of unknowns in the statistics are very large
- Demand for larger training sample size grows with dimensionality of the input feature set
- Difficult with coarse resolution hyper spectral imagery
- For n-band image, the covariance matrix contains n.(n + 1)/2 unique elements to be determined

Figure 11.3 explains the process of dimensionality reduction.

11.2.5.2 Dimensionality Reduction Techniques

There is lot of redundancy (overlap) between adjacent bands of satellite image. The information content of one band can be fully or partly predicted from the other bands in the data. Dimensionality reduction techniques are prominent tools in data pre-processing. Feature elimination and feature extraction these are the mainly two techniques for dimensionality reduction.

11.2.5.3 Principal Component Analysis

Principal component analysis (PCA) is a technique used for extracting features. It combines input variables in a specific order. It drops the least important variables

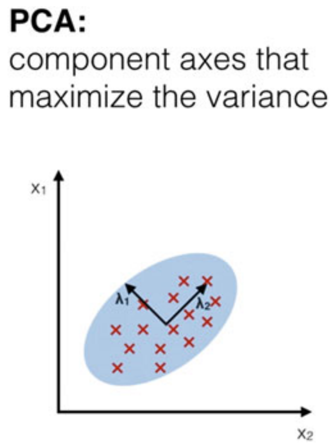

Fig. 11.4 Diagram for principal component analysis

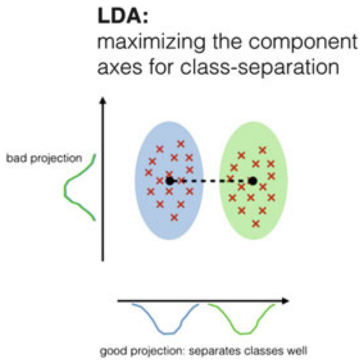

Fig. 11.5 Diagram for Linear discriminant analysis

while still retaining the most valuable parts of all of the variables. PCA is an important technique to understand in the fields of statistics and data science. Matrix operations such as matrix multiplication, matrix transposition, matrix inverses, matrix decomposition, eigenvectors/eigenvalues and statistics/machine learning like standardization, variance, covariance, independence, linear regression, feature selection all these things are important for understanding this technique.

Figure 11.4 shows the PCA method. In order to avoid overfitting of model, the number of dimensions of feature space must be reduced and fewer relationships between variables need to be considered.

11.2.5.4 Linear Discriminant Analysis

Linear discriminant analysis is used to reduce a worse feature space to lesser number of components. It picks a new dimension that gives maximum separation between the means of the projected classes.

Figure 11.5 explains LDA. It means that we want the maximum separation between our response variables and minimum variance within each of the projective classes.

11.2.5.5 Independent Component Analysis Algorithm (ICA)

ICA is a method of calculation to break an identified important into its underlying elements. ICA is calculated using normalized weight (w) and input (x).

$$S = w^{*}x$$

11.3 Applications of Geospatial Big Data for Monitoring Hazards

In order to offer spatial analysis knowledge not only to a wide audience of GIS practitioners but also to users of mobile apps, social media and open data initiatives, emerging geospatial big data technologies are working towards scalability, storage efficiency and geospatial analytics delivery efficiency. The key objective is to switch from basic event monitoring and reporting to a range of high-end spatial services that can provide valuable analytics to end-users and professionals engaged in spatial information applications such as agriculture, climate, forestry, etc. with daily requirements (Sharma and Goyal 2018; Shivam et al. 2017). More precisely, we foresee a transition not just from data analytics and real-time applications to real-time change monitoring in actual environments. In addition, a paradigm shift to daily surveillance of the entire earth is anticipated in geospatial big data, not only by microsatellites, in a spatial resolution of a few meters, but also through hyperspectral imagery from drones and satellites in subsequent years. In addition, the emerging video streaming technology from earth observation satellites will receive considerable publicity, which will bring a massive evolution of available spatial data from space, with simultaneous explosion in data storage requirements and compression rates from new techniques.

Figure 11.6 shows the software architecture of geospatial application. The availability of large, easy to access and secure geoformation is the basis of reasonable strategic planning and hazard mitigation judgement. The clear goal of most German countries in the region has been to encourage sustainable growth and innovation in efforts to progress awareness and insight in the area of risk mitigation. This initiative, sponsored by some national and European-funded projects, was introduced through the organization of a National Meteorological Administration unit capable of carrying out technical and economic assessments to establish a spatial data mechanism to record extreme meteorological/hydrological phenomenon (Goyal and Ojha 2011; Goyal et al. 2012).

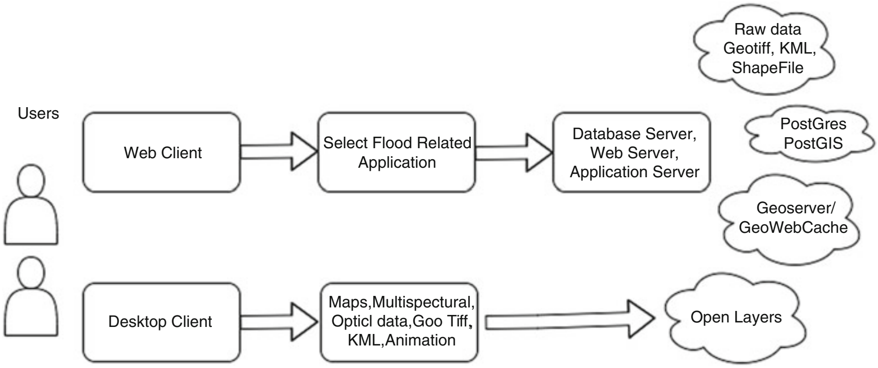

Fig. 11.6 Software architecture of geospatial application

11.4 Case Study

In this chapter we have discussed two case studies related to meteorology and hydrology domain.

11.4.1 Flood Change Detection Using Satellite Images

The biggest disaster that affects many countries in the world, year after year, is floods. From Romania's viewpoint, in terms of human misery and economic damages, floods are among the most destructive natural disasters. Flood situations can be monitored with the help of satellite images. Optically remote sensed satellite images from INSAT-3D/3DR provide information in less time. This information is very valuable (SCATSAT-1). Satellite images come with the cloudy data. Cloudy data makes surface water monitoring very difficult. Microwave remote sensed images have a unique advantage.

The electromagnetic radiations can be easily penetrated through the clouds. They are useful to sense the surface hydrological characteristics. SCATSAT-1 is one of the best satellites available for the monitoring of the flood situations.

Scatterometer Satellite-1 is used for weather forecasting, cyclone detection and shift detection for the Scatterometer. The satellite carries a Ku-band Scatterometer which scans HH and VV polarizations in a conical fashion and enables high-resolution datasets to be established due to high overlapping areas. SCATSAT-1 Ku-band observations for backscattering and brightness temperatures were analyzed in Gujarat and Rajasthan for flood detection and monitoring over India with special emphasis.

The combination of data on backscattering and brightness temperature helped to delineate the regions that were underwater, partially submerged, or existed under various conditions of soil wetness. The Fig. 11.7 is used to show the output of

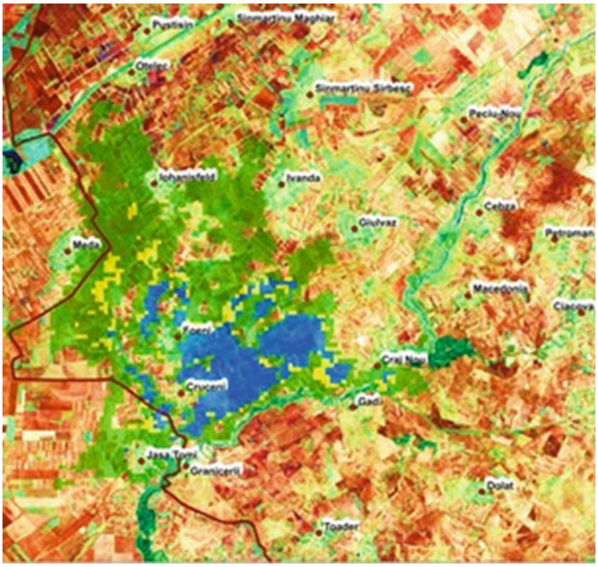

Fig. 11.7 Flood detection output using classification

classification. Water is marked in blue in this image. Flooded areas were acquired over Ganga and Brahmaputra flood plains during the second week of July. In contrast to the relatively dry conditions in Bharuch during the fourth week of July, severe flooding conditions were observed in Ahmedabad, Mehsana, Kheda, Banskantha and Bhavnagar, along with mild flooding in parts of West Bengal. Sentinel-1A, a high-resolution data SAR imaging satellite, helped to compare flooded regions over parts of Gujarat (India). Observations on flooding conditions were well correlated in

- Scatterometer Satellite-1 and
- Sentinel-1 satellite data.

Algorithm used for flood detection can be given as follows (More et al. 2020).

Algorithm: Flood Detection
Input: Satellite image dataset (Sentinel 2/LANDAT 7/MODIS)
Output: Classified image with the flood shown in blue color
Begin

Step 1: Select a satellite image for a particular date and time (Spatio temporal data)
Step 2: Select the area of interest
Step 3: Create a dataset for flood detection
Step 4: Spilt it into training (70%) and testing (30%) dataset.
Step 5: Apply a classification algorithm (SVM/Random Forest)
Step 6: Show the results of classification with water marked in blue color.

Step 7: Carry out steps 1 to 6 for an image Before Flood situation to the area of interest and save the results
Step 8: Carry out steps 1 to 6 for an image After Flood situation to the desired area of interest and save the results
Step 9: Compare the results obtained in the step 7 and 8 to observe the change in the area of interest.

End

11.4.2 Wind Power Prediction

Due to the decline of traditional energy sources, such as fossil fuels, and pollution generated by the combustion of such fuels, renewable energies, such as solar and wind, are gaining significance and exposure. Wind power is a source of electricity that is efficient and reliable and does not subject to any potential pollution. Electricity production with renewable energy of wind has now become the main objective of many communities. Even so, according to the chaotic and erratic associated with wind availability, effective power generation with wind power is quite an elusive operation. Wind Energy Prediction plays an increasingly important role in the maintenance and monitoring of an electricity system, with the exponential rise of wind power adoption into the power system. The wind power time series, however still exhibits nonlinear and non-stationary characteristics, which is still a major challenge to accurately predict. A number of previous studies have shown that the deep learning network can perform better in complex problems of function approximation, discovering the data's depth characteristics through its powerful nonlinear mapping capability. The researchers decided to apply deep learning networks to wind speed and power simulation, inspired by these achievements. SAE, SDAE, DBN, and CNN are popular models or methods for deep learning. Table 11.1 offers descriptions of studies produced for wind power forecasting. Various Studies developed for wind power forecasting are summarised here.

11.5 Summary

Geospatial data possesses many characteristics of big data. This book chapter tried to explain geospatial data as a big data as it possesses all the characteristics of big data. There are various application of geospatial big data in real world. Geospatial data is not like traditional data. Basically it comes in two forms. Raster data model and vector data model are explained over here with their fundamental properties. As pre-processing is an integral part of any analysis, the techniques used to pre-process this data are also explained in detail. After pre-processing this data it can be used in

Table 11.1 Descriptions of studies produced for wind power forecasting

DL technique	Model type	Preferred dataset	Preprocessing methods used	Evaluation criteria	Referenced papers
Pi-Sigma Neural Network (PSNN)	Hybrid model	Australian dataset	Nearest neighbour method	Mean Absolute Error (MAE) and Root mean square error (RMSE)	Zhang et al. (2019)
Long Short Term Memory (LSTM)-Recurrent Neural Network	Hybrid model	Sotavento, a wind farm in Spain	Auto encoders	MAE and RMSE	Shao et al. (2018)
Stacked Denoising Auto-Encoder (SDAE)	Hybrid model	Global Energy Forecast Competition 2012 (GEFCOM2012)	Auto encoders	RMSE	More et al. (2020)
Long Short Term Memory (LSTM)	Single Model	Europe Wind Farm dataset	Auto Encoder is employed to reduce the data Dimension	MAE and RMSE	Zeiler (1999)
Recurrent Neural Network (RNN)	Single Model	National Renewable Energy Laboratory (NREL)	Infinite feature selection (Inf-FS)	RMSE	Davis (1996)

various applications. The geospatial is useful in many applications ranging from weather forecasting to defence and disaster related applications.

This book chapter focuses on mainly two applications. One application is from disaster management domain i.e. Flood change detection using satellite images and second one is wind power prediction domain. First one uses the raster data as an input and second one uses vector data as an input. Further the algorithm used in these applications is described with the help of available literature survey.

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Part III
Case Studies

Chapter 12
Quantitative Assessment of Impact of Climate Change on Crop Yield over Sikkim and Central Region of India

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Abstract The present work focuses on (1) assessing the yield of rice, wheat crop under RCPs scenario 4.5 and 8.5 using AquaCrop yield simulating model and (2) determining the best sowing date of crops for maximum yield output across Sikkim and Central region of India. The bias corrected GCM outputs were utilised to simulate the yields of wheat and rice. The AquaCrop model was first calibrated (1998–2007), validated (2008–2015) and then future yield of wheat and rice was simulated for years 2021–2099. The Aquacrop simulated results over Sikkim shows an increase in yield of 0.5–20% for rice crop and 2–44% for wheat crop during the future years 2021–2099. For the Central region of India, the result depicts the highest impact of future climate with reduction in crop yields particularly during for future period (2081–2099) under RCP 8.5 climate scenario. Under the changed climate over Central India, shifting of planting date of rice (5 days later for period 2021–2060, 10 days later for period 2061–2099) and for wheat (15 days later for

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period 2021–2099) is proposed as a practical adaptation measure for sustaining the future yields.

Keywords Aquacrop · Climate scenarios · GCMs · RCP 4.5 · RCP 8.5

12.1 Introduction

The performance of crops is majorly dependent upon the phenomenon of climate. Agriculture, more than any other economic sector, is most affected by climate change due to its global distribution and strong ties to and reliance on climatic and environmental elements. As a result, climate change's effects on agricultural productivity have an impact on the socio-economical component at both the macro and local levels. Climate change has arisen as a major worry worldwide in terms of socioeconomic and environmental sustainability as greenhouse gas concentrations have risen (Simonovic 2017; Das et al. 2020; Poonia et al. 2021a, b, c). Furthermore, rising greenhouse gas levels exacerbate extreme weather patterns, aids in occurrence of flood – drought events frequently (Das and Umamahesh 2017). The levels of carbon dioxide gas have been found rising in the atmosphere since the late nineteenth century's industrial revolution, and it is anticipated that by 2056, the concentration will have doubled (Simonovic 2017). According to the intergovernmental report of climate change (IPCC AR5 2013), mean temperature has risen by around 0.6° Celsius at global scale, and based on future estimates under various climate projections, it is expected to rise by 1 till 5 degrees Celsius by 2100 years. Temperature data spanning more than 100 years shows that India has warmed by around 0.5 degrees Celsius (Subash et al. 2013), Whereas forecasts based on various climate change scenarios show a rise of roughly 3–5 degrees Celsius by the completion of 2100 years (Kumar et al. 2006). Looking at this prospective, an agriculture-based economy such as India, will get severely impacted by the negative effects of climate change. For example, the catastrophic drought in 2016 claimed the lives of over 330 million people and caused an estimated $100 billion in economic losses (ASSOCHAM Report 2016).

The climate system can be analyszed by the GCMs that have necessary information of climate structure in a basic form. These GCMs are thus powerful enough to develop specific climatic conditions and aid to analyze the impacts of climate change (Johnson and Sharma 2009; Balvanshi and Tiwari 2018). Crop models aids to diminish the time required in field experiments and also reduction in risks involved (Foster et al. 2017). This alternative method to employ the crop models for prediction of crop yields is quite accurate and cost effective. Crop yield simulation models like APSIM (Wang et al. 2002), DSSAT (Jones et al. 2003), and FAO AquaCrop (Sandhu et al. 2015; Steduto et al. 2009; Sethi et al. 2016) model has been utilized for developing proper management practice in the agricultural division. The AquaCrop model consists of several sets of incorporated in a user-friendly interface. The model is preferred for simulation of yields of various crops (Foster et al. 2017). Calibration and validation was conducted for maize crop by employing the Aquacrop model for diverse watering conditions. The water productivity (WP) fluctuated in the range of 2.35–27.5% (Abedinpour et al. 2012). APSIM wheat simulating model was employed for the Bhopal study area of India. A decline of 8% wheat yield was observed on every 1 °C enhancement in temperature and it was concluded that environmental factors have significant effects on wheat grain and biomass yield (Mohanty et al. 2015). Another yield model DSSAT CERES using GFDL CM3 GCM was employed to find the effect of climate change on Wheat crop. It was found that RCP 8.5 resulted in severe impact and yield decreased by 61% (Patel et al. 2018). CROPGRO Soybean model was employed at Jabalpur to find the impact of climate change on the yield. RCP 8.5 showed a marginal decline in yield by 2020 while by the year 2050 RCP 2.6 and 8.5 showed decline in crop yield (Walikar et al. 2018). AQUACROP model for Soybean crop was employed on study at Ujjain district in Madhya Pradesh.

Across Sikkim and Central part of India, there is a scarcity of thorough studies that look at key crop productivity on a regional basis. Furthermore, in the context of crop yield model, the uncertainty information provided by climate models and scenarios appears restricted. Despite the fact that a small number of studies have been undertaken in this region to assess the impact of climate change on crops, past research has been confined to a single crop study and has been based on previously defined climate change scenarios (Deb et al. 2015a, b). Keeping in view the economic importance of agriculture in Sikkim and Central Region of India, the present study was conducted for rice and wheat crops under future climate scenarios RCP 4.5 & RCP 8.5. The Aquacrop models was checked for its accuracy and reliability in determination of future yield and the impact of climate change on the crop yields over the study regions was quantified in this research work.

12.2 Study Area and Data Utilized

12.2.1 Study Area Description

This research work has been carried out on the two diverse regions which are situated in Sikkim and Central state of India (Fig. 12.1a).

Sikkim (Fig. 12.1b), is the first selected study area located in the East-Himalayas portion, with a physical occupancy of roughly 7096 km^2 with latitudes of 27° 07′ E – 28° 13′ E and longitudes of 88° 01′ N – 88° 92′ N. The area's elevation goes from minimum 192 m to 7403 m of maximum elevation above M.S.L. The area's elevation spans from 192 to 7403 metres above sea level. Over the surveyed sites, yearly mean precipitation ranges from 2300 to 3400 mm. The monsoon season (May–September) is when the majority of the rain falls, accounting for 85% of the total annual rainfall. Precipitation during the monsoon season lies in between 2000 and 2900 mm per year. The annual maximum temperature lies in range of 30–33 °C

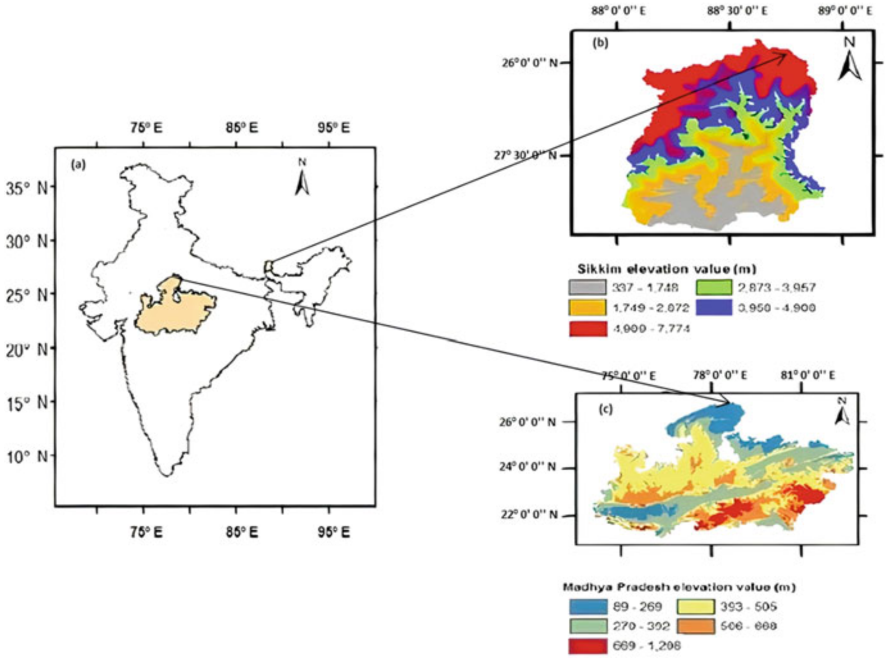

Fig. 12.1 (**a**) Location map of Sikkim and Central state over India; (**b**) DEM of Sikkim region; (**c**) DEM of Central Region Madhya Pradesh state of India

while minimum temperature lies in range of 1–6 °C. Sikkim's steep terrain makes it unsuitable for agricultural techniques. Soil erosion and water loss are aided by the sloping landforms. Despite these drawbacks, agricultural techniques are carried out by using terraces to transform rocky terrain to cultivated land. Maize, rice, and wheat are the main crops farmed in Sikkim.

The second selected study area is the Sehore district Central India which stands in the foothills of Vindhyachal Range (Fig. 12.1c). On the basis of physiography, Sehore district comprises of valleys formed by the three major rivers i.e. Narmada basin, Chambal, and Betwa. Sehore district lies between 22°32′N – 23°40′N latitude and 76°22′E – 78°03′E longitude. The Sehore district comprises of Aashtha, Icchawar, Budhni, and Nasrullaganj tehsils. The region encompasses an area of 6578 km^2 with an average elevation of 502 m. The average precipitation in the region is 1217.7 mm, average min-max temperatures are 10.4 °C & 40.7 °C respectively. Wheat, Rice, Maize, Soybean are the principal crops grown in this central region of India.

12.2.2 Meteorological Data Utilized

The India Meteorological Department high resolution (0.5° × 0.5°) gridded precipitation and temperature data was employed in this research work. IMD dataset has been used in many recent studies (Kumar et al. 2021; Poonia et al. 2021a, b). The wind speed data was downloaded from Terrestrial Hydrology Research Group accessible at a resolution of (0.5° × 0.5°), while the relative humidity statistics were taken from NCEP/NCAR reanalysis dataset. The GCMs viz. "ACCESS1.0, CanESM2, CCSM4, CNRM-CM5, and MPI-ESM-LR" have been employed in this research work. The high-resolution future dataset for the climate scenarios RCP 4.5 & RCP 8.5 were utilized as inputs to Aquacrop model to determine crop yields. The historical period (1998–2015) for the Aquacrop model calibration (1998–2007) and validation (2008–2015) was considered as the base period for setup of the Aquacrop model. The future period (2021–2099) with RCP projections 4.5 & 8.5 were subdivided into years (2021–2040, 2041–2060, 2061–2080 & 2081–2099) for better projected yield analysis. For the crop yield simulation, the typical sowing dates prevalent in the respective study regions were determined based on important literature work (Deb et al. 2015b; Balvanshi and Tiwari 2019).

12.3 Methodology

To complete the objective of this research work, historic climatological data (precipitation, relative humidity, wind speed, and max-min temperatures) from 1998 to 2015 were gathered. The future projected climatic data for years 2021 to 2099 for scenarios RCP 4.5 and 8.5 were also collected to do simulation of yield using Aquacrop model. The 1st study area Sikkim is divided into East Sikkim, West Sikkim, and South Sikkim while for the 2nd study area Sehore region which comes under the central part of India is considered for the yield forecast.

12.3.1 Crop Yield Simulation Using Aquacrop Model

AquaCrop is a menu-driven program with a well-developed user interface. The model is preferred for simulation of yields of various crops. Input consists of weather data, crop characteristics, and soil and management characteristics (Raes et al. 2009; Foster et al. 2017). Soil characteristics are divided into soil profile and groundwater characteristics and management practices into field management and irrigation management practices (Mohammad et al. 2018).

The historic data from year 1998 to year 2015 is used for the Aquacrop model calibration and validation. The future projected data was used as input to the calibrated Aquacrop model and future yields were obtained under RCP scenarios 4.5 & 8.5 for the years (2021–2040, 2041–2060, 2061–2080 & 2081–2099).

12.3.2 Model Performance Evaluation Using RMSE and Coefficient of Determination (r^2)

The accuracy in simulating the yield of the model was evaluated using the Root Mean Square Error, RMSE, and Coefficient of Determination r^2 criteria's (Das et al. 2020).

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \tag{12.1}$$

Where, O and P are observed and predicted values, respectively.

A models fit improves as RMSE approaches zero.

$$r^2 = \left(\frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)\left(P_i - \overline{P}\right)}{\sqrt{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2}\sqrt{\sum_{i=1}^{n}\left(P_i - \overline{P}\right)^2}}\right)^2 \tag{12.2}$$

A models fit improves as r^2 approaches unity.

12.3.3 Evaluating Uncertainty of GCMs for Future Yield Simulation

For accurate generation of future projections, it is necessary that GCM used for climate studies should have least level of uncertainties. For this, the possibility theory (Zadeh 1999) is utilized to evaluate the uncertainty of GCMs. The probabilistic analysis helps to induce higher accuracy in finding more suitable GCM with lesser uncertainties for the study region.

12.3.4 Adaptation Strategy to Combat Impact of Climate Change on Crop Yield

Firstly, the AQUACROP model was employed for simulating the yield in the future periods (2021–2040, 2041–2060, 2061–2080 & 2081–2099) with RCPs 4.5 and 8.5 climate scenarios with normal planting date. However, the simulated yield with normal planting date shows significant increase in yield over the Sikkim region while remarkable declination in the yield particularly was found in the Central Region of India. Hence it necessitates the need to adopt a suitable and economic measure so as to reduce the impact of future climate for the Central region of India.

The shifting of planting dates was chosen as adaptation measure and new simulated yield was generated using AQUACROP for all future scenarios. The simulation for wheat crop with a shift of 15 days later in planting date gives maximum wheat yield and simulation for rice crop with shift of 5 days later during period (2021–2060) & 10 days later during the period (2061–2099) resulted in maximum future yield.

12.4 Results and Discussion

12.4.1 Aquacrop Model Efficiency During Calibration and Validation for the Sikkim Region

The crop yield model was calibrated (1998–2007) and validated (2008–2015) over the historic period (1998–2015) for the rice and wheat crops. The Table 12.1 and Fig. 12.2 ahead depicts the accuracy values during the years 1998–2007.

The model showed satisfactory efficiency values during the calibration (refer Fig. 12.2) and validation (refer Fig. 12.3), hence the calibrated parameters values were fixed for the future yield prediction of the region.

12.4.2 Aquacrop Model Efficiency During Calibration and Validation for the Central Region of India

The crop yield model was calibrated (1998–2007) and validated (2008–2015) over the historic period (1998–2015) for the rice and wheat crops for the Sehore region on Central India. The Fig. 12.4 and Table 12.2 ahead depicts the accuracy values during the years 1998–2007.

From the Fig. 12.4 and Table 12.2, it was found that the Aquacrop model perform efficiently during the calibration the validation periods for the Sehore region. The calibrated parameter values were now fixed and utilized in the future crop yield simulation for the RCP scenarios 4.5 and 8.5.

Table 12.1 Model efficiency during calibration and validation over Sikkim region

		Rice		Wheat	
Period	Stations	r^2	RMSE	r^2	RMSE
Calibration	East Sikkim	0.81	5.35	0.76	17.20
	West Sikkim	0.73	4.77	0.76	10.72
	South Sikkim	0.93	7.32	0.71	14.33
Validation	East Sikkim	0.86	3.82	0.72	5.56
	West Sikkim	0.76	1.64	0.68	19.38
	South Sikkim	0.86	1.42	0.67	9.44

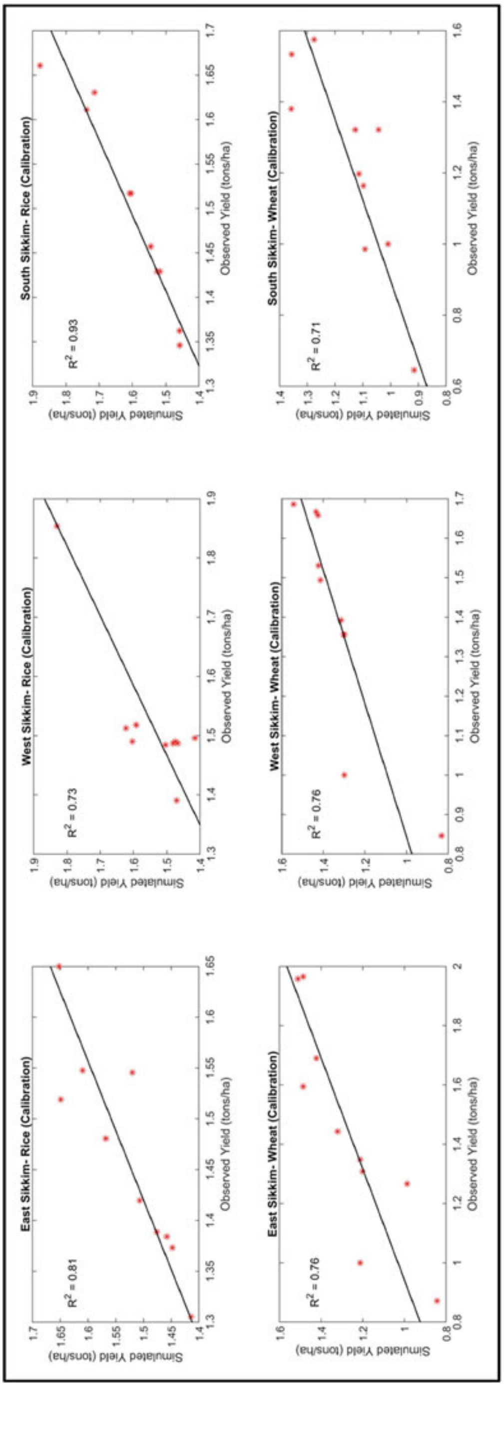

Fig. 12.2 Coefficient of determination charts during calibration for the Aquacrop model over the Sikkim region

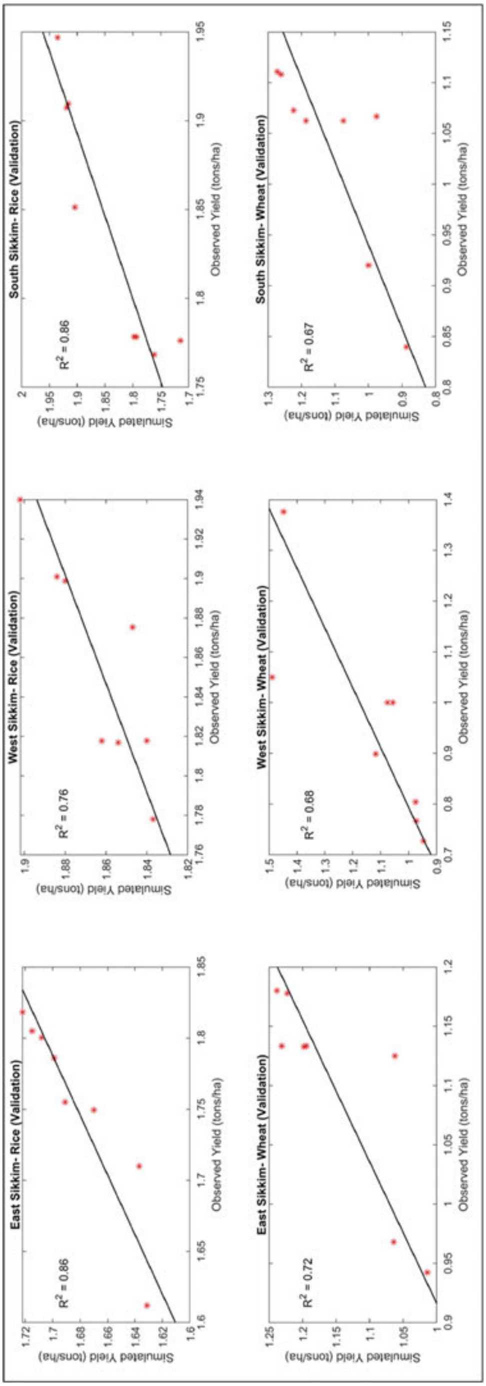

Fig. 12.3 Coefficient of determination charts during validation for the Aquacrop model over the Sikkim region

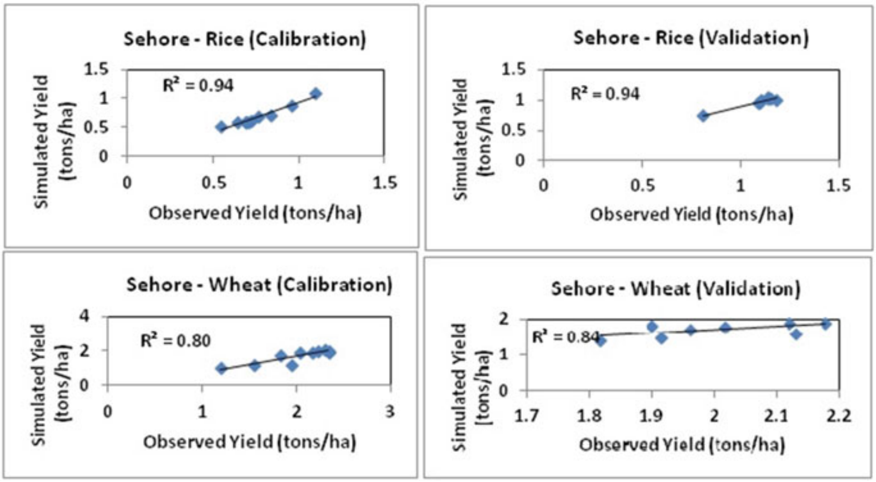

Fig. 12.4 Coefficient of determination charts during calibration and validation for the Aquacrop model over the Central region of India

Table 12.2 Model efficiency during calibration and validation over Central region of India

Period	Stations	Rice		Wheat	
		r^2	RMSE	r^2	RMSE
Calibration	Sehore- Central India	0.94	0.08	0.80	0.34
Validation	Sehore- Central India	0.94	0.11	0.84	0.33

12.4.3 Future Simulated Yield of Crops

The future yield was predicted for the future years 2021–2099 by employing the calibrated Aquacrop model over the selected study areas. The Sections 12.4.3.1 and 12.4.3.2 ahead portrays the future predicted yields by the selected GCMs under RCP scenarios 4.5 and 8.5 for the Sikkim and Central region of India respectively.

