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Climate Change Impacts in India

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ISSN 2730-6674 ISSN 2730-6682 (electronic)
Earth and Environmental Sciences Library
ISBN 978-3-031-42055-9 ISBN 978-3-031-42056-6 (eBook)
https://doi.org/10.1007/978-3-031-42056-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Preface

This book deals with the Climate Change impact on India, environment problems and climate change impact analysis and discusses the related resulting mitigation process. Soil capability, soil erosion, soil salinity and watershed planning, groundwater and climate change impact on the water resources involve important parameters from the nearby areas where climate change, soil erosion, and natural resources and farm practices direct or indirect contact with the water, vegetation, irrigation planning and environment present. This book summarizes the various aspects of climate change impacts on soil erosion, soil compaction, soil nutrients, water resources agriculture and their sustainable yield for the development of the communities taking into account sustainable development and management for India's future. A special attention was given to sustainable crop yield, agriculture practices, drone use in agriculture, Google Earth Engine Application in climate, vegetation and water resources, crop pest and diseases planning, biomass estimation, natural resources and agricultural region along with the capacity and flexibility of water resources, and agricultural societies under climate change challenges. The more important topics such as land use change analysis, rainfall, crop yield, sustainable agriculture development, pest and diseases etc. were included for understanding of the climate change impacts that can impacted by climate change impact are discussed. No doubt, the covered topic will be useful to help policy planning, decisionmakers and stakeholder to face climate change impacts by adaptation and/or mitigation. The book is divided into four parts including (1) Introduction, (2) Impact of Climate Change and Water Resources, (3) Impact of Climate Change on Agricultural, (4) Conclusion.

The first part contains three chapters. In the first chapter, we present an "Introduction to Climate Change Impact on India" to show the importance of the volume. While in the chapter titled "Climate Change Effect On-Climate Parameters Like Temperature, Rainfall and Water Resources Sectors in India", the authors present an overview about the climate impact on India. This chapter focuses on the Climate change effect on the on-climate parameters like Temperature, rainfall and water resources sectors in India. The information presented in this chapter can support the stakeholders to achieve sustainable goal development in 2030. The information presented in the two chapters is a valuable overview of climate change effect on India and presents an introduction to the book.

Four chapters are presented in part two to focus on the impact of climate change on water resources. The chapter titled "Externalities of Climate Change on Urban Flooding of Agartala City, India" identifies the causal interference of urban flooding in the city of Agartala and explores technical strategies for managing urban flooding in Agartala and minimizing the damages due to floods for mankind. While the chapter titled "Natural Resource Planning Under Climate Change Issue Using Advanced Remote Sensing and GIS Technology: A Review" provides an overview of some of the very broad themes in natural resource management for in-depth analyses of natural resources under climate change scenarios. Additionally, the chapter titled "Self-Generating Training Model (SGTM) Algorithm to Estimate Groundwater Level in Consensus with Climate Change Impact Study in Cauvery Delta Zone, Tamil Nadu, India" investigates the connection between the climate change impact and rainfall variability where the temporal trends of rainfall variability are studied extensively to predict the future scenario using the Self-Generating Training Model (SGTM) algorithm. The last chapter in this part is titled "Impact of Climate Change on Climate and Water Resources and Thus on Agriculture in India" discusses the integration of agro-climatological such as crop-soil-water balance simulations and agrometeorological results such as crop-soil-weather modelling is critical to achieve sustainability in agriculture. Issues related to climate change form part of agro-climatological studies. Part III deals with "Impact of Climate Change on Agricultural" in 12 chapters. The chapter titled "Assessment of Climate Change Impact on Agricultural Crops' Growth and Yield Over Indian Subcontinent Using Remote Sensing, GIS and Modelling Approach" focuses on the use of remote sensing satellite data in coupling with a crop-growth simulation model and a data assimilation approach to monitor the crop development and grain production. While the chapter titled "Monitoring of Natural Resources Using Remote Sensing and GIS Technology Under Changing Climate Scenario" presents comprehensive review on the use of the integration of remotely sensed data, GPS, and GIS to monitor the land resources and which is helpfult to an enable different stakeholders to develop management and protection plans for different natural resources to cope with the changing climate condition.

Additionally, the chapter titled "Climate Change: Its Impact on Land Degradation and Plant Nutrients Dynamics" focuses on land degradation and soil nutrient dynamics as a result of climate change as both of them are equally important from the food and ecological sustainability viewpoint. While the chapter titled "Climate Change and Its Impact on Soil Carbon Storage: An Indian Perspective" conveys sound understandings of land quality and soil C status of India for better implementation of mitigation strategies to combat the adverse impact of climate change. On the other hand, the chapter titled "Potential Impacts of Climate Change on the Sustainability of Crop Production in the West Bengal, India" discusses how the climate change affects the physical and chemical properties of the soil and hence reduction of the soil fertility and hence lower crop production and highlights the importance of using the technology to reduce the impact of climate change on soil and crop productivity in the West Bengal of India.Furthermore, the chapter titled "Potential Impacts of Climate Change on the Sustainability of Crop Production: A Case in India" focuses on the impact of changing climate on India's crop production sustainability indicating that measures and action should be considered to sustain the crop production in India in the changing climatic conditions.

The chapter titled "Elucidating Revival Measures to Extenuate Expanse of Fallow Lands and Climate Change: An Empirical Analysis of Jharkhand" aims to delineate broad characteristics of different 'agro-climatic zones' of India, explore rainfall trend & climatic effects, analyse irrigation & extent of fallow lands of households, go into reasons for leaving land fallow and suggest observation-based action points. Moreover, the chapter titled "Potential Impact of Changing Climate on the Sustainability of Potato (*Solanum Tuberosum* L.) Production in India" presents the impact of climate change and its consequences on the production of potato in India. Additionally, the chapter titled "Building Climate Resilient Agriculture in the Indian State of Assam in Foot Hill Himalayas" discusses several vital important adaptations strategies for building climate-resilient agriculture in Assam. Furthermore, the chapter titled "Effect of Nutrient Management on Production Potential and Energy Budgeting of Soybean-Based Crop Sequences" presents the results of an experimental investigation at MPKV, Rahuri, Maharashtra to study the response of nutrient management on productivity and profitability of soybean-based cropping systems. Added to the above-presented chapter, a chapter titled "Monitoring Agriculture Land Use and Land Cover Changes of Rahuri Region, (MS), India Using Remote Sensing and GIS Techniques" is devoted to identify changes in agriculture and non-agricultural land over the years from 2015 to 2019 in the Rahuri region using remote sensing technology. The final chapter in this part titled "Climate Effects of Sea Levels Rise Change on Vulnerability in the Coastal Area of Nagapattina in India" discusses how the ocean level ascent and its effects cause environmental change along the waterfront zone of Nagapattinam. The last part has one chapter titled "Conclusions" to highlight the most important conclusions of the book and At this point, the editor ensure the book has invaluable strategies for facing situation of the climate change impact in India to help policy planners and stakeholders to develop the necessary plans for fighting the climate changes impacts and how to reduce its negative impacts on different sectors particularly water and agriculture sectors in India.

This book is a compilation of chapters from multi-disciplinary experts who are involved in the various aspects of climate changes impact on groundwater quality, hydrological process, pollution mitigation strategies techniques, sustainable development, planning and management. They belong to various organizations including Smt. Shahenaz Mulla (India Meteorological Department, Pune, India), Vinay Kumar Gautam (Department of Geography and Disaster Management, Tripura University, Department of Soil and Water Engineering, College of Technology and Engineering, MPUAT, Udaipur—313001, Rajasthan, India), Senthil Kumar (School of Science and Humanities, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai 600 062), Dr. S. Jeevananda Reddy (Tamil Nadu, India, Formerly Chief Technical Advisor—WMO/UN & Expert—FAO/UN Fellow, Telangana Academy of Sciences [Founder Member], Convenor, Forum for a Sustainable Environment Hyderabad, TS, India), Agniva Mandal (Department of Agricultural Chemistry and Soil Science, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur-741252, West Bengal, India), S. K. Sadikur (Department of Horticulture, Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh), Kousik Atta (Department of Plant Physiology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India), Dr. Rajiv Kumar Sinha (Agro-Economic Research Centre for Bihar & Jharkhand", T. M. Bhagalpur University, Bhagalpur—812007(Bihar), Prasanta Neog (Department of Agrometeorology, BN College of Agriculture, Biswanath Chariali, Assam 784176), Chaitanya B. Pande (India and Indian Institute Tropical Metrology, Pune). The first editor want to thank the Editor of the series (Prof. Abdelazim Negm) for his support during all the stages of the book production including the review of the draft of all chapter.

Pune, India — Chaitanya B. Pande
Jaipur, India — Kanak N. Moharir
Zagazig, Egypt — Abdelazim Negm

Acknowledgements Also, the first editor appreciate the help, support, advice, and review process provided for the proposal and the drafted chapters by the series editor.

Contents

Impact of Climate Change on Agricultural

Introduction

Introduction to Climate Change Impact on India

Chaitanya B. Pande, Kanak N. Moharir, and Abdelazim Negm

Abstract Climate Change impact on the India, environment-problems, and climate change impact analysis discuss the related resulting mitigation process. Soil capability, soil erosion, soil salinity and watershed planning, groundwater and climate change impact on the water resources involve important parameters from the nearby areas where climate change, soil erosion, and natural resources and farm practices direct or indirect contact with the water, vegetation, irrigation planning and environment present. India is under semi-arid region, and most of the land depends on the rainwater with 70% population in India located in the rural area. In this view, climate change factors are most affected by human, environments and agricultural crops. The main objective of this book everyone could be understood which area more affected by climate change, however which plans and management reduce the effect of climate change parameters. The main challenges we will look at in the directive to familiarize us with the effects of climate change in the twenty-first century will be defined.

Keywords India · Semi-arid region · Climate change · Impact

1 Introduction

Climate change has been imaginatively defined as a "vicious" problem because there is no clear definition, there is great scientific ambiguity, and the suggested solutions are confounded by the fact that they are ingrained in social, governmental, and market economies [1]. Nowadays, climate changes have dramatic changed in the overall

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_1

global environment, water, air and agriculture production system, everyone realizes the so many changes in the rainfall pattern and disaster activities are increasing the entire world [2]. Hence, whole countries governments, NGO and science organizations should take action on the monitoring, planning and reducing the climate change policy in entire world. Otherwise, after some years would be major problems created due to climate changes and anthropogenic activates [3]. While a few people view climate change as an issue of the nature, others see it as mainly a matter of fairness and equity, while still others see it as mainly a financial and scientific problem. Variations in interpretation further complicate disparities in interests. In this area most of the land is semi-arid regions, most of the summers time many state are facing drought problems and reducing crop production due to climate change and unpreditiable climate with monsoon season [4].

In comparison to “tame” issues, even for the research problem is unclear, making it challenging to discuss and argue climate change [5], action on climate change proceeds at a glacial pace, seemingly embedded in endless and protracted debate. From an Indian viewpoint, the difficulties of contributing to the climate change discussion are exacerbated for both practical and political reasons. On a practical level, India must overcome massive and urgent obstacles to elevate its people out of poverty, provide access to basic necessities such as energy, water, free air pollution cities, foods and sanitation, and solve governance issues like corruption and intercommunal strife [6, 7]. By comparison, climate change appears less immediate, less certain, and, therefore, less of a priority. Politically, there is a long-standing perspective that India has contributed relatively little to causing the climate issues and should not be asked to be in the forefront of solving it. India’s contribution to the stock of emissions that has built up in the atmosphere is low (4% from 1950 to 2019), and its emissions per person are far lower than the global average [8, 9]. Indian agriculture emanates about 0.23% and Climate change will be significant and dwindle agriculture. Komuscu et al. [10] suggested a raising of 4–43% soil water deficit by experiencing the warming (2 °C), 8–91% (4 °C) according to Thornthwaite’s water-balance model plus boosting of evapotranspiration of hydrological simulation model. The land is a fixed resource for agriculture, but increased food demand (yield per land) can be fulfilled by the precise use of water, energy, time management, and farm level adaptation. Chung [11] estimated that during year 2070–2099, the projected mean temperature is likely to increase by 1.1 and 1.6 °C which ultimately will reduce mean precipitation by 30%, these facts resulted a remarkable 16% reduction in agricultural field [12–16]. It is also confirmed that 1–2 °C increase of temperature under climate change effect will benefit and at 2 °C effects will be completely inverted [17–22]. The remaining portion of this “Introduction” is a useful starting point for each of the following parts. I explain the contributions’ theoretical underpinnings, place them in their proper historical and cultural contexts, and show connections between chapters.

2 Sections of the Book

This book is call for chapter into four sections: (I) Introduction; (II) Impact of Climate Change and Water Resources (III) Impact of Climate Change on Agricultural (IV) Conclusion.

Eighteen chapters have been discussed in this above sections. In this chapter discussed about the climate change impact on India, which are introduction of this book. The second chapter has been discussed on the climate change effect on the on-climate parameters like Temperature, rainfall and water resources sectors in India. In this chapter, more important discussion on the Indian climatology and climate change impact on the natural resources, climate and water resources. Third type of chapter discussed on the appraisal of climate change studies of arid regions Involving weather variables. The fourth chapter has been explained related to urban flooding due to climate change parameters, which factors play an important role on the externalities of climate change on urban flooding of Agartala City, India. Fifth chapter have included the most important topic of natural resource planning under climate change using advanced remote sensing and GIS technology: A Review. The sixth chapter is related to training model algorithm. This chapter title is a self-generating training model algorithm to estimate groundwater level in consensus with climate change impact study in Cauvery Delta Zone, Tamil Nadu, India. The seven chapter have been discussed on the Impact of Climate change on Climate & Water Resources and, thus on Agriculture in India and rainfall is the primary source [as well snow melting] for water availability in India. In India, both rainfed and irrigated agriculture are being practiced. The former relates to "in-situ" and the later "ex-situ" (river basin) rainfall. India being a tropical country, temperature is not a limiting factor for agriculture but increased levels of evapotranspiration during drought years play an important role based on the crop season. The eighth chapter focuses on the climate change impact on the cropping production in India. Now, a day's climate change is continuing to directly affect Indian agriculture and crop production. Hence, chapter eight discusses more details on the assessment of climate change and its impact on growth and yield of agricultural crops over Indian subcontinent using remote sensing and modeling approach. The ninth chapters are related to monitoring natural resources using remote sensing and GIS technology under changing climate scenarios. The teen number chapter more important discussion on the impact of climate change on nutrient dynamics in Indian soils, which climate factors more affected on the nutrient in the soil and reducing fertility of soil in the India. The eleventh chapter discusses the soil carton storage and land degradation effect due to climate changes, authors have been details discussion on the climate change and its impact on land degradation and soil carbon storage: An Indian perspective. Chapter twelve presents the potential impacts of climate change on the sustainability of crop production in West Bengal, India. The thirteen-chapter important discussion on the Potential Impacts of climate change on the Sustainability of Crop Production: A case in India. The fourth-teen chapter introduced the Elucidating Revival Measures to Extenuate Expanse of Fallow Lands & Climate Change: An Empirical Analysis of Jharkhand.

The fifteenth chapter detailedly explained the potential impact of climate change on Potato crop cultivation in India. The sixteenth chapter disused on the northeast problems because always facing climate change problems during two decades and details discussed on the Building climate resilience in Assam, a state of India situated in the foot hill Himalayas. The seventeenth chapter introduces rainfed crops of soybean and what effect of nutrient management on production potential and energy budgeting of soybean-based crop sequences. The eighteen chapter includes the conclusion and recommendation for sustainable development goals and climate change policy.

3 Chapters of the Book

In this book four parts such as, Introduction, Impact of Climate Change on Agricultural, Impact of Climate Change and Water Resources, Conclusion. Therefore twenty chapter collected on the related to climate change, water resources, climate change impact analysis, climate change impact water resources and agricultures.

References

1. Hulme M (2009) Why we disagree about climate change: understanding controversy, inaction and opportunity. Cambridge University Press, Cambridge
2. Kandekar VU et al (2021) Surface water dynamics analysis based on sentinel imagery and Google Earth Engine Platform: a case study of Jayakwadi dam. Sustain Water Resour Manag 7:44. https://doi.org/10.1007/s40899-021-00527-7
3. Shahid M, Rahman KU, Haider S et al (2021) Quantitative assessment of regional land use and climate change impact on runoff across Gilgit watershed. Environ Earth Sci 80:743. https://doi.org/10.1007/s12665-021-10032-x
4. Pande CB, Kushwaha NL, Orimoloye IR et al (2023) Comparative assessment of improved SVM method under different kernel functions for predicting multi-scale drought index. Water Resour Manage.https://doi.org/10.1007/s11269-023-03440-0
5. Steffen W, Rockström J, Richardson K, Lenton TM, Folke C, Liverman D, Summerhayes CP et al (2018) Trajectories of the earth system in the Anthropocene. Proc Natl Acad Sci 115(33):8252–9. https://doi.org/10.1073/pnas.1810141115.
6. Pande CB, Moharir KN, Singh SK, Varade AM, Ahmed Elbeltagie SFR, Khadri PC (2021) Estimation of crop and forest biomass resources in a semi-arid region using satellite data and GIS. J Saudi Soc Agric Sci 20(5):302–311
7. Pande CB, Moharir KN (2021) Groundwater resources development and planning in the semi-arid region, vol 1. Springer, Cham, pp XIV, 571.https://doi.org/10.1007/978-3-030-68124-1
8. Orimoloye IR, Olusola AO, Belle JA et al (2022) Drought disaster monitoring and land use dynamics: identification of drought drivers using regression-based algorithms. Nat Hazards. https://doi.org/10.1007/s11069-022-05219-9
9. Pande CB, Kadam SA, Jayaraman R, Gorantiwar S, Shinde M (2022) Prediction of soil chemical properties using multispectral satellite images and wavelet transforms methods. J Saudi Soc Agric Sci 21(1):21–28

10. Komuscu AU, Erkan A, Oz S (1998) Possible impacts of climate change on soil moisture availability in the southeast Anatolia development project region (GAP): an analysis from an agricultural drought perspective. Clim Change 40:519–545. https://doi.org/10.1023/A:1005349408201
11. Chung CE (2006) Weakening of north Indian SST gradients and the monsoon rainfall in India. AMS J Clim 19(10):2036–2045. https://doi.org/10.1175/JCLI3820.1
12. Khadri SFR, Pande C, Moharir K (2013) Groundwater quality mapping of PTU-1 Watershed in Akola district of Maharashtra India using geographic information system techniques. Int J Sci Eng Res 4(9)
13. Pande CB (2020) Thematic mapping for watershed development. In: Sustainable Watershed Development. Springer briefs in water science and technology. Springer, Cham. https://doi.org/10.1007/978-3-030-47244-3_3
14. Patode et al (2017) Planning of conservation measures for watershed management and development by using geospatial technology–a case study of Patur watershed in akola district of Maharashtra. Curr World Environ 1(10). https://doi.org/10.12944/CWE.12.3.22
15. Moharir et al (2014) Analysis of morphometric parameters using Remote-sensing and GIS techniques in the lonar nala in Akola district Maharashtra India. Int J Technol Res Eng 1(10):1034–1040
16. Pande CB, Moharir KN, Khadri S (2021) Watershed planning and development based on morphometric analysis and remote sensing and GIS techniques: a case study of semi-arid watershed in Maharashtra, India. In: Groundwater resources development and planning in the semi-arid region. Springer, Cham. https://doi.org/10.1007/978-3-030-68124-1_11
17. Lele S, Srinivasan V, Thomas BK, Jamwal P (2018) Adapting to climate change in rapidly urbanizing river basins: insights from a multiple-concerns, multiple-stressors, and multi-level approach. Water International. https://doi.org/10.1080/02508060.2017.1416442
18. Khosla R, Dukkipati S, Dubash NK, Sreenivas A, Cohen B (2015) Towards methodologies for multiple objective-based energy and climate policy. Econ Pol Wkly 50(49):49–59
19. Gunathilake MB, Amaratunga YV, Perera A, Chathuranika IM, Gunathilake AS, Rathnayake U (2020) Evaluation of future climate and potential impact on streamflow in the upper nan river basin of Northern Thailand. Adv Meteorol 8881118
20. Rathnayake U (2015) Migrating storms and optimal control of urban sewer networks. Hydrology 2(4):230–241. https://doi.org/10.3390/hydrology2040230
21. Chathuranika et al (2022) Implementation of water-saving agro-technologies and irrigation methods in agriculture of Uzbekistan on a large scale as an urgent issue. Sustain Water Resour Manag 8:155. https://doi.org/10.1155/2021/4913824
22. Ekanayake et al (2021) Regression-based prediction of power generation at samanalawewa hydropower plant in Sri Lanka using machine learning. Math Probl Eng 1–12 ArticleID 4913824. https://doi.org/10.1155/2021/4913824

Climate Change Effect On-Climate Parameters Like Temperature, Rainfall and Water Resources Sectors in India

Shahenaz Mulla, Rizwan Ahmed, K. K. Singh, Sudhir Kumar Singh, Naseem Deshmukh, and F. Kurne Inamdar

Abstract Climate change is currently the world's most serious environmental and meteorological challenge. Climate change has a negative impact on agriculture, water resources, forests, health, biodiversity, ecology, socioeconomics, and coastlines. Agriculture is the most vulnerable to climate change, and it is India's backbone, with 70–80% of the population relying solely on rainfed crop production for food. In the unprecedented increasing population, urbanization, industrialization creating additional stress and facing pressure with limited sources of water demands. Adaptation strategies must be designed to accommodate climatic and non-climatic stress for existing anthropogenic driven beyond climate change control. Climate change is the foremost environmental challenge associated with climate variability. It is impact on the decline of agricultural production and crop areas, to fulfil increasing food demand, water resources, forest and biodiversity, health, coastal management, ecological, socioeconomic (rapid industrialization, urbanization, economic development and increase in temperature). Climate change or climate variability also brings a susceptible epidemic pests and diseases over Indian continents. Stamping out the poverty thereby rendering good living standards and basic amenities (food, water and shelter) to Indian citizens is India's utmost task. India has a target of mitigation towards less emission of GHG.

Keywords Climate change · Meteorological · Climate parameters · Temperature

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_2

1 Introduction

Mega-droughts, wildfires, flooding, extreme heat or extreme weather events, melting of glaciers, sea level rise etc. are growing parts of our planet uninhabitable. Climate change is a worldwide issue facing by all countries. There are many clear evidences of climate change noted with concerned to meteorological and environmental observations and has already accelerated over Indian region. Under global warming scenario (by 1.5 °C) climate change effects observed by almost all regions in India. This effect in the field of water resources, biodiversity, ecology, health issues, threat for loss of life and property, coastal management, agriculture, land management, food security, GHG in ecosystem, occurrences of extreme weather events, declining of ISM, land degradation (detrimental soil quality), desertification, socio-economical stress in form of unequivocal rapid urbanization (heat island) and industrialization. Tackling the adverse effects of climate change is a great challenge and a threat to scientific, agronomist, meteorologist communities and to all mankind.

Agriculture, the backbone of country, most climate-sensitive and susceptible to climate inconsistency and predictability. Hence, it is, noteworthy to know the important climate-sensitive elements like agriculture, forestry, fishery for livelihood, poverty alleviation, preparation for mitigation and adaptation strategies. Predictable changes in agricultural, ecological droughts are based on soil moisture analysis. The land–ocean-atmosphere-cryosphere interaction on regional level varies over timescale and space in addition to human anthropogenic activities that influences the regional climate. Changes in global surface temperature at an instant is due to its substantial natural variability or by earth's climate fluctuations on planetary scales (orbital changes) plus volcanic eruption. Earth's mean climate is balance between incoming and outgoing solar insolation, energy budget, anthropogenic (human-caused) emissions of greenhouse gases (GHGs), aerosols and changes in land use and land cover (LULC) [1–5].

Impact is discernible increases in an intensity and occurrences of extreme weather events viz. heatwaves, heavy rainfall, super cyclones, droughts (agricultural, ecological, meteorological and hydrological). These results are accomplished with projected climate model for various RCP scenarios. Since pre-industrial era (1850–1990) up to latest decade (2010–2019), increased in anthropogenic (GHG) have enhance global temperature to 1.09 °C, over ocean 0.99 and over land by 1.59 °C i.e. land surface will continue to warm more than the ocean surface and Arctic and will be continued to warm more than (3 times) to global surface temperature. Further, evidences showed that most of the warming (0.1 °C/decade), observed over the last 50 years, attributable to human activities [6]. GHG concentration (the main drivers) are responsible for climate changes are amplified to 19 ppm for CO_2, 63 ppb for CH4 and 8 ppb for N_2O since year 2011 by contributed warming of 1.0 °C to 2.0 °C and internal variability by −0.2 to 0.2 °C. Since 1979, these well-mixed aerosols (GHG) are the main reason for tropospheric warming and cooling of lower stratosphere (stratospheric ozone depletion). Other the human driver aerosols contributed the cooling range 0.0–0.8 °C. Under increasing global warming and enhanced extreme weather events has degraded land, deteriorated or shifted the cultivational crop areas, season and precipitation alteration, water scarcity etc. are still uncertain in magnitude for every region in India and attributed to climate change impacts in India. Orographic features render spatial variability with heaviest rainfall along western ghats, Himalayan foot hills during Indian Summer monsoon rainfall and over central India due to low level convergence zone.

Deepen understanding of climate change risk, overcome its knowledge gap (spatial/temporal scales), counteract the negative impact, development of policy decision, mitigation/adaptation of new strategies is continuously under progress in India. A step towards improvement and to overcome uncertainties of climate change according to climate model, framing and implementation of policy decision, mitigation adaptation strategies over Indian subcontinents is briefed in this chapter. Present topic also described historical weather analysis and projected estimates of meteorological parameters by climate models such as temperature, precipitation, water resources etc. Review of articles related to global warming over Indian continents becomes important point for well preparedness in over India. India, the developing country distinguishing and understanding pattern and magnitude of natural variation or anthropogenically force, is still in exploring. Indian Institute of Tropical Meteorology (IITM), Pune has initiated a step towards climate change study by establishing the Earth System Model (ESM) in the Centre for Climate Change Research (CCCR) in the Indian Institute of Tropical Meteorology (IITM), Pune (Swapna et al. 2018). Earth's climate system has demonstrably changed on global and regional scales since the pre-industrial era.

2 Global Climate Change

It is unprecedented from observations that global warming is to continue. The world is hurtling towards 1.5 °C temperature rise up to the year 2040. Figure 1 shows huge wide-scale devastation of present temperature(1.09 °C) rise since 1880s (Industrial Revolution times) needs to understand, how dire climate change happening. The Global Mean Surface Temperature (GMST) comprising of global land surface air temperature (LSAT) and sea surface temperature (SST), are key points of climate change which extended farther than any other global instrumental series.

At 1 °C increase in the temperature, projected atmospheric water content will have increased by 6–7%. Further, 1.5 °C increase may enhance atmospheric moisture by 09–10% has major impact on storm formation subsequent rainfall which is concluded in Clausius-Clapeyron relationship. Global warming, water cycle is positively correlated with updraft, hail size, heat wave but negatively correlated with precipitation (Berthed et al. 2010). In tropical belts, the summer hemisphere has 90% lightening and the winter hemisphere accounts for 10% over warm ocean currents (Gulf stream and Mediterranean Sea). Almost 75% lightening occurs in tropical region during late afternoon and evening. London city is probable to face more climate change

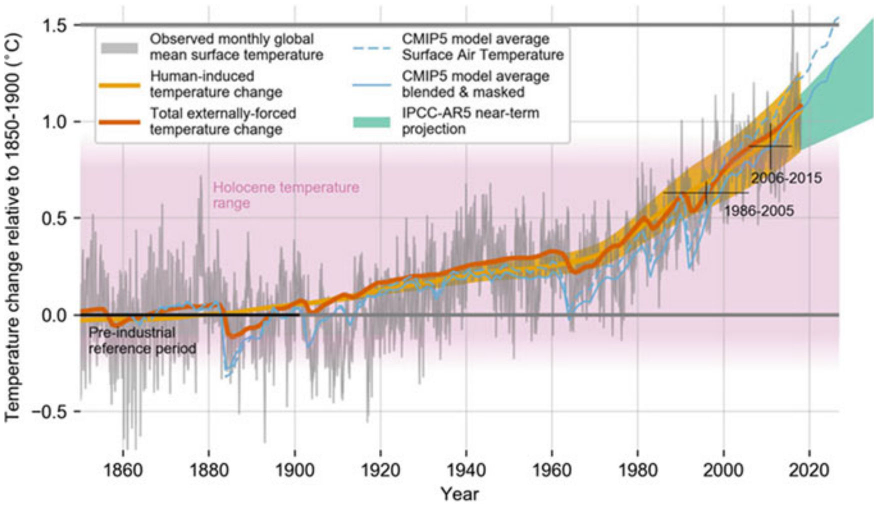

Fig. 1 Temperature change relative to 1850–1900

such mild dry winter and mild summer similar to south zones of France. Migration of many species and ecosystems from the temperate zone are useful tool and guide to mark climate change but possibility has been explored that these may be diminished in the tropical lowlands. Equatorial Singapore will become the warmer place on the earth with persistent rainfall round the year. It is also warned that insects, frogs, small birds, honey bees, ants and tree seedlings will disappear due to warming. Prominent fear is that warming (irrespective of change of rainfall pattern) currently existed in tropical forests as a heat sink for CO_2 may be converted into the large heat source by more absorption and less emission. Eastern Amazon(forest) is estimated to get warmer, drier over forthcoming periods, this may possibly be subjected to huge forest die-back. The latest Climate change impacts can be seen in latest Greece wildfires caused by extreme heat and moisture loss, devastating floods in China, toppled houses and buildings of Germany, Canada's extreme heat event, occurrences of intense tropical cyclone like 'AMPHAN', the major damaging source. Extreme weather events around the globe started from extensive wildfires upto risky heating, excessive rainfall and flash flooding. Meaning of global warming is stronger summer heat waves, warm tropical nights (above 20°). Moreover, many glaciers like Shamrock, Alaska are retreating since 1950s (Alex Crawford). There is strong connection between tropics-poles, land–ocean with regard to climate change. If the front of the Thwaites glaciers and West Antarctic Ice sheet breaks up, it would expose an even larger body of ice to warm waters (Karen Alley). 98% of emperor penguin colonies could be extinct by 2100 for ice melt reason. Before 150 years, the Glacier National Park in North America had 147 sites glaciers but only 37 nos. of glaciers remain. It is further added that there are growing evidence of storms in China or tropical oceans becoming severer, longer droughts, more deadly typhoons/tropical cyclones/ hurricanes/ willy etc. Rising sea surface temperature (SST) of Pacific Ocean feeds typhoons that blow harder and causes damaging rain and shifts of global ocean currents results in melting of Antarctica ice. These circumstances slowly rise sea level and feeling a threat that New York may be under water.

The earth's natural cleaning system is that ocean, soil, forest absorbs 50% of emission released into atmosphere. But without these sinks, global temperature has already breached to 1.5 °C and will continue to rise further. Therefore, global net zero emission plan has to be revised by all countries. Faster GHG emission means more sensitive climate which is to be restricted to stay below 2 °C". Constant isotope confirmed for soil wetness source in the Asian summer monsoon for current and ancient climatic system reveals a strong association through moisture generator and their transportation pattern. The Philippines, Vietnam, Thailand and Bangladesh have specified the isotope composition of groundwater records, confirming sufficient amount of soil moisture via earlier period's isotopic composition of precipitation. It specifies the dissimilarity in soil moisture regimes which was conserved during the previous glacial era. The physical science of climate change theme will provide best information for long-term policy-makers from infrastructure to energy and social welfare.

3 Indian Climatology

The peninsular Indian region have smaller temperature variations and heavier rains than in the inner continental zones. Inner continental temperature ranges from near-freezing levels during winter to 40 °C or more in summer over Himalayan states (northern part) experiences sub-freezing temperatures during the winter and elevated regions receives sustained snowfall. Indian subcontinent is protected from large-scale incursions of extra-tropical cold winds during the winter season. Seasonal warming of Himalayas and Tibetan Plateau starts during summer, with north–south thermal contrast over land and oceanic area. This is important for initiating the large-scale summer monsoon circulation. The Himalayan states experiences two additional seasons autumn and spring. Temperature and rainfall are the preliminary weather parameters impacts on GHG emission. Fluctuations of these have impacts on sea level, melting rate of glaciers, occurrences of extreme weather events viz. frequent and intense droughts, cyclones, heat/cold wave and flash floods etc. Indian continents comprise distinct topographical and geographical range i.e., from the arid Thar NW-desert, Tundra in the north, humid-SW areas, central and NE with various microclimate. Indian Summer Monsoon (ISM) is the main feature of regional climate and is characterized by noticeable seasonal migrations of the tropical rain belts related to Inter-Tropical Convergence Zone (ITCZ), with large-scale seasonal wind reversals [7] (Schneider et al. 2014).

4 Literature Review of Climate Change

The comprehensive anthropogenic GHG emission inventory sources are industry, agriculture, land use, land use change, forestry, waste management practices already invented in year 1991. Later on, UNFCCC (NATCOM-2004) has prepared the GHS emission inventory estimates under the aegis of India's Initial National Communications. The compounded Annual Growth Rates (CAGR) of CO_2 equivalent emissions from India between 1990 and 2000 shows an overall increase by 4.2% per annum (Gaikwad et al. 2004). CO_2 is vital contributor to climate change and responsible for about half of global warming. The significant contribution of air pollution specifically is black carbon, tropospheric ozone and some of its precursors and sulphates. Black carbon, the dark part of soot produced by diesel engines, power plants, and household and small industry burning of solid fuels and biofuels (wood, coal, cow dung, crop waste), is estimated to have about 55% of the warming impact of CO_2, Ozone. About 20% of the impact of CO_2 on Ozone precursors oxides of nitrogen (NO_2) and sulphates affects climate change in a more complex way because they interact with better-recognized greenhouse gases to have their warming impacts. These two pollutants can increase the potency of methane gas widely and later on CO_2. Government of India (2004:62) noted an increased in temperature as 0.4% and the IPCC [8] observed it as 0.68%. Temperature increased happened during 1950–75 are in two phases over India i.e., without any trend and other series as mid 1970s upto twentieth century with well-known drifts. Indian Continental warming is more concentrated in post-monsoon season, maximum daytime temperatures (than night minimum temperatures) followed by mild winter seasons. During SW-monsoon, temperatures exhibit a declining trend over northwest India. Higher surface air temperatures compared to climatological normal temperatures are observed over most locations in India. Since pre-industrial times, the overall human-induced climate forcing effect has increased global average near-surface air temperature by approximately 1 °C (Allen et al. 2018). After industrial revolution, several self-determining investigations provided more compelling signs that human activities have significantly altered the Earth's climate (Stocker et al. 2013).

Over the past 100 years more than 60% of greenhouse gases have been added in the atmosphere (WRI 2001). Global population (25%) from an unsustainable industrial fossil fuel area emits GHG for more than 70% and consumes about 75–80% by other resources which are threats for climate change [9]. Year 2005 accounted CO2 emission was 1.1BT, 4.7BT and 5.9BT from India, China and USA respectively. ICAR estimated that the main responsible methane and nitrous oxide gas emissions from Indian agricultural soils are 0.23% and 0.1% respectively [10]. Aerosols tend to cool the surface by scattering or absorption of solar radiation (direct effect), or by increasing cloud formation (indirect effect) and this Aerosol pollution is a part of warming by anthropogenic GHG emissions (Myhre et al. 2013). From ice core records, existing GHGs level (CO_2, CH_4, NO_2) warms surface by trapping terrestrial radiation in atmosphere with increased mean rate (Stocker et al. 2013). Observational records show that since year 1850, current decade (2001–2018) is warmer (Stocker et al. 2013). It is indicated in variability of trend/patterns of rainfall, temperature, humidity, melting of continental ice, sea-level rise, ocean heat content, ocean acidification and rapid intensification of cyclones are anticipated changes from warming of earth planet (Stocker et al. 2013). The rising temperature rate is increasing and global warming will likely reach upto 1.5 °C during 2030–2052, and 3–5 °C by the end of this century as compared to pre-industrial times (Allen et al. 2018). Warming and thermal expansion of ocean would continue after twenty-first century and will trigger rising of sea level. Although climate change is global but it will not be uniform in the earth such as faster rising of arctic temperatures than global average temperature (Stocker et al. 2013). Variation in the rates of rise of sea-level across the world (Church et al. 2013a) and global scale climate change is robust and irreversible (Flato et al. 2013). Dudu and Cakmak (2018) explained that climate change will not be more significant before year 2030s whilst in the twenty-first century the negative effect. Their will likely go faster and become a serious threat for all places i.e., drastic change in production patter and commodity prices. The Intergovernmental Panel on Climate Change (IPCC), AR6 reported that "there are clear global warming evidence seen in surface/ocean temperatures, widespread melting of snow and ice, rising of sea level" (Soloman et al. 2007). Even with advanced green technologies, India cannot even reach upto China's current total income without a significant increase in GHG emissions. So, restrictions on CO_2 and other GHG emissions will be daunting and undermine India's poverty alleviation objective. Therefore, few mitigation strategies to consider uncertainty are accounted for (i) Precise future responses of temperature, rainfall, GHG emissions: (ii) precise quantitative effect of rising temperatures ("global warming") on glacier melting, sea levels, and extreme weather and (iii) quantitative response of agricultural productivity, GDP (gross domestic product) growth, health, pattern of migration, and poverty.

Indian agriculture emanates about 0.23% [10] and Climate change will be significant and dwindle the agriculture. Komuscu et al. [11] suggested a raising of 4–43% soil water deficit by experiencing the warming (2 °C), 8–91% (4 °C) according to Thornthwaite's water-balance model plus boosting of evapo-transpiration of hydrological simulation model. Land is a fixed resource for agriculture but increased food demand (yield per land) can by fulfilled by precise use of water, energy, time management, and farm level adaptation. Cline (2007) estimated that during year 2070–2099, the projected mean temperature is likely to increase by 1.1 °C and 1.6 °C which ultimately will reduce mean precipitation by 30%, these facts resulted a remarkable 16% reduction in agricultural field. It is also confirmed that 1–2 °C increase of temperature under climate change effect will be benefitted and that 1–2 °C increase of temperature under climate change effect will benefit and at 2 °C effects will be completely inverted. Dudu and Cakmak (2018) stated that the crop production and are dependent on the B1 scenario as per IPCC (RCP 8.5) scenario. Global inhabitants will probably boost upto 09 billion in 2050 and will definitely decline in the later period. Allen et al. (1998) stated that upto twenty-first century, subsequent implementation of global circulation model (GCM) and Penman–Monteith model, the extensive use of Water Requirement Model in the agricultural sector will be more prominent.

Water is vital source of life, livelihood and the whole ecosystem. Now a day's, water resource availability or deficit is global concerned as it does not obey any political boundaries. Rapid development, demographic change by urbanization, growing industries, globalization of trade unequal water distribution than its supply and climatic conditions like ashes, reduced river flow, muddy and flash floods, earthquakes, agriculture, and sewage treatment factors are main contributors to water pollution or water quality degradation and scarcity in drinkable water resources. This leads to intersectoral conflicts and ticking of water pollution. The highest risks are fiscal disasters in economics, unemployment, underemployment and water crises. Climate change risk is interconnected and has solid impact on natural resources to be addressed and planned for mitigation. Also, extensive use of water resources will deplete its storage and have adverse consequences for users and ecosystems, over-exploitation of aquifers than natural water replacement. Water resources maintenance is a big challenge and needs management and implementation of strong future strategy because ignorance of water has made it a limited source. India has made development and progress in the field of water resources, its supporting infrastructures by installation of many hydropower with capacity 30,000 MW and over irrigated area almost 90Mha etc. Further we know that progress report of WMO during the year 2012 announced to increase monitoring programme for water supply and sanitation, improved drinking water sources. Whereas water resources should be considered for usable purpose, quality which covers pollution, contamination and its management. Water management is central pillar of sustainable development containing extraction, storage and equitable distribution to end users.

5 Uncertainties of Climate Change

Brown coal power cooling towers at Loy Yang, in Victoria is Australia's biggest capacity power station. Understanding of increase in GHG persisted many uncertainties that affects warming on emission pathways (RCPs) subjected to cloud formation includes changes in water vapour, ice feedback, ocean circulation, natural GHG cycle. Rate of forthcoming global warming depends on future emissions, feedback processes and unpredictable natural influences (volcanic eruptions, earthquake, cloud burst). Similarly, past climate changes are also uncertain due to less accurate data and many incomplete information and future changes is also questionable. Despite uncertainties, a unanimous pact has done amongst climate scientists that human-caused global warming is more, factual and uncertain. The consequences of increased industrial revolution enhance GHG concentration and relevant warming effect, and high emission pathway would also increase planet temperature. In such situations, the identification/resolving and public policy formation will be not certain under the risk of Climate Change. According to reliability ensemble average (REA) and multi-model ensemble estimation all India mean surface air temperature change for the mid-term period is projected in the range of 1.39–2.70 °C with 13% uncertainty which is more than the natural internal variability (Table 1).

Table 1 Uncertainties in Annual mean surface air temperature

Emission scenario	Model name	Annual mean temperature (°C)	
		2040–2069	2070–2099
RCP2.6	CDX-ENS (5)	1.38 ± 0.17 (12.3%)	1.31 ± 0.24 (18.3%)
	CDX-REA (5)	1.39 ± 0.18 (12.9%)	1.33 ± 0.24 (18.0%)
RCP4.5	CDX- ENS (16)	1.92 ± 0.30 (15.6%)	2.34 ± 0.44 (18.8%)
	CDX-REA (16)	2.03 ± 0.28 (18.8%)	2.44 ± 0.41 (16.8%)
RCP8.5	CDX- ENS (15)	2.66 ± 0.37 (13.9%)	4.31 ± 0.56 (13.0%)
	CDX-REA (15)	2.70 ± 0.31 (11.5%)	4.44 ± 0.45 (10.1%)

According to IPCC (2021), the warming of the climate system is unequivocal due to increased anthropogenic GHS, but there still remains inevitably significant uncertainties regarding the precise magnitude of increase in temperature, rainfall qualms across seasons and regions. Uncertainty relates to the presence of factors other than GHG emissions that contributes to warming (in Pielke et al. 2005: 1574). The IPCC predictions on variation of temperatures, rainfall, natural phenomena, simulation models output should consider in the climate system model. But climate models cannot reproduce/include El Niños, La-Nina, or the "blocking highs" (brings heat waves to Europe-or even the ice ages) such model prediction are highly uncertain. It is suggested that any analysis of optimal mitigation policies is likely to carry a significant speculative element in it and the truth is the quantitative estimates of costs and benefits of mitigation. Projected Climate Change Consequences are worse than portrayed. Climate sensitivity (relationship of emissions and temperature changes) is main source of uncertainty. Any temperature/rainfall change are disruptive for crops. Climate change has a ubiquitous direct or indirect impact on agriculture. Primary purpose of mitigation is to maintain plant health, conserve biodiversity and ecosystem service under climate change impact. To maintain ecosystem health, a more resilient system, research and breeding network with involvement of stakeholders, scientist, and meteorologists is needed. Comprehensive analysis in the diverse range of crop, biotic and abiotic system is to be improved further. Every part of the world is still in distress and will bear more negative impact by elevated temperatures. Impact assessment on climate changes, during initial phase will be more prone in the direction of the agricultural uncertainties and threats attributed to the models. However, some areas will depressingly affect every zone and for all periods. Furthermore, Fig. 2 shows the dissimilarity and decreasing trend in crop yield and will be more than the variation of climatic circumstances. Many studies predicted that most of the technical conditions become more favourable for agricultural production at an early stages of projected climate change scenario.

Local circumstances of climate change effect on agricultural harvest are still unsure and changeable for both kharif and rabbi seasons. Whereas tropical lowlands will be affected in a most pessimistic and unsafe way, its extent so far is not confident under the effect of rising sea level. Also, there will be constantly increase in the

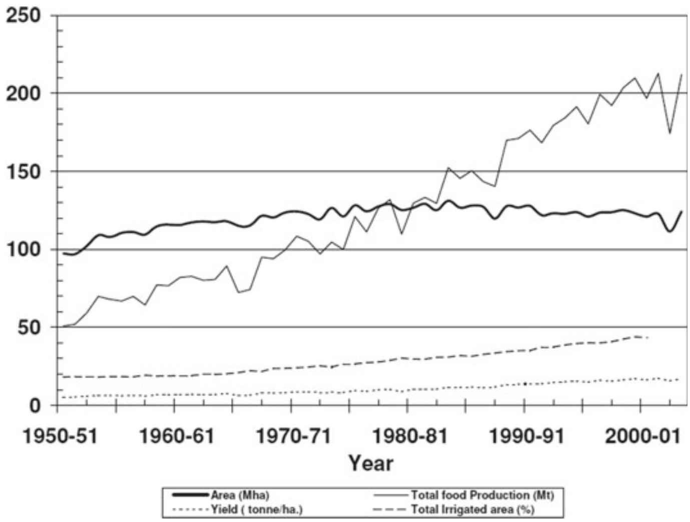

Fig. 2 Production of yield and food from year 1950–2004 under irrigation in India (*Source* Central Statistical Organisation, New Delhi, DES-2004)

temperature tolerance crops with majority of natural vegetation. The probable benefits of carbon dioxide on fertilization is a big uncertainty. Many field observations during the past-era revealed that growing level of carbon dioxide are likely to enhance the photosynthesis rate and therefore, there will be dry substance production and areas of C3 plant yield. But it appears that augmentation in temperature is likely to counterbalance the useful effects of CO_2. Further, the challenge of increased population is to maintain food productivity under uncertain changing weather scenarios. These uncertainties in weather events and their threshold of climate change in agriculture production need to be further analysed.

There is no clear picture of how weather change will affect agricultural drought because in India 70% agrarian are reliable on monsoon rainfall. But a nice figure can be put with various metrics providing diverse imitation of future climate threat. In the current scenario the collective effect of climate change on a global scale agricultural efficiency cannot be consistently quantified. The increasing temperature, CO_2 and variable rainfall may influence future food security in developing countries like India because of its large population and limited sources.

There is negative commodities prices impact due to uncertain weather of Indian Monsoon Season (ISM), drought, cyclone, heat/cold wave effect on crop cultivation areas, irrigated water accessibility are important in daily routine. Hence, to increase the crop useful zones at least for rainfed crops in the successive period are the most probable solution (Kumar et al. 2004). About 30% of crop areas are irrigated and remaining 70% crop areas are still under rain-fed areas (uncertain monsoon). But drastic declination in Gross Domestic Product (GDP) is mainly because of land holdings that leads to inefficient food productivity. The compensation for these problems is to implement latest technology for boosting food production. After year 2003, food production will increased sufficiently by virtue of advanced technology applied in India's agricultural field. Kirtman et al. (2013) found basic cause of projected model's uncertainty which can be further included in future analysis of data (Fig. 2). More uncertainty observed over NW arid zone as compare to monsoon dominating zones (west and central parts) of India.

Thus, preparedness of adaptation and mitigation policy, number of uncertainties are key factors to quantify and know its reality for future assessments. This management is most useful in local, regional, sub-regional and national levels to implement strategies/policy (Hawkins and Sutton 2009; Terray and Boe 2013). Singh and AchutaRao (2018) has quantified sources of uncertainty's complex process in projected data which are: (i) scenario uncertainty (ii) internal variability from chaotic nature of the climate system, and (iii) model performance.

6 Warming Consequences in India

Ocean acts like a buffer that absorbs heat from the atmosphere and transfers it into the ocean's depth. Ocean stored numerous amounts of heat (93%) due to anthropogenic emission for 50–100 years, remaining 7% heat is utilised in the warming of atmosphere which melts sea/ice/glaciers (Levitus et al. 2012; Von Schuckmann et al. 2016). Ocean warming or thermal expansion (non-uniform) has risen sea level from last few decades (Church et al. 2011b). Melting of mountainous glaciers (about 25%), small ice caps, exchange of freshwater between ocean and land water reservoir, groundwater, steric effect (non-uniform thermal expansion and salinity variation) etc. are responsible for sea level rise. In NIO, more than 70% of sea level rise is by thermosteric (3.72 ± 1.04 mm/year) variability and halosteric (6.41 ± 0.62 mm/year) sea level rise at SE tropical Indian Ocean and near west Australian coast. Steric sea level associated with atmosphere (surface wind) and ocean circulation dynamics. Halosteric changes are more in the Bay-of-Bengal and SE-Indian Ocean (e.g., Nidheesh et al. 2013; Llovel and Lee 2015). Over east–west coast of Indian ocean sea level rise is measured by tide-gauge measurement instrument, satellite-based radar altimeter observations showed that there is basin-wide pattern i.e., falling sea level over SW tropical ocean and rising level elsewhere since year 1960 (Han et al. 2010) which is attributed to dominant thermosteric variation. During 2004–2013, NIO has showed increased basin-wide rise at rate of 6 mm/year (Srinivasu et al. 2017), mean sea level rise about 3.28 mm/year during 1993 to 2017 (Unnikrishnan et al. 2015), a sharp increase in North–South about 1.06–1.75 mm/year during 1874–2004 (Unnikrishnan et al. 2006; Unnikrishnan and Shankar 2007) and fall in sea level in the open ocean upwelling dome. NIO sea level rising at faster rate is similar to global mean sea level. It is projected that NIO sea level rise will be in the range 0.25–0.30 m and that of global sea level rise under RCP4.5 scenarios will be 0.19 m upto twenty-first century. Indian Ocean Sea level shows large temporal and regional variability and a steric effect is major contributors for Indian sea level changes, with El-Nino Southern oscillation (ENSO), Indian Ocean dipole (IOD) (Parekh et al. 2017; Palanisamy et al. 2014).

Significant weakening of Indian summer monsoon (ISM) during 1950–2015, over north and central India is noted due to reduction in tropospheric thermal contrast associated with rapid ocean warming (Mishra et al. 2012; Saha et al. 2014; Roxy et al. 2016). Recently, widespread extreme rains occurred over Western Ghat and Central India due to warming which induces fluctuations in monsoonal winds and enhanced moisture transportation from the Arabian Sea towards the Indian continents [12]. Also, reduced rainfall during onset, and withdrawal phase is noted on the same reasons (Chakravorty et al. 2016).

6.1 Sea Surface Temperature and Impact on Tropical Cyclones

Sea Surface Temperature (SST) warming is non-uniform and shows a rapid increase. Ocean-atmospheric conditions regulate the regional weather-climate system. Recent Studies by Krishnan et al. [13] showed that between 1951 and 2015, average sea surface temperatures in the tropical Indian Ocean rose by one degree Celsius. This temperature increase was 0.3 °C higher than the global average of 0.7 °C. Ocean heat content in the top 700 m of the tropical Indian Ocean increased during the same time period, with an abrupt increase over the last two decades. The oceans absorb approximately 90% of the warming caused by greenhouse gas (GHG) emissions, which can result in more intense cyclones, sea level rise, and faster melting of polar ice shelves. Even though the overall frequency of cyclones declined in the latter half of the twentieth century and the first two decades of the twenty-first, the frequency of very severe cyclones (VSCS) in the region climbed by one per decade in the previous two decades. All of these trends will continue to rise if GHG emissions are not reduced. Global warming caused by GHG emissions poses unique challenges for India [13]. Warm ocean alters rainfall characteristics i.e., many episodes of heavy rainfall in Indian continents and are becoming more intense, recurrent around Indian Oceanic zones whereas regional climate pattern responds to anthropogenic climate change (Collins et al. 2019). Rise in surface air temperature leads to warming of SSTs, increase in the evaporation and cloud formation process thereby creating low pressure system development which ultimately converts into the tropical cyclones. Devastating weather (heavy precipitation, gale winds, storm surges, tidal wave) are associated with cyclones and accounts for huge loss of properties and lives. Hence, understanding the present and future development of Indian Ocean Warming and its influence on the regional climate under the global warming system needs an urgent and most priority attention point [13].

Another study [14] on the climate change impact on Tropical cyclones over the Arabian Sea shows that in a recent year a greater number of TCs forming in the Arabian Sea than in the Bay of Bengal due to impact of global warming. Although, climatologically the frequency of TCs formation in Bay of Bengal is more than the Arabian Sea. TC development frequency at 0–10° N latitude is enhanced by about 52% in the Arabian Sea (2001–2019) and incremental in the TC duration is 80% (fourfold) and also increased of mid-level Relative humidity in post-monsoon season. Over the Arabian Sea, there is threefold incremental in VSCS in recent years as compared to 1982–2000 [14]. It is pragmatic that that TC genesis activity is more over AS and the damaging landfalling tendency is more over BoB. Under the influence of climate change, destructive potential of Landfalling TCs have increased over period because of higher landfalling frequency, intensity, landfall travelling distance, low weakening rate of TCs over mainland [15]. Warming SST over coastal region enables favourable dynamic (low vertical wind, high upper tropospheric divergency and thermodynamic conditions. which are responsible to rapid intensification (RI) of TCs prior to landfalling.

The super cyclone of Orissa (1999) was India's most severe cyclone in recent memories. This cyclone has wind speed exceeding 250 km/h. The massive destruction caused by winds, surges, and torrential rains resulted in total damage up to 19 lakh houses, affected over 25 lakh people, claimed almost 10,000 human lives, and injured many more. During past three years, lot of variability pattern appeared in the occurrence of tropical cyclones. The number of cyclones formed over Bay of Bengal from 1887 to 1997 has almost remained constant, but rapid intensification of storms took place in the recent period. Majority of cyclones formation takes place over North Indian Ocean (NIO). After cyclone Bhola (1979), climate change triggered Super Cyclone AMPHAN in May, 2020, one of the worst and most expensive natural disasters, with wind speeds reaching 270 km/h. It is accounted for the greatest loss of life, property, and area when landfall occurred in West Bengal's coastal districts. The total economic impact is 13 billion (Rs. 96,000 crores) by the Super Cyclone AMPHAN (Fig. 3). It crossed the west Bengal state and took 90 lives and about 4,000 livestock mainly from West Bengal. It is understandable that high SSTs of BoB in the vicinity of TC (>30 °C) resulted in RI of TC, AMPHAN, and other favourable parameters such as vertical wind shear (VWS) of the horizontal wind [16].