12.4.3.1 Sikkim Region

The future yield of rice and wheat crops was simulated using the calibrated Aquacrop model for the Sikkim region. The Fig. 12.5 ahead portrays the comparison in yields of rice and wheat future yields with their observed yield.

During the period 2021–2099, the average projected rice yield (refer Fig. 12.5) in East Sikkim is expected to increase by 11–20%, in West Sikkim by 5–17%, and in South Sikkim by 0.5–14%. During the period 2021–2099, the increase in the mean wheat yield (refer Fig. 12.5) varies between 2% and 5% in East Sikkim, 21–41% in West Sikkim, and 26–44% in South Sikkim. Overall it is found that the current

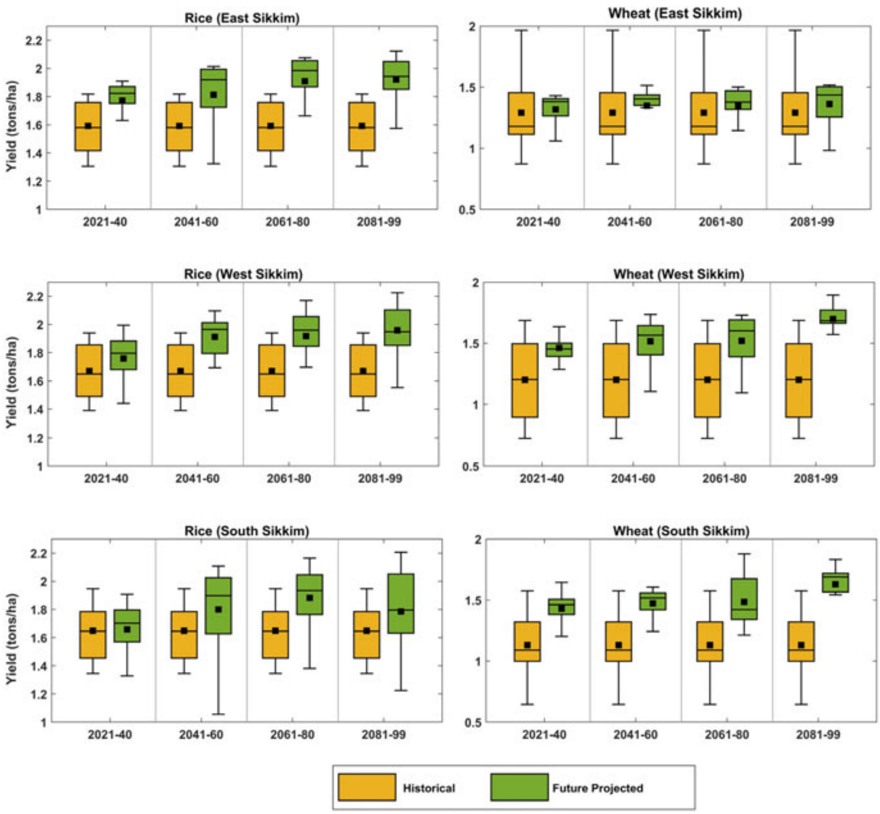

Fig. 12.5 Future projected yield of Rice and Wheat for Sikkim region

practices in growing of the rice and wheat crop is adequate for the future also and no adaptation measure is further required for Sikkim region.

12.4.3.2 Central Region of India

The calibrated Aquacrop model for the Central region was utilized to project the future yield under climate scenarios RCP 4.5 & RCP 8.5 (refer Fig. 12.6). The average observed yield of rice crop in central region Sehore during the period (1998–2015) is estimated to be 0.90 tons/ha. The average observed yield of wheat crop in central region Sehore during the period (1998–2015) is estimated to be 1.99 tons/ha.

The simulated future yield of rice shows a gradual decrease in the future periods and depicts high declination towards the years (2081–2099). The worst scenario is found to be RCP 8.5 under which the simulated yield drops till 0.72 tons/ha (Refer

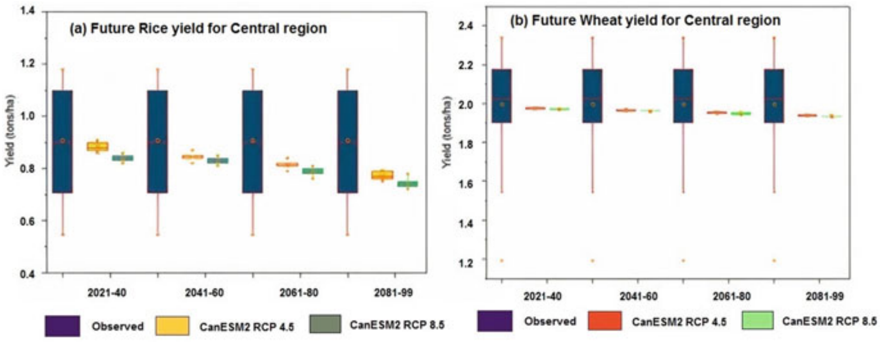

Fig. 12.6 Future projected yield of Rice and Wheat crop for the Central region

Fig. 12.6a). During the period (2081–2099), the simulated wheat yield drops to 1.93 tons/ha under the climate scenario RCP 8.5 (Refer Fig. 12.6b).

It can be concluded that the current crop growing practices prevalent in the Central region are not efficient enough to safeguard yield against the future climate change.

Adaptation Strategy by Shifting Sowing Dates

The yield simulating model AQUACROP was employed again keeping in priority to minimize the impact of climate change on the yields of rice and wheat crops in the Central region of India.

The plantation dates of the crops rice and wheat were altered (15 days ahead, 10 days ahead, 5 days ahead, 5 days later, 10 days later, 15 days later) and an optimum date was obtained that provides maximum yield to withstand negative impact of climate change in the future periods.

From Tables 12.3 and 12.4, it is seen that the future yield of rice and wheat is deteriorating under RCP 8.5 climate scenario. The prime reason for the decrease in yield can be the inclination in maximum-minimum temperatures over the study region.

The optimum dates obtained after multiple Aquacrop model simulations with alteration in planting dates for rice was 5 days later for period 2021–2060 then 10 days later for period 2061–2099 and for wheat crop was 15 days later for period 2021–2099 (refer Tables 12.3 and 12.4). The new plantation date proposed for crops resulted in maximum value of simulated yield in future periods and thus it can reduce the negative impact of climate change on agricultural crop yield.

Table 12.3 Percent changes in yield for rice crop with changed planting dates

Normal planting date: 15th November	Climate scenario	Average yield year (1998–2015)	% change year (2021–2040)	% change year (2041–2060)	% change year (2046–2060)	% change year (2061–2080)	% change year (2081–2099)
Planting 15 days ahead	RCP 4.5	1.993	−0.3	−0.5	−0.8	−0.9	−1.2
	RCP 8.5		−0.3	−0.6	−0.9	−1.0	−1.3
Planting 10 days ahead	RCP 4.5	1.993	−0.2	−0.5	−0.8	−0.9	−1.2
	RCP 8.5		−0.2	−0.6	−0.9	−0.9	−1.2
Planting 5 days ahead	RCP 4.5	1.993	−0.2	−0.5	−0.8	−0.9	−1.1
	RCP 8.5		−0.2	−0.5	−0.9	−0.9	−1.2
Planting 5 days later	RCP 4.5	1.993	−0.2	−0.5	−0.8	−0.9	−1.1
	RCP 8.5		−0.2	−0.5	−0.9	−0.9	−1.2
Planting 10 days later	RCP 4.5	1.993	−0.2	−0.4	−0.7	−0.9	−1.1
	RCP 8.5		−0.2	−0.5	−0.9	−1.1	−1.1
Planting 15 days later	RCP 4.5	1.993	**−0.1**	**−0.4**	**−0.7**	**−0.8**	**−0.9**
	RCP 8.5		**−0.2**	**−0.5**	**−0.8**	**−1.0**	**−1.0**

Table 12.4 Percent changes in yield for wheat crop with changed planting dates

Normal planting date: 24th June	Climate scenario	Average yield year (1998–2015)	% change year (2021–2040)	% change year (2041–2060)	% change year (2046–2060)	% change year (2061–2080)	% change year (2081–2099)
Planting 15 days ahead	RCP 4.5	0.90	0.0	−0.3	−0.6	−0.7	−2.4
	RCP 8.5		−0.4	−1.0	−0.7	−2.3	−5.0
Planting 10 days ahead	RCP 4.5	0.90	0.1	−0.3	−0.5	−0.7	−2.3
	RCP 8.5		−0.3	−0.9	−0.6	−2.2	−5.0
Planting 5 days ahead	RCP 4.5	0.90	0.1	−0.2	−0.5	−0.6	−2.3
	RCP 8.5		−0.1	−0.8	−1.6	−2.2	−5.0
Planting 5 days later	RCP 4.5	0.90	**0.2**	**−0.2**	**−0.5**	**−0.6**	−2.2
	RCP 8.5		**0.0**	**−0.8**	**−1.5**	**−2.1**	−5.0
Planting 10 days later	RCP 4.5	0.90	0.0	−1.3	−1.9	−2.6	**−2.0**
	RCP 8.5		−0.8	−2.0	−3.9	−5.2	**−4.1**
Planting 15 days later	RCP 4.5	0.90	0.0	−1.3	−2.0	−2.6	−2.2
	RCP 8.5		−0.8	−2.1	−3.9	−5.3	−4.2

12.5 Conclusions

In this research work, the Aquacrop yield simulating model was tried and tested on the two diverse regions of India viz. Sikkim and Central India. The model was first calibrated and validated during the historic years so that the efficiency in model results can be seen. Further the model was simulated for the future period

(2021–2099) by using the GCM data as input and the future crop yields of rice and wheat crops under climate scenarios RCP 4.5 and RCP 8.5 were estimated. It was found that the 1st selected study area-Sikkim, have increased yield results for the future years especially during (2081–99). The reason here can be presumed for the increase in yield of rice and wheat that the altitude is higher as well as temperatures are low in addition with increasing the CO_2 is facilitating the crop growth. On the other hand, the 2nd selected area – Central Region of India, have shown decrease in the yield of rice and wheat. The RCP scenario 8.5 portrays the maximum yield reduction and hence a sustainable adaptive measure by altering the planting dates was adopted to address the losses in this agricultural economy. It was concluded that the Aquacrop model performs quite accurately over the selected regions of India and can be furthermore utilized in other parts to reduce the agricultural risks due to climate change.

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Chapter 13
Understanding of Future Water Challenges in a River Basin Under Ensemble of CORDEX Simulated Projections

Brij Kishor Pandey, Vikas Poonia, Deepak Khare, and Manish Kumar Goyal

Abstract The impact of climate change and anthropogenic activity on climatological parameters influence the hydrological processes and water resources availability. These issues in particular are disturbing the sustainable development planning and management of water resources. In this study, water balance components under futuristic scenarios were simulated using Coordinated Regional climate Downscaling Experiment (CORDEX), based on four general circulation models (GCMs). A semi-distributed hydrologic model, Soil and Water Assessment Tool (SWAT) was used to estimate the hydrology over a large basin under climate change sceneries. The water balance of the river basin was estimated under baseline (1971–2000) and three futuristic classical climatic periods (2011–2040; 2041–2070; 2071–2100), considering the medium (rcp4.5) and high (rcp8.5) emission representative concentration pathways (RCP). The present analysis also investigates the temporal distribution meteorological, hydrological, soil moisture and vegetation drought individually as well as concurrently. Moreover, drought trend is also examined with respect to mean areal extent, mean duration, and frequency over Narmada river basin.

Keywords Climate change · CORDEX · Drought concurrence · Hydrological modeling · SWAT · Regional climate model

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13.1 Introduction

The global warming and anthropogenic activities influence the occurrence of extreme events, which causes water scarcity and hurdles in sustainable development of water resources planning and management. Intergovernmental Panel on Climate Change (IPCC), the Fifth Assessment Report (AR5) highlighted the rising temperatures and altering the frequency and intensity of precipitation, which are likely to intensify the hydrological cycle process and affect the availability of water resources (Pachauri et al. 2014). Evaluation of water balance under effect of climate change at regional and local scales have been an crucial issue to the research community in the field of hydrology and water resources (Camici et al. 2014; Pandey et al. 2021; Liu et al. 2015; Sethi et al. 2015). It is imperative to assess the exact measurement water availability for policymakers and engineers to achieve the sustainable planning and management providing various adaptation strategies towards climate change (Chen and Sun 2015; Goyal and Surampalli 2018; Pandey et al. 2016). The global climate models (GCMs) and regional climate models (RCMs) were introduced by the climate researchers and scientist to perceive the projection of climate change under various emission scenarios. GCMs are the basic tools and sole means to detect and evaluate the climate change impact. GCMs were developed to assess the historical climate and to project the future climatic conditions at a coarser scale (300–450 km spatial resolution) (Ghosh and Katkar 2012; Pandey et al. 2021). Moreover, GCMs accuracy decreases by increasing finer resolution, which unsuitable for evaluating significant impact studies at a local scale. It is a complex numerical model to formulate the global climate system (Fetene et al. 2016; Mondal and Mujumdar 2012). Therefore, the reliability of projection of hydrological responses depend upon the simulated output from climate model.

In order to analyze the local and regional climate impact studies, it is required to downscale the GCM data, from coarser resolution to finer resolution. Transforming coarser scale information to finer scale, two downscaling techniques, dynamic and statistical downscaling have been proposed (Pandey et al. 2019). Therefore, downscaling methods available in the literature vary from the very simple rule-based method to complex modelling of the spatial dynamics downscaling. RCMs, a dynamical downscale fines scale model driven by GCMs are more popular for regional and local climate impact studies (Ficklin et al. 2009; Goyal and Ojha 2012; Liu et al. 2015; Pandey et al. 2017; Pingale et al. 2014; Sneyers 1997; Tiwari and Pandey 2019). According to Wilby (2008) the uncertainty in climate simulation depends upon downscaling method, GCM structure, and climate change scenarios (which is mainly associated with socioeconomic development). McAlpine et al. (2007) reported the impact of regional climate change on the vegetative cover. They found consistent changes in regional climate with a shift from humid and cooler to warmer conditions, particularly in southeast Australia. Kay et al. (2009) reported that the selection of GCM and RCM structures are the main cause of uncertainty in climate modeling.

Moreover, the both GCMs and RCMs can project the climate variables (precipitation and temperature) and can be utilized for hydrologic simulation of basin. However, the systematic errors in climatic variables caused by model structure, internal variability and boundary conditions of the climate models. Thus, there are number of bias correction methods available to improve the regional climate downscaling simulations such as histogram equalizing, quantile mapping, change factor approach and rank matching. The significance of bias correction methods has been mentioned in the special report of IPCC (Senevirantne et al. 2012). To estimate probable hydrologic responses under the impacts of climate change (e.g., Arnell 2004; Oki and Kanae 2006), a suitable bias correction has been applied to projected temperature and precipitation for error free projections. Dettinger et al. (2004) assessed the impact of climate change in the Sierra Nevada of California, using bias-corrected temperature and precipitation data, simulated from GCM. Lehner et al. (2006) also predicted the risk of flood and drought due to climate change by employing a hydrologic model, embedded with the bias- corrected climatic data. Hay et al. (2002) applied the bias correction on simulated climate output from regional climate model (RCM) over four basins of the United States. Gosain et al. (2006) simulated the discharge in 12 Indian river basins under climatic conditions considering different scenarios. Authors present the worst affected two river basins (Krishna and Mahanadi), one is under droughts and other with respect to floods under climate change effect. Narsimlu et al. (2013) assessed the water availability of upper Sind river basin under climate change and found that mean annual runoff would increase by 94% at the end of twenty-first century.

However, due to climate change, temperature is rising and altering the frequency and intensity of precipitation extreme values, which advances the flood and drought events. Moreover, water is the basic need for development at regional or local scale but its availability influenced by many factors including hydro-meteorological and climate variability, and anthropogenic activities. In the recent past, many studies indicate that global warming is one of the main reasons in reduction of the water availability in many regions. The aim of this study is to identify the contribution of climate change on the future projection of water resources at basin scale. Moreover, hydrological simulations were carried out at regional scale by coupling of output from four climate models of Coordinated Regional Climate Downscaling Experiment in South Asia experiments (CORDEX-South Asia).

Further, study of all major drought types over Narmada river basins is carried out for the period of 1982–2013. In the past, researchers have developed various drought indices for drought monitoring such as standardized precipitation index (SPI, McKee et al. 1993), etc. It is one of the world's costliest natural disasters, causing an average of 6–8 billion USD in global damage (Poonia et al. 2021c; Soľáková et al. 2014; Wilhite 2000). Broadly, droughts are classified into 3 types: meteorological, agricultural and hydrological droughts. In this study, we have further categorized the agricultural drought into two droughts, i.e., soil moisture and vegetation droughts. Recent studies focus only on one drought type mainly meteorological drought. Drought is a multivariate disaster characterized by mutually correlated parameters; therefore, a combined study is required for better drought characterization (Poonia et al. 2021b). In this study, we estimate the meteorological, hydrological, soil moisture, and vegetation droughts over Central India during the period 1982–2013 respectively.

13.2 Study Area

Narmada River is largest westward flowing river of India. It is one of the holy rivers of central India. It originates from Amarkantak and extends over the three states of India, Madhya Pradesh, Maharashtra, and Gujarat. The upper part of the river basin is mountainous and receives mean annual precipitation about 1400 mm, whereas the lower part is mainly covered by natural vegetation and forest and receives about 1000 mm of mean average precipitation. Tropic of Cancer passes through the upper part of the basin. Thus, April to June and October to February, consider as summer and winter season, respectively. Most of the area of basin, covered by agricultural land (about 56%), natural forest (about 33%), water bodies (about 3%) and barren land (*Source:* Report of Irrigation Commission, 1972) (Figs. 13.1 and 13.2).

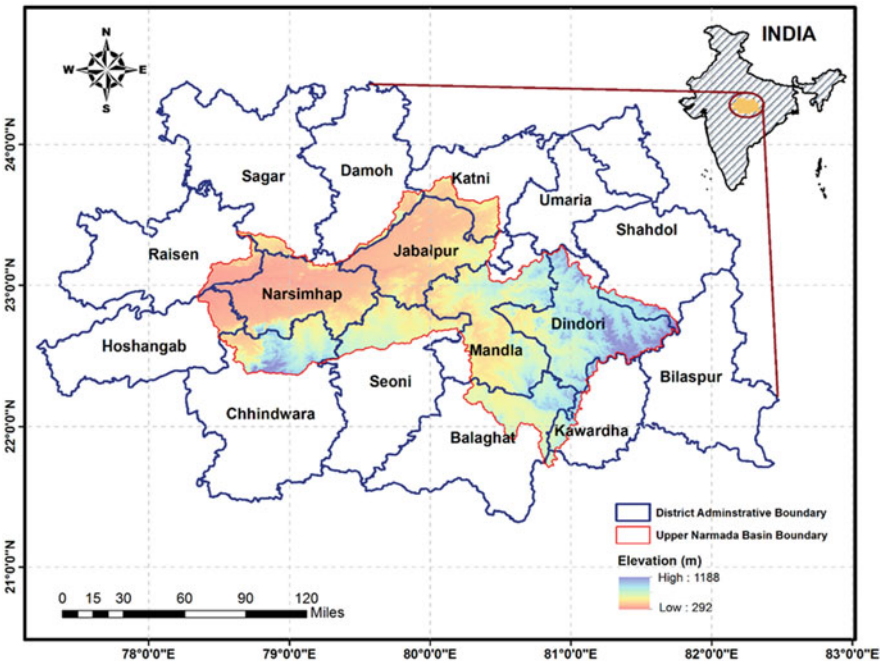

Fig. 13.1 Location map of the upper Narmada river basin

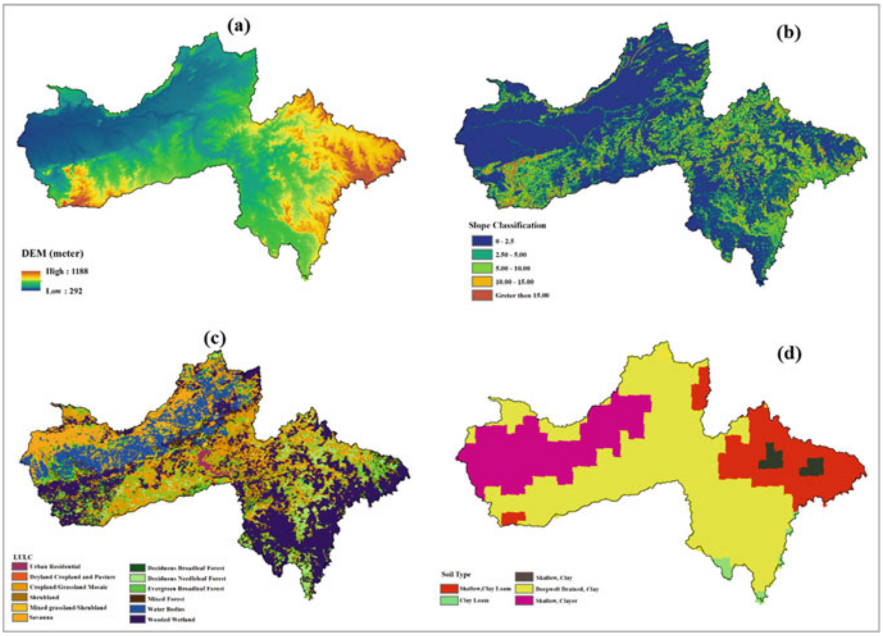

Fig. 13.2 (**a**) digital elevation model, (**b**) slope map, (**c**) land use land cover map, and (**d**) soil map of the study area

13.3 Data Used

In this study, digital elevation model (DEM) of resolution of 90 m horizontal grid spacing from Shuttle Radar Topography Mission (SRTM) was used to generate the topography and drainage network of the river basin. The soil map of the study area presented at 1:2.5 $\times$ 10^5 scale was procured from National Bureau of soil survey and Land Use Planning (NBSSLUP), Nagpur.

For the meteorological drought condition, the standardized precipitation index is computed using SPI. For SPI computation, daily precipitation is derived from IMD (0.5°*0.5°). IMD4 dataset is widely used in recent studies (Das et al. 2020; Goyal et al. 2012; Poonia et al. 2021a; Shivam et al. 2017; Sinha et al. 2018). The soil moisture and runoff data are derived from the Modern-Era Retrospective analysis for Research and Applications-2 (MERRA-2) re-analysis product. Runoff and soil moisture data are available at a spatial resolution of 1/2°*2/3°. Finally, the NDVI data is downloaded from GIMMS. Further, the vegetation, soil moisture, and runoff datasets are regridded to 0.5°*0.5° using Inverse distance weighting (IDW) method.

13.4 Methodology

The Soil and Water Assessment Tool (SWAT), a physical based, semi-distributed hydrological model is widely use to simulate the hydrological responses, at sub-daily, daily, monthly or yearly time scale (Arnold et al. 1999; Neitsch et al. 2011). The semi-distributed hydrological model has the ability to compute the hydrological processes under futuristic climatic projections and land management practices at watershed scale (Abbaspour et al. 2015; Debele et al. 2006; Liu et al. 2015; Pandey et al. 2016, 2021).

To evaluate the water balance, the model delineates the basin from DEM and subdivides into small sub-basins, and sub-basins in to small spatial unit, hydrological response unit (HRU). HRU is not distributed unit (lumped unit) which is comprised of unique combination of land use land cover, soils, and slope characteristics of the basin.

The water balance equation (Arnold et al. 1999):

$$W_t = W_o + \sum\nolimits_t^{i=1} \left(P_{day} - Q_{sur} - ET - W_{seep} - Q_{gw}\right) \tag{13.1}$$

In which, W_t, W_o, P_{day}, Q_{surf}, E_a, W_{seep} and Q_{gw} are the final, initial soil water, rainfall surface runoff, evapotranspiration, vadose zone water, and return flow in day i (mm water).

Moreover, model was calibrated and validated considering the evaluation parameters of coefficient of determination (R^2), and Nash-Sutcliffe efficiency (NSE). In general, the model is acceptable if the coefficient of determination (R^2) is greater than 0.5, and calculated as:

$$R^2 = \frac{\left[\sum_i \left(Q_{m,i} - \overline{Q}_m\right)\left(Q_{s,j} - \overline{Q}_s\right)\right]^2}{\sum_i \left(Q_{m,j} - \overline{Q}_m\right)^2 \sum_i \left(Q_{s,i} - \overline{Q}_s\right)^2} \tag{13.2}$$

Nash-Sutcliffe efficiency (NSE) ranges from $-\infty$ to 1, where 1 indicates perfect simulation against observed value.

$$NSE = 1 - \frac{\sum_i \left(Q_o - Q_s\right)^2{}_i}{\sum_i \left(Q_{o,\mathrm{i}} - \overline{Q}_o\right)^2} \tag{13.3}$$

Percent Bias (PBIAS) indicated the underestimated or overestimated observed variable.

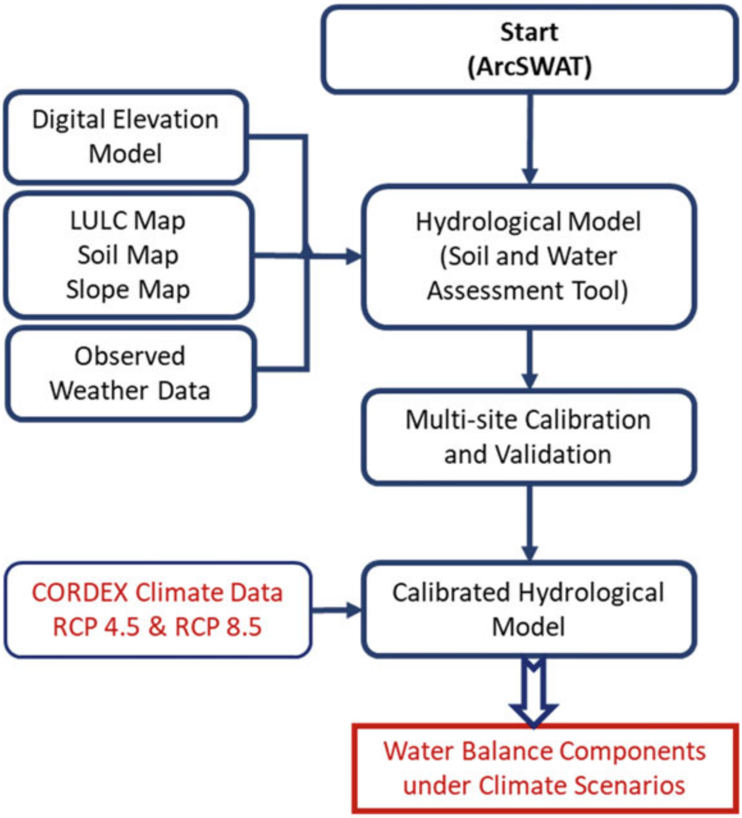

Fig. 13.3 The framework of hydrological model setup

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_o - Q_s)_i}{\sum_{i=1}^{n} Q_o} X100\% \tag{13.4}$$

Where, Q_o, Q_s and $\overline{Q}_o$ represent the observed, simulated and mean observed discharge respectively (Fig. 13.3).

In the drought analysis, most widely used drought indices, i.e. SPI, SSI, SRI and VCI were selected for drought characterization. The occurrence and severity of all major drought types are computed using monthly data of drought indices. After drought characterization, the drought trend is examined with respect to frequency, mean duration, and areal extent. Drought frequency can be defined as the count of drought events in a given time period, though, this study computes drought frequency for 11 years. The spatial extent shows the area (in%) under drought in the given time period. In case of concurrent drought, two or more than drought indices are taken together at the same time. The mean duration of each drought in the decade can be defined using Eq. 13.6.

$$\text{Mean Duration} = \frac{\text{Total duration time}}{\text{Drought concurrence numbers}} \tag{13.5}$$

13.5 Results and Discussion

In this study, the climate data driven by four different GCMs (MIROC5, MPI, CNRM and GFDL) under RCP4.5 and 8.5 scenarios using CORDEX South East Asia was used to project the hydrological responses over the river basin. The quantile mapping was applied to remove the systematic biases in rainfall and temperature series. Gamma distribution was used for rainfall, whereas Gaussian distribution was applied on temperature data to remove the bias correction.

$$\text{Gamma distribution}: \; f(x|\alpha,\beta) = x^{\alpha-1}\frac{1}{\beta^{\alpha}.\Gamma(\alpha)}.e^{-\frac{x}{\beta}}; \;\; x \geq 0; \;\; \alpha,\beta > 0 \tag{13.6}$$

Where, α is the shape and β is a scale parameter.

$$\text{Gaussian distribution}: \quad f\left(x|\mu,\sigma^2\right) = x^{\alpha-1}\frac{1}{\sigma\sqrt{2\pi}}.e^{\frac{-(x-\mu)^2}{2\sigma^2}}; \;\; x \in R \tag{13.7}$$

Where, σ and μ are scale parameter and location parameters, respectively.

The SWAT model was calibrated and validated considering seven gauging site of the basin at monthly scale to mimic the basin and to quantify the best simulation ranges of SWAT variables. Moreover, Nash-Sutcliffe efficiency (NSE) was used as an objective function to calibrate the model, due to its extensive applicability and dependability in hydrological modeling. After fine tuning of the parameters, NSE value was observed as 0.77 for calibration, whereas 0.73 evaluated for the validation. Therefore, R^2 was found 0.76 and 0.70 for calibration and validation respectively, which is good and satisfactory, as per the Moriasi et al. (2007).

Simulated and bias corrected data of climate models, MIROC5, MPI, CNRM and GFDL driven by 4.5 and 8.5 were used to evaluate the water balance under climate change. Ensemble of four climate models were used to project the precipitation, mean temperature and simulate the hydrological responses for twenty first century. The SWAT model computed the hydrological responses, surface runoff (SURQ), evapotranspiration (ET) and water yield (WYLD) for period 2011–2100 under future climate scenarios.

However, Fig. 13.4 indicates the variability of precipitation for twenty first century, under RCP4.5 and RCP8.5 scenarios driven by four climate models. It was observed that the number of extreme events may increase most likely during the mid-twenty-first century (~ 2050–2080) under moderate and high emission scenarios, RCP4.5 and RCP8.5. In this present study, percentage changes in water balance

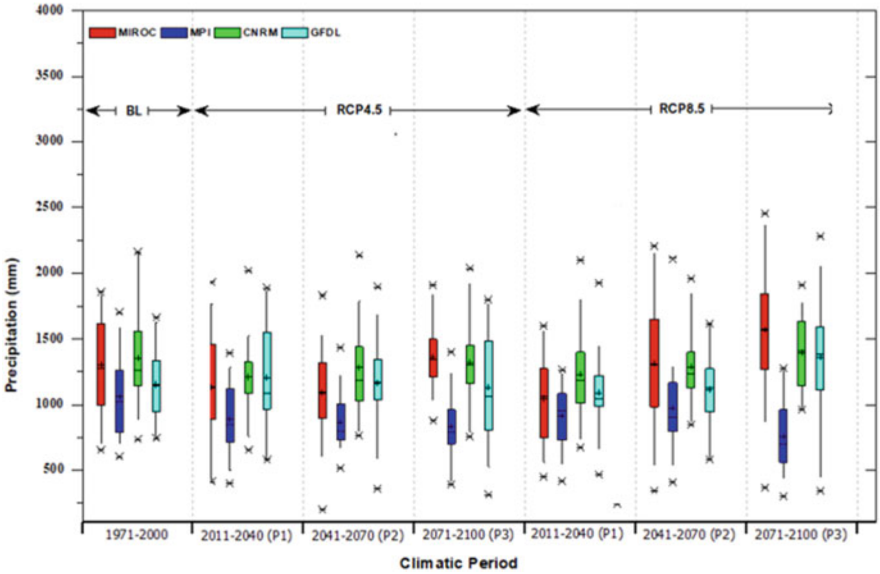

Fig. 13.4 Mean annual precipitation variations in four climate models under RCP4.5 and RCP8.5 scenarios in early (P1: 2011–2040), mid (P2: 2041–2070), late (P3: 2071–2100) of twenty-first century, and baseline (1971–2000)

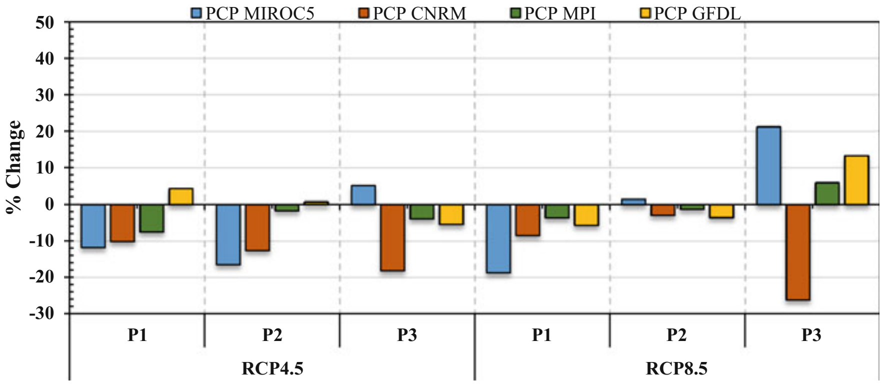

Fig. 13.5 Change in precipitation under RCP4.5 and RCP8.5 scenarios in early (P1: 2011–2040), mid (P2: 2041–2070), and late (P3: 2071–2100) of twenty-first century with reference to baseline (1971–2000)

components; precipitation (Fig. 13.5), evapotranspiration (Fig. 13.6), surface discharge (Fig. 13.7), and water yield (Fig. 13.8) were simulated by calibrated semi-distributed model, SWAT. It was observed that precipitation from various climate models varies from 40.8% to −18.2%, and 80.6% to −26.2%. and water yield varies from 70.6% to −31.3% and 91.2% to about −36% under moderate and high scenarios respectively, with reference to base line scenarios.

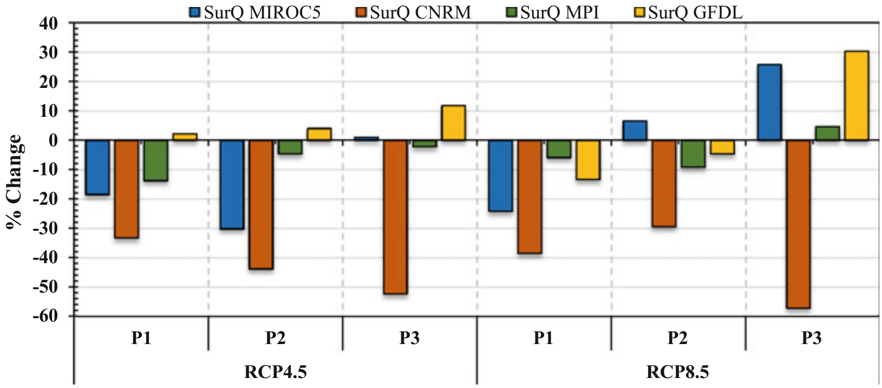

Fig. 13.6 Change in surface flow under RCP4.5 and RCP8.5 scenarios in early (P1: 2011–2040), mid (P2: 2041–2070), and late (P3: 2071–2100) of twenty-first century with reference to baseline (1971–2000)

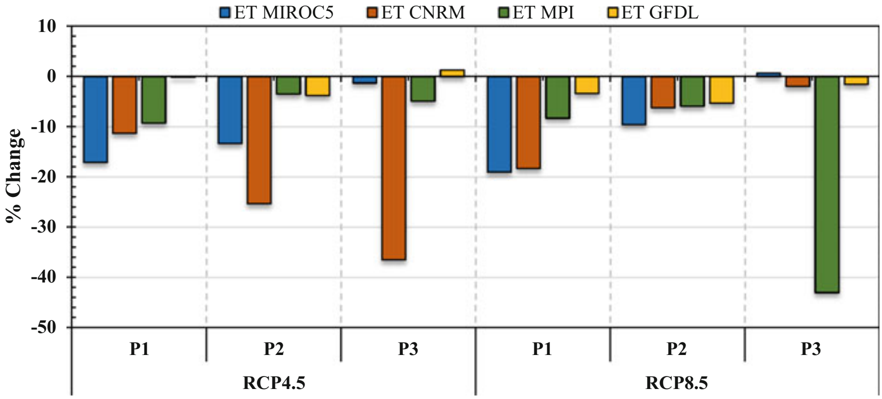

Fig. 13.7 Change in evapotranspiration under RCP4.5 and RCP8.5 scenarios in early (P1: 2011–2040), mid (P2: 2041–2070) and late (P3: 2071–2100) of twenty-first century with reference to baseline (1971–2000)

13.5.1 Drought Occurrence and Temporal Extent

In the preliminary investigation, it was found that, vegetation and meteorological droughts are more influential as compared to other two drought types in terms of severity as well as areal extent over Narmada river basin (Fig. 13.9).

Figure 13.9 presents temporal extent of droughts for monsoon and non-monsoon season during 1982–2013. From the investigation, it was noticed that hydrological and soil moisture droughts are showing less monthly discrepancy, however, meteorological droughts occur during monsoon season over study area. Importantly, vegetation drought shows heterogeneous distribution i.e., vary from 0 to 24 drought years (Fig. 13.10).

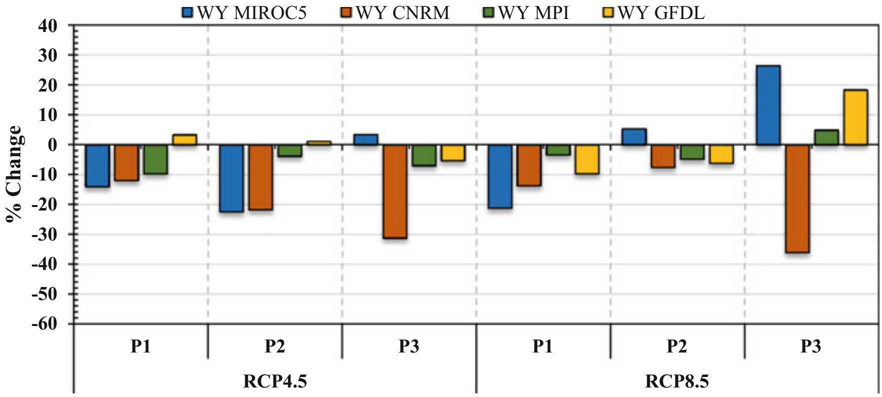

Fig. 13.8 Change in water yield under RCP4.5 and RCP8.5 scenarios in early (P1: 2011–2040), mid (P2: 2041–2070) and late (P3: 2071–2100) of twenty-first century with reference to baseline (1971–2000)

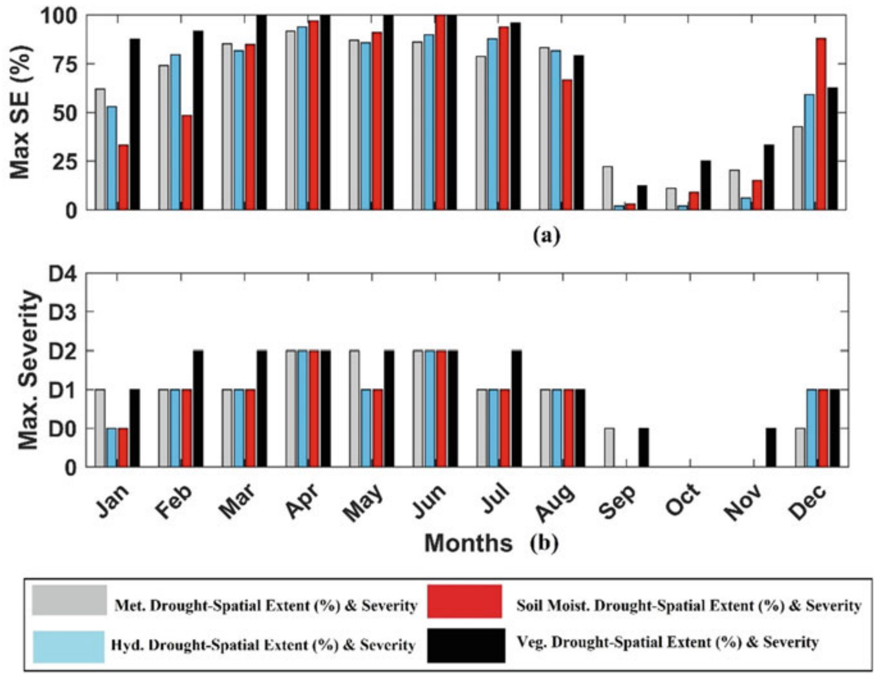

Fig. 13.9 Major droughts based on (**a**) maximum spatial extent (%) and (**b**) drought severity

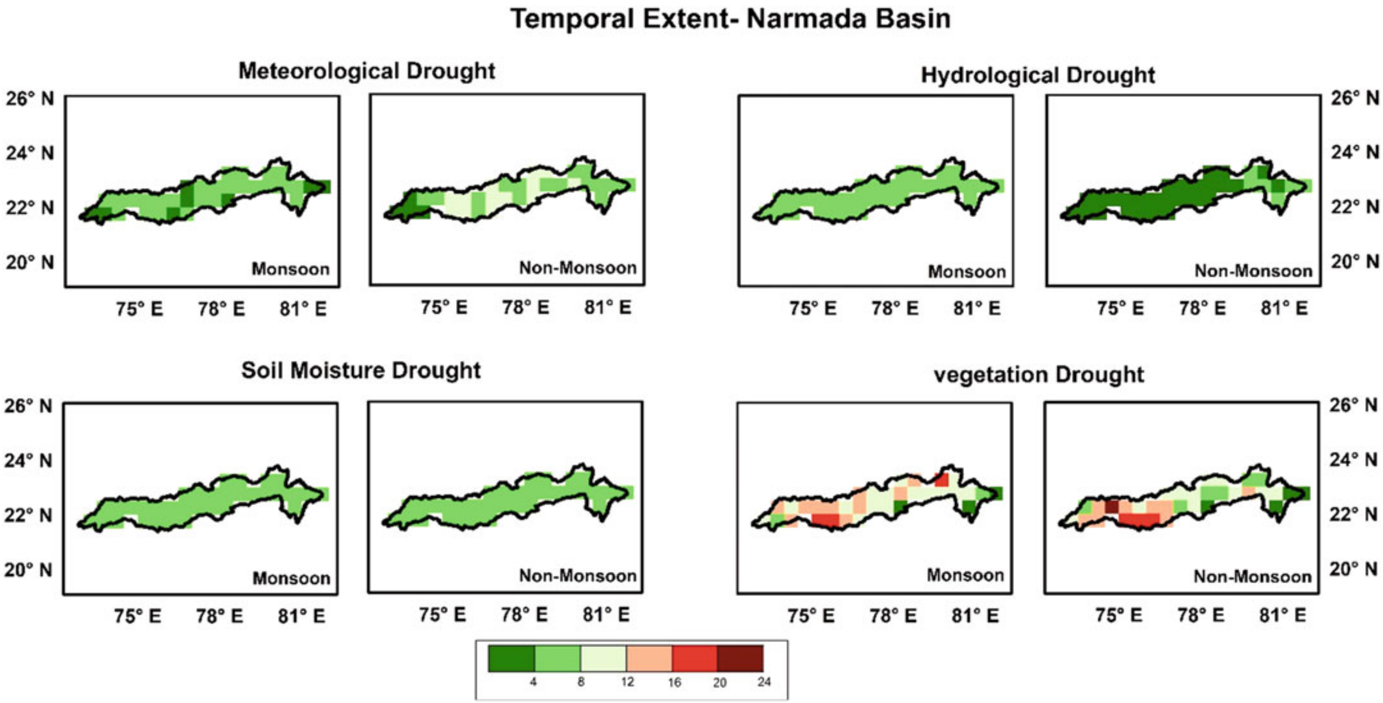

Fig. 13.10 Temporal extent of droughts for monsoon and non-monsoon season over Narmada River basin

13.5.2 Drought Trend

The present study presents the drought trend with respect to mean duration, frequency and areal extent (Fig. 13.11). In the drought trend investigation, it was observed that all major drought types are indicated by less duration, frequency and mean areal extent over Narmada river basin.

13.5.3 Drought Concurrence

The concurrent drought can be computed by considering two or more than two drought indices values together for the same month. Table 13.1 describes the concurrent droughts throughout the year from 1982 to 2013 for Narmada river basin. From the concurrence examination, it is observed that 72 concurrent droughts

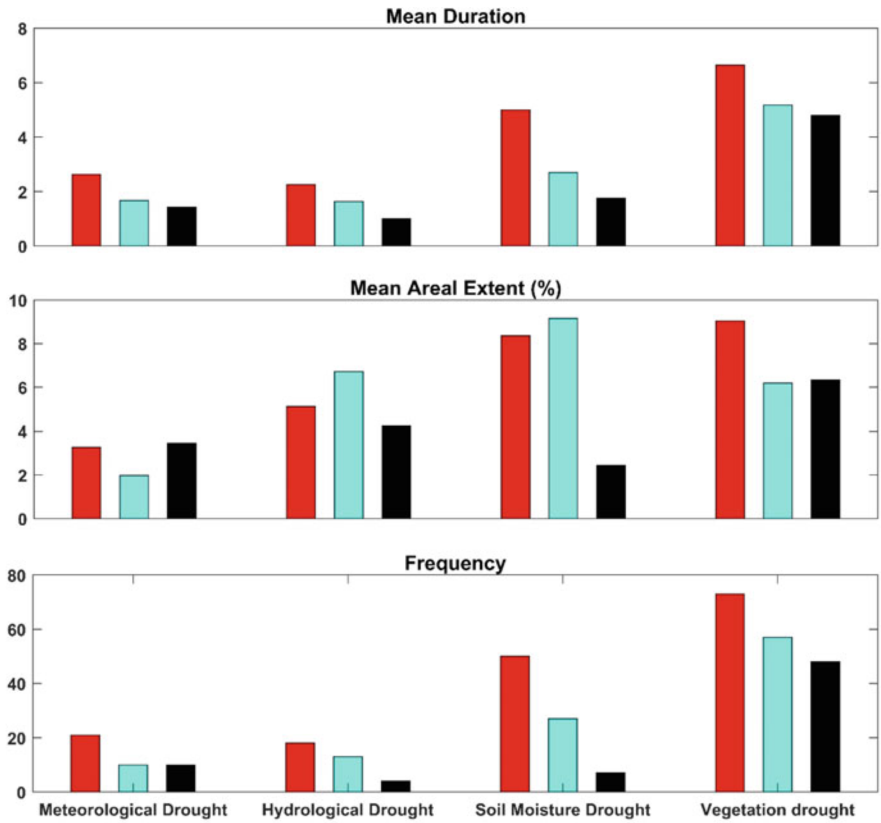

Fig. 13.11 Drought trend of all major drought types in terms of mean areal extent, frequency and mean duration during 1982–2013

Table 13.1 Concurrent droughts for every month in the 1982–2013 for Narmada river basin

Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
1983	S + V				S + V	H + S + V						
1984				S + V	M + S + V		M + S + V		H + S		H + S	
1985	S + V	S + V	S + V		S + V		S + V		M + H + S			
1986	M + S + V			S + V					H + S	M + H + S	M + S	M + S + V
1987							H + S		M + H + S			
1988		S + V	S + V									
1989		M + S						H + S		H + S	M + S	M + S
1990				S + V								
1991			S + V	S + V	S + V			H + V	M + H + S	H + S		M + S + V
1992	S + V	M + H + V	M + H + V	M + H + V	S + V		H + S + V					
1993	M + S	S + V										
1995						H + S + V		M + H				
1996						M + H + S + V						
1997			S + V			H + S + V	S + V					
1998						H + S + V	H + S + V					
1999								H + S + V				
2000				S + V					M + H + S	M + H + S	M + S	M + S
2001									M + H + S			
2002							H + V			H + S		
2003					S + V							
2004			M + S + V	S + V								
2008					S + V	M + V	M + V					
2009		M + S + V				S + V						
2012			S + V	M + S + V								

The symbol of "+" represents the concurrent situation occur over study area during 1982–2013. Moreover, two-drought based combinations is approximately 64% of concurrent drought types over Narmada basin. Interestingly, 89% of concurrent droughts include soil moisture drought.

13.6 Conclusion

The CORDEX experiments consists of RCM simulations can provide climatic characteristics at the regional and local level in relatively finer scale. Consequently, simulated outputs of RCM are indispensable in evaluating the hydrological responses under climate change impact and providing the adaptation and coping strategies. Climate models (MIROC5, MPI, CNRM and GFDL) were used to simulate historical (1971–2000) and three future climate periods (2011–2040; 2041–2070; 2071–2100) under RCP4.5, RCP8.5 scenarios. Climate data were bias corrected before coupling with the hydrological model, using the observed meteorological data. It was observed that water yield and precipitation have been significantly decreasing during the late twenty-first century (2071–2100) under both emission scenarios, RCP4.5 and RCP8.5. In this study, the ensemble of regional climate models show that the increased magnitude of the monsoon rainfall has a impact on the hydrology of the basin and may increase the flow discharge in the river stream. A semi distributed hydrological model, SWAT was employed to evaluate the water balance under climate change projections. The intensity of the monsoon rainfall is likely to rise during the mid-twenty-first century, which may trigger the severe floods across the basin. Monsoon flow in the basin is likely to increase during mid-twenty-first century under climate change. The hydrological cycle is likely to intensify during mid-twenty-first-century (~ 2050–2080) and increase the monsoon flow of the basin under climate change.

The case study examines the different characteristics of meteorological, hydrological, and agricultural droughts over Narmada river basin. The key findings of the present analysis are as follows: drought trend analysis suggests that all major drought types are indicated by less duration, frequency and areal extent over Narmada river basin. Further, concurrent drought analysis concludes that about 64% of concurrent droughts include conjunctions of two drought types. Interestingly, 89% of concurrent droughts include soil moisture drought that indicates that soil moisture is a very significant parameter over Narmada river basin rather than precipitation and runoff.

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Chapter 14
Drought as a Disaster and Its Characterization over Central India

Vikas Poonia, Manish Kumar Goyal, Anil Kumar Gupta, and Akhilesh Gupta

Abstract Drought is a natural hazard, which has widespread, significant impacts on the world's economy, environment, industries, and the community. This study includes a comprehensive discussion on drought types, drought indices, and the impact of droughts. Further, a case study is presented to investigate meteorological, hydrological, vegetation, and soil moisture drought over Central India during the period 1982–2013. Further, drought concurrence over Central India is also examined. Finally, drought adaptation and mitigation strategies were discussed. Examinations indicate that 82% of concurrent droughts include soil moisture drought as a major part over Central India. This study facilitates a comprehensive approach to better understand the dynamic characteristics of all major droughts and their complex interaction from various perspectives over Central India, and thus provides useful insights for policymakers to develop effective strategies for drought mitigation and sustainable ecosystem management.

Keywords Desertification · Drought concurrence · Drought extent · Drought index · Extreme · Severity · Streamflow

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14.1 Introduction

Drought is an extreme natural phenomenon resulting from an abnormal deficit in precipitation (Huang et al. 2014, 2015; Wilhite 2000), which can give rise to a large loss in the terms of people, ecology, economy, and environment such as desertification and degradation, crop losses, forest fires, etc. (Evans and Geerken 2004; Nicholson et al. 1998; Yuan et al. 2017). It is one of the world's costliest natural disasters, causing an average of 6–8 billion USD in global damage (Kumar et al. 2021; Soľáková et al. 2014; Wilhite 2000). Among all-natural disasters, the spatial extent of drought is extremely larger, thus damages caused are also expected to be highly larger than other disasters (Xu et al. 2015). Drought has no universal definition (Wilhite 2000). Its definition is region-specific, reflecting the differences in climatic characteristics as well as incorporating different biological, physical, and socio-economic variables (Zeleke et al. 2017; Sharma and Goyal 2018). In general, it is defined as a marked deficiency of precipitation over an extended period of time (season or more) (McKee et al. 1993; Poonia et al. 2021b, 2022). Drought is a precipitation deficiency that can cause serious hydrological imbalance (IPCC fourth assessment report). Mishra and Singh (2010) summarized some of the commonly used drought definitions as (i) the percentage of years when crops fail from the lack of moisture (FAO 1983) (ii) drought is the smallest annual value of daily streamflow (Gumbel 1963), (iii) it is a significant deviation from the normal hydrologic conditions of an area (Palmer 1965), (iv) Drought as extended, sustained deficiency in precipitation (WMO 1987). However, drought definition can be classified in two ways: conceptual and operational droughts (Wilhite 2000). The conceptual definition helps to understand the concept of drought and focuses on drought impacts such as economic and social damage. The latter focuses on understanding the onset and evolution of droughts, degree of severity, and termination of droughts. As per WMO recommendations, operational definition is generally made by comparing the present condition to the historical average (usually 30 years). Such definitions can also be used to analyze drought duration, severity, and frequency for a given historical period (Mishra and Singh 2010). Based on operational drought definitions, drought can be categorized into meteorological, hydrological, agricultural drought, and socio-economic drought (Bhuiyan et al. 2006; Muhammad et al. 2020).

Droughts are a widespread event as more than 50% of the earth's surface is sensitive to them (Kogan 1997; Poonia et al. 2021a). Mishra and Singh (2010) found that India is among the most drought-prone countries in the world where drought occurs in every three years in the last 50 years (Mishra et al. 2016; Mukherjee et al. 2018). Nagarajan (2003) suggests that drought-prone areas are confined mainly to the western part and peninsular India. This is mainly due to unfortunate monsoons, high temperature, and adverse meteorological conditions (Goyal and Ojha 2011; Goyal et al. 2012; Shivam et al. 2017). Also, an increasing trend is observed in the drought frequency. Mallya et al. (2015) suggest the increase in drought frequency and severity during 1972–2004 as compared to 1901–1935 and 1936–1971. Recent studies focus only on one drought type mainly meteorological drought. Drought is a multivariate disaster characterized by mutually correlated parameters; therefore, a combined study is required for better drought characterization (Zhang et al. 2017). In this study, we conducted a complete examination of the drought trend in terms with respect to frequency, areal extent, and mean duration for meteorological, agricultural and hydrological drought. The study is carried out over Central India using high-resolution rainfall and soil moisture data series during the period 1982–2013.

14.2 Drought: The Creeping Hazard

According to the World Meteorological Organization (WMO 1986), natural hazards are severe and extreme weather and climate events that occur naturally in all parts of the world. A hazard such as droughts, floods, hurricanes, earthquakes, and landslides can have devastating effects on human life and economies. Drought as a natural hazard differs from other hazards (earthquakes, floods, cyclones) in various manners (Wilhite 2000). Initially, it is important to recognize that drought often accumulates slowly and continues for a considerable period of time beyond the termination of drought. Secondly, there is no universal definition of drought leads to confusion of drought existence and its severity. Thirdly, drought impacts are less clear as compared to other natural hazards (Wilhite 1993). Due to these unique features of drought as a hazard, it is necessary for better understanding and awareness of drought characteristics, so that policymakers can provide better adaptation and drought mitigation strategies at a national scale. Figure 14.1 presents the general sequence of drought occurrence.

14.2.1 Drought Types: Meteorological, Agricultural, and Hydrological Drought Types

14.2.1.1 Meteorological Drought

The occurrence of any drought type is started with the severe persistence of rainfall shortage over a period of time say season or more (Mishra and Desai 2005). Meteorological drought is defined based on precipitation deficit compared to normal conditions (Keyantash and Dracup 2002; Mishra and Singh 2010). Standard precipitation index is a globally used index for meteorological drought because it is a powerful, flexible index that is simple to calculate. In fact, precipitation is the only required input parameter (Guenang and Kamga 2014). Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation total for a station (Tsakiris and Pangalou 2009).

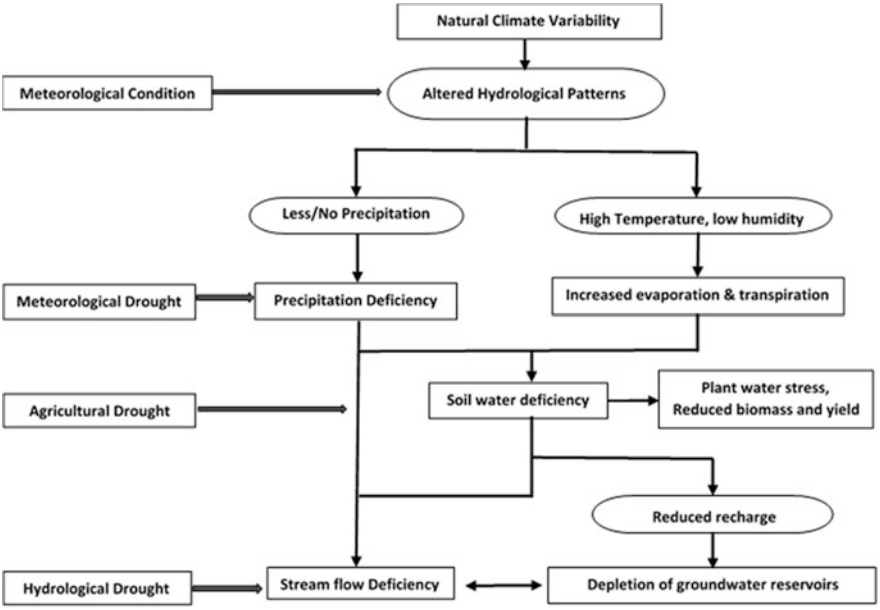

Fig. 14.1 The general sequence for the occurrence of different drought types. (Source: NDMC 2006)

14.2.1.2 Agricultural Drought

When meteorological drought continues for some period, particularly in the crop growing period, it may lead to agricultural drought. The water deficiency from meteorological or hydrological sources declines the water availability for crop production. In addition to precipitation deficit, soil moisture deficit also plays a very vital role in defining agricultural drought severity. Hence, agricultural drought indicates the period with decreasing soil moisture content and resulting to crop failure. Due to high water holding capacity, some crops are more resistant to such droughts, while others are not and become highly vulnerable to drought.

14.2.1.3 Hydrological Drought

When meteorological drought continues for a longer period, resulting in streamflow and groundwater reduction, drying up of lakes, rivers, reservoirs (Hayes et al. 2012). Hydrological drought is often related to a period with insufficient surface and subsurface water resources for established water uses of a given water resources management system. Surface water availability is the important deciding factor in case of hydrological drought; hence, streamflow is globally employed to develop a hydrological drought index (Clausen and Pearson 1995). Also, it is important to note that hydrological measurements are not the first indicators of drought as there is a time lag between lack of rain and less water in rivers, lakes, streams, and reservoirs.

14.2.1.4 Socio-Economic Drought

Socio-economic drought is associated with the impact of drought events on socio-economic activities instead of spatio-temporal characteristics of drought (AMS 2004). It is associated with the supply and demand of economic goods and it occurs when demand surpasses the supply of economic goods due to a weather-related shortfall in the water supply (Zhao et al. 2019). This drought may occur either from meteorological, agricultural, or hydrological drought or their combined effects for an extended term (Ziolkowska 2016). This drought occurs when physical water storage affects individually or collectively. Hydropower deficit and water supply shortage are examples of such drought.

All the above four drought types are interactive with each other and all are important to provide the best solutions in drought risk management, for example, drought response action, drought preparedness, early warning system, etc.