6.2 Surface Air Temperature Impact

Increased occurrence of hot days, heat waves, droughts, reduction of water levels, crop failures and natural disasters resulting from cyclones are attributed to increased temperature. Kothawale [17] studied that 40 nos. of Indian station's temperature data (1970–2002) and found extant of increased heat wave incidences in month of May than June, few heat wave occasions in March–April. He also observed that during pre-monsoon season, the maximum number of hot days available over central part of India and minimum hot days lie along the west coast. Surface air temperature 2 m above the ground fluctuates over various regions. Temperature projection including external forcing and model differences stated that occurrence of internal variability and uncertainty is largest over small areas and limits accuracy on country-wide

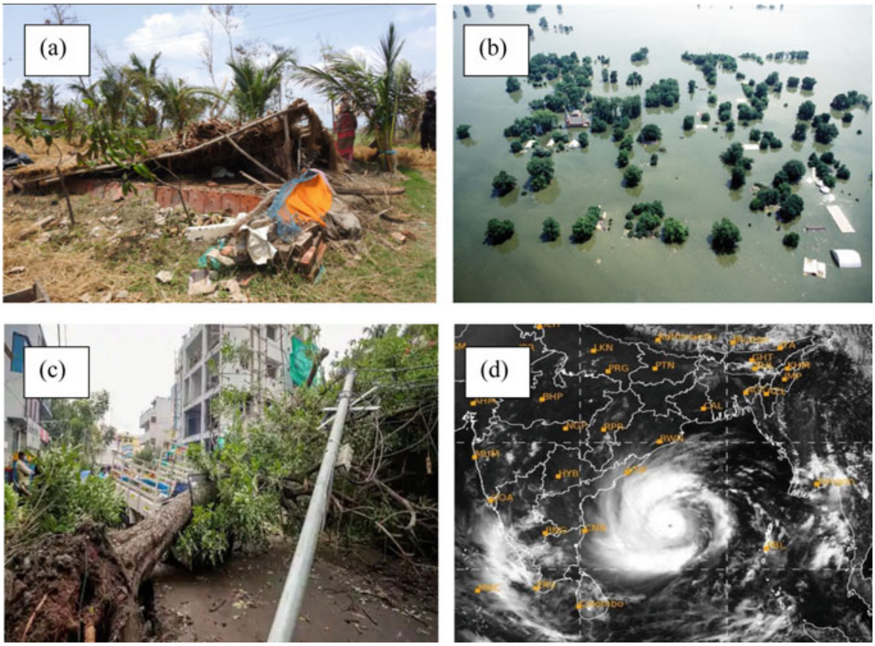

Fig. 3 **a**–**c** Super Cyclone-AMPHAN devastated impact. **d** INSAT-3D Visible image of AMPHAN formed over Bay of Bengal at 0600 UTC on 18th May, 2020 (*Source* www.imd.gov.in)

w.r.t. global scale (Collins et al. 2013). Recent incidences of increased heat wave in Rajasthan, west Bengal, and Maharashtra between the two time periods. Estimated anthropogenic emissions and temperatures due to increased key drivers of climate change and warming contributions for the five scenarios are given (Table 2).

A set of five emissions (RCP 1.9/2.6/4.5/7.0/8.5) scenarios projections account for solar activity and background forcing (anthropogenic drivers) from volcanoes for the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100) as compare to 1850–1900 is shown in above Table 1. This report assesses results from

Table 2 Details of five scenarios

Scenario	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
	Best estimate (°C)	Very likely range (°C)	Best estimate (°C)	Very likely range (°C)	Best estimate (°C)	Very likely range (°C)
SSP1-1.9	1.5	1.2–1.7	1.6	1.2–2.0	1.4	1.0–1.8
SSP1-2.6	1.5	1.2–1.8	1.7	1.3–2.2	1.8	1.3–2.4
SSP2-4.5	1.5	1.2–1.8	2.0	1.6–2.5	2.7	2.1–3.5
SSP3-7.0	1.5	1.2–1.8	2.1	1.7–2.6	3.6	2.8–4.6
SSP5-8.5	1.6	1.3–1.9	2.4	1.9–3.0	4.4	3.3–5.7

climate models participated in the Coupled Model Inter comparison Project Phase-6 (CMIP6) of the World Climate Research Programme. These models included new and better representation of physical, chemical and biological processes and also is a higher resolution report. The CMIP6 historical simulations assessment reported ensemble mean global surface temperature change within 0.2 °C but other models show above or below this value. The latest IPCC report adopted the robust method of evaluation of AR6 climate sensitive and forthcoming variation in global surface temperature, ocean warming and sea level, etc., constructed by combining multi-model projections with observational constraints based on past simulated warming.

More summer monsoon expected in the warming atmosphere, reduced snowfall over the Himalayas and high mountain ranges of the Alps in a warming climate (Cyranoski 2005). Reduction of cloudiness in south India and lesser summer monsoon rainfall due to small dust particles in the lower troposphere are found to effect climate change (Ramanathan et al. 2002). There are large trend differences in the minimum temperature and cloud amount between North and South India. July 1988 was the worldwide (July 1988) ever hottest month was noticed and year 1998 was the major El-nino year which experienced worst hot spell in 50 years took a toll of over 3,000 lives. Warmings are retreating Himalayan glaciers at the rate of 18 m/year in Gangotri. Upto twenty-first century, India's climate could warmer by 2.33 to 4.78 °C under doubling of CO_2 concentration (Longern 1998) and increase in annual temperature ranges between 0.7 and 1.0 °C by year 2040 w.r.t. 1980 is predicted (Lal et al. 1995). The impact of climate change, climate variability and policy will definitely affect socioeconomic, technology, development paths, adaptation/mitigation capabilities. Moreover, heat waves, droughts, floods, cyclones, tidal waves are incidences of extreme weather events De et al. (2005).

According to India Meteorological Department (IMD), daily maximum and minimum temperature data analysed over Indian region and found that there is an increase in the occurrences of warm days and nights, decreased in cold days and cold nights after 1951. It is also observed that there is yearly increased 7.4 days/decade, extreme warm nights for about 3.1 days/decade and annual decreased of cold days for about 1.4 days/decade. Findings of increased in the occurrence of warm days by 2.4 days/decade in the monsoon season, for winter 2.2 days/decade, overall seasonal rise of warm days are 9.9 days/decade, warm nights 7.7 days/decade and decreased of cold nights by -6.9 days/decade. Recently, it is pragmatic of winter seasons extension, cold night reduction and these observations are consistent with the earlier studies of gradual increasing trends in warm days (Kothawale et al. 2010b; Revadekar et al. 2012). Consequences of increasing and decreasing trends of heat-wave and cold wave respectively were also detected in the hot and cold weather over largest parts of India [12] (Rohini et al. 2016; Ratnam et al. 2016; Pai et al. 2017). Extreme hot or cold day is declared when its daily temperature departure is above or below pre-defined threshold value (Pai et al. 2017). In the northern and NW parts of India, most places showed a sustained duration of heat waves in the summer season/hot weather (Rohini et al. 2016) and these semi-arid zones are will likely to become warm more rapidly than other parts of India. Such warming is attributed to the upper-level cyclonic anomaly in west of North Africa and a cooling anomaly in the Pacific

(Ratnam et al. 2016). Other reason for such variability of heat wave between tropical Indian Ocean and central Pacific sea surface temperature anomalies Nino (La-Nina) event. Impact of heat wave is occurrences of meteorological droughts (Sharma and Mujumdar 2017).

6.3 Temperature Impact and Health

Relationship between climate change in terms of warming and health outcomes is a bit complex, if temperatures rise in warmer parts of the country, then intense heat waves may sustain for longer time and induces frequent heat stroke, related disease that causes deaths alongwith harmful air pollution. Increased humidity, water pollution or contamination accompanied by floods are likely to increase spreading of diseases such as malaria, cholera, diarrhea, intestinal disorder etc. Warming in colder region will have mild winter. Malnutritional upsurges, deaths, alteration in the spatial distribution of infectious diseases, injuries due to occurrence of extreme weather and elevated ozone concentration events will be frequent in urban areas and will directly impact human health under climate change scenario [8]. In India, there will be more than half children (05 years old), every 02 nos. out of 05 women and almost 1/3rd adults will face undernourishment problems especially in Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, and Orissa. Anemia is major nutritional health problem in India, 55% of women, 70% of children results in maternal/perinatal mortality, weakness, reduction of physical/mental capacity, increased morbidity from infectious diseases, premature delivery, low birth weight, and impaired cognitive performance in children [8]. It is estimated that child stunting will increase by 35% upto year 2050. Many parts of India have negative climate change impact such as malnutrition, health disorder, reduction of immune power (expose to disease). The health system should be strengthened enough to identify the hotspot zones on priority basis.

Higher wet bulb temperatures will have thermal stress impact like mosquitoes-born, waterborne-pathogens, poor water–air-food quality, thus, climate change is, a novel challenge for ongoing efforts to protect human health [6]. It is likelihood that frequency and transmission of season period may alter the geographical range and source of spreading the vector-borne epidemical diseases, which triggers asthma mostly caused by plant pollen. Link between malaria and climate in irrigated areas (like Punjab) have massive epidemic malaria. Excessive monsoon rainfall causes increase in mosquito breeding risk and its survival, epidemic malaria which is observed after EL-NINO episode (Bouma and van der Kaay 1996). Almost 6% of children and 2% adults will suffer from respiratory tract infection(asthma) [6] may increase troll of almost 20% of deaths of live during next decade, if an urgent action to curb climate change and preparedness for its consequences are not taken (WHO 2008).

6.4 Mean Temperature (T_{mean})

Analysis of mean temperature (other than RCP scenario) stated that if the global mean temperature is at low-warming stage i.e., below 2.0 °C then projected rate of heatwave will be lesser by 2.5times. But under increasing population, projected data investigated that India will be the most vulnerable country to heat stress based on anticipated increased in heat index (Im et al. 2017; Mishra et al. 2017). Since 1980s, India's averaged annual plus seasonal near-surface specific humidity is too much increased. Increasing trend of this (specific humidity) during pre-monsoon season is in agreement with largest surface warming trend obtained. In the projected Heat wave scenario (based on wet-bulb temperatures) humidity effect will be more in the densely populated, agricultural areas of Ganges and Indus River basins (Im et al. 2017). High humidity will expose crops to disease and decline of crop production. In the twenty-first century under RCP4.5, too much increased wet-bulb temperatures will be dangerous for human life and will let down humanoid comfort levels (Im et al. 2017). Wet-bulb temperature is likely to reach upto 35 °C in coming years (2070) for RCP8.5 scenarios, is unbearable and threat for human survival (Coffel et al. 2018). Heat index calculated from both temperatures and relative humidity (Russo et al. 2017) will also be in the higher range and will cause more risks of deaths as well as variable/unpredictable India's Summer Monsoon (ISM).

Figure 4 showed during the mid-20th century (period 1986–2015), India's mean temperature has amplified with a warming rate of minimum temperature, annual mean and maximum temperature per decade as 0.13 °C, 0.15 °C and 0.15 °C respectively. Mean temperature rise over Indian latitude is attributed to warming triggered by GHG (partially offset by forcing due to anthropogenic aerosols), changes in Land Uses and Lan Cover (LULC). This warming is uneven across all seasons, i.e., there will be more warming in pre-monsoon season (March–May) than any other seasons. Temperatures change are statistically significant at the 90% confidence level, consistent with long-term variations and global, regional gridded temperature data estimated trends calculated by different models In twenty-first century, under extreme RCP (8.5) scenario, the annual average projected temperature in India is likely to rise in the range of 4–5 °C compared with past year (1975–2005) data throughout the country except few parts of southern peninsula and up to 5 °C temperature in the semi-arid NW and N zones of India. Table 3.2, shows the mid-term (2040–2069) low emission RCP 2.6 scenario, estimated long-term variation of mean temperature below 2 °C, over NW and N and more than 1 °C warming in the remaining parts of the country. For period 2031–2060, temperature projections during summer monsoon season indicates mean warming more than 1.5 °C in central and northern parts of India (Sanjay et al. 2017a). Figure 5 shows the CORDEX data that provides higher temperature change value of 5.4 °C in winter and 4.9 °C in summer monsoon over the hilly NW-Himalaya and Karakoram region. Projections indicated strong warming in the range of 0.03–0.09 °C/year irrespective of all seasons in the Indian latitudes. Overall view is that northern India will experience higher warming than southern peninsula (Chaturvedi et al. 2012) and large warming range of 1–8 °C under RCP8.5

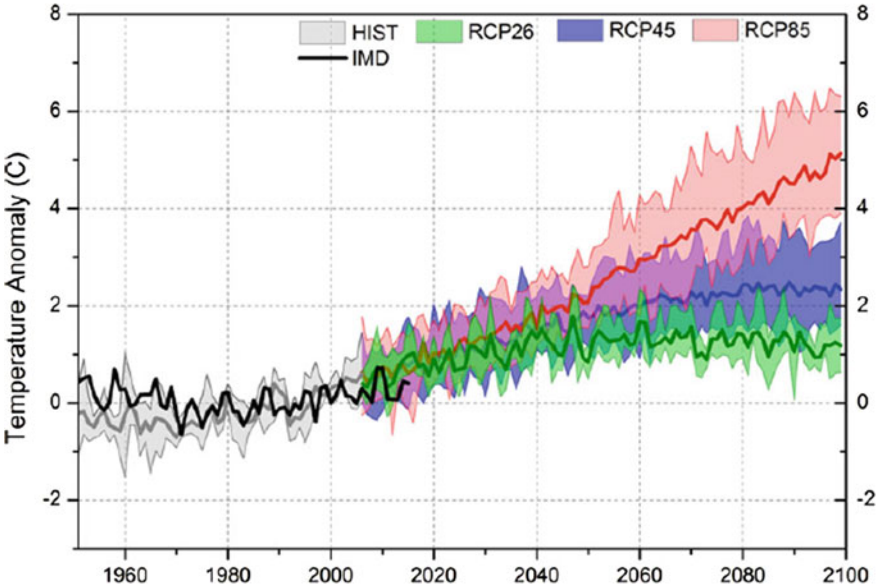

Fig. 4 Based on IMD gridded data: annual mean surface air temperature (°C) anomalies (1976–2005) from cordex experiment, historical data (1951–2005), projected data (2006–2099), anomaly (1951–2015)

scenario will likely too happened in Himalaya and Kashmir region by year 2099. Table 3.2 showed all India mean surface air temperature estimated to rise by 1.33 ± 0.24 °C under RCP2.6, 2.44 ± 0.41 °C for RCP4.5 and 4.44 ± 0.45 °C at RCP8.5 scenarios during the far future period (2070–2099) respectively.

CORDEX South Asia multi-RCM historical temperature simulations evaluated and found cold bias over of Indus basin and Himalayan water shed (Jhelum, Kabul and upper Indus basin; Hasson et al. 2018, Mishra 2015; Sanjay et al. 2017a, b; Nengker et al. 2018). These findings cannot reproduce the observed warming in the Himalayan watershed region. During period 1880–2099, the indicated range of temperature (1–8 °C) uncertainties and limitation are due to natural internal variability, climate model and future scenario uncertainties (Chaturvedi et al. 2012; Singh and Achuta Rao 2018). Natural variability in India is estimated after linearly detrending (to remove century-scale trends), maximum and minimum temperature difference for 30 years (1901–2005) moving average for annual mean, maximum and minimum surface air temperatures are estimated to be 0.347 °C, 0.513 °C and 0.213 °C respectively. The maximum warming trend is seen during the pre-monsoon season in recent 30-year period (1986–2015).

Figure 6 given above is analysis of data for 1986–2015 that warming is scatter Ly spreaded over India and the highest (more than 0.2 °C/decade) rise of annual mean temperature over northern Indian latitude and weaker (less than 0.1 °C/decade) in

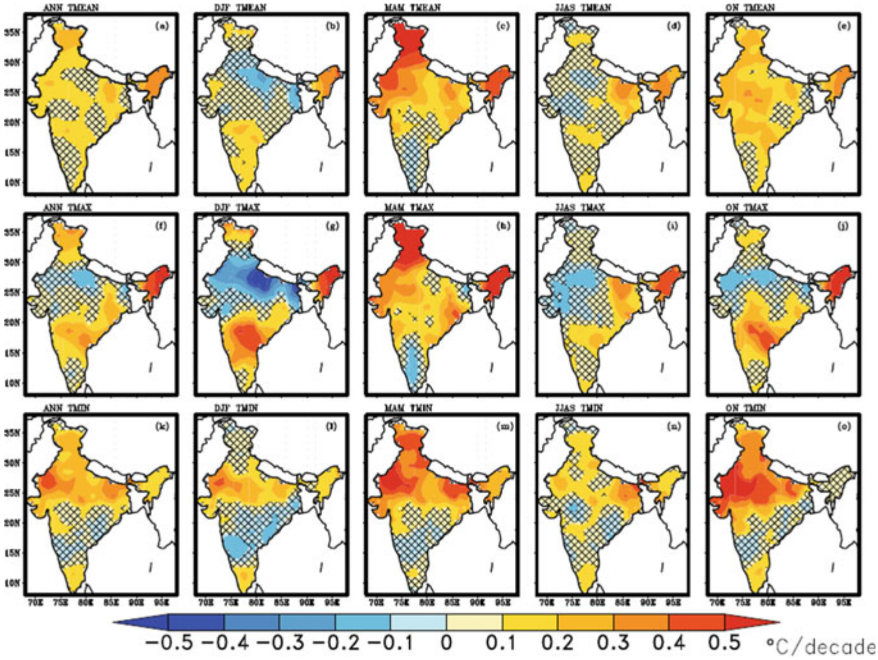

Fig. 5 Spatial seasonal and annual temperature distribution from 1986–2015

southern peninsular region. Less winter warming over southern parts of India. Pre-monsoon season gave more warming (than 0.5 °C/decade but uniformly distributed over country) similar warming pattern to that of post-monsoon season over north India. Eastern region of Indo-Gangetic plains and adjoining central part shows more warming in the summer monsoon season. These forecasted values are based on simple trend line analysis (Vinnarasi et al. 2017).

6.5 *Temperature from Tree-Ring Proxies*

Recent study showed warming trend over eastern Himalayan region (Yadava et al. 2015; Borgaonkar et al. 2018; Krusic et al. 2015). For the past 150 years, the late summer period (July–August–September) warming started in the 1930s and became highest between 1996–2005 (Yadava et al. 2015). Late-summer temperature of Sikkim is found to be in a slight cooling trend since 1705 C.E. and noticeable increasing trend noticed from 1850 C.E. temperature record based on tree-rings. Palaeoclimatology is restricted for Asian monsoon over Himalayan region. Tree-ring based on summer climate (temperature and rainfall) of Indian Himalaya, Nepal, Tibet, Karakoram region of Himalaya not shown significant increasing or decreasing trend for last 2–3 decades (Esper et al. 2002; Hughes 2001; Borgaonkar et al. 1994,

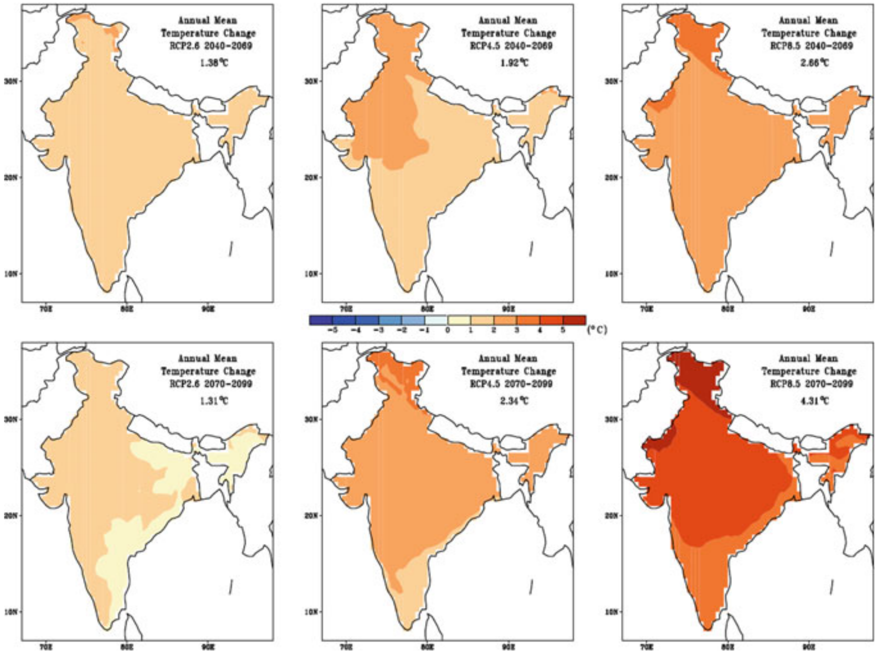

Fig. 6 Projected Mean Surface Air Temperature change under RCP2.6 and 8.5

1996; Pant et al. 1998; Yadav et al. 1999; Cook et al. 2003; Thapa et al. 2015; Wu and Shao 1995). It is indicated that Little Ice Age (LIA) phenomenon was not prominent over these regions except few warm/cold epochs, even at monsoon-shadow zone in the western Himalaya (Yadav et al. 2011). From the eleventh-fifteenth century, cooling episodes followed a warming trend in the twentieth century. At higher altitude tree-ring chronology matching with warming trend and resulted into the rapid retreat of the Himalayan glaciers (Borgaonkar et al. 2009, 2011).

7 Extreme Weather Events in India

7.1 Heavy Rainfall

Ambiguous global warming impact is evidence for occurrences of severe weather. The serious consequences of climate change are footprint and will become part of our daily routine in future. It is analysed that year 2016 was the 6th warmest year since 1901 (Analysis, 14, Jan. 2021) followed by 2020 the 8th warmest year. IMD (2020), the land surface and annual mean temperature was above normal by the value of 0.29 °C in year 2020. Monsoon and post-monsoon mean temperature anomaly has contributed to warming by +0.43 °C and +0.53 °C, respectively, whereas mean temperatures during the winter and pre-monsoon season were normal w.r.t. anomaly. Nine warmest years recorded in India are 1958 (0.25 °C), 2002 (0.24 °C), 2009 (0.55 °C), 2010 (0.53 °C), 2015 (0.42 °C), 2016 (0.71 °C), 2017 (0.54 °C), 2018 (0.40 °C), 2019 (0.36 °C). The warmest decade recorded in India are 2001–2010 and 2011–2020 i.e. anomalies were of 0.23 °C/0.34 °C above average. For every 1 °C increase in temperature, monsoonal rain enhances by 5% [18]. Climate Change impact in terms of horrific extreme weather events will experience not only by India but also parts of Europe, China, Germany, Africa, Belgium, Netherlands. Thus, climate extreme will be hitting the developed country's industrialised field and the uncontrol GHG will in turn give grim scenario of climate change impact, cause for escalating damages to infrastructure and lives.

Year 2018 was the 6th warmest year since 1901 followed by 2019 in the 7th warmest year rank i.e. more than 0.36 °C annual mean temperature gave maximum rainfall due to occurrences of severe cyclone (Koshy 2020). Year 2018 has a single heavy rainfall episode that recorded the highest number of deaths, landslides, delayed withdrawal of SW-monsoon, more (than normal) formation of a low-pressure system, occurrence of floods in Goa, North Bihar and in Maharashtra, occurrences of rock-slides, cloudburst, the landslide in Himachal Pradesh, Uttarakhand and J&K. Heavy rainfall over shorter time span occasions are growing cases now a day, can be attributed to adverse climate change impact [19]. During past five years, IMD recorded manifestations of 125 nos. of extreme weather event occurred in SW-monsoon season amongst. Which 89 episodes were of extremely heavy rainfall (recorded) in 2018 of September, 61 nos. of events in September 2020, 59 nos. in year 2019, twenty-nine in year 2017 and 35 nos. in year 2021 (NDTV, 2021). Reason of such unprecedented catastrophic weather episodes is late withdrawal of the monsoon, more (than normal) formation of low-pressure systems and the interaction of active western disturbances with low-pressure systems. The live example of such weather systems are flash floods, land-slide in Uttarakhand and riverine flooding in Uttar Pradesh, Himachal Pradesh which claimed 79 nos. of loss of lives.

Likewise, against 35.3 mm normal rainfall, Himalayan states recorded 203.2 mm rainfall in the month of October 2021 (https://sandrp.in/, 2011). According to IMD's annual report (Report, n.d.), year 2020 showed a positive (wet conditions) standardized precipitation index (SPI) because of 110% of annual rainfall of LPA is observed in India. During SW-monsoon season, 12 nos. of low pressure (LPs) systems (01 severe cyclonic storm, 06 well marked low pressure areas and 05 low pressure areas) were formed. Heavy rainfall and flood related incidents claimed more than 600 losses of lives. Number of loss of lives is 578 nos., 237 nos., 150 nos., 16 nos., 06 nos. happened in incidences of thunderstorm, lightning, cold wave, snowfall and squall respectively. Even year 2019, SW-monsoon was 9% excess to LPA in which Bihar and Maharashtra states were the worst flood affected states followed by UP, Kerala, Rajasthan and Karnataka which kills more than 2000 lives. 25th October 2019 was the 7th late SW-monsoon withdrawal against its normal retreating date as 15th October and the year recorded excess rainfall [19].

7.2 Cloudburst

Indian scientists introduced ‘mini-cloudbursts’, which occurs when more than 5 cm rain within two consecutive hours [20]. Such heavy rain incidences can be identified in short period of time over high altitudinal/topographical regimes. Hence it is advised to observe the convective activity over the Himalayan and other high altitudinal zones. Occasion of mini-cloudbursts in Mumbai [21] (heavy rain 944 mm) on 27th July 2005, 304 mm on 20.09.2017 and almost 26 nos. of cloudbursts in Uttarakhand [22] are the live examples in the recent decade which caused urban floods. Hitting of cloudburst fatalities, injuries and casualties are increasing day by day. Dimri [23] stated that since 1970s, almost 30 cloudbursts occurred over Indian region. Models have limitation to capture cloudburst due to lack of understanding of microscale interactions, odd orography, ratification of observation etc. But climate model simulation projected that CAPE will increase TS intensity and its associated rainfall. Hence, improvements in the model to reduce uncertainties, inhomogeneities and monitoring networks is needed. A P. [23] in the 21st century, India will experience increase in the annual warm extremes, frequent warm nights/days enhance from 10 to 80% showed in all emission scenario of CORDEX data as shown in Fig. 3. In the tropical belt (India) there will not be any cold nights or cold days under RCP8.5 scenario. In the CORDEX data analysis after quantile mapping bias-correction application, it is forecasted that there will be upsurge in the heat wave duration for about 25–35 days per summer season. Over NW parts of country. These findings agree with heatwave climatology estimated using the CMIP5 multi-model ensemble and from the observation data of India Meteorological Department (IMD) over NW-India [12]. Also, after year 1951, the annual warm days are hiked than warm nights, reduction in number of cold days and highest annual increase in the number of warm days already happened in Monsoon and winter months. After 1986, annual number and frequency of warm days/nights have been enhanced faster and reduced in cold nights. The warming during pre-monsoon and winter seasons gives rise to India’s warmest day. From year 1951–2015, Indian Summer Monsoon (ISM) has declined by 6% which is well noticed in Indo-Gangetic plains and Western Ghats [13]. IPCC, AR6 report on Oceans and Cryosphere (SROCC) stated occurrence of warming of ocean, rapid change in Indian Summer monsoon and forecasted a long drought or a heavy downpour may be the new rainfall normal.

The CMIP5 ensemble had projected warm season (March to June) will exhibit the occurrences of intense, longer duration and frequent heat waves in India (Intensification of future severe heat waves in India and their effect on heat stress and mortality, 2015) [24]. The southern India will also be under impact of heatwaves in the far future period. These long-lasting heatwave event and higher frequency of extreme El Nino events (et al. 2015) are projected to impact Indian subcontinent as well as tropical Indian Ocean [25]. Climate change is making monsoon/rainfall more chaotic and threat to agriculture and economy of country. Surface warming trend has enhanced atmospheric moisture content (specific humidity) especially in pre-monsoon season. This is positive feedback with concerned to man-made climate change because water vapour is the greatest supplier to the natural GHG [26] (Boucher et al. 2013). The rise in annual mean temperature is due to drastic increases in GHG, doubled increase in minimum temperature and reduction of solar radiation at all parts of the country [27]. Changes in GHG, consequently alters the hydrological cycle in a more prominent way by radiative forcing than thermal forcing [28–30]. According to monthly gridded data derived from India Meteorological Department (IMD), the significant warming trend over India for period 1901–2010 is observed in the average annual surface air temperature. The observed changes in the surface air temperature over India are attributed to anthropogenic forcing [31].

7.3 Thunderstorm and Lightening

Disastrous Thunderstorm (TS) is mesoscale short lived (30–60 min). Weather phenomena has convective overturning available potential energy (CAPE), sufficient moisture, deep-tropospheric wind shear and strong parcel lifting mechanism [32, 33]. TS goes upto height of 2–20 km and associated with devastating gale wind, thunder, tornado, lightening, squall and torrential rain. Cloudburst is also a severe outbreak feature of TS, mostly occurs in S-Himalayan region during ISM [23] (Deshpande et al. 2018). In 2019, lightning and thunderstorms took more than 880 number of lives and exceeded 1500 live during year 2018 across the country [19]. TS is low latitude phenomena categorized into single cell, multiple cell and squall line (hail storms). More frequently formed during pre-monsoon season over eastern/north-eastern states of India known as 'Nor'wester or Kal-Baisakhi, and over NW parts of India is it called as "Andhis". Low pressure monsoon clouds travels in northern parts of Himalayan Mountain region and gives heavy downpour known as cloudburst. As per IMD's annual weather report 26 nos. of cloudbursts occurred in the year 2021 followed by eight in year 2018. TS moves from western India to north-eastwards towards Himalayan region. TS occurs in the late afternoon over continental areas and higher consistent with migration of inter tropical convergence zone (ITCZ) which is solar heating of Indian continents [34].

Lightening hits ground 08 million times per day and directly proportional to warming, 1 °C of warming could increase 50% TS. Also, higher CO_2 level will warm land surfaces, consequently stronger updrafts, results stronger storms (25%) and 5% higher lightening incidences. Lightening is a meso-scale, high spatial and temporal variability phenomena related with TS. Monsoon trough is a semi-permanent run from NW-India (Sriganganagar-prone to TS and lightening may trigger dangerous wildfires) to Head. After year 1970, lightning strikes frequency and intensity increased over South Asian region caused 33% troll of deaths than casualties caused by floods but still not recognized as a disastrous event. A belt of rapid heating and cooling of gases exists during downwind/upwind movement of lightening and nitrogen oxide production (pollutant) causes environmental as well as ground level ozone changes. Few Indian states initiated lightening risk management which reduced 70% of death caused by lightening.

7.4 Wildfire and CO_2 Due to Climate Change

Apart from floods, landslides, pests and diseases, droughts effect and heatwaves sustained by high temperatures pushes humidity and soil moisture degradation and favourable for wildfire trigger. Jolly [35] stated wildfire trends w.e.f. 1979 to 2013 has increased global mean fire season length by 18.7% and global frequency of long fire by 53.7%. Worsening of wildfires could jeopardise plans for future carbon removal and offset. Wildfires emanates a pall of increasing smoke trend from Siberia to North pole. In India, Simplipal forest of Odisha has ongoing forest fires [35] (https://en.wikipedia.org/wiki/2021_Simlipal_forest_fire). The ever-recorded forest fire happened in Peshtigo during 1871 which burnt 490,000 ha of land followed by California, 6 million burnt (40%) 6 million lands burnt followed by Antelope, Nevada placer, Caldor, Walkers, Dixie, Brazil, Bolivia during year 2021. Eastern Russia wildfire season took almost 1.6 and 5 million ha and release many millions of CO_2 in atmosphere. Extensive wildfire is alarm for extreme weather and needs urgent action to prevent catastrophic climate change. Carbon operated by Green Diamond Resource Company could engulf a quarter of the carbon offset (https://en.wikipedia.org/wiki/2021). Summit Creek and Shoal Creek has operated carbon offset projects by petroleum, they are best runaway for fires scorch. Carbon offset projects going up in smoke releases stored carbon back into atmosphere.

The IPCC [6] assessment report no. 6 (AR6) stated that under increased climate variability. There will be rise in the severity, recurrence of wildfires across many biomes, including tropical rainforests, Arctic and boreal ecosystems, Mediterranean-type ecosystems, degraded tropical forests, and tropical forest-savanna transition zones. IPCC report concedes that risks from wildfires are yet to be fully incorporated into climate models, a partial representation of wildfires project increases of 8–58 percentages in carbon emissions by fire and its varying mortality rate will have larger influence on carbon cycle rather than productivity. With the risk of fire releasing carbon, the question arises how to plant a tree with a physiology to cope with changing climate. Elevated CO_2 could lead to higher metabolism and growth rates in plants with restricted nutrients availability in soil. Such hinderance of critical nutrients may convert vegetation from being net carbon sinks to net carbon sources, denting the reliability of forests as dominant mode of carbon storage. Climate pressures and unmitigated fires have converted Amazon basin a net carbon source, rather than a sink, by reversing the historic trend of carbon absorption.

7.5 Glacier Melting and Sea Level

Westerly winds are a major source of moisture over NW Himalayan Glaciers and Karakoram range, but these glaciers' sufficient moisture intake during summer is already in the retreating mode. India: Climate Change Impacts [36] in the expected warming of about 2.5 °C, there will be glaciers and snow cover melt which will have threat of floods in Indus, Brahmputra rivers and Ganges have less risk due to its high annual downstream in monsoon season and less dependent on meltwater. River flow alterations could significantly impact on irrigation and may affect food production in the nearby basin for millions of livelihoods. Sea level rise can be determined by decrease rate in the mass of ice melt from Greenland and Antarctica. Before 1980, there was less ocean heat content and which increased after the year 1990. (IPCC, AR4). According to IPCC AR4, sea level rise was about 15% (1993–2003) but in the later years (2003–2010) enhanced by 40%. It is predicted that total loss of Greenland ice will increase sea level by 7 m as seen from Fig. 7. Ganaseelan [37] decadal sea level variability over SW tropical Indian ocean region known as Thermocline Ridge Region of Indian Ocean or open ocean upwelling region, decreasing towards south of the equator. Thermocline belt is associated with surface wind stress and has decreasing trend due weaker circulation of Indian ocean Hadley and Walker cell circulation can be attributed to increase GHG [38]. Consequences of exacerbated mean sea-level rise via coinciding with high tides and extreme weather events will threaten flood risk in coastal zones. Southern part of East coast viz. Andhra Pradesh, Orissa, Assam of India are more vulnerable place for climate change. However, global warming will persuade storm surges, wind wave, coastal flood risk during cyclones [39, 40]. Tide guage measurement observation noted highest water level plus existence of maximum force over North BoB and less force in south-west BoB. BoB has 64 almost 80% mortality caused by TCs (Paul 2009). In coastal catastrophes low lying region people (almost 310million) will be susceptible of extreme rise of sea level (ESL) [41]. Projected rise of sea level is a real caution for dense coastal population and poor infrastructure. Krishnan, A Report of the Ministry of Earth Sciences (MoES), Government of India) Cyclone conflates storm surge are due to climate change inducing sea level rise (Han et al. 2010). It is estimated that global steric sea level rise will be 18 $\pm$ 5 cm (relative to 1986–2005), under RCP4.5 scenario. Surge and tidewater glaciers have been expanding and most crop production is shrinking. There will be water shortage (drought) for nope water replacement situation whenever glaciers melts. Existing 11 nos. of Indian Himalayan glaciers are in the retreating phase. According to Naithani et al. (2001) and NASA earth observation news dated 09 Sept 2001 that 30.2 km $\times$ 0.5–2.5 km biggest range Gangotri in Uttarkashi district (Garhwal Himalaya) is too in the receding mode since year 1780. Since 1936–1996 (61 years), 1147 m glaciers have already melted with retreating rate as 19 m/year. In another series of data 1975–1999 (25 year), analysis, showed that glaciers retreated rate further accelerated to 34 m/year with 850 m melt of ice. According to Naithani et al. (2001), there is a sharp rate of retreating of glaciers of snout of Gangotri in the 1st half of twentieth century (from 1780s).

7.6 Aerosols and Pollutant

(Krishnan, A Report of the Ministry of Earth Sciences (MoES), Government of India), changes in the concentration of atmospheric constituents of GHGs by burning

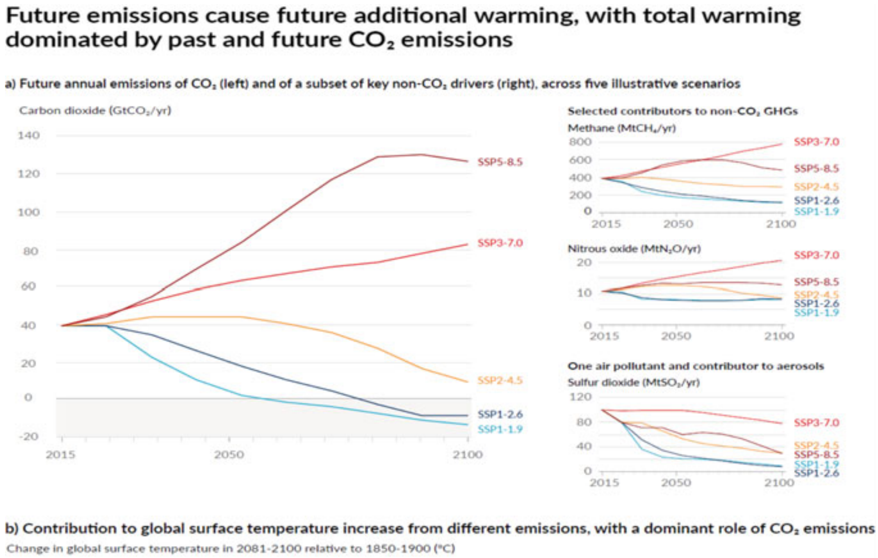

Fig. 7 Changes in global surface temperature in 2081–2100 w.r.t.1850–1900

of fossils, aerosols and LULC known as anthropogenic drivers of global climate change. Increased in global CO_2 from 280 to 407 ppm in 2018, radiative forcing (RF) about 2.1 W/m^2 in the topmost layer of atmosphere and further enhanced to 520 ppm in year 2021 this concept is known as "Climate Sensitivity". [36] IPCC, AR5 assessment predicted the radiative forcing range from −1.9 to −0.1 W/m^2 (excluding black carbon on snow and ice) and projected range −15 to +8 W/m^2 (top of the atmosphere), −49 to −31 W/m^2 in surface (Nair et al. 2016). (IPCC, AR6, 2021) IPCC AR6 reported already increased of aerosols (CH_4 as 1866 ppb and N_2O: 332 ppb) in year 2019.

Aerosols exhibits huge spatio-temporal variability, complex interactions with clouds and snow gives uncertainties in the estimation of the aerosol. These pollutants/aerosols further combine with melting glacier water (caused by warming) and produce everlasting foggy weather, reducing visibility and hampers air navigational services, producing respiratory diseases in human and crop-prone diseases. Also, in the risk of increasing population, industries, automobiles, volcanic eruption threatens air pollution by warming the environment and contributes devastating regional climate change. However, the deposition of black carbon on the Himalayan are accelerating melting of glaciers. Transportation of black carbon in the Artic circle is major cause in melting of ice caps [42]. The so-called "Atmospheric Brown Cloud," a transcontinental plume of air pollution affecting on earth and strongly linked with changes in Indian Summer monsoon (ISM) pattern, dimming of sunlight affecting on crop productivity. Black carbon responsible for unclean water is larger part of indoor pollution that causes illness, premature death, asthma, allergies, cardiac attacks etc. Panagariya mentioned that CO_2 is more beneficial for crops than offset effects of ozone, which interferes with photosynthesis and damages plant cells. Global yield fatalities due to ozone are estimated in the range 7–12% for wheat, 6–16% for soybean, 3–4% for rice, 3–5% for maize. In business scenario, India would account for half of this additional yield loss over the next two decades [43].

Simply addressing or citing air pollution for public health is not enough but state capacity and allocation of public resources to tighten regulation of air quality mandatorily be addressed. Cleaning up urban air pollution for ozone reduction will focused on public health benefits. Acknowledgment cum discussion towards improvement in air quality will support in cost–benefit analysis and Crop yield protection, redistribution of rural and urban pollution constituents should be bifurcated. Air pollution control, particularly ozone and black carbon are emerging topic in international discussions for mitigation. Existing international efforts to reduce air pollution have mostly been regional emissions commitments (such as the UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution Agreement) or voluntary collaboration across international networks such as the Clean Air Initiative for Asia's Cities.

7.7 Indian Agriculture, Forestry System and Climate Change

The incomparable flooding threat will unfit arable land for cultivation, will create food insecurity problems, farmer's revenue loss, negative GDP impact [9]. The UN's report of FAO stated that India will lose 18% of its rainfed cereal crop production, more than 400 million people at hander risk, 3 billion at risk of flood and without access of fresh water (Government of India). In view of increasing population, food grain requirement in India would be more than 250mt, arable areas by 191–215 mha and cropping intensity increase to 150% (Sinha et al. 1998). Mall [44] stated significant drop in yields of cereal crops like rice sugarcane, cotton, sunflower and wheat under climate change conditions.

Increasing temperature, water scarcity, sea level rising, intense cyclone and its associated rainfall, storm surge led inundation of salty water over land, risky for crop yield and drinking water are consequences climate change. These jeopardizing situations make soil incapable for agricultural land and create food insecurity. Under changes of rainfall variability and pattern stances the risk of 70% global rainfed agriculture land and 1.3 billion people who reliant on degrading agricultural land. Almost 60,000 people are killed yearly in the climate-related calamities doubled during the last two decades [45]. The agricultural field contributes almost 25% of GDP (Agriculture, 2002–2007 (TENTH FIVE YEAR PLAN 2002–07). Therefore, the application of modern technology may increase food grain such as rice, wheat, pulses etc. but climate change may decline. Further 0.5 °C rise in temperature may reduce wheat yield by 0.45 ton per ha (Jatav). World Bank report studied two drought-prone zones in India under climate change impact i.e. Andhra Pradesh, Maharashtra and one flood-prone region-Orissa have serious effects. In Andhra Pradesh, dryland farmers may see their incomes plunge by 20%. In Maharashtra, sugarcane yields may fall dramatically by 25–30%. In Orissa, increased flooding will drop rice yields by almost 12% in few districts (New World Bank Report Calls for Action to Reduce Climate Change Impacts, 2009).

Worst phases of the agricultural sector due to climate changes are scarcity of water, amplified atmospheric temperature, flooding/droughts and rise of sea level, decline arable land but this effect will be compensated by enhance CO_2 level. It will be more beneficial for C3 plants (rice, wheat, soybeans, fine grains, legumes, and most trees, etc.) than C4 plants (maize, millet, sorghum, and sugarcane etc.). (Mall) simulate various IPCC climate change scenarios over all parts of India and estimated increase in rice grain from 1.3% (the year 2010) to 25.7% (year 2070). An estimated 2 °C increase of maximum, 4 °C in minimum temperature, 10% reduction in monsoon rains, 5% reduction in the rainy days, and rise in carbon dioxide levels from 430 to 550 ppm, the overall 9% reduction of rice crop and growth of groundnut, Jowar, sunflower maize by 2%, 3%, 10% and 3% respectively. Predicted changes in temperatures and rainfall must be assess with impact of higher CO_2 emission. Agriculture sources are responsible for almost 18% of worldwide GHG emissions, potentially threatening the stratospheric ozone layer. If modern technology in cropping area, fertilizers application, animal population then the emission range will further be provoked from 32.84 Gg (1980–81) to 93.82 Gg (2000–01) per year over Indian continent. Nearly 20–100 times carbon converts into cropland with more carbon storage than vegetation and soils [10]. Environmental factors affected by climate change are:

Alteration in normal ISM rainfall pattern results yield reduction over rainfed areas, subdued fruit, vegetables quality, hampering coastal conventional agriculture practices, degradation of soil organic matter, fertility, erosion by inundation of salty water by sea level rise.

Alteration of application in pest and diseases due to increased pathogen transmission and sensitivity.

Eminent increase in concentration of CO_2 enhances C: N ration in plant which reduces decomposition and supplies nutrient, boost photosynthesis especially for C3 crop lessen evaporative losses. Decrease of grain filling duration because of higher respiration in deficient/scanty rainfall supplies [46, 47].

Higher sea surface temperature (SST) enhances, cyclonic activity, coral bleaching, breeding, migration and harvesting of fishes. Higher soil temperatures boost nitrogen mineralization, reduces accessibility due to increase of gases loss in volatilization and de-nitrification process.

Agro forestry is one of the best tool for compensation of CO_2 emission. It's smart farming offers resilient, future-proof viable production, land restoration, protection of biodiversity/food for growing population and powerful mitigation tool for global climate change. It is quickest and cheapest way to create and lock carbon stocks on behest of highly emitting businesses and polluting industries (Lovett, 2019). Forest ecosystem takes longer to adapt changes caused by migration or regrowth but a better way to reduce CO_2 [48]. Climate change causes irreversible damage to unique forest ecosystem and biodiversity with extinct of local, global species [6]. Longer period is needed for development and adaptation of forest biodiversity under climate change impact and requires shifts in forest/vegetation types for about 57–60% grid and 77% under climate projections (2085), forest dieback during the transient phase sectors. Variation in the global vegetation, forest ecosystem is impacted by climate change. There will be burden of unchanged biodiversity and exacerbation by socioeconomic pressures. According to State Forest report, India is a mega-biodiversity country that occupies almost 20% (64 million ha) of the geographical area (200,000 villages) classified as forest villages with large dependence on forest resources [49]. Being diverse and heterogeneous nature, Indian forests comes under the 'Miscellaneous Forest' category and shows the highest (63%) proportional area. Two most dominant forests are Shorea robusta or sal (12%) available in the eastern part of Central India and Tecton grandis or teak (9.5%), spread across Central India and in parts of Western Ghats over southern India. Non-uniform climate change in forest area varies precipitation ranges 550 mm/year for hardwood and 220 mm for bamboo forests/lue pine forests (Birundha, 2012). Paris agreement has done towards expansion of afforestation and almost 20 numbers of Nationally Determined Contributions (NDCs) participated to increase forest cover and trees, however, these targets were unequal and abysmally low. India is the third-highest annual polluter of GHG but scale of contribution is so insignificant and not comparable with the developed countries.

7.8 Afforestation

All levels track is recorded to understand impact of forest, and climate change on human beings, animals, birds, and ecology and inspire meaningful action. To face challenges without fear or favour of commercial or political influence, few action already being implemented by India [50].

Afforestation is resilient path to carbon sequestration and central planks of India's commitments towards the Paris Agreement. India plans to increase 10% of its existing forest-held carbon stock of 26.12 Gt CO_2eq. in the next decade upto year 2030, restoration of degraded (26 million ha) land for the additional sink (2.5–3.0 billion tonnes) of CO_2eq. Indian State of Forest Report (ISFR) stated in year 2019 that India is adding almost 76.86 million tonnes of CO_2eq. per year which is low rate to meet NDC as per the Paris agreement. Till 2050, India plans to increase about 30% of afforestation to offset emission and generate tradeable offset credits. Also, for wasteland utilization nearby 15% of land will be acquired for forest cover.

The recent escalation of wildfires across the world is a great challenge for mitigation plans, particularly in arid and semi-arid zones which are already prone to fire weather and ill-suited for soil nutrient profiles in woody vegetation. An increasing length/season trends of fire is risky for land and forest hence carbon sequestration is not whole option but best alternative choice which is still lagging behind. It disrupts natural cycles over non-forest ecosystems, affects interconnections on stored carbon, water, soil and bio-diversities. This risk is excluded in the afforestation project. Rather, biodiversity collaboration should boost data-based decision decision-making, generating trade-offs in local hydrology and livelihoods in some biomes.

Afforestation is a fastest and easiest path to remove CO_2 from the atmosphere. Ecological rebuilding is to make lowest risks, highest restoration of natural cycles in least damage. Every ecosystem has its own natural cycle that contribute significantly towards regulating and mitigating carbon.

7.9 Climate Change Impact on Indian Summer Monsoon (ISM)

In the last 65 years, India seen a three-fold increase in extreme rain events attributed to climate change [51]. Year 2020, India experienced abnormally high monsoon season rainfall, causing almost 2067 nos. deaths during floods/landslides and almost $10 billion property damages. In Kerala a single landslide in tea plantation triggered by rain has killed many lives, Assam floods affected more than 60,000 people. Hyderabad recorded 29.8 cm extreme rainfall in 24 h with much more casualties, deaths, and huge property losses. Climate change is making monsoon more chaotic and big threat to agriculture plus economy of country [52]. Generally, 110% of LPA, annual monsoon rainfall occurred in the country as a whole. And positive (wet conditions) standardized precipitation index (SPI) was noted in India during year 2020. In year 2020, SW-monsoon season experienced 12 nos. of low-pressure systems (01 severe cyclonic storm, 06 well marked low (WML) pressure areas and 05 low pressure areas). Heavy rainfall and flood related incidents claimed more than 600 lives. Serially 578, 237, 150, 16, 06 numbers of loss of lives occurred in the weather calamities viz. thunderstorm, lightning, cold wave, snowfall and squall respectively [53].

SW-monsoon for 2019 was 9% excess compare to long period average (LPA). Bihar was the worst affected state followed by Maharashtra, Uttar Pradesh, Kerala, Rajasthan and Karnataka by heavy rains and floods putting more than 2000 nos. of deaths. Year 2019 was the 7th late withdrawal (from entire country) of southwest monsoon on 25th October against normal date as 15th October since year 1975 [19]. With regard to Ocean and Cryosphere (SRCC), IPCC, AR6 reported warming of ocean, rapid changes in ISM, lengthy drought or heavy downpours spells and may have new rainfall normal. It is well noticed that ISM is already declined by 6% in areas of Indo-Gangetic plains and Western Ghats since year 1951–2015 (IPCC AR6, 2021 and MoES).

Clouds are warming wild card as they create feedback to warming in the climate change game since it reflects incoming sunlight i.e. more cloud more reflection more warming. Clouds act as insulator for longwave(earth's) radiation and more traps heat in the atmosphere. More cloud amount during day time could amplify warming and consequently thunderstorm event. Cloud feedback properties regarding warming issue is dependent on the type, altitude, season of cloud [54]. Warm air holds more moisture, more evaporation from land and leads to droughts, wildfires or excess amount of moisture may produces precipitation causing floods. When warm and moist air with slow wind speed blows over region, it gives cloudburst rainfall incidents. When compare in the past scenario, now a days India is experiencing more cloudburst over Uttarakhand, Mumbai, Himachal Pradesh, Kashmir, Kerala etc. almost many parts of country. These events are likely to alter hydrological cycle [55]. 1951–2010 data analysed that there is considerable decreased in the northward propagation of ISM by 20–60 days may be attributed to weakening of global circulation in monsoon season. This propagation reduction is compensated by variability in the active phase of monsoon. But during monsoon break or transition phase, extreme rainfall events are increasing [56, 57]. Analysis of data series 1981–2011, increase in the frequency of dry spell (27%) than wet spell compares to data series 1951–1980. But, in break monsoon situation, monsoon active spells increased about 12% (by 3–6 days) compare to period 1951–2010 [58] According to Singh [59] there is statistically significant increase in the frequency of dry spells and intensity of wet spells, and statistically significant decreases in the intensity of dry spells has been observed [59]. All changes are attributed to warming of sea surface temperature of Indian Ocean (Sabeerali et al. 2015).

7.9.1 Weather System Associated with ISM and Climate Change

Southwest monsoon normally sets in over Kerala around 1st June, advances northwards, in surges, and covers the entire country around 15th of July. Withdrawal of SW monsoon takes place from NW part of India during September. Since year 1976, shift of monsoon onset over India is noticed may be due to less moisture supply from Arabian Sea [60] variability of monsoon onset date relates with ENSO or La Nina [61]. Rise in the mean daily rainfall over Kerala is the special characteristic for declaring onset of Indian summer monsoon and is indicator of transition from dry season to wet rainy season [62] (IMD criteria), [63, 64]. Robust rise in SST over the warm pool may be due to increase in GHG gives east–west shift of monsoon rainfall. This gives more rain in tropical western Pacific and less precipitation in South Asia i.e., alters atmospheric circulation. Dry and cool air in BoB is advected from NE which is the main source of E-W shift of monsoonal trough. SST warming is augmented [65].

Decadal, Intra-seasonal Fluctuations, Synoptic Systems

After 1980, an increased in the global mean precipitation will be increased with rates as 0–5% (RCP1.9), 1.5–8% for (RCP4.5) 1.5–8%, (RCP8.5) as 1–13% is estimated for years 2081–2100 with respect to reference years as 1995–2014. Moderately increasing tendency of ISM over 27 out of 36 subdivisions in India and decreasing seasonal rainfall trend observed in Jharkhand, Chhattisgarh, and Kerala, and eight subdivisions viz. Gangetic WB, West UP, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra, Rayalaseema, Coastal AP and North Interior Karnataka [66]. In the observational data set 1979–2005, it was noticed that east-central India categorized with high rainfall zone, NW India, northern Kashmir, Northern Himalayan

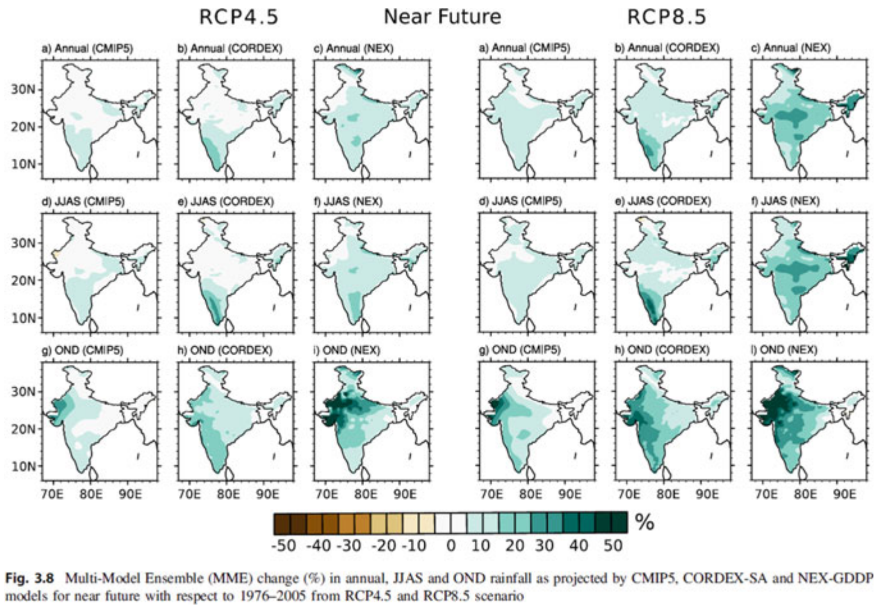

Fig. 8 Mean precipitation (1976–2005) from multi-model ensemble simulation for annual, JJAS, OND seasons from CMIP5, CORDEX-SA and NEX-GDDP experiments

region, SE-India recognized under rain shadow areas [67, 68]. Gridded data from 1901 to 2015 showed statistically significant decreasing annual and seasonal rainfall trends over Kerala, western Ghats, few NE states. But significant increasing trend in rainfall over Gujarat, Konkan coast, Goa, J&K, and east coast. Rainfall data (1959–2016) observed that Climate change affects SW or NE monsoon season which observed in increased seasonal variability over India and enhances extremely heavy rainfall intensity when compare with data 1901–1958 [69].

Spatial variability in precipitation is observed during 1976–2015 rainfall over central India has considerable reduced by 1–5 mm/day in comparison with period 1901–1975 (Kerala, NE-India and increased over J&K, Western-India (Precipitation Changes in India, 2020, MoES). Spatial changes may be attributed to anthropogenic aerosols, land-use-land-change (LULC), urbanization, agricultural intensification etc. [70]. Almost for three decades (1951–2015 and 1986–2015) declining trend without statistically significant of ISM is observed. However, in data period 1951–2004, 1971–2002 showed downward trend of ISM and attributed to (a) Weakening monsoon Hadley circulation, (b) E-W shifting of monsoon belt by anomalous warming of the Indo-Pacific warm pool [65, 66] and (c) Land–ocean temperature gradient weakening (Figs. 8 and 9) [13].