14.2.2 Drought Indices

Drought indices are quantitative measures based on physical and/or empirical approaches to investigate different drought properties either qualitatively or quantitatively (Hayes 2006). Generally, drought indices integrate several meteorological and hydrological parameters like runoff, rainfall, temperature, evapotranspiration, and other water supply indicators into a single number leading to a complete portrait of decision making. The drought indices are majorly categorized into four categories: meteorological, agricultural, hydrological drought indices, and remote sensing data-derived drought indices. It is important to note that a single drought definition does not work in all conditions, and that's the big reason why the resource planners, policymakers, and others have more trouble planning for drought than they do for natural disasters. Nowadays, most of policymakers now rely on mathematic drought indices to decide when to start implementing drought response measures.

It is important to recognize that most of the drought indices had been developed were regionally based (Hayes 2006) and hence a proper review is necessary before adopting any of the existing drought indices to use in any study area. In past, several drought indices were developed such as the Palmer drought severity index, PDSI (Palmer 1965); standardized precipitation index, SPI (McKee et al. 1993); an surface water supply index, SWSI (Shafer and Dezman 1982), etc. Details of some of the well-known drought indices and their usefulness are presented below.

14.2.2.1 Standardized Precipitation Index (SPI)

Standard precipitation index (SPI) is a globally used index because it is very simple to calculate, requires modest data, and is comparable over a range of climatic zones (McKee et al. 1993). It is based on only one input parameter (precipitation accumulations), and thus it is less complex to compute than other drought indicators. It has greater spatial consistency, therefore, a more recommendable drought index as compared to others such as Palmer Drought Severity Index (PDSI). The raw precipitation data are typically fitted to gamma or a Pearson Type III distribution and then transformed to a normal distribution (Tsakiris and Pangalou 2009). Usually, a negative SPI indicates the drought condition while a positive value indicates the end of the drought. Therefore, SPI has been chosen for the present study.

14.2.2.2 Standardized Runoff Index (SRI)

SRI is used to estimate hydrological drought using runoff data series and developed by Shukla and Wood (2008). For SRI computation, stream records of a specific region are fitted inappropriate distribution. After this, Probability Density Function and Cumulative Distribution Function are processed and it is changed over to a standardized normal deviate with zero mean and unit variance. Subsequently, this methodology at last outcomes in SRI. Utilizing this, 1, 3, 6, 9, and year scale, SRI can be determined.

14.2.2.3 Standardized Soil Moisture Index (SSI)

The Soil Moisture Index was developed by Bergman et al. (1988) to characterize droughts considering soil moisture data. For SSI computation, soil moisture data of a particular location is fixed in suitable distribution. Then, Probability Density Function and Cumulative Distribution Function are computed and it is converted to a standardized normal deviate with zero mean and unit variance and finally, SSI is determined.

14.2.2.4 Vegetation Condition Index (VCI)

The vegetation condition index is used to estimate agricultural drought, more precisely vegetation using NDVI data. It can be computed as the ratio of the difference between NDVI of the current month and NDVI minimum to the difference between NDVI maximum and NDVI minimum. Bad and good vegetation situation is given by the low and high value of VCI respectively. VCI can be computed as:

$$\text{VCI} = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100$$

14.2.3 Impact of Droughts

The impact of droughts is diverse and affects various sectors of the ecosystem, human activities, and environment hence results in human life losses and economic damage. Drought generates a multifaceted impact because water is important to society in order to produce goods and deliver services. Drought impacts are generally categorized into two categories i.e., direct and indirect impact. Direct impacts include high livestock and wildlife mortality rates, reduced water levels, and harm to fish habitats. While, indirect impacts deal with crop yield reduction, unemployment, migration, reduced forest productivity leading to increased prices for timber and food (Ferrer Polo et al. 2008). However, the severity of these impacts depends on the drought characteristics, such as spatial extent, duration, severity, etc. (Mishra and Singh 2010). Drought impacts can be classified into three categories: environmental, economic, and social impacts (Joshi 2019).

14.2.3.1 Environmental Impact

Environmental losses occur due to the damages to animal and plant species, water and air quality, wildlife habitat, forest fires, soil erosion, loss of biodiversity, landscape degradation (Ferrer Polo et al. 2008). Drought also affects ecosystems as well as the environment (Al-Kaisi et al. 2013). Some of the effects are only short-term and when the drought is over, the normal conditions are quickly re-established. However, some of them stay for a longer time or even become permanent. For instance, the degradation of landscape quality may result in a permanent loss of productivity of the region, moreover, habitat destruction may result in permanent loss of an endangered species.

14.2.3.2 Economic Impact

Drought causes massive economic loss. Many economic impacts arise in many sectors of society, energy production, energy production, agriculture, and related sectors, including fisheries, forestry as these sectors are highly dependent on surface and groundwater supplies. The occurrence of forest fires rises abruptly during droughts, results in a higher risk to both human and wildlife populations. One of the important indicators is income loss to assess the impacts of droughts. Reduced income for farmers, retailers, and others has a ripple effect. This results in capital shortfalls, increased credit risk, unemployment, and ultimate tax loss for federal and state governments. Reduction in supplies of food, and other products also leads to increase in prices (Ferrer Polo et al. 2008).

14.2.3.3 Social Impact

Societal impact is not the immediate impact. Social impacts involve health, public safety, stress, anxiety, conflicts between water users, disaster relief, particularly in rural areas where social stability is associated with water accessibility. Stanke et al. (2013) identified a few health impacts related to drought, for example, water-related disease, mental health effects, airborne-related disease, and nutrition-related disease.

Impacts may last for months or even years beyond the drought is over. The environmental, economic, and social impacts of drought are difficult to quantify due to their complex interaction between social and physical systems. Hence, there is an urgent need to understand the drought characteristics and complexity of droughts to reduce social vulnerability and proper response strategies to be established.

14.3 Case Study over Central India

14.3.1 Study Area and Data Used

The study area comprises of four river basins i.e., the Godavari, Narmada, Tapi, and Mahanadi river basins located in Central India. For the meteorological drought condition, the standardized precipitation index is computed using SPI. For SPI computation, daily precipitation is derived from IMD (0.5°*0.5°). The soil moisture and runoff data are derived from the MERRA-2 product. Runoff and soil moisture data are available at a spatial resolution of 1/2°*2/3°. Finally, the NDVI data is downloaded from GIMMS. To match the resolution of the precipitation dataset, the vegetation, soil moisture, and runoff datasets are regridded to 0.5°*0.5°.

14.3.2 Drought Frequency, Mean Areal Extent, and Mean Duration

Drought frequency can be defined as the count of drought events in a given time period, though, this study computes drought frequency for eleven years. The spatial extent shows the area (in%) under drought in the given time period. In case of concurrent drought, two or more than drought indices are taken together at the same time. The mean duration of each drought in the decade can be defined using Eq. 14.1.

$$\text{Mean Duration} = \frac{\text{Total duration time}}{\text{Drought concurrence numbers}} \tag{14.1}$$

Drought indices such as SPI, VCI, SSI, and SRI are used to monitor drought conditions. After drought characterization, the drought trend is examined with respect to frequency, mean duration, and areal extent. Finally, drought concurrence is quantified in the present study.

14.3.3 Drought Trend

The present case study presents the drought trend in terms of mean areal extent, frequency, and mean duration. For comparison, the time period 1982–2013 is further divided into three subparts i.e., 1982–1992, 1993–2003, and 2004–2013. Regarding the frequency (drought events per 11 years), meteorological, hydrological, vegetation, and soil moisture drought shows decreasing fashion (from 1982–1992 to 2004–2013) for central India (Fig. 14.2).

Regarding duration trends, it was observed that only meteorological drought persisted comparatively for a longer duration for the Godavari basin, however, other regions of central India show a reduction for meteorological, hydrological, soil moisture, and vegetation drought (Fig. 14.3).

From the perception of the areal extent (see Fig. 14.4), meteorological drought shows an increasing trend from 1982–1992 period to 2004–2013 period for central India except for Mahanadi basin while hydrological, soil moisture drought shows a reduction in areal extent during 1982–1992 to 2004–2013 respectively.

Based on the mathematical assessment, a more persistent, less frequent, and larger areal extent of the meteorological drought was observed for the Godavari. Further, Tapi and Narmada basins also show a larger area of meteorological drought. Whereas, soil moisture, vegetation, hydrological droughts were relieved by smaller spatial extent, less frequency, and shorter duration.

14.3.4 Drought Concurrence

The concurrent drought can be computed by considering two or more than two drought indices values together for the same month. Table 14.1 (a), (b), (c) & (d) describes the concurrent droughts throughout the year from 1982–2013 for Godavari, Mahanadi, Tapi, and Narmada river basins respectively. Considering all four river basins, it is observed that approximately thirty concurrent droughts occur in each part of the study area during 1982–2013. Moreover, two-drought based combinations vary from 30% to 46% of concurrent drought types over Central India. Interestingly, 82% of concurrent droughts include soil moisture drought over Central India.

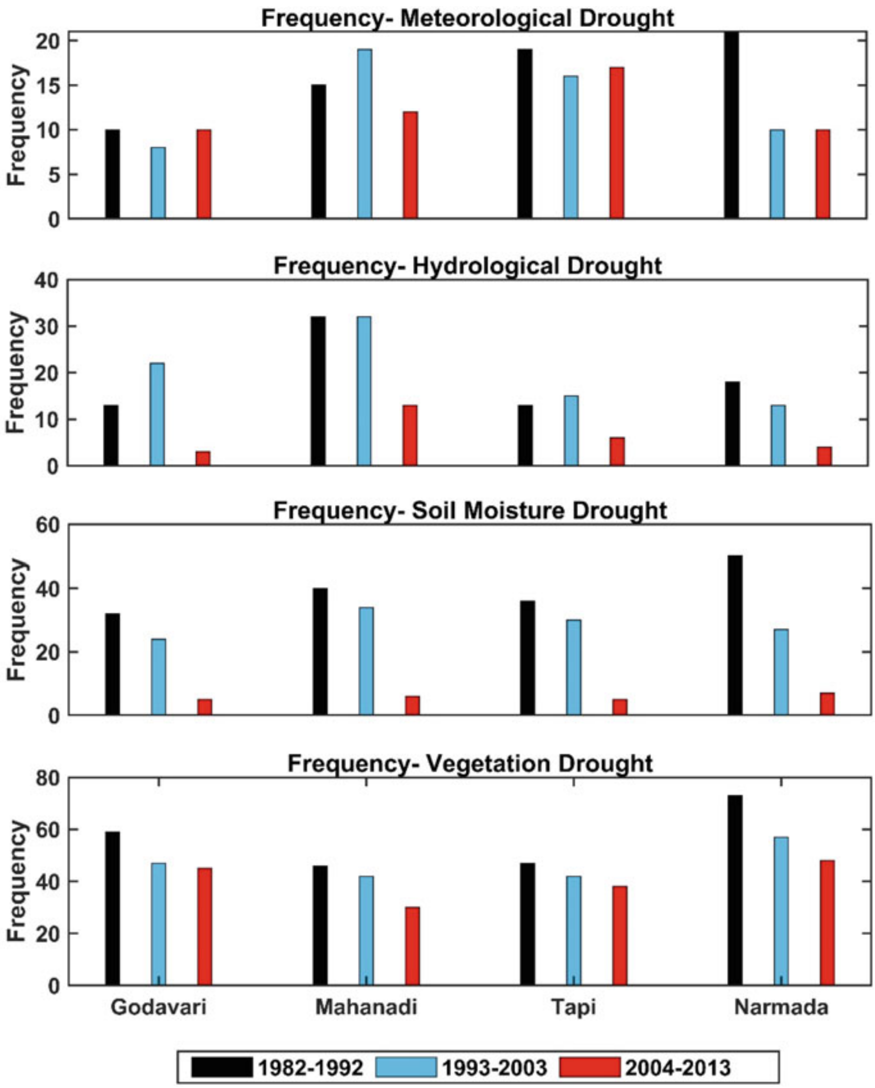

Fig. 14.2 Drought trends based on drought frequency

14.4 Drought Mitigation

In India, IMD predicts drought-like situations in a region or state of the country, based on that local, state, and centre governments draw guidelines for forthcoming drought to reduce losses in terms of food, energy, livestock, and human population in the affected areas. Drought mitigations need to be concealed through Centre and State government programmes, such as National Rural Drinking Water Programme,

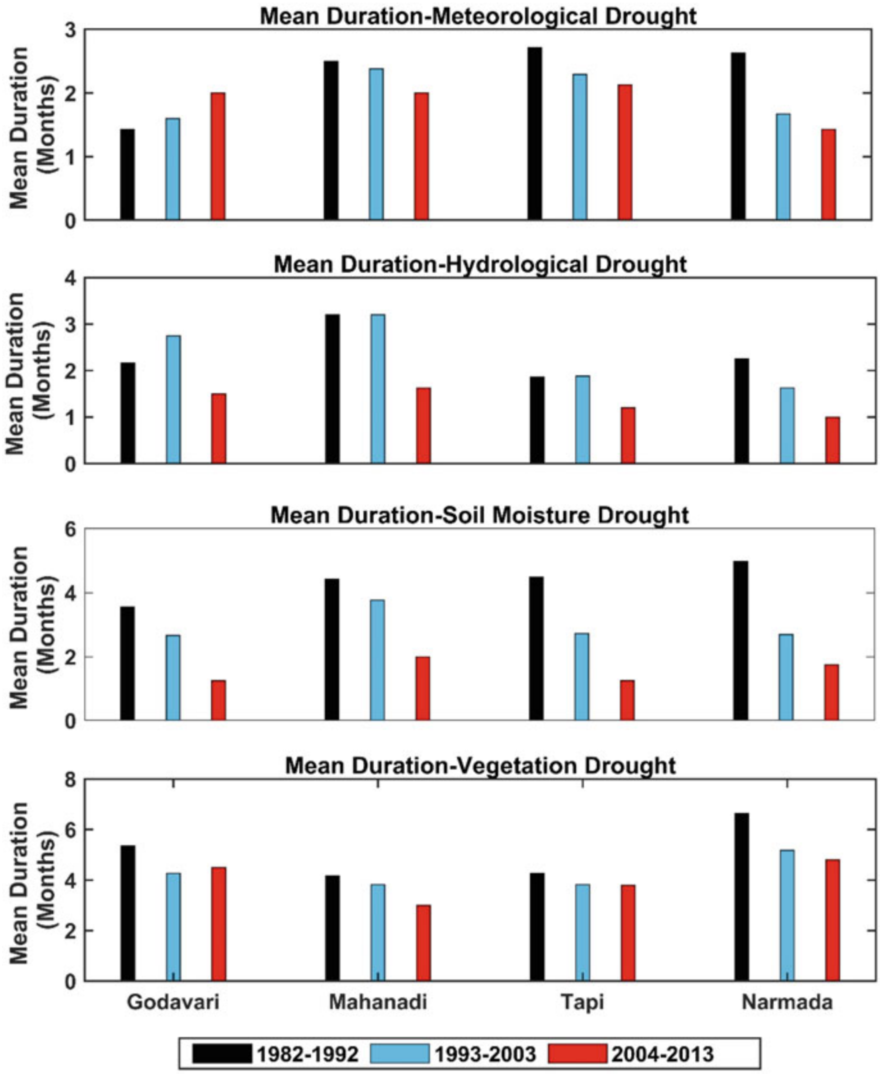

Fig. 14.3 Drought trends based on drought mean duration (months)

National Rainfed Area Development Programme, and Pradhan Mantri Krishi Sinchayee Yojna. Many of these programmes have a significant bearing on a drought mitigation strategy (Bandyopadhyay et al. 2020). Hence, we need an integrated approach to mitigate the drought effects in India as (Samra 2004; Samra et al. 2006):

- Prepare a separate water budget for each irrigation reservoir. Additionally, monitoring of the probable damage to the groundwater regime is also important.

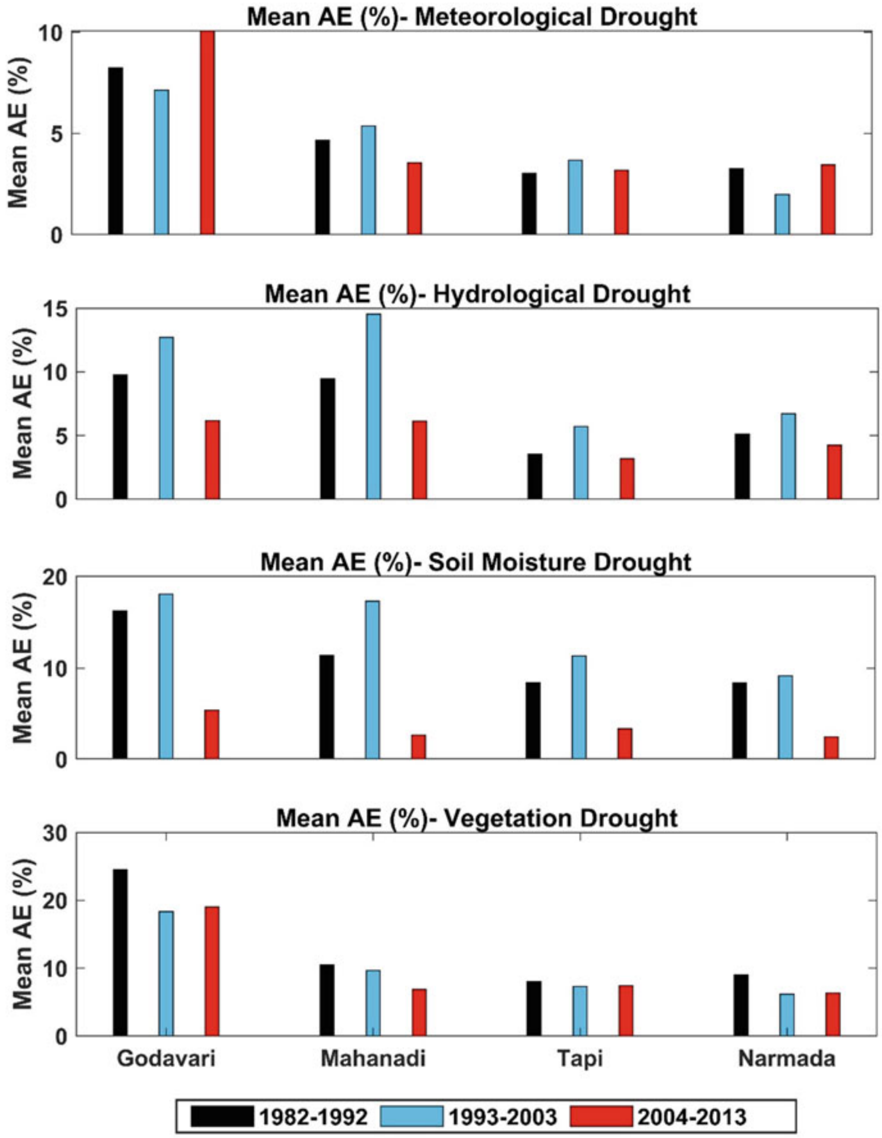

Fig. 14.4 Drought trends based on drought mean areal extent (%)

- Construction of micro irrigation structures to supplement source creation activities including tube wells and dug wells
- Provide a livelihood environment to upkeep the cattle wealth during and after drought.
- It is necessary to provide additional employment through labor-intensive works for water harvesting.

Table 14.1 (a), (b), (c) & (d). Concurrent droughts for every month in the 1982–2013 for Godavari, Mahanadi, Tapi, and Narmada respectively

GODAVARI (a)

Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
1983				S + V		S + V						
1984					M + S + V			H + V	H + S	M + S	H + S	
1985			S + V		S + V				M + H + S			
1986									H + S	H + S	M + S	
1987				S + V					M + H + S			
1989		M + S			S + V							
1990				S + V								
1991			S + V	H + S + V	H + S + V				H + S	M + H + S	M + S	
1992			M + S + V	M + S + V			H + S + V					
1993		M + S										
1996					H + V	M + H + S + V						
1997						H + S + V	H + S + V	H + S				
1998					S + V	H + S + V	H + S	H + S				
1999				H + S + V								
2000				S + V						H + S	M + H + S	M + S
2001							H + V					
2002							M + H		M + H	H + S		
2003	M + H + S				H + S + V							
2007			M + V									
2009		M + S + V				M + S + V						
2011												M + S
2012			S + V	M + V	M + V							

(continued)

Table 14.1 (continued)

MAHANADI (b)												
Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
1983	H + S + V		S + V			S + V	H + S	H + S				
1984					S + V						M + H + S	
1985			H + S + V	H + S + V	H + S + V	H + S + V						
1986									M + H			
1987				H + S + V		M + H + V	H + S + V	M + H + S	H + S	M + S		
1988									H + S	H + S		
1989	M + H + S	M + H + S	M + H + S + V	M + H + S + V	M + S + V						H + S	
1991				H + S + V	H + S + V							
1992			M + H + V									M + S
1993	H + S	M + H + S	M + V									
1994			H + V									
1996					H + S + V						M + S	
1997		H + S	S + V			H + S + V	H + S + V	H + S				
1998						H + S + V	H + V	M + H				
1999			M + H + V	M + H + S + V								
2000			H + V	S + V				M + H + S	M + H + S	M + H + S	M + H + S	M + H + S
2001	M + H + S	M + H + S + V	S + V									
2002							M + H + S	M + H + S	H + S			
2003	M + H + S				H + S + V							
2005						S + V						
2006		M + H										
2008												M + H
2009		M + H	M + S + V	M + H + S + V		M + H + S + V						
2010			H + S + V	M + S + V								
2012				M + V								

TAPI (c)

Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
1982							M + V					
1984					S + V		M + H				M + H + S	
1985			S + V		S + V	S + V	S + V					
1986										M + H + S	M + S	
1987							M + H + S	M + S	M + H			
1988			S + V									
1989	M + S	M + S			S + V			H + S		H + S	M + S	
1991			S + V	S + V	S + V					M + H + S	M + S	M + S
1992		M + S	M + S + V	M + S + V			M + H + S + V					
1993	M + S	M + S										
1994			S + V									
1995						H + S + V						
1996					M + V	M + H + S + V						
1997						H + S + V	H + S + V					
1998						H + S + V	H + S	H + S				
1999				S + V								
2000			M + V	S + V				H + S	M + H + S	M + H + S	M + H + S	M + S
2001									M + H + S			
2002	M + S						M + H + S			H + S		
2003					M + S + V							
2004				M + V								
2006		M + S										
2007										M + H		
2009				M + V		M + S + V		H + S				
2010				S + V		M + V						
2012				M + V	M + V	M + V						

(continued)

Table 14.1 (continued)

NARMADA (d)												
Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
1983	S + V				S + V	H + S + V						
1984				S + V	M + S + V		M + S + V		H + S		H + S	
1985	S + V	S + V	S + V		S + V		S + V		M + H + S			
1986	M + S + V			S + V					H + S	M + H + S	M + S	M + S + V
1987							H + S		M + H + S			
1988		S + V	S + V									
1989		M + S						H + S		H + S	M + S	M + S
1990				S + V								
1991			S + V	S + V	S + V			H + V	M + H + S	H + S		M + S + V
1992	S + V	M + H + V	M + H + V	M + H + V	S + V		H + S + V					
1993	M + S	S + V										
1995						H + S + V		M + H				
1996						M + H + S + V						
1997			S + V			H + S + V	S + V					
1998						H + S + V	H + S + V					
1999								H + S + V				
2000				S + V					M + H + S	M + H + S	M + S	M + S
2001									M + H + S			
2002							H + V			H + S		
2003					S + V							
2004			M + S + V	S + V								
2008					S + V	M + V	M + V					
2009		M + S + V				S + V						
2012			S + V	M + S + V								

Note: M, H, S, and V indicate meteorological, hydrological, soil moisture, and vegetation drought respectively
The symbol of "+" represents the concurrent situation

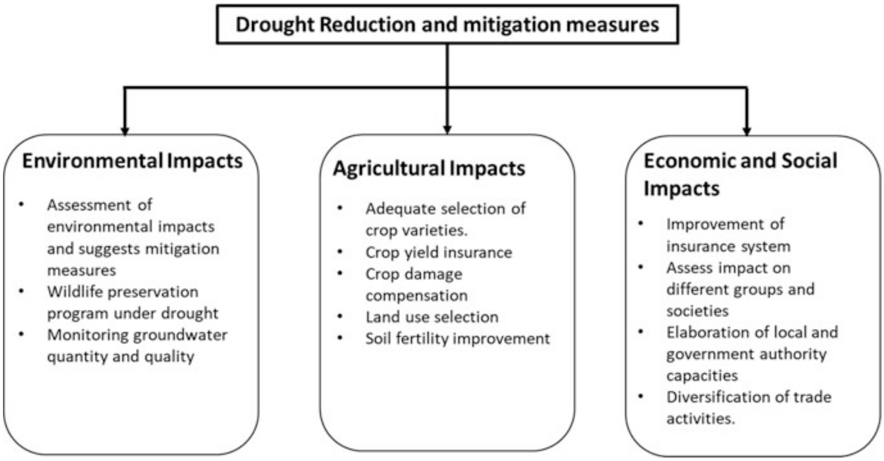

Fig. 14.5 Drought adaptation and mitigation measures

- Immunization and surveillance of public and livestock health measures should be taken.
- Public awareness programmes need to be carried out to learn about various natural calamities.
- Diversification of cropping systems is required in particular areas to save water and its efficient management.
- Encourage an integrated watershed approach for maximizing rainwater use.
- Alternative crop planning needs to be planned as per the nature of the drought.

Figure 14.5 presents the drought impact i.e., environmental, agricultural, economic, and social impact minimization measures.

It is very necessary to adopt some drought-management practices by the administration after experiencing the drought effects in the agricultural field that include:

- Encourage adoption of drought-tolerant crops.
- Promote to adopt drip-farming and integrated watershed approach.
- Encourage recycling of runoff water after drainage.
- Operate an early warning system to mitigate forthcoming drought.
- Implement drought preparedness measures.
- Water conservation through various ways including careful use of irrigation water, management of groundwater, rainwater harvesting.
- Assurance of food and security to the affected population.
- Promote effective management for stabilizing crop production.

14.5 Conclusion

Drought is a recurrent, inevitable natural hazard whose onset and termination are very difficult to define. It can cause massive environmental, social and economical consequences globally. The present chapter describes the outline of different drought types, drought monitoring using different drought indices, drought impact, and discusses the drought adaptation and mitigation strategies from different perspectives. Integrated long-term as well as short-term mitigation strategies, must be employed to enhance the consistency of the water supply system.

Toward the end of the chapter, a case study on Central India including, Narmada, Godavari, Tapi, and Mahanadi river basins is presented. The case study examines the different characteristics of meteorological, hydrological, and agricultural droughts over Central India. The key findings of the present analysis are: drought trend analysis suggests that meteorological drought has a larger area, more prolonged and less frequent for Godavari basin while Tapi and Narmada river basins also show a larger area of meteorological drought. Results indicate serious challenges towards agricultural productivity; therefore, irrigation can be considered as the best approach to stabilizing vegetation productivity. While, hydrological and agricultural droughts were showing less frequency, smaller area, and less duration. Further, concurrent drought analysis concludes that about 30–50% of concurrent droughts include conjunctions of two drought types. Interestingly, 82% of concurrent droughts include soil moisture drought that indicates that soil moisture is a very significant parameter over Central India rather than precipitation and runoff. Since the analysis has been done at a one-month scale, therefore, change in the time scale and threshold for the drought index may result in more vigorous results. The overview of drought types, indices, impact, adaptation, and mitigation strategies from several perspectives, and finally a case study of all major drought types is described in the chapter.

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Chapter 15
The Implications of Climate Change on Water Resources of Rajasthan

R. K. Goyal and Mahesh K. Gaur

Abstract Climate change is expected to have a significant impact on the hydrological cycle, which includes precipitation, evapotranspiration, and soil moisture. The most visible sign of climate change is change/increase in temperature. The evapotranspiration or crop water requirement is the most sensitive to temperature changes. Therefore, any temperature change will have a profound effect on the overall crop water requirement and in turn on the water resources of any area. The current study attempts to comprehend the likely impact of climate change on Rajasthan's water resources. Reference evapotranspiration (ET_o) was calculated using the Penman-Monteith equation and the sensitivity of ET_o was examined by increasing the temperature from 1% to 3% while keeping other parameters constant. A temperature increase of 1% ($\leq$0.42 °C based on Rajasthan's normal maximum temperature) will augment the evapotranspiration demand by 11.7 mm on an annual basis. This will further add annual water demand of 718 mcm and 2245 mcm for the whole state based on net irrigated area and total cropped area respectively. The drought-prone region like Rajasthan is not blessed with worthy perennial river systems, so any surge in water demand requires watchful planning for future water resource development.

Keywords Climate change · Rajasthan · Water resources

15.1 Introduction

Global warming is a worldwide phenomenon that causes an increase in temperature, which has an impact on water resources, crop productivity (Das et al. 2020; Goyal and Ojha 2011; Poonia et al. 2021a; Sinha et al. 2018), and climate change is regarded as a major anthropogenic threat to the global environment (Shivam et al. 2017; Sharma and Goyal 2018). Evidence suggests that the earth has warmed by

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more than 0.5 °C since 1880, and that it is continuing to warm at a faster rate (Martinez-Austria 1994). The rise in sea level is another visible sign of climate change (Schneider 1989; Houghton et al. 1990). The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 in response to these climate change evidences. Since the formation of the IPCC, numerous studies have been conducted around the world to better understand and predict the effects of global warming on various ecosystem aspects (Ravindranath and Sukumar 1996; Mendelsohn and Dinar 1999; Mathauda et al. 2000; Roos et al. 2002; Mall et al. 2004 & others). The main cause of global warming is thought to be an increase in greenhouse gas concentrations. Combustion of fossil fuels, agriculture, and changes in land use are the main sources of these gases (Singh and Kumar 1997). Climate change is expected to have a significant impact on the hydrological cycle, which includes precipitation, evapotranspiration, and soil moisture (Nemec and Schaake 1982; Gleick 1986; Bultot et al. 1988 and others). Global groundwater withdrawals have tripled in the last 50 years, with unequal volumes in the arid zone, causing instabilities. Sustainable management will be the foundation of conservation to adapt to the new climate change facies (Campos et al. 2019). The current study attempts to comprehend the likely impact of climate change on Rajasthan's water resources.

15.2 Study Area and Climate of Region

The study was carried out for the Rajasthan state, which is India's largest state, that cover 3,42,239 km^2 area and is located between 23°3′ N and 30°12′ N latitudes and 69°30′ E and 78°17′ E longitudes. The western and northern boundaries defines the eastern boundaries of Pakistan. The rest of the boundaries in the north, east and south are marked by the other Indian states (DST 1994). Rajasthan is divided into two major physiographic divisions: the Great Plains and the Central Highlands. The area located west of the *Aravallis* is known as Western Sandy Plains and it occupies the western part of the Great Plains, whereas the area east of *Aravallis* covers northern part of the Central Highlands. Similar to other desert and semi-desert regions, the climate of western Rajasthan is characterized by great extremes of temperatures and long periods of severe drought, which are accompanied by high wind velocity and low relative humidity. The winter is bitterly cold, and the temperature goes below freezing point resulting in frost. Summer, on the other hand, brings intense and scorching heat. The arid region of western Rajasthan is the hottest region in India. There is a substantial deviation in rainfall and temperature distribution in east and south of the *Aravallis*.

The State's annual rainfall varies considerably. Isohytes have a general north-west to south-east trend. The west of the Aravalli range experiences a rapid and marked decrease in rainfall, making western Rajasthan the driest part of the state. Based on rainfall data from 1901 to 2019, the average annual rainfall in the western arid region is 317 mm, while the rest of eastern Rajasthan receives 680 mm, for a total of 554 mm in the state. The annual total rainfall is highly variable throughout the state, but it is most erratic in the western half, with frequent drought spells. Rainfall has a coefficient of variation (CV) ranging from 30% to 50%. The southwest monsoon, which begins in the eastern parts of the country in the last week of June, may last until mid-September. Pre-monsoon showers begin in mid-June, and post-monsoon rains can occur as late as October. There is also some rainfall associated with the passing western distribution over the region during the winter season. The months of July and August have the highest average monthly rainfall in most places. The number of rainy days varies greatly by location, ranging from ten to forty. Every other year, the state experiences a drought. Drought has a 47% chance of occurring in the state. Most environmental variables now experience changes in their dynamics and magnitude as a result of climate change, and arid zones, in particular, suffer the most loss due to evapotranspiration and soil water stress.

There are 33 districts in the state. The state's gross cropped area is 192,302 260,358 Km^2 (cropping intensity 143%), including double cropped land (DES 2002). The total irrigated area is 107,244 Km^2 from all sources (130% irrigation intensity). Wells and tube wells are the most common sources of irrigation (72.14%). In 2010, the state's annual average demand was 31333.74 million cubic meters (MCM), with annual average surface water availability of 10448.59 MCM (with 75% dependability) and annual average ground water availability of 10563.01 MCM. As a result, there is a 30% gap between demand and supply (GoR 2002). According to hydrological water balance, the overall groundwater stage of development for the entire state is 125%, which is classified as "over-exploited" (Table 15.1). The drafting of water has exceeded the estimated replenishable resource in 164 blocks out of 249 blocks. Only 44 blocks are in the safe category, as the stage of development has reached critical levels in 9 blocks and semi-critical levels in 28 blocks (Ground water resource estimation 2013).

15.3 Climate Change v/s Evapotranspiration (ET), and Data Used

The ET is influenced by temperature changes because the capacity of air to hold water vapour increases. Globally averaged surface temperature is expected to rise by 1.4–5.8 °C between 1990 and 2100, according to general circulation models (GCMs) with various greenhouse gas emission scenarios. By the end of the century, Rosenberg et al. (1989) predicted a temperature change ranging from −4 to +10 °C.

Changes in temperature at the regional and global levels are the most visible and measurable effect of climate change. Because specific data on climate change for the state of Rajasthan isn't available, the current study was based solely on temperature increases within a likely range of 1–3% above normal. Although climate change is linked to changes in other climate parameters such as humidity, wind velocity, and sunshine hours, evapotranspiration or crop water requirements are the most sensitive to temperature changes, hence changes in temperature alone are considered in this

Table 15.1 District-wise present status (2017) of cropped area and stage of groundwater development in Rajasthan state

Districts	Total area (Km^2)	Gross cropped area (Km^2)[a]	Gross irrigated area (Km^2)	Net annual groundwater availability (mcm)	Existing gross groundwater draft (mcm)	Stage of groundwater development (%)	Category of ground water development under increased temperature scenario			
							Present	1%	2%	3%
Ajmer	8423	7179	1573	321	471	147	OE	OE	OE	OE
Alwar	7829	8707	5110	855	1489	174	OE	OE	OE	OE
Banswara	4536	3431	1099	237	115	49	S	S	S	S
Baran	6997	6633	3536	506	606	120	OE	OE	OE	OE
Barmer	28,173	18,932	3827	252	312	123	OE	OE	OE	OE
Bharatpur	5071	6063	3636	457	543	119	C	C	OE	OE
Bhilwara	10,475	6,77	2657	430	603	140	OE	OE	OE	OE
Bikaner	30,356	20,261	7828	242	359	148	SC	C	OE	OE
Bundi	5819	4959	3012	349	332	95	S	SC	SC	C
Chittorgarh	10,357	5764	2675	344	464	135	OE	OE	OE	OE
Churu	13,859	14,709	2346	135	125	93	S	S	SC	SC
Dausa	3405	3774	1371	254	416	164	OE	OE	OE	OE
Dholpur	3009	2304	1296	275	339	123	OE	OE	OE	OE
Dungarpur	3856	1959	494	133	96	72	SC	SC	SC	SC
Ganganagar	10,930	12,069	10,528	364	163	45	SC	OE	OE	OE
Hanumangarh	9703	12,917	7993	164	141	86	SC	OE	OE	OE
Jaipur	11,055	10,364	3766	650	1495	230	OE	OE	OE	OE
Jaisalmer	38,392	10,841	3849	64	158	249	SC	C	OE	OE
Jalore	10,566	9485	4036	427	832	195	OE	OE	OE	OE
Jhalawar	6322	6428	3246	547	539	99	C	C	OE	OE
Jhunjhunu	5917	6275	2414	251	567	226	OE	OE	OE	OE
Jodhpur	22,564	17,877	7512	396	908	230	OE	OE	OE	OE

Karauli	5052	3322	1598	324	474	147	SC	C	C	C
Kota	5211	5137	2851	523	547	105	S	S	SC	SC
Nagaur	17,644	16,507	3614	519	1016	196	OE	OE	OE	OE
Pali	12,331	8944	1948	295	349	118	SC	SC	C	C
Pratapgarh	4117	3054	1207	156	180	116	OE	OE	OE	OE
Rajsamand	4551	1419	522	112	119	106	C	C	C	C
S.Madhopur	4994	4263	2691	379	469	124	SC	SC	C	C
Sikar	7742	7164	2668	298	450	151	OE	OE	OE	OE
Sirohi	5179	2266	1317	275	318	115	C	C	C	C
Tonk	7180	7032	3662	442	441	100	S	SC	SC	SC
Udaipur	13,883	3545	1063	284	273	96	OE	OE	OE	OE
TOTAL	3,42,648	260,358	107,244	11,257	15,706	140	OE	OE	OE	OE

Source: GoR (2016–2017)

S safe zone (<65%), *SC* semi critical (65–85%), *C* critical (85–100%), *OE* over exploited (>100%)

[a]Gross cropped area includes area sown more than once, i.e. double cropped area also

study. Change in CO_2 concentration and precipitation are not considered in this they are related to the changes in other meteorological parameters in a indirect way.

In order to obtain normal representative values of the meteorological parameters for the study area, the whole of Rajasthan state has been divided into seven subclimatic zones, i.e. (i) arid western plains, (ii) northwestern plains, (iii) flood-prone eastern plains, (iv) humid southern plains, (v) sub-humid southern plains and *Aravalli* hills, (vi) semi-arid eastern plains and (vii) humid southeastern plains. A representative meteorological station was selected for each climate zone for which sufficient data are available. Long-terms weekly meteorological data from selected stations were used as the reference point for the study. The selected period takes into account all the typical climatic characteristics of Rajasthan, including droughts and good rainy years. In order to reduce the discretion of the climatic parameters, weekly mean values from different years were used in the analysis. Maximum possible sunshine hours (N) and radiation (R_a) have been interpolated for given range of latitudes and time from the standard tables. The psychrometric constant (γ) depends on the atmospheric pressure, which in turn depends on altitude. The value of 'γ' was estimated at 0.064506 based on the average altitude of 370 m of the state (Goyal 2001).

15.4 Estimation of Evapotranspiration

There are several models developed by Eagleson (1970), Viessman et al. (1977), Doorenbos and Pruitt (1977) and others for the estimation of the reference evapotranspiration (ET_o). FAO recommended the universal application of the Penman-Monteith combination method to estimate reference evapotranspiration. The reference crop is defined as a hypothetical crop with an assumed height of 0.12 m with a surface resistance of 70 s m^{-1} and an albedo of 0.23, which is very similar to evaporation of an extension surface of green grass of uniform height and actively growing and adequately watered (Allen et al. 1998; Poonia and Tiwari 2020). According to Penman-Monteith combination equation, ET_o can be expressed as

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34u_2)} \tag{15.1}$$

Where,

ET_o = reference evapotranspiration (mm day^{-1})
R_n = net radiation at the crop surface (MJ m^{-2} day^{-1})
G = soil heat flux density (MJ m^{-2} day^{-1})
T = mean daily temperature at 2 m height (°C)
u_2 = wind speed at 2 m height (m s^{-1})
e_s = saturation vapor pressure (kPa)

e_a = actual vapor pressure (kPa)
$e_s - e_a$ = saturation vapor pressure deficit (kPa)
Δ = slope of vapor pressure curve (kPa°C^{-1})
γ = psychrometric constant (kPa°C^{-1}) = 0.665×10^{-3}.P
P = atmospheric pressure (kPa)

In recent years, several studies have been carried out on the implementation of machine learning (ML) models for the estimation of evaporation in various regions (Baydarolu and Koçak 2014; Di et al. 2019; Fotovatikhah et al. 2018; Lu et al. 2018; Majhi et al. 2019; Moazenzadeh et al. 2018). Innumerable versions of ML models have been developed for evaporation modeling, including evolutionary computing, classical neural networks, kernel models, fuzzy logic, decision trees, deep learning, complementary wavelet-machine learning, and hybrid machine learning, among others (Danandeh Mehr et al. 2018; Fahimi et al. 2016; Jing et al. 2019; Yaseen et al. 2019). The performance of these models and their hybrid combinations has been impressive in terms of predictive accuracy (Ghorbani et al. 2017; Yaseen et al. 2018). Most of these studies, however, focus primarily on examining the generalized capabilities of ML models in different climates, as each climate has its own characteristics of stochasticity and non-stationarity.

15.4.1 Evapotranspiration v/s Water Resources

The crop-water requirement (or ET) depends upon numerous climatic parameters, namely precipitation, temperature, humidity, hours of sunshine, etc. The arid zone of Rajasthan is characterized by higher values of the annual potential evapotranspiration ET_0 that exceed the annual rainfall P (with aridity index $P/ET_0 < 0.2$). The proportion of rainfall water that seeps into the deeper layers of the soil and is protected from surface evaporation is a complicated function of rainfall patterns, topography, vegetation, and soil texture (Goyal et al. 2012; Hinge et al. 2018; Gee et al. 2005). Approximately 75.13% of the total population of Rajasthan lives in rural areas and 78.4% of the rural population depends on agriculture. Approximately 85% of the total available surface and groundwater is used for agriculture. Table 15.2 shows Rajasthan's projected water demand for different sectors. Agriculture will

Table 15.2 Projected sectoral water demand for Rajasthan (Billion cubic meter)

Purpose/Year	2005	2015	2045
Domestic	2.6 (6.5%)	3.2 (7.1%)	4.7 (8.2%)
Livestock	0.9 (2.2%)	1.1 (2.4%)	1.3 (2.3%)
Irrigation	35.9 (89.5%)	40 (88.7%)	49.1 (86.0%)
Others	0.7 (1.7%)	0.8 (1.8%)	2 (3.5%)
Total	40.1	45.1	57.1

Source: Report of expert committee on integrated development of water resources, Government of Rajasthan, June 2005
Figures in parenthesis indicate % of total water demand

continue to be the most important sector for water demand in next four decades. Water, as such and also as carrier of large amount of nutrients is required in a large measure for the successful growth of the plants. The metabolic activity of cells and plants is closely related to their water content.

The total amount of water needed by different crops/plants for essential physiological functions is less than 1% of the total water absorbed. Most of the water that enters the plant is lost through transpiration and evaporation from the soil surface. However, if the water lost by the plant through transpiration and evaporation from the soil surface is not replaced, it will result in loss of turgor, cessation of growth, and eventually death of the plant due to desiccation. Therefore, for successful crop production, the evaporation demand of the soil surface and the transpiration demand of the plant/crop can be satisfied. About 84–85% of total water resources are used to meet evapotranspiration needs, Thus, the evapotranspiration demand has a direct influence on the total water demand.

15.5 Water Resources Management Options

An increase in the productivity of rainfed agricultural economy, which still provides about 60% of the world's food and occupies almost 75% of agricultural area, would have a significant impact on world food production. However, the potential to improve agricultural yields is highly dependent on the pattern of precipitation and its distribution. In the arid areas of western Rajasthan, harvesting rainwater can reduce risk and increase yields, as shown in the Fig. 15.1.

There are different ways of using rainwater:

- Use of microstructure in the fields to conserve water in situ;
- Collection and channeling of external water from catchment area to the fields where crops are grown (flood water harvesting);
- Collection of external water from the catchment area and storing it in reservoirs, tanks and other structures for the dry season (supplementary irrigation) (Prinz and Wolfer 1999).

Research results show a significant increase in crop yield when relatively small amounts of additional irrigation are used. Average increases in wheat grain yield with low, medium and high annual rainfall were approximately 400%, 150% and 30% with additional irrigation of about 180 mm, 125 mm and 75 mm respectively.

15.6 Results and Discussion

The greatest assured threat from climate changes is increased evaporative losses and the demands for water from higher temperature (Minitzer 1993). Worldwide there will be an increase in evapotranspiration from +5% to +10% due to a temperature

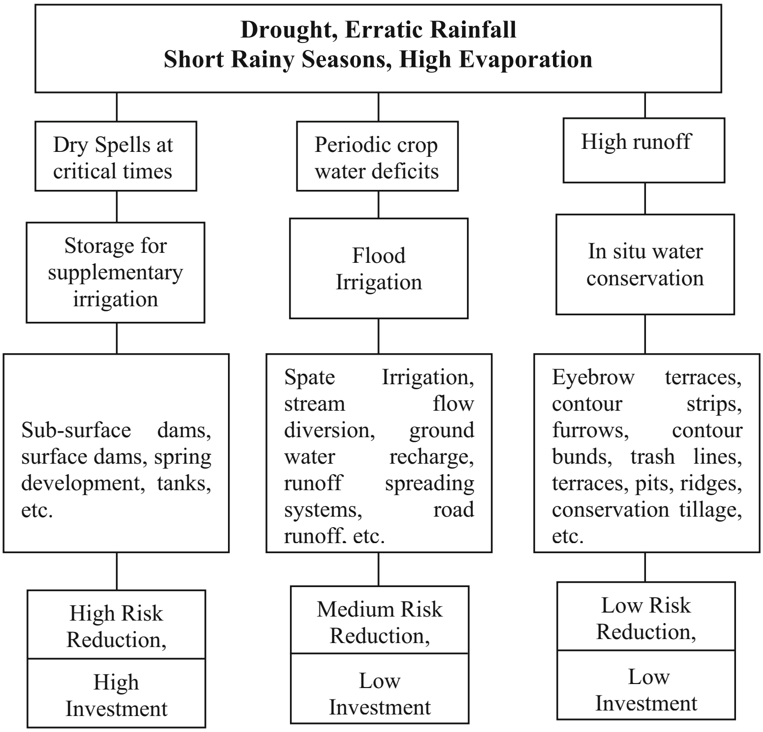

Fig. 15.1 Improving rainfed production with alternative water management in arid & semi-arid regions. (Prinz and Singh 2000)

increase from +2 to +5 °C with an equivalent doubling of atmospheric CO_2 as compared to pre-industrial level (Schneider et al. 1990). Wetherald and Manabe (1981) found that global evaporation changes by 3% when the temperature changes by 1 °C. Similarly, Budyko (1982) suggests a 5% increase in evapotranspiration demand for each degree Celsius rise in temperature. Usually, actual crop evapotranspiration (ET_a) can be derived from reference evapotranspiration (ET_0) by means of appropriate crop and water stress coefficients. Consequently, understanding of the temporal and spatial variations of ET_0 is a vital component in regional hydrological studies. From the practical point of view, in semi-arid climates where water resources are limited and irrigation is the largest user of water, temporal variations of ET_0 and quantification of its trend can produce valuable reference data for regional studies, hydrological modeling, agricultural water requirement, irrigation planning and water resources management (Liang et al. 2010). Enhanced evapotranspiration would be primarily a consequence of higher air and land surface temperature. Even in the tropics, where temperature rise is expected to be less than elsewhere, the highest rate of moisture loss from plants and soil could be considerable (Rind et al. 1989; Parry 1990). The effects of greenhouse warming on the water resources of the Indian subcontinent and suggested an increase in annual average

Table 15.3 Prospective effect of global warming on water resources of Rajasthan State

Category of groundwater development stage	No. of districts under different groundwater zone			
		Temperature increase		
	Present status (2018)	1% (0.4 °C)	2% (0.8 °C)	3% (1.2 °C)
Safe zone (<65%)	6	3	1	1
Semi critical zone (65–85%)	8	6	6	5
Critical zone (85–100%)	4	7	5	6
Over exploited zone (>100%)	15	17	21	21
Total	33	33	33	33
Additional groundwater demand based on irrigated area alone (mcm)		718	1436	2154
Additional groundwater demand based on total cropped area (mcm)		2250	4500	6750
Addition water loss as evaporation from wet-lands (mcm)		40	81	121

surface temperature of 2.0–3.5 °C over the Indian subcontinent by the year 2090 (Lal and Chander 1993). According to them warming would be most pronounced over the northwestern India.

Weekly reference evapotranspiration was calculated using the Penman-Monteith equation as described above. The sensitivity of ET_o was examined by increasing the temperature from 1% to 3%, as described above, while keeping other parameters constant. The normal average annual evapotranspiration of the state of Rajasthan is estimated as 1701 mm. A temperature increase of 1% ($\leq$0.42 °C based on Rajasthan's normal maximum temperature) will augment the evapotranspiration demand by 11.7 mm on an annual basis. This will further add an additional annual water demand of 718 mcm and 2245 mcm for the whole state based on net irrigated area (61,345 Km^2) and total cropped area (1,92,302 Km^2) respectively. As per 2018 records, the total available utilizable ground water for whole Rajasthan is 11,159 mcm and increase of 1% in temperature will put additional stress of 6.43–22.16% on existing groundwater resources based on present land use pattern. Increase in temperature by 1% will reduce number of safe districts from 6 to 3 and bring additional districts in the category of 'critical' and 'overexploited'. Similarly, an increase in temperature by 2–3% from normal data (i.e. 0.82–1.24 °C) due to increased concentration of greenhouse gases will leave only 1 district in the category of 'safe' zone and remaining 32 districts will be mostly in the category of 'overexploited' (Table 15.1). The satellite data of IRS 1A/1B and LISS for 1992–1993 shows a total wetland area of 3450 Km^2 (i.e. average exposed area of all natural and manmade water bodies), comprising 1239 Km^2 as natural and 2210 Km^2 as man-made wetland area. An increase in evaporation due global warming will cause additional annual water loss of 40.4, 80.7 and 121 mcm for 1, 2 and 3% increase in temperature, respectively (Table 15.3).

Globally, projected increase in temperature/evapotranspiration requirement is associated with an increase in precipitation of almost the same order of magnitude. However, the change is predicted to have shifted more towards extreme events, with less rainfall. Some of the most pronounced year to year variability in extreme weather events such as droughts in many parts of Asia has been linked to El Niňo events. At least half of the severe failures of the Indian summer monsoon since 1871 occurred during El Niňo years (Webster et al. 1998). In case of increased warming, a higher frequency of droughts is expected in some part of the India (Kumar et al. 2021; Poonia et al. 2021b, c).

Since this state is not always blessed with worthy perennial river systems, so any surge in water demand require watchful planning for future water resource development. More emphasis is desired to develop technologies for decreasing water losses in reservoirs, conservation of rainwater and expansion of such crop varieties that require much less water. So it is high time for the planners/users/water resource managers to deliberate in term of predicted water demand due to global warming and its expected impact on water resources of Rajasthan. The availability of water has direct bearing on the nature of crops to be grown and will decide the economy of the state.

15.7 Conclusions

Water will remain a vital resource in arid and semi-arid regions of the world, and conflicts over its access and ownership are likely to intensify in arid regions such as Rajasthan. According to the IPCC (2007), climate variability combined with human-induced emission of greenhouse gases over the past 50 years has led to an increase in the earth's surface temperature of about 0.13 °C per decade. Even without changing other parameters, water availability can be reduced by 10% or more due to the temperature increase of 2 °C (≈ 4.8% increase over the average maximum temperature of the state i.e. 41.6 °C)–very well within the expected range of change. Global average rainfall is expected to increase, but increases and decreases are forecast at regional level. No clear trend of increasing or decreasing mean annual rainfall has been observed in India (Lal 2001). Water availability is expected to decrease in arid and semi-arid regions around the world due to lack of precipitation and temperature rise, leading to an increase in the arid areas as climate affects the water balance to a change in evaporation and transpiration of plants (Bhatt and Hossain 2019). In view of the current uncertainties, no meaningful prediction can be made about regional rainfall patterns. However, a relatively small decrease in water availability can easily lead to drought conditions. In India, for example, below average rainfall in 1987 reduced food grain production from 152 to 134 million tons and reduced food reserves from 23 to 9 million tons. The increased risk and intensity of droughts, particularly in drought-prone regions such as Rajasthan, potentially represent the most severe impact of climate change on agriculture, both regionally and globally. These effects are independent of the increasing demand of human users and the natural ecosystems, which will occur simultaneously.

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Chapter 16
Thar Desert of India: Application of Geospatial Technology for Extreme Weather Events

Mahesh K. Gaur and R. K. Goyal

Abstract The meteorological phenomenon are the prime agents in causing extreme events in the arid and semi-arid areas. These are drought and famines, flood, sand and dust storms, etc. The response to the climate change varies with the deterioration of global climate warming. GIS, Remote Sensing and GPS are the modern tools which play significant role in the management of extreme events. These have proved their importance in the rapid assessment of the pre- and post-events through the spatio-temporal variabilities of terrain properties. Satellite images of varied resolution, provide a synoptic evaluation and offer valuable environmental details, for a vast range of scales. The most important methods currently in vogue are the conventional synoptic and numerical methods to monitor changes in the weather. Droughts mainly depends on precipitation, temperature and evaporation. The western part of Rajasthan, known as the Thar Desert, often experiences several consecutive years of droughts and famine cause various kinds of socio-economic and environmental hazards. The other important one is the sand and dust storms. Flash floods do occur to cause land degradation and damage crops. Application of Geospatial technologies in the management of the extreme events helps to reduce the risk as well as control the impact of such events. Further, the integration of weather data and GIS helps to quantitatively monitor storm impact. The present paper deals with the application of geospatial technologies in their prediction and management.

Keywords Extreme events · Drought · Flood · Sand and dust storms · NDVI · LST · Geospatial technologies

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16.1 Introduction

Extreme climate events have a significant impact on ecological systems and socio-economic systems. The global climate is getting warmer and warmer, so extreme climate events are likely to increase in both frequency and intensity. Its effects on the natural environment and society have been observed around the world over the past few decades. In addition to natural climate variability and greenhouse-induced climate change, extreme weather and climate events have the greatest impact.

With global warming, extreme weather events have become more common. The third and fourth assessment reports of the IPCC gave a clear definition of extreme weather events: for a certain location at a certain time, extreme weather events are of low probability and their probability of occurrence is around 10% or even more (IPCC 2007a) meteorological elements defined and investigated extreme climate events (Frich et al. 1993; Gong et al. 2009; Manton et al. 2001; Pan 2002; Ping et al. 2010; Qian and Huang 2008; Sun and Ning 2008; Zhai and Pan 2003), which are mathematically strictly extreme value events. The cause for society and economy depends on its strength, affected area and duration, so it is very important to focus on the process, i.e. the increase, development and decrease of extreme weather events. Recently, some researchers have been looking into this topic (Zhang and Feng 2010; Zhang and Qian 2011), although these methods are not objective enough and require artificial judgment.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007b) identified a warming trend of 0.13 °C/10a over the past 50 years. The increase in average temperature not only affects the change in temperature extremes (Goyal and Ojha 2011), but can also lead to climatic events (Sharma and Goyal 2018), such as heat waves and thunderstorms, which show trends of increasing frequency, strength and intensity (Li et al. 2011). Numerous studies have indicated that frequent extreme weather events cause enormous losses to society and the economy, as well as loss of life (Easterling et al. 2000). The most recent statistics show a tenfold increase in economic losses resulting from global climate change and associated extreme weather events over the past 40 years.

Global warming or climate change has been identified by (IPCC 2007a) as the main cause of the variation in atmospheric and hydrological cycle, which changes the intensity and spatial distribution of precipitation (Goyal et al. 2012). Global warming, in turn, modifies local drought and flood conditions and influences the regional agricultural sector. The frequency of extreme weather events can also induce change in the context of climate change (Rosenzweig et al. 2001). It can trigger various meteorological threats such as floods, droughts and rainfall amount. Drought usually occurs when rainfall in an area falls below normal levels for a prolonged period. Depending on the components of the hydrological cycle affected by a drought event, the drought can be categorized as meteorological, agricultural, or hydrological (Shivam et al. 2017). The Standardized Precipitation Index (SPI) of McKee et al. (1993) is used to define meteorological droughts. The other types of droughts such as agricultural, hydrological and economic droughts depend upon the meteorological droughts. The hydrological droughts are comparatively long-lasting and usually result in low flow rates in rivers and depleted reservoirs. The concept of drought can vary from place to place as rainfall varies greatly between different regions and spaces. For a more effective assessment of drought phenomena, the World Meteorological Organization (2012) therefore recommends adopting the Standardized Precipitation Index (SPI) for monitoring the severity of drought events. The precipitation deficit is represented by negative SPI values. Positive values indicate excessive precipitation (Wu 2013). SPI is widely used in many countries and regions to characterize dry and wet conditions. According to Green (2010), among many other symptoms, climate change is just one symptom that we have not achieved sustainable development in the past. The meteorological factor results from the impending drought, which mainly depends on precipitation, temperature and evaporation in a region, but with the deterioration of globalisation and global warming, the response to the climate change varied from region to region.

WMO Meteoterm defines the term “extreme weather event” as an extreme weather event that is rare at a certain location and at a certain time of the year. Definitions of infrequent vary, but an extreme weather event would normally be as infrequent as the 10th or 90th percentile of an observational estimated probability density function. By definition, the properties of extreme weather can vary from place to place in the absolute sense. If an extreme weather pattern persists for some time, for example during a season, it can be classified as an extreme weather event, especially if it produces an average or a total that is itself extreme (e.g. drought or heavy rainfall during a season).

According to Easterling et al. (2000) “There are several ways to define extreme weather events, such as extreme daytime temperatures, extreme daytime precipitation, large areas with unusually warm monthly temperatures or even storms such as hurricanes. for the impact an event has on society. This can mean excessive loss of life, excessive economic or financial loss, or both” (Easterling et al. 2000).

According to the IPCC report (2012), some types of extreme weather and climate events have increased in frequency or extent. Vulnerable populations and assets have also increased, with consequences for disaster risk. And climate-related disasters exist or can develop on any scale, from local to international.

16.2 Indian Scenario

The monsoon aberrations have become more common in rainfed agriculture regions. The years of 2014 and 2015 were recorded as monsoon drought years and the 2018 monsoon also ended with a precipitation deficit of 9% compared to the long-term average. The year 2015, 2016 and 2017 were recorded as the warmest years in India after 2009 and 2010. Over the past 50–60 years there has been a decrease in rainfall and an increase in temperature across the country, and is reported to be increasing in the semi-arid belt. Heavy rains, avalanches, landslides, heat and cold waves, cyclone storms, thunderstorms, hailstorms, sandstorms and cloudbursts are not uncommon and are likely to occur frequently in the following decades in the forecasted climate change scenario. The effects of the drought on Indian food grain production are much more prevalent compared to flooding/heavy rainfall during the monsoons, as large arable land is affected by a drought situation during a monsoon break or failure. Years 1997, 2002, 2004, 2009, 2012, 2014 and 2015 were drought affected periods and affected the production of *kharif* food crops. The *Rabi* crop is harvested during March and April are the months, but heavy rains accompanied by high winds have damaged production. Rains caused by western disturbances generally occur in winter, and late rains near the Rabi crop have caused widespread damage to crops. Landslides and snowfalls often block the Jammu and Kashmir highways, stranding thousands of people. Such events are repeated almost every year.

The dry and semi-arid areas are expanding whereas the moist sub-humid, humid and per-humid areas are shrinking. The semi-arid area that occupies the large and central part of the country is expanding significantly. The overall effect is that the country has recently been experiencing dry weather with a shift in rainfall to the west. From 1965 a decreasing trend of the monsoon rains can be observed. This is largely due to the dwindling of the Tibetan anticyclone coupled with the cooling of the upper troposphere (600–150 h Pa) over the Himalayan region and the surrounding atmosphere. The recent significant upsurge trend in surface air temperature in India is due to a downward rainfall trend during winter and summer monsoons.

16.3 Geospatial Technologies for Extreme Events

Many sorts of facts which might be wanted in natural disaster management have an crucial spatial component. Spatial data are records with a geographic component, which includes maps, aerial photography, satellite imagery, GPS records, rainfall records, borehole records etc. Many of these records have a unique projection and co-ordinate system, and required to be geo-referenced for mapping, to superimpose them. We now have access to information accumulating and establishing technology like remote sensing and geographic information systems (GIS), that have proven their effectiveness in disaster management. Remote sensing and GIS offers a database. Remote sensing data, which includes satellite images and aerial photos permit us to map the spatio-temporal variabilities of terrain properties, like vegetation, water, and geology. Satellite images deliver a synoptic evaluation and offer very valuable environmental details, for a vast range of scales, from whole continents to info of some metres. Secondly, many kinds of disasters, which includes floods, drought, cyclones, volcanic eruptions, etc. could have positive precursors. The contemporary set of satellites are capable to locate the early phases of various activities as anomalies in a time series. Images are accessible at usual quick time intervals, and may be used for the prediction of swift and measured disasters.

Furthermore, remote sensing enables us to monitor the event as it occurs while the forces are in full swing, and the advantageous position of the satellites makes it ideal for us to think, plan, and operationally monitor the event. Planning of evacuation routes, for the design of emergency response centers and for the integration of satellite data with other relevant data in the design of disaster warning systems. GIS, in combination with Global Positioning Systems (GPS), is extremely useful in search and rescue operations. in areas that are devastated and difficult to drive. The effects and outcome of the disaster left an area of immense devastation. Remote sensing can help with damage assessment and monitoring of the consequences and provide a quantitative basis for relief efforts. In the disaster recovery phase, the GIS is used to organize damage information and post-disaster census information, as well as in site assessment for reconstruction. They are used to map the new situation and update the databases used to rebuild an area, and these databases are useful in preventing such disasters during their reviews.

16.3.1 Droughts

The western part of the state of Rajasthan, which consists of the Thar Desert, often experiences several consecutive years of droughts and famine. Drought is the result of prolonged drought and/or inadequate rainfall resulting in depletion of soil moisture, depletion of groundwater supplies and decreased flow rates.

Drought is often defined from a disciplinary outlook. Bandyopadhyay (1988) lists four types of drought, namely (i) meteorological drought, (ii) surface water drought, (iii) groundwater drought, and (iv) soil-water drought. Studies have argued that the various drought forms arise independently of one another but are inseparable and are linked by the water cycle.

The National Agricultural Commission of India defines three types of drought, namely meteorological, agricultural and hydrological drought. *Meteorological drought* is defined as a situation in which the normal precipitation in an area decreases significantly (i.e. by more than 25%). *Agricultural drought* occurs when soil moisture and rainfall during the growing season are insufficient to support healthy plant growth to maturity and cause plant stress and wilting. *Hydrological drought* may be result of drying of streams, and rivers and depleting of water table.