The average ISM for a long period shows increasing heavy rainfall (Goswami et al. 2006). Projected changes in rainfall analysis is very important for policy making, mitigation/adaptation strategies and preparedness for extreme weather hazards. Such future changes are categorized as near future (2040–2069) and far future(2070–2099)

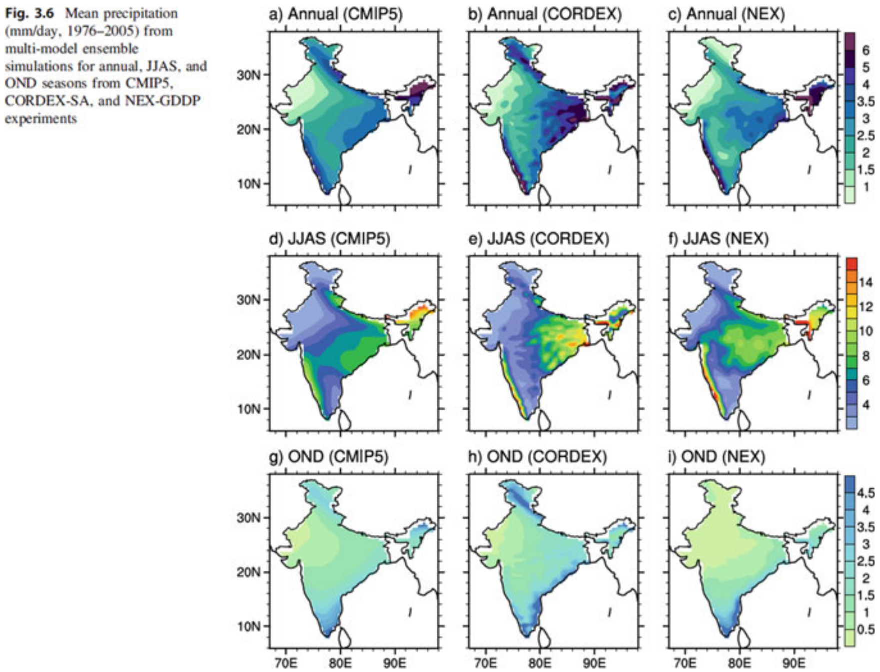

Fig. 9 Annual, seasonal mean precipitation from data 1976–2005

epochs which describes annual, summer (JJAS) and winter (OND) season rainfall over the Indian continent. Reference year for projected data is 1976–2005.

RCP8.5 scenario, winter season showed maximum variability (Singh and Achutarao 2018), RCP4.5 emission scenario models suggested wetter condition over India but winter season at NE-India showed deficit rainfall in near future. CORDEX model gave less rain Himachal Pradesh and Jammu belt. An increase in the annual mean rainfall at West coast (10%) and southern India (20%) and rest of country precipitation changes are not significant till 2100 AD. But Reliability Ensemble Average (REA) gave uncertainty for projected annual rainfall. Li et al. (2017) showed that simulated CMIP5 models has +ve IOD and associated with less ISM rainfall with uncertainties while increased SST may give weak ENSO-monsoon relationship. Further, natural variability plays the main role in varied ENSO-monsoon relationship during twentieth and twenty-first century (Li and Ting 2015). Wetter future scenarios in the near future are estimated by CMIPS multi-model with increase 6% in (RCP4.5), 8% in (RCP8.5) in the twenty-first century which will be further increased by 10% (RCP4.5) and 14% (RCP8.5) over central Indian region (core monsoon zone defined [63]). Most of CMIP models shows higher monsoon precipitation due to global warming (e.g., Kitoh et al. 1997; Douville et al. 2000; Ueda et al. 2006; Cherchi et al. 2011; Rajendran et al. 2012; Krishnan et al. 2013). But weakening of large-scale monsoonal circulation is quoted by Krishnan et al. 2016, with many ambiguities in understanding the future changes in projected monsoon rainfall or hydroclimatic response (e.g., Chaturvedi et al. 2012; Saha et al. 2014; Sharmila et al. 2015; Krishnan et al. 2016) (Assessment of Climate Change over Indian Region-Report_MoES, pg. 78).

Water holding capacity of the atmosphere is expected to increase by about 7% per degree of warming after application of Clausius–Clapeyron equation [71]. More global precipitation may take place due to increased moisture supply in atmosphere with favorable local dynamic, thermodynamic systems [72, 73]. Most of simulation models estimates increased ISM by almost 5–10% while some models suggested it in a lower range. Movements of ITCZ brings rainfall and convective cloud belts over Indian land, this is exclusively related with circulation pattern (MoES, pg. 60, and Goswami 2006; Joseph and Sabin 2008; Gadgil 2018). Such convective link shows weak in CMIP5 models with increased precipitation irrespective of anomalous decrease of monsoon circulation (Krishnan et al. 2016). Sabeerali et al. (2015) suggested that increase in future ISMR is solely due to local convective systems and not related to large-scale monsoon dynamics.

Analysis of CMIP5 output by Sabeerali and Ajaymohan (2018) showed likelihood of shorter rainy season possibility in the end of twenty-first century under RCP 8.5 emission scenario (defined using tropospheric temperature gradient as outlined by Goswami and Xavier (2005). With uncertainties of CMIP5 model showed enhance interannual variation in mean value of ISM (Menon et al. 2013). Sarita and Rajeevan (2016) recommended serious effect of El-Nino on monsoon interannual timescale and predicted increase of precipitable water over Indian continents by almost 8–16 mm/day, evapotranspiration by 0.6 mm/day, change of moisture convergence around 2.4 mm/day under RCP8.5 scenario. Variations in ISM rainfall(above/below/normal) for three decades are studied. (e.g., Parthasarathy et al. 1991a, b; Kripalani and Kulkarni 1997). All observational, paleo-climate and simulated studies shows increased ISM rainfall during positive phase of Atlantic Multidecadal Oscillation (AMO) (Goswami et al. 2006; Joshi and Rai 2015; Krishnamurthy and Krishnamurthy 2015).

Increased SSTs over North Pacific Ocean (decadal), Pacific Decadal Oscillation (PDO-two decades) (e.g., Mantua and Hare 2002), may lead to decreased ISM rainfall (e.g. Krishnan and Sugi 2003; Krishnamurthy and Krishnamurthy 2013). Interdecadal component of variability of ISM and Nino-3 SST relationship reflects the importance of El Nino-Monsoon relationship (Parthasarathy et al. 1994; Kripalani et al. 1997; Kripalani and Kulkarni 1997; Mehta and Lau 1997; Krishnamurthy and Goswami 2000). Summer monsoon has large impact on rainfall of Indian continents with variability(decadal) of alternate wet (above normal) and dry (below normal) spells of monsoon for a period of almost 150 years (Kripalani and Kulkarni 2001; Joseph et al. 2016; Preethi et al. 2017).

Strength of summer monsoon rainfall is modulated by the intra-seasonal variability characterized by the active/break spells of enhanced/decreased precipitation over India whether to keep these many authors or delete it-[74] (Ramamurthy 1969; Rodwell 1997; Webster et al. 1998; Krishnan et al. 2000; Krishnamurthy and Shukla 2000, 2007, 2008; Annamalai and Slingo 2001; Goswami and Ajayamohan

2001; Lawrence and Webster 2001; De and Mukhopadhyay 2002; Goswami et al. 2003; Waliser et al. 2003; Kripalani et al. 2004; Wang et al. 2005; Mandke et al. 2007; Goswami 2005; Waliser 2006). The decadal analysis of ISM by IITM (Sh. C. Gnanaseelan, Scientist 'C'), Pune revealed that magnitude of rainfall received in the Southern western ghat is increased by 1.5 or 2 times with each passing decades (i.e., during the latter half of twentieth century). This decadal variation in rainfall is attributed to changes in the circulation of Pacific Ocean, deforestation, migration, mining, industrialization etc. Later, in 1978, western ghats decadal rainfall variation became more prominent and receives 14 mm/day whereas other parts of the country receive 7 mm/day rainfall during SW-Monsoon season. However, the study observed that western ghats experienced excess rainfall as well as deficit rainfall years. We know that western ghats is well known for its biodiversity, endemicity and is internationally recognized and windward side always gets more annual rainfall than other regions.

Monsoon variability is governed due to gradual change in surface features. ISOs are influenced by continental monsoon trough, tropical nature synoptic systems such as lows, depressions, deep depression develops over Head or north Bay of Bengal (Shukla 1987; Yasunari 1979; Sikka and Gadgil 1980). Synoptic system moves along monsoon trough in W or NW direction during monsoon season and play important role for declaration of onset, withdrawal and propagation of Indian summer monsoon. Within 30–60, ISM propogation take place in northward and westward propagating in 10–20-day (e.g., Krishnamurti and Bhalme 1976; Keshavamurty and Sankar Rao 1992). Monsoon intra-seasonal oscillation plays vital role in influencing the seasonal mean, and its interannual variability (e.g. Goswami and Chakravorty 2017). Climate or seasons is defined as reversal of wind or seasonal migration of Inter Tropical Converse Zone (ITCZ) and its associated shifting of rain belt from southern hemisphere to northern hemisphere or vice-versa. The global phenomena known as Indian summer monsoon, or South Asian monsoon or South-west summer monsoon is global phenomena. Indian summer monsoon contributes more than 80% of annual rainfall (Porter et al. 2014, Parthasarathy et al. 1988; Gadgil 2007). Crop simulation model and worldwide high-resolution climate model showed the abrupt changes (declining trend with high variability) and extending period in Indian Summer Monsoon (Berkelhammer et al. 2012; Sanyal and Sinha 2010).

India has huge coastline and facing enormous iconic climate change implications. Global warming linkage with El-Nino impacts on Indian monsoon is likely to be doubled in future. Economical survey stated that average 100 mm drop of rainfall will reduce farmer's income by 15% in the *Kharif* season and 7% in rabi crop season, overall reduction of annual agriculture income ranges from 15 to 18% for irrigated and 20–25% over unirrigated areas [75]. Increase in farmer's uncertainty needs crop insurance, technology for irrigation for farming resilient towards susceptibility minimization. In the winter season (December-February), a low-pressure system known as Western disturbances (WD) originated in the Mediterranean Sea travel towards Indian northern latitudes and give rainfall due to orographic land–atmosphere interactions in the Himalayan region [76, 77]. Cold masses from Siberian High travels in a southward direction towards tropics and interacts with northern latitudes of

India cools surface air temperature and consequently formation of fog persists. SE-peninsular India comes under rain shadow category in the SW monsoon season. During October-December rainfall belt shifts towards South-India, wind direction reversed and becomes NE termed as NE-Monsoon season. Normal onset dates of NE monsoon are 20th October with deviation of 7–8 days (Raj 1992). The northeast monsoon rainfall has more (28%) interannual variability than SW-monsoon rainfall (11%) (Nageswara Rao 1999; Sreekala et al. 2011). Kumar et al. [78], found strong relationship between ENSO and NE-monsoon in the analysis of data from 1979 to 2005, weak association for decade of 2001–2010 [79]. Impact of IOD, wind-sea interaction in Indian Ocean led to alter NE-monsoon rainfall [80, 81].

Over Indian continent (Tamil Nadu and Coastal Andhra Pradesh) projected (RCP4.5 and RCP8.5 emission scenario) data demonstrated modest increased rainfall CMIP5 (10–20%), CORDEX (10–25%) and NEX (15–35%). NE-monsoon while actual data showed it larger compared to the SW-monsoons. In the twenty-first century NE-monsoon will have strong reduction in wind intensity (average 3.5% in RCP4.5 and 6.5% for RCP8.5) and shows increased rainfall (10 $\pm$ 2%) over equatorial Indian ocean.

Madden–Julian Oscillations (MJO) originates in Indian Ocean, travels eastward (30–40-day scale) along near-equatorial belt triggers northward moving convective clouds. Occasionally MJO interact with northern extratropical systems and gives extremely heavy rainfall in northern India [82]. ENSO, MJO, EQUINOO and IOD has major role in for changes of ISM rainfall variability under climate change impact. IOD and EQUINOO are positively related to ISM rainfall and weakens El-Nino impact on ISM. The index of EQUINOO is "EQWIN" calculated from zonal wind anomaly or OLR anomalies in central equatorial Indian Ocean. EQWIN is oscillation between enhance and suppressed convection/precipitation. The major findings of Gadgil [83] from 1958 to 2004 that separation of drought from excess rainfall is well-defined and in phase-plane of EQWIN and ENSO index. Climate model simulation analysis EQUINRAIN is useful index to study EQUINOO and its linkage with regional climate. The inter-annual variation of ISMR is marked by drought, characterized by negative and excess rainfall value by positive index values. Despite of IOD, ENSO, there is a strong link between ISM rainfall and equatorial Indian Ocean oscillation (EQUINOO; [83]). Rapid warming of Indian ocean affects negatively on ISM rainfall [84]. Robust rise in SST over the warm pool may be due to increase in GHG gives east–west shift of monsoon rainfall. More rain in tropical western Pacific and less precipitation in South Asia i.e. alters atmospheric circulation. Dry and cool air in BoB is advected from NE which is the main source of shift of E-W monsoonal trough.

Winter and Spring season's positive Eurasian snow cover anomalies give deficit ISM rainfall and negative snow cover anomaly give excess ISM rainfall [85–87]. Non-ENSO droughts in India are associated with excessive snow depth of Eurasia [88]. Drought related to ENSO episodes, weaker ENSO-Monsoon also gives drought (Kripalani and Kulkarni 1997; Krishna Kumar et al. 1999). Mountainous terrains of Western Ghats (WG), Himalaya, North and NE India acts as barrier to warm moist SW-monsoonal wind and have maximum rainfall episodes (upto 800 m height) in the windward side and leeward side turns out to be rain shadow area [89, 90]. Nearly 80% of the annual rainfall occurs in the Himalayan and WG regions. Changes in frequency, intensity and speed of intra-seasonal oscillations are attributed to warm Sea Surface Temperature (SST), low-level convergence, high convective available potential energy (CAPE) and low convective inhibition (CIN) [59] (Maheskumar et al. 2014). Convective system varies from western side to eastern (foothills of Himalayas). Climate change has reduced rainy days (>15 days) in western and central parts of India while Himalayan foothills and NE-India rainy days increased by 5–10 days.

The monsoonal paleo-climatological data shows reduction of solar radiation in Northern hemisphere which causes southwards migration ITCZ (Cheng et al. 2016; Chao and Chen 2001). Also, tree ring-based study for the last 200 years in the Himalayan region found declining trend of ISM may be attributed to decreased solar insolation, higher GHG warming, and anthropogenic aerosol emissions (Xu et al. 2013; Shi et al. 2017). Moreover, several wet/dry spell occurrences on multi-decadal and centennial scale give summer monsoon reduction (Chao and Chen 2001; Sinha et al. 2011; Prasad et al. 2014).

7.9.2 Anthropogenic, Upper Air Circulation, ISM and Climate Change

Aerosols of earth-atmosphere interacts with solar radiation, clouds influences monsoon circulation and effective rainfall distribution. Crop model simulation shows high dry bias in ISM in western and central parts of India Sabin et al. (2013).

Observed changes in mean monsoon rainfall in India during 1951–2005 may attributed to anthropogenic aerosol effect, warming of equatorial Indian Ocean, land-use/land-cover change (Krishnan et al. 2016) plus other regional forcing. Global warming is due to rise in atmospheric GHG which alters global and regional rainfall pattern [91].

Shrinking of Thermal Tropical Easterly Jet (TEJ) areas (Pattanaik and Satyan 2000) and easterly shear before year 2005 (Sathiyamoorthy 2005) but later on increased it @ of 1 m/s/year (Roja Raman et al. 2009; Venkat Ratnam et al. 2013) over South Asian region may be attributed to:

Reduction of N-S temperature gradient from equator and 20° N long. belt of 40° E–100° E (i.e., more temperature in equatorial side compare to North) and such variation is more prominent above 500 hPa level [23].

Equatorial Indian Ocean warming resulted declining trend of upper-tropospheric meridional temperature gradient.

Excessive convection arose due to increase SST in Indian Ocean (Joseph and Sabin 2008), Cooling of upper-tropospheric temperature over Tibetan anticyclone region.

Decrease of tropospheric temperature over Asia region affects thermal contrast in meridional and zonal land-sea thermal contrasts weaken ISM.

After year 1950, weak monsoonal Hadley cell circulation reduces SW flow (Low level Jet-LLJ) (Joseph and Simon 2005; Krishnan et al. 2013). Such circulation anomalies make Indian continent as Heat Sink (Zuo et al. 2012).

In 2002–2014 decade, more warming of Indian sub-continents and slower rate of warming ocean are favorable land–ocean temperature gradient enables Indian Monsoon revival on short term basis (Jin and Wang 2017). Then faster warming of Indian Ocean than global oceans have impact on ISM variability (Roxy et al. 2014) and has a powerful role in decreasing trend of ISM rainfall (Preethi et al. 2017). Singh et al. [59] found statistically significant increase in the intensity and frequency of extreme wet or dry spells of ISM during the 1951–2011 but increased local heavy rainfall frequency observed in India in years from 1951 to 2015, attributed to aerosol concentration, urbanization, land use in northern hemisphere. Climate models projection that global warming circumstances and anticipated reduction of aerosol concentrations, increase annual rainfall, heavy rainfall frequency, inter-annual variability of summer monsoon rainfall over many parts of the India. Evidence of such extremely heavy rainfall and vigorous SW-monsoon are observed in cloudburst event ensued in Kerala, Uttarakhand, Himachal Pradesh and Mumbai city causes loss of properties, livelihood, economy and agriculture. Year 1998 was the warmest year since then no such significant warming took place. Tropical zone may repeatedly face severe droughts with increased probabilities. Therefore, drought predictions should be also operationalized. Global warming makes weak association between ENSO and ISM (Krishna Kumar et al. 1999).

7.9.3 Causes of Changes in ISM

Changes in land use/land cover (LULC) (Niyogi et al. 2010; Pathak et al. 2014; Paul et al. 2016; Krishnan et al. 2016).

Strong Atlantic Multidecadal Oscillation (AMO), weakening meridional temperature gradient causes early withdrawal of monsoon from India and ultimately reduction of mean monsoonal rainfall (Goswami et al. 2006).

Rapid warming in western Indian ocean, reduces meridional temperature gradient and effectively monsoon circulation [25] (Roxy 2015; Roxy et al. 2015). Enhancement of anthropogenic aerosols in Northern hemisphere reduces tropical meridional upward circulation (Ramanathan et al. 2005; Chung and Ramanathan 2006; Bollasina et al. 2011, 2014).

Increasing trends in decadal oscillation over Pacific ocean (Salzmann and Cherian 2015).

Increase in the duration and frequency of 'monsoon-breaks' over India is observed since 1970s (e.g., Ramesh Kumar et al. 2009; Turner and Hannachi 2010).

Weakening of low-level jet stream, upper-tropospheric tropical easterlies and large-scale monsoon meridional circulations (Rao et al. 2010; Joseph and Simon 2005; Sathiyamoorthy 2005; Fan et al. 2010; Krishnan et al. 2013).

7.9.4 Daily Extreme and Projected Precipitation

Unexpected abrupt exceeding (more than 100 mm) precipitation within less than an hour's time is known as **cloudburst** usually associated with hail and thunder. Majority of cloudbursts occurs in mountainous region due to low-pressure formation. Western elevated (1000–2500 m) Himalayan region over geographical area between 20 and 30 km is more prone to cloudburst. During 1970–2016, more than 30 cloudbursts occurred over south rim of Himalayan region amongst which 17 cloudbursts happened over Garhwal (Uttarakhand district). It is observed that annual weather-related disasters have been increased since year 1980. Accurate QPF and numerical weather prediction (NWP) model forecasting is prime factor. Sometimes flash floods, i.e., rapid submerging of rainwater within several hours caused by heavy rain from downstream of storm or melting of snow, which has been seen in the Indian cities since last few years. Extreme rainfall event has devastating impact such as landslide, damage of properties. Loss of livelihoods. Fresh live instance experienced in Uttarakhand, Himachal Pradesh, Mumbai (2015), Pune, Kolhapur, Kerala (2018, 2021), Hyderabad etc. largely attributed to anthropogenic climate change. Anticipated warming trend may give more dangerous and severe weather consequences.

Singh et al. [59] found an increase in Dry spell (05 days) spell, lessening wet days and prolonged break spells for rainfall data (1951–2015). More intensity and frequency of heavy rainfall events over central India and declining or moderate trend over south Indian zone is also noted [51] (Goswami et al. 2006; Dash et al. 2009; Kulkarni et al. 2017; Krishnan et al. 2016). But more prominent reason are low dynamical energetics and thermo-dynamical factors are found by Krishnan et al. 2016. Higher atmospheric moisture weakens easterly vertical shear of South Asian Monsoon (SAM). In monsoon season, dynamic factor (deep local convection), sufficient atmospheric moisture, anthropogenic pollution, weak vertical shear etc. are responsible for local heavy rainfall. Large variability of low-level monsoon westerlies, warming phase of north Arabian Sea enhances moisture supply needed for extreme rainfall events to occur [51] (Mishra et al. 2018).

Climate modelers used *representative concentration pathways (RCP)* or *shared socioeconomic pathways (SSP)* as a standardized future scenarios. Globally averaged precipitation over land is increased since 1950 compare to 1980. It is observed that human influence and surface ocean salinity contributed the changes in rainfall pattern during the mid-20th century. Since 1980 mid-latitudinal storm tracks, extratropical jet of austral summer are shifted poleward (with marked seasonality trend) in both hemispheres. Projected model simulation showed 15 days decline of rainy days over western and central parts of India. But there will be rise (5–10 days) in the rainy days over foothills of Himalayas and northeast India during future 50 years. But rainfall intensity is predicted to rise in the range of 1–4 mm/per day except for small areas of NW-India. Further, the severity of droughts and intensity of floods in many parts of India is projected to increase with reduction in existing run-offs. Extreme rainfall and its intensity will rise over Indian continents (Sillmann et al. 2013; Goswami et al. 2006; Rao et al. 2014). Mukherjee et al. (2017) found 10–30% increase in the precipitation maxima under RCP8.5 scenario over southern and central parts of India up to twenty-first century. The multi-model also projected that there will be modest enhancement of intense wet days w.r.t. total wet days precipitation. Evidences of increase in the rainfall maxima by 5-days along west-coast, central and northern India under RCP4.5. While in the near and far future under RCP8.5 emission scenario there will be increased in dry days' frequencies over peninsular India is projected. Such analysis is in agreement with the study of Mukherjee et al. (2017).

7.9.5 Climate Change and Water Resources

Everyone must be aware and motivated to adopt water conservation techniques (micro-irrigation system), use of water infiltration, decreasing runoff, soil aggregation, trimming down soil evaporation by mulching or crop residues etc. Constant isotope from soil wetness source over Asian summer monsoon in current and ancient climatic system reveals a strong association between moisture generator and their transportation pattern. It is specified by dissimilarities in soil moisture regimes which was conserved in the previous glacial era. Maximum investments needed for water storage capacity benefits from. According to ministry of Water Resources, water demand will be enhanced in future due to increasing population, expansion of agriculture, industrialization etc. Shortage of water and water availability per person from 3,450 cm (1951) to 1,250 cm (1999) and expected to further decrease up to 760 cm till year-2050. Sustained warming will give less rainfall, more evapotranspiration, significantly lowering of runoff, decline soil moisture, more soil temperature etc. will increase arid zones. In the year 2050, annual runoff of Brahmaputra River will decline by 14%, rapid decay of Himalayan glaciers shrinks from 5,00,000 to 1,00,000 km^2. One worried situation in Himalayan area is hydropower which is partial solution of India's energy requirement. Thus, climate change will reduce efficient planning of investment in India. Surplus changes in the global hydrological cycle affects ground water, surface water supply, variation in the runoff (may create flood runoff or water deficit scenario) which will give drought like situation. India is the developing country plus more climate variability and has a low capacity for adaptation. Gosain et al. (2006) analysed from HadRM2 daily weather data and revealed that under GHG emission there will be substantive reduction in the quantity of existing available runoff. Status of few rivers in India can be narrated here to know the water resources. West-flowing rivers of Kutch, Saurashtra, Luni which occupies 1/4th area of Gujrat and 60% area of Rajasthan and rivers such as Mahi, Pennar, Sabarmati, Tapi, basins of Cauvery, Ganga, Narmada and Krishna will face water shortage on regular or seasonal basis. On the contrary, river basins of Godavari, Brahmani and Mahanadi are predicted to face severe flood conditions. Under continued global warming, it is projected that global water cycle variability will further intensify alongwith global monsoon precipitation and severity of wet or dry events in surface water flow on seasonal as well as annual basis over Indian landmasses. However, few findings which may shorten water resources are mentioned as:

Shifting of mid-latitudinal storms track and its associated rainfall towards pole will be counteracted by stratospheric ozone effect.

In higher emission scenario, the ocean and landmass carbon sinks will turn out to be less effective, rather they will act as source for CO_2 concentration upto twenty-first century. Climate models have not included warming effect on CO_2 and CH_4 fluxes from wetlands, permafrost thaw, wildfires etc. which will be increased further. But projected CO_2 concentration is still uncertain and carbon sinks need to be stabilized. Atmospheric CO_2 concentration will be accounted in the Carbon Cycle budget.

In the historical period (1850–2019) land and ocean sink acquired 59% of the emissions. This emission is calculated from the net biome productivity on land (irreversible for any ice sheet, sea level rise), reduction of CO_2 by land-use changes emissions, net ocean CO_2 flux in the CMIP5 simulation.

Projected model analysis threatened sea level rise issue to be happened for centuries to millennia period and will continue to remain elevated for many years due to ongoing deep ocean warming, ice sheet/glaciers melting and increasing of black carbon concentration. Under restricted warming up to 1.5 °C, likelihood sea level rise will be 2–3 m, at 2 °C warming, sea level may reach up to 2–6 m and for 5 °C warming, sea level is predicted to rise by 19–22 m.

7.9.6 Water Resource Shortage and Consequences

Economic development is intrinsically related with global warming caused by indiscriminate exploitation of natural resources and destruction of environment. Anthropogenic made year 2016 treated as hottest with highest deaths, loss of properties followed by other years. Planet's warm years started from 2001, scientist pinioned that global warming should not exceed 2 °C. Consequences of global warming scenario are major threat for acidification, hastening land degradation, desertification, wildfires, droughts, poor water quality, loss of trees, plants (crucial for absorbing atmospheric CO_2), exacerbation of frequency and intensity of extreme weather events like cyclones, fire, floods, vast coastline implications, twice melting of Artic ice than other parts of globe. Shortfall in rain will make major rivers in stressful condition. Gujrat, MP and Indo-Gangetic plains are well irrigated while Karnataka, Maharashtra, Madhya Pradesh, Rajasthan, Chhattisgarh and Jharkhand states are most vulnerable to climate change since of poor irrigated. Indian country has almost 400 nos. of rivers amongst which 08 nos. are of major type. Increasing water demand in growing population, industries, agriculture coupled with economic activity are adding pressure on already accentuated uneven distributed water stress. Hence, application of augmentation of water supply in rich water-region and supply it towards water scare region will the effect way to overcome water stress.

Groundwater is not uniform, plays an important role in the India's economy but unregulated extraction and its overuse causes plummet, drying springs and aquifers in many parts of the country. Now, situation became alarming where groundwater exploitation exceeds replenishment like Haryana, Punjab and Rajasthan draws more water than annually replenished. Many places water has high salt concentration which is not potable. Agricultural sector consumes maximum water escalate from urbanization and industrialization with more prone to droughts. Hence management of water resources is very precious. Fortunately, India is endowed and surrounded with vast sea water resources so purification of seawater supply with formulated strategy and development plan which will help people immensely. In seawater purification project, energy or fuel utilization should be taken from natural abundance available solar or wind energy source to reduces production cost. India also has few pragmatic issues which are narrated in the next para.

7.9.7 Highlights of Water Dispute in India

Much of India's water comes from China, if China faces water shortage problems or diverts these waters northwards then what should be the steps of India in such situation? As per policy perspective, climate induced changes necessitate more exploration measures for conservation and development of water resources. India must undertake and implement schemes even in the absence of climate change scenario. Requirement of more prudent utilization of surface and ground water through appropriate planning such as pricing, training, harvesting of rainwater, building of dams, development of water distributional networks, re-forestation and restock of ground water must be executed. Because everyone knows that conservation of agriculture and for import of food grains proper utilization of water becomes mandatory for its survival. Maximum parts in India are already facing water scarcity issue with and without Climate change and the situation is worsening day-by-day. Urbanization, population growth, economic development, increasing demand for water in agriculture and industries are likely to aggravate the situation further and will become a big challenge. Various studies showed that increase in the variability of monsoonal rainfall will enhance water shortage and is a big threat for central India, mountain ranges of Western Ghats and NE states of India.

Incentivize people towards efficient use of ground water resources, implementation of drip irrigation system, rain water harvesting for controlling water wastage. Prior to climate Change announcement, 15% groundwater resources are already overexploited in India due to increasing water demand under growing population, affluent life styles, industrialization, anthropogenic emission. Further, to adopt crop diversification, efficient and improved soil management practices, development of drought-resistant crops can help to reduce negative impacts of climate change to some extent. The Indus and the Ganges–Brahmaputra-Meghna Basins are major trans boundary rivers, and increasing demand for water sharing is already leading to tensions in the country. Economic status is directly or indirectly impacted by variety of natural phenomena.

India has a vast coastline and facing enormous iconic climate change implications. Global warming linkage with El-nino impacts on Indian monsoon is likely to be doubled in future. Economical survey stated that average 100 mm drop of rainfall will reduce farmer's income by 15% in the kharif season and 7% in rabi crop season, overall reduction of annual agriculture income ranges from 15 to 18% for irrigated and 20–25% over unirrigated areas. Increase in farmer's uncertainty will need crop insurance, application of irrigation technology for farming resilient to minimise susceptibility. Shortfall in rain will make major rivers in stressful condition.

8 Climatic Risk Assessment

Need of adaptation and mitigation is to avoid substantial human interference in climate system, alleviate GHG level in a typical timeframe so that ecosystem can adopt natural climate change. Facing climate change is tough and largest challenges for scientists, economics, politics, meteorologist and agro-meteorologist community. CO_2 trapped heat lingers in environment for about 100 years but due to higher heat capacity of ocean, it takes time to warm-up. Presently, even if we stop emitting all GHG still global warming and climate change will continue to affect our future generations. India's, mitigation mainly impose/ focus on two sets which compromises poverty alleviation and provision of basic amenities (food, shelter, clothing) against extreme weather events. Lengthy observation and prolonged modelling are critical to understand and predict ocean and cryosphere, therefore risk assessment and adaptation planning becomes mandatory for India. Indian government and semi-government institutions launched lightening app, setting up of lightening detection instrument network, extreme/short weather forecast within a radius of 40–50 km.

India's trial to contribute towards mitigation obligation has already begun. Being developing country with limited resources India will be more vulnerable to climate change impact. Hence, it is advisable to actively seek post-kyoto climate change treaty held at Copenhagen conference in December 2009 after fulfilment of primary objectives to provide adequate access of basic amenities (food, shelter, water, electricity) to citizens because more than 300 million Indians are still living in a miserable poverty level. India is also grappling health, urban infrastructure, local pollution and facing of local weather hazardous impact to compromise with mitigation obligation. On the other hand, if India manages to postpone mitigation commitment and continue towards growth, development, poverty alleviation then it can become significant deal to face natural hazardous arise by climate change. Active movement should be given priorities towards welfare i.e. building of dikes to protect against water rise, availability of resources to alleviate water shortage, enhance living standard in such a manner that individual can also have preparedness for emergency.

9 Summary

9.1 Observed and Projected Global Climate

1 °C global warming due to climate change is due to industrial revolt, alteration of atmospheric constituents and earth energy balance. Consequences of global warming are weather modification, extreme events, change of ecosystem and weather patterns, rise in sea surface temperature (SST) and its acidification, receding glaciers/snow, intensification of cyclone, heat wave increment etc. Upto twenty-first century global warming range will reach the range between 5 and 8 °C although emission is restricted or zero emission is implemented or follow Paris Agreement/Kyoto protocol in all scenarios climatic system will be accelerated.

9.2 Temperature Rise Over India

Average temperature over an Indian region is already raised by 0.7 °C according to the analysis of data series 1901–2018. In the RCP8.5 scenario, it is estimated that warmest day, coldest night and average temperature will further rise by 4.4 °C, 4.7 °C and 5.5 °C respectively and further increase in the frequencies of warm days/night, heat wave, heat stress in the twenty-first century and beyond.

9.3 Indian Ocean Warming

Markedly 1 °C increased in the sea surface temperature (SST) of Tropical Indian Ocean. This increased of SST is more than global mean SST warming (0.7 °C). Also, increasing trend initiates in the upper level (700 hpa) during 1951–2015. Also, during past two decades increasing warming trend has already increased in an abrupt way.

9.4 Changes in Rainfall

From data 1951–2015, a noticeable decreased (6%) in the Indian Summer Monsoon (ISM) and same declining trend is observed over Indo-Gangetic plains, western ghats. Projected data as per climate model simulation analysis showed same rainfall trend.

From 1951 to 2015, aerosols offset precipitation and GHG warming declined precipitation in the Northern Hemisphere. 27% shifts of dry spell are analysed from data 1981–2011. In the worldwide level, it is projected that more intense wet spells and increased in the frequency of local precipitation will occur on the worldwide level. In the central India occurrence of daily extreme rainfall intensity has increased about 75% (150 mm/day) during 1950–2015. Under projection of global warming and reduction of aerosols, there will be increase in the daily rainfall extreme as well as in the variability and mean rainfall amount.

9.5 Droughts

Central India, SW coast, Peninsular India, NE-India showed more frequency and spatial scale of drought spells according to data 1951–2016 along with increased in its area by 1.3% per decade. Projected simulation data also exhibited the same results.

9.6 Sea Level Rise

In response to global warming (CO_2 and BC) inland ice melting, thermal expansion of ocean has increased global sea level. In the same line global sea level increase, North Indian Ocean Sea level accelerated to 3.3 mm (1993–2017) per year with the rate 1.06–1.75 mm during 1874–2004. RCP 8.5 scenario, projected global sea level rise is almost 180 mm while in the North Indian Ocean it is 300 mm for data 1986–2005).

9.7 Tropical Cyclones

Analysis of data (1951–2018) showed that there will be considerable reduction in the occurrences of TCs over NIO basin but increase in the intensity of TCs during post-monsoon season and the same results are projected by the climate models. However, anthropogenic warming trend is not yet appeared.

9.8 Changes in the Himalayas

In Hind Kush Himalayas deteriorating snow, retreat glaciers and escalation of temperature about 1.3 °C as per studied years 1951–2014. However, Karakoram Himalayas have inverse effect i.e. more winter snowfall safeguard from melting of glaciers. In the twenty-first century, it is projected that Hind Kush Himalayas will face rise of temperature by 5.2 °C under RCP8.5 scenario.

9.9 Agriculture

Climatic changes and climatic variability have negative impact on soil, food and water. According to climate model output increased temperature, shortage of water resources and uncertain precipitation will decline yield production, soil moisture and water use efficiencies. This will restrict crop selection, sowing zones, soil deficiency, developing climate and water accessibility throughout the crop growth period. Higher latitudes will have less harmful effects than tropical areas.

To identify probable environmental limitations for agricultural production, alteration of crop calendars, cropping systems, market strategies (capital, labour, land, trade etc.), expansion of ecological information system, qualitative and quantitative universal databases acquisition its dissemination should be included in adaptation and mitigation. Extreme rainfall will weaken adaptation and mitigation capabilities for poorer especially residing in tropical belts, may permanent damage agricultural land and water resources. There will be threat of hunger by year 2080 and undernourished places will be more affected. Publishing farmer's awareness programme, climate-smart agriculture knowledge, implement disaster risk management should be executed in a very much keen and advance manner.

9.9.1 Energy and Water Resources Security

Water resources can undermine dominant form of hydro and thermal power generation which depends on adequate and fresh water supplies to maintain efficient functioning. Temperature increase will reduce water resources will cause major risk to thermal power generation, hydropower plants, physical damage from landslide, flash floods, glacial lake outbursts and other climatic hazards. Hence, these should be properly plan out with consideration of all climatological risk factors.

9.9.2 Climate Change

To face extreme weather, keep high GDP rate, poverty alleviation can be achieved by applying Carbon tax or international tradable emission permit and mitigation and adaptation strategy implementation. But mitigation may hinder due to asymmetric distribution between developing and developed countries as developed countries are not ready to bear bulk responsibility of their past emission. Climate change will have impact on capitals, ecosystem, environment, disease and migration socio-economic, investments availability, commodity price, infrastructures, land restructuring, inter-and-intra national dealings and other large/small scale industries. A meaningful development has least transformation from agricultural to a non-agricultural economy and reduce agriculture dependency.

10 Conclusion

There are evidences of rise of average temperature, decline ISM, increase of extreme weather events, enhancement of droughts, sea level, intensity of cyclone which influenced human lives. Anthropogenic influenced climate estimated to continue in future and can become less effective under zero-emission plan and by preparing solid adaptation/mitigation strategies, boosting of observational/research networks and associated climate models utilizations.

References

1. Pande CB, Moharir KN, Singh SK, Varade AM, Ahmed Elbeltagie SFR, Khadri PC (2021) Estimation of crop and forest biomass resources in a semi-arid region using satellite data and GIS. J Saudi Soc Agric Sci 20(5):302–311
2. Orimoloye IR, Olusola AO, Belle JA et al (2022) Drought disaster monitoring and land use dynamics: identification of drought drivers using regression-based algorithms. Nat Hazards. https://doi.org/10.1007/s11069-022-05219-9
3. Shahid M, Rahman KU, Haider S et al (2021) Quantitative assessment of regional land use and climate change impact on runoff across Gilgit watershed. Environ Earth Sci 80:743. https://doi.org/10.1007/s12665-021-10032-x
4. Pande CB, Moharir KN, Khadri SFR et al (2018) Study of land use classification in an arid region using multispectral satellite images. Appl Water Sci 8:123. https://doi.org/10.1007/s13201-018-0764-0
5. Pande CB, Moharir KN, Khadri SFR (2021) Assessment of land-use and land-cover changes in Pangari watershed area (MS), India, based on the remote sensing and GIS techniques. Appl Water Sci 11:96. https://doi.org/10.1007/s13201-021-01425-1
6. IPCC, Climate Change (2001) TAR & synthesis report. In: Watson RT, Core writing team, Albritton DL, Barker T (eds) Contribution of working groups I, II, and III to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Press, ISBN 0-521-80770-0 (pb: 0-521-01507-3)
7. Gadgil S (2003) The Indian monsoon and its variability. Ann Rev Earth Planet Sci 31:429–467
8. IPCC (2007) Climate change 2007: synthesis report. In: Core Writing Team, Pachauri RK, Reisinger A (eds) Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland, 104 pp
9. Parikh KS (2001) Indian agriculture and climate sensitivity. Glob Environ Chang 112(2):147–154. https://doi.org/10.1016/S0959-3780(01)00004-8
10. Bhatia A (2004) Inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential. Curr Sci 87(3):317–324
11. Komuscu AU, Erkan A, Oz S (1998) Possible impacts of climate change on soil moisture availability in the southeast anatolia development project region (GAP): an analysis from an agricultural drought perspective. Clim Change 40:519–545. https://doi.org/10.1023/A:1005349408201
12. Rohini P (2019) Future projections of heat waves over India from CMIP5 models. Clim Dyn 53(2):975–988. https://doi.org/10.1007/s00382-019-04700-9
13. Krishnan R et al (eds) (2020) Assessment of climate change over the indian region-a report of the ministry of earth sciences (MoES). Government of India, chapter 3-precipitation changed in India, pp 47–72. https://doi.org/10.1007/978-981-15-4327-2_3
14. Deshpande (2021) Changing status of tropical cyclones over the north Indian Ocean. Clim Dyn 57:3545–3567. https://doi.org/10.1007/s00382-021-05880-z

15. Liu L, Wang Y, Zhan R, Xu J, Duan Y (2020) Increasing destructive potential of landfalling tropical cyclones over China. J Clim. https://doi.org/10.1175/JCLI-D-19-0451.1
16. Ahmed R (2021) Characteristic features of super cyclone 'AMPHAN'—observed through satellite images. Tropical Cycl Res Rev 10(1):16–31. ISSN-2225–6032. https://doi.org/10.1016/j.tcrr.2021.03.003
17. Kothawale DR (2008) Temperature variability over the Indian Ocean and its relationship with Indian summer monsoon rainfall. Theor Appl Climotol 92(1–2):31–45. https://doi.org/10.1007/s00704-006-0291-z
18. Niranjan A (2021) Climate change makes Indian monsoon season stronger and more chaotic. Environment News. https://www.dw.com/en/indian-monsoon-climate-change-rainfall/a-57187793
19. IMD (2018) India meteorological department (IMD) annual report 2018 IMD, 2019: India Meteorological Department (IMD) Annual Report 2019 IMD, 2020: India Meteorological Department(IMD) Annual Report 2020
20. Fernandis S (2018) New weather phenomenon: Beware of the mini-cloud bursts. https://www.hindustantimes.com/mumbainews/new-weather-phenomenon-beware-of-the-mini-cloud-bursts-says-study/story-XjKINfMtUTF8BzZ8d29yIJ.html
21. Wikipedia (2005). Wikipedia. https://en.wikipedia.org/wiki/Maharashtra_floods_of_2005
22. NDTV News (2021) 125 extremely heavy rainfall events in September, October. Weather Office, NDTV, New Delhi, India
23. Dimri AP et al (2017) Cloudbursts in Indian Himalayas: a review. Earth Sci Rev 168:1–23. https://doi.org/10.1016/j.earscirev.2017.03.006
24. Murari K (2015) Intensification of future severe heat waves in India and their effect on heat stress and mortality. Reg Environ Change 15:569–579. https://doi.org/10.1007/s10113-014-0660-6
25. Gnanaseelan C et al (2017) Variability and trends of sea surface temperature and circulation in the Indian Ocean. In: Rajeevan MN, Nayak S (eds) Observed climate variability and change over the Indian Region, vol 10. Springer, Singapore, pp 165–179. https://doi.org/10.1007/978-981-10-2531-0
26. Willett KM (2007) Attribution of observed humidity changes to human influence. Nature 449(7163):710–712. https://doi.org/10.1038/nature06207
27. Kumari BP (2007) Observational evidence of solar dimming: offsetting surface warming over India. AGU Adv Earth Space Sci 34. https://doi.org/10.1029/2007GL031133
28. Kumari BP (2010) Seminal role of clouds on solar dimming over the Indian monsoon region. Geophys Res Lett Clim 37:L06703. https://doi.org/10.1029/2009GL042133
29. Padmakumari B (2013) In situ measurements of aerosol vertical and spatial distributions over continental India during the major drought year 2009. Atmos Environ 80(2013):107–121. https://doi.org/10.1016/j.atmosenv.2013.07.064
30. Soni VK (2011) Evaluation of long-term changes of solar radiation in India. Int J Climatol RMetS 32(4):540–551. https://doi.org/10.1002/joc.2294
31. Srivastava AK, Kothawale DR, Rajeevan MN (2017) Variability and long-term changes in surface air temperatures over the Indian subcontinent. In: Rajeevan MN, Nayak S (eds) Observed climate variability and change over the Indian region. Springer Geology, pp 17–35. https://doi.org/10.1007/978-981-10-2531-0_2
32. Raut B (2009) Spatial distribution and diurnal variation of cumuliform clouds during Indian Summer Monsoon. J Geophys Res Atmospheres 114(D11):D11208. https://doi.org/10.1029/2008JD011153
33. Doswell CA (eds) (2001) Severe convective storms part of the book series: meteorological monographs (METEOR). American Meteorological Society Boston, MA, Springer Book Archivepringer Book, pp 1–26. https://doi.org/10.1007/978-1-935704-06-5_1
34. Kesrkar (2005) Climatology of thunderstorm activity over the Indian region: III-Latitudinal and seasonal variation. Mausam 56(3):581–592. https://doi.org/10.54302/mausam.v56i3.987
35. Jolly W et al (2015) Climate-induced variations in global wildfire danger from 1979 to 2013. Nat Commun 6:7537. https://doi.org/10.1038/ncomms8537

36. IPCC, Climate Change (2014) Synthesis report. In: Core Writing Team, Pachauri RK, Meyer LA (eds) Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change, vol 151. IPCC, Geneva, Switzerland
37. Ganaseelan (2021) The decadal sea level variability observed in the Indian Ocean tide gauge records and its association with global climate modes. Glob Planetary Change 198(C10). https://doi.org/10.1016/j.gloplacha.2021.103427
38. Wahl T (2017) Understanding extreme sea levels for broad-scale coastal impact and adaptation analysis. Nat Commun 8(1). SN 2041–1723. https://doi.org/10.1038/ncomms16075
39. Jonathan D (2013) Review-coastal flooding by tropical cyclones and sea-level rise. Nature 504(7478):44–52. https://doi.org/10.1038/nature12855
40. Hermer MA (2013) Projected changes wave climate from a multi-model ensemble. Nat Clim Change 3(5):471–476. ISSN 1758-678X, E-ISSN 1758-6798. https://doi.org/10.1038/NCLIMATE1791
41. Hinkel J (2014) Coastal flood damage and adaptation costs under 21st century sea-level rise. 111(9):3292–3297. https://doi.org/10.1073/pnas.1222469111
42. Bachmann J (2009) Black carbon: a science policy primer. Pew Centre on Global Climate Change, Arlington, VA 22201
43. Van Dingenen R (2009) The global impact of ozone on agricultural crop yields under current and future air quality legislation. 43(3):604–618. https://doi.org/10.1016/j.atmosenv.2008.10.033
44. Mall RK et al (2006) Impact of climate change on Indian agriculture: a review. Clim Change 78:445–478. https://doi.org/10.1007/s10584-005-9042-x
45. Mahapatra R (2020) 20 years into 21st century: 70% global agriculture under climate threat news from down to earth news report. https://www.downtoearth.org.in/author/richard-mahapatra-46
46. Kirschbaum MU (2006) The sensitivity of C3 photosynthesis to increasing CO_2 concentration: a theoretical analysis of its dependence on temperature and background CO_2 concentration. 17(6):747–754. https://doi.org/10.1111/j.1365-3040.1994.tb00167.x
47. Srivastava SK (2009) Climate risk assessment of rice ecosystems in India. J South Asia Disaster Stud 2(1):155–166. https://www.researchgate.net/publication/265652002_Climate_Risk_assessment_of_Rice_ecosystems_in_India
48. Leemansa R (2004) Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. 14(3):219–228. https://doi.org/10.1016/j.gloenvcha.2004.04.009. https://www.sciencedirect.com/science/article/pii/S0959378004000391
49. Ravindranath NH (2006) Impact of climate change on forests in India. Curr Sci 90(3):354–361. https://www.jstor.org/stable/24091869
50. Gupta A, Pathak H (2016) Climate change and agriculture in India. Ministry of Science & Technology, Government of India, New Delhi
51. Roxy MK (2017) A threefold rise in widespread extreme rain events over central India. Nat Commun 708(8):78. https://doi.org/10.1038/s41467-017-00744-9
52. Basu J (2020) Down to earth news report on India bore maximum brunt of extreme weather events (2020) in Climate Change
53. India Meteorological Department (IMD) Annual Report 2020. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1686173#:~:text=Press%20Information%20Bureau,India%20during%202020
54. Crawford A (2021) IPCC report on climate science, retrieved from down to earth. https://www.downtoearth.org.in/climate-change
55. Joshi A et al (2021) video interview meeting on youtube: India to face irreversible impacts of climate crisis: flags IPCC report. Climate Change. https://youtu.be/wF92Of5YKys
56. Karmakar N (2015) Decreasing intensity of monsoon low-frequency intraseasonal. Environ Res Lett 10:054018. https://doi.org/10.1002/qj.3715
57. Karmakar N (2017) Space–time evolution of the low- and high-frequency intraseasonal modes of the Indian summer monsoon. Am Meteorol Soc (AMS) 145(2):413–435. https://doi.org/10.1175/MWR-D-16-0075.1

58. Pai DS (2016) Active and break events of Indian summer monsoon during 1901–2014. Clim Dyn 46:3921–3939. https://doi.org/10.1007/s00382-015-2813-9
59. Singh D (2014) Observed changes in extreme wet and dry spells during the South Asian summer monsoon season. Nat Clim Chang 4:456–461. https://doi.org/10.1038/nclimate2208
60. Sahana A (2015) Shift in Indian summer monsoon onset during 1976/1977. Environ Res Lett 10(5):054006. https://doi.org/10.1088/1748-9326/10/5/054006
61. Noska R (2016) Characterizing the onset and demise of the Indian summer monsoon: Indian summer monsoon. Geophys Res Lett 43(9). https://doi.org/10.1002/2016GL068409
62. Ananthakrishnan R (1988) The onset of the southwest monsoon over Kerala,1901–1980. R Meteorol Soc (RMetS) 8(3):283–296. https://doi.org/10.1002/joc.3370080305
63. Rajeevan DS (2009) Prediction of summer monsoon onset over Kerala, India. J Earth Syst Sci 118(2):1–13. https://doi.org/10.1007/s12040-009-0020-y
64. Krishnamurthy TN (1982) Sensitivity of the monsoon onset to differential heating. J Atmos Sci 39(6):1290–1306. https://doi.org/10.1175/1520-0469(1982)039%3c1290:SOTMOT%3e2.0.CO;2
65. Annamalai H (2013) Global warming shifts the monsoon circulation, drying south Asia. J Climatol 26(9):2701–2718. https://doi.org/10.1175/JCLI-D-12-00208.1
66. Guhathakurta P (2008) Trends in the rainfall pattern over India. Int J Climatol 28(11):1453–1469. https://doi.org/10.1002/joc.1640
67. Prakash S (2015) Comparing two high-resolution gauge-adjusted multisatellite rainfall products over India for the southwest monsoon period. Meteorol Appl Sci Technol Clim Weather. https://doi.org/10.1002/met.1502
68. Bidyabati S (2018) Uncertainties in observations and climate projections for the North East India. Global Planetory Changes 160:96–108. https://doi.org/10.1016/j.gloplacha.2017.11.010
69. Nageswararao MM (2019) Characteristics of various rainfall events over South Peninsular India during northeast monsoon using high-resolution gridded dataset (1901–2016). Springer, Theor Appl Climatol 137:2573–2593
70. Paul S (2018) Increased spatial variability and intensification of extreme monsoon rainfall due to urbanization. Sci Rep 8(1):3918. https://doi.org/10.1038/s41598-018-22322-9
71. Skliris N (2016) Global water cycle amplifying at less than the Clausius-Clapeyron rate. Sci Rep 6(1):2045–2322. https://doi.org/10.1038/srep38752
72. Mheel GA (2005) Overview of the coupled model intercomparison project. Am Meteorol Soc (AMS) 86(1):89–94 https://doi.org/10.1175/BAMS-86-1-89
73. Trenberth KE (1998) Atmospheric moisture residence times and cycling: implications for rainfall rates and climate change. Clim Change 39:667–694. https://doi.org/10.1023/A:1005319109110
74. Sikka DR (1980) Some aspects of the large scale fluctuations of summer monsoon rainfall all over India in relation to fluctuations in the planetary and regional scale circulation parameters. Earth Planet Sci 89:179–195. https://doi.org/10.1007/BF02913749
75. Bera S (2018) Mint news: economic survey News_Mint
76. Dimri AP (2015) Western disturbances: a review. Rev Geophys. https://doi.org/10.1002/2014RG000460
77. Dimri AP et al (2013) Intraseasonal oscillation associated with the Indian winter monsoon. J Geophys Res 118:1–10. https://doi.org/10.1002/jgrd.50144
78. Cai W (2018) Stabilised frequency of extreme positive Indian Ocean Dipole under 1.5 °C Warming. Nat Commun 9(1):1419. https://doi.org/10.1038/s41467-018-03789-6
79. Rajeevan M (2012) Northeast monsoon over India: variability and prediction. Meteorol Appl 19(2):226–236. https://doi.org/10.1002/met.1322
80. Kripalani RH (2004) Northeast monsoon rainfall variability over south peninsular India vis-à-vis Indian Ocean dipole. Int J Climatol 24(10):1267–1282. https://doi.org/10.1002/joc.1071
81. Yadav RK (2013) Emerging role of Indian ocean on Indian northeast monsoon. Climatol Dyn 41:105–116. https://doi.org/10.1007/s00382-012-1637-0
82. Ramaswamy C (1962) Breaks in the Indian summer monsoon as a phenomenon of interaction between the easterly and subtropical westerly jet streams. Tellus 14(3):337–349. https://doi.org/10.3402/tellusa.v14i3.9560

83. Gadgil S (2004) Extremes of the Indian summer monsoon rainfall, ENSO and equatorial Indian ocean oscillation. Geophys Res Lett 31:L12213. https://doi.org/10.1029/2004GL019733
84. Cai W et al (2015) ENSO and greenhouse warming. Nat Clim Change Nat 5(9):849–859
85. Bamzai AS (1997) Climatology and interannual variability of northern hemisphere snow cover and depth based on satellite observations. Center for Ocean-Land-Atmosphere Studies, Cola Report 52, Calverton
86. Blanford HF (1884) On the connection of Himalayan snowfall and seasons of drought in India. Proc R Soc Lond 37(232–234):3–22. https://doi.org/10.1098/rspl.1884.0003
87. Bhanu Kumar OSRU (1987) Eurasian snow cover and seasonal forecast of Indian summer monsoon rainfall. Hydrol Sci J 33(5):515–525. https://doi.org/10.1080/02626668809491278
88. Kripalani RH (1999) Climatology and variability of historical Soviet snow depth data:some new perspectives in snow Indian monsoon teleconnections. Clim Dyn 15:475–489. https://doi.org/10.1007/s003820050294
89. Patwardhan SK (2000) Meso-scale distribution of summer monsoon rainfall near the Western Ghats (India). Int J Climatol 5:575–581. https://doi.org/10.1002/(SICI)1097-0088(200004)20:5%3c575::AID-JOC509%3e3.0.CO;2-6
90. Tawde SA, Singh C (2015) Investigation of orographic features influencing spatial distribution of rainfall over the Western Ghats of India using satellite data. Int J Climatol 35(9):2280–2293. https://doi.org/10.1002/joc.4146
91. Daniel A (2019) Agroforestry news: how regenerative agroforestry could solve the climate crisis. World Economic Forum. https://www.weforum.org/agenda/authors/alexander-daniel

Impact of Climate Change and Water Resources

Externalities of Climate Change on Urban Flooding of Agartala City, India

Saptarshi Mitra, Stabak Roy, and Samrat Hore

Abstract Urban flooding has been a crucial issue of urban India for an extended period. According to the 2011 Census of India, the second-largest and fastest-growing city of Northeast India is Agartala, the capital city of the State of Tripura. They are located on the right bank of river Haora, with a total population of 404,004 persons. Due to micro-level climate change and its geophysical location, Agartala has witnessed seasonal urban flooding, which has become a regular event every year. With the increasing effects of climate change, the flood occurrences in Agartala city may likely increase shortly. In order to safeguard from the pluvial hazard of Agartala focus should be on the city drainage system and to prevent the city from flooding. The main objective of this study is to be identifying water logging areas and different factors for water-logging in the city. Also, assess the socio-economic impact of the flood on local communities and draft alternative strategies for strengthening the city drainage system against urban flooding. The study is based on primary and secondary data. Primary data was collected from the city dwellers by door-to-door household survey and stake holder consultation. Secondary data has been collected from the office of Agartala Municipal Corporation, Census operation of India, Agartala etc. To understand the city topography and identify areas prone to water-logging and flooding, satellite imagery has been analysed. The study reveals that the central part of the city located between river Haora and Kata Khal is more vulnerable than any other place of the city. In order to devise a coping mechanism for Agartala city, stakeholders from different sectors were identified to mitigate and understand the strategies to prevent urban flooding. Strategies may help Agartala city as an urban flood-resilient city and safeguard its citizen.