Many others have also considered economic or socio-economic factors. *Social drought* refers to the effects of drought on human activities, including direct and indirect effects; and the *economic drought* – "a meteorological anomaly or extreme event of intensity, duration (or both) that is outside the normal range of events that corporations and public regulators have normally considered in their economic decisions and which therefore lead to unforeseen events (generally negative) effects on production and the economy in general" (Benson and Clay 1998).

Since drought is a complex phenomenon that can be defined from multiple perspectives, the definitions of drought are divided into conceptual (broadly worded definitions) and operational (Hisdal and Tallaksena 2003). Generally, operationally defined droughts can be used to analyze the frequency, severity and duration of droughts for a specific return period (Mishra and Singh 2010).

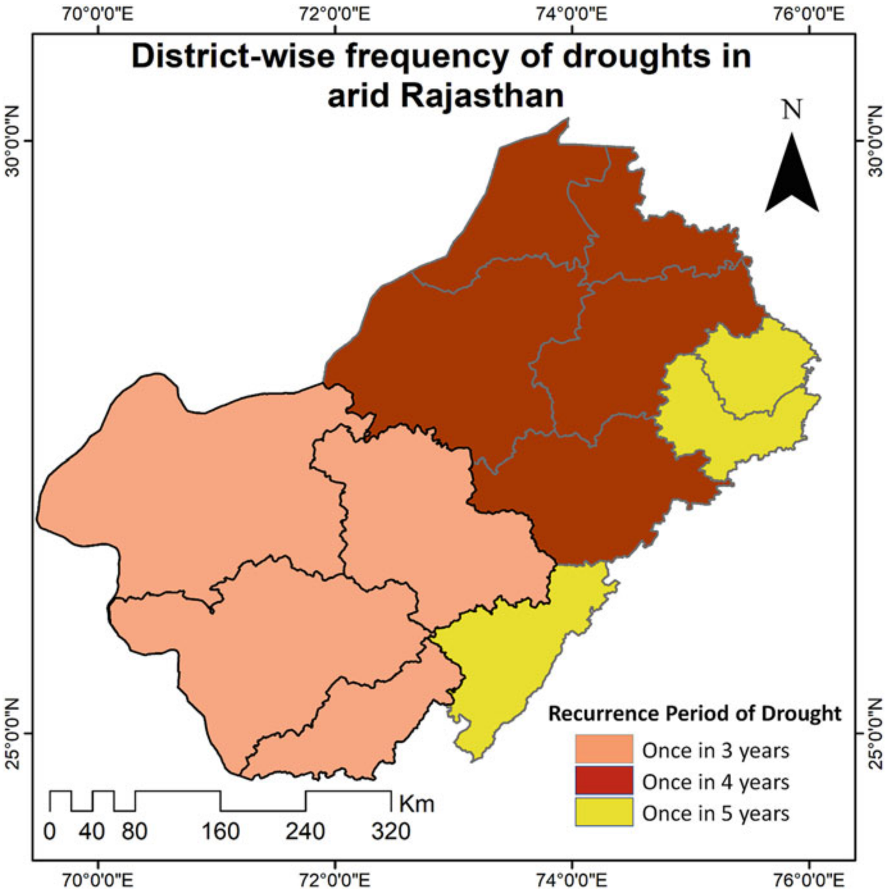

Fig. 16.1 District-wise frequency of droughts in arid Rajasthan

An evaluation of 100 years of rainfall records exhibits that the frequency of ‘below-normal rainfall’ in arid, semi-arid and sub-humid areas is 54–57%, even as intense and uncommon droughts happened as soon as each 8 to 9 years in arid and semi-arid zones. In those zones, infrequent droughts of intense depth occurred once in 32 years, with nearly each 3rd year being a drought year (PACS Programme 2001–08). Between 1871 and 2002, India has witnessed 22 main droughts in 1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987 and 2002 (Fig. 16.1). India experienced one of the severest droughts of the century in 1987, with an average rainfall deficiency of 19%. It affected 59–60% of the crop extent and a population of 285 million. During the drought year 2002 in India, it was predicted that the regular loss in rainfed rice production was round Rs. 2000 crores. According to India Meteorological Department (IMD), the country experience a drought when the overall rainfall deficiency is greater than 10% of the Long Period Average (LPA) and greater than 20% of its area is affected by drought-like situations. IMD has categorized the year 2002 as the *first-ever all-India severe drought year* since 1987. The rainfall deficiency of this order has only occurred thrice before in the last century in 1917, 1972 and 1987.

16.3.1.1 Role of Remote Sensing and GIS in Drought Studies

In order to adapt to the negative effects of drought, the main tasks should be the assessment of agricultural drought and the identification of risk zones, among other things based on long-term precipitation and evapotranspiration data analysis (Lemma 1996). This conventional method lacks the identification of spatial variations (Jeyaseelan 2004). Topography and poor accessibility, so the use of satellite data is of the utmost importance.

Disaster detection, monitoring and containment require rapid and continuous collection of relevant information that traditional methods cannot effectively collect. Remote sensing techniques use electromagnetic radiation in the visible, infrared, and microwave ranges to collect reflectance measurements from plants, soils, water, and other materials. Coverage of large areas in real time and rapid continuous information on large areas in multispectral bands. These are used to identify early stages of drought events as anomalies in a time series. Early warning and drought risk assessment are shown in Fig. 16.2.

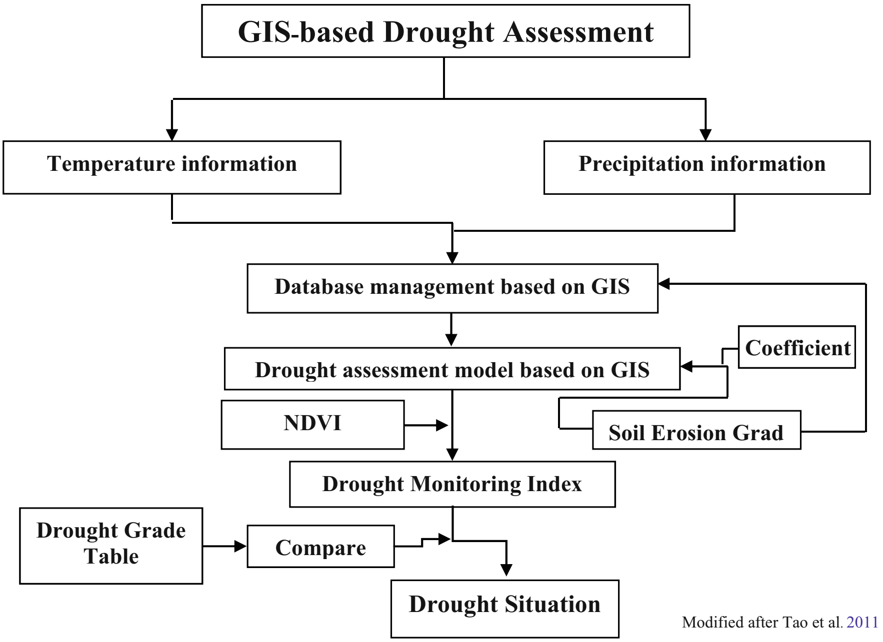

Fig. 16.2 Information system implementing procedure for early warning drought risk assessment

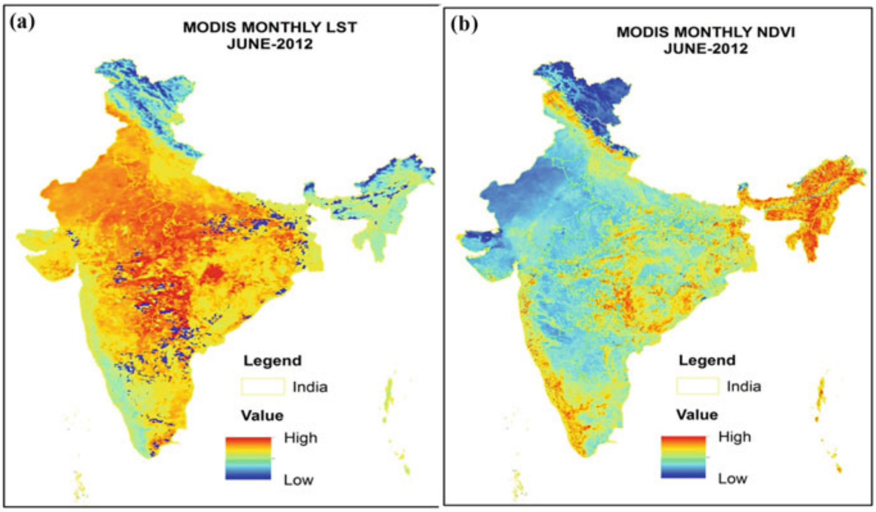

Fig. 16.3 (**a**) MODIS monthly LST_June 2012. (**b**) MODIS monthly NDVI_June 2012

The NDVI has been used successfully to identify stressed and damaged crops/plants and grasslands, but only on homogeneous terrain. The NDVI is used to calculate:

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{R})/(\mathrm{NIR} + \mathrm{R})$$

where NIR and R are reflectivities in the near infrared and the red region of an electromagnetic spectrum.

Other vegetation indices commonly used in conjunction with remote sensing data are the Difference Vegetation Index (DVI), Ratio Vegetation Index (RVI), Perpendicular Vegetation Index (PVI), Soil Adjusted Vegetation Index (SAVI), Transformed Soil Adopted Vegetation Index (TSAVI), Weighted Difference Vegetation Index (WDVI), Vegetation Condition Index (VCI), Transformed Vegetation Index (TVI), Green Vegetation Index (GVI) etc. (Kasturirangan 1996).

MODIS monthly raster datasets for the year 2009–2013 were processed to map the spatial and temporal analysis of the Indian context. Bands 31 (10.28–11.72 μm) and 32 (11.78–12.28 μm) are used for land surface temperature (LST) estimation, while the NIR and IR bands are used for NDVI transformation will.

Spatial and temporal pattern inferences: The spatial and temporal analysis is derived for the year 2009–2013. The change in the spectral reflectance in relation to the land cover classification was carried out with ENVI and ArcGIS software. Figure 16.3a shows the range of the minimum and maximum land surface temperature. Similarly from Fig. 16.3b, the NDVI are classified the vegetation with increase in above ground biomass. The soil heat flux is derived from which clearly determine that decrease in LST leads to increase in NDVI and soil heat flux as well (Fig. 16.4).

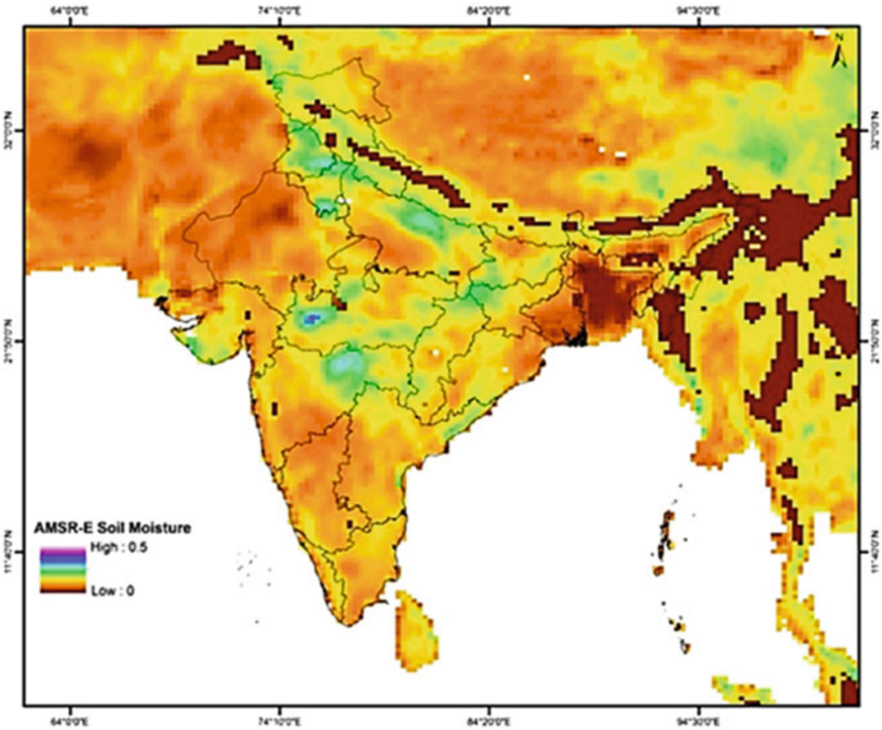

Fig. 16.4 AMSR-E Soil Moisture for the year June 2012

Thus the probability of decrease in above ground vegetative biomass will shows decreases in soil heat flux, which helps to monitor the drought occurrence. It is very important for the evapotranspiration (ET) and the estimation of the soil moisture (Fig. 16.5). Less vegetative biomass areas and the soil heat flux have a spectral pattern which is responsible for the monitoring of the drought.

16.3.1.2 Normalized Difference Wetness Index

The Normalized Difference Wetness Index (NDWI) is expected to indicate the turgor and health of the vegetation or crop. It is based on the use of the short-wave infrared band (SWIR), which is sensitive to the moisture present in the soil and in the plant cover. At the beginning of the growing season, the soil dominates, which means that SWIR is sensitive to soil moisture in the upper 1–2 cm. As cultivation progresses, SWIR is sensitive to the moisture content of the leaves. The growing season. Higher NDWI values mean more surface moisture.

The various components of the drought forecast are shown in Fig. 16.6, which includes input variables, methodology and the products obtained (Mishra and Singh 2011). However, drought forecasting is a critical part of drought hydrology that

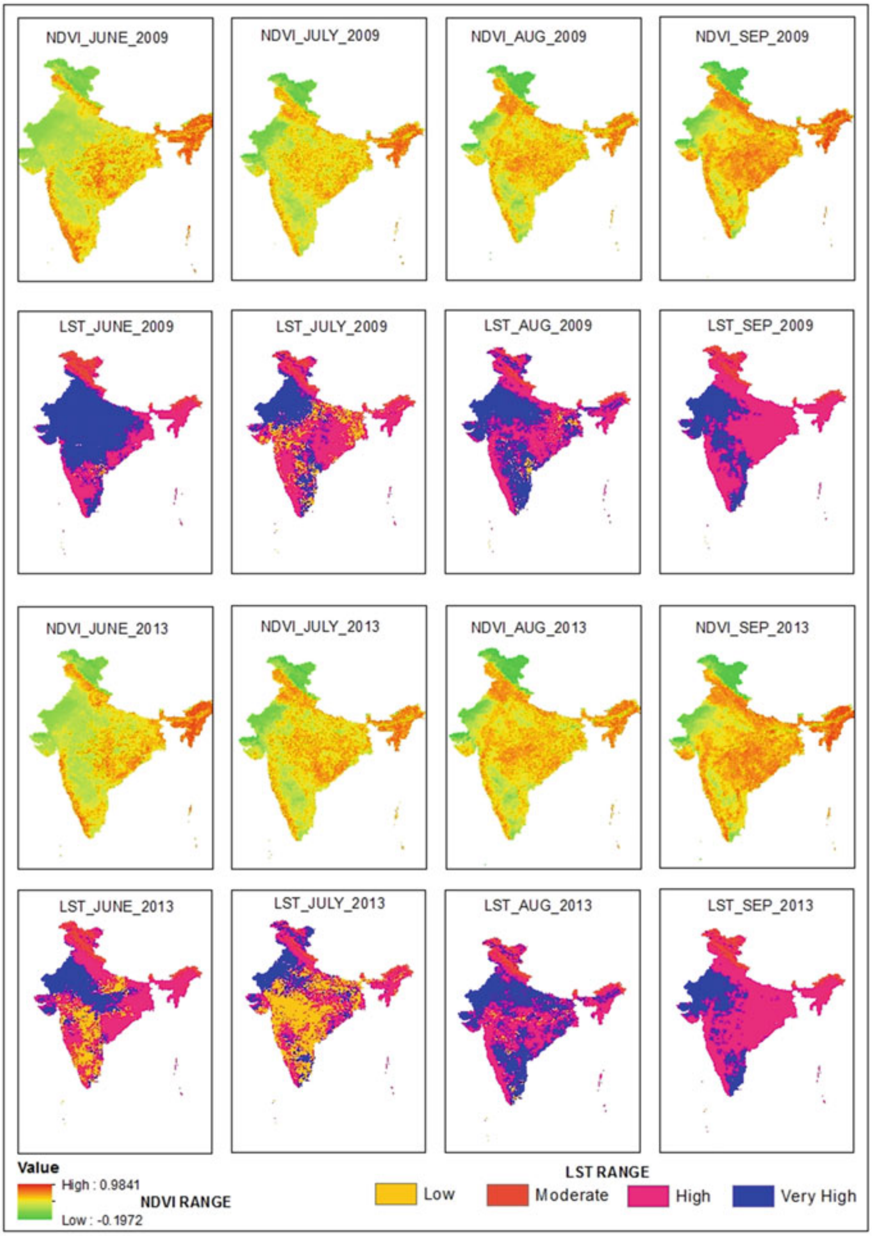

Fig. 16.5 MODIS LST & NDVI patterns for the year 2009 & 2013 (JJAS)*
(*June, July, August, September)

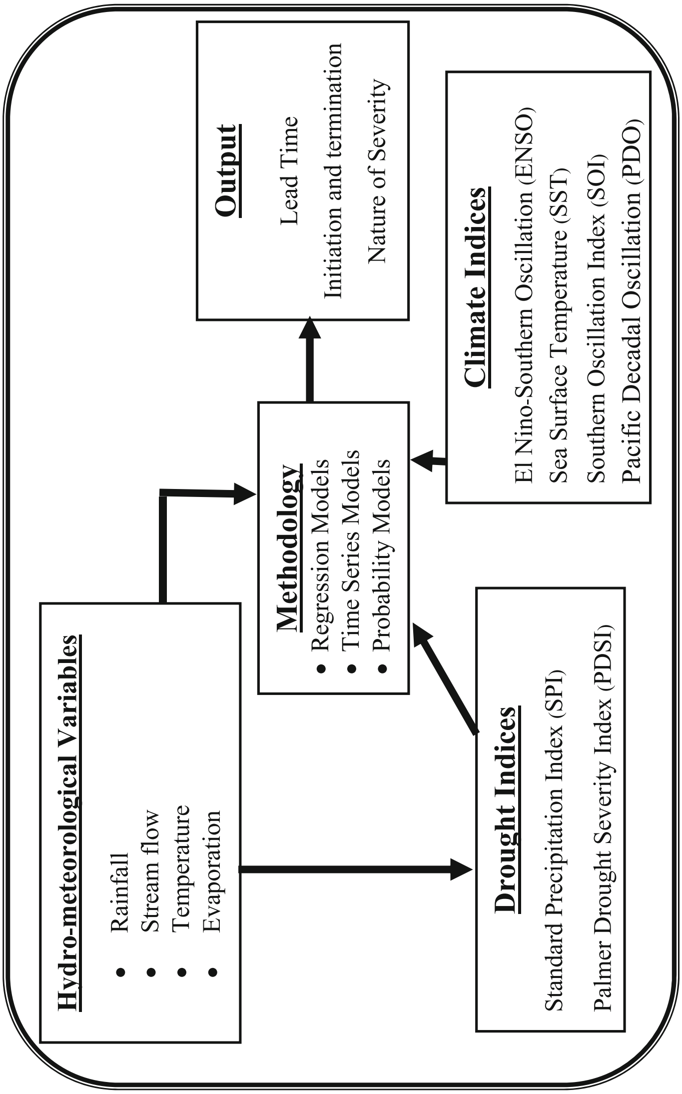

Fig. 16.6 Different components for drought forecasting (Mishra and Singh 2011)

plays an important role in risk management. Drought preparedness and containment. One of the shortcomings in mitigating the effects of drought is its inability to accurately predict drought conditions in advance.

16.3.2 Floods

Remote sensing has made a substantial contribution to flood monitoring and damage assessment that guide disaster management authorities. Flooding hit the whole country inconsistently during the monsoon season between July and September and most of the country experiences flooding every year including Bihar, Jharkhand, Madhya Pradesh, Eastern Rajasthan, Assam, Bengal, Maharashtra, etc. Progress in remote sensing and geographic information system have greatly facilitated flood mapping and flood risk assessment. It is obvious that GIS has an important role to play in the management of natural risks because natural risks are multidimensional and the spatial component is intrinsic. The main benefit of using GIS for flood management is that it not only generates a visualization of the flood, but also creates the potential to further analyze this product to estimate the likely damage from flooding. The European Union's Copernicus program Sentinel constellation provides synthetic aperture radar (SAR) and multispectral data with global coverage, high frequency pass and high spatial resolution. Other examples of free remote sensing programs are Landsat, which has been providing data since 1972, and the daily MODIS satellites which provide multispectral imagery. In addition to the medium resolution images (Multispectral Landsat Scanner (MSS) with a 7-band resolution of 80 m (0.8–1.1 μm); Landsat Thematic Mapper (TM) images with a resolution of 30 m; multispectral images SPOT, IRS images), coarse resolution images such as AVHRR (Advanced Very High Resolution Radiometer Radiometer) data have also proven useful for regional flooding. In addition to its all-weather capability, the most important benefit of using SAR imagery is its ability to clearly distinguish land and water.

Change detection can be used as a powerful tool to detect the flooded area in SAR images. It is usually done by capturing two images taken before and after the flood. The techniques of coherence detection and amplitude change are widely applied in the SAR field. Multi-data SAR scenes for the same area can be projected onto the red, green, and blue channels to create a colour composite. The composite image effectively represents the course of a flood over a specific period of time. This methodology is simple to perform and offers the possibility of easily identifying the area which remains blocked for a maximum period of time. The combination of wavelength, angle of incidence, and polarization play an important role in influencing the performer's ability to separate flooded areas from non-flooded areas. Multispectral satellite data acquired by MODIS, ProbaV, Landsat and Sentinel-2 and Synthetic Aperture Radar (SAR) data collected by Sentinel1 are often used to detect flooded areas using different methodologies (e.g. and supervised classification). Then the automatic mapping can be further improved and refined manually with the help of free auxiliary data such as the water depth model based on the digital elevation model and the available ground truth data. Among the various factors, the transit time of the satellite in relation to the flood peak is the most important.

16.3.2.1 Case Study

Relentless rains are not very common in the Thar Desert, but whenever they occur, the streams of the dry sand-bed suddenly swell and cause flooding. Generally small in size, and consequent the floods that generate rain are very localized (Fig. 16.7). For example, in 1979, when large parts of Pali and Jodhpur districts, containing the northern half of Luni Basin, suffered extreme flooding. The 1990 flood was concentrated in the southern half of the Luni basin (in the Jawai River basin), in the districts of Pali, Jalor and Sirohi. There were 5 years of maximum (moderate to severe) flooding per decade over the past 100 years in 1951–60, 1971–80, and 1991–2000. In recent memories, large desert floods occurred in 1967, 1975, 1979, 1983, 1990 and 2006 (Kar 2011).

The desert district of Barmer in Rajasthan received abundant, widespread and continuous rainfall for almost a week, notably from 20 to 23 August 2006, for a total of nearly 650 mm of rain in 4 days (average annual rainfall 277 mm). Water bodies filled in and ephemeral streams drained significant runoff in low lying areas (Fig. 16.8). As a result, the settlements, which were located in low lying areas (plains and interdune depressions) were submerged, causing severe damage to

Fig. 16.7 Flood incidence in Thar Desert in 2005–2019

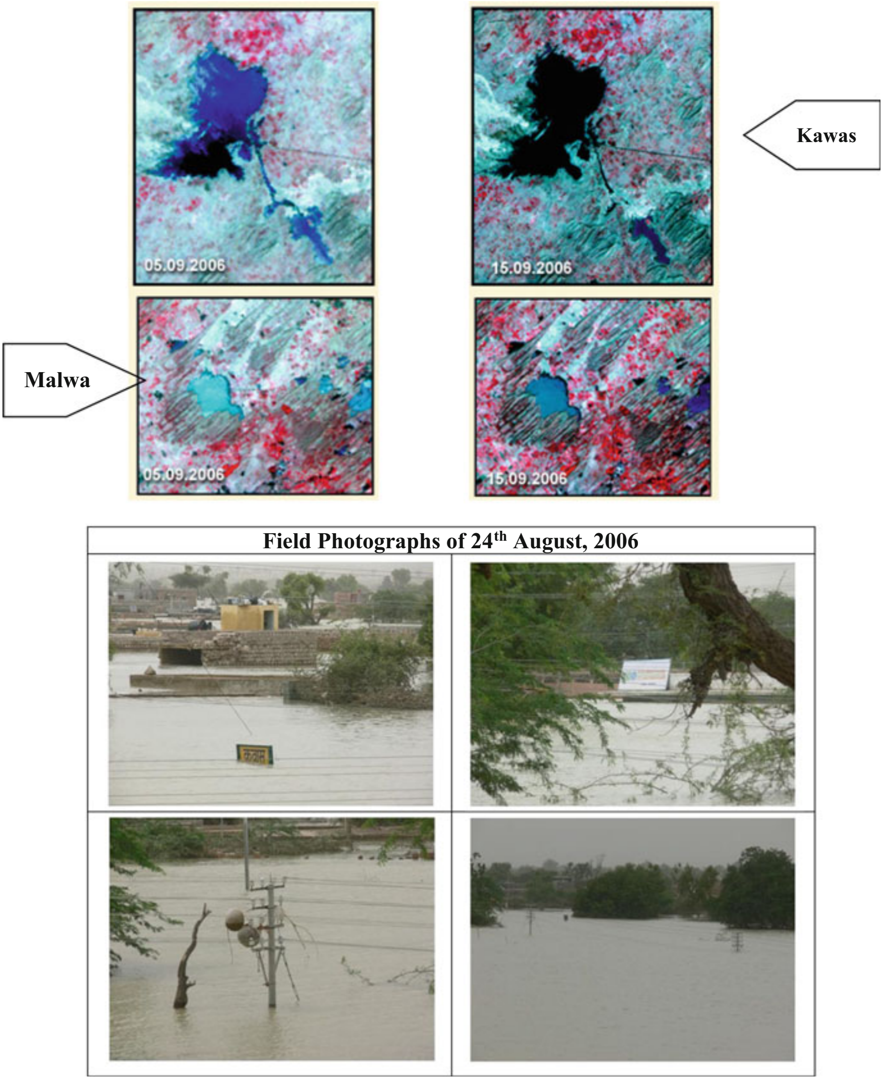

Fig. 16.8 Flood condition in Kawas and Malwa areas, Barmer district in 2005

people, livestock, property and infrastructure, including Kawas/Sar ka Par and Malwa and six small villages. In addition to these, in total, more than 80 villages with 11,000 families and 61,000 people were affected by the floods.

The water diffusion area was analyzed using data from August 24, 2006 and September 5 and 15, 2006. The total water diffusion in the entire Barmer district was 244.51 km^2 on August 24, then it fell to 171.91 km^2 on September 5, 2006.

Consequently, flooding in Rajasthan is mainly caused by heavy rainfall concentrated during the monsoon season (July–September). The frequency of flooding over several decades in western Rajasthan has shown that flooding occurs in the region with an average frequency of 2–3 years out of 10. The decades 1911–1920, 1941–1950 and 1981–1990 were characterized by severe flooding. Although widespread flooding is not common in arid Rajasthan, such flooding occurred in arid Rajasthan in 1908, 1917, 1944, 1975, 1983 and 1997. In 1917, the average precipitation of 12 arid districts exceeded +161% and in the following years, there were no floods of this intensity at 925 mm at Gorawar, located in the Luni basin, causing the severe flood. Pali (Luni Basin region) recorded the highest number of floods in 11 years, while the lowest number of floods occurred in Hanumangarh and Jhunjhunun districts (in 4 years each).

Based on the simulation results, four fourth-order basins responsible for the Kawas flood were identified: (1) the Mehreri Nagurda watershed (927.9 km^2), (2) the Jhanphali-Shiv-Kotara watershed (525.5 km^2), (3) Baisala-Rohli-Kawas watershed (319.0 km^2) and (4) Lunu-Lakhe talai sub-basin of (3) (191.5 km^2). River basins 3 and 4 are flanked downstream by a few small interdunal basins (133.9 km^2) from which the Rohili receives water as it flows to the Kawas depression (Kar 2011).

Remote sensing is a valuable source of observational data that could mitigate the decline of field surveys and measuring stations locally, especially in remote areas and hilly terrain. Integrating remote sensing variables (such as land elevation, river width, extent of flooding, water level, land cover, etc.) with flood modeling promises to improve significantly our understanding and forecasting processes.

16.3.3 Surface Temperature

A climate change monitoring system integrates satellite observations, ground data, and forecasting models to monitor and forecast weather and climate change. In recent decades, climate variability and climate extremes have produced increasingly evident impacts on societies in countries around the world. The 4th Assessment Report states: “The warming of the climate system is unambiguous, as now shown by observations of increasing global average air and ocean temperatures, widespread snowmelt and snowmelt ice and global mean sea level rise. At continental, regional and ocean basin scales, many long-term climate changes have been observed. These include changes in temperature and ice, widespread changes in the amount of precipitation, ocean salinity, wind patterns, and aspects of extreme weather conditions including drought, heavy precipitation, ocean waves heat and intensity of tropical cyclones. “Various methods have been used by meteorologists for weather forecasts. The most important methods currently in vogue are the conventional synoptic and numerical methods of weather forecasting (NWP). The first method is human subjective and the second is objective and deterministic. The ability of these predictions can be improved through the use of GIS by relating different characteristics of the atmosphere and their correct visualization. These models are commonly referred to as Global Circulation Models (GCMs), but there are many limitations in the GCM-based weather forecasting method. Consequently, a mixed man-machine approach is currently recommended for the preparation of meteorological forecasts from GCM tracks, in particular in the medium term.

The land surface temperature (LST) has gained in importance over the years and there is a need to develop approaches capable of determining LST using satellite images. Temperature data is derived from Landsat images using remote sensing algorithms to assess LST from thermal infrared (TIR) data (bands 6 and 10). This data is processed and analyzed using various software tools. Being measured near the surface of the earth, LST is primarily influenced by the Land Use/Land Cover Distribution (LULC) of the land. The spatio-temporal semantic kriging (ST-SemK) approach is presented in two variants: non-separable ST-SemK ($ST\text{-}SemK_{NSep}$) and separable ST-SemK ($ST\text{-}SemK_{Sep}$). Geostatistical spatial interpolation (Dixon and Uddameri 2016) is a popular LST remote sensing technique that predicts missing pixels from surrounding measured positions. The existing spatial interpolation methods for LST-based applications are inverse distance weighting (IDW), nearest neighbors (NN), splines (SP), and several variants of kriging. The computer models used to predict changes in the Earth's surface temperature (LST) are very useful in assessing and predicting rapid climate change. Soft computational techniques, namely, multivariate adaptive regression splines (MARS), wavelet neural network (WNN), adaptive neurofuzzy inference system (ANFIS), and dynamic evolving neurofuzzy inference system (DENFIS), are applied and compared to predict the LST changes.

Poonia and Rao (2013) showed that air temperatures by the end of the twenty-first century are expected to increase by +3.3 °C in Bikaner, +3.4 °C in Jaisalmer, +2.9 °C in Jodhpur and + 2.5 °C in Pali. Annual precipitation is expected to increase by +100 mm in Bikaner, +124 mm in Jaisalmer, 40 mm in Jodhpur and + 21 mm in Pali. Analysis of MODIS AQUA data for a period from May 2010 to June 2020 revealed that the spatial and temporal variation of the potential evapotranspiration requirements of the Thar region ranged from 2.1 mm/day to 12.2 mm/day and up to annual basis between 1500 mm and 2220 mm. In addition, the predicted air temperature impact of up to an increase of 4 °C by the twenty-first century increases the need for evapotranspiration by 9–23% during the monsoon period and by 13–47% during the winter period and this increase in water demand due to the warming will reduce the water and food resources of the Thar region (Fig. 16.9). Studies for the Jodhpur region have shown that changes in precipitation and air temperature are not alarming, but the increase in human (400%) and animal (127%) populations during the twentieth century led to a major change in land use patterns and put enormous pressure on surface and groundwater resources (Rao 1996; Rao and Miyazaki 1997) resulting from excessive grazing and loss of vegetation cover resulting in greater loss of radiant energy and reduced convective activity (Sikka 1997). On a smaller scale, land use changes affect local temperatures.

The Thar region experienced severe drought in 1918, 1987, 2002 and 2009, when rainfall deviated from normal by −81%, −65% and −70%, respectively. In 2009, a

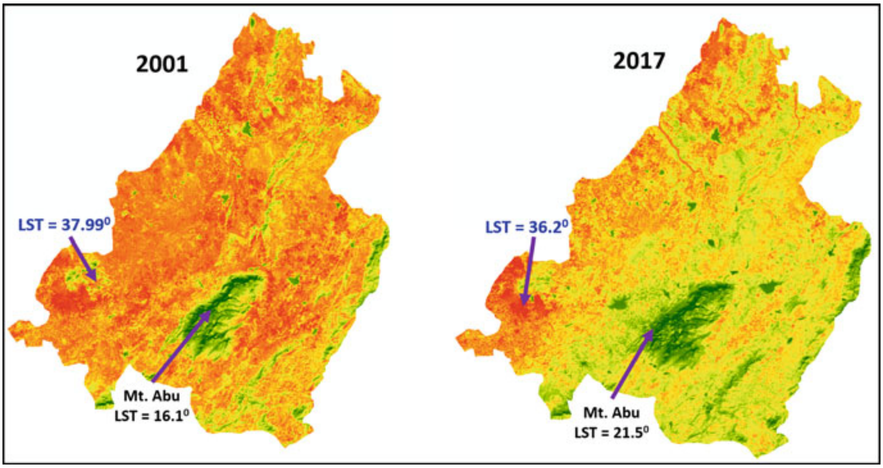

Fig. 16.9 Land surface temperature in Mt. Abu and adjoining areas, Sirohi district (Rajasthan)

precipitation deficit of 40% compared to normal precipitation caused a drought affecting desert fauna due to the scarcity of food and drinking water. Drought followed by high temperatures reaching 45–49 °C during the late summer period of June 2010.

16.4 Sand and Dust Storms (SDS)

Sand and dust storms (SDS) are common meteorological hazards in arid and semi-arid regions. They are usually caused by thunderstorms – or the strong pressure gradients associated with cyclones – that increase wind speeds over a large area. These strong winds lift large amounts of sand and dust from bare, dry soil into the atmosphere, carrying them hundreds to thousands of kilometers. SDS, also known as sirocco, haboob, yellow dust, white storms and harmattan, are a natural phenomenon related to soil and water management and climate change, they are a combination of different risks, such than sand, dust and wind. Most locations are in arid, low latitude areas, but sources of dust can develop in almost any environment, often under the influence of humans. Important potential drivers of future wind erosion and SDS occurrence include desertification, land degradation and climate change, high latitudes, industrial activities, especially due to unsustainable land management and water, more extreme wind events, greater aridity in some areas, and greater frequency, severity and duration of drought (https://www.unccd.int/actions/sand-and-dust-storms) (Fig. 16.10).

Early warning is a key element in mitigating the impact of SDS. Early warning of the upcoming SDS would allow people to take precautionary measures and help minimize its disastrous effects on daily life. This requires continuous monitoring of

Fig. 16.10 Incidences of sand storms in Thar desert

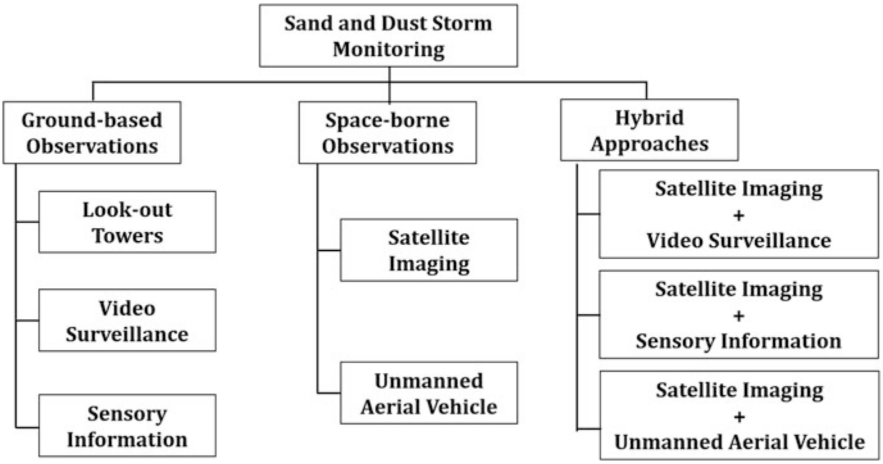

Fig. 16.11 Technologies for sand and dust storm monitoring. (Source: Akhlaq et al. 2012)

dust, sandstorms and movement of sandbanks in a given area. Several technologies are available to monitor dust and other environmental changes, such as lookout-tower, video-surveillance, sensory information, satellite imagery, unmanned aerial vehicle and hybrid approaches. A particular technology is only suitable for detecting certain types of SDS, but a hybrid approach can detect many types of SDS (Fig. 16.11). Accurate and timely warning of the upcoming SDS would minimize its serious consequences by giving people enough time to take precautionary measures, such as seeking shelter, harvesting mature crops, etc.

There are many types of SDS when it comes to coverage. A local or small-scale SDS emerges in a small geographic area, while a global or large-scale SDS covers a very large geographic area. A short-term SDS is one that persists for a few minutes or hours, while a long-term SDS would prevail for several days or months (Gao and Han 2010). However, based on the intensity of the SDS, the World Meteorological Organization (WMO) has classified dust events into four types: Dust-in-Suspension (visibility: up to 10 km), Blowing Dust (visibility: 1–10 km), Dust storm (visibility: 200–1000 m) and Severe dust storm (visibility: <200 m) (WMO 2005).

The MODIS (Moderate Resolution Imaging Spectroradiometer) subsets of terrestrial products can provide high-quality basic knowledge for the quantitative inversion of terrestrial and atmospheric parameters. Using the land surface reflectance (LSR) dataset, dust storm remote sensing monitoring was performed through quality control and data synthesis.

However, modern research in this area is directed towards the development of integrated dust models that incorporate all related models, including the following (Shao and Dong 2006):

1. Atmospheric model: It includes atmospheric dynamics and physical processes, such as radiation, clouds, convection, diffusion, etc., and it also affects all the other models.
2. Land surface model: It includes data on soil particle-size distribution, soil surface characteristics such as moisture and temperature, vegetation coverage, leaf-area index, and energy and mass fluxes.
3. Dust emission model: It includes threshold velocity of wind, saltation flux and dust emission rate.
4. Dust transport: It includes data on horizontal and vertical advection, vertical diffusion, and dry and wet convection.
5. Dust deposition: It includes data on dry and wet deposition of the dust.
6. External components: The other useful components of an integrated dust storm model are Geographic Information System (GIS) databases, dust monitoring technologies, etc.

The most important factors in these dust models are: threshold velocity of wind, particle-size distribution (PSD), dust emission rate and surface conditions (Marticorena et al. 1997).

16.5 Conclusion

Incidents such as heavy downpours, flash floods, hurricanes and heat waves are increasingly common. Experts predict more extreme events such as severe winter storms and flooding due to climate change in the years to come. Near real-time satellite data is very useful for examining and confirming predictions of weather systems approaching land from the oceans. They provide a glimpse of impending severe storms. Heatwave or landslide, extreme weather phenomena are becoming more severe than before. Rising temperatures and high winds have increased the risk to property and life. A strong system is needed to address the knowledge gap of data on the ground, whether it is periods of drought, drought or flood damage. As such, the primary role of addressing the negative impact of extreme events within Agromet Advisory Services (AAS) is to uncover the basic requirement to generate means to adjust crop/practice plans cultures depending on when the extreme events occur. However, farmers use these alerts for planting and transplanting crops, applying fertilizer, forecasting and pest and disease control measures, weeding/thinning, irrigation (quantity and calendar) and crop harvest. As these events occur more often now, a geospatial data collection technique can provide better accessibility and understanding among the public, government and decision makers.

Geospatial data is already used for mapping and resource management. Integrating meteorological data with GIS can solve many underlying problems and facilitate resource planning and restoration. The Geographic Information System enables easy sharing of coordinated information to build long-term resilience to extreme weather events. GIS improves data integration and usability, spatial analysis and increases the potential for wider applications. GIS makes weather and climate information more usable in various related fields and is also used in visualizing weather models. Instruments like MODIS on NASA's Aqua and Terra satellites give a clear picture of typhoons and snowstorms. NASA's Aqua and Terra satellites provide valuable information about thermal energy on the Earth's surface. Find out about climate change trends around the world. High-resolution remote sensing data allows comparison of longer time periods. Researchers and decision-makers. They can compare spatial temperature measurements with soil data. Since hot and drought conditions can also cause forest fires, it is essential to understand temperature patterns. An interactive web-GIS-based spatial decision support system (SDSS) is needed to cater to various requirements in the field of agriculture, hydrology, weather forecasting, pest and disease forecasting.

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Chapter 17
Addressing Hydro-climatic Risks Through Sectoral Planning: A Case of National Agriculture Disaster Management Plan (NADMP)

Sanayanbi Hodam, Richa Srivastava, and Anil Kumar Gupta

Abstract Agriculture is the primary source of income for almost two-thirds of India's population and third largest contributor to the Indian economy. However, it is frequently threatened by natural and anthropogenic disasters of which majority of the disasters are hydro-climatic disasters. With India aiming to achieve Doubling Farmers' income by 2022 and ease by living by 2024, it is important to identify the hazards, risks and vulnerabilities of various elements of the agriculture sector from disaster and climate change perspective. Furthermore, the agenda 1 of India's PM's Agenda 10 on Disaster Risk Management also envisages every ministry/department to prepare its own disaster management plan utilizing the legal mandate under Disaster Management Act 2005. Accordingly, National Agriculture Disaster Management Plan (NADMP) for the Ministry of Agriculture and Farmers Welfare (MoAFW) was prepared. This chapter highlights about hydro-climatic disasters that are affecting the agriculture and the farming community. It also talks about integrating Climate Change Adaption-Disaster Risk Reduction into sectoral planning in the context of NADMP of the MoAFW, Government of India.

Keywords Hydro-climatic disasters · Sectoral planning · Disaster risk reduction · Indian agriculture · NADMP

17.1 Introduction

The earth, water, atmosphere, and biosphere make up the environment. We are a part of this natural ecosystem and live within it. Our social and economic actions have an effect on the environment, and they can change how its elements interact. Any changes in this may lead to environmental degradation which will then lead to rise in frequency and intensity of disasters (UNDP 2009). One of the most important natural

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resources is water, supporting both fundamental human needs and the ecosystems that keep life on Earth alive. The majority of economic activity, including agriculture, energy production, and manufacturing, is dependent on water (Server Global 2018). Nevertheless, water induced climatic disasters like floods and droughts are affecting different sectors in many countries especially India. One of frequent and devastating natural disasters around the world is flooding and the amount of flooding is anticipated to be increasing under the impact of increasing climate change and economic development (Jonkman and Kelman 2005; IPCC 2007). Subsequently, flooding risk will increase throughout the world, particularly in the underdeveloped countries. According to reports, in the last decade, hydro-climatic disasters and extreme weather events have given rise to more than 90% of natural disasters (UNDRR 2015). India, being the worst flood affected country next to Bangladesh, accounts one fifth of the global deaths by flood and on an average 30 million people are evacuated every year (Kapri 2016). Of all the sectors, agriculture sector is one of the most important sector in India and also one of the sector highly affected by hydro-climatic disasters. Climate change has already created challenges for the agricultural sector – and will continue to do so. Temperature rises, rainfall variability, and the frequency and intensity of extreme weather events are all being exacerbated by climate change, putting additional strain on the world's agricultural and food systems (OECD 2016). The effects on agriculture, on the other hand, are rarely quantified or thoroughly examined (FAO 2017).

In order to ensure a long run sustainable growth of the overall economy it is required to devise appropriate sectoral policies based on the requirements of the sectors matching with regional & national requirements. A well devised sectoral plan provides a comprehensive affirmation of sector functioning, challenges and opportunities, sectoral development goals, policies and strategies that support national development plan (Beingachhi 2016; Govt. of Mizoram 2021). Planning can be of various types, depending upon the purpose. Regional planning and sectoral planning are two common approaches of planning for development. Within the territory of a country the economic and social development is uneven i.e. some areas lag behind while others get better developed. This uneven pattern over space creates regional imbalance in development. This creates a push for the planners to have a spatial perspective and draw the plans to reduce this imbalance. This type of planning is termed as regional planning. Sectoral planning, the most commonly adopted form of planning these days, is essentially a special purpose planning to develop the various (key) sectors of economy (Beingachhi 2016). Key sectors are those sectors which influence the economy in a significant way through their capacity to stimulate the growth of other sectors either through providing their own output to other sectors, or through taking inputs from other sectors (Beingachhi 2016). Key sectors could be economic, social and/or infrastructural. 'Sectoral planning, therefore, means only a single sector being considered under the spatial planning (e.g. tourism, agriculture etc. as shown in Fig. 17.1). It covers formulation and implementation of the sets of schemes or programs aimed at development of that one particular sector.

The plan acts as a structure for identifying of policies and schemes in the private and public sectors, to identify and address challenges such as weak economic

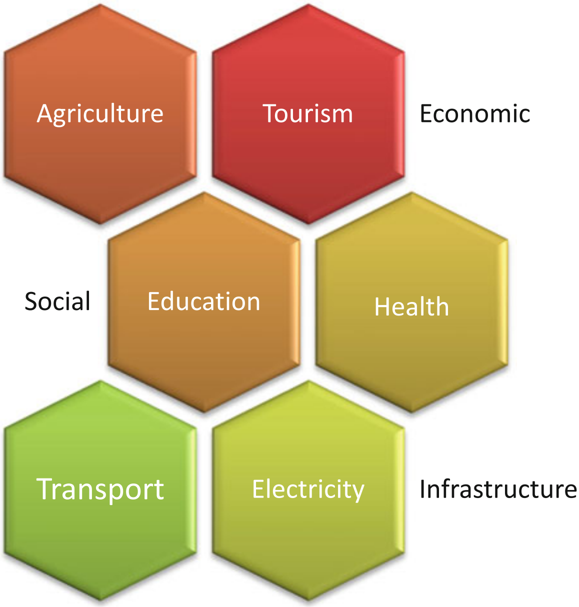

Fig. 17.1 Different sectors of strategic planning

performance and large scale job losses (distressed sectors) as well as regeneration of economic pursuits in specific places and locations. Sectoral plan plays a crucial role in encouraging investments in these sectors. Well devised sectoral plans:

- Bring economic stability, as this is the most important factor for development.
- Enable systematic participation of the private sector as well as other stakeholders.
- With systematic input from stakeholders, better co-ordination and support might be expected to result in more effective resource utilization.
- Provide the additional documentation required to explain and justify the budget to ensure continuing budgetary supports
- With budget linked to plan implementation and stakeholder participation in the planning process is one of the most important aspects of fostering sustainable development.
- Budgetary resources enable the concerned department to produce and deliver the outputs that directly contribute to achieving the predetermined objectives
- A sectoral plan provides opportunities to address key challenges that affect different sectors differently through integrating various sector specific possible solutions/options within the policy cycle. In relation to climate change, for example, adaptation to climate change can be integrated within the sectoral policy cycle at the policy formulation stage, the planning stage, the resource allocation stage and the sector programming stage (Government of Somoa 2003).

17.2 Adaptation at Sectoral Level

It is increasingly clear that if business as usual continues and due consideration is not given climate-associated risks will increase vulnerability. Vulnerabilities to climate change and response options are highly sector-specific. Some sectors are particularly vulnerable –including agriculture, water, forestry and health. Adaptation techniques and procedures also differ greatly between sectors. This highlights the significance of sectoral strategies as these offer opportunities for integrating sector specific adaptation tools at various levels in the planning cycle. A well thought out long term strategy, therefore, reduces the chances of mal-adaptation. A prior recognized and assessed risks of climate change and necessary measures required in specific sectors, stakeholder's involvement and inter-ministerial co-ordination can also avoid conflicting or duplicative measures by multiple sectors.

17.3 Agriculture Sector and Disasters

Agriculture, along with its related sectors, is India's most important source of income. It has influence on food industry, employment, agri-business, farm industries and many more associated sectors which are directly or indirectly connected with this sector. So any adverse impact on agriculture sector will directly affect the economy of the sector and country. One of the key drivers behind increasing economic loss due to disasters is the lack of appropriate disaster management including risk reduction strategy based on knowledge about hazard impacts and access to risk information (Gupta et al. 2016). Climate change is adding a new dimension to India's existing catastrophe risk profile by increasing the frequency and intensity of climate-related hazards and threats. According to a recent research (2018) by the Agriculture Ministry, climate change is expected to have a rising impact on agricultural productivity from 2020 onwards, and might go up by as much as 40% by 2100 unless proper adaption measures are adopted in the agriculture sector. Today agriculture remains as the primary source of income for 70% of India's rural households, with 82% of farmers being small and marginal (India at a Glance, FAO 2021). Agriculture sector is also largely affected by the hydro-meteorological disasters. Climate change is global issue and extreme events are leading us towards disasters more frequently. According to IPCC, the global warming is likely to reach 1.5 degrees during 2030–2052 if it continues to rise at the current rate. If we look at the facts, India will be among the worst hit countries that may face wrath of calamities and extreme events like flood, high intensity rainfall, landslides etc. (IPCC 2019). The economic survey 2018 says climate related extreme events are taking toll on India's Agriculture in socio economic context (Economic Survey 2018). India ranked 5th in the global climate risk index done by German Watch. The Climate Risk Index may act as a warning sign for current vulnerabilities that may worsen when extreme events become more common and intense as a result of

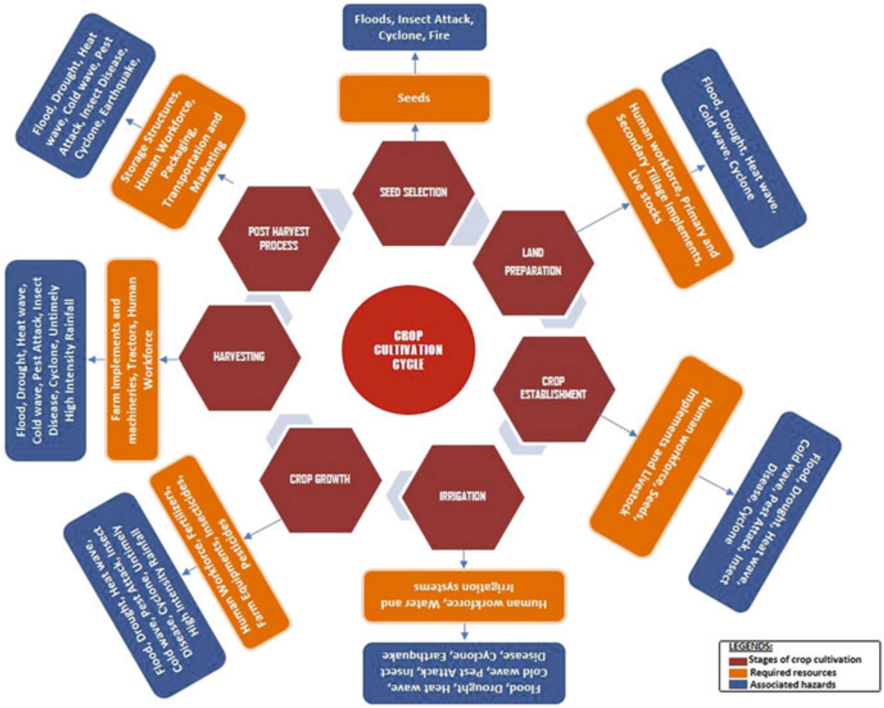

Fig. 17.2 Crop cycle and associated hazards

climate change (Eckstein et al. 2019). Climate data is explicitly included in the disaster risk management cycle to highlight the sorts and timing of data that might assist disaster risk managers in planning for and responding to climate-related incidents.

Climate change impact and challenges in agriculture are being witnessed all over the world, but countries like India are more vulnerable due to huge population dependence on agriculture sector giving excessive pressure on natural resources (Gupta et al. 2020). Also, change change and disasters affects all stages of crop cultivation. The process of crop cultivation, resources associated with each phase of crop cycle, and related dangers capable of disturbing the process of crop cycle are depicted in Fig. 17.2.

From this crop cycle, it can also be seen that almost all types of disasters are affecting agriculture sector. Lately, India has witnessed and experienced different types of disasters namely cyclones, pandemic, locust attack, forest fire, etc. and all these disasters have affected this sector directly and indirectly. Agriculture in India is subject to a variety of natural and manmade calamities and climate change, which is exacerbated by variety of factors, ranging from frequent natural disasters, climate variability, uncertainties in yields and prices, weak rural infrastructure, imperfect markets, lack of appropriate financial services, etc. Climate change's impact on agriculture might jeopardize food security and livelihood activities on which a large portion of the population relies. Climate change can affect crop yields (both positively and negatively), as well as the types of crops that can be grown in certain areas, by impacting agricultural inputs such as water for irrigation, amounts of solar radiation that affect plant growth, as well as the prevalence of pests. Every year our Indian agriculture is affected by natural disasters like floods, droughts (Kumar et al. 2021; Poonia et al. 2021b, c), hailstorms, pest attacks, etc. All these hazards have the potentials to create risks of disasters when exposed to vulnerable physical, economic, social and environmental conditions. Unlike any time in the past, challenges to the agriculture sector in India have to be understood concurrently in many dimensions. The increased frequency and severity of climate-related hazards and risks induced by climate change are adding a new dimension to the existing disaster risk profile of India. Though, there is visible improvement brought by the adoption of management practices through on-farm and off-farm operations in this sector, there is also a growing risk of disaster-related damages and losses to the agriculture systems.

17.4 India's PM Agenda 10

Sectoral Plans gives a detailed statement of sector performance. It discusses current concerns and possibilities, as well as sectoral development goals, policies, and strategies, as well as the government agency's role in growing the sector in collaboration with other government agencies. Designated government agencies are responsible for preparation of Sector Plans through a process of stakeholder consultation and participation. Disaster can be a big hurdle in development of any sector and is inversely proportional to each other. If there is no planned development the risk of disaster may increase. Disaster can be aggravated in loop-holed planning. The risk of disaster is widely talked but less grasped especially how hazard proceeds into disaster.

India's Prime Minister's 10 Point Agenda on Disaster Risk Reduction (Fig. 17.3) draws integrated approach towards implementing the Sendai Framework for Disaster Risk Reduction, Paris Climate Agreement and the SDGs, through its Agenda 1, i.e. all sectors to imbibe the principles of disaster risk management, and utilizes the legal mandate under the Disaster Management Act 2005 and the National DM Policy 2009. The statement emphasizes the importance of incorporating DRR into all development projects and sectors. It also says that development must progress along with the concern of DRR (Gupta et al. 2016).

Fig. 17.3 India's Prime Minister's 10 Point Agenda on Disaster Risk Reduction

17.5 Purpose and Scope of NADMP

The basic purpose of NADMP is to guide the Agriculture Ministry to manage the risks of disasters before, during, and after disasters. These include assessing the risks of disasters, mitigating the existing risks of disasters, preventing creation of new risks of disasters, presenting the status of its preparedness to perform its role and responsibilities as defined under the Disaster Management Act 2005 and the National DM Policy 2009 (Gupta et al. 2020). The Indian Government has set a target of doubling farmers' income by the year 2022, 5 trillion dollar economy and ease of living by 2024. These targets can be achieved by improving the scenario of Indian agriculture and protecting them from natural disasters through proper mitigation and going in accordance with Prime Minister's Ten-Point Agenda on Disaster Risk Reduction. Indian agriculture, like India's agricultural landscapes, is subjected to a variety of natural and man-made calamities, which are exacerbated by the influence of climate change (Gupta et al. 2019a, b). Unlike any time in the past, India's agriculture challenges have to be understood concurrently in many dimensions. To ensure food security and also to strengthen our Indian economy, different challenges before, during and after the process of cultivation needs to be understood and addressed. Therefore, National Agriculture Disaster Management Plan (NADMP) has been prepared to better prepare for the impacts of disasters and to avoid potential new risks, reduce the existing risk of disasters, and to manage the actual and potential events of disasters.

17.6 Significance of NADMP

The DM Plan of the Ministry of Agriculture & Farmers Welfare addresses multi-hazard risk and vulnerabilities, multi-layer approach to resilience building, and covering all aspects of agriculture system in India as a whole with focus on agriculture sector as depicted under the allocation of business to the Ministry. It includes infrastructure/establishments, resources, people, services and activities associated with the mandates of the MoAFW including Deptt. of Agriculture & Cooperation, Deptt. of Fisheries, Dairy, etc. and Deptt. of Agriculture Research & Education, their interdependence among and with other sectors/Ministries/Departments and stakeholders at various levels. It also addresses the disaster safety and resilience of physical assets and resources associated with the sector. The plan is drawn in coherence with the National DM Plan developed by National Disaster Management Authority (Gupta et al. 2020).

17.6.1 Addressing Hydro-meteorological Disasters

Twelve disasters that affects Indian agriculture have been identified in the plan out of which seven disasters are hydro-meteorological disasters. Table 17.1 shows the 12 disasters and also can be seen that almost, all disasters are directly or indirectly Hydro-meteorological. If we talk about recent Locust attack the connection is irregular climatic events. According to Locust Warning Organization (LWO) pre monsoon rain triggers the growth of vegetation in the arid are where dessert locust can grow and breed. In past 2 year this Pest attack has been a threat and hugely affecting the agriculture sector (Gupta et al. 2020). The disaster prevention and mitigation measures for each hazard such as drought, flood, cyclone etc., have been included in the plan highlighting the roles and responsibilities of agencies at the

Table 17.1 Type of disasters affecting agriculture sector

S. no	Nature of disaster	Frequency	Type of disaster
1	Flood	Regular	Hydro-meteorological
2	Drought	Regular	Climate change
3	Heat waves/cold waves	Regular	Climate change
4	Pest attack/diseases	Regular	Indirectly hydro-meteorological
5	Hail storms	Regular	Hydro-meteorological
6	Landslides	Regular	Indirectly hydro-meteorological
7	Cyclones	Regular	Hydro-meteorological
8	Tsunami	Rare	Hydro-meteorological
9	Fire	Regular	Natural
10	Earthquake	Intermittent	Natural
11	High intensity rainfall pattern	Regular	Hydro-meteorological
12	Lightning and thunderstorm	Intermittent	Hydro-meteorological

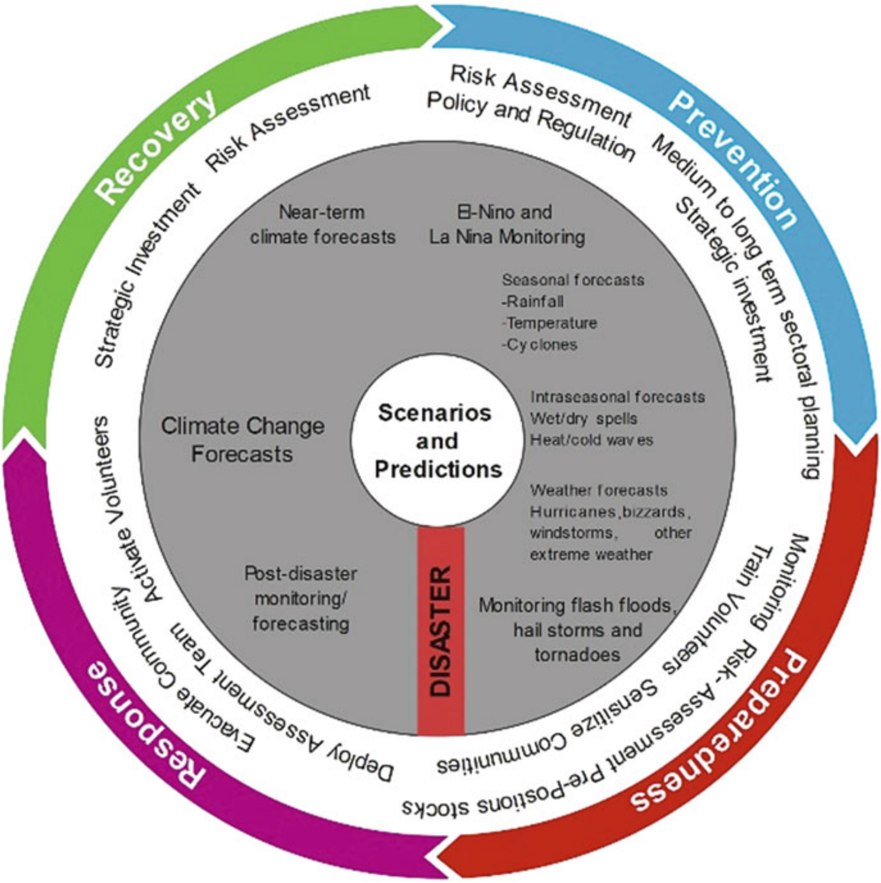

Fig. 17.4 The use of climatic data in the disaster risk management cycle demonstrates the types of data that can be used to make specific decisions. (Adapted from Kelly and Khinmaun 2007; Hellmuth et al. 2011)

national and state level. In a study, climate data has also been explicitly included in the disaster risk management cycle to highlight the sorts and timing of data that might assist disaster risk managers in planning for and responding to climate-related incidents (Hellmuth et al. 2011; Fig. 17.4). Coming to the farming community, the plan addresses the unequal disaster coping capabilities of the vulnerable section by recognizing that due to inequalities and social exclusions some sections suffer more than others in extreme events and disasters because of their place within the social system. It details out the various programmes and schemes of MoAFW for vulnerable groups and their linkages with disasters (Gupta et al. 2020).

17.6.2 Human Resource Resilience

Majority of India's workforce are dependent on agriculture for their livelihood, the impact of any disaster will also affect farmers community and their livelihood. Therefore, the plan has been prepared keeping farmers' community in priority. The vulnerability of a community to disaster depends on the social, cultural, economic and political environment in which it lives. A cycle of deprivation not only increases their vulnerability, but gradually alienates them from the decision-making process by denying them access to basic permits. The various programmes and schemes for vulnerable groups like gender based vulnerabilities, sexual and gender minorities, scheduled caste and schedules tribes, children, persons with disabilities and farm labours have been emphasized and detailed out in the plan.