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_3

Keywords Urban water system · Resilient · Water logging · Geo-physical

1 Introduction

Climate change and urbanisation pose remarkable threats to flooding and degradation of water quality in urban areas [42]. Urban flooding is the greatest challenge to human safety and sustained economic growth [25]. Climate change is a concerning factor in changing the precipitation patterns worldwide. Every year, rainstorms and related urban flooding issues are exaggerated in terms of frequency and severity. The main reason for urban flooding is the accumulation of local rainfall runoff due to inadequate drainage and buffer capacity, known as Pluvial flooding [20]. Pluvial flooding is a new approach that updates the current urban drainage models to urban flood models [9]. The externalities of urban flooding can be triggered by intensified rainfall, long-duration precipitation, close repetition of precipitations or a combination of externalities create a full-scale urban crisis by electrical failure, road congestion, interruption in business and influx of polluted water. These are the major problems which can impact heavily in the city dwellers. In order to adapt and mitigate climate change, the local urban body has critical roles. But, local urban bodies in low and middle-income countries cannot reduce climate change impacts [62]. Flood protection is one of the traditional functions of any drainage system and it remains a significant issue in many cities because of economic and health impacts [13]. The main challenges to implementing a sustainable urban drainage system and developing an urban flood resilience model [24]. There has been considerable research and tools developed to analyse fluvial and coastal flooding, but models for pluvial flooding are less advanced. Therefore, modelling and a better understanding of the risk of stormwater flooding is needed urgently for flood risk management [12].

Climate change has varied consequences in different parts of the world [36]. North-East India can be considered a distinct macro-region within the Indian landmass [49, 71]. The Northeast has a diversified climate, with extremely cold winters and semi-humid summers, particularly in the south. The region has a monsoon climate, which gets high or extremely heavy rainfall only during the summer months of June to September. The primary source of rain is the south-west monsoon, with June being the wettest month. There are three seasons in the area, i.e., winter, summer and rainy season. Between valleys and mountains, there is a climate variation. In January, the average temperature in the Assam Valley region is around 16 °C. In contrast, the maximum temperature in the hilly parts of Arunachal Pradesh and Nagaland is 14 °C and the minimum temperature is below freezing. Summer temperatures in the lowlands range from 30 to 33 °C, while in the hills, the average summer temperature is 20 °C and the average lowest is 15 °C [18]. The average annual rainfall is 2000 mm with local variations (1500–12,000 mm). North East India's climate has drastically changed over the last couple of years. Rainfall patterns over the region in the last century have considerably changed, resulting in its overall drying up [60].

This region had been treated as a backward region because of its rurality. However, but in the second half of the twentieth century, the urbanisation process blooms up in the northeastern region [35]. Agartala is the -growing and second-largest city in Northeast India, located in Tripura [16]. Due to the rapid unplanned urbanisation of Agartala. The city faces urban issues like road congestion, solid waste management, development of slums, sanitation and urban flooding [22–46]. Urban flooding is the most crucial issue in cities with significant impacts on the man-environment relationships [24, 26, 30]. The degree and intensity of urban flooding have increased in many Indian cities, as has been reported in the past two decades [1, 5–7, 15, 17, 23, 32, 37, 45, 51, 53, 72]. The spatiality of urban units plays an essential role in urban flooding along with meteorological, hydrological and anthropogenic factors [42, 67]. Due to those inevitable factors, the city's drainage system is facing delinquency. As a result, urban flooding has taken place, especially during the monsoon season [22, 28, 29]. Infrastructure planning is required to improve the city's drainage system, especially for sewage and stormwater [3, 11, 48, 73]. The cities are expanding and growing exponentially, simultaneously the natural drainage systems are traumatised due to development activities in the city [32, 33]. The capacity of water retention and surface runoff of the city has a negative relationship, increasing flood potentiality [38–40, 64, 69]. Unplanned urban infrastructure consequences urban flooding where environment and resource conservation are least prioritised in the development process of urbanisation, through such relationship between urbanisation and development is a vital policy concern [68]. But in micro-level planning, some important parameters such as city slope and its topography, watershed and its catchment areas are needed to be given prior attention which is eventually not being paid.

Agartala is frequently affected by floods during monsoon after heavy rainfall [4, 59]. The present scenario of the city drainage infrastructure system in terms of coping up with urban flooding is not up to the mark. Therefore, the study aims to identify the causal interference of urban flooding in the city of Agartala and explore technical strategies for managing urban flooding in Agartala and minimising the damages due to floods for mankind.

2 Study Area

Agartala, the capital city of Tripura, is located in between 23°45′ to 23°55′ N latitudes and 91°15′ to 91°20′ E longitudes (Fig. 1). The city is located on the flood plain of the Rivers Haora and Kata Khal. The physiographic structure of Agartala City is just like saucer-shaped and characterised by Tilla (relatively high land) and Lunga (low land) topography [63]. Maharaja Krishna Manikya built the old Agartala City in the year of 1748. That city was situated in between two uplands, Kunjaban tilla (23°51′ N and 91°16′ E) in the northern side and college tilla (23°49′ N and 91°17′ E) in the southern side. Due to the regular water logging situation, Maharaja Krishna Kishore Manikya had shifted his capital from old Agartala to present Agartala (our study area) in 1849. After 25 years of its establishment, in 1874, the Agartala Municipal

Council was formed to provide better services to the city dwellers [61]. In 2014, it became upgraded into Agartala Municipal Corporation (AMC) which represents the local urban governance of the Agartala City [16]. Since its statehood in 1972, the city has become the nerve centre of all administrative, political, cultural and commercial activities of the state. The city has emerged as an essential border-trading centre with international linkage with Bangladesh. National Highway (NH-8 is passing through the city (Fig. 1. Maharaja Bir Bikram Airport [23°53′33.96″ N and 91°14′37.81″ E] is located about 11.75 km north-west from the Central Business District (CBD of Agartala City. Agartala railway station is [23°47′35.83″ N and 91°16′42.92″ E] located in the south-eastern part of the city. The city consists of 49 wards which are broadly divided into four planning zones (North, Central, East and South and shares. An international border with Bangladesh on the western side, and Jirania Rural Development (RD Block, Mohanpur R.D. Block and Dukli R.D. Block are situated in the east, north, and south of the city. The total area of AMC is almost 76.150 km^2 with 5,26,292 population.

The city holds on important international significance due to its strategic location with Bangladesh. Integrated Check Post (ICP) for trans-border trading is located only about 3 km west of the CBD of Agartala City. Agartala serves good regional connectivity with all the nearby cities of North East India as well as with other cities of India as the city has good connectivity through Roadways, Railways and Airways [27–55, 63]. The recent construction of a broad-gauge railway line in 2016 have also strengthened railway connectivity [57].

The city population varies from the inner to the outer part of the city. High population distribution can be observed in the central part of Agartala, whereas a sparse population is observed in the peripheral region of the city. So, most city people started to live in the central part of the city to avail the basic services and infrastructure facilities. From 1971 to 2011, there has been an upward trend of population density in the city. The highest rate of increase in population density has been observed from 1971 to 1981 due to political migration [16]. However, in 2016 when the city was expanded from 35 to 49 wards by accumulating more than 17.31 km^2 area.

3 Methodology and Database

In order to identify the flooding areas, the general slope of the city has been analysed through the Digital Elevation Model (DEM). SRTM DEM has been collected from the USGS earth explorer platform and United States Geospatial Server (USGS). Drainage dynamics have been analysed through stream order and the watershed map has been depicted to identify the flow of the water's direction. In the next step, the land use map has been overlaid to analyse the relationship between catchment areas to see whether the urbanisations are swallowing those or not. Triangular irregular networks (TIN) map has been prepared to understand the overall physiographic structure of the city. Simultaneously, satellite-based Tropical Rainfall Measuring Mission (TRMM) data from 1989 to 2019 has also been collected and analysed. A drainage network

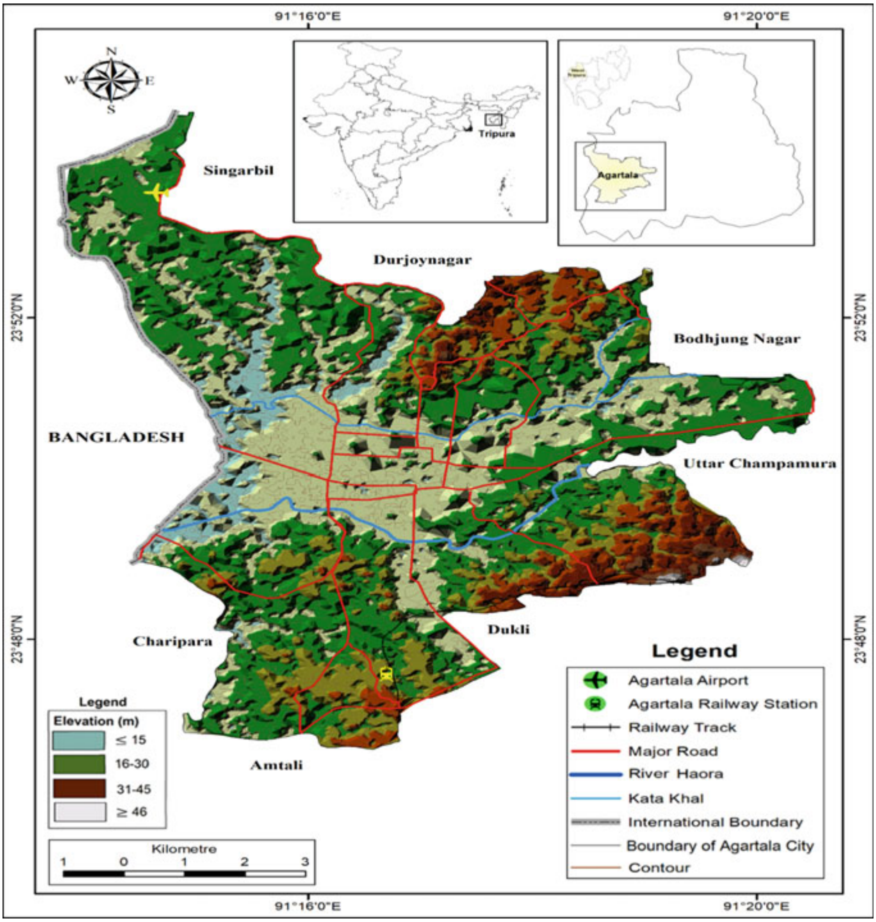

Fig. 1 Location map of the study area (*Source* Prepared by the authors, 2021; Data extracted from SRTM DEM, Google Earth and Hand-held GPS Receiver, 2021)

map based on SRTM DEM has prepared to identify urban flooding and respective flood vulnerable areas. According to the duration of waterlogging, the city has been classified into four different vulnerable zones, very high, high, low and very low (Fig. 2). In the very high zone the duration of water logging is more than 72 h. Between 48 and 72 h water logging situated areas are demarketed as high zone. Wherever, 24–48 h and less than 24 h water logging areas of the city are classified as low and very low vulnerable zone, respectively. The Spatio-temporal changes of the urban areas have been monitored through Landsat Satellite Imageries of different years and respective data have been collected from USGS earth explorer. The detailed data summary between (2000–2021) is reported in Table 1.

To represent the LULC for change detection and analysis of urban land use with respect to urban flooding, a series of processes have been done like data acquisition,

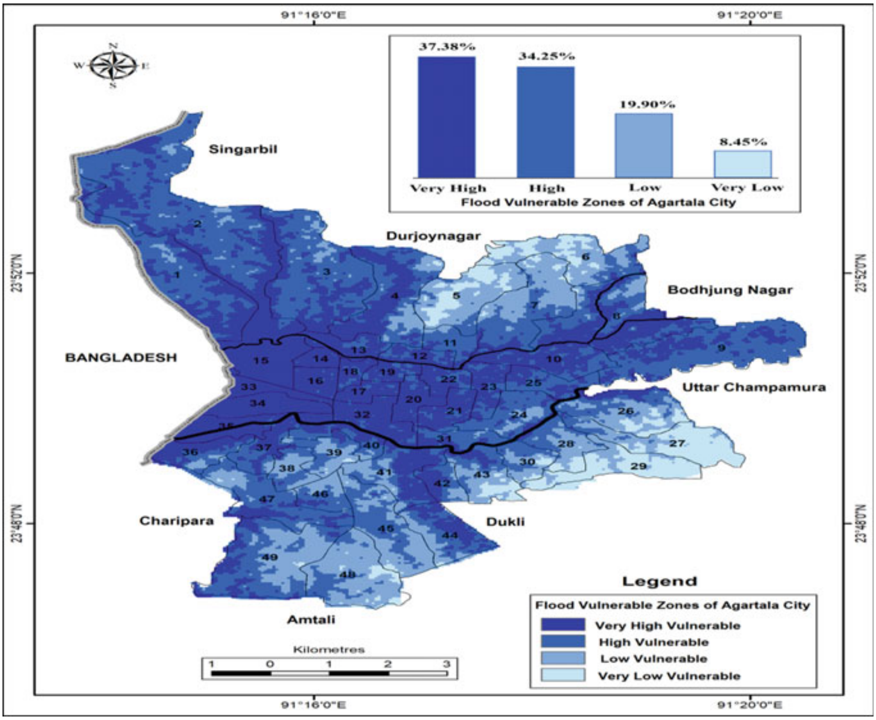

Fig. 2 Flood zonation map of Agartala city (*Source* Prepared by the authors, 2021 using ArcGIS v.10.8, 2021; Data extracted from TRMM and SRTM DEM)

geometric correction, image extraction, training site collection and supervised classification using the Maximum Likelihood Estimation (MLE) method. The Images are processed by the GIS and RS software like ArcGIS v.10.8 and Map Info v.17 to analyze the Agartala urban area change detection. The Maximum Likelihood (ML) classification algorithm is a well-known parametric classification used for supervised classification [47]. Handheld GPS receiver used for ground verification. A rainfall zonation map has been prepared based on TRMM data (1989–2019) using Inverse Distance Weightage (IDW) method in ArcGIS v.10.8 and Global Mapper v.22 software. Geospatial techniques like GIS and RS have represented the correlation between flooded areas, population density and road density of Agartala City.

Table 1 Sources of the data set[a]

Data	Product details	Date of acquisition	No of bands	WRS path/raw	UTM zone	Datum	Scale/resolution
Landsat 8 OLI	LC08_L1TP_13644_20210222_20210303_02_T1	22.02.2021	11	136/44	46	WGS84	30 m
Landsat 8 OLI	LC08_L1TP_136044_20141118_20200910_02_T1	18.11.2014	11	136/44	46	WGS84	30 m
Landsat 7	LE07_L1TP_136044_20070312_20200913_02_T1	12.03.2007	8	136/44	46	WGS84	30 m
Landsat 7	LE07_L1TP_137043_20000228_20200918_02_T1	22.08.2000	7	137/43	46	WGS84	30 m
Shuttle radar topography mission (SRTM) DEM	SRTM1N23E091V3	2015	1	–	46	WGS84	90 m
Ground verification	Garmin eTrex 30x	2019–2021	–	–	–	–	N/A

[a] USGS: United States of Geological Survey

4 Results and Discussion

4.1 Characteristics of Urban Flooding in Agartala City

Agartala receives a huge amount of rainfall during the monsoon from May to September [14] in the effect of south-west monsoon wind flowing over the Bay of Bengal. The city receives an average annual rainfall of 211.7 cm with 95 rainy days. The city receives maximum rainfall during the monsoon period [41]. During post-monsoon to pre-monsoon seasons (dry period), the city's groundwater level dries up because of the massive extraction of groundwater by the city to meet the water supply demand for the city dwellers [31]. The main reason, the fluctuation of ground water levels in the city is that there are no recharge techniques in the city and individual household levels and river water lifting from Haora River [10]. Therefore, the city needs to take long term measures to tap the excess rainfall during the monsoon in order to reduce the dependency on groundwater during the dry period. In previous flooding events of Agartala City, critical flood zone is located in the low-lying areas. Where around 4–5 days are required to drain out the water because the city does not have any high-tech water lifting stations to drain out the floodwater from those low-lying areas [8, 29, 65, 66]. As a result, urban flooding has become a regular event in the low-lying areas of Agartala City in every monsoon (Fig. 2).

In Agartala, about 37.38% area has been identified where water logging extends more than three days especially ward numbers 4, 15, 16, 17, 18, 22, 23, 24, 32, 33, 34, 35, 36 and 42. Maximum wards (16.48%) of AMC characterised with very high flood vulnerability are located in the central-west part of the city. About 34.32% of Agartala City falls under a high flood vulnerability zone where water has been logged for 2 to 3 days (Fig. 2). It has been observed that 19.90% and 8.45% of the area have low and very low flood vulnerability, respectively. Those areas are located in northern, south-eastern and southern parts of the city and the relative height of those areas is comparatively higher than the central and central-western parts of the city (Fig. 1). Vegetation cover is a commonly used indicator to evaluate terrestrial environmental conditions [34, 70]. The cumulative consequences of climate change and urbanisation on surface runoff get measure of the impact of climate change on urban flooding [2]. Enhanced green infrastructure (GI) in urban areas, such as green roofs, parks and green spaces, can significantly enhance the provision of fundamental ecosystem services through nature-based solutions, prevention of urban flooding one of that [75]. Due to climate change and anthropogenic activities, vegetation degradation has taken place in Agartala city significantly (Fig. 3). This change impacts urban flooding. Because GI always acts as a sponge that absorbs a huge amount of Strome water during monsoon. The drainage system is the most crucial factor for urban flooding [19]. A natural drainage system has been identified through the process of stream order. Strahler suggested an ordering technique, still is considered as most reliable method to categories the stream segments into different classes based on their significance and contribution to the drainage pattern [21, 27, 50, 52, 74].

Agartala City had well natural drain network to move out the flooded water from the city (Fig. 4). However, due to rapid urbanisation, the natural stream network has been changed. By using the Strahler method, about 56.20% were a first-order stream, 24.05% second-order stream, 11.46% third-order stream, 5.44% fourth-order stream and 2.69% fifth order stream are found in Agartala City (Fig. 4). The lower order stream takes a longer time (more than 72 h) to subside the flood situation wherever the higher-order stream takes a longer time to develop the flood situation by reducing flood with quicker time (less than 24 h) flood level. In Agartala City, only 0.16% of higher-order streams are observed. As a result, having immense pressure on higher-order streams required more time to subside the flood situation.

This morphometric pattern is one among the response to hydrologic and anthropogenic conditions. However, due to rapid urbanisation since 1991, the maximum first, the second and third-order stream has been either wiped out or the stream has been converted into the respective lower-order stream. Surface runoff in those drainage networks has been obstructed and causes the water to be logged in the city for a couple of hours to a few days and creates a situation of urban flooding. Due to lack of water retention points, in few wards of Agartala City were severely flooded during every monsoon (see Table 2).

The average rainfall intensity of Agartala city is more than 204.5 mm, which is considered as extremely heavy rain [41]. The average annual rainfall of Agartala is

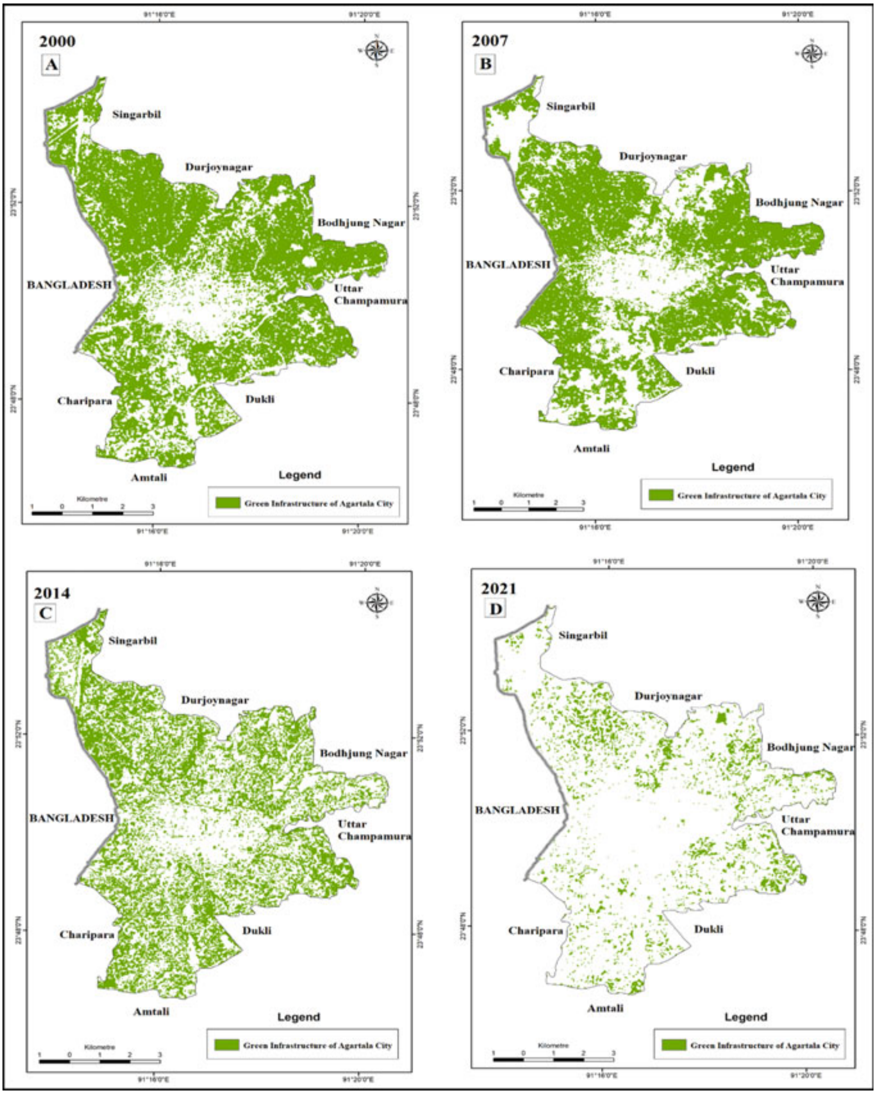

Fig. 3 Green infrastructure of Agartala city [A. 2000, B. 2007, C. 2014 and D. 2021] (*Source* Prepared by the authors, 2021 using ArcGIS v.10.8, 2021; Data extracted from LANDSAT Series)

about 2146 mm. The seasonal rainfall varied from 68% (monsoon) to 1.4% (post-monsoon). It has been recorded that floods in Agartala city due to intense rainfall over just two days point to immediate attention required towards building urban climate resilience [66].

Due to flooding in Agartala, almost more than half of the city, that is 65% of people, have to struggle with their days without having any alternative occupation

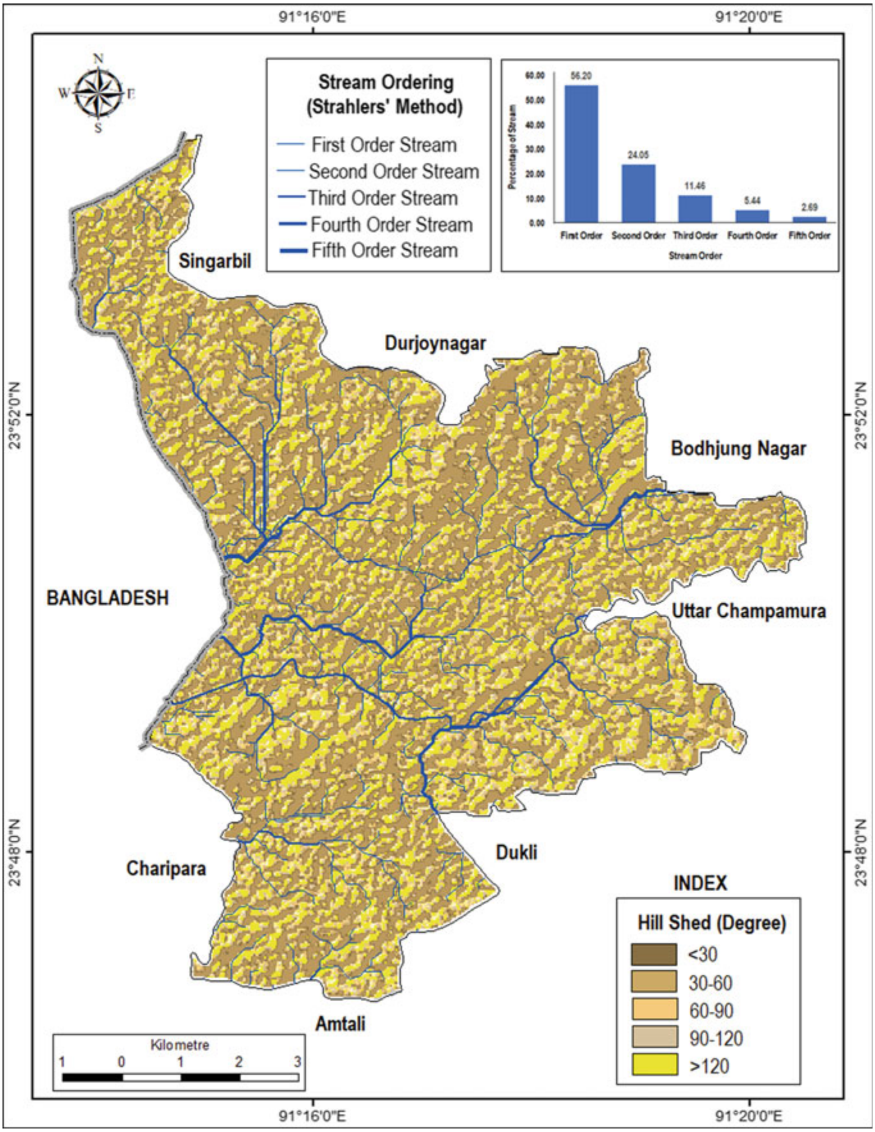

Fig. 4 Hill shed map with stream ordering (*Source* Prepared by the authors, 2021; Data extracted from SRTM DEM through Hydrological Modelling)

Table 2 Externalities of urban flooding

Nature of flooding	Climate change	Urbanisation	Combination
Pluvial features	Rainfall intensity Rainfall amount Rainfall frequency	Green infrastructure Population Surface runoff	Flooding Population affected

and cannot meet the demand of their daily basic needs. During flood time people have to take shelters in schools, colleges, or even on the rooftop as there are no proper flood shelters in Agartala city. Therefore, the socio-economic analysis of Agartala city have been categorised into four parts. The flood can be categorised in the following physical characteristics such as floodwater height, frequency and duration of the flood. The longer period of floodwater stagnation in the city rises the level of vulnerability impact upon the people. Surveys have been done for analysing the communities affected during a flood. Through which it is being observed most vulnerable communities are farmers, daily labours, rickshaw pullers and small business holders in the city. From the above chart, it is seen that the most vulnerable community during flood time is the farmer community because most of the farmers agricultural land are in a low lying region which gets waterlogged very frequently resulting in damage to agricultural crops. Whereas during flood causes death and leads to miseries to the communities like labours and rickshaw pullers as they become homeless, jobless and suffer from starvation. Poor household communities have to face great difficulty in balancing the loss of income than the non-poor community. Similarly, during flood time, the small business holder community faces the problem in storing and carrying their goods in godowns as half of the city goes under the water and most of their goods get damaged, and they have face loss in their income.

Agricultural crops and the damage of shelters are severely damaged due to floods as livelihood assets and property are closely related to each other. When property assets are affected, it directly impacts change of livelihoods. The survey shows that 60 and 44% properties are being damaged in terms of Houses and Agricultural lands. Due to intense flooding in Agartala, the agricultural lands and houses are being submerged severely, and most of the houses are made through local materials like bamboo, muds so, during flood time, the entire houses get washed away along with households furniture. The agricultural lands located near the river yearly lose a huge amount of agricultural crops due to heavy river bank silt erosion due to heavy siltation during flood have made the agricultural land more infertile and have decreased the productivity of the land. Financial losses depend on the city's intensity, duration and frequency of flooding; the average financial loss is 20,000–25,000 rupees per flood per family belonging to a poor, vulnerable community. Apart from the direct income loss, there are loss of retail goods and loss of working days, there is a direct economic loss of 5% of the monthly income due to flooding, with major loss of working days is about 3–5 days due to intense water logging in the city. Most of the community affected by the flood come from middle to lower-income groups. As a result, most people suffer from water-born and vector born diseases such as diarrhea, dysentry, cholera, maleria and respiratory problems. As the people belong to lower-middle-class communities, a result, they are more vulnerable to flood than that person living who live in high-class communities. Therefore it can be said that there is a significant correlation between the people's income and the impact of flood, where the poor people fails to maintain the balance in terms of living standards during the time of the flood. Hence these people can afford neither medicine nor medical check-up during the time of the disaster, which results in death and chronic suffering from the water and vector born diseases.

5 Findings

From the above analysis following are the significant findings**-**

- Urban flooding intensity in the city is very high due to high population density and poor drainage infrastructure.
- The city's natural drainage system has been chocked due to the unscientific construction.
- The city has a mayhem flood due to the degradation of the drainage network and pluvial activities.
- The rapid change in the change in green infrastructure of Agartala results in the increase of surface runoff in the city.
- The pluvial flooding of Agartala city mainly affected the poor and people living in low-lying areas.
- Financial and property losses are common phenomena of urban flooding, mostly depending on the intensity, duration and frequency of flooding in the city.

6 Conclusion

Pluvial events change nature due to climate change. Spatial prioritisation based on urban flood analysis of Agartala City has been spotted. To resolve the issue of urban flooding, sustainable strategic city drainage network planning is needed for making the plan. As Agartala City has grown up in an unexpected way, like unfollowing the city development control rules, regulations and guidelines, the city is frequently facing urban flooding. Along with pluvial events, anthopogeomorphic factors are also responsible for hazards impacting human lives and livelihood.

Acknowledgements This publication results (in part) from the research project supported by the Department of Science and Technology (DST), Ministry of Science and Technology, Government of India. The project entitled "**Identification, Assessment and Model Building of Urban Morphology using Geospatial Techniques: A Study of Border City Agartala**" (File No. NRDMS/UG/S.Mitra/Tripura/e-10/2019 (G) dated 15.05.2019). The content is solely the authors' responsibility and does not necessarily represent the official views of the DST, New Delhi.

References

1. Ahmed Z, Rao RM, Reddy RM, Raj EY (2016) Integrated storm water management—an approach for urban flooding in Hyderabad, India. Am J Eng Res 5(10):102–110. Retrieved from https://www.academia.edu/29121344/Integrated_Storm_Water_Management_An_Approach_for_Urban_Flooding_In_Hyderabad_India
2. Alam MS, Willems P, Alam MM (2014) Comparative assessment of urban flood risks due to urbanization and climate change in the turnhout valley of Belgium. ABC J Adv Reseach 3:15–24

3. Arisz H, Burrell CB (2006) Urban drainage infrastructure planning and design considering climate change. In: EIC climate change technology, 2006. IEEE, pp 1–9. IEEE. https://doi.org/10.1109/EICCCC.2006.277251
4. Asian News International (ANI) (2019, July 14) Heavy rain hits normal life in Agartala. Agartala, Tripura, India. Retrieved from https://www.aninews.in/news/national/general-news/heavy-rain-hits-normal-life-in-wbs-agartala20190714195753/
5. Avinash S (2014) Flood related disasters: concerned to urban flooding in Bangalore, India. Int J Res Eng Technol 1–9. Retrieved from https://www.academia.edu/49317657/Flood_Related_Disasters_Concerned_to_Urban_Flooding_in_Bangalore_India
6. Baghel A (2016) Causes of urban floods in India: study of Mumbai in 2006 and Chennai in 2015. In: International Conference on Disaster and Risk Management, Sohna, Haryana. Retrieved from https://www.researchgate.net/publication/332696866_Causes_of_Urban_Floods_in_India_Study_of_Mumbai_in_2006_and_Chennai_in_2015
7. Banerjee S (2018) An analysis of urban flooding scenario in the city of Kolkata, West Bengal. Int J Innov Knowl Concepts 6(5):1–9. Retrieved from https://core.ac.uk/download/pdf/233155235.pdf
8. Bhattacharjee B (2018) Tripura floods displace 23,000 people. Times of India, Agartala. https://timesofindia.indiatimes.com/city/agartala/tripura-floods-displace-23000-people/articleshow/64266838.cms
9. Cedo M, Dusan P, Surajate BA, Joao PL, Slobodan D, Richard A (2009) Overland flow and pathway analysis for modelling of urban pluvial flooding. J Hydraul Res 47(4):512–523. https://doi.org/10.1080/00221686.2009.9522027
10. Central Ground Water Board (2020) Master plan for artificial recharge to ground water-2020. Ministry of Water Resource, Government of India, New Delhi. http://cgwb.gov.in/Master%20Plan%20to%20GW%20Recharge%202020.pdf
11. Central Public Health & Environmental Engineering Organisation (CPHEEO) (2019) Manual on storm water drainage systems. Ministry of Housing and Urban Affairs, Government of India, New Delhi. Retrieved from http://mohua.gov.in/upload/uploadfiles/files/Volume%20I%20Engineering(3).pdf
12. Chen H, Xu CY, Guo S (2012) Comparison and evaluation of multiple GCMs, statistical downscaling and hydrological models in the study of climate change impacts on runoff. J Hydrol 434–435:36–45. https://doi.org/10.1016/j.jhydrol.2012.02.040
13. Cherqui F, Belmeziti A, Granger D, Sourdril A, Gauffre PL (2015) Assessing urban potential flooding risk and identifying effective. Sci Total Environ 514:418–425. https://doi.org/10.1016/j.scitotenv.2015.02.027
14. Das R, Purkayastha N, Phukan R, Saha D (2020) Performance of monsoon 2020 in Tripura–a report. India Meteorological Department, Government of India, Agartala. https://agartala.imd.gov.in/special_report/Monsoon%20Report%20Tripura%202020.pdf
15. De US, Singh GP, Rose DM (2013) Urban flooding in recent decades in four mega cities of India. J Indian Geophys Union 17(2):153–165. Retrieved from http://iguonline.in/journal/Archives/17-2/4usde.pdf
16. Debbarma D, Roy S, Santra A, Mitra S (2018) A spatial analysis of population distribution, density and growth in Agartala city. Asian J Spat Sci 6(1):24–36. https://www.researchgate.net/publication/330578562_A_Spatial_Analysis_of_Population_Distribution_Density_and_Growth_in_Agartala_City
17. Dhiman R, VishnuRadhan R, Eldho TI, Inamdar A (2019) Flood risk and adaptation in Indian coastal cities: recent scenarios. Appl Water Sci 9(5):1–16. https://doi.org/10.1007/s13201-018-0881-9
18. Dikshit KR, Dikshit JK (2014) North-East India: land, people and economy. Springer, New York. https://doi.org/10.1007/978-94-007-7055-3

19. Eldho TI, Zope PE, Kulkarni AT (2018) Urban flood management in coastal regions using numerical simulation and geographic information system. In: Samui P, Kim D, Ghosh C (eds) Integrating disaster science and management. Elsevier, Amsterdam, pp 205–219. https://doi.org/10.1016/C2016-0-02482-8
20. Falconer RH, Cobby D, Smyth P, Astle G, Golding DB (2009) Pluvial flooding: new approaches in flood warning, mapping and risk management. J Flood Risk Manag 2(3):198–208. https://doi.org/10.1111/j.1753-318X.2009.01034.x
21. Fenta AA, Yasuda H, Shimizu K, Haregeweyn N, Woldearegay K (2017) Quantitative analysis and implications of drainage morphometry of the Agula watershed in the semi-arid northern Ethiopia. Appl Water Sci 7:3825–3840. https://doi.org/10.1007/s13201-017-0534-4
22. Firstpost (2021) Explainer: what makes Mumbai flood every monsoon? Clogged drains, rivers and receding mangroves likely reasons. Mumbai: The Network 18. Retrieved from https://www.firstpost.com/india/explainer-what-makes-mumbai-flood-every-monsoon-clogged-drains-rivers-and-receding-mangroves-likely-reasons-9700391.html
23. Goswami D (2020) Urban flood risk reduction, case area: Bhopal. Int J Archit 6(2):9–18. Retrieved from http://www.iaeme.com/IJA/issues.asp?JType=IJA&VType=6&IType=2
24. Gupta K (2007) Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India. Urban Water J 4(3):183–194. https://doi.org/10.1080/15730620701464141
25. Hall JW, Sayers PB, Dawson RJ (2005) National-scale assessment of current and future flood risk in England and wales. Nat Hazard 36:147–164. https://doi.org/10.1007/s11069-004-4546-7
26. Hammond MJ, Chen SA, Djordjević S, Butler D, Mark O (2015) Urban flood impact assessment: a state-of-the-art review. Urban Water J 12(1):14–29. https://doi.org/10.1080/1573062X.2013.857421
27. Hughes RM, Kaufmann PR, Weber MH (2011) National and regional comparisons between Strahler order and stream size. J N Amn Benthol Soc 30(1):103–121. https://doi.org/10.1899/09-174.1
28. Indo-Asian News Service (2017, September 11) Poor drainage and sewage system is the real cause of urban flooding: experts. New Delhi, India
29. Jainer S, Rohilla SK, Pasricha D (2020) An every monsoon affair: how to tackle urban flooding. Down to Earth, New Dehli. https://www.downtoearth.org.in/blog/urbanisation/an-every-monsoon-affair-how-to-tackle-urban-flooding-72558
30. Jang JH, Hsieh CT, Chang TH (2019) The importance of gully flow modelling to urban flood simulation. Urban Water J 16(4):1–12. https://doi.org/10.1080/1573062X.2019.1669198
31. Jha BM, Sinha SK (2020) Towards better management of ground water resources in India. Central Ground Water Board, Ne Delhi
32. Jha SK (2018) Urban floods—a case study of Araria, Bihar. Ambedkar University, Delhi. Retrieved from https://www.researchgate.net/publication/326655201_Urban_Floods-A_Case_Study_of_Araria_Bihar
33. Jia N, Sitzenfrei R, Rauch W, Liang S, Liu Y (2019) Effects of urban forms on separate drainage systems: a virtual city perspective. Water 1–18. https://doi.org/10.3390/w11040758
34. Jiang L, Jiapaer G, Bao A, Guo H, Ndayisaba F (2017) Vegetation dynamics and responses to climate change and human activities in Central Asia. Sci Total Environ 599–600(1):967–980. https://doi.org/10.1016/j.scitotenv.2017.05.012
35. Khawas V (2005) Urbanisation in the North-East: patterns, trends, and policy prongs. Soc Chang 35(2):47–69. https://doi.org/10.1177/004908570503500204
36. Klingelhofer D, Muller R, Braun M, Bruggmann D, Groneberg DA (2020) Climate change: does international research fulfill global demands and necessities? Envernmental Sci Eur 32(137):1–21. https://doi.org/10.1186/s12302-020-00419-1
37. Lavanya K (2012) Urban flood management—a case study of Chennai city. Archit Res 2(6):115–121

38. Li C, Liu M, Hu Y, Shi T, Zong M, Walter MT (2018) Assessing the impact of urbanization on direct runoff using improved composite CN method in a large urban area. Int J Environ Res Public Health 15(775):1–14. https://doi.org/10.3390/ijerph15040775
39. Ligtenberg J (2017) Runoff changes due to urbanization: a review. Umea University, Umea. Retrieved from https://www.divaportal.org/smash/get/diva2:1067287/FULLTEXT01.pdf
40. McGrane SJ (2016) Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. Hydrol Sci J 61(13):2295–2311. https://doi.org/10.1080/02626667.2015.1128084
41. Meteorological Centre, Agartala (2020) Climate of Tripura. Indian Meteorological Department, Government of India, Agartala. Retrieved from https://agartala.imd.gov.in/Tripura-Climatology/
42. Miller JD, Hutchins M (2017) The impacts of urbanisation and climate change on urban flooding and urban water quality: a review of the evidence concerning the United Kingdom. J Hydrol Reg Stud 12:345–362. https://doi.org/10.1016/j.ejrh.2017.06.006
43. Mitra S, Roy S (2020) Infrastructural development and future scope of railway transport system in Tripura: a spatial analysis. In: Mukherjee D, Saha M (eds) Purvottaran-the rise of North East: paradigms of development in the VUCA world. Bloomsbury, New Delhi, pp 500–531. https://www.bloomsbury.com/in/purvottaran-9789390513017/
44. Mitra S, Debbarma D, Santra A, Roy S (2018) Road network system in Agartala municipal corporation: a geographical analysis. Indian J Reg Sci, 66–77. https://www.researchgate.net/publication/333246169_Road_Network_System_in_Agartala_Municipal_Corporation_A_Geographical_Analysis
45. Nath S (2014) Addressing. Guru Gobind Singh Indraprastha University, New Delhi. Retrieved from https://www.academia.edu/7076587/Addressing_Delhis_Urban_Flooding_Problem
46. Neog R (2021) Evaluation of temporal dynamics of land use and land surface temperature (LST) in Agartala city of India. Environ Dev Sustain, 1–21.https://doi.org/10.1007/s10668-021-01572-0
47. Otukei JR, Blaschke T (2010) Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. Int J Appl Earth Observ Geoinf 12(Special):27–31. https://doi.org/10.1016/j.jag.2009.11.002
48. Parkinson J (2003) Drainage and stormwater management strategies for ow-income urban communities. Environ Urbanization 15(2):115–126. Retrieved from https://doi.org/10.1177/095624780301500203
49. Parthasarathy B, Sontakke NA, Munot AA, Kothawale DR (1987) Droughts/floods in the summer monsoon season over different meteorological subdivisions of India for period 1871–1984. J Climatol 7:57–70. https://doi.org/10.1002/joc.3370070106
50. Pradhan MP, Ghose MK, Kharka YR (2012) Automatic association of strahler's order and attributes with the drainage system. Int J Adv Comput Sci Appl, 30–34. https://www.researchgate.net/publication/236868521_Automatic_Association_of_Strahler's_Order_and_Attributes_with_the_Drainage_System
51. Rafiq F, Ahmed S, Ahmed S, Khan AA (2016) Urban floods in India. Int J Sci Eng Res 7(1):721–735. https://www.ijser.org/researchpaper/Urban-Floods-in-India.pdf
52. Rai PK, Mohan K, Mishra S, Ahmad A, Mishra VN (2017) A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Appl Water Sci 217–232. https://doi.org/10.1007/s13201-014-0238-y
53. Ray K, Pandey P, Pandey C, Dimri AP, Kishore K (2021) On the recent floods in India. Curr Sci 117(2):204–218. https://doi.org/10.18520/cs/v117/i2/204-218
54. Roy S, Mitra S (2016) Railway transport system in Tripura, India: an geographical analysis. Geogr Rev India 78(1):40–57
55. Roy S, Mitra S (2020) Railway stations of Tripura, India: an assessment of infrastructural conditions. In: Bandyopadhyay S, Pathak CR, Dentinho TP (eds) Urbanization and regional sustainability in South Asia. Springer, Belgium, pp 177–200

56. Roy S, Mitra S (2016) Infrastructural status of railway transport system in Northeast India: a geographical analysis. Asian J Spat Sci 4:89–100. https://www.researchgate.net/publication/318909107_Infrastructural_Status_of_Railway_Transport_System_in_Northeast_India_A_Geographical_Analysis
57. Roy S, Mitra S (2021) Rail freight transport system in Tripura: an analysis of performances and prospects. In: Mitra S, Bandyopadhyay S, Roy S, Dentinho TP (eds) Railway transportation in South Asia. Springer, Chem, pp 103–130. https://doi.org/10.1007/978-3-030-76878-2
58. Roy S, Mitra S (2018) Intra state mobility pattern of railway passengers in Tripura, India. In: Gogoi L (ed) Land, people and environment. Suprava Publication, Guwahati, pp 70–92
59. Sangomla A (2020) Extreme weather in North East: floods in some districts, others stay dry. Down to Earth, New Delhi. https://www.downtoearth.org.in/news/climate-change/extreme-weather-in-north-east-floods-in-some-districts-others-stay-dry-71950
60. Sangomla A (2021) Climate crisis in North East India: why are rainfall patterns changing? Down to Earth, New Delhi. https://www.downtoearth.org.in/news/climate-change/climate-crisis-in-north-east-india-why-are-rainfall-patterns-changing--78879
61. Santra A, Mitra S, Debbarma D (2018) Impact of urbanisation on land use changes in Agartala city, India. Res J HumIties Soc Sci 9(2):1–8. https://www.researchgate.net/publication/327144012_Impact_of_urbanization_on_land_use_changes_in_Agartala_City_India
62. Satterthwaite D (2008) Climate change and urbanisation: effects and implications for urban governance. United Nations Secretariat, New York. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/unpd_egm_200801_climate_change_and_urbanization_effects_and_implications_for_urban_governance_satterthwaite.pdf
63. Sen S, Santra A, Debbarma D, Mitra S, De SK (2015) Morphology of Tilla-Lunga topography in West Tripura District, Tripura, India. Ann NAGI 35(2):77–93. Retrieved from https://www.researchgate.net/publication/316668526_Morphology_of_Tilla-Lunga_Topography_in_West_Tripura_District_Tripura_India
64. Shinde S, Pande CB, Barai VN, Gorantiwar SD, Atre AA (2023) Flood impact and damage assessment based on the Sentitnel-1 SAR data using google earth engine. In: Pande CB, Moharir KN, Singh SK, Pham QB, Elbeltagi A (eds) Climate change impacts on natural resources, ecosystems and agricultural systems. Springer Climate. Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_20
65. Sinha B (2017) Lessons from Agartala's flood fury. Agartala: India climate dialogue. https://indiaclimatedialogue.net/2017/08/18/lessons-agartalas-flood-fury/
66. The Hindu (2019) Heavy rain in Agartala city in Tripura. N. Ravi, Chennai
67. Tucci CE (2007) Urban flood management. World Meteorological Organisation, Geneva. Retrieved from https://www.floodmanagement.info/floodmanagement/wpcontent/uploads/2020/06/Cap-Net-WMO-Urban-Flood-Management.pdf
68. Turok I, McGranahan G (2013) Urbanization and economic growth: the arguments and evidence for Africa and Asia. Environ Urbanization 25(2):465–482. https://doi.org/10.1177/0956247813490908
69. Wakode HB, Baier K, Jha R, Azzam R (2018) Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad, India. Int Soil Water Conserv Res 6(1):51–62. https://doi.org/10.1016/j.iswcr.2017.10.003
70. Wang J, Wang K, Zhang M, Zhang C (2015) Impacts of climate change and human activities on vegetation cover in hilly southern China. Ecol Eng 81:451–461. https://doi.org/10.1016/j.ecoleng.2015.04.022
71. Winstanley D (1973) Recent rainfall trends in Africa, the Middle East and India. Nature 243:464–465. https://doi.org/10.1038/243464a0
72. World Resources Institute (2019) Urban flooding: insights from Hyderabad. WRI India Ross Center, Delhi
73. Yazdanfar Z, Sharma A (2015) Urban drainage system planning and design—challenges with climate change and urbanization: a review. Water Sci Technol 72(2):165–179. https://doi.org/10.2166/wst.2015.207

74. Zhang L, Guilbert E (2012) A study of variables characterising drainage patterns in river networks. In: International archives of the photogrammetry, remote sensing and spatial information sciences. XXII ISPRS Congress, Melbourne, Australia, pp 29–34. https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XXXIX-B2/29/2012/isprsarchives-XXXIX-B2-29-2012.pdf
75. Zimmermann E, Bracalenti L, Piacentini R, Inostroza L (2016) Urban flood risk reduction by increasing green areas for adaptation to climate change. Procedia Eng 161:2241–2246. https://doi.org/10.1016/j.proeng.2016.08.822

Natural Resource Planning Under Climate Change Issue Using Advanced Remote Sensing and GIS Technology: A Review

Pritam Das, Abhinav Kumar, Vinay Kumar Gautam, and Nirmalya Kumar Nath

Abstract Forest ecosystems are an example of a natural resource that is frequently at the focus of divisive and international discussions on biodiversity, climate change, and carbon sequestration. A large portion of human society has become interested in natural resource management as a result of a growing understanding of the role that natural resources like forests, land use, etc. play in the global carbon cycle, including the potential to decrease carbon emissions and increase carbon sequestration through forest growth processes. GIS is basically a computer-based system that manages, examines, and modifies geographic data, usually to produce visualizations (2-D or 3-D), including maps. RS stands for the use of aerial or satellite imagery to examine features on the Earth's surface. For exploration, environmental impact assessment, continuing mine management, mapping, disaster management, and civil and military intelligence, remote sensing from airborne and spaceborne systems delivers useful data to fully utilize the value of these data, the right data must be retrieved and presented in a standard manner so that it can be imported into geo-information systems and facilitate effective decision-making. Water information must be retrieved promptly and correctly for a variety of purposes, including wetland conservation, coastal alteration, flood prediction assessment, water resource study, water resource synoptic monitoring, and post-disaster analyzation. The creation of software for the analysis of complicated systems is Defines' primary goal. This paper is designed to provide an overview of some of the very broad themes in natural resource management for in-depth analyses of natural resources under climate change scenarios.

Keywords Natural resource · Climate change · GIS · Remote sensing · Impact assessment

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_4

1 Introduction

The constraints imposed on the world's natural resources are becoming more and more of a problem as the human population approaches 7.95 billion in 2021. Disputes over carbon sequestration, climate change, and biodiversity frequently centre on natural resources like forest ecosystems. A large portion of human society has become interested in natural resource management as a result of a growing understanding of the role that natural resources like forests, land use, etc. play in the global carbon cycle, including the potential to decrease carbon emissions and increase carbon sequestration through forest growth processes. In a recent paper, the United States Climatology Program investigated management approaches for reducing the impact of climate change [1, 2].

The biggest examination of managerial adaptations to date, the paper was authored by a team of 61 scientists and managers. It focused on specific management practises for the nation's protected lands and waters, including Nature Reserves, National Forests, National Wildlife Reserves, Wild and Scenic Rivers, National Estuaries, and Marine Protected Areas. Changing management and goal-setting approaches—from a static equilibrium view of the natural world to a highly dynamic and variable approach will be necessary if considerable progress in adapting to climate change is to be made. The ideas and methods examined in this article are culled from all of the management systems examined in the report [3].

A natural resource is "any component of the natural environment, such as soil, water, rangeland, forest, wildlife, and minerals that species depend on for their welfare," according to Curlander and Cober [5]. Thus, managing natural resources means managing them for objectives of use, conservation, and preservation. Making decisions on how to use resources, including deciding to do nothing at all, is a fundamental part of management [4].

Remote sensing data is a very useful source of accurate and advanced information for environmental management and impact studies. A useful source of information for mapping, environmental monitoring, disaster management, and civil and military intelligence, remote sensing via airborne and spaceborne platforms. To fully utilise the value of these data, the right data must be retrieved and presented in a standard manner so that it can be imported into geo-information systems and facilitate effective decision-making. For the majority of remote sensing applications, the object-oriented approach can contribute to powerful automatic and semiautomatic processing. Utilizing statistical or pixel-based signal processing techniques in concert examines the rich information contents. With the aid of several models and the first object-oriented image analysis programme on the market, e-Cognition, which provides a suitable connection between remote sensing imagery and GIS, the major goals are to demonstrate real-world phenomena. Powerful signal processing methods are developed to explore the hidden information in advanced sensor data [5, 17, 22, 26, 28], e.g., for hyper spectral or high-resolution polarimetric SAR data [3, 4].

2 Importance of Advanced Remote Sensing and GIS Technology for Natural Resources Management/Planning

Advanced remote sensing and GIS technology may be used for management of natural resources like forest areas, lakes and ponds and streams, wetlands, agricultural fields and urban areas. Some of the applications of remote sensing and GIS are mentioned below: (a) Significant objects identification: River, Water body, Pool, Roads, Bridge, etc.; (b) Water resources: groundwater and surface water management: Gaps and issues to Indian water resources, Spatial and temporal variation in availability, Falling per capita availability of the country, Expanding multi-sectoral demand, Under and inefficient utilization of irrigation potential, Loss of surface storage due to reservoir sedimentation, Frequent floods severely affecting the flood prone area development, Recurring droughts, NDVI, Water resources assessment, Water resources management, Water resources development, Watershed management, Flood disaster support, Environmental impact assessment & management, Water resources information and Decision support systems, Mapping regional inundation with spaceborne L-band SAR; (c) in Glaciology: Powerful and efficient method of gathering data about glaciers, Studying glaciers usually located in remote, inaccessible and inhospitable environments, Status of snow cover during accumulation, Status of snow cover during ablation, To detect glacier features; (d) in Agriculture: Identification, area estimation and site suitability for different crops, Soil mapping, Sodic land mapping and reclamation at plot level, Crop nutrient deficiency detection and Pre-harvest crop acreage, Crop condition assessment at block level, Crop yield modelling and production forecasting, Agricultural drought assessment, Reflectance modelling; (e) Horticulture: Orchard average and Production estimation, Mapping and monitoring of extension of fruit belts, Detection, Mapping and monitoring of Insect, pest and disease infestation, discrimination of different species; (f) in soil resource: Command area development, soil conservation in catchment areas, Sustainable agriculture, Watershed management, reclamation of degraded lands, land irrigability assessment, land productivity assessment, soil erosion assessment; (g) in earth resources: land slide studies, geo-morphological studies, seismotectonic studies, engineering geological studies, mineral targeting, selection of suitable bridge, barrage and road alignment etc., lithological and structural mapping; (h) in land use planning: mapping urban sprawl, Infrastructure planning, Environmental planning etc.

3 Effect of Climate Change on Natural Resources

3.1 Agriculture

In the early phases of satellite remote sensing, the majority of researchers concentrate on the use of data for the classification of land cover types, with crop types being a primary focus among those interested in agricultural applications. Finding plant biophysical characteristics has been a recent focus of agricultural remote sensing research. Remote sensing has long been used to track and study agricultural operations. On a number of agronomic subjects, the study of agrarian canopies using remotely sensed data has yielded important data. Remote sensing has the benefit of being able to offer repeated data without affecting the crop, which can be used to supply vital data for smart agriculture applications.

The cost-effective method for gathering data across large geographic areas is remote sensing. In India, satellite remote sensing is mostly used to calculate agriculture productivity and crop acreage. The detection and characterization of agricultural output has the potential to be improved by the application of remote sensing technologies based on the functional traits of crops and/or soils. Remote sensing satellite data can be utilized for yield estimation, crop phenological information, and disturbance detection.

Together, satellite data and Spatial analysis may produce spatiotemporal fundamental informative layers which can be used for a multitude of activities, such as mapping flood plains, hydrological modelling, surface energy flow, urban development, and changes in land uses, as well as crop development monitoring and stress detection. The development of narrow band or hyperspectral sensors, as well as excellent spatial resolution aircraft or satellite based sensors, has enabled breakthroughs in the application of remote sensing systems. Additionally, hyperspectral remote sensing has contributed in more complete analyses of crop classification. For the purpose of classifying crops, hyperspectral sensors (from 400 to 2500 nm) can be thoroughly analyzed using data mining techniques such as principal components analysis, lambda-lambda models, stepwise discriminant analysis, and derivative analysis.

3.2 Vegetation Monitoring

In a variety of research projects where remote sensing is critical, aerial imagery and image analysis methods are used. However, remote sensing can decreases the quantity of field data needed and enhances estimate accuracy. Hyperspectral data can dramatically improve crop and vegetation characterization, discrimination modeling, and mapping when compared to broadband multispectral remote sensing. In order to characterises, identify, model, and map significant agricultural crops around the world as well as to examine specific biophysical and biochemical factors, this resulted in the creation of 33 ideal HNBs and an equal number of distinct two-band normalized difference HVIs.

3.3 Crop Assessment

Farmers can benefit from remote sensing by receiving timely spectral data. Information on the biophysical plant health indicator that can be utilised to make a decision. the physical modifications that occur in a person's body. Stress can cause plants to change their spectral properties. Because of the reflectance/emission characteristics, tactics for monitoring stress can be detected remotely. Crop growth is checked periodically. It is crucial to take the necessary safety precautions and to be aware of the possibility of output loss due to any stressor. A multitude of factors, including soil moisture availability, planting date, and air temperature, affect the phases of crop development and how they progress. the time of day, as well as the soil's condition These components control the environment and productive capacity of the plant [11].

3.4 Nutrient and Water Status

Two of the most crucial areas where remote sensing and GIS can be utilised in conjunction with precision farming are nutrient and water stress management. Our ability to control nutrients on a site-specific basis with remote sensing and GIS helps us reduce cultivation expenses while improving the effectiveness of fertilizer use for crops. Arid and semi-arid areas can use precision farming technologies to use water more productively. To enhance water use efficiency by reducing runoff and percolation losses, drip irrigation, for instance, can be used in conjunction with data from remote sensing data such as canopy air thermal gradient.

3.5 Crop Evapotranspiration

Crop productivity has decreased as a result of rainfall anomalies and an increase in the temperature rate, and so forth, all of which result in a decrease in Moisture in the soil Drought is an occurrence. which can be characterized as an average over a long period of time the state of the precipitation-temperature balance in a certain location, and evapotranspiration, this is also dependent on the commencement of Wilhite and monsoon, as well as their potency. Vegetation indices, in turn, CWSI, for example (Crop Water Stress Index) ST (Surface Transport), (Temperature), WDI (Water Depth Indicator), and SI (Standard Index) describe the (Stress Index). There is a link between water stress and Plants' thermal properties Sruthi et al. investigated the effects of vegetation stress.

3.6 Weed Management

Precision weed management aids in the implementation of better weed management strategies. Remote sensing in combination with Precision agriculture holds a lot of promise. Now, technology is very important. Ground, on the other hand, surveying techniques for mapping site-specific information Weed information is quite a time—consuming. demanding and time–consuming, However, Remote sensing based on images offers promising weed detection apps for site—particularly weed control. Based on the spectral differences, the differences in reflectance qualities between weeds and grasses crops, remote sensing technology offers a solution. a term used to describe the process of finding weeds in a crop taking a position and contributing to the growth of weed maps in the field to ensure site-specific and effective weed control. Herbicides that are depending on the needs of the situation can be used. Weed control is a term used to describe the process of removing weeds.

3.7 Crop Yield and Production Information

Crop forecasting has been done using remote sensing. yields are based mostly on statistical—empirical correlations between yield and indicators of vegetation. The data found on Crop output prior to harvest is important for the development of national food policies. Crop yield consistency is a crucial factor for the purpose of crop output forecasting. The crop production is influenced by a number of things such as crop type, water availability, and fertilizer levels, Weeds, pests, and disease all have an impact on the field. Infestation, weather conditions. The spectral analysis. These variables influence the response curve. The spectral response increase and declines, the crop condition is represented by a curve. performance. Using IRS P3 WiFS (Wide Format Standard), IRS-1C WiFS with LISS3 (Field Sensor).

Precision Agriculture

Remote sensing technologies are becoming more and more popular among scientists, engineers, and large-scale crop growers as an essential part of precision farming. Precision farming uses data gathered by sensors embedded in farm equipment in order to reduce cultivation expenses, enhance management, and increase resource efficiency. Variable rate technology is the most advanced aspect of precision farming (VRT). On moving farm equipment, sensors are installed. This apparatus consists of a computer that supervises the delivery of inputs based on GPS receiver data and produces input recommendation maps. The benefit of precision farming is that it can gather crop data at the spatial and temporal resolution required for management choices.

Land Use Planning

Remote sensing's key purpose in land management and planning has been to offer information about the physical qualities of the land that influence the management of particular land parcels or the allocation of lands to diverse uses. Aerial photography has already been used to evaluate these physical attributes, which are then utilized to produce resource maps and track changes in environmental conditions. These applications have been thoroughly developed in the United States and are now effectively integrated into the municipal, state, and federal planning infrastructures.

Established use cases of remote sensing

Two of the most well-known applications of remote sensing in land-use planning and management are mapping and environmental monitoring. Almost all of these applications make use of photographic photographs. When used for remote sensing, aerial photographs, also referred to as air photos, are simply images captured from an aeroplane. Utilizing air pictures has the advantage of allowing the viewer to view vast areas all at once from the unusual vantage point of being in the air. This frame of view is particularly useful when analyzing the regional distribution of ground phenomena.

Aerial photography is used to extract information by manually interpreting the things on the photographs and measuring the size and shape of the objects using photogrammetric algorithms or a visual assessment. Identifying things by connected phenomena, such as detecting a given rock type by identifying an associated flora type, is a common task for the interpreter. The interpreter must also be able to distinguish complicated items from their constituent objects, such as recognizing an industrial region based on the size and shape of the buildings. The interpreter must be skilled at problem-solving and have a solid knowledge of physical, biological, or impacts on environment in addition to their photo interpretation abilities.

Maps Mainly Obtained from Aerial Photos

Aerial photography is often used to create or combine the physical environment maps that are frequently utilised in land-use planning and management. The primary source of maps and data pertaining to the nation's physical environment has historically been the United States Geological Survey (USGS). In order to combine four earlier topographic and geologic mapping organisations, Congress passed an act in 1879 creating the United States Geological Survey (USGS). Charting the terrain of all fifty states and updating those maps is one of the USGS's most significant duties. Since this cannot be completed all at once, the states assist by determining their most urgent mapping needs and establishing cooperative programmes to aid.

Almeida et al. [1] discovered that the urban land dynamics models, powered by GIS and remote sensing data, have proven to be useful in the identification of main urban development vectors and their existing land tendencies, enabling local planning authorities to manage and reorganize (if it comes into the equation) city growth in accordance with an environmental load capacity of concerned sites and their current and anticipated infrastructure availability.

4 Environmental Conditions Monitoring

Despite the fact that applications for land have shown aerial photography to be most useful, it has also showed promise as a tool for planning and management by monitoring surface conditions. The following two examples Surface mining reclamation and other forms of it are examples of this kind of use. control over forestry Surface mines have been decontaminated. Aerial photography is used by both state and federal entities to monitor the situation. A governmental body that oversees the mining sector is the Federal Office of Surface Mining. In the western US and Appalachia, aerial photography is used to evaluate the environmental impact of mining. The Oklahoma Geological Survey uses aerial photographs to collect data. surface-mining activity in each county should be identified and located. Field investigation is used to explore the locations and classify the Unclaimed, partially reclaimed, or fully reclaimed. Monitoring surface condition by air photo interpretation is also used in forestry operations. Air photos have been used to test for the presence of agents that harm forests ever since the 1920s when the extent of damage brought on by pest damage was optically assessed from a stationary airplane. Air photographs can be used to detect trees that have been defoliated completely or partially, or that have foliage that has an aberrant hue or reflectance at non-visible wavelengths. Insects, like bark beetles, create stress-induced foliage discoloration, which can be seen in color and color infrared photography. Because the damage is first seen in the tops of trees, air images are often more accurate than ground observations in detecting the effects of defoliating insects.

5 Water Resources: Groundwater and Surface Water Management

5.1 Gaps and Issues to Indian Water Resources

Goyal and Surampalli [15] studied the trend and projections of rainfall and temperature for the Teesta River basin and upper Narmada River basin. They used GCM-simulated climatic variables for the downscaling of the precipitation and temperature for both basins and used hydrological models (SWAT and MIKE NAM) for the evaluation of the impact of climate change on the watershed hydrology and water yield. The study found that the water resources planning and management would be affected in several ways due to changes in precipitation will, including the design of hydrological structures, flood and drought management, and urban planning and development.

Rashid et al. [25] studied the implications of fast-developing urban life and its influence on water supplies in Muzaffarabad City. The data required for the study was collected by conducting 20 in-depth interviews in 2015 with representatives of the local government, political workers, and local citizens to determine how increased urbanization affects water quality in the region. The data reveal that local inhabitants were contaminating the waters of both the Jhelum and Neelum rivers, resulting in a lack of drinking water and a multitude of viral infections.

Although India has 16% of the world's population, the country possesses just 4% of the world's freshwater resources. India is water-stressed due to the changes in weather patterns and recurrent droughts. However, due to excessive groundwater pumping, an ineffective and wasteful water management system, and years of insufficient rainfall, 12% of India's population is now living in the 'Day Zero' situation. Aside from this, a number of government initiatives, particularly those relating to agriculture (minimum support price), have resulted in water overuse.

5.2 Spatial and Temporal Variation in Availability

Raj and Azeez [24] examined the spatiotemporal variation in water quality and quantity of the Bharathapuzha river basin using multivariate statistical analysis tools. The result showed that the monsoonal discharge was substantially greater in more disturbed basins than in other seasons, whereas the somewhat disturbed basin had a steady amount of flow throughout the season. They concluded that the changes in land use and the influence of dams caused spatiotemporal fluctuations in the river's surface water chemistry.

5.3 Falling Per Capita Availability of the Country

With India's growing population and overall development, water consumption is expanding at a rapid pace. Annual water availability per capita has decreased from 5,177 m^3 in 1951 to 1,508 m^3 in 2014 and is likely to reduce further to 1,235 m^3 by 2050. If it falls below 1,000–1,100 m^3, India may be classified as a water-stressed country.

6 Under and Inefficient Utilization of Irrigation Potential

The gap between irrigation potential provided by major and minor projects and actual utilization is widening, reducing agricultural production in the country. Agriculture consumes around 80% of current water consumption. Irrigated land accounts for about 48.8% of India's 140 million hectares (mha) of agricultural land. The remaining 51.2% is fueled by rain.

6.1 Water Resources Assessment

Within the boundaries of the uncertainty of the climate change projections, Gosain et al. [14] investigated the potential consequences of climate change on the water resources of Indian river systems. Water supply in river systems is evaluated using the daily weather data from PRECIS. referring to the SWAT simulation of all river basins throughout the nation.

Kumar et al. [19] presented the different difficulties and solutions for building a comprehensive strategy for sustainable development and management of the country's water resources, as well as the availability and needs for water resources in India. They also emphasised the combination of blue and green flows, as well as virtual water transfer principles, for sustainable management of water resources to fulfil current demands without jeopardising future generations' requirements. The study concluded that hydrological studies must be conducted in order to analyse water supplies under changing climatic conditions. A comprehensive general circulation model for India is required to anticipate future climatological variables on micro, meso, and macro watershed dimensions.

Remotely sensed indirect indication of groundwater may provide important data where practical alternatives are not available [8, 9]. The measurement potential, storage, and fluxes of ground water are examined in relation to satellite technology. It is claimed that satellite data can be applied if the supplementary analysis is employed to relate to surface expressions and groundwater behavior. When paired with numerical modeling, geographic information systems, and ground-based data, remotely sensed data are most beneficial [9].

6.2 Water Body Identification

The most successful and efficient way for investigating water resources, assessing flood risks, and planning for water has been water body extraction utilising remote sensing. Numerous methods, including single-band threshold, inter spectrum relation method, unsupervised classification, supervised classification, and water index method, can be used to analyse water bodies (normalised difference water index, modified normalised difference water index, and new water index) [10].

Miyun reservoir and the Miyun cit zone were chosen as the study locations by Haibo et al. [16] in order to determine the most efficient water extraction technique for various water usage scenarios across time. By applying both supervised and unsupervised classification separately, they came to the conclusion from their investigation that the area of the Miyun reservoir varied just slightly. The main distinction is caused by the disturbance of the town, the bare ground, and other features outside the reservoir. Both NDWI and MNDWI can swiftly extract water information and produce reliable water extraction results when the right threshold is used. The MDIWI model is appropriate for district background ground objects with buildings, bare terrain, or

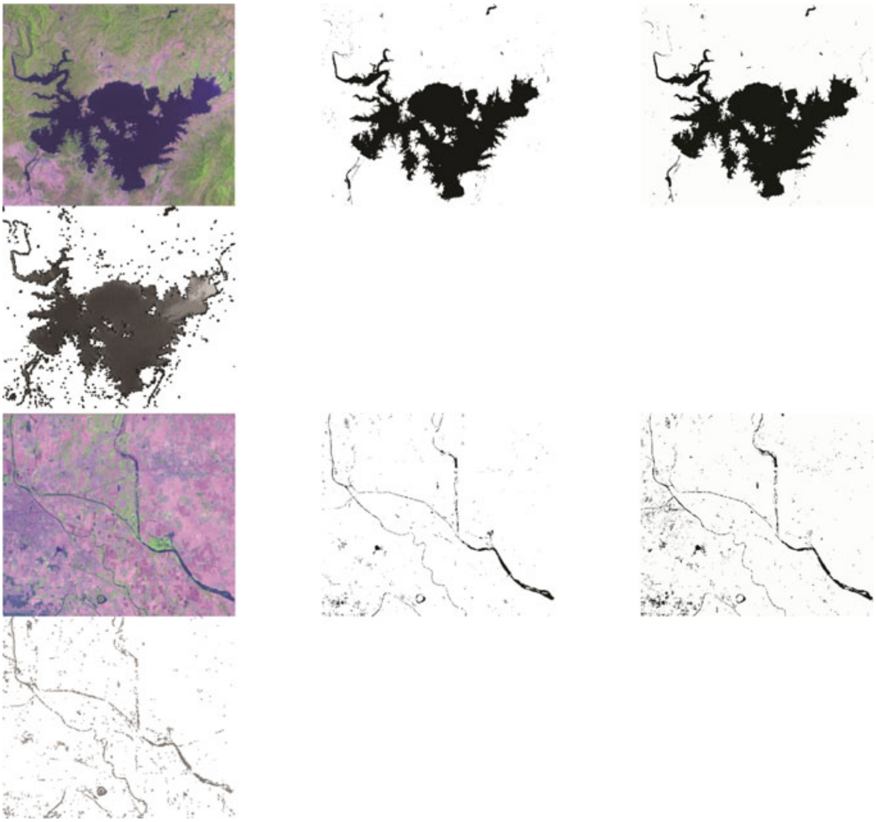

Fig. 1 Original ETM, single-band threshold approach, NDWI, and supervised classification method) Miyun reservoir and Miyun county water system (Haibo et al. [16])

urban areas, while the NDWI model is appropriate for district background ground objects with vegetation (Fig. 1).

7 Soil Resource

7.1 Soil Erosion

USLE, along with its family of soil erosion models viz. RUSLE and RUSLE based InVEST-SR/SDR models are the most extensively applied models. Although these models are recommended for small scale spatially distributed catchments, it has been established that these models estimate soil losses and sediment delivery ratios accurately in different geographical scales such as large catchment, divisional secretariat, province, and whole country scales. the different erosion modeling components (R factor, K factor, LS factor, C factor, and P factor) can be derived using many data sources and materials viz. DEM data, rainfall data, the spatial distribution of soil types data, and delineated river basin maps and some advance equations in soil erosion studies and this information can be collected by remote sensing and GIS techniques.

Piyathilake et al. [23] recommended for future soil erosion studies for Sri Lanka with USLE, RUSLE, and RUSLE based InVEST-SR/ SDR models in a GIS/RS environment. Their review clarifies how future researchers will be able to select the best method of deriving R, K, LS, C, and P factor overcoming the challenges viz. limited data availability and complexity of applying soil erosion models that are associated with running soil erosion models.

Gelagay and Minale [12] analysed the RUSLE parameter and integrated utilising raster calculator in the geo-processing tools in ArcGIS 10.1 environment to estimate and plot the yearly soil loss of the research region, Koga Watershed, Northwestern Ethiopia. The study found that the watershed's annual soil loss varies from none in the lower and mid portions to 265 t ha^{-1} $year^{-1}$ in the portion with a steeper slope, with an average yearly soil loss of 47 t ha^{-1} $year^{-1}$. The watershed saw a total annual soil loss of 255,283 tonnes, of which 181,801 (71%) tonnes covered 6691 (24%) hectares of land. The most of the places affected by soil erosion are geographically situated in the watershed's uppermost inlet, which has the sharpest slope. These are areas with higher soil nitosol and alisol content. Their study establishes that the slope gradient and length followed by soil erodibility factors were found to be the main factors of soil erosion. They concluded that sustainable soil and water conservation practices should be adopted in steepest upper part of the study area by respecting and recognizing watershed logic, people and watershed potentials (Fig. 2).

8 Soil Degradation

The physical and chemical deterioration of soil brought on by wind and water erosion is increasing at an alarming rate all over the world, yet it is still challenging to estimate and quantify the breadth and severity of these processes at the regional level. Intensive agricultural and social growth do not necessarily result in soil degradation. The majority of degradation processes and the unfavourable effects they cause can be avoided, eliminated, minimised, or at the very least regulated. The loss of land or its "productive capacity," the restriction of normal soil functions, and/or the decrease in soil fertility as a result of unfavourable changes in soil processes and, consequently, in soil properties are all common outcomes of soil degradation, which is typically a complex process.

In order to develop useful and accurate spatial information to support decision-making, advanced GIS technologies (including geostatistics and machine learning) and enough information provided by Earth Observation must be combined with trustworthy ground truth data. Although spatial inference of different land-related surface properties is made possible by digital soil and environmental mapping, it

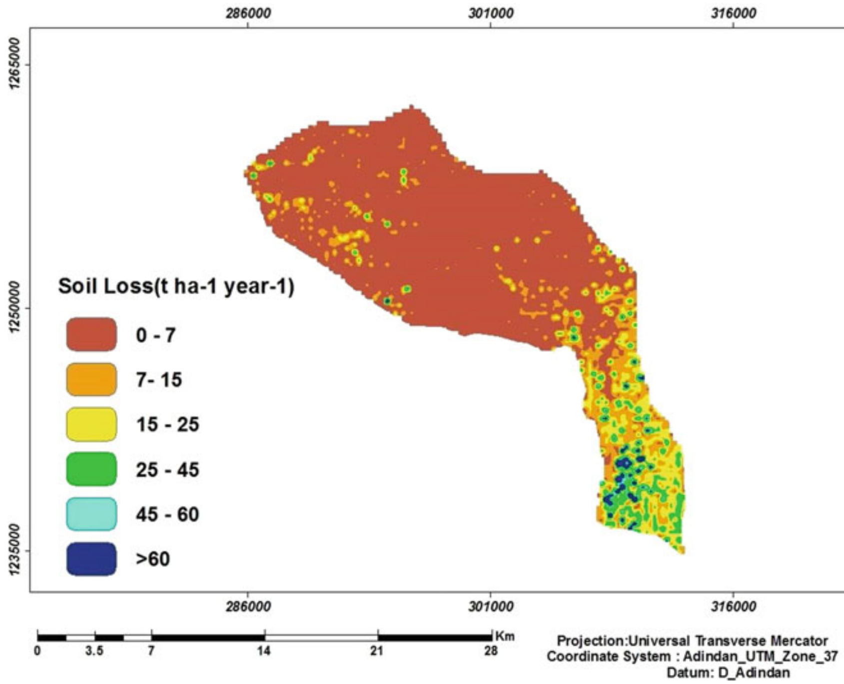

Fig. 2 Soil loss rate map (Gelagay and Minale [12])

is still difficult to assess the functions, processes, and services of soil in a spatially explicit manner. Earth observation may be very helpful in identifying various soil and land degradation processes. Remote sensing is one of the primary instruments in monitoring regional environmental processes. Although there have been many efforts to use satellite imagery to identify, map, and/or monitor various types of land degradation processes, the adoption of advanced geostatistical, data mining, machine learning, and deep learning methods in spatial and process modelling opens up new opportunities for effective assessment and mapping of soil and land degradation.

Fernández et al. [7] conducted a multitemporal examination of gully erosion in olive trees using Digital Elevation Models created using aerial photogrammetric and LiDAR data. For the analysis of the DSM of differences, they created digital surface models (DSMs) and orthophotographs using historical flights aligned in a common coordinate reference system with a recently assessed LiDAR point cloud. This allowed them to identify gullies and calculate the affected areas as well as estimate height differences and volume differences between models.

9 Landslide Susceptibility Mapping

Landslides are occurring more frequently lately on river banks and in mountainous terrain. In hilly places, the majority of these landslides happened on cut slopes or embankments alongside roads and highways. Many people experienced severe anxiety as a result of some of these landslides that happened close to apartment complexes and in residential areas. Within the past ten years, there have also been a few significant and devastating landslides. Significant harm to lives and property has been caused by these landslides. For probabilistic landslide susceptibility analysis, precise landslide location detection is crucial. In-depth and reasonably priced information about landslides can be obtained by using remote sensing techniques, such as the application of aerial and satellite photos.

10 Mining

One of the few industries that alters entire landscapes is mining, which has a number of negative effects [2, 21]. Due to the unequal distribution of mines throughout the world and their disproportionate influence on nearby communities and ecosystems, these effects are geographical in nature [27]. Modern mines can be identified from above by the presence of open cut pits, waste rock dumps, tailings dams, water storage ponds, access roads, infrastructure for milling and processing, supporting infrastructure (such as housing for workers), and in some cases, block cave areas, heap leach pads, or quarries. These characteristics are frequently suggestive of repercussions in the neighbourhood. Some of these effects, like deforestation, may be seen in aerial or satellite photos, and some typically not. As a result, different impacts call for various spatial analysis techniques. These techniques typically make use of geographic information systems (GIS) and remote sensing (RS), Two programmes that are frequently employed in geographic information science [13]. GIS is primarily a computer-based system that manages, examines, and modifies geographic data, frequently to produce visualizations (2-D or 3-D), such as maps. RS is the term that describes the investigation of surface features using aerial or satellite imagery. Major mining corporations routinely use these techniques for investigation, environmental assessment, and ongoing mine management. They have traditionally been regarded by leading mining industry organisations [20]. Software developers, such as ESRI [6] and Kim et al., have in fact designed especially GIS solutions to suit to the operational needs of mining experts [18].

11 Conclusion

Extracting water data quickly and accurately is crucial for wetland protection, coastal change, flood range assessment, and post-disaster evaluation. It also helps with water resource surveys and macro monitoring. Software development for the analysis of complex systems is Definiens' primary objective. Only by taking into consideration the complex web of interdependencies and interactions at many sizes, including context information, semantics, and hierarchical structure, can this be accomplished. With the help of Definiens' Cognition Network Technology, the foundation is now available for analysing not only photos but also texts from numerous other fields and combining data from disparate sources to assist decision-makers. While RS and GIS alone cannot withstand or forecast changes, the data gathered by RS can be fed into various models to produce results or simulations that are realistic to the real world.

References

1. Almeida CMD, Monteiro AMV, Câmara G, Soares-Filho BS, Cerqueira GC, Pennachin CL, Batty M (2005) GIS and remote sensing as tools for the simulation of urban land-use change. Int J Remote Sens 26(4):759–774
2. Bebbington A, Hinojosa L, Bebbington DH, Burneo ML, Warnaars X (2008) Contention and ambiguity: mining and the possibilities of development. Develop Change 39:887–914
3. Coulde SR, Pottier E (1996) A review of target decomposition theorems in radar polarimetry. IEEE Trans Geosci Remote Sens 34(2):498–518
4. Curlander J, Kober W (1992) Rule based system for thematic classification in SAR imagery. Proc. IGARSS. IEEE Press, New York, pp 854–856
5. Curlander JC, Kober WO (1992) Rule based system for thematic classification in synthetic aperture radar imagery. In: [Proceedings] IGARSS'92 international geoscience and remote sensing symposium, vol 2, pp 854–856. IEEE
6. ESRI (2018) The geographic advantage: GIS solutions for mining
7. Fernández T, Pérez-García JL, Gómez-López JM, Cardenal J, Calero J, Sánchez-Gómez M, Tovar-Pescador J (2020) Multitemporal analysis of gully erosion in olive groves by means of digital elevation models obtained with aerial photogrammetric and LiDAR data. ISPRS Int J Geo Inf 9(4):260
8. Gautam VK, Pande CB, Kothari M, Singh PK, Agrawal A (2023) Exploration of groundwater potential zones mapping for hard rock region in the Jakham river basin using geospatial techniques and aquifer parameters. Adv Space Res 71(6):2892–2908
9. Gautam VK, Trivedi A (2023) Decadal analysis of water level fluctuation using GIS in Jabalpur district of Madhya Pradesh. Indian J Soil Conserv 51:1–8
10. Gautam VK, Pande CB, Moharir KN, Varade AM, Rane NL, Egbueri JC, Alshehri F (2023) Prediction of sodium hazard of irrigation purpose using artificial neural network modelling. Sustain 15(9):7593
11. Gautam VK, Awasthi MK, Trivedi A (2020) Optimum allocation of water and land resource for maximizing farm income of Jabalpur District, Madhya Pradesh. Int J Environ Clim Change 10(12):224–232
12. Gelagay, HS, Minale, AS (2016) Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. Int Soil Water Conserv Res 4(2):126–136
13. Goodchild MF (2003) Geographic information science and systems for environmental management. Annu Rev Environ Resour 28:493–519

14. Gosain AK, Rao S, Arora A (2011) Climate change impact assessment of water resources of India. Curr Sci 356–371
15. Goyal MK, Surampalli RY (2018) Impact of climate change on water resources in India. J Environ Eng 144(7):04018054
16. Haibo Y, Zongmin W, Hongling Z, Yu G (2011) Water body extraction methods study based on RS and GIS. Procedia Environ Sci 10:2619–2624
17. Haverkamp D, Tsatsoulis C (1992) The use of expert systems in combination with active and passive microwave data to classify sea ice. In: IGARSS'92; proceedings of the 12th annual international geoscience and remote sensing symposium, Houston, TX, May 26–29, vol 2 (A93–47551 20–43). Institute of Electrical and Electronics Engineers, Inc
18. Kim S-M, Choi Y, Suh J, Oh S, Park H-D, Yoon S-H et al (2012) ArcMine: a GIS extension to support mine reclamation planning. Comput Geosci 46:84–95
19. Kumar R, Singh RD, Sharma KD (2005) Water resources of India. Curr Sci 794–811
20. Legg CA (1990) Applications of remote sensing to environmental aspects of surface mining operations in the United Kingdom. Remote sensing: an operational technology for the mining and petroleum industries. Springer, Netherlands, Dordrecht, pp 159–164
21. Mudd GM (2010) The environmental sustainability of mining in Australia: key megatrends and looming constraints. Resour Policy 35:98–115
22. Pierce E, Ulaby F, Sarabandi K, Dobson M (1994) Knowledge based classification of polarimetric SAR images. IEEE Trans Geosci Remote Sens 30(4):697–705
23. Piyathilake IDUH, Udayakumara EPN, Gunatilake SK (2021) GIS and RS based soil erosion modelling in Sri Lanka: a review
24. Raj N, Azeez PA (2009) Spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha, India. Curr Sci 96(2):245–251
25. Rashid H, Manzoor MM, Mukhtar S (2018) Urbanization and its effects on water resources: an exploratory analysis. Asian J Water Environ Pollut 15(1):67–74
26. Serpico S, Roli F (1995) Classification of multi sensor remote sensing images by structured neural networks. IEEE Trans Geosci Remote Sens 33(3):562–577
27. Sonter LJ, Moran CJ, Barrett DJ, Soares-Filho BS (2014) Processes of land use change in mining regions. J. Cleaner Prod. 84:494–501
28. Tsatsoulis C (1993) Expert systems in remote sensing applications. IEEE Geosci Remote Sens Newsletter 7–15

Self-Generating Training Model (SGTM) Algorithm to Estimate Groundwater Level in Consensus with Climate Change Impact Study in Cauvery Delta Zone, Tamil Nadu, India

A. Stanley Raj, J. P. Angelena, R. Damodharan, and D. Senthil Kumar

Abstract Cauvery Delta Zone is present in the eastern part of Tamil Nadu, popularly known as 'rice bowl' of Tamil Nadu. It constitutes of about 11.1% of total area of the state. It lies between 10.00 and 11.30° N latitude and 78.15°–79.45° E longitude. Cauvery Delta Zone includes the districts of Thanjavur, Thiruvarur, Nagapattinam, Mayiladuthurai, Perambalur and some parts of Pudhukottai and Cuddalore Districts. This zone plays a vital role not only in rice production but also in other varieties of crops and raw materials for industries. It receives more than 50% of rainfall in North East monsoon. Variation in rainfall in this zone causes serious environmental effects. Sources of groundwater recharge zones are mostly influenced by rainfall variability. In this research work, the connection between the climate change impact and rainfall variability has been studied and the successive study has been made. The temporal trends of rainfall variability are studied extensively to predict the future scenario using the Self-Generating Training Model (SGTM) algorithm. This work is potentially helpful for farmers to identify the threatening zones and can understand the fluctuations in groundwater level due to implications of climate change.

Keywords Rainfall variability · Climate change impact · Machine learning algorithm · SGTM

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_5

1 Introduction

Tamil Nadu is a state that lies in the Southernmost part of the India. Kerala bounds it on the West and Karnataka and Andhra Pradesh along the North-West and North respectively. Bay of Bengal is present at Eastern part and also the state encircles the Union Territory Puducherry on its East. Kanyakumari, the Southernmost tip of Indian subcontinent, is where Arabian Sea, Bay of Bengal and Indian Ocean meet. The state spreads over 130,058 km^2. It covers for about 4% of the total area of the India [3]. The Western and North-Western part of the state are of hilly in nature. This State comprises of 38 Districts with diversified Geography and Geology. The Coastline of Tamil Nadu is the Third longest in India. There are 13 districts along the East coast of the state which extends up to 1076 km. It possesses 16 non major, 3 major ports and many coastal industries like nuclear and thermal power plants, refineries etc., 8 districts are present over the Eastern slope of Western Ghats.

The impact of various natural hazards with differing intensities on Tamil Nadu is more than that of the other states in India [21]. The phenomenal occurrence of the historical cyclonic storms in Tamil Nadu shows its necessity to study the impact of climate change over the state. The studies show that an average of two cyclonic storm has occurred in a decade. In November 2000, a severe cyclone crossed at the coast of cuddalore district with wind speed of 110 kmph [12, 14] Further Cyclone Nisha has hit in 2008, Cyclone Laila in 2010 and Cyclone Thane hits in 2011, there were worst hit cyclones in the state includes Jal in 2010, Cyclone Nilam and Cyclone Phailin in 2012 and 2013 respectively. The tsunami of the Indian Ocean in 2004 has had a tremendous, long-lasting impact on the state [31]. SGTM algorithm is used to analyse the rainfall variability.

On addition to this, there are several environmental problems occurred due to the impact of various factors in climate change of Tamil Nadu. Rainfall is one of the important climate factors that plays a vital role in socioeconomic and environmental conditions of Tamil Nadu. The profound trends in the environment affecting the natural resources and setup of the Earth is due to the unpredictability nature of rainfall [16]. This state experiences wet subtropical climate and mostly hot temperature throughout the year except in the period of the monsoons. Tamil Nadu possess three different monsoon periods of rainfall. The *south west monsoon* occurs between the month of June and September. The *north east monsoon* occurs from the period of October to December *dry season* extends from January to the end of May. This state has an annual rainfall of 945 mm of which 32% of rainfall is obtained through the South West monsoon and 48% of rainfall through the North East monsoon. Tamil Nadu is the only state in India's Meteorological sub division that receives less rainfall in South West Monsoon than that of North East Monsoon. Tamil Nadu being an agricultural state, is mostly depends on monsoonal rains, which shows internal variability and also variations due to external factors such as the El Nino-Southern Oscillation, so monsoon failures result as water scarcity and drought. Moreover, climate factors like rainfall variability have also had an impact on the climate change over past year.

El Nino and La Nina are associated together with the oscillation of atmospheric pressure throughout the southern Pacific Ocean, which is termed as Southern Oscillation [1]. This shows the contrast between the warm phase and Southern Oscillation (SO), which is known as El Nino—Southern Oscillation (ENSO) cycle. Both the El Nino and La Nina which are the extreme events of El Nino-Southern Oscillation (ENSO). ENSO have been in association with the rainfall and temperature anamolies globally [10] It is an important climate process associated with climate variability regionally throughout the world [9, 28]. The El Nino and Southern Oscillation are allied with each other whenever an El Nino process headed in the Pacific Ocean. An ENSO event is a cyclical event, which occurs every 2–7 years and can last for up to eighteen months. The frequency and intensity of ENSO has been variable, this ENSO variability leads us to have concern about the possibility of impact of climate change over Pacific Ocean which creates impact to the global climate change [11].

McBride et al. [20] and Rotstayn et al. [29] have studied and reported the influence of El Niño-Southern Oscillation (ENSO) effects in both the Eastern and Western part of the Pacific Ocean. Pramanik and Jagannathan, Parthasarathy, Parthasarathy et al. [22–24] studied the long term trends of Indian monsoon rainfall for Indian subcontinent. Rao and Jagannathan [27], Thapliyal and Kulshrestha [34] and Srivatsava et al. [33]. Southwest monsoon and annual rainfall throughout the country has no particular significant trend which was studied by and Thapliyal and Kulshrestha [34], Jagannathan and Bhalme [13] and Srivatsava et al. [33]. Jagannathan and Bhalme [13], and Singh and Sontakke [32] reported the long term rainfall trend over smaller scale in space. The fore mentioned a study evidences the variability of Monsoonal rainfall throughout the country.

The anomalies of both temperature and rainfall are connected to ENSO [6, 15] over several parts of the world and also in India. In the Indian Ocean and the Equatorial Pacific Ocean, the sea surface temperature anomalies has been inter linked to the variability of Indian Summer Monsoon Rainfall which was reported by [5]. The relationship between the Indian Summer Monsoon Rainfall and the El Nino shows the inverse relationship as the result of analysis of long term data. The relation between ENSO and global rainfall [4] which has been investigated in previous studies most part of India has less rainfall during El Nino and more rainfall during La Nina. Even though there is no direct relationship between years of El Nino and Droughts in Indian union, there were many severe remarkable droughts occurred with the association of El Nino in the country [26]. The remarked influence of the ENSO events over the rainfall with inverse relationship for North East Monsoon particularly in Tamil Nadu which was highly variable from rest of the India had studied by [16].

2 Cauvery Delta Regions

The Cauvery river with its tributaries are situated in the Sothern peninsular of India. This river is a major water source for the domestic, irrigational and industrial needs of two states i.e. Karnataka and Tamil Nadu. The drainage of the river is almost

90,000 km^2. It starts from Coorg (Karnataka) which is situated in the Western Ghats, which flows through North-Western and Central parts of Tamil Nadu and empties in the Bay of Bengal. Vennaru, Kudamuruti, Paminiar, Arasalar and Kollidam are the major rivers in its watershed. The important contributories in Tamil Nadu include Noyyal, Bhavani and Amaravathi rivers. Grand Anicut, Bhavanisagar and Mettur Dams are the major dams functioning in this river. The Cauvery basin in Tamil Nadu has an average annual rainfall of 956 mm and over 4.4 million people are working in the agricultural fields over this area. The upper catchment area receives more rainfall in South West Monsoon and the delta regions of Cauvey River receive more rainfall during North East Monsoon. The river before emptying into the Bay of Bengal, divides as 36 distributaries which results as the wide deltaic formation (Fig. 1).

Cauvery Delta Zone is present in the eastern part of Tamil Nadu, which is popularly known as 'rice bowl' of Tamil Nadu. It constitutes of about 11.1% of total area of the state. It lies between 10.00–11.30° N latitude and 78.15°–79.45° E longitude. Cauvery Delta Zone includes the districts of Thanjavur, Thiruvarur, Nagapattinam,

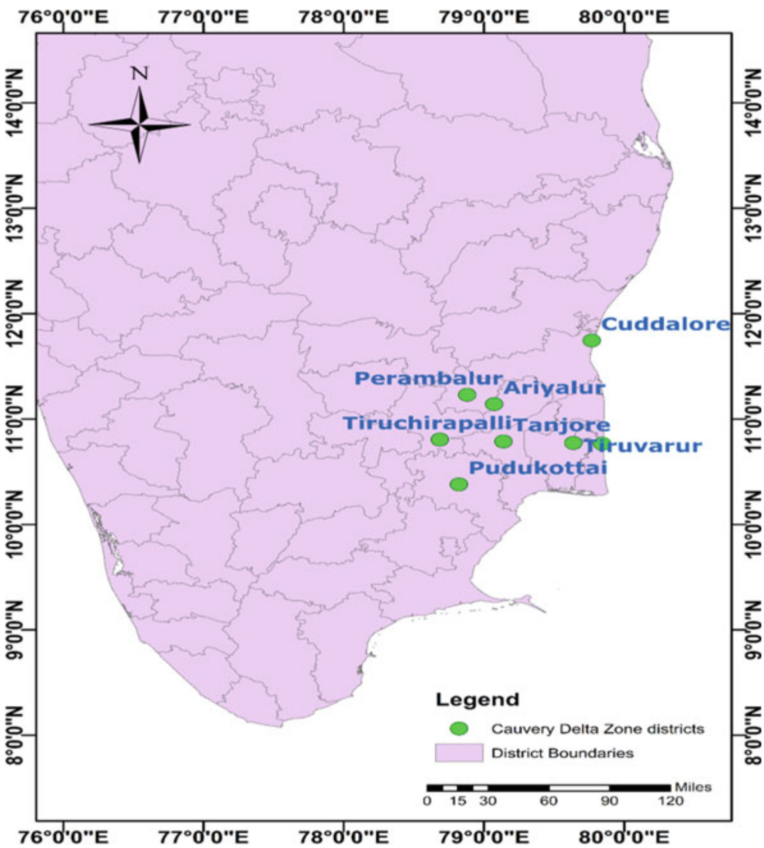

Fig. 1 Shows the Cauvery delta regions in Tamil Nadu

Mayiladuthurai, Perambalur and some parts of Pudhukottai and Cuddalore Districts (Fig. 1). This zone plays a vital role not only in rice production and other varieties of crops and raw materials for industries. It receives more than 50% of rainfall in North East Monsoon. Variation in rainfall in this zone causes environmental severe effects.

3 Impact of ENSO on Tamil Nadu

In Tamil Nadu, the role of rainfall during October to December is vital in nature. This is because their increased activity in North East Monsoon over the state. So, It is crucial to study the link between North East Monsoon Rainfall (NEMR) of the state and global telecommunication indicators.

Influence of ENSO over South West Monsoon rainfall is lower than that of in North East Monsoon Rainfall of the state (Goutham 2019). Larger variation with respect to the location and the year has been exhibited by North East Monsoon. Bhatnagar [2] indicated that several climate factors such as El Nino-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are the reason for the difference in amount and distribution of North East Monsoon Rainfall. But their limited number of studies carried out on the influence of IOD and ENSO over NEMR [17, 19].

Most of the country receives less rainfall during El Nino years and more rainfall during La Nina years. This is in contrast with the Southernmost state Tamil Nadu which follows an opposite trend to that. A positive correlation of both El Nino and La Nina years with the South West Monsoon Rainfall had been observed by Goutham (2019). The inter relationship of Nino-3 sea-surface temperature and SOI with the Tamil Nadu's North East Monsoon Rainfall have shown the result that SOI has been negatively correlated with the NEMR of the state [8]. The Nino-3 SST has positive correlation [7], which shows that the precipitation in autumn–winter season has effected by global climate signals.

Kumar et al. [19] reported that the relationship of North East Monsoon Rainfall with ENSO is gaining its strength. Even though the less summer monsoon rainfall has been observed in ENSO years, in last decade, it has been recorded that the summer monsoon rainfall was above normal, when the two ENSO events occurred [18]. So the detailed investigation has to be done, to explore the long term relationship of ENSO with the local and regional variability of Rainfall over Tamil Nadu. The variable nature of rainfall in Cauvery Delta Zone have been reported by [30]. The varying trends of rainfall pattern, temperature and other climate parameter in this region has been reported by [25].

3.1 Nagapatinam

Nagapattinam district covered 5 taluks, 434 villages, 8 town panchayats, 4 municipalities, 31 firkas and 523 revenue villages. The district is channelled by Kollidam

Table 1 Shows the statistical variations of rainfall in Nagapattinam during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	136.8633	167.4686	2.068794	1.635995	0.2	531.4
2011	169.9558	81.26093	1.582689	0.894336	67.66	358.98
2012	126.8825	89.44489	−1.58198	0.01646	14.6	262.17
2013	83.55417	85.16287	0.287902	1.148475	0.39	263.41
2014	110.2825	138.3214	1.051412	1.448417	0	410.02
2015	142.5508	236.7422	3.835941	2.151878	0	750.46
2016	54.51833	57.27833	0.476448	1.04025	0	176.79
2017	92.64917	129.1121	8.016623	2.666687	0	473.35
2018	80.07667	128.1614	4.877189	2.296603	1.31	425.29
2019	115.8975	148.0234	−1.11032	0.863992	0.2	347.28

and Cauvery River. Crystallic metamorphic and sedimentary formations underline it. Wide variety of topographical formulations constitutes the primary factor of rainfall and groundwater recharge. The groundwaters in fractured zones are extended to the maximum of 30 m and average of 10–15. Hard rock formations like Granitic Gneiss, Charnockite makes the water table conditions more stable in the district (Table 1).

3.2 *Tiruvarur*

Tiruvarur district receives from northwest and south west monsoon season. Average rainfall in the district ranges from 1100 to 1260 mm. The district is covered with semi consolidated formation with lower Miocene and Pliocene quaternary shallow aquifer system. Tiruvarur has 10 blocks with 2097.97 km^2 geographical area. It receives the average annual rainfall of 1184 mm. Based on the geological formation the water table depth ranging from 4.36 to 23 m. Canals contributed more in the irrigation of the district (Table 2).

3.3 *Tanjavur*

Tanjuvur has 14 blocks, 589 villages covered with three river basins: Vennar sub basin, Cauvery sub-basin and new delta area. The major rock types are sedimentary and hard rock with geological formations of sandstone, Laterite, Clay, Alluvium, Gneiss and Quartzite. The district receives the average of 1013 mm rainfall. The depth of aquifer is 1–8 m. The groundwater level in the district during the premonsoon and postmonsoon are 13.6 and 19.9 m in average respectively. There are 5 firkas in critical groundwater condition and more than 24 firkas are over exploited (Table 3).

Table 2 Shows the statistical variations of rainfall in Tiruvarur during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	152.1675	176.5941	1.87677	1.544164	0.15	562.74
2011	173.4	81.58333	1.58726	0.911664	72.17	363.29
2012	129.1008	90.94857	−1.57858	0.024433	15.03	264.46
2013	78.95417	65.43641	−1.411	0.561834	2.19	177.23
2014	105.535	126.5206	0.460028	1.2393	0	361.07
2015	139.1475	187.5237	2.149698	1.767224	0	574.5
2016	54.375	58.40456	1.146308	1.211848	0	187.24
2017	85.62	197.9184	7.047761	2.451454	0	396.69
2018	85.5472	146.3247	7.52335	2.072672	0.54	512.12
2019	105.6483	127.148	−1.4851	0.667417	0	306

Table 3 Shows the statistical variations of rainfall in Tanjavur during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	135.1917	147.8096	1.894151	1.433675	0.02	490.29
2011	178.48	87.2477	1.614567	0.995428	70.04	312.07
2012	132.9183	96.26128	−1.59522	0.049755	13.93	264.94
2013	69.95833	56.62338	−1.52257	0.42082	2.71	151.64
2014	90.77167	101.4174	−0.32397	0.940799	0	219.6
2015	110.205	124.0989	2.070899	1.623882	0	402.85
2016	53.4175	46.84705	−0.33928	0.38994	0	145.03
2017	50.38917	58.66345	3.249278	1.795775	0	200.15
2018	63.0075	99.04784	6.117469	2.491226	0.06	341.06
2019	92.5225	107.4919	−1.69396	0.573016	0.06	257.29

3.4 Trichirapalli

Tiruchirapalli district has 14 blocks, 404 villages lie in the central part of the state. Major geological formations are Charnockite, Gneiss, Quartzite, Pegmatite, Sandstone, Shale, Limestone and Alluvium. The district receives 818 mm of average rainfall. The depth of water level is 3 m to 15 m with a premonsoon average of 12.8 and an average postmonsoon of 16 m. There are 13 firkas which are over exploited and 7 and 5 firkas are critical and semicritical respectively. Table 4.

3.4.1 Cuddalore

Cuddalore district is covered with Villupuram in north and northwest, Perambalur in southwest, Ariyalur and Nagapatinam in south, and Bay of Bengal in east. It consists

Table 4 Shows the statistical variations of rainfall in Nagapatinam during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2011	165.085	105.9779	0.473363	0.946385	38.68	395.54
2012	126.1467	103.9506	−1.47034	0.239112	7.21	297.02
2013	51.205	52.0238	−1.45266	0.696473	1.35	129.34
2014	57.78917	62.57243	0.32973	1.012532	0.05	193.13
2015	78.47917	74.60123	1.486493	1.15741	0.97	253.06
2016	45.44667	48.15813	−0.37168	0.875956	0	140.46
2017	30.5825	28.37592	−0.13631	0.837402	0.05	88.92
2018	34.89917	43.17087	0.873997	1.362805	0.34	131.94
2019	61.95333	71.94282	−0.45681	0.962276	0.02	196.65

Table 5 Shows the statistical variations of rainfall in Cuddalore during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	105.0477778	179.3798	6.970174	2.574342	0	563.56
2011	92.0075	110.6719	3.81935	1.94005	21.45	235.75
2012	104.85	72.20781	1.03996	0.10431	4.38	217.66
2013	84.8125	91.61312	0.382528	1.187928	0	262.45
2014	110.568333	118.1069	0.593376	1.049303	0	372.32
2015	155.2516667	230.7571	4.655382	2.245427	0	771.66
2016	46.78833333	41.45805	−1.3031	0.261377	0	110.91
2017	90.3125	110.0262	2.272451	1.514823	1.66	248.09
2018	66.68166667	95.68196	2.202898	1.745997	0	295.44

of 13 blocks and 683 villages. Major geological formations are sandstone, Conglomerate, Gneiss, Charnockite, marine deposits and Alluvium. The district receives 1206.7 mm of rainfall. Average groundwater level of the district in premonsoon and post monsoon ranges from 23 m and 20.3 m respectively. There are 6 firkas with over exploited, 2 in critical and 7 firkas in semi critical condition (Table 5).

3.5 Ariyalur

Ariyalur has 6 blocks and 201 villages. The district is covered with parts of Vellalar and Cauvery river basin. The district receives an average of 107.8 mm of rainfall. The average groundwater level in the pre monsoon and post monsoon for the past five years were 23.2 and 28 m respectively. There are two sectors in semi critical condition (Table 6).

Table 6 Shows the statistical variations of rainfall in Ariyalur during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	123.7758	155.1392	3.150657	1.828646	0	525.38
2011	169.8067	94.077	0.877471	0.953011	53.51	379.99
2012	128.1167	96.80474	−1.58455	0.083045	10.26	281.78
2013	73.61167	79.17487	−0.12333	1.022054	0.5	233.9
2014	94.20833	101.4326	−0.13266	0.857404	0	306.85
2015	117.1875	155.3911	5.693227	2.327941	0	548.65
2016	51.6	53.96355	1.868417	1.293091	0	179.49
2017	58.57833	71.28856	5.182427	2.034845	0	254.12
2018	63.8075	91.92927	2.288062	1.811847	0.01	279.22
2019	100.6367	120.5404	−1.43508	0.667186	0	293.44

3.6 Pudukottai

Pudukottai is located in central region of Tamil Nadu and its boundry extend upto 4,663 km^2 and the population is 145269. The district surrounded with Tanjavur and Tiruchirapalli. There are two municipalities in this district are Pudukottai municipality and Tiruchirapalli in northeast. The district is located in 10.3833° N, 78.8001° E. There are eleven taluks in Pudukottai district (Pudukkottai, Gandarvakottai, Alangudi, Thirumayam, Kulathur, Illupur, Arantangi, Ponamaravathy, Karambakudi, Avudayarkoil and Manalmelkudi). The taluks are further classified to thirteen blocks, eight town panchayats, 757 revenue villages and 498 village panchayats. The district receives highest rainfall of 397 mm during northwest monsoon and it receives 303 mm rainfall in average during southwest monsoon. The summer and winter receive 81 and 40 mm of rainfall respectively. During summer the temperature is very high and low during the winter and average in other months (Table 7).

4 Results and Discussion

4.1 Model Development and Application

SGTM algorithm is framed specifically to predict the rainfall variability if the available data source is very minimal. With less number of data, SGTM can perform well using the multiple level of self generating module. These multiple sets of training levels will enhance the algorithm's performance (Fig. 2).

Table 7 Shows the statistical variations of rainfall in Pudhukottai during 2010–2019

Year	Mean	Std dev	Kurtosis	Skewness	Minimum	Maximum
2010	98.855	100.6635	1.244477	1.204878	0	332.68
2011	182.9508333	88.19446	1.557815	1.027391	73.14	387.92
2012	135.7825	98.6251	−1.58912	0.059832	14.16	283.01
2013	52.70333	39.08259	−0.41933	0.546415	1.94	131.12
2014	66.8175	69.727976	−1.73119	0.442642	010	181.85
2015	85.60667	81.86026	2.080076	1.320527	0.6	285.53
2016	41.46083	34.47911	−1.51901	−0.0833	0	93.81
2017	27.13083	32.89075	4.962191	2.114235	0.13	1116.7
2018	43.20083	52.21239	2.630649	1.781476	0.04	170.1
2019	71.392	86.02486	−0.78714	0.862776	0	133.43

Step 1:

The user can import the data for training the model. The imported data must be of any form, including text files, excel spreadsheets, CSV, etc.

Step 2:

For ANFIS training is more important. Thus based on the number of iterations and random permutations of data, SGTM generates synthetic data. This self-generation of synthetic data will be helpful to evaluate noisy and missed data. Thus this step is a very important step in this algorithm.

Step 3:

This the key step where the neuro fuzzy algorithm generates synthetic dataset for each data with connection to the adjacent data that controls the noises and errors present in data.

Step 4:

In this step the algorithm calculates the error percentage of the data based on the coefficient of variation.

Step 5:

Every iteration the system generates one synthetic data and a model is generated based on the number of iterations decided by the user. More the number of synthetic data better the performance of the algorithm.

Step 6:

Finally, the developed model is based on variable rate of synthetic data predicted by the neuro fuzzy algorithm.

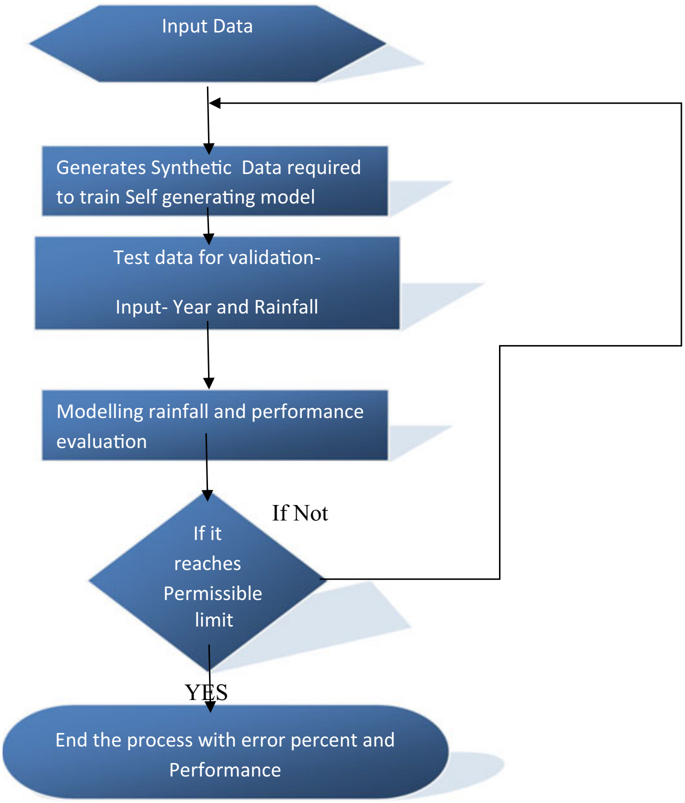

Fig. 2 Flow chart for self generating training model (SGTM) to predict rainfall variability with minimum number of training dataset

5 Algorithm Description and Application

This algorithm works on the basis of self-generating training dataset. In self-generating model, the system considers the mean, standard deviation, upper (Maximum value) and lower (minimum value) bounds. Rainfall data of 2001–2019 are taken into account for analysing the rainfall variability. After considering all the statistical values from the given input data, the algorithm generates the synthetic data using random permutations. Figures 3 and 4 represents the training dataset used for SGTM algorithm for rainfall variations and groundwater level variations in Nagapatinam district respectively. For every iteration, it generates one synthetic data. For getting more number of synthetic data, user has to fix the number of iterations. Figures 5 and 6 represents the tested results of rainfall and groundwater level variations. The consistency may be lost once the user fixes more number of iterations than the memory allocated by the system to train the data. The system became unstable after a particular number of epochs. Figures 7, 8 and 9 represents the Gaussian membership function, comparative results of rainfall and groundwater results of conventional fuzzy and SGTM algorithm.