17.6.3 Rural Development

Agriculture is still the primary source of income for people living in rural areas. The well-being of the rural population is determined by their control and ownership of the land, which is also of paramount importance to millions of people. In India, promoting sustainable livelihoods for the poor continues to be a major problem in development policy and practice. The distribution of land and water resources, as well as the nature and management of these resources, all play a role in the incidence of rural poverty (ADI 2021). Therefore, NADMP focused on rural development, sustainable land water resource management and other need based livelihood generation. It also highlights the need for improvising and mainstreaming programmes like Skill Development, National Handicraft Development Programmes to focus more on other rural livelihood options like handicraft, handlooms, paintings, pottery, etc.

17.6.4 Agro Industries and Agribusiness

The post-harvest food losses is another challenge to achieve food and nutritional security. Farmers have very poor access to agro industries. Above that, the poor storage structures and transportation facilities adds to the worry. Farmers and food vendors have been concerned about losses since farming began (Kiaya 2014). As such, there should be proper and sufficient storage structures where natural disasters cannot affect them and agricultural processing plants should preferably be located near production sites in rural areas. There is a need for policy reform related to agriculture, agribusiness and rural development to hold migrant workers back (Gupta et al. 2020). In NADMP, the scheme Rashtriya Krishi Vikas Yojna (RKVY) which is an umbrella scheme for ensuring holistic development of agriculture and allied sectors has been identified as a possible scheme where disaster risk reduction can be integrated.

17.6.5 Green Growth and Sustainable Development

Lack of preparedness and adequate coping strategies make people more vulnerable to risk. Agriculture sector is a climate sensitive sector and India needs to be concerned about the impact of climate change in agriculture (Das et al. 2020; Poonia et al. 2021a). There are several ways for building and improving agriculture of which green growth is one. Green growth refers to supporting economic growth and development while also ensuring that natural resources continue to deliver the resources and environmental services that we rely on (OECD 2021). There are four pillars of green growth as in Fig. 17.5. In the agriculture sector, this entails implementing techniques that have a favourable impact on the environment and societal welfare (Gupta et al. 2019a, b). In NADMP, green growth has been identified as one of the strategy for sustainable development. This strategy will help in adopting rationalization of fertilizer use and adoption of organic cultivation practices.

17.6.6 Overall Economy

The key importance of NADMP is to safeguard and improve the economy of India and to ensure food security. According to data presented by the government in the Lok Sabha in 2021, India suffered a massive crop loss on 18.176 million hectares (mha) of land, or nearly 8.5% of the total gross cultivated area, owing to floods from 2017 to 2019 (Kapil 2021). Since agriculture sector is the 3rd largest contributor to the economy of the country, the overall economy can only be improved when these

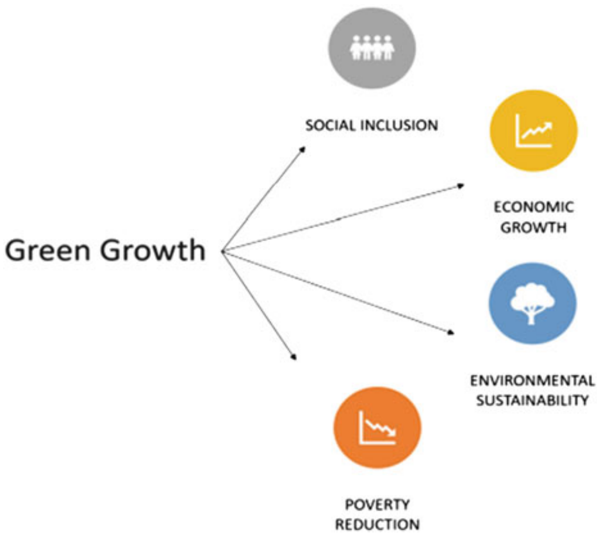

Fig. 17.5 Green growth pillars. (Source: Gupta et al. 2019a, b)

disaster losses are minimized. The plan encompass the strategy and action plan for making agriculture system and sector inculcate the concept of disaster prevention, mitigation and resilience through an integrated manner. It also utilize the opportunity of mainstreaming piece-meal endeavors of crisis management, relief, prediction – forewarning, risk mitigation, prevention and preparedness approaches for different disasters and climate risks/weather events.

17.7 Conclusions

Hydrological disasters are common due to large seasonal temperature variations. Because India's agriculture is completely reliant on natural weather and climate, this environmental issue will have a significant impact. Agriculture must adopt particular techniques to manage with the consequences of climate change and to survive climate change's weaknesses. Integrating DRR into policies and programmes is one of the technique for proper mitigation and preparedness. The development of the NADMP demonstrates the various steps involved in integrating CCA-DRR into sectoral plans, beginning with hazard, risk, and vulnerability assessments, multi-stakeholder engagement, policy and institutional support, implementation mechanism, and monitoring and evaluation framework. The NADMP's overarching purpose is to create a roadmap and a strategy to better understand the impact of climate change on agriculture-dependent populations and to generate knowledge for improved adaptation measures. It will also contribute to achieving the Sustainable Development Goals by eradicating extreme poverty (Goal no. 1.1), ending hunger through a sustainable food production system (Goal no. 2.4), and combating climate change impacts by strengthening resilience and adaptive capacity (Goal no. 13.1), all of which are based on the Paris Agreement, which was adopted at the COP 21 in Paris.

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Chapter 18
India's Health Adaptation Plan: Strategic Tool for Minimizing Disaster Related Losses and Damage

Anjali Barwal, Atisha Sood, and Anil Kumar Gupta

Abstract Climate change and natural disasters have serious consequences for human health across the world. Climate change, as well as climate-sensitive risks that result in disasters, have both direct and indirect health consequences. The most significant geophysical global climate change is the continuous rise in global temperatures. The incidence of extreme weather events or variations in temperature and precipitation are obvious direct results of climate change, but indirect impacts are more difficult to observe. Poor air quality and the ongoing COVID-19 pandemic has added emergent new dimensions to the public health crisis. The current healthcare system, facilities, and services seem to be insufficient and unprepared to cope with the evolving and multiplying risk scenarios. Disaster health implications are best addressed by enhancing health systems resilience through a well-designed systemic mechanism. The National Health Adaptation Plan for disaster related illnesses has been developed aiming for the resilient healthcare system and strengthening the existing knowledge gaps. This is a model approach which would help to minimize the disaster related losses and damage.

Keywords Disaster management · Climate change · Disaster risk reduction · Health adaptation plan · Resilience · Public health

18.1 Introduction

During the past decades, there has been increasing interest to understand the climate change and its impact on crop productivity (Das et al. 2020; Poonia et al. 2021a), and public health nexus (McMichael 2020). Climate change is becoming more dangerous as we learn more about its possible consequences for global health and security. Not only is our physical footprint, but also our carbon footprints, contributing to the

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spread of illness through habitat loss and ecological disturbance (Kilpatrick et al. 2017).

The changing climate is heavily impacting the health sector and aggravating several communicable and non-communicable diseases such as malaria, dengue, yellow fever, diarrhea, meningitis, asthma, heat stroke, heart diseases, lung cancer, etc. Many governments, regions, and cities throughout the world are currently implementing various plans and policies to adapt to and minimize the effects of climate change.

The burden to the health services would increase as climate change aggravates natural disasters that would cause social instability, physical damage, morbidity and mortality. Extreme weather events such as floods, droughts, cyclones, heat waves, cold waves, forest fires, poor air quality and food insecurity etc. in many parts of India are anticipated to worsen as the prevalence and range of infectious diseases rises, which would destruct the health infrastructures unless otherwise preventive measures taken ahead.

One challenge in preparing public health agencies has been identified as the fact that climate change is a relatively new concern, and frontline health workers in state and local agencies are unprepared to address the challenges posed by climate change due to a lack of knowledge, staffing, and capacity building required to facilitate climate change and health adaptation. For successfully incorporating resilience into socio-economic processes, it is also necessary to form partnerships between government agencies and important stakeholders while undertaking specific actions in the climate change and related disaster sectors (Barwal et al. 2021). The number of extreme weather occurrences has increased considerably during the last two decades, owing in part to rising global temperatures and other climate changes. There have been 7348 catastrophic natural disasters globally between 2000 and 2019, killing 1.23 million people and inflicting $2.97 trillion in global economic losses. It was also discovered in the report that Asia had the largest amount of extreme weather events, with 3068 over a 20-year span. Figure 18.1 shows that China had the most major natural disasters, with 577, followed by the United States with 467 and India with 321 disasters (Yale Environment360 2020).

18.2 Disaster Implicated Losses and Damage

People are grappling with the reality of climate change all over the world, which is manifesting itself in increased volatility of extreme weather occurrences in many parts of the globe. Disasters raise mortality and morbidity rates by causing injuries, toxic exposure, sickness, and mental health issues, among other things. Between 2000 and 2019, about 475,000 people died as a direct result of more than 11,000 extreme weather events., resulting in losses of US$ 2.56 trillion (Eckstein et al. 2021). By 2030, these costs are estimated to range between US$ 140 billion and US$

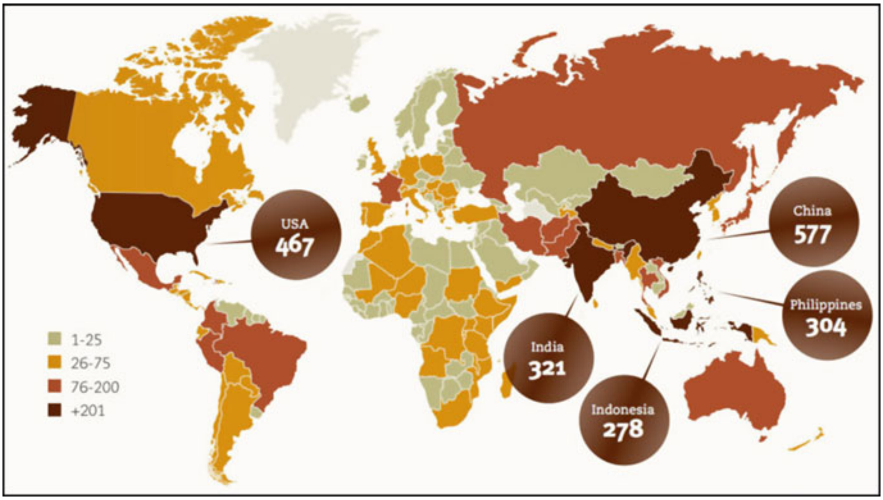

Fig. 18.1 Number of disasters reported per country during the period 2000–2019. (Credit: United Nations Office for Disaster Risk Reduction; Source: Yale Environment360 2020)

300 billion per year, rising to between US$ 280 billion and US$ 500 billion by 2050 (UNEP 2016) Climate financing needs for residual loss and damage in developing countries are now estimated to be between US$ 290 billion to US$ 580 billion in 2030. The Intergovernmental Panel on Climate Change (IPCC) estimates that the "mean net present value of the costs of damage from warming in 2100 for 1.5 °C and 2 °C, respectively, is US$ 54 trillion and US$ 69 trillion, respectively, relative to 1961–1990" in its Special Report "Global Warming of 1.5 °C." (Masson-Delmotte et al. 2018). This suggests that the funding shortfall for addressing climate-related risks and consequences is significantly worse than previously estimated. Figure 18.2 shows the world map of global climate risk index ranking of 2019.

Table 18.1 displays the ten most impacted nations (bottom 10) in 2019, together with their average Climate Risk Index score (CRI score) and detailed data for fatalities, losses in USD $, Losses per unit Gross Domestic Product (GDP) percentage and Human Development Index Ranking 2020.

The annual monsoon season, which generally lasts from June to early September, had an impact on India. The monsoon conditions in 2019 lasted a month longer than usual, with the excess rain creating significant hardship. Rainfall totalled 110 percent of average from June to September 2019, the highest since 1994 (Anupam et al. 2020). Heavy rains triggered floods that killed 1800 people and forced 1.8 million people to flee their homes across 14 states. The severe monsoon season impacted 11.8 million people, causing an estimated US$ 10 billion in economic damage. Additionally, 2019 was a year with the most active Northern Indian Ocean cyclone seasons with a total of eight tropical cyclones. Out of the eight, six cyclones augmented to being "very severe". Cyclone Fani, which struck in May 2019, was the deadliest, affecting a total of 28 million people and killing almost 90 people in

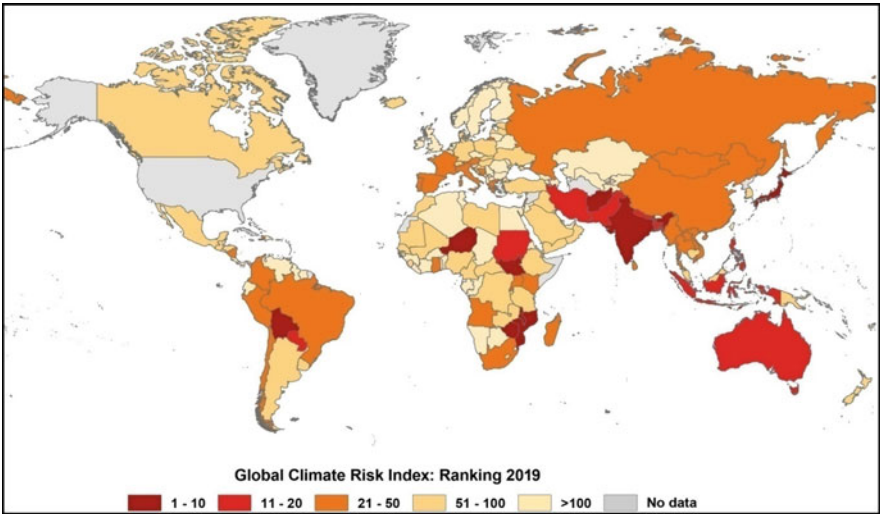

Fig. 18.2 Global Climate Risk Index Ranking 2019. (Source: Eckstein et al. 2021)

India and Bangladesh, as well as inflicting US$ 8.1 billion in economic losses (Mishra et al. 2020; Chauhan et al. 2021).

18.3 How Does Climate Change Affect Human Health?

Climate change has a variety of consequences, including an increase in the frequency and intensity of heat waves, a decrease in cold-related deaths, increased floods and droughts, changes in the distribution of vector-borne diseases, and effects on the risk of hunger and catastrophes. Even little variations in temperature and precipitation have a significant impact on disease transmission and the development of severe chronic diseases (Watts et al. 2019).

The overall balance of health implications is likely to be negative, with populations in low-income countries particularly vulnerable to severe repercussions. The health impacts of increasing heat are particularly severe among children, low-income households, those with preexisting illnesses, pregnant women, and the elderly. Rising temperatures may have an immediate impact on human gestational time, increasing the likelihood of preterm delivery and birth abnormalities making pregnant women more vulnerable to such climate extremes (Gupta et al. 2021a; Barreca and Schaller 2020).

Notably, the number of individuals exposed to yearly heat waves is increasing: 475 million additional vulnerable people were exposed to heat waves globally in 2019, considerably exceeding previous records (Watts et al. 2020).

Climate change affects people's health in a variety of ways (Fig. 18.3). Temperature and rainfall extremes, such as heat waves, floods, and drought, have both

Table 18.1 Top 10 countries affected by climate risks in 2019

Ranking 2019 (2018)	Country	CRI score	Fatalities	Fatalities per 100,000 inhabitants	Absolute losses (in million US$)	Losses per unit GDP in %	Human Development Index 2020 Ranking
1 (54)	**Mozambique**	2.67	700	2.25	4930.08	12.16	181
2 (132)	**Zimbabwe**	6.17	347	2.33	1836.82	4.26	150
3 (135)	**The Bahamas**	6.50	56	14.70	4758.21	31.59	58
4 (1)	**Japan**	14.50	290	0.23	28899.79	0.53	19
5 (93)	**Malawi**	15.17	95	0.47	452.14	2.22	174
6 (24)	**Islamic Republic of Afghanistan**	16.00	191	0.51	548.73	0.67	169
7 (5)	**India**	16.67	2267	0.17	68812.35	0.72	131
8 (133)	**South Sudan**	17.33	185	1.38	85.86	0.74	185
9 (27)	**Niger**	18.17	117	0.50	219.58	0.74	189
10 (59)	**Bolivia**	19.67	33	0.29	798.91	0.76	107

Source: Eckstein et al. (2021)

Fig. 18.3 Potential health effects of climate change and variability

immediate and long-term consequences on mortality. Flood-affected communities, for example, may see a persistent rise in prevalent mental illnesses. Climate change will undoubtedly have an impact on biodiversity as well as the ecosystem products and services that we depend upon for public health. Temperature and rainfall fluctuations may impact the spread of disease vectors, such as malaria and dengue fever, as well as the occurrence of diarrhoeal illnesses (Gupta et al. 2021b). Climate and weather have a major impact on the geographical and temporal distribution of air pollution concentrations. For instance, at increasing ambient temperatures, ozone and PM 2.5 precursor emissions rise (Gupta et al. 2021c; Kinley 2018). Rising sea levels are projected to endanger low-lying coastal towns, particularly in countries where economic limitations hinder the building of sea walls and other remedies. There are also fears that climate change-related flooding, drought (Kumar et al. 2021; Poonia et al. 2021b, c), and environmental degradation would result in greater human displacement and environmental refugees (Gupta et al. 2021d; Buchanan et al. 2020).

The worldwide development, recurrence, and redistribution of infectious illnesses globally is being more influenced by a warming and unpredictable environment (El Samra 2019). Many of the most prevalent infectious illnesses, especially those spread by insects, are extremely sensitive to changes in climate (Caminade et al. 2019). Dengue fever, malaria, hantavirus, and cholera are among the new and resurgent vector-borne infectious illnesses (Bordoloi and Saharia 2021). Other infectious illnesses, such as salmonellosis, cholera, and giardiasis, may see an upsurge in epidemics as a result of the warmer weather and flooding (Anas et al. 2021) As a result, long-term cooperation are required to create Early Warning Systems (EWS) for infectious illnesses that take climate change into account (Morin et al. 2018).

18.4 Strategic Tools Addressing Health Adaptation

The public health adaptation plans are the possible strategies by which communities can address anticipated, current and future climate change related disasters and threats to public health.

The United States Centers for Disease Control and Prevention's (CDC) Building Resilience Against Climate Effects (BRACE) program developed a five-step process for health officials to develop strategies and programs to help communities prepare for the health effects of climate change related disasters (CDC, Climate & Health 2021). These five steps represented in Fig. 18.4.

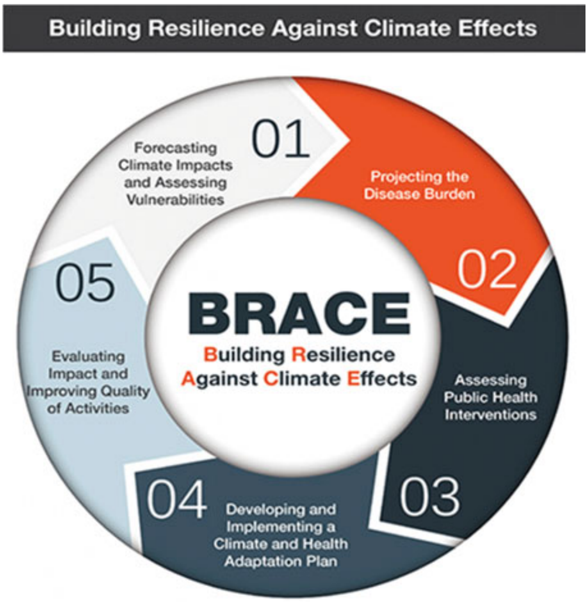

Fig. 18.4 CDC's Building Resilience Against Climate Effects (BRACE) framework. (Source: CDC, Climate & Health 2021)

18.4.1 Need for a Strategic Tool

Climate change has a significant impact on the burden of diseases and other public health issues that the country faces. There is a need to evaluate, prioritize and implement the health adaptation interventions and activities through existing national policies and programmes, rather than as an independent process.

National public health programmes are already in place in most nations to limit the burden of water and vector-borne diseases, as well as other ailments (e.g. national malaria control programmes, maternal and child health programmes, nutrition, water, sanitation and hygiene programmes etc.). It is the time for every country to implement climate change adaptation policies and programmes that are integrated into specialized public health programmes. As a result, at the operational level, strategies and measures to enhance resilience through these programmes must be adopted (WHO 2014).

18.4.2 Global Context

Heat waves are one of the major weather-related causes of death in the United States. The New York City Panel on Climate Change (NPCC) applied the most up-to-date international climate models at the time to assess the threat of future extreme heat events, indicating that the number of heat waves could increase from two to seven per year by 2050. New York City is currently refining its climate projections in order to better assess climate vulnerability using the most up-to-date science and policy programmes.

In Canada, the Climate Change and Health Adaptation Program (CCHAP) supports one programme in the south and one in the north. The CCHAP funds community-based research and adaptation programmes in areas such as water quality, land-based activities, food security, mental health, and traditional medicines, among others (Richards et al. 2019).

National-level public health adaptation to climate change in ten OECD countries aimed to address the health hazards, types of adaptation initiatives, establishment of inter-sectoral schemes, and state of national level health adaptation planning. National government adaptation initiatives in OECD Countries are shown in Fig. 18.5. Most of these countries have reported >10 initiatives are of planning or implementing some adaptation types. The United States and United Kingdom reports the similar groundwork vs. adaptation initiatives (Austin et al. 2016).

For more than 25 years, the World Health Organization has been working on climate change and public health, building on its extensive experience in assisting countries in building health system resilience and facilitating system modifications to reduce the health risks posed by climate variability and change (WHO 2014).

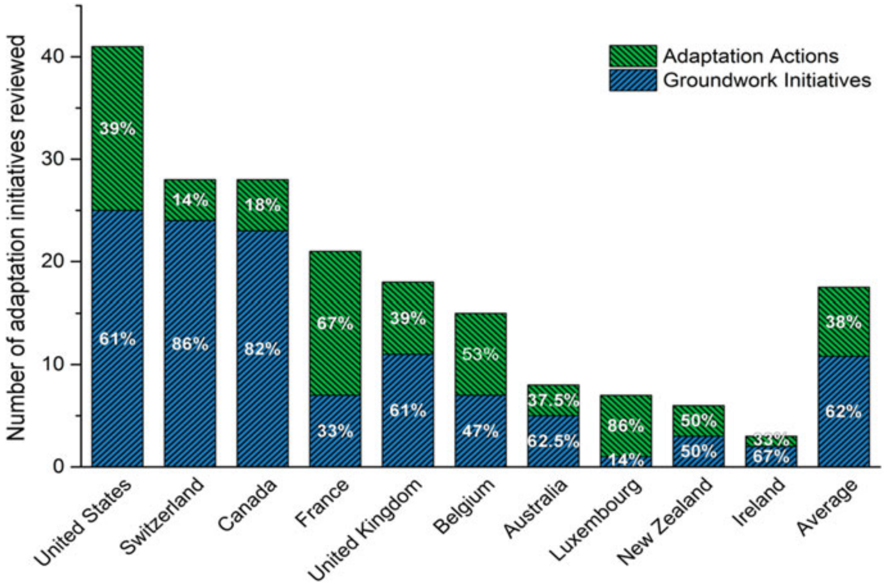

Fig. 18.5 Percentage of groundwork initiatives and adaptation actions by OECD countries. (Source: Austin et al. 2016)

18.4.3 Indian Context

It is more important than ever to plan ahead for communicable diseases epidemics, whether they occur naturally or as a result of bioterrorism. Any such epidemic poses a threat to national and international security, as well as the risk of causing a public health emergency. To deal with such a public health catastrophe, legal frameworks, protocols, and Health Adaptation Plans (HAP) must be prepared and implemented. This can help to define the scope of healthcare professionals' and the government's interventions to public health emergencies (Sood et al. 2020).

Climate change is also posing significant health risks in India. The diverse climatic conditions and unbalanced socio-economic development in different geographic areas of the country, it is critical for public health decision-makers, service providers and community members to perceive the impacts of climate-sensitive diseases from climate change, recognize the most vulnerable populations and project futuristic impressions on population health under various climatic and demographic change scenarios, and most importantly, develop and implement climate sensitive disease prevention and control strategies at all levels.

The National Health Adaptation Plan (NHAP) has been developed in India to create enabling environment, build the capacity of climate resilient healthcare system; help institutions strengthen their preparedness, enhance the health system resilience in terms of universal health coverage; early warning, surveillance and

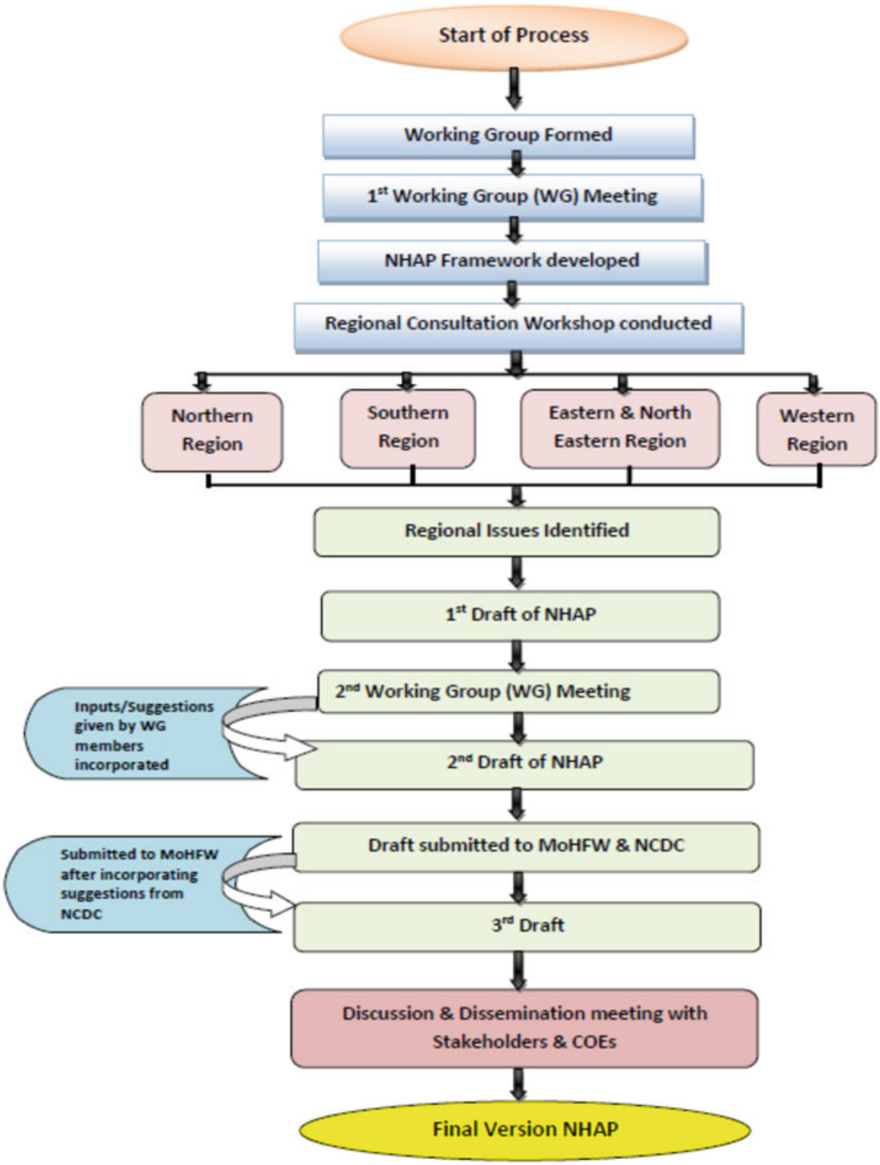

Fig. 18.6 Methodology adopted for drafting the National Health Adaptation Plan

community mobilization in the context of health emergency risk management. The methodology adopted for drafting the NHAP is mentioned in Fig. 18.6.

The primary intervention areas to implement NHAP are strengthening and expanding health infrastructure, identifying and assessing health hazards and vulnerabilities associated with climate change related disasters, building human

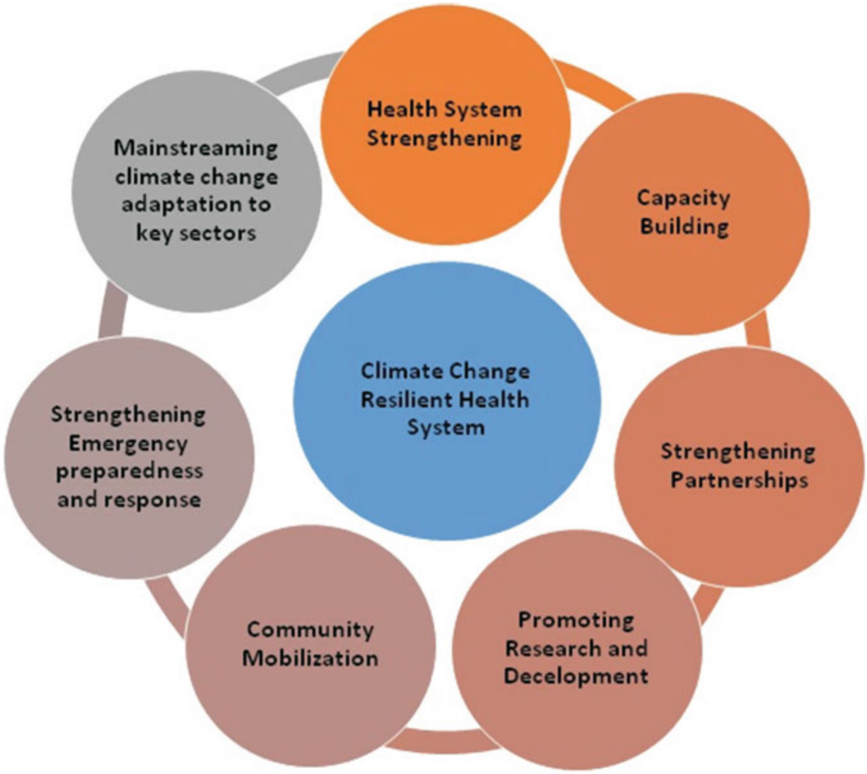

Fig. 18.7 Seven-pronged strategic approach to develop a climate change resilient health system

resource capacity through policy planning, advocacy, research, training, education and knowledge management, promoting climate resilient water and sanitation facilities, revising building codes of health facilities, promoting community health insurance scheme, advocating and creating awareness on climate change and health as well as encouraging research and development programmes on health and climate change.

The NHAP proposes a seven-pronged strategic approach to achieve its goal of developing a climate change resilient health system (Fig. 18.7).

18.5 Conclusion

As a result of continuous climate change, extreme weather-related phenomena such as floods, droughts, cold and heat waves, and others are expected to become more frequent and severe, it is necessary that more attention be paid to the issue of loss and damage. Health practitioners must be properly trained to diagnose, treat and prevent climate-related illnesses due to the potential severity of diseases linked to climate change. COVID-19's global pandemic has eloquently highlighted that our health system and society as a whole should be prepared to deal with unexpected health impacts of climate change and extreme events. Climate change necessitates mitigation, adaptation, and policy development for changing the existing framework. Health system strengthening and capacity building of health professionals could be the most vocal advocates for climate change education, since they foresee the uncertainties of future health effects on humans in a rapidly changing environment.

In the current scenario, there is a need to integrate the systems to develop a common database that serves as an important policy and decision making tool. The health facilities need to strengthen their surveillance systems to monitor food, air and water quality, vector breeding, malnutrition and other risk factors and behaviors, which make the community more vulnerable to the consequences of climate-related calamities. Furthermore, in order to build effective mitigation and adaptation methods, information gaps must be addressed.

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