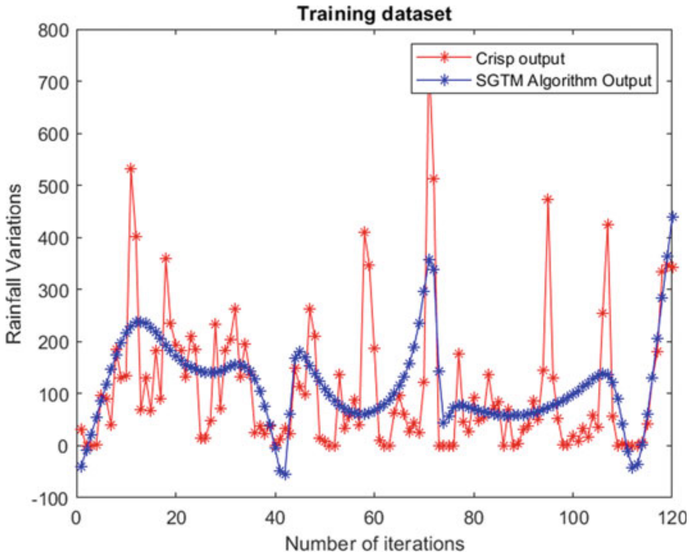

Fig. 3 Training dataset for SGTM for Nagapatinam district rainfall variations

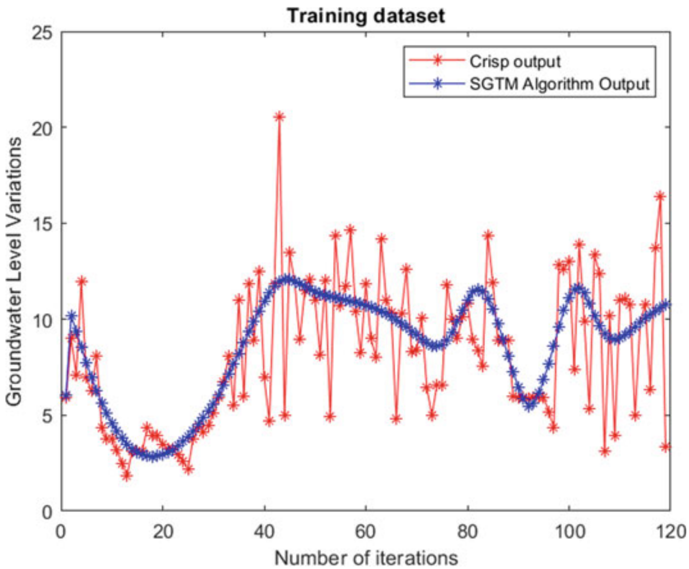

Fig. 4 Groundwater level data used for training SGTM algorithm

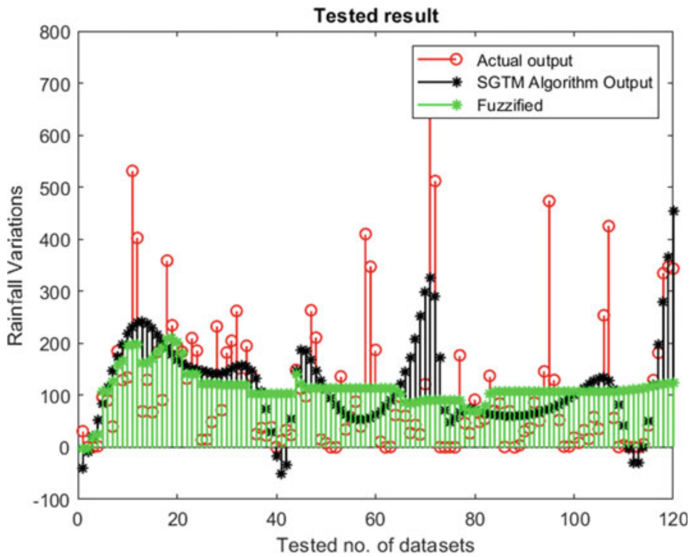

Fig. 5 Testing dataset for SGTM for Nagapatinam district rainfall variations

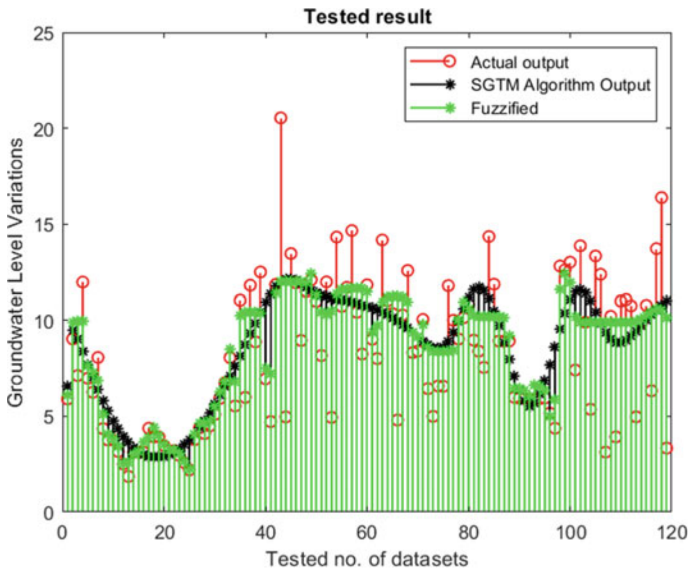

Fig. 6 Tested result for SGTM for Nagapatinam district groundwater variations

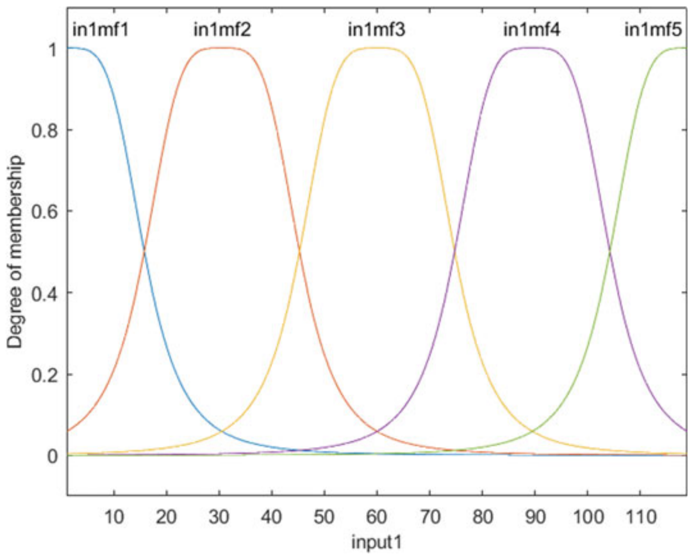

Fig. 7 Gaussian membership function used for SGTM

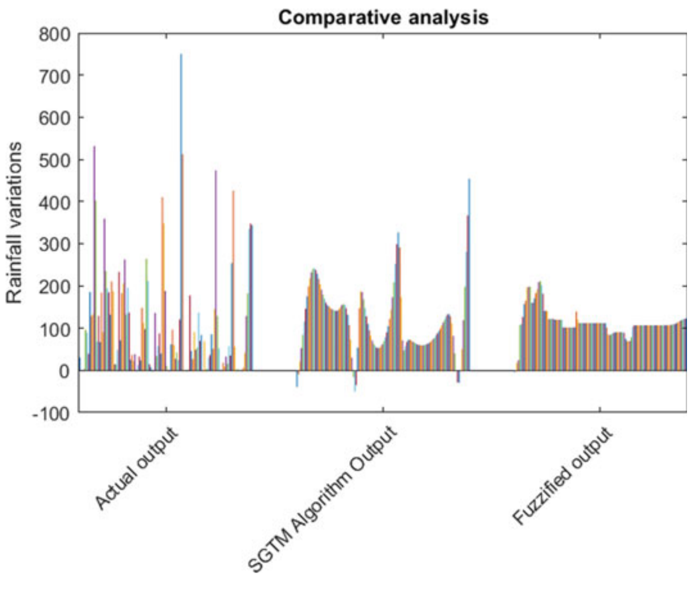

Fig. 8 Comparative results for SGTM and conventional fuzzy interpretation results for rainfall variation

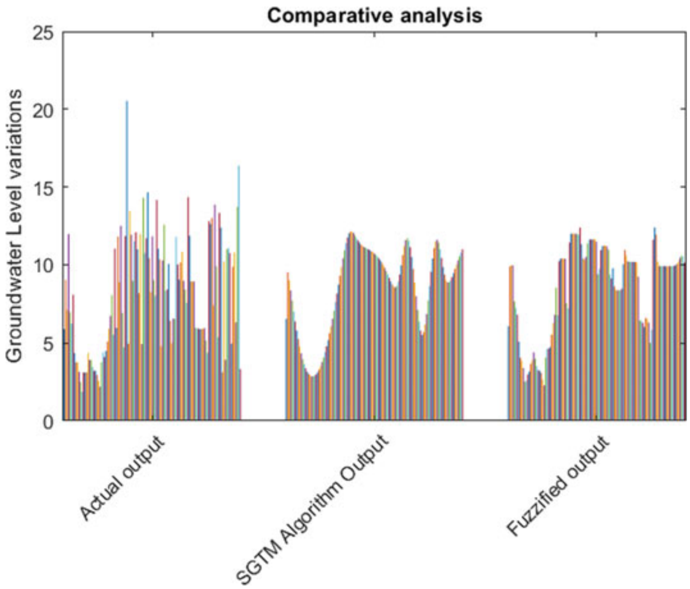

Fig. 9 Comparative analysis of SGTM and fuzzy interpretation results for groundwater level fluctuation

6 Conclusion

Self-generation of data has certain advantages Errors or noises in the data can be eliminated. It can be interpolated if there is any missing data between two data points, based on the standard deviation and the trend. The trend will be maintained. Synthetic training datasets are elastic because the datasets can run between maximum and minimum of the original data and predict the exact results though the data is nonlinear. Developing synthetic data using this algorithm helps the ANFIS system to decide the output very easily. Fixing the membership functions for a bunch of data, though it consumes time, it will predict the exact result after defuzzification. Many hybrid systems can be built on the combining platform of neural networks, fuzzy logic and neuro fuzzy networks. For example, fuzzy logic can be used to combine results from several neural networks; although some hybrid systems have been built, this present work has attained promising results when combining the fuzzy logic and neural networks. The field validation proves that this algorithm can have the bright future for estimating many non-linear problems. If the available data is very minimum, this type of algorithm will generate its own training dataset to predict the output more lucidly.

Acknowledgements I sincerely thank Loyola college management for giving permission to communicate and publish this research work. I thank Head of the Department of Physics for supporting all the students and researchers to complete the work successfully.

Compliance with ethical standards.

References

1. Allan RJ, Lindesay JA, Parker DE (1996) El Nino southern oscillation and climate variability. CSIRO publishing, Collingwood, p 405
2. Bhatnagar AK (2003) Chennai online: another rainless year. http://www.chennaionline.com/cityfeature/Chennai/2004/11meterology.asp [March 2007]
3. CPEES (2015) Ecologically sensitive area and environmental management in Tamil Nadu coast. Centre with potential for excellence in environmental science, Anna University, Chennai, Tamil Nadu, India. Available at https://www.annauniv.edu/cpees/cost.html
4. Curtis S, Adler R, Huffman G, Nelkin E, Bolvin D (2001) Evolution of tropical and extratropical precipitation anomalies during the 1997–1999 ENSO cycle. Int J Climatol 21:961–971
5. Gadgil S, Gadgil S (2006) The Indian monsoon, GDP and agriculture. Econ Polit Weekly 4887–4895
6. Glanz MH, Katz RW, Nicholls N (1991) Teleconnections linking worldwide climate anomalies. Cambridge University press, Cambridge, 1–535
7. Geethalakshmi V, Balasubramanian TN, Selvaraju R, Bride JM, Huda AKS, Vasanthi C, George D, Clewett J, Thiyagarajan TM (2003) Length of growing period as influenced by El Nino and La Nina over Coimboatore, Tamil Nadu, India. J Agric Resour Manage 2(3,4):31–38
8. Geethalakshmi V, Bride JM, Huda AKS (2005) Impact of Tamil Nadu rainfall. Vatavaran 29(2):9–16
9. Gowtham R, Geethalakshmi V, Pannerselvam S, Bhuvaneswwari K, Divya K (2019) Influence of El Nino and the southern oscillation (ENSO) on climate of Tamil Nadu. J Pharmacognosy Phytochem. Online at www.phytojournal.com
10. Halpert MS, Ropelewski CF (1992) Surface temperature patterns associated with the southern oscillation. J Clim 5:577–593
11. Hunt AG (1999) Understanding a possible correlation between El Nino occurrence frequency and global warming. Bull Am Metrol Soc 80:297–300
12. IMD (2011) Meteorological data: Cuddalore meteorological station. Tamil Nadu. Office of the Deputy Director General of Meteorology, Regional Meteorological Office, India Meteorological Department, Chennai, Tamil Nadu, India
13. Jagannathan P, Bhalme HN (1973) Changes in pattern of distribution of southwest monsoon rainfall over India associated with sunspots. Monthly Weather Rev 101:691–700
14. Khan AS (2013) Climate change induced sea level rise projection and its predicted impact on the Tamil Nadu coast, India: framing ecosystem and community based adaptation strategies. Ph.D Thesis, Anna University, Chennai, India, pp 226
15. Kiladis GN, Diaz HF (1989) Global climate anomalies associated with extremes in the southern Oscillation. J Climate 2:791
16. Kokilavani S, Ramaraj AP, Panneerselvam S (2015) Exploring the relationship of ENSO and rainfall variability over southern zone of Tamil Nadu. Int J Sci Environ Technol 4(4):955–965
17. Kripalani RH, Kumar P (2004) Northeast monsoon rainfall variability over south peninsular India vis-à-vis India Ocean dipole mode. Int J Climatol 24:1267–1282
18. Krishna Kumar K, Rajagopalan B, Cane MA (1999) On the weakening relationship between the India monsoon and ENSO. Science 284:2156–2159
19. Kumar P, Kumar KR, Rajeevan M, Sahai AK (2007) On the recent strengthening of the relationship between ENSO and northeast monsoon rainfall over South Asia. Clim Dyn 28:649–660
20. McBride JL, Nicholls N (1983) Seasonal relationships between Australian rainfall and the Southern Oscillation. Mon Weather Rev 111(10):1998–2004
21. NIDM (2015) Tamil Nadu: national disaster risk reduction portal. National institute of disaster management, New Delhi, India. http://nidm.gov.in/pdf/dp/TamilNadu.pdf
22. Pramanik SK, Jagannathan P (1954) Climate change in India-1: rainfall. Indian J Meteorol Geophys 4:291–309
23. Parthasarathy B (1984) Inter annual and long term variability of Indian summer monsoon rainfall. Proc Indian Acad Sci (Earth Planetary Sci) 93:371–385

24. Parthasarathy B, Rupakumar K, Munot AA (1993) Homogeneous Indian monsoon rainfall: variability and prediction. Proc Indian Acad Sci (Earth Planetary Sci) 102:121–155
25. Rajalakshmi D, Jagannathan R, Geethalakshmi V (2013) Comparative performance of RegCM model versions in simulating climate change projection over Cauvery delta zone. India J Sci Technol 6(8):5115–5119
26. Rajeevan M, Pai DS (2006) On El Niño-Indian summer monsoon predictive relationships. Res. Rep. No 4/2006, National Climate Centre, India Meteorological Department, Pune – 411 005, pp 20
27. Rao K, Jagannathan P (1953) A study of the northeast monsoon rainfall of Tamil Nadu. Indian J Meteorol Geophys 4:22
28. Rao VUM, Subba Rao AVM, Bapuji Rao B, Ramana Rao BV, Sravani C, Venkateswarlu B (2011) El Niño effect on climatic variability and crop production: a case study for Andhra Pradesh, Research Bulletin No. 2/2011, Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Andhra Pradesh, India, p 36
29. Rotstayn LD, Collier MA, Dix MR, Feng Y, Gordon HB, O'Farrell SP, Smith IN (2010) Improved simulation of the Australian climate and ENSO-related rainfall variability in a global climate model with an interactive aerosol treatment. Int J Climatol 30(7):1067–1088
30. Sathyamoorthy NK, Jagannathan R, Ramaraj AP (2016) Rainfall profile of Cauvery delta zone of Tamilnadu. Curr World Environ 11(2). https://doi.org/10.12944/CWE.11.2.21
31. Sheth A, Sanyal S, Jaiswal A, Gandhi P (2006) Effects of the december 2004 Indian ocean tsunami on the Indian Mainland. Earthq Spectra 22(S3):S435–S473
32. Singh N, Sontakke NA (1999) On the variability and prediction of rainfall in the postmonsoon season over India. Int J Climatol 19:309
33. Srivatsava HN, Dewan BN, Dikshit SK, Prakasa Rao GS, Singh SS, Rao KR (1992) Decadal trends in climate over India. Mausam 43:7–20
34. Thapliyal V, Kulshrestha SM (1991) Climate changes and trends over India. Mausam 42:333–338

Impact of Climate Change on Climate and Water Resources and Thus on Agriculture in India

S. Jeevananda Reddy

Abstract Rainfall is the primary source [as well snow melting] for water availability in India. In India both rainfed and irrigated agriculture have been practiced from centuries. The former relates to "in-situ" and the later "ex-situ" (river basin) rainfall. India being a tropical country temperature is not a limiting factor for agriculture but increased levels of evapotranspiration during drought years play an important role based on the crop season. However, crops/varieties are selected for the season and region based on temperature regimes. Droughts are common in India's tropical semi-arid zones, reaching as high as 60% of the years, mainly along the shadow zones of Western Ghats—after 1960s crop-based drought entered. The occurrence of droughts and floods follow the natural rhythmic variations in rainfall. With this, for example, for Kurnool in AP with the average drought proneness of 45% of the years, the averages for below and above the average 28-year periods of 56-year cycle in rainfall are 70 and 30% of the years. Water flows in the rivers like Krishna, Godavari, and Brahmaputra and NW Indian Rivers follow the natural rhythmic variations in rainfall. However, the method and period used in the water availability estimates play a vital role in getting reliable inferences. Integration of agro-climatological such as crop-soil-water balance simulations and agrometeorological results such as crop-soil-weather modelling is critical to achieve sustainability in agriculture. Issues related to climate change form part of agro-climatological studies. This chapter discusses these issues in brief with few examples.

Keywords Climate · Climate change · Global warming · Natural variability · Rainfall · Temperature · Water resources · Agriculture · Climate system · General circulation patterns

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_6

1 Introduction

History says that man has been on Earth for approximately two million years. Before 1960, the farmers used indigenous technologies evolved over hundreds and thousands of years, experiences and passed them on to generation after generation. These technologies were weather and soil driven farming systems that include crop/cropping patterns, crop rotation, land and water management practices, traditional seed, farmyard manure, drought animal based implements, etc. That is animal husbandry is part of agriculture that provides economic and nutrient security to farmer's families. With the present green revolution chemical fertilizer tailored seed mono crop technologies, crop based drought, a new concept entered in to the definition of drought hither to be associated with weather. Reddy [22] reported that "Vedic literature provides insight in to the earliest written records of agriculture in India—some such local reports are available all over the World also–. Rigveda hymns describe cultivation systems existing in India at that time of the history. Also, several other inscriptions/excavations showed the ancient agriculture practices followed in those Eras in those areas. The recent research by a team of researchers from IIT Kharagpur, Institute of Archaeology, Deccan College Pune, and Physical Research Laboratory and Archaeological survey of India (ASI) also shows that the civilization itself was much older than thought—it is at least 8,000 years old. They claim that their study suggests that the climate was probably not the sole cause of Harappa decline. Despite the monsoon decline, civilization did not disappear. The people changed their farming practices. They switched from water-intensive crops when monsoon was stronger to drought-resistant crops when it was weaker. They also argued that they did not give up despite the change in climate conditions. They argued that other causes, like change in subsistence strategy, by shifting crop patterns rather than climate change was responsible for the Harappa collapse. The findings have been published in the journal *Nature Scientific Report* on May 25, 2016.

On the Indian subcontinent, the major centers of this civilization include Harappa and Mohenjo-Daro in Pakistan and Lothal, Dholavira and Kalibangan in India. These people shifted their crop patterns from the large-grained cereals like wheat and barley during the early part of intensified monsoon to drought-resistant species of small millets and rice in the later part of declining monsoon thereby changed their subsistence strategy. The findings come from a major excavated site of Bhirrana in Haryana that shows preservation of all cultural levels of this ancient civilization from the pre-Harappa Hakra phase through the Early Mature Harappa to the Mature Harappa time. Bhirrana was part of a high concentration of settlements along the now dried up mythical Vedic river 'Sarasvati', an extension of Ghaggar River in the Thar Desert."

Figure 1 presents the generalized major crop zones in India. However, the percent area under cash crops showed a rapid growth while the area under staple millets based food crops dropped drastically and so also pulses [22]. Still to date Bullock drawn equipment is common in India (Fig. 2) along with modern tractors of several types. The mono-crop chemical inputs technologies by not including animal husbandry component changed the entire agriculture scenario in India. Farmers' suicides became common with high inputs and weather risk at harvesting. Post-harvest losses increased with area under cultivation increase and no facility to protect harvest from unseasonal rains. Now governments are thinking to build shelters and food processing activities.

India's total geographical area is 329 million hectares [**Mha**] of which 195 Mha is gross cropped area and 141 Mha is net cropped area. That means, only in 54 Mha more than once crops are cultivated in a crop year on the same piece of land. In the net

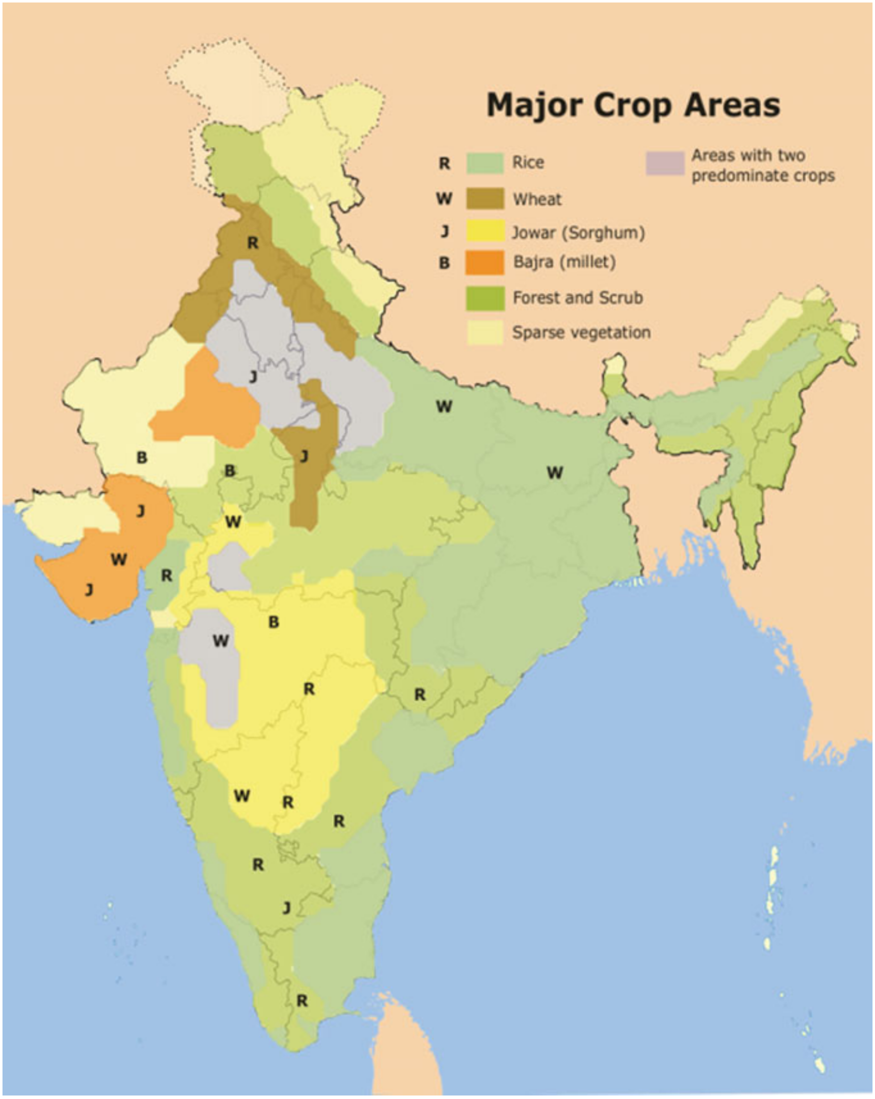

Fig. 1 Major crops by region in India

Fig. 2 Traditional bullock drawn plough cultivation method

cropped area the net irrigated area is only 65.3 Mha and the rest of the cropped area is rainfed. Human population in India increased from 20 to 134 crores by 1880–2019. This resulted large changes in land use patterns in the same period. Forests reduced from 89 to 63 Mha during the same period with relatively greater deforestation during British rule [1880–1950] and in contrast to forests, cropland area has increased from 92 to 140.1 Mha during 1880–2010. Greater cropland expansion has occurred during 1950–1980s that coincided with the period of farm mechanization, electrification, and introduction of chemical fertilizers tailored high yielding crop varieties. The rate of urbanization was slower during 1880–1940 but significantly increased after the 1960s with modern technological innovations in infrastructure to meet the modern life styles. In India small and marginal farmers with less than 2.0 ha of land account for 82.6% [126 million farmers] of all farmers but just own 47.3% [74.4 Mha] of the crop area in 2015–16; just 13.2% of farmers with 2.0–10.0 ha constituted 43.6% of the crop area. Average size in ha of operational holdings varied from 2.28 in 1970–71 to 1.55 in 1990–91 to 1.08 in 2015–16. That shows a steady decline in the average operational holding size with increasing population. This may further come down with the time. For rainfed agriculture in-situ rainfall is the main source; and under irrigated agriculture ex-situ [river basins—dams, lakes/tanks and groundwater] rainfall plays the role. However both the systems fail in drought conditions.

Water is a natural renewable resource, fundamental to life, livelihood, food and nutritional security, sustainable development. It is also a scarce resource. It is generally said that “Two thirds of the Earth are covered by water, of which 97% of it is saline. That means fresh water covers only around 3%. However, of this 68.7% is in icecaps and glaciers and 30.1% as groundwater, wherein a large part of it is not available for fresh water. Only small part of groundwater and ice melt is available as fresh water. Around 0.3% is only available as surface water and of which 87% is in lakes, 11%in swamps and 2% in rivers". India has around 18% of the world's population, but has only 4.6% of world's water resources with 2.3% of world's land area but uses around 25% of global groundwater. China has area three times to India but both have nearly the same population and irrigated area.

2 State of the Art Review

2.1 Climate Change

2.1.1 Weather and Climate

Weather is the mix of events that happen each day in our atmosphere that includes measured and estimated. They are meteorological parameters such as temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and Atmospheric Pressure; and Sunshine, radiation, evaporation, hail, sleet, freezing rain, flooding, blizzards, snowstorms, thunderstorms, steady rains from a cold front or warm front, excess heat, heat waves, excess cold, cold waves and more; Majority of them are inter-related. However, in averaging these met network plays critical role. They were around 10 stations in 1850 and reached as high as 6000 stations in 1970 but with satellite data they started declining reaching less than 3000 by 2000. Satellite data covers the entire globe but met stations cover only one-third of the globe [land area] and that too concentrated in urban areas. Climate refers to the weather over very long period i.e., the average weather at a place. Climate is what you expect, like a very hot summer, and weather is what you get, like a hot day. They present wide variations in space and time at local, regional, national and global scales. They vary with Climate System and General Circulation Patterns. The two most important parameters that determine an area's climate are air temperature and precipitation. Climate normal is quite different from the average. Normal is for 30 years average as fixed by WMO, like 1931–60; 1961–90; 1991–2020; etc. Average/mean—normal is not average—is for any length of the data series which serve the relative comparison of data series. A book edited by Gupta and Reddy [4] presented related issues.

2.1.2 Definitions of Climate Change

WMO [46] brought out a manual titled "Climate Change" wherein they proposed methods relating to this. IPCC in its AR3 defined it as "Climate Change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period [typically decades or longer]; change may be due to natural internal processes or external forcings or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Also, UNFCCC-Article-1 presented a definition: "Climate change is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period". According to these definitions, climate change consists of:

Natural variability

- ***Irregular Variations that includes inter-annual and intra-seasonal variations***
- Systematic variations/Rhythmic Variations or Cyclic Variations.

Human induced variations expressed by trend.

Greenhouse Effect Component

- ***Anthropogenic greenhouse gases effect [global warming]***
- ***Aerosols effect,*** **etc**.

Non-Greenhouse Effect Component/land use and land cover changes, which includes

- ***Urban-Heat-Island Effect***
- ***Rural Cold-Island Effect***.

2.2 Global Warming

WMO [46] presented a manual that help in separating rhythmic/cyclic variations from the trend. One such simple technique is "Moving Average Technique". Figure 3 presents the annual march of observed dates of onset of southwest monsoon over Kerala superposed on it the 10-year moving average curve relative to the average. This presents no trend but showed 52-year cycle pattern [14]. Figure 4 presents the adjusted annual march of global annual average temperature anomaly along with 10-, 30- and 60- years moving averages [2]. Under 60-year moving average it clearly shows a linear trend with 60-year cycle.

Figure 5 presents the adjusted annual March of global average temperature anomaly from 1880 to 2010. The figure presents the natural variability [cyclic pattern, inter-annual variations] and human induced trend for the adjusted data series. The 60-year cycle (sine curve) varied between −0.3 and +0.3 °C; and the trend presented 0.6 °C per century [41]. According to IPCC's AR5 greenhouse effect part is more than half and non-greenhouse effect part is less than half of the trend; and the starting year of global warming is 1951. Under linear trend if around 50% of this is global warming—total greenhouse effect component is more than 50% of the linear trend–, then the global warming from 1951 to the end of the century, 2100, is 0.45 °C. In nature in reality it is not linear as the energy from the Sun is constant and over

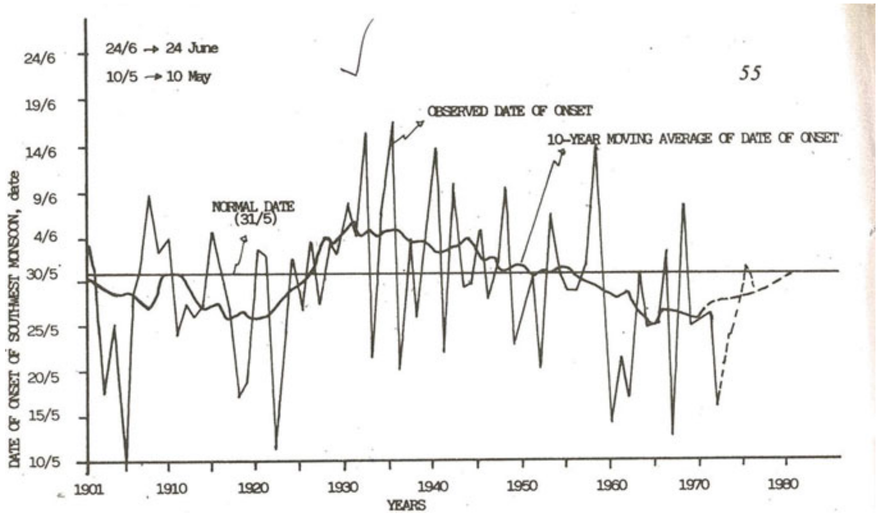

Fig. 3 Annual March of dates of onset of southwest monsoon over Kerala in India along with 10-year moving average

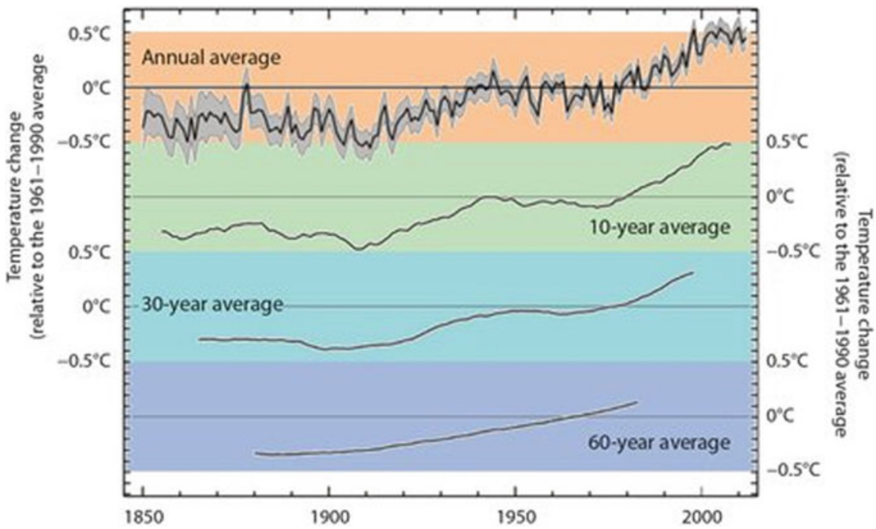

Fig. 4 Annual March of global adjusted average annual temperature anomaly along with 10-, 30- and 60-year moving averages

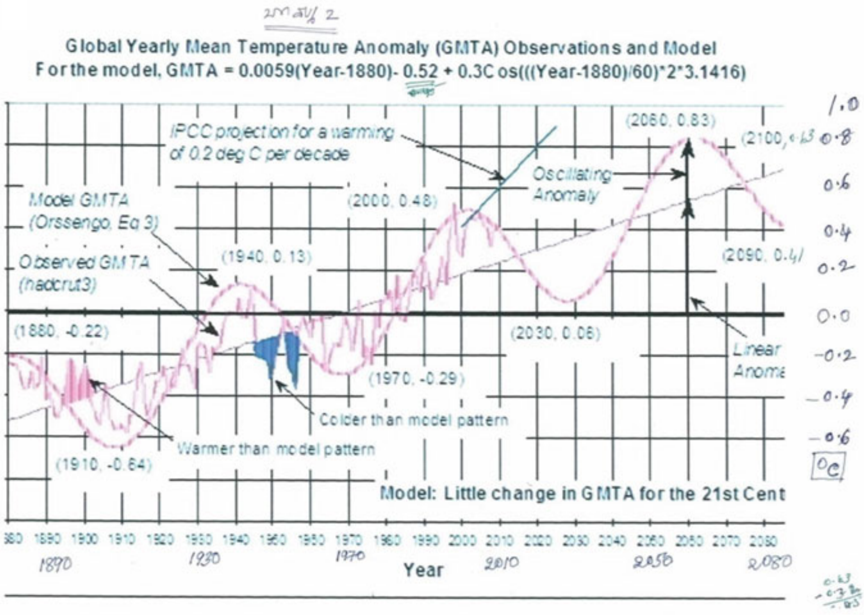

Fig. 5 Global adjusted average annual temperature anomaly: 1880–2010 [*Note* 60-Year cycle of Natural variability: −0.3 to +0.3 °C; Trend [1880–2100]: 1.30 °C; GW [1951–2100]: 0.45 °C; Trend [1850–2100]: 1.34 °C; GW [1951–2100]: 0.40 °C]

which superposed the natural variability associated with the sunspot cycles [11-years and its multiples—[34]]. That is global warming is nearly negligible in real scenario. However, the linear trend is far smaller than the annual variations and as well seasonal variations at a location or region. The US raw data series [unadjusted] that form major part of global met network and uniformly distributed showed no trend but showed rhythmic pattern [21]. Later this was adjusted by bringing down the initial periods temperature to show the presence of trend.

2.3 Land Use and Land Cover Changes

Luke Howard, an amateur meteorologist in England, first recorded the heat-island effect more than 200 years ago. He noticed that the city was consistently warmer by around 1.5 °C. He brought out a book "The Climate of London" in 1818. Over four years, researchers from NASA Marshall Space Flight Centre in Huntsville, Al., have flown jets equipped with infrared cameras over Salt Lake City, Sacramento, Baton Range, La., and Atlanta, producing block-by-block temperature maps reveal surface temperatures on a summer day in 1998 in down town Sacramento—blue areas are vegetated and relatively cool, 77–86 degrees; red areas are 120 degrees and above. Air temperatures differ, depending on meteorological conditions and ground conditions [41]. With the growth of urban areas, the impact is also felt in rural areas with advection. These are termed as urban-heat-island effect.

India annual average temperature series at state level showed [12, 21, 24, 25, 45] increasing, decreasing and no change trends in line with land use and land cover changes. The decreasing and no trend are associated with rural cold island effect—irrigated agriculture—[41]. Also, based on the general circulation patterns, heat waves and cold waves influence some regions [30]. De et al [3] presented state-wise number of heat and cold waves during 1911–1999 and 1901–1999, respectively in India. IMD identified Core Heatwave zone that span over Punjab, Himachal Pradesh, Uttarkhand, Delhi, Rajasthan, UP, Gujarat, MP, Chhattisgarh, Jharkhand, WB, Odisha, Telangana and more sub-divisions of Madhya Maharashtra, Marathwada, and Coastal Andhra Pradesh. However, they are highly variable with space and time [30].

2.4 Natural Variability in Rainfall

The Earth's climate is not static but it is dynamic; climate change is real; climate change was there in the past, it is there now and will be there in future; and it is always changing through the natural cycles wherein extremes are part of it. What we are experiencing now is part of this system only. It is beyond human control and we need to adapt to them. Global warming is a hoax. Reddy [20, 38] presented the cyclic variation in Indian rainfall using the data published by Parthasarathy et al. [11]. The all-India southwest monsoon rainfall data series of 1871–1990 showed a 60-year cycle—by simply presenting 10-year averages, it clearly showed sinusoidal variation. All India annual rainfall [June to May] also followed the 60-year cycle (Fig. 2) similar to 60-year Astrological Cycle—lagged by three years to Chinese Astrological Cycle [43]. The starting year of Astrological cycle "Prabhava" started in 1987, which is the starting year of the 3rd 60-cycle (Fig. 6).

In the 3rd and current cycle which started in 1987/88, the first 30 years are above the average. Previous 30 years presented below the average. Here it is pertinent to mention that, Indian Parliament raised a question whether Indian rainfall is increasing or decreasing? Ministry of Earth Sciences [MoES] friendly institutions prepared a report saying that the Indian rainfall is decreasing. This was informed to parliament. On this I informed the Minister of MoEF&CC as "In fact Indian rainfall has no trend. Scientists who prepared the report used data of 2nd cycle wherein in the sine curve, the first 30-years form above the average and the second 30 years form below the average pattern that shows decreasing trend. By shifting 30 years forward or backward, they would have got increasing trend" [21, 42]. In fact, they would have used moving average technique to understand this [46]. CWC used above the average rainfall data series [1985–86 to 2014–15] for the estimation of water availability at all India level and the same we can see in Fig. 6.

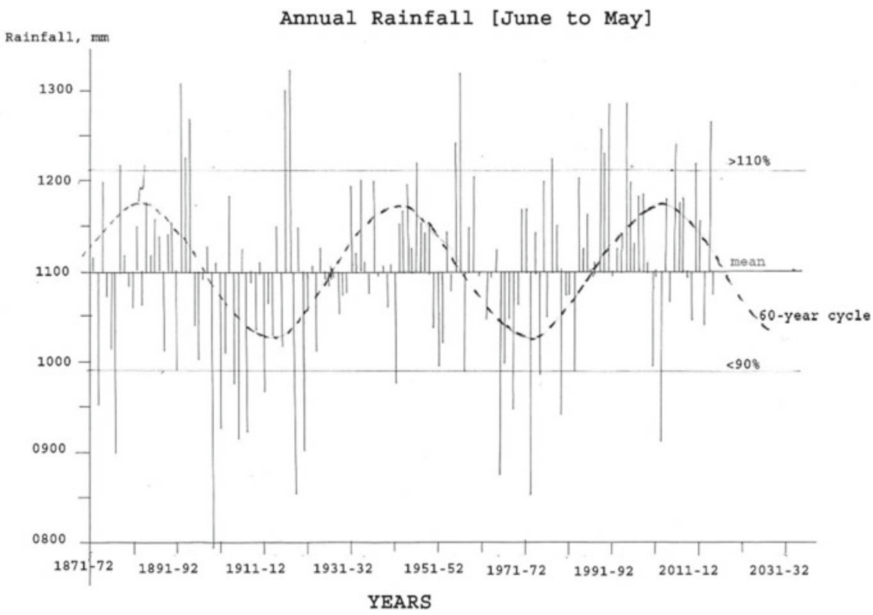

Fig. 6 Annual March of all-India average annual rainfall [June to May]

2.5 Indian Temperature Scenario

Figure 7 were taken from http://berkeleyea...ns/india, respectively representing (a) mean annual daily temperature march, (b) mean annual minimum daily temperature, (c) mean annual maximum daily temperature and (d) mean annual daily diurnal range in temperature over India for the period 1880–2020. The figures clearly demonstrate the fact that in India night temperatures have gone up steadily (Fig. 8) and day temperature doesn't present such sharp rise (Fig. 9), which is clearly reflected in diurnal range (Fig. 10) that decreased with the time during 1900–1980 and there onwards showed increasing trend. These results reflect the impact of air pollution and associated urban heat-island effect plus cold-island effect with irrigated agriculture and reservoirs that relate to changes in land use pattern and not greenhouse factor [41].

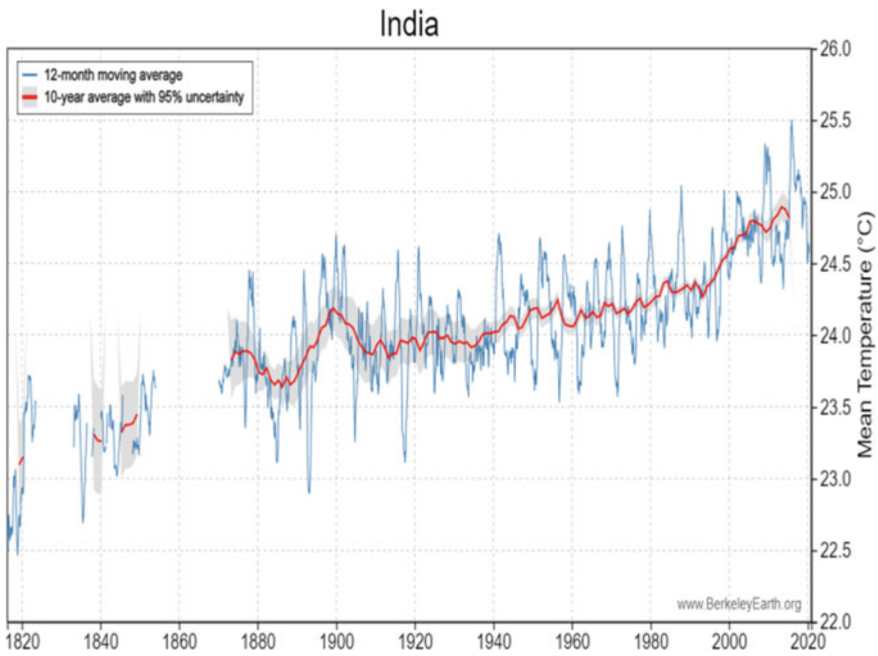

Fig. 7 Annual March of average annual mean daily temperature of India

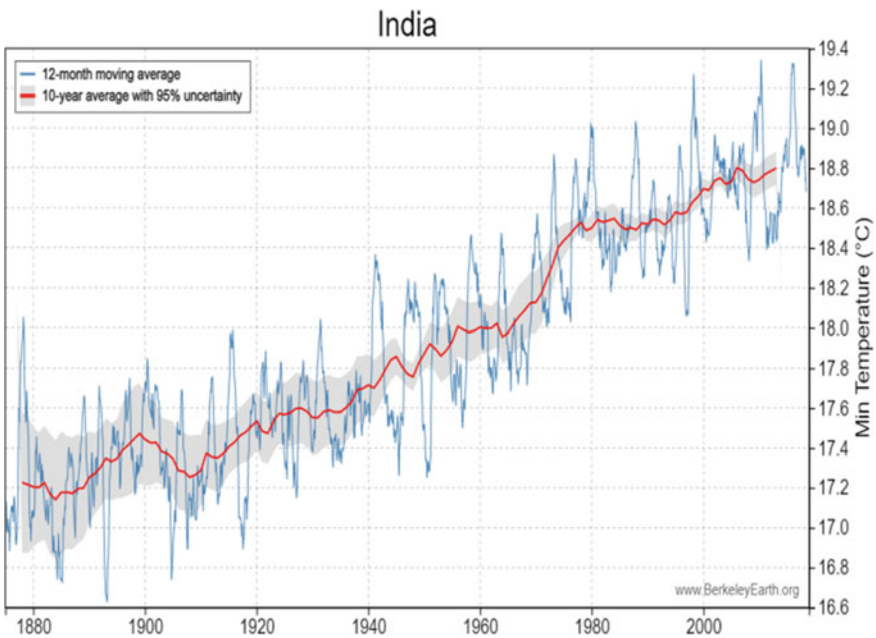

Fig. 8 Annual March of average annual mean daily low [minimum] temperature in India

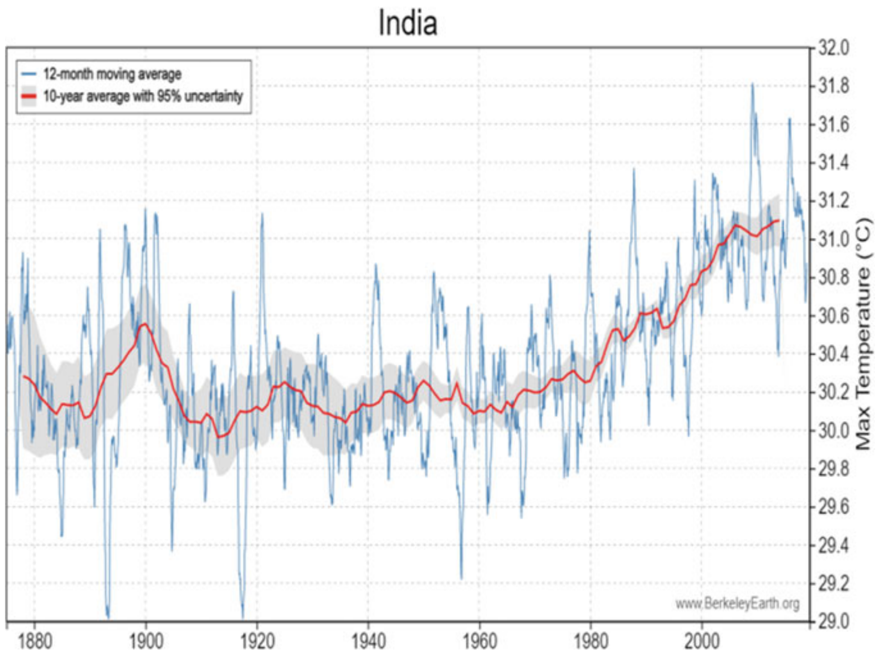

Fig. 9 Annual March of annual average mean daily high [maximum] temperature in India

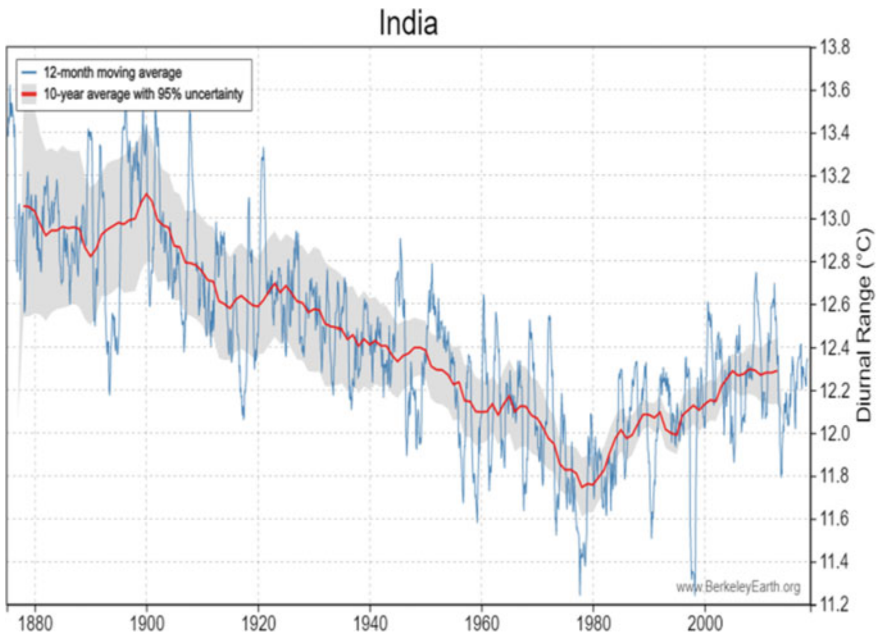

Fig. 10 Annual March of annual average diurnal daily temperature range in India

3 Material and Methods

3.1 Introduction

Farmers are aware that crop production is limited by climate. They also know that some crops do well in his region whereas others do not. Even though the traditional crop production systems of the farmers are stable the yields are low. Here the objective of the farmer is to reduce the year-to-year variations but not optimise the yield or profit.

The natural input to any surface water system is rainfall and snow melt within its watershed. In India around 78% of annual average rainfall occurs in June to September, known as southwest monsoon. However at regional level they are highly variable. In addition, regionally rainfall also occurs during October to December, known as northeast monsoon. Also some parts receive rains through western disturbances in winter and cyclonic activity in the pre-monsoon and in the post-monsoon seasons from both Arabian Sea and Bay of Bengal. More severe cyclonic storms occur in summer [May] and winter [November]. Humans have no control on precipitation and snowfall. They present high variations with both space and time. Also, climate change plays significant role in defining the rainfall and snowfall with the time. All these define water availability in space and time. However, this is contaminated through man's actions by several sources that make unsuitable for use causing innumerable health hazards.

3.2 Climate System and General Circulation Patterns

Local/regional climates will be modified with the changes in local climate system (Fig. 11) and general circulation patterns (Fig. 12) also will be modified the local/regional climate. This is the case with Western disturbances (Fig. 13)—taken from Reddy and Rao [30], which presented the heat and cold waves impact in space with the changes in circulation patterns. The nature of climate is sometimes complicated because of the wide range of ecological and topographical diversities, known as climate system, and hence requires in-depth studies to develop such adaptive measures.

3.3 Rainfall Effect on Temperature

Indian annual rainfall presents the impact on annual temperature (Fig. 14). During 2002 and 2009 presented rainfall deficit by 0.81 and 0.78 of annual rainfall at all India level and in association with this annual temperature at all India level increased by 0.7 and 0.9 °C. This is in line with the following.

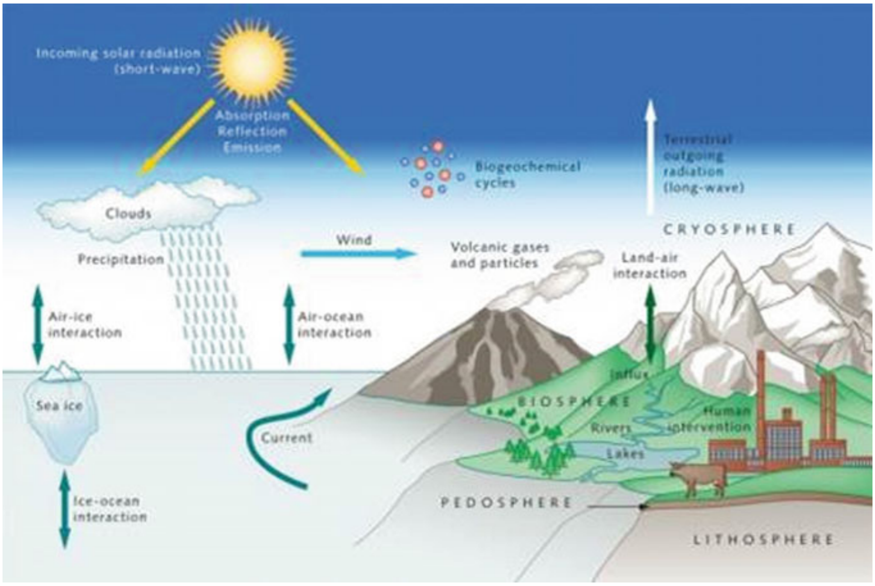

Fig. 11 Climate system [IPCC]

Precipitable water versus wet bulb temperature: Reddy [13] presented a method for the estimation of wet bulb temperature (T_w) through dry bulb temperature (T), relative humidity (h) and station level pressure (p) as follows:

$$T_w = T \times \left[0.45 + 0.006 \times h \times (p/1060)^{1/2}\right]$$

Also presented a method for the estimation of precipitable water in the atmospheric column (W) using wet bulb temperature (T_w) as follows:

$$W = c' \times T_w^2$$

Relative humidity versus solar and net radiation and evaporation: Reddy and Rao [30] presented a relationship between cube root of rainfall with the incoming and net radiations and evaporation. Reddy and Rao [29] showed evaporation doubling with relative humidity decreasing from 100% to ≤35%. All these indirectly support increasing temperature under dry conditions and decreasing temperature under humid conditions.

Western disturbances versus winter rains, and others: Western Disturbances also cause winter rains over north western parts of India. The onset of Northeast Monsoon in some years overlaps with the withdrawal of Southwest Monsoon. 78% of the annual rainfall on an average received during Southwest Monsoon period. However, the onset and withdrawal over India is highly variable [20, 38].

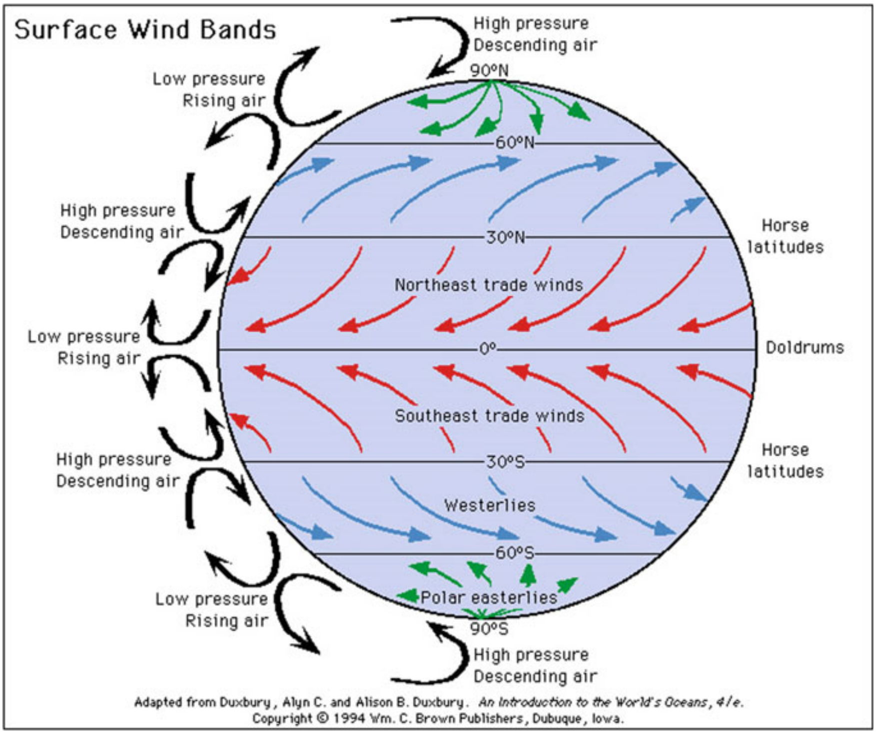

Fig. 12 General circulation pattern

Reddy [20, 37, 43] presents the methods of agro-climatimatological and Agrometeorological techniques as applicable to dry-land agriculture in developing countries & analysis. 1993 [43] book dealt the issues at global level and 2002 book dealt the issues at Indian level. Reddy [22, 23] presented issues related to agriculture and water resources in India.

4 Results and Discussion

4.1 Introduction

This section looks into few examples of ago-climatic analysis, such as soil water balance simulations. That help to understand probability of success and failure of dry-land agriculture; crop-soil-weather model simulations for dry matter and grain yields; and drought proneness and their association with climate change. We must remember the fact that under irrigated agriculture annual rainfall data series in the ex-situ/catchment and on the contrary for dry-land agriculture, rainfall in-situ for the

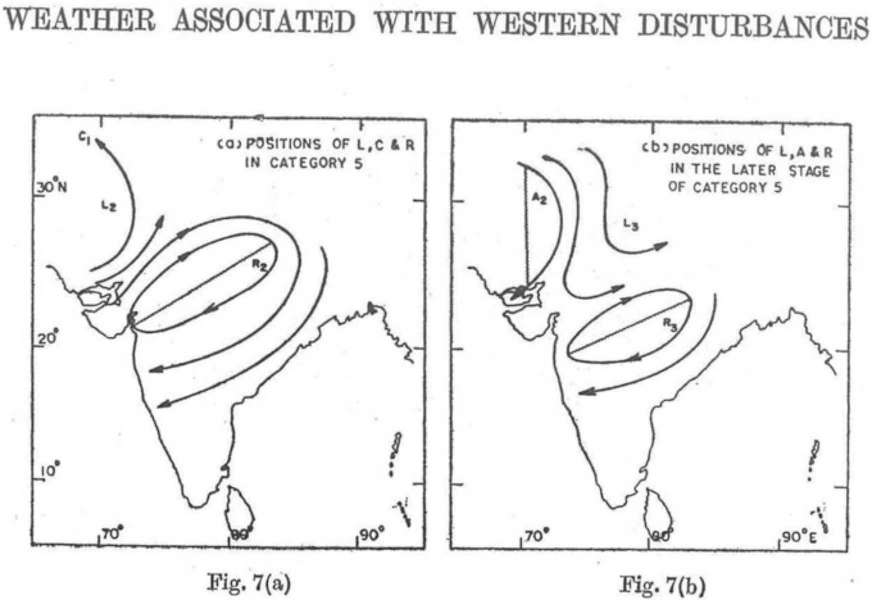

Fig. 13 Weather patterns with western disturbances

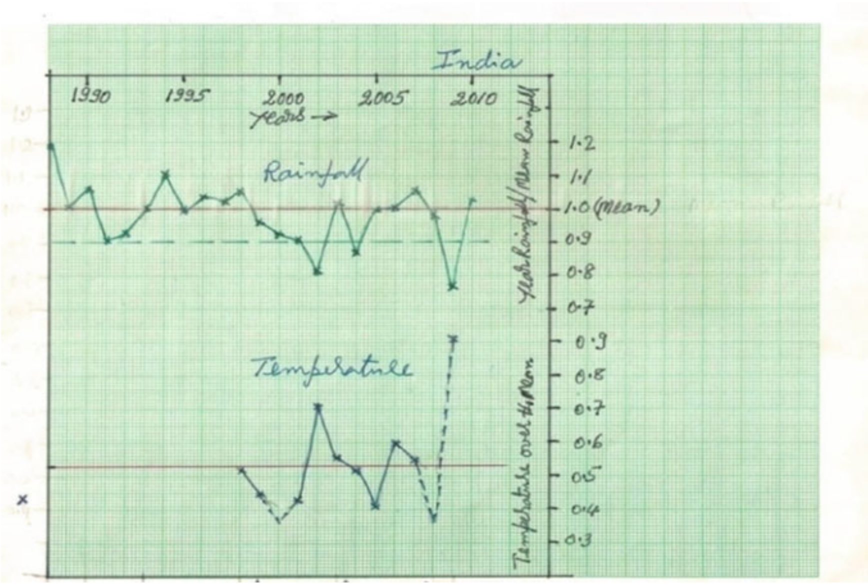

Fig. 14 Annual March of all-India rainfall and temperature

crop season are important. These present wide variations in space and time. Thus, for dry-land agriculture detailed analysis play important role at local level.

Undivided Andhra Pradesh receives rainfall in southwest monsoon season [June to September] and northeast monsoon season [October to December]. However severe cyclonic activity is in both pre-monsoon and post-monsoon seasons. During south-west monsoon season low pressure systems, depressions are common. Cyclones give widespread rains. The Coastal Andhra Met sub-divisional rainfall during the southwest monsoon present 56-year cycle and during the northeast monsoon it is presenting exactly opposite to it (Fig. 15). In Fig. 15 solid lines represent the 10-year moving averages and dotted lines represents the 28-year averages of above and below the average parts of 56-year cycle, wherein the top pattern refers to northeast monsoon [October to December] and the bottom pattern refers to southwest monsoon [June to September]. The patterns were the same for Rayalaseema and Telangana Met Sub-divisions [27, 28, 40, 41].

Table 1 presents the spatial and temporal variations in rainfall over India, Coastal Andhra, Rayalaseema and Telangana during southwest monsoon, northeast monsoon and annual levels. In the three met sub-divisions of undivided Andhra Pradesh, the % of annual rainfall during SW and NE monsoons present wide differences, basically because of the level of influence of northeast monsoon over the three regions [38]. The contribution of NE monsoon % decreased from Coastal Andhra to Rayalaseema to Telangana and is another way for SW monsoon.

The number of cyclones per year in Bay of Bengal followed the 56 year cycle of the southwest monsoon rainfall (Fig. 16)—see the X-Axis curve [41]. During the

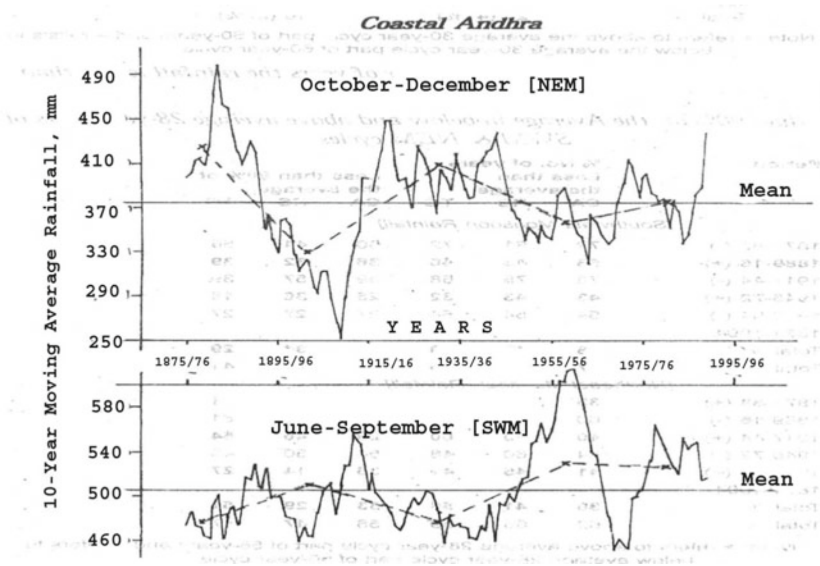

Fig. 15: 10-year moving average rainfall of Coastal Andhra met sub-division

Table 1 Mean rainfall during 1871–1990

Region	Parameter	SW	NE	Annual
India	Mean, mm	852 (78%)*	120 (11%)	1090
	C.V., %	9.9	29.0	19.5
CA	Mean, mm	507 (52%)	375 (39%)	971
	C.V., %	22.2	38.8	19.8
RS	Mean, mm	422 (60%)	204 (29%)	709
	C.V., %	28.8	41.9	21.6
TS	Mean, mm	722 (80%)	107 (12%)	899
	C.V., %	23.5	60.3	21.7

CA = Coastal Andhra, RS = Rayalaseema and TS = Telangana; SW = southwest monsoon and NE = northeast monsoon; C.V. = coefficient of variation; * = % of annual; *Source* Reddy [38]

above the average 28-year period of the 56-year cycle more than 10 cyclones per year occurred [except for one year] and the corresponding below the average 28-year period received less than 10 cyclones per year. Reddy [41] presented a table of monthly cyclonic disturbances in Arabian Sea and Bay of Bengal from 1891 to 1990. Maximum severe cyclonic storms were recorded in both Bay of Bengal and Arabian Sea in May [summer—pre-monsoon] and November [winter—post-monsoon].

These clearly present the high variability in rainfall with seasons and with the time. These indirectly give us insight in to floods and droughts and help in selecting crops/cropping patterns or long-term agriculture planning. However, under different soils they may differ. Mono crop versus multiple crops or intercropping scenarios have different types of risks.

A report of 23rd July 2021 says that "Why Arabian Sea Cyclones have increased by 52% in twenty years: A new study by Indian Scientists [published in the journal Climate Dynamics on July 17th—link.springer.com/article/10.100…—finds alarming rise in the frequency, intensity and duration of cyclones in the last 20 years". The number of very severe cyclonic storms has increased by 150% in the Arabian Sea and attributed these to Global warming with slightly decrease in frequency in the Bay—see, Fig. 17 presents a study of 1982–2000 and 2001–2019. Such inferences made with 20 years data has no meaning as Indian rainfall and cyclonic activity presents a natural variability as presented above.

4.2 *Dry-Land Agriculture*

4.2.1 Soil Water Balance: An Example

Figures 18 and 19 present the soil, crop and water balance simulation results, wherein soil water balance model [15] takes in to account soil, crop and open pan evaporation with mesh cover factors [32, 47]. For Katherine in the Northern Territory and

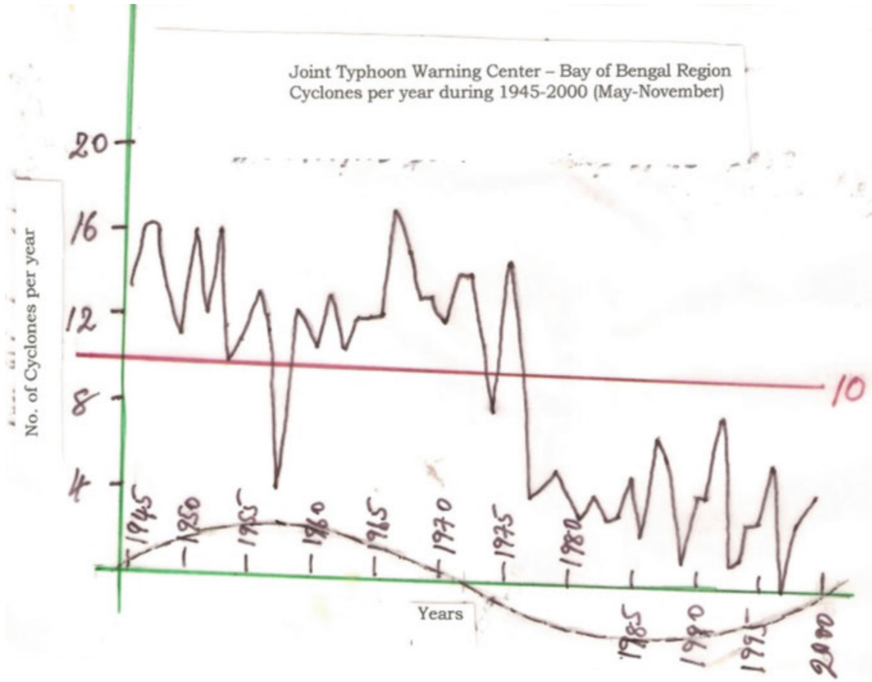

Fig. 16 Cyclones per year during 1945–2000 (May to November) in bay of Bengal Region as presented by Joint Typhoon Warning Centre (*Source* Reddy [41])

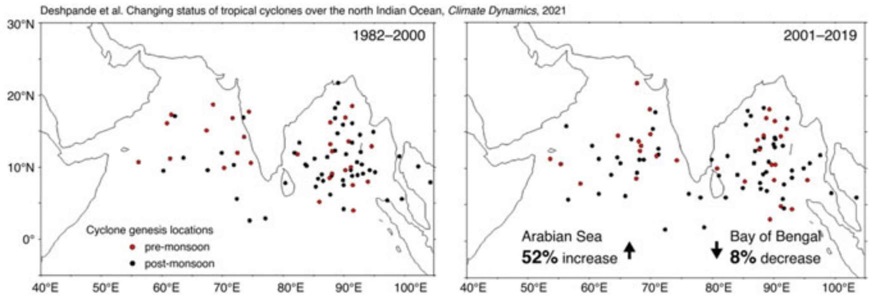

Fig. 17 Frequency of occurrence of cyclones in Bay of Bengal and Arabian Sea

Townsville in Queensland in Australia for three levels of available water capacities in the root zone (K = 50, 100 and 200 mm) taken to represent shallow sandy soils (aridisoils), sandy loam (alfisols), and moderately deep to deep black soils (vertisols) or Alluvial soils. In general terms these represent shallow, medium deep and deep soils, respectively. Both areas have a similar mean annual rainfall.

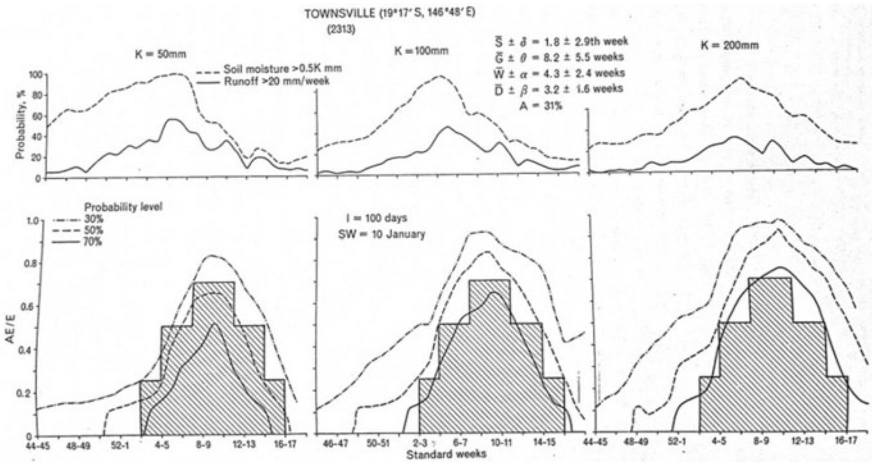

Fig. 18 Soil water balance simulation results for Katherine/Australia

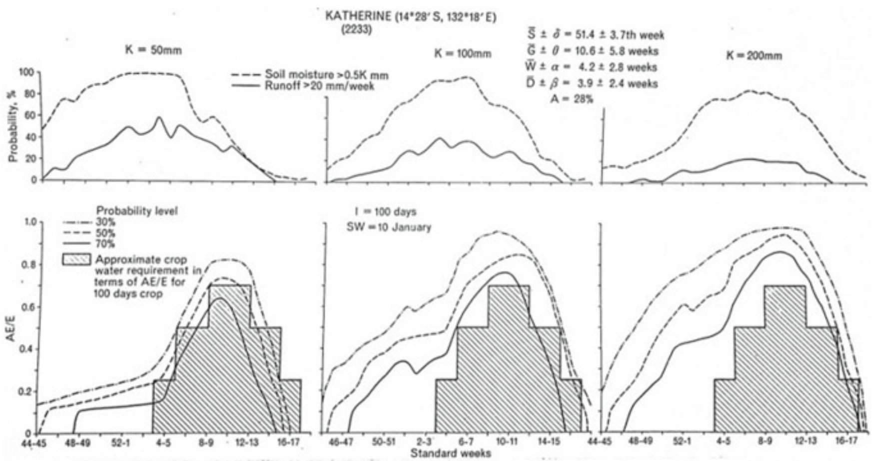

Fig. 19 Soil water balance simulation results for Townsville/Australia

In Figs. 18 and 19, bottom diagrams present the expected AE/E in 30, 50 and 70% of the years and have been constructed from weekly probability data over the period for which climatic data are available. Here AE is the actual evapotranspiration derived from the water balance model of Reddy [15] and E is the observed open pan evaporation with mesh cover. The crop simulation assumes a fixed planting date of January 10 and a 100-day crop. In all cases the hatched area represents the crop-water requirement histogram during that 100-day. The upper curves show probabilities of soil water storage exceeding 50% capacity (K/2) and runoff exceeding 20 mm/week in any week. The time axis runs from the week 44–45 (i.e., last week of October) to the week 18–19 (i.e., end of April).

With the shallow sandy soils single cropping could be successful with a planting date after the mean week of commencement time of sowing rains (S) [35] when the top 30-cm soil layer is at field capacity. Intercropping (100/180 days) could be successful with deeper soils. In the case of moderately deep to deep clay soils, planting can be started with the first good rains, while sandy loam soils can be successfully harvested in 70%. It is always better to wait until the top-soil attains field capacity with the initial rains. On sandy loam soils at Katherine, groundnut (100-days)/Pigeonpea (180-days) intercrop sown after the mean week of commencement time of sowing rains, when the top 30-cm soil is at field capacity with initial rains. For more details it is suggested to refer Reddy [36] wherein presented such analysis for Jodhpur, Anantapur, Bangalore, Hyderabad, Sholapur, Akola and Indore. Table 2 presents results of crop-soil–water simulation for Sholapur, Hyderabad, Akola and Indore. Table is self-explanatory.

Table 2 Success of different crops in rainy and post-rainy seasons at four stations[a]

Duration of crop	Percentage success of different duration crops					
	Sholapur	Hyderabad		Akola		Indore[b]
(Days)	1	2	1	3	1	1*
(a) Rainy season crop						
70a	75	–	–	–	–	–
70b	17	–	–	–	–	–
91a	58	91	91	100	100	100
91b	25	36	43	22	28	62
105a	58	91	91	100	100	100
105b	11	17	41	19	14	43
119a	–	80	90	94	97	100
119b	–	4	30	00	03	00
(b) Intercropping						
91/180	78	83	90	81	83	97
(c) Double cropping[d]						
70 + 100	81	–	–	–	–	–
91 + 100	81	27	56	33	42	81
105 + 100	67	13	36	14	19	51

* 1 = Vertisols (K = 250 mm), 2 = Alfisols (K = 125 mm), 3 = Alfisols (K = 175 mm)
a = percentage number of years for successful kharif crop
b = percentage number of years in which rains of more than 50 mm occurred at harvest maturity
[a] *Source* Reddy [36]
[b] 40% of the years represent a problem for interculture
[d] 70 + 100 refers to a 70-day rainy season crop followed by 100-day post-rainy season crop (for example, a 70 day cowpea followed by a 100 day sorghum

4.2.2 Crop Weather Modelling: An Example

If we look at three neighbouring districts, namely Anantapur (red soil zone), Kurnool (medium deep soils) and Kadapa (deep black soils) in the state of Andhra Pradesh the annual average temperatures [from normal book of 1931–60, IMD] presented as 27.6, 28.1 and 29.3 °C. Accordingly the crops and cropping patterns have been practiced. Reddy et al. [28] discussed the phenology sensitivity to temperature among different varieties in sorghum crop. Reddy [18] discussed the issue of over-emphasis on energy terms in crop yield models. Reddy and Timberlake [31] presented a simple method for the estimation of potential primary pasture productivity over Mozambique and observed that pasture production not only depends on precipitation amount and distribution patterns, but also on soil type and evaporative demands.

A study was carried out at ICRISAT Hyderabad on sorghum yield and dry matter production using Arkin Model. In this process a comparison was made by replacing soil water balance model of Ritchie with Reddy [15] model output [36]. Figure 20 presents the comparison of observed and predicted dry matter and grain yields. The observed data refers to 1979 and 1980 kharif and Rabi seasons refer to sorghum cultivars CSH1, CSH6, CSH8, M35-1 and SPV-351. With the Ritchie model the root mean square errors (RMS) and correlation coefficients (R) for dry matter and grain yields are 27.58 and 17.39 q/ha, and 0.35 and 0.37, respectively. The corresponding values with Reddy [15] model are 15.06 and 8.49 q/ha, and 0.85 and 0.81. This is basically because Ritchie model works under conserved soil moisture [as of middle latitude] while Reddy [15] model works with daily rainfall as input. The group who studied Arkin et al. model tried to improve the prediction by changing energy factor but failed to achieve improvement in the results. The improvement was achieved by changing water balance part of input only.

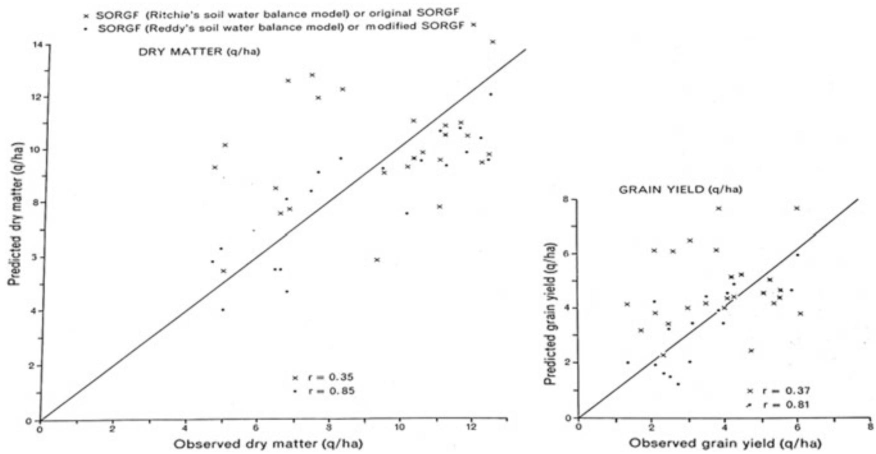

Fig. 20 Comparison of observed and predicted dry matter and grain yields

4.2.3 Climate Change: An Example

Reddy [37, 43] has presented agrometeorological analysis for several countries. Figure 21 presents the drought proneness index for India; and Fig. 22 presents for Maharashtra using the same method [1]. These present average condition but they follow the natural variability in rainfall. For example, Kurnool in AP presented drought proneness on an average 45% of the years but during above and below the average periods of 56-year cyclic variation, the averages are 30 and 70% of the years (Fig. 23). Figure 23 presents the annual march of effective available rainy period in weeks (G) (below part), and the starting week number of effective planting rains (S) [above part] as defined by Reddy [35]; and the curve presents the 56-year cycle [38]. The table in the Fig. 23 shows: the average of G is 6.1 weeks and S is week no. 31; below the average period they are 3.1 weeks and week no. 34; above the average period they are 9.05 [= (8.0 + 10.1)/2] weeks and week no. 29 [= (30 + 28)/2)].

In any given year, if G is less than or equal to 5 weeks, then it is defined as drought year [35]. Figures 21 and 22 present the percentage years of such drought proneness; but presented under different ranges of drought proneness index in percentage years. In both the figures, it is clearly seen the impact of shadow zone of Western Ghats on drought proneness. However, some of these are attributed to global warming without considering the long-term patterns that come under natural variability of climate change. ENSO showed its impact on Indian southwest monsoon rainfall. ENSO includes three phases, namely El Nino, neutral and La Nina. During 1880–2006 [126 years] the number of years they occurred under deficit, normal, excess, below normal and above normal—31% below normal years; 39% normal years and 30% above normal years. Natural variability in rainfall cyclic variations follows this type of percentages. Northeast monsoon rainfall follows opposite to southwest monsoon [38]. Same is the case with Australian rainfall [26]. Asmara in Eritrea, northeast Brazil, Mozambique, Botswana/India, South Africa, Andhra Pradesh respectively showed 22, 52, 54, 60, 66, 132-year cycles in annual rainfall. G = affective available rainy period in weeks, S = starting week number of effective planting rains—56-year cycle.

5 Irrigated Agriculture

5.1 Water Availability

Reliable estimates of water availability in a given river water basin is very important to take right decisions on inter-linking of Rivers and sharing of water among the riparian states on the o side and on the other its use for drinking, irrigation, industry, etc. Some of the factors that play vital role in this direction are (a) Method(s) of estimation, (b) Period(s) of data series used and (c) natural variability in rainfall. Let

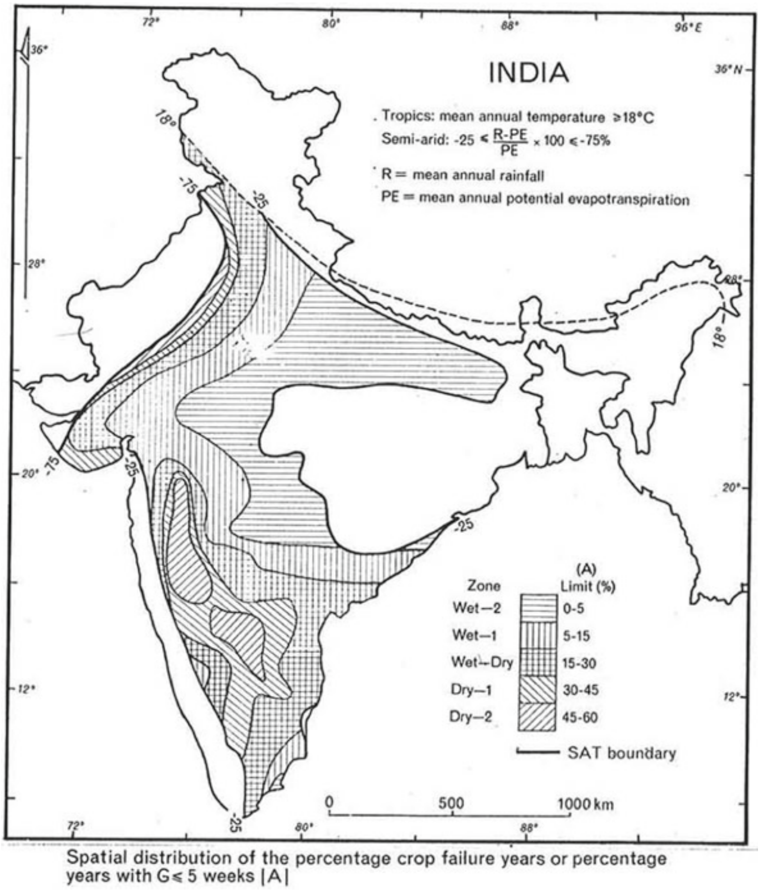

Fig. 21 Drought proneness index of India

us see these with reference to Krishna and Godavari Rivers along with Brahmaputra and NW Indian Rivers.

5.2 Importance of Data Series Selection

Water availability is highly variable with year to year and follows natural rhythmic patterns in line with rainfall. To get the best estimates under a given probability level, the selected data series must follow normal distribution, wherein mean = median = mode. If the data series follow positively skewed or negatively skewed the estimates will be biased towards higher or lower values, wherein mean moves away from

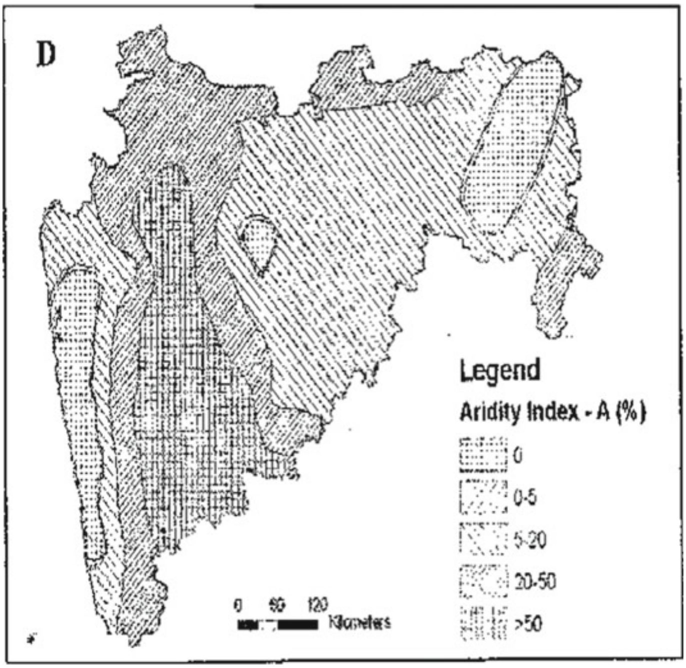

Fig. 22 Drought proneness index of Maharashtra

median [50% probability] on to the right or to the left sides, respectively. Tables 3 and 4 presents the cases under Krishna and Godavari Rivers.

The mean of the 47 years data series of KWDT-II is 2578 tmc ft and under KWDT-I 78 years data series mean is 2393 tmc ft. The means respectively fall at 58% and 43% probability levels, and thus are respectively fall under positively and negatively skewed data series and thus estimates are biased towards higher and lower values respectively. Preferred estimates under probability curve are the normally distributed data series wherein mean and median coincides. 114 data series follow the normal distribution which has the mean of 2443 tmc ft. For allowing Almatti Dam height, KWDT-II have chosen 26 years fictitious data series, whose mean is 3050 tmc ft but the 26 years data series subset of 47 years data series of KWDT-II for the same period followed normal distribution similar to 114 data series with mean of 2400 tmc ft. The 114 years data series is observed data.

3, 4 and 6 are normally distributed data series, wherein mean coincides with median—data series followed symmetrical distribution; 1 and 2 followed skewed distributions with 2 under negatively skewed that is biased towards lower values and 2 under positively skewed that is biased towards higher values. 1–4 observed data series; 5 is based on fictitious data used by KWDT-II instead of 4 or 2 [to show there is plenty of water in Krishna and recommended to raise the Almatti Dam height]. 6 is an estimated data series that overestimates the water availability.

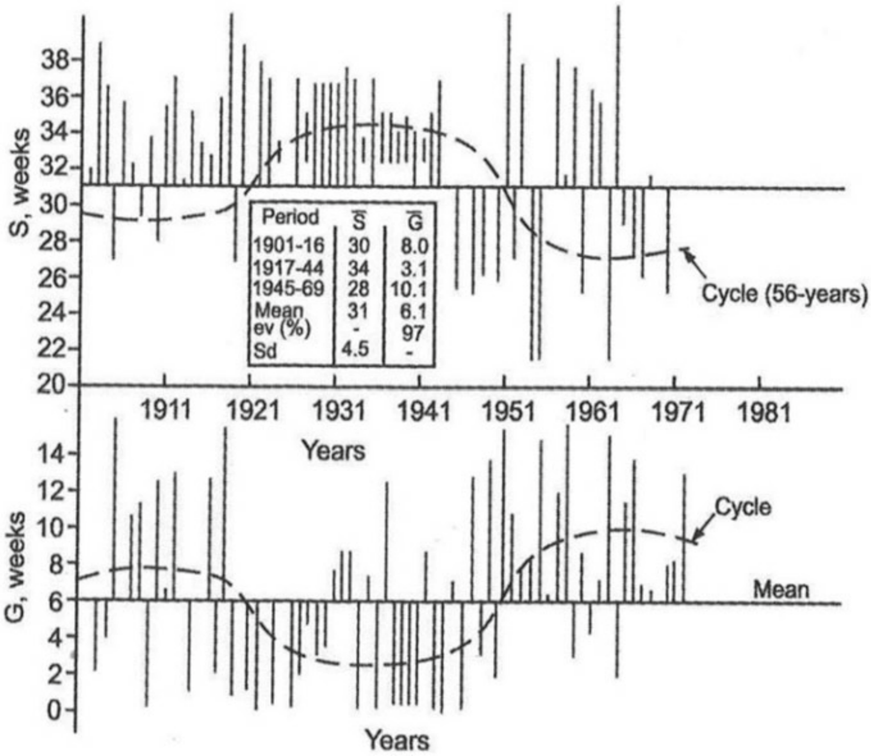

Fig. 23 Annual March of G and S for Kurnool in AP and 56-year cycle

Table 3 Water availability in Krishna River under different methods/data series

	Method/data series	tmc ft	
	Mean/probability	Lowest	Highest
1. KWDT-I [1894–95 to 1971–72]	2393/43%	1007	4166
2. KWDT-II [1961–62 to 2007–08]	2578/58%	1239	4194
3. S.J. Reddy [1894–95 to 2007–08]	2443/48%	1007	4194
4. KWDT-IIa[1981–82 to 2006–07]	2400/50%	1239	3624
5. KWDT-IIb[1981–82 to 2006–07]	3050/–	–	–
6. CWC [1985–86 to 2014–15]	3144/50%	1934.89	4165.42

Table 4 Water Availability in Godavari River under different data series

		Method and [Data series]	tmc ft	
		Mean/probability	Lowest	Highest
1. Bachawat	[1881–1946]	4000/50%	1000	6500
2. -	[1968–1994]	4792/50%	1540	8360

Table 5 Rainfall 60-year cycle

Year	tmc ft	Year	tmc ft
1987	1540	1991	2990
1988	7180	1992	4170
1989	4120	1993	2550
1990	8360	1994	7720

1 follows the all-India annual Rainfall 60-year cycle—during below the average 30 years only 9 years received above the average but only in 5 years expected floods and in the remaining below the average 21 years in 17 years expected droughts and 3 years normal [one year no data]; during above the average 34 [18 + 16] years, 12 years were below the average but only in 5 years were drought and in 7 years were normal; and 22 years were above the average in which 18 years were flood years and 4 years were normal (see Table 5).

To achieve the sustainability in water availability for different projects under Krishna River, government of India appointed Justice Bachawat Tribunal in 1969 [KWDT-I] and in 1976 submitted its report. As per this award, still to date River Krishna water is distributed among the three riparian states, namely Maharashtra, Karnataka and undivided Andhra Pradesh [now known as Andhra Pradesh (AP) and Telangana (TS)]. In 2004/06 Government of India appointed 2nd Tribunal, namely Justice Brijesh Kumar Tribunal [KWDT-II] and it submitted its report in 2013 but Supreme Court of India issued stay order on this award implementation. KWDT-II is a classic example for "Technical Fraud" under unfettered powers [42]. They used five different data sets to prove their specific objectives to favour Karnataka state—now Karnataka is building several illegal projects for one such project NDA government even gave national status. Even though KWDT-II have 114 years data series, on some fictitious grounds used 47 years data series.

With the changes in rainfall patterns, Andhra Pradesh annual rainfall presented 132 year cycle (Fig. 24a) unlike all-India annual rainfall (Fig. 6)—Fig. 25 presents the severe drought conditions prevailing in Bangalore during 1876–78. KWDT-II's 47 years' data set fall under above the average part of 132-year cycle (Fig. 24a). Figure 24b presents the annual march of the water availability in Krishna River for 114 years that follows the 132-year cycle of annual rainfall—predicted curve shifted forward by 10-years (Fig. 24b).

5.3 Importance of Method of Estimation

Bachawat Tribunal used observed data series both in the case of Krishna River and Godavari River (Tables 3 and 4). Central Water Commission (CWC) used estimated 30 years [1985–86 to 2014–15] data series. This period comes under normal distribution in the case of Krishna River [Fig. 24a] and thus mean coincides with median;

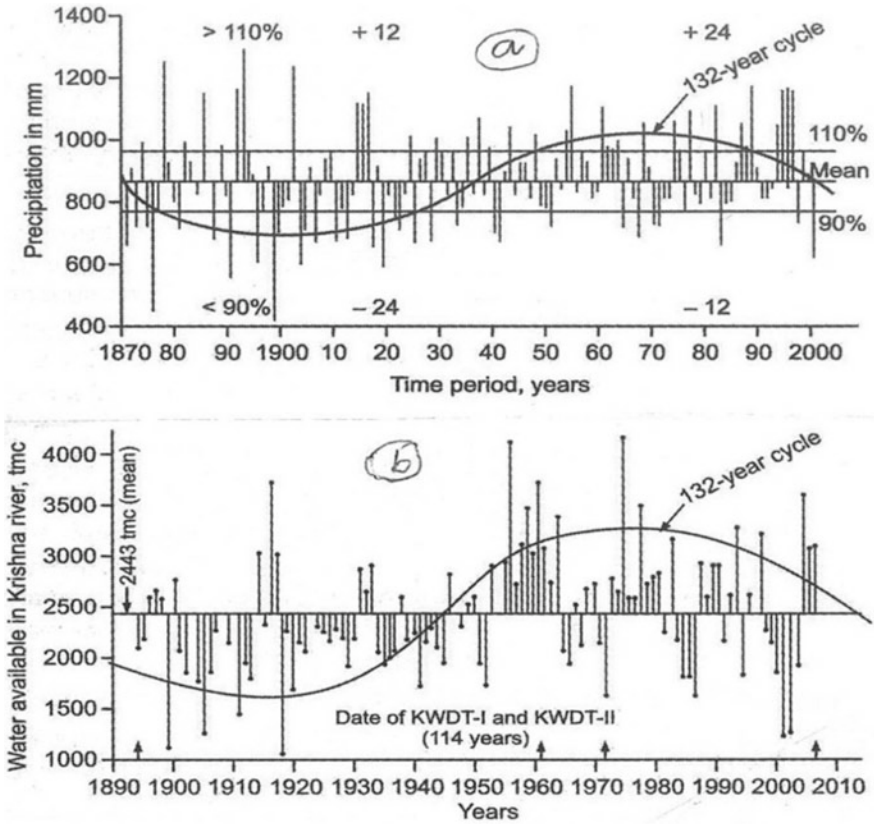

Fig. 24 Annual march of **a** Andhra Pradesh three sub-divisions rainfall and **b** water flows in Krishna River—in b predicted curve of 132-year shifted forward by 10-years

but in the case of Godavari River the period comes under positively skewed distribution and thus biased towards higher values (Fig. 6). However, in both the cases the model presents over estimates—Godavari by around 25 + 15% and Krishna River by around 30%. As a result, CWC said "plenty of water available" in both Krishna and Godavari Rivers. The issue of overestimation can be seen from the generalized soil, crop and water balance equation as presented by Reddy [15] is given as:

$$\mathrm{SM}_n = \mathrm{R}_n - \mathrm{AE}_n - \mathrm{RO}_n - \mathrm{D}_n$$

wherein SM refers to soil moisture change, R is the rainfall, AE is the actual evapotranspiration, RO is the surface runoff and D is the deep drainage. In CWC estimates, R & D are observed data. AE is estimated using the potential evapotranspiration and crop factor. Reddy [15] followed the following way to estimate actual evapotranspiration.

Fig. 25 British era severe drought in Bangalore during 1876–78 [*Note* you can see the rainfall during this period from Fig. 24]

$$\begin{aligned}
\mathrm{AE}_n &= f(E_n) \times f(S) \times f(C) \\
\mathrm{AE}_n &= f(E_n) \times f(S, C) \text{ and } f(S, C) = K \times b_n \\
\mathrm{PE} &= 0.85 \times E \text{ [with mesh cover]} \\
&= 0.75 \times E \text{ [without mesh cover]}
\end{aligned}$$

wherein E is the open pan evaporation with mesh cover and PE is the potential evapotranspiration derived from $E, f(S)$ is the soil factor given by soil water holding capacity in the root zone (K, mm), $f(C)$ is the crop factor given by b_n crop growth stage factor. CWC used estimated values of PE using Thornthwaite and Mather method, which presents underestimates [5, 18]. "Although temperature-based methods are useful when data on other meteorological parameters are unavailable, the estimates produced are generally less reliable than those which take other climatic factors into account. Penman method that takes in to account all relevant meteorological parameters presented 1500 mm and Thornthwaite method that only uses the temperature presented 750 mm." As a result, AE presents underestimates and thus RO presents overestimates under CWC method.

Under CWC, the mean estimate in Krishna [1985–86 to 2014–15] is 3144 tmc ft. The observed data series of 26 years [1981–82 to 2006–07] part of 47 years of KWDT-II, the mean is 2400 tmc ft. However, both the series followed normal distribution but the CWC mean is more by 44 tmc ft over the observed data set mean which is 31% higher. This is due to the method adapted by CWC wherein it presents the overestimates. KWDT-II fictitious data series of 26 years the mean is 3050 tmc ft is nothing but CWC estimate only [23, 43].

According to the observed data series, water availability in Krishna and Godavari Rivers varied between 1000 and 4500 with a mean of about 2400 tmc ft and 1000–6000 with a mean of about 4000 tmc ft, respectively with continuous years presenting below and above the average. The coming periods are under below the average system only in both the rivers. That means we expect more drought years or less rainfall years. These factors must be taken in to account in interlinking of rivers or sharing of water among riparian states or sharing of water. Unfortunately, this is not happening under Krishna and Godavari Rivers projects as politics are outplaying. Table 6 presents the water reaching Srisailam Dam in Krishna River and Table 7 water entering the Bay of Bengal for few years after 2000. This clearly demonstrate the fact; it is under below the average conditions of 132-year cycle.

Table 6 Monthly water received by Srisailam Dam during 2014–15 to 2020–21

Year	Water received in tmc ft							
	Total	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2014–15	636.52	000.00	001.93	336.35	235.92	030.87	007.49	011.71
2015–16	073.61	000.00	000.00	000.00	044.13	017.11	004.45	002.52
2016–17	384.30	001.97	019.90	184.74	104.66	039.30	000.61	000.13
2017–18	485.48	001.47	001.62	004.53	184.49	266.08	010.47	012.77
2018–19	583.68	000.31	142.98	317.36	072.34	022.86	011.90	006.99
2019–20	1780.68	000.00	003.61	864.88	429.87	384.13	068.32	015.02
2020–21	1766.92	000.60	094.15	420.85	420.56	530.73	041.76	002.41

Table 7 Water released for few years from Prakasham Barrage in to Bay of Bengal*

Year	tmc ft	Year	tmc ft	Year	tmc ft	Year	tmc ft
2000–01	365	2002–03	111	2003–04	013	2004–05	012
2005–06	023	2006–07	1273				
2010–11	411	2011–12	209	2012–13	055	2013–14	399
2014–15	073	2015–16	009	2016–17	055	2017–18	000
2018–19	039	2019–20	798	2020–21	1278		

* In few years a part of water entering in to Bay of Bengal after 2015–16 is Godavari water released in to Prakasham barrage through Polavaram Right Canal through Pattiseema

Table 8 Additional water distribution by KWDT-II to Karnataka and Maharashtra

Method	Probability level	Water distributed among Riparian States, tmc ft			
		Maharashtra	Karnataka	AP	Total
KWDT-I	75%–no change	585	734	811	2130
KWDT-II	Mean (58%)	666	911	1005	2578 (4)

Table 9 Additional water distributed over 75% probability level, tmc ft

Probability level (%)	Water distributed among Riparian States, tmc ft			
	Maharashtra	Karnataka	AP	Total
75–65	46	72	45	163
65–58	35	105	145	285
75–58	81	177	191 + 4	448

5.4 Fallacies in Water Distribution Under Tribunal Awards

Tables 8 and 9 presents an example of fallacies in the water distribution in favour of certain states in the case of Krishna River water. Table 8 presents the additional water distributed by KWDT-II [Brijesh Kumar Tribunal] over and above KWDT-I [Bachawat Tribunal]. KWDT-II distributed 448 + 4 tmc ft of water in two steps in addition to 75% value as per KWDT-I to the three riparian states. However, in the case of AP, of the 191 + 4 tmc ft, 150 [= 30 + 120] tmc ft is carryover allocations as allocated by KWDT-I in lieu of deficit [<811 tmc ft] in 25% of the years. That means AP received only 41 + 4 tmc ft of additional allocation over 811 tmc ft under KWDT-II. Here we must remember the fact that in the deficit years, the deficit is not distributed among the three riparian states. Yet, tribunal gifted Karnataka and Maharashtra 177 and 81 tmc ft respectively.

Table 10 presents the probability levels at which KWDT-I and KWDT-I+II data series occur 2578 tmc ft [KWDT-II data series mean, at 58%]. This is available at 30% probability level under KWDT-I data series and at 39% probability level under KWDT-I+II data series [114 years]. That means under realistic conditions of natural variability, 2578 tmc ft occurs at 39% probability level and thus beyond this level only surplus water is available for AP [42].

5.5 River Water Flows Versus Climate Change

Here let me give a case of Brahmaputra River [44]. Very recently Scientific Groups studied tree rings for 7 centuries [1309–2004] for the reconstruction of water flows in the river Brahmaputra. In fact, the two major dry periods [1835–66 and 1956–1986] identified by them followed the 60-year cycle in all India annual rainfall [June to

Table 10 Probability levels of occurrence of 2578 tmc ft under KWDT-I, KWDT-I+II and KWDT-II

Data set	Parameter	Median	Mean	2578 tmc ft
KWDT-I	tmc ft	2305	2393	–
[78-years]	Probability (%)	50	43	30
KWDT-I&II	tmc ft	2374	2443	–
[114-years]	Probability (%)	50	48	39
KWDT-II	tmc ft	2626	2578	–
[47-years]	Probability (%)	50	58	58

Note When we say the data series is "normally distributed", mean = median. That is on either side of the mean equal number of years are distributed. We call such data series as unbiased and give reliable estimates at a given probability level. In the Table 7 114-years data series comes closely to normal distribution with median at 50% and mean at 48%

May] Fig. 6. Also frequency of occurrence of heavy floods in Chenab, Ravi and Beas [data of MoEF/GoI, 2009] followed this 60-year cycle [21, 42]. Here we must remember the fact that 100–75% of probability levels we experience deficit towards 1000 tmc ft with few tmc ft going in to the Sea; and from 25 to 1% of probability level we experience excess towards 4500/6500 tmc ft that help more water going in to the Sea. 75 to 25% probability levels surplus water is rarely available except under heavy rains.

CWC used poor model on one hand and on the other the estimates under Godavari River refers to high rainfall 30 year period of 60 year cycle and thus mean is biased towards higher value (Fig. 6). Godavari River water used by the Bachawat Tribunal followed the 60-year rainfall cycle seen in Fig. 6 and thus followed normal distribution (Fig. 26). This figure presents one full 60-year cycle wherein the below the average 30-years in the centre and above average 34 years combine on the two side [19 + 15] of it.

5.6 *Groundwater*

According [unpublished] Central Ground Water Board nearly one-sixth of India's 6965 ground water assessment units (blocks/tehsil/taluks) are 'over exploited' and this along with two other categories of concern—'critical' and 'semi-critical'—account for 35% of total assessed units. Though the report says depletion of ground water continues to be a concern due to indiscriminate extraction in several states, the latest assessment of 'dynamic groundwater Resource' in the country shows signs of improvement due to increased recharge and water use efficiency in 2020 compared to 2017. As a result, number of 'overexploited' and 'critical' assessment units have declined while number of 'safe' units has increased compared to the previous assessment done three years ago (Fig. 27). However, in any given year groundwater depends upon the primarily to rainfall and secondly with development of recharging projects.

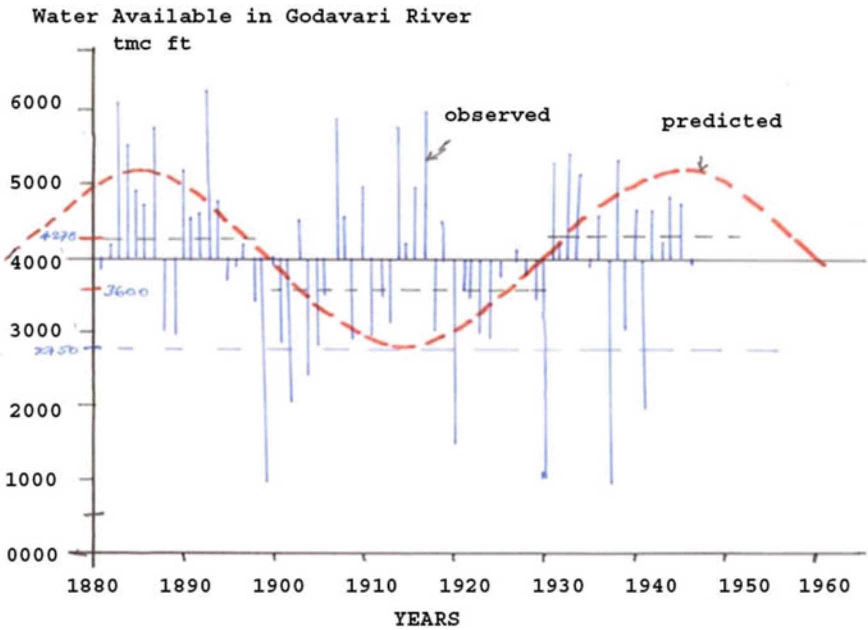

Fig. 26 Annual march River of flows in Godavari

Natural variability in rainfall (Figs. 6 and 24) plays pivotal role on groundwater recharging capacity.

6 Conclusions

In agriculture soils and climate plays an important role. Climate is influenced by soil, climate system [local conditions] and general circulation patterns at local and regional levels. Rainfall follows the natural rhythmic variations at local and regional levels. Soils influence both the temperature and the soil moisture availability at local level. The water flows in rivers follow the natural variability in rainfall. Thus, agro-climatic techniques help to integrate these and to get useful information. Few agro-climatic concepts are: (a) the rhythmic variations in Indian rainfall, (b) the impact of rhythmic variations on agroclimatic variables, such as drought proneness, water availability in some Indian rivers, etc., (c) models that integrate soil–water-crop factors and (d) Crop-weather model related issues. (a) Still to date, major part of agriculture is under dry-land and it depends upon in-situ rainfall. Rainfall is highly variable with space and time which directly influences the dry-land agriculture. Indian rainfall follows rhythmic pattern—very recently tree rings based study relating to water flows in Brahmaputra River presented two major 30 year dry periods coinciding with the below the average 30 years periods in “60-year cycle in all-India annual rainfall”

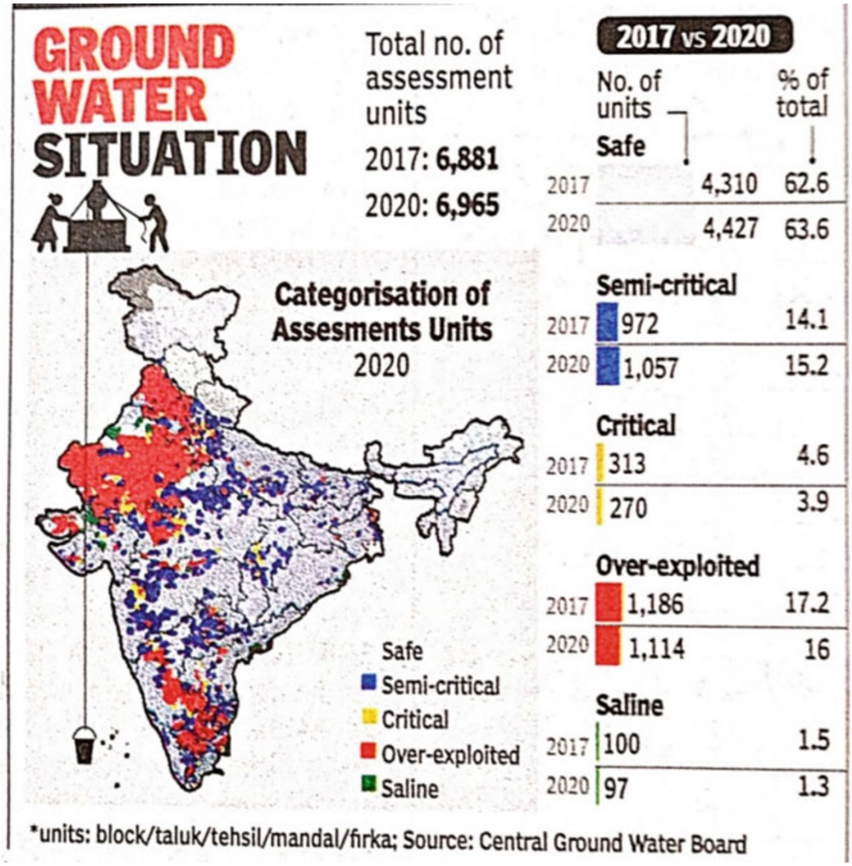

Fig. 27 Ground water situation in India

(Fig. 6—prior to starting of 1st cycle 30 year period and 2nd cycle below the average 30 years period).

(b) Irrigated Agriculture: Dry and wet periods of natural cycles were not taken into account while distributing water to riparian states and interlinking of rivers. Irrigated agriculture depends upon ex-situ rainfall and thus reliable estimates of water availability in rivers is an important issue. Selection of data series that follows natural variability part of climate change plays an important role in estimating unbiased water availability. Moving Average Technique helps to identify the presence or absence of such variations. If the data series follow the rhythmic variation then the selected data series must follow normal distribution pattern wherein mean coincides with median—that is, equal number of data points will be on either side of the mean [114 years data series of KWDT-I&II]. Skewed data series presents biased water availability towards higher values if it is positively skewed [KWDT-II] and lower values if negatively skewed [KWDT-I]. Such data series are not good for interlinking rivers and water distribution among the riparian states. Unfortunately, CWC has not followed this basic path and thus helping future water wars among riparian states [7–10]. Though CWC refers to climate change, it uses it as an adjective; and says 30 years data is enough to get average water availability at river basin and national levels. Following the footsteps of CWC, KWDT-II also used 47 years data series, though 114 years data series was available at the time of working on the award with few fictitious objections. The 30-year period refers to "climate normal" for inter comparisons around the world as proposed by WMO like 1931–60, 1961–90, 1991–2020, etc. or to define a climate of the place. Average refers to any period of data series.

However, to get reliable estimates at different probability levels the selected data series must follow normal distribution pattern. KWDT-II data series are positively skewed and thus the mean is over estimated; in the case of CWC data series. In the Godavari River case it is positively skewed and thus present overestimate; and in the case of Krishna River it follows normal distribution. KWDT-I and KWDT-II data series are observed and CWC data series are estimated wherein they present overestimates by around 30%. Under CWC scenarios, during below the average rainfall periods create war zones among riparian states under given river basin. To avoid such tragedies, CWC must study natural variability in rainfall using historical data for different river basins in India to get unbiased estimates. Use observed data series instead of model estimates. These are some of the practical problems. However, very few are interested in such careful analysis. This needs water resources ministries attention [17, 19, 27, 33].

Whatever may be the water availability, misuse of upper riparian states with poor quality Jal Shakti ministry, create water wars? Courts are filled with such cases by wasting public money. The main beneficiaries are Advocates and losers are farmers. Unless these are settled there is no way to stop water wars among riparian states in future. In the case of Krishna Basin, Karnataka state constructed and constructing more projects that severely affect lower riparian states—for one such illegal project central government issued national status. Telangana State is following the footsteps of Karnataka. To overcome these problems AP state is wasting public money for re-structuring projects to get water under low water inflows. Also, CWC/Jal Shakti Ministry to serve political interests imposing inter-linking of Godavari with Cauvery instead of Ganga with Cauvery. Here CWC using their overestimated data series to manipulate.

7 Recommendations

It is recommended to study agro-climate of the location/region. Agro-climatological analysis using daily/weekly data help to understand droughts and floods and their association with natural variability in rainfall. This will help long term agricultural planning;

While selecting the models for such analyses need careful study; and avoid location specific, soil specific and crop specific analysis models and also avoid adapting extra-tropical models where such models represent in majority of the cases conserved soil moisture scenario;

Select the length of the data series to avoid bias in terms of natural variability in rainfall—preferably select normal distributed data series;

Look at natural variability in rainfall. Here it is appropriate to look in to rainfall versus seasons;

Suggested references: Reddy [15, 16, 20, 21, 23, 34, 35, 37, 41, 43].

8 Special Recommendations

Suggest avoid using CWC water availability estimates in interlinking of rivers projects and sharing of river water by riparian states as this has two severe flaws, namely:

CWC method of estimation of water availability in any given river presents overestimates by around 30% as the Thornthwaite model of estimating potential evapotranspiration underestimates—the present author presented this as back as 1995 in an international journal; and thus over estimates runoff water as rainfall and deep drainage are observed data in the model;

CWC used 30-year period by referring 30-year period used by IMD for normal books, where the purpose is different. Here the period selected must cover the natural variability in rainfall and thus data series must follow "Normal Distribution" pattern wherein mean and median coincides. CWC hasn't looked in to natural variability in Indian rainfall. This is a must. Skewed [positively or negatively] data series present biased estimates [over or under estimates];

Suggest avoiding wasting water through power production. Let us see two cases under Krishna River, namely:

Tata Power primarily uses water allocated to Maharashtra. The water from the power project goes in to Arabian Sea as wastewater. In this connection AP government proposed that "we give you power and you allow that quota of water for use in drought prone areas in AP". But, it was turned down;

TS government killed the Pranahita-Chevella project that provides water through mainly gravity with low lift component and built Kaleswaram a huge "White Elephant" project that lifts the water using huge quantity of power. TS have not created a provision to generate power to meet that demand except using that was created prior to TS formation. So, to meet the current power needs started producing hydel-power illegally from other projects depriving AP to get its share of water. TS uses water far below the dead storage in Srisailam Dam and produces power. Also power is produced from Nagarjunasagar Dam even with low inflows. This is going to create a war between AP and TS. This is a dangerous tendency for the country and it needs to be stopped.

Suggest better utilization of water through crop rotation – rain-fed + irrigated, namely:

States must look in to ways and means of bringing 100% cultivated area under equitable irrigation systems;

Instead of using water for irrigation of multiple-crops on a piece of land, use water for one season and another season grow dry-land crops. This will improve the health of the soil and also at the same time provides opportunity to provide water to rain-fed areas also.

Acknowledgements This research is self-funded; and most of the work presented in this article is from my own work since early 1970s to date. I am herewith acknowledging with thanks to authors whose work was used from the internet sources for the continuity of the stories presented in the article.

References

1. Akumanchi et al (2009) Agro-climatic zonation of Maharashtra state using GIS. Trans Inst Indian Geogr 31(1)
2. BRS (British Royal Society), USNAS (United States National Academy of Sciences) (2014) Climate change-evidence and causes
3. De US, Dube RK, Rao GSP (2005) Extreme weather events over India in the last 100 years. J Indian Geophys Union 9(3):173–187
4. Gupta RK, Reddy SJ (eds) (1999) Advanced technologies in meteorology. Tata McGraw-Hills Publ. Comp. Ltd., New Delhi, India, p 549p
5. McKenny MS, Rosenberg NJ (1993) Sensitivity of some potential evapotranspiration estimation methods to climate change. Agri For Meteorol 64:81–110
6. Mishra AP, Khali H, Singh S, Pande CB, Singh R, Chaurasia SK (2021) An assessment of in-situ water quality parameters and its variation with Landsat 8 level 1 surface reflectance datasets. Int J Environ Anal Chem pp 1–23
7. Moharir KN, Pande CB, Singh SK, Del Rio RA (2020) Evaluation of analytical methods to study aquifer properties with pumping test in Deccan basalt region of the Morna River basin in Akola District of Maharashtra in India. Groundw Hydrol. https://doi.org/10.5772/intechopen.84632
8. Pande CB, Kadam SA, Jayaraman R, Gorantiwar S, Shinde M (2022) Prediction of soil chemical properties using multispectral satellite images and wavelet transforms methods. J Saudi Soc Agric Sci 21(1):21–28
9. Pande CB (2020) Sustainable watershed development planning. In: sustainable watershed development. Springer briefs in water science and technology. Springer, Cham. https://doi.org/10.1007/978-3-030-47244-3_4
10. Pande CB, Moharir KN, Singh SK et al (2022) Groundwater flow modeling in the basaltic hard rock area of Maharashtra, India. Appl Water Sci 12:12. https://doi.org/10.1007/s13201-021-01525-y
11. Parthasarathy B, Munot AA, Kothwale DR (1995) Monthly and seasonal rainfall series for all-India homogeneous regions and meteorological subdivisions: 1871–1994, IITM, Pune [ISSN 0252-1075], 113P
12. Rathore LS, Attri SD, Jaswal AK (2013) State level climate change trends in India. Met. Monograph No. ESSO/IMD/EMRC/02/2013, GoI, MoES, Earth System Science Organization, IMD

13. Reddy SJ (1976) Simple formula for the estimation of wet bulb temperature and precipitable water. Indian J Meteorol Hydrol Geophys 27:163–166
14. Reddy SJ (1977) Forecasting the onset of southwest monsoon over Kerala. Indian J Meteorol Hydrol Geophys 28:113–114
15. Reddy SJ (1983) A simple method of estimating the soil water balance. Agri Meteorol 28:1–17
16. Reddy SJ (1984) Climatic fluctuations and homogenization of northeast Brazil using precipitation data. Pesq Agropec Bras (Brasilia) 19:529–543
17. Reddy SJ (1987) The estimation of global solar radiation and evaporation through precipitation–a note. Sol Energy 38(2):97–104
18. Reddy SJ (1995) Comment: sensitivity of some potential evapotranspiration estimation methods to climate change. Agric For Meteorol 77:121–125
19. Reddy SJ (1995) Discussion: over-emphasis on energy terms in crop yield models. Agric For Meteorol 77:113–120
20. Reddy SJ (2002) Dry-land agriculture in India: an agro-climatological and agrometeorological perspective. BS Public, Hyderabad, p 429p
21. Reddy SJ (2016) Climate change and its impacts: ground realities. BS Public, Hyderabad, India, p 276p
22. Reddy SJ (2019) Workable "*Green*" green revolution: a framework [Agriculture in the perspective of Climate Change]. Brillion Publishing, New Delhi, p 221p
23. Reddy SJ (2019) Water resources availability over India. Brillion Publishing, New Delhi, p 224p
24. Reddy SJ (2020) Agro-meteorology: an answer to climate crisis. Brillion Public, New Delhi, p 242p
25. Reddy SJ (2020) Indian temperature scenario: "No Global Warming Trend." Op Acc J Bio Sci Res 1(1):6p
26. Reddy SJ (2021) World environment day [WED]–2021: a note. Aditum J Clin Biomed Res 2(5):7
27. Reddy SJ (2021) A note on: "Climate Change/Global Warming versus Climate Crisis. J Agric Aquac 3(1):23p
28. Reddy SJ, Maite RK, Seetharama N (1984) An iterative regression approach for prediction of sorghum (sorghum bicolar) phenology in the semi-arid tropics. Agric For Meteorol 32:323–338
29. Reddy SJ, Rao KR (1973) An empirical method for estimation of evaporation from the free surface of water. India J Met Geophys 24:137–152
30. Reddy SJ, Rao GSP (1978) A method of forecasting the weather associated with western disturbances. Indian J Meteorol Hydrol Geophy 29:515–520
31. Reddy SJ, Timberlake JR (1987) A simple method for the estimation of primary pasture productivity over Mozambique. Agric For Meteorol 39:335–349
32. Reddy SJ (1985) An agroclimatic classification of the semi-arid tropics: an agroclimatic approach for the transfer of dry-land agricultural technology. PhD (Thesis), 260p [ANU Library/Canberra]
33. Reddy SJ (1986) Climatic fluctuations in the precipitation data of Mozambique during the period of meteorological record. Comm. No. 39, Series Terra e Agua, INIA, Maputo, Mozambique, 40p
34. Reddy SJ, Juneja OA, Lahori SN (1977) Power spectral analysis of total & net radiation intensities. Indian J Radio Space Phys 6:60–66
35. Reddy SJ (1983) Agroclimatic classification of the semi-arid tropics: I & II. Agric Meteorol 30:185–200 & 201–219
36. Reddy SJ (1984) Agroclimatic classification of the semi-arid tropics: III & IV. Agric Meteorol 30:269–292 & 293–325
37. Reddy SJ (1993) Agroclimatic/agrometeorological techniques: as applicable to dry-land agriculture in developing countries, www.scribd.com/Google Books, 205p; (1994) Book review appeared in agricultural and forest meteorology 67:325–327
38. Reddy SJ (2000) Andhra Pradesh agriculture: scenario of the last four decades, Hyderabad, India, 104p

39. Reddy SJ (2004) Rainfall prediction for agriculture: past, present & future. Presented at international conference on “Agricultural Heritage of Asia”, Organized by Asian agri-history foundation, held on 6–8 December, 2004, Rajendranagar, Hyderabad, pp 147–154
40. Reddy SJ (2007) Agriculture & environment–few thoughts–. Hyderabad, 112p
41. Reddy SJ (2008) Climate change: myths & realities, www.scribd.com/Google Books, 176p
42. Reddy SJ (2016) Irrigation and irrigation projects in India: Tribunals, disputes and water wars perspective. BS Public, Hyderabad, India, 132p
43. Reddy SJ (2019) Agroclimatic/agrometeorological techniques: as applicable to dry-land agriculture in developing countries, 2nd ed. Brillion Publishing, New Delhi, 372p
44. Reddy SJ (2021) Assessment of Pros & Cons of three Agri Bills 2020 of India. Aditum J Clin Biomed Res 1(2):15. 04.2021/1.1009
45. Rose RS, Krishnamurti TN, Patnaik S, Pai DS (2018) Decadal surface temperature trends in India based on a new high-resolution data set, Sci Rep/Nat Res 8(1)/7452
46. WMO [World Meteorological Organization] (1966) Climate change. Geneva, Switzerland, WMO Tech Note 79, WMO, 195 TP 100, pp 81, (Prepared by Mitchel JM, Dzerdzeevskii B, Flohn H, Hofmeyer WL, Lamb HH, Rao KN, Wallen CC)
47. Williams J, Day KJ, Isbel RF, Reddy SJ (1985) Soils and climate. In: Muchou RC (ed) Agro-research for the semi-arid tropics: Northwest Australia, University of Queensland Press, St. Luis, Brisbane, pp 31–92

Impact of Climate Change on Agricultural

Assessment of Climate Change Impact on Agricultural Crops' Growth and Yield Over Indian Subcontinent Using Remote Sensing, GIS and Modelling Approach

Atin Majumder, Sony Bora, P. K. Kingra, and Agniva Mandal

Abstract Clear proof of climate change's existence has been shown over the past decade, and it is having an influence everywhere. As a result, the scientific community is placing more and more attention on food security and its regional effects. In the face of climate change, food production and supply are likely to be most vulnerable. Agricultural systems need to opt for measures that not only boost food supply to feed the worldwide growing population but also nullify the destructive impacts on earth and humankind. In future, under the effect of global warming, plant transpiration and soil evaporation are likely to greatly alter water productivity. The climate science community is facing the significant challenge of dealing with a continuously changing observing system. In India, significant research has been done to comprehend the nature and expanse of variations experienced in yield of various crops due to projected climate change. To analyse the potential impact of changing climate on agriculture, the advent of remote sensing techniques along with GIS and crop simulation models have proven to be a boon for the agriculture sector. Different crop simulation models can be employed in crop improvement programmes by modifying the characteristics showing the most significant effect on yield. It provides informative strategies to avoid risks imposed by climate variations but also helps in understanding the bio-phyical processes. These models can project the possible impacts of climate change on future crop productivity and inspect the mitigation measures that will guide the farmers and policy makers towards proper decision making. Similarly, remote

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_7

sensing can assess the impacts of climate change on various spatial and temporal scales that help in monitoring and forecasting the agricultural production and also help in substantial resource management. Hence, Crop models and remote sensing are efficient tools for coping with the challenges of climate change on agriculture.

Keywords Climate change · Crop yield and growth · Remote sensing · Simulation models

1 Introduction

1.1 Climate Impact and Food Security

Climate change refers to deviation from the average atmospheric conditions caused by both natural and artificial factors. Natural factors include orbit of earth's revolution, crustal movements and volcanic activities whereas, artificial factors include the accumulation of greenhouse gases and the aerosol. Changing climate scenarios hamper the global food production system. It affects four main dimensions of food system: food production, availability, accessibility and utilization. Climate change led extreme weather events have doubled since the early 1990s. Higher ocean and land temperatures, depleting ground water table, greater carbon dioxide concentrations, frequent droughts and floods have already started to show its impact on staple crops around the globe. This can be due to the presence of huge amount of greenhouse gases in the lower troposphere. The two primary causes are the adoption of intensive agriculture to satisfy the rising food demand, which is frequently accompanied by deforestation, and the burning of fossil fuels (coal, oil, and gas) to meet the rising energy demand. First, agriculture generates the food that people consume, and second, it is the major source of income for 40–50% of the population, making it essential for food security. Long-term climate changes adversely impact food production- more than any of the other sectors of global economy. In developing countries, the impact to agriculture from disasters accounts for 63% [18].

Agriculture and food production are impacted by climate change in a variety of ways. Changes in agro-ecological conditions have a direct impact on food production, while income development and distribution have an indirect impact on food demand. Higher temperatures reduce yields along with encouraging weed and pest proliferation. Further it may result into shifts in the geographical distribution of certain pests. Extreme periods of high temperature are harmful, particularly during the flowering stage, because if this critical stage is disrupted, there may be no seed production. Variability in rainfall patterns like droughts in some region and torrential rains and flooding in other regions may induce crop failure in short term and subdue the long term crop production. In coastal areas, increasing sea level may lead to complete loss of agricultural land. Although climate change can show positive impacts in some of the crops in some regions of the world. It is anticipated that climate change events like heat and cold waves during anthesis stage would have negative effects generally on agriculture, which ultimaterly threatening the global food security. Different crops behave differently to the changing climate. For instance, photosynthesis in C3 crops like wheat, rice, soybeans, etc., can get enhanced due to carbon emissions, whereas C4 crops like sugarcane, maize, etc., don't behave similarly.

2 Climate Change Impact on Agriculture

To quantify the consequences of climate change and environmental variation, data on the frequency of stress events, their impact on day-to-day activities, and harm to agricultural products are gathered. Harsh impacts on plant production are becoming more severe as a result of both direct and indirect effects of abiotic stressors in response to quick changes in environmental conditions. CO_2 concentrations are expected to rise from 400 to 800 mol^{-1} by the end of the century, due to continued deforestation and excessive usage of fossil fuels [54]. Studies predict that during the next 30 years, the earth's average surface temperature will increase by 0.2 °C per decade [56]. In addition, by the end of this century, it is anticipated that the temperature of greenhouse gases in the atmosphere will have increased by 2.5–4.5 °C [25]. According to the recent sixth assessment report of IPCC "It is only possible to avoid warming of 1.5 °C or 2 °C if massive and immediate cuts in greenhouse gas emissions are made and to achieve that the world would need to cut emissions by 50% by the year 2030 and by 100% by the year 2050" [26]. The root causes of climate change and its effect on agriculture and its related industries have been discussed in Fig. 1.

The combination of unpredictable rainfall, drought, and increasing extreme weather is predicted to have a significant negative impact on agriculture. The agricultural industry is one of the main producers of greenhouse gases. In exchange, the climate has the capacity to change crop yields both directly and indirectly through the provision of fertiliser, pests, and diseases, among other abiotic stressors including heat stress and water stress [39]. The majority of people throughout the world perceive cereal grains like wheat, maize, and rice to be staple foods. By raising plant respiration rates, global warming is diminishing the net assimilation of carbon, which might reduce agricultural yields and potentially lead to the invasion of weeds, diseases, and pests [5]. Various implications of climate change in agriculture are discussed here [34].

According to global statistics, crop productivity will decline by 10–40% by 2100.

By the middle of the twenty-first century, South Asian nations should expect an average 30% decline in agricultural production. Increased temperature would necessitate more fertilizer to achieve the same production goals, resulting in increased emissions.

Productivity of cereals in Indo-Gangetic plains showed declining trends due to rise in temperature and decrease in water availability.

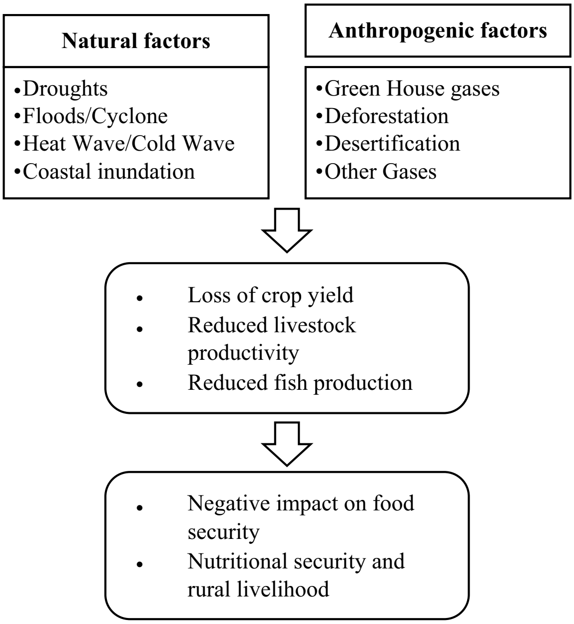

Fig. 1 Climate change's root causes and effects on agriculture and related industries

Rabi crops are projected to have a higher loss due to increase in minimum temperature. Wheat production is reduced by 4–5 million tons for every 1 °C increase in temperature. If farmers could plant in time, the loss would be only 1–2 million tons.

Less frost damage: potato, peas, and mustard will suffer less harm.

Rising river and sea water temperature highly affected the spawning, migration, and harvests of fishes. Coral reefs are also projected to deteriorate till 2030.

3 Sector Wise Impact of Climate Change

3.1 Agriculture

Temperature variations during the growing season can result in catastrophic crop losses. The rate of development will be accelerated as the temperature rises. The time between sowing and harvesting for an annual crop will be shorter. Because of shortening of this cycle, senescence will occur sooner, which could negatively impact output [21]. "During the cultivation of wheat, an increase in temperature by 1 °C could reduce production yields by 3–10%" [58]. Temperature of 30 °C during wheat's flowering and grain filling stages can severely impact seed set and weight [9]. According to Sun et al. [51] heat stress (>30 °C) during the reproductive stage of wheat results in a significant reduction in number of seed, also a stress exposure from 2 to 30 days can alter the seed weight significantly. "Furthermore, a meta-analysis indicated that yield loss may occur with the rise of every 2 °C of temperature in sub-tropical and temperate regions" [1]. In India, a rise in temperature of 1.5 °C and a fall in precipitation of 2 mm result in a 3–15% reduction in rice productivity [3]. In India, rainfed rice yields are expected to decrease by somewhat 2.5% in 2050 and 2080, but irrigated rice yields are expected to increase by 7% in 2050 and 10% in 2080 scenarios. Wheat yields are expected to drop by 6–25% by 2100, while maize yields will drop by 18–23%. Chickpeas are anticipated to profit from future climates as their yield rises (23–54%) [35]. According to Singh [48] exposure of rice to 1 °C for more than one hour can produce sterile grains. According to studies on the impact of global warming on agricultural output in India, yields of wheat, rice, and maize decreased by 5%, 6–8%, and 10–30%, respectively [33].

Heat stress combined with drought condition at the time of seed development can reduce the seed weight, seed number and seed setting in legumes and as well as in cereals [6, 7, 45]. The studies of Daryanto et al. [14] found that cereals often survive drought better than legumes, tubers and root crops. Except for wheat, which was sensitive during the vegetative phase, most crops were more sensitive to drought during their reproductive (i.e., grain filling, tuber beginning) than during their vegetative phase. The most severe effects of climate change are anticipated to be felt by cereal crops like wheat and rice, whereas legumes like soybean and peanuts are expected to benefit from the shift in temperature. By 2030, soybean yields are expected to increase by 8–13%, and groundnut yields up to 7% [44].

3.2 Horticulture

When vegetable crops are subjected to extremely high temperatures, transpiration loss enhances, fruit set in citrus fruits gets limited and burning or scorching of blooms, especially on young trees occurs. In litchi plantations, temperature increases during the ripening stage cause fruit burning and cracking. It also causes moisture stress on fruit trees such as apples, apricots and cherries resulting in physiological disorders like sunburn [30]. Vegetable crop yields will be lowered by 5–15% if ozone level exceed 50 parts per billion per day [40]. The projected impact of climate change on horticulture are as follows.

The areas presently favourable for horticultural crops would become unfavourable in another 25 years.

Production timings may change due to rise in global surface temperature.

Higher temperatures will impair tuber initiation in potatoes, tomato quality, and pollination in various crops. It may lead to bolting in case of crucifers; reduced anthocyanin production in apples and capsicum; blossom end rot and tip burn in tomatoes.

A greater temperature may negatively affect pollination, resulting in floral abortions, fruit and blossom drop, and other problems. With increase in temperature, crops in temperate regions will experience reduced chilling and cold injuries.

The annual irrigation demand will rise, and the heat unit requirement will be met in a much shorter period of time. Elevated temperature will induce annual irrigation demand and heat unit requirement will fulfil in much shorter duration.

3.3 Fruits

Yields of several horticulture crops are drastically reduced as a result of air pollution. The severity of physiological disorders like black tip of mango is rising, due to increase in air pollutant likesulphur dioxide, ethylene, fluorides and carbon monooxide. High temperature also causes physiological disorder like girdle necrosis of mango, flower and fruit abscission and fruit cracking of citrus. Increase in temperature upto 31–32 °C enhances plant maturity in annual species, hence reducing the time it takes for developing fruits and suckers to absorb photosynthetic products [16]. High temperatures and moisture stress can make apples, apricots, and cherries more susceptible to sunburn and cracking [30]. The current area suited for the quality production of Dashehari and Alphonso mango types may vary with 0.7–1.0 °C of the temperature rises. The regions that are suitable for the development of red colour on guava may significantly decrease with a 0.2 °C rise in temperature [23]. Cold winter temperatures impact some tropical fruit crops, such as bananas, causing chilling injury and choke throat. Frost also have adverse impact on crops, Aonla, Phalsa, Ber, Moringa, Ficus species are adversely affected, moderately affected is the pomegranate, less affected are sapota and bael and unaffected is the date palm [41].

3.4 Vegetables

Air pollution damages many crops like carrot, turnip, soyabeans, potato, tomato, beet etc. Elevated CO_2 can also show positive effect on various vegetable crops. Hazra et al. [24] reported many reproductive abnormalities due to high temperature in chilli fruits like deterioration of the red colour development and in tomato poor pollen production, bud drop, dehiscence, abnormal flower development, and ovule abortion etc. [4]. If no specific techniques are adopted, Luck et al. [32] predicted a 16% drop in potato tuber yield in West Bengal by 2050. Temperatures above 21 °C significantly reduce potato tuber yield, while temperatures above 30 °C completely prohibit tuber formation [47]. Drought is a serious problem for potatoes. Reduced tuber yields can also be caused by moderate water stress [29]. Devi et al. [17] also reported a yield loss of 50–60% caused by drought in Chilli. A documented decrease in vegetable crop production due to the daily ozone concentration rising to 50 ppb has also been noted [40].

3.5 Plantation Crops and Flower Crops

Cashew experiences drying of flowers which results into reduction of yield when exposed to a temperature more than 34.4 °C and relative humidity lower than 20%. Jasmine is susceptible to low temperature and less than 19 °C inhibit flowering and ultimately reduces flower size whereas, orchids are affected by high temperature (>35 °C) which leads to bud drop and ultimately reduces flower yield [16].

3.6 Livestock, Poultry and Fishery Sectors

Variety of parameters that are linked to animal productivity, reproduction, health, and adaptability have been affected due to change in climatic condition. Erratic changes in weather directly impact animal output by 58% and reproduction by 63.3% [49]. Heat stress is common in dairy breeds than in meat types. Higher milk producing breeds are more vulnerable compare to the low milk yielding breeds due to their high metabolic heat generation [15]. The 1 °C rise in temperature will affect the fish distribution and its mortality [55]. An increase in temperature from 0.37 to 0.67 °C can alter the mating season of Indian main carps in fish hatcheries of West Bengal and Orissa from June to March.

4 Key Roles of Geospatial Technology in Climate Impact Assessment

Geospatial technology is a vital tool for climate impact assessment. It contains of multiple types of data that can be remotely gathered and analysed to determine the impact a change in weather, climate or regional geography has on socio-economic development. The effect of climate change on agricultural, forest, and water and livelihood security in India are of critical relevance to local and regional stakeholders and policymakers. Geographical study of climate changes and related repercussions in a spatially explicit manner is increasing relevance throughout the world to better address the issue. To begin with, Geospatial technologies are used to develop maps, models, and geographical information systems (GIS) that are critical for understanding climate impacts and helping to mitigate them. A key role of geospatial technology is to support climate impact assessment. In particular, new high-resolution terrestrial and space-based data sources are providing us with information that can be used to link environmental changes with other global environmental conditions like atmospheric circulation or water availability (e.g., evapotranspiration). However, it is important to understand how specific spatial layers—such as soil data or vegetation/vegetation cover—contribute to these models' performance. Apart from multivariate regression model and agro-climatic indices, the inclusion of satellite remote sensing, GIS and crop simulation modelling have enhanced the opportunity to study the and analyse the climate change impact in agricultural system.

4.1 Geographical Information System

It is an information system that involves gathering, storing, manipulating, analyzing and retrieving geospatial data. Many agricultural issues, such as agro-climatic risk assessment and agronomic decision-making, can be solved spatially with the help of GIS. The GIS has seen broad usage in land suitability classification, demarcation of watershed, and agro-ecological classification in the presence of varying degrees of terrain [31, 37]. Agro-climatic indices are generally employed as proxies to quantify regional or national crop development and present a complete picture of climate change. Temperature, precipitation, potential evaporation etc. are some of the important meteorological parameters which are used either single or in combination to build the agro-climatic indices. The International Institute for Applied Systems Analysis (IIASA) together with the United Nations Food and Agricultural Organization (FAO) developed a methodology and database, which is able to map accumulated temperature, moisture index, length of growing period, chilling unit accumulation, and other major agro-climatic indices using GIS environment [36].

5 Impact Assessment of Climate Change Using Satellite Remote Sensing

The use of satellite remote sensing technology as a tool to determine the impact of climate change has been considered rather limited even though satellites provide high spatial and temporal resolution observations over many years. Here we demonstrate that by combining satellite observations from sensors measuring atmospheric constituents with ground-based mapping of vegetation dynamics, remote sensing can be used for assessing the impacts of climate change on vegetation and ecosystem services in tropical regions. We found high agreement between satellite data and ground-based measurements for drought indicators, such as canopy decline rates and leaf area index values, as well as crop yield functions, particularly during the dry season (June–October). Area burned data exhibited high correlation with satellite remote sensing for two indices suggesting wildfire activity is influenced by weather conditions. There was also a significant positive relationship between canopy cover and land use efficiency suggesting that conversion of forested lands to other land uses may be more intensive in those areas where there is both low rainfall and soil fertility potential due to anthropogenic factors. To evaluate the active processes of the climate system and to enhance the climate projections, satellite data is playing an important tool along with climate models. Satellite data also helps to enhance

Atmospheric ECV	Oceanic ECV	Terrestrial ECV
• Wind speed and direction, CO_2 and O_3 • Radiation budget, wind speed and direction, water vapour, cloud properties and aerosol properties • Precipitation, upper air temperature	• Ocean salinity • SST, sea-ice extent • Sea level • Ocean colour, sea state	• Biomass, glacier and ice caps • Land cover, fire disturbance • Albedo, lakes (water levels and areas) • fAPAR LAI, soil moisture • Snow cover

Fig. 2 Essential climate variables retrieved from satellite observation

meteorological reanalysis outputs, which are the major inputs for climate change research. According to Yang et al. [57], essential climatic variables (ECVs) which are significantly dependent on satellite data are mentioned in Fig. 2.

Data from various satellites has been frequently employed to develop different strategies from climate change mitigation to adaptation. Satellite remote sensing is particularly useful for monitoring the earth's surface over large areas and in a consistent way. This allows us to better understand how our climate system works, as well as its changes over time.

A significant heat reservoir, the seas absorb and release heat in response to climatic changes. Furthermore, the atmospheric processes that generate wind and waves have a direct impact on the ocean's surface layer. As a result, variations in sea surface temperature (SST) can provide light on important climate system components including El Nio occurrences and tropical cyclone activity. The Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), TRMM Microwave Imager (TMI), Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E), Wind SAT, these sensors on different satellites allows us to monitor the SST worldwide (Fig. 3). According to Gnanaseelan et al. [22] and Beal et al. [8] the Indian Ocean is one of the world's fastest-warming ocean basins. According to Roxy et al. [43], during the period 1951–2015, the worldwide average increase in SST was 0.7 °C (0.11 °C/decade), while the Indian ocean SST increased by about 1.0 °C (0.15 °C/decade) (high confidence level). Satellite data also reveals a trend of unequal warming though out the ocean surface.

Romshoo et al. [42] utilised satellite data from1980 to2018 to assess the glacier health in the Kashmir Valley, which is crucial to understand the long-term sustainability of rivers that originate in the area. From the 1980 satellite image, 147 glaciers were mapped, 72% of the glaciers had an area of less than 3 km^2 and the bulk of them (123) have a size of less than 1 km^2.The glaciers have shrunk by 28.82% from 1980 to 2018. They concluded that rising temperatures and a decrease in snowfall have caused glacier retreat, resulting in stream flow depletion, which, if prolonged, would have a negative impact on the region's economy. To assess the effect of natural variations in

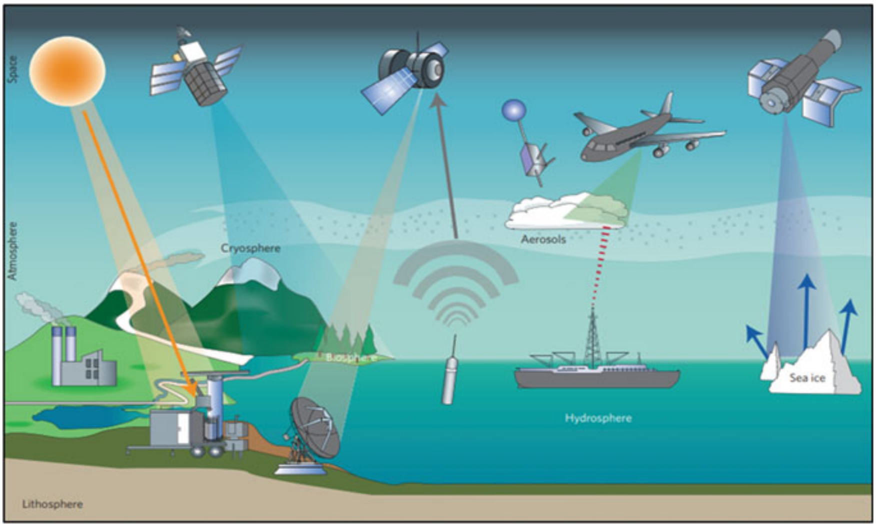

Fig. 3 Various remote sensing platforms, including planes, boats, and Argofloats

solar irradiation in modern climate change, researchers have examined the total solar irradiance (TSI). According to the spectrum irradiance monitor of SOURCE satellite, UV radiation has fallen four to six times more than model projections predicted across the solar magnetic energy cycle. This decrease is largely offset by an increase in visible-wavelength radiation. Aerosols, which are microscopic particles in the atmosphere, can chill the atmosphere, offsetting the warming impacts of GHG by altering both cloud precipitation processes and atmospheric radiation. Satellite data of aerosol-induced direct and indirect climate forcing offer climate models with independent comparisons. The direct radiative forcing by anthropogenic aerosols is computed by integrating satellite data of the radiation budget and AOD. The connections between cloud, aerosols, and precipitation are also better known with satellite remote sensing monitoring. The creation of ice crystals in supercooled clouds is enhanced by dust particles transferred to the cold cloud layer, according to data from cloud-aerosol LIDAR. Lower cloud albedo also means less solar radiation reflection and cooling effects [12].

6 Impact Assessment of Climate Change Using Simulation Modelling

Crop models appear to be a useful tool for studying and calculating the impact of climate change since they allow us to link various climate factors as well as crop development processes that are directly influenced by changing climate condition. In 2002, Aggarwal and Mall investigated climate change and rice yields in a variety of Indian agro-environments. They discovered that without CO_2 fertilisation, an increase of temperature by 1 °C in the north, west, east, and south reduces grain yield of rice by 5, 8, 5, and 7%, respectively. If the temperature is raised by 1 °C, yields are lowered by 10–16% in various parts of India, whereas an increase of 5 °C can reduce the yields by 21–31%. Aggarwal and Mall [2] observed that grain yields increased by 28–35% as atmospheric CO_2 concentrations increased from 350 to 700 ppm. If the temperature was increased by 1, 2, 3, 4, 5 °C at 350 ppm of CO_2 concentration, there was a change of –5, –12, –21, –25 and –31% in grain production of rice, but at 550 ppm yield changes were 12, 7, 1, –5 and –11% respectively. Jalota et al. [28] conducted a location specific climate change studies in a rice–wheat cropping system. They concluded that rainfall and temperature would increase in the mid-century (MC) and end-of-century (EC), but projected crop yields would decline due to shortening of crop duration. Delaying of rice transplanting and wheat seeding by 15–21 days could be the optimum adaptation strategy that can be followed in MC and EC to cope up with changing climate conditions. Jalota et al. [27] assessed the climate change impact in a rice–wheat cropping system by using CropSyst model. They predicted that growth period of the crop will be declining in near future which ultimately reduce the crop yield in long term. Increases in maximum temperature reduced yield more than decreases in minimum temperature. Future rainfall increases would decrease the need for crop irrigation water, but they wouldn't make up for the negative consequences of temperature increases. Dar et al. [13] predicted a decrease in rice crop irrigation requirements and a boost in wheat crop irrigation requirements. The model also forecasted future agricultural output declines due to a shortening of the growth period as a result of rising temperatures.

Dubey and Sharma [20] simulated the yield of Wheat, Barley and Maize from 1981 to 2010, in Banas basin of Rajasthan, then compared the predicted yield with observed yield data. They have found an increasing trend of crop yields for all three crops from 2021 to 2050. Boote et al. [10] used the DSSAT crop simulation model for peanut, soybean, dry bean, chickpea, sorghum, and millet to simulate yield sensitivity to increased temperature. The crop biomass was under represented by the CROPGROW-dry bean model, despite simulated biomass being zero at 35 °C. The CROPGRO-Peanut model, as modified by Vara Prasad et al. [53], was employed in this research, and no further modifications were required for that study region. At 40 °C, simulated biomass was zero, indicating that it was more heat resistant than dried bean. The CROPGRO-Chickpea model was recalibrated and parameterized using extensive growth and yield data on chickpea provided by ICRISAT scientists for several sites. When the mean temperature climbed from 26 to 35 °C, they built a function that enabled them reproduce the yield loss from optimal to zero.

Chandran et al. [11] assessed the impact of predicted climate on the performance of a rice–wheat–groundnut cropping sequence in Mohanpur, India, during end and mid-century of RCP4.5 and RCP8.5 scenarios. Results showed that all four future scenarios predicted a significant decline near about 4–17 days in crop duration for rice and 1–16 days for wheat. The duration of groundnut, on the other hand, rose by 1–4 days. For all three crops, increasing trends in biomass was observed when CO_2 levels were raised. Rice yields tend to increase during future periods of elevated

CO_2, although wheat and groundnut experienced an yield reduction in all future scenarios. Poonia et al. [38] studied the impact of climate change under RCP 4.5 and RCP 8.5 scenarios on crop water dynamics in eastern Himalayan region, Sikkim. Climate datasets are collected for the future period (2021–2099) from CORDEX's four climate models namely ACCESS1-0, CCSM4, CNRM-CM5, and MPI-ESM-LR. In comparison to the baseline era, the study's findings imply an increase in the crop water requirement for rice by 8% and wheat by 39% towards the end of the twenty-first. In the case of maize, crop irrigation requirement has escalated in the majority of cases since the end of the twenty-first century. Dubey et al. [19] used InfoCrop model to determine the effects of terminal heat stress on wheat production and adapting strategies. In the year 2050 there will be decrease in wheat yield by 11.1% due to terminal heat stress. Advancement of the sowing date, an additional nitrogen dose, and watering during the seed setting stage were proven effective methods to minimize yield loss. In the year 2050, adaptation of above mentioned methods will help reducing the heat stress impact by 9%.

7 Impact Assessment of Climate Change Through Integration of Crop Models and Geospatial Technology

The integration of Crop models and geographic information systems (GIS) has showed great potential in solving a variety of environmental and agricultural decision-making issues. According to Subash and Mohan [50], several crop models, such as the DSSAT models, EPIC, and WOFOST, are now coupled to GIS environment and extensively employed in field applications. Additionally, by combining crop growth models and satellite data in a GIS, depending on researchers' interpretation, may anticipate agricultural production and aid in risk management, problem-solving, and decision-making. In India, the wheat growth simulation model (WTGROWS) and GIS were used to develop a basic crop growth monitoring system (CGMS) for monitoring wheat growth and yield for Haryana [46]. Tripathy et al. [52] simulated wheat grain yield for Punjab (India) by assimilating remote sensing inputs in the mechanistic WOFOST model. In order to analyse the degree of changes in rice, wheat, and maize crop production, Patel et al. [36] employed a GIS-based EPIC model in Dehradun (India). The simulation model findings demonstrated considerable spatial variability in estimated crop yields during three different future climate change scenarios and the baseline. Even raising CO_2 levels would not be enough to compensate for the losses experienced due to the significant rise in temperature in the 2080s, according to the findings. The decline in crop yields (percent) without CO_2 fertilisation in the 2080s was found to be in the range of 14, 19, and 42% for maize, rice, and wheat, respectively.

7.1 Key Limitations of Geospatial and Modelling Approach

Concerns have been raised about satellite data's reliability for monitoring and understanding of climate change. Climate change research required calibrated/validated datasets that are consistent through time, as well as accurate sampling in both time and space. On the other hand, satellite image data typically includes uncertainties because of sensor biases, retrieval methods, and variations across satellite missions employing the same sensors. Understanding these limitations in depth is necessary for the use of satellite observations in climate change research. Model construction necessitates specialised training. It is a skill that is developed over time and through practise. It might be difficult to comprehend simulation findings at times, and it can also be difficult to simulate an exact thing. Any flawed model may produce erroneous results when used with confidence. Because simulation does not supply answers on its own, the decision-maker must provide all information (depending on the model) regarding the limitations and conditions for evaluation.

8 Conclusions

Agriculture is extremely vulnerable to weather fluctuations, both short-term and long-term, as well as seasonal, yearly, and long-term climatic variations. It will eventually have an impact on the availability, accessibility, and stability of the food supply, threatening the nation's food security. In the face of changing climate, for managing agriculture and its resources accurate crop yield estimation and forecasting at regional and global scales is critical. The growth and development of crops at a field scale under diverse biotic and abiotic conditions may be accurately predicted and simulated using crop growth simulation models. Crop monitoring over a vast area can also benefit from satellite remote sensing. On a local and global level, using data assimilation to combine remote sensing data with crop models can improve the precision of crop model yield predictions. The use of remote sensing satellite data in coupling with a crop-growth simulation model and a data assimilation approach is proving to be a viable monitoring technique for crop development and grain production as it fixes the problems and enhances the advantages of earlier work. Furthermore, incorporating remote-sensing data into a data assimilation method could reduce crop growth model uncertainty and make sure that predicted values are closer to the observed ones.

References

1. Abhinandan K, Skori L, FStanic M, Hickerson N, Jamshed M, Samuel MA (2018) Abiotic stress signaling in wheat–an inclusive overview of hormonal interactions during abiotic stress responses in wheat. Front Plant Sci 9:734–739

2. Aggarwal PK, Mall RK (2002) Climate change and rice yields in diverse agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. Clim Change 52:331–343
3. Ahluwalia VK, Malhotra S (2006) Environmental science. Anne Books India, New Delhi
4. Arora SK, Partap PS, Pandita ML, Jalal I (1987) Production problems and their possible remedies in vegetable crops. Indian Horti 32:2–8
5. Asseng S, Foster IA, Turner NC (2011) The impact of temperature variability on wheat yields. Glob Change Biol 17:997–1012
6. Awasthi R, Kaushal N, Vadez V, Turner NC, Berger J, Siddique KH et al (2014) Individual and combined effects of transient drought and heat stress on carbon assimilation and seed filling in chickpea. Funct Plant Biol 41:1148–1167
7. Barnabás B, Jager K, Feher A (2008) The effect of drought and heat stress on reproductive processes in cereals. Plant Cell Environ 31:11–38
8. Beal LM, Vialard J, Roxy MK (2019) IndOOS-2: a roadmap to sustained observations of the Indian Ocean for 2020–2030
9. Bheemanahalli R, Sunoj VJ, Saripalli G, Prasad PV, Balyan HS, Gupta PK, Grant N, Gill KS, Jagadish SK (2019) Quantifying the impact of heat stress on pollen germination, seed set, and grain filling in spring wheat. Crop Sci 59:684–696
10. Boote KJ, Prasad V, JrLH A, Singh P, Jones JW (2018) Modeling sensitivity of grain yield to elevated temperature in the DSSAT crop models for peanut, soybean, dry bean, chickpea, sorghum, and millet. Eur J Agron 100:99–109
11. Chandran MS, Banerjee S, Mukherjee A, Nanda MK, Mondal S, Kumari VV (2021) Evaluating the impact of projected climate on rice–wheat-groundnut cropping sequence in lower Gangetic plains of India: a study using multiple GCMs, DSSAT model, and long-term sequence analysis. Theor Appl Climatol 10:1–6
12. Choi YS, Lindzen RS, Ho CH, Kim J (2010) Space observations of cold cloud phase change. Proc Natl Acad Sci 107:11211–11216
13. Dar MU, Aggarwal R, Kaur S (2017) Effect of climate change scenarios on yield and water balance components in rice-wheat cropping system in Central Punjab, India. J Agrometeorol 19:226–229
14. Daryanto S, Wang L, Jacinthe PA (2017) Global synthesis of drought effects on cereal, legume, tuber and root crops production: a review. Agric Water Manag 179:18–33
15. Dash S, Chakravarty AK, Singh A, Upadhyay A, Singh M, Yousuf S (2016) Effect of heat stress on reproductive performances of dairy cattle and buffaloes: a review. Vet World 9:235–244
16. Datta S (2013) Impact of climate change in Indian horticulture-a review. Int J Sci Environ Tech 2:661–671
17. Devi AP, Singh MS, Das SP, Kabiraj J (2017) Effect of climate change on vegetable production-a review. Int J Curr Microbiol Appl Sci 6:447–483
18. Dobush BJ, Gallo ND, Guerra M, Guilloux B, Holland E, Seabrook S, Levin LA (2021) A new way forward for ocean-climate policy as reflected in the UNFCCC ocean and climate change dialogue submissions. Climate Policy 19:1–8
19. Dubey R, Pathak H, Chakrabarti B, Singh S, Gupta DK, Harit RC (2020) Impact of terminal heat stress on wheat yield in India and options for adaptation. Agric Syst 181:102826. https://doi.org/10.1016/j.agsy.2020.102826
20. Dubey SK, Sharma D (2018) Assessment of climate change impact on yield of major crops in the Banas River Basin, India. Sci Total Environ 635:10–19
21. Fahad S, Hussain S, Saud S, Khan F, Hassan S, Nasim W, Arif M, Wang F, Huang J (2016) Exogenously applied plant growth regulators affect heat-stressed rice pollens. J Agron Crop Sci 202:139–150
22. Gnanaseelan C, Roxy MK, Deshpande A (2017) Variability and trends of sea surface temperature and circulation in the Indian Ocean. In: Rajeevan MN, Nayak S (eds) Observed climate variability and change over the Indian Region, vol 10. Springer, Singapore
23. Haokip SW, Shankar K, Lalrinngheta J (2020) Climate change and its impact on fruit crops. J Pharmacogn Phytochem 9:435–438

24. Hazra P, Samsul HA, Sikder D, Peter KV (2007) Breeding tomato (Lycopersicon esculentum Mill) resistant to high temperaturestress. Int J Plant Breed 1:31–40
25. IPCC (2019) Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge University Press, Cambridge, UK
26. IPCC (2021) Sixth assessment report. https://www.ipcc.ch/assessment-report/ar6/
27. Jalota SK, Kaur H, Kaur S, Vashisht BB (2013) Impact of climate change scenarios on yield, water and nitrogen-balance and -use efficiency of rice–wheat cropping system. Agric Water Manag 116:29–38
28. Jalota SK, Vashisht BB, Kaur H, Kaur S, Kaur P (2014) Location specific climate change scenario and its impact on rice and wheat in Central Indian Punjab. Agric Syst 131:77–86
29. Jefferies RA, Mackerron DKL (1993) Responses of potato genotypes to drought. II. Leaf area index, growth and yield. Ann Appl Biol 122:105–112
30. Kumar R, Kumar KK (2007) Managing physiological disorders in litchi. Indian Horticult 52:22–24
31. Kumar S, Patel NR, Sarkar A, Dadhwal VK (2013) Geo-spatial approach of agro-climatic suitability of soybean in Rainfed agroecosystem. J Indian Soc Remote Sensing 41:609–618
32. Luck J, Asaduzzaman M, Banerjee S, Bhattacharya I, Coughlan K, Debnath GC, De Boer D, Dutta S, Forbes G, Griffiths W, Hossain D (2012) The effects of climate change on pests and diseases of major food crops in the Asia Pacific Region. Final Report for APN (Asia-Pacific Network for Global Change Research) Project. 73
33. Morey DK, Sadaphal MN (1981) Effect of weather elements on yield of wheat at Delhi. PKV Res J 5:81–83
34. NAARM (2020) Climate change and Indian agriculture: impacts, coping strategies, programmes and policy. ICAR Policy Paper. https://naarm.org.in/wp-content/uploads/2020/06/ICAR-NAARM-Policy-on-Climate-Change-and-Agriculture_compressed.pdf
35. PIB (2021) https://pib.gov.in/indexd.aspx
36. Patel NR, Akarsh A, Ponraj A, Singh J (2019) Geospatial technology for climate change impact assessment of mountain agriculture. In: Remote sensing of northwest Himalayan ecosystems. Springer, Singapore, pp 381–400
37. Patel NR, Endang P, Kumar S and Pande LM (2005) Agro-ecological zoning using remote sensing and GIS: a case study in part of Kumaon region. In: Bandopadyay B, Sundaram KV, Moni M, Zha M (eds) Sustainable agriculture development. Northen Book Depo, New Delhi, pp 265–280
38. Poonia V, Das J, Goyal MK (2021) Impact of climate change on crop water and irrigation requirements over eastern Himalayan region. Stoch Environ Res Risk Assess 35:1175–1188
39. Porter JR, Xie L, Challinor AJ, Cochrane K, Howden SM, Iqbal MM, Lobell DB, Travasso MI, Netra Chhetri NC, Garrett K (2014) Food security and food production systems. Geneva, Switzerland, IPCC
40. Raj N (2009) Air pollution-A threat in vegetable production. In: Sulladmath UV, Swamy KRM (eds) International conference on horticulture (ICH-2009) horticulture for livelihood society and economic growth, pp 158–159
41. Reddy AGK, Kumar JS, Maruthi V, Venkatasubbaiah K, Rao CS (2017) Fruit production under climate changing scenario in India: a review. Environ Ecol 35:1010–1017
42. Romshoo SA, Fayaz M, Meraj G, Bahuguna IM (2020) Satellite-observed glacier recession in the Kashmir Himalaya, India, from 1980 to 2018. Environ Monit Assess 192:1–7
43. Roxy MK, Gnanaseelan C, Parekh A, Chowdary JS, Singh S, Modi A, Kakatkar R, Mohapatra S, Dhara C, Shenoi SC, Rajeevan M (2020) Indian ocean warming. In: Assessment of climate change over the Indian region. Springer, Singapore, pp 191–206
44. Scidevnet (2011) Climate change will hit Indian cereals, benefit legumes. https://www.scidev.net/global/news/climate-change-will-hit-indian-cereals-benefit-legumes
45. Sehgal A, Sita K, Kumar J, Kumar S, Singh S, Siddique KH, Nayyar H (2017) Effects of drought, heat and their interaction on the growth, yield and photosynthetic function of lentil (Lens culinaris Medikus) genotypes varying in heat and drought sensitivity. Front Plant Sci 8:1776

46. Sehgal VK, Rajak DR, Chaudhary KN, Dadhwal VK (2002) Improved regional yield prediction by crop growth monitoring system using remote sensing derived crop phenology. The International Arch Photogramm Remote Sens Spatial Infor Sci 34:329–334
47. Sekhawat GS (2001) Potato. In: Thumbraj S, Singh N (eds) Vegetables tuber crops and spices. Directorate of Information and Publication in Agriculture, Indian Counsil of Agricultural Research, New Delhi, pp 320–340
48. Singh SK (2016) Climate change: impact on Indian agriculture and its mitigation. J Basic Appl Eng Res 3:857–859
49. Singh SK, Meena HR, Kolekar DV, Singh YP (2012) Climate change impacts on livestock and adaptation strategies to sustain livestock production. J Veterinary Adv. 2:407–412
50. Subash N, Mohan HR (2012) Evaluation of the impact of climatic trends and variability in rice–wheat system productivity using cropping system model DSSAT over the Indo-Gangetic plains of India. Agri Forest Meteorol 164:71–81
51. Sun A, Somayanda I, Sebastian SV, Kanwardeep S, Gill K, Prasad PVV, Jagadish SVK (2018) Heat stress during flowering affects time of day of flowering, seed set, and grain quality in spring wheat. Crop Sci 58:380–392
52. Tripathy R, Chaudhari KN, Mukherjee J, Ray SS, Patel NK, Panigrahy S, Parihar JS (2013) Forecasting wheat yield in Punjab state of India by combining crop simulation model WOFOST and remotely sensed inputs. Remote sens lett 4:19–28
53. Vara Prasad PV, Boote KJ, Hartwell Allen Jr L, Thomas JM (2003) Super-optimal temperatures are detrimental to peanut (Arachis hypogaea L.) reproductive processes and yield at both ambient and elevated carbon dioxide. Glob Change Biol 12:1775–1787
54. Vaughan MM, Block A, Christensen SA, Allen LH, Schmelz EA (2018) The effects of climate change associated abiotic stresses on maize phytochemical defenses. Phytochem Rev 17:37–49
55. Vivekanandan E, Ratheesan K, Manjusha U, Remya R and Ambrose TV (2009) Temporal changes in the climatic and oceanographic variables off Kerala. In: Vivekanandan E et al (eds) Marine ecosystems challenges and opportunities. Book of Abstracts, Marine Biological Association of India, Cochin, pp 260–261
56. Wang Z, Zhong R, Lai C, Zeng Z, Lian Y, Bai X (2018) Climate change enhances the severity and variability of drought in the Pearl River Basin in South China in the 21st century. Agric Fore Meteorol 249:149–162
57. Yang J, Gong P, Fu R, Zhang M, Chen J, Liang S, Xu B, Shi J, Dickinson R (2013) The role of satellite remote sensing in climate change studies. Nat Clim Chang 3:875–883
58. You L, Rosegrant MW, Wood S, Sun D (2009) Impact of growing season temperature on wheat productivity in China. Agric Meteorol 149:1009–1014

Monitoring of Natural Resources Using Remote Sensing and GIS Technology Under Changing Climate Scenario

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Abstract One of the major threats in the twenty-first century is the Earth's climate change, which bestows conspicuous effects on natural resources and human health. Remote sensing and Geographical Information System (GIS) create a profuse opportunity to monitor and manage the natural resources at multi-spectral, multi-spatial and multi-temporal resolution. Agricultural production systems are highly unfortified to alteration in environmental factors at different ecological regions in India. Under the changing climatic conditions, quick spatiotemporal assessment of extreme weather events and crop growth only possible with geospatial technology i.e. Remote sensing and GIS along with digital maps and simulation models. Water scarcity is one of the major problem that has been experienced at global and national level. Therefore, state of the art technologies like geospatial technologies and modelling will be necessary for judicious management of water resources under changing climate scenarios. Based on the area statistics, the total area under degraded and wastelands in the country stands at 114.01 m ha. Therefore, timely monitoring and maintaining of the land resources in larger scale would be possible with remote sensing satellite with high temporal resolution. Forests occupy about 19.4% of the total geographical area of the country against the ideal requirement of 33% therefore remote sensing and GIS technology provide a crucial part in monitoring and protecting the Forest resources under changing climate scenario. Therefore, the integrated use of remotely sensed data, GPS, and GIS will enable consultants, natural resource managers, researchers in government agencies, conservation organizations, and industry to develop management and protection plans for different natural resources to cope with the changing climate condition.

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_8

Keywords Natural resource management · Remote sensing · GIS · Modelling · Climate change

1 Introduction

Global warming, caused by the greenhouse effect, has threatened natural resource sustainability in many parts of the world. In the recent past, significant increases in extreme weather events have been observed. Amphan cyclone of 2020, Tautae cyclone of 2021 and variable rainfall that have led to long dry spells in some places, and cloudbursts and flooding in other places are the recent examples which have long-term socio-economic consequences in India. Information on the nature, extent, availability, spatial distribution along with the condition of natural resources is a prerequisite to achieving sustainable resource development goals [25]. Spaceborne multispectral measurements possess the ability to provide a synoptic view of a relatively large area at regular intervals, hence, it holds great promise in generating reliable information on various natural resources, such as minerals, soils, surface and ground water, marine resources, forest cover in a timely and cost-effective manner. Geospatial technologies are very efficient in acquiring and managing massive spatio-temporal data sets by making use of various satellite information, maps and simulation models etc. This technology is extremely advantageous because of rapid and continuous availability of data, quick analysis and generation of valuable information for planners and decision-makers. Resources are biotic and abiotic based on their origin. Under changing climate scenario, there is more concern regarding the biotic resources.

2 Status of Natural Resources of India

Some of the very significant natural resources available in the country include: land resources, water resources, food resources, forest resources etc.

2.1 Land Resources

The rapid pace of economic development along with population growth, urbanisation and industrialisation exert tremendous pressure on the limited natural resource base of a country. Land, being one of the most basic natural resource, is under the constant threat of degradation [4]. In terms of area, the global ranking of India is seventh (329 million hectare), accounting for 2.42% of the total global area. Statistics on land use are available for approximately 92.9% of the total geographical area. The forest covers 21.02% of the country's total land area. Around 170.0 million hectares of the total land area of 304.2 million hectares is under cultivation. Fallow land accounts for nearly 5% of the total land. It includes arid, rocky or sandy deserts. First amongst various problems include, land fragmentation, according to the Agricultural Census, the area operated by large holdings (ten hectares or more) has decreased while the area operated by marginal holdings (less than one hectare) has increased [1]. Secondly, land degradation includes soil fertility loss, erosion, water shed and catchment area deterioration, and deforestation. Efforts are being made for vertical growth of cities and towns rather than horizontal and the researchers and the policy makers are also realizing the benefits of integrated land use planning.

2.2 Water Resources

Water is a vital natural resource affecting every sphere of life. It is involved in multiple purposes like drinking, power generation, agriculture, as a solvent in chemical industries, waste disposal, transportation etc. The total water statistics over the globe accounts to $140 * 10^{16}$ m^3. Rain water, surface and ground water and sea water constitute the chief sources of water. The oceans contain approximately 97% of the world's water supply, which is unfit for human consumption or other uses due to high salt content. Of the remaining 3%, 2.3% is trapped in the polar ice caps and thus inaccessible. The remaining 0.7% is available as fresh water. A very limited stock of usable water, which is 0.03% of the mass balance, is currently available. Further ground water constitutes 0.66% with recharge from infiltration, evapotranspiration and seepage. The annual rainfall received by the country accounts to $400 * 10^{10}$ m^2. The water resources are under constant threat due to continuous release of hazardous industrial and municipal waste water. It contains heavy metals, radionuclides and other harmful substances that not only deteriorate water bodies but also pose threat to aquatic life. With an estimated 251 km^3/year usage, India is the world's greatest groundwater user [34]. In India, GW accounts for 85% of rural water supply and 84% of net irrigated land [3] and 90% of fresh water usage is accounted by agriculture itself [9]. Water levels have depleted by nearly 8 m on an average since the 1980s [29] and the estimates of Ministry of Water Resources, predict the increase in irrigation demand by 56% by 2050 [22].

2.3 Food Resources

Wheat, rice, maize, barley, pulses, cereals, potato, sugarcane, sorghum, millet, oats, cassava, fruits, vegetables, milk, and sea food are the major food resources. Wheat and rice are staple foods for approximately 4 billion people in developing countries. Fish and seafood provide approximately 70 million metric tonnes of high-quality protein to the global diet. However, we have already exceeded sustainable fish harvests in most of the world's oceans. Food production is being affected by the catastrophic climate change. According to world estimates, on an average 71% yield losses in agricultural crops are caused by abiotic factors [15]. These comprise high temperature (40%), salinity (20%), drought (17%), low temperature (15%) and other forms of stresses [2]. To meet this demand, the global food production needs to increase by over 40% by 2030 and 70% by 2050 [13]. Future predictions suggest that there will be an increased demand for wheat by about 60% in 2050 to feed an estimated 9.7 billion populations in the world [35].

2.4 Forest Resources

India ranks tenth in the world in forested area, but only 120th in the percentage of land area covered by forest. The Forest Survey of India [10] estimates a total of 807,276 km^2 of forest and tree cover, accounting for 24.56% of the land area. It has commercial uses, ecological uses, regulates climate, reduces global warming, conserves soil, regulates hydrological cycle and, food products etc. Exploitation of forest is occurring at a very fast rate. Commercial demand for pines, teak, sal and conifers, use of timber, wooden crates for manufacturing railway sleepers and furniture, pulp for paper industries, plywood for packing in tea industries, fir tree for packing apples, all these activities have exploited forest resources to a great extent. Various projects (hydroelectric projects, railways, highways, power stations, roads, and dams) have resulted in vast deforestation, ultimately affecting the equilibrium of various flora and fauna. The Sunderbans tidal mangrove forests have been depleted, and the Southern Peninsula has become an acacia scrub semi-desert. Due to over-exploitation, the tropical deciduous forests of Mirzapur's Vindhyan range have been replaced by a savannah ecobiome and near barren wasteland. The country's per capita forest area is 0.08 ha, compared to the global average of 0.64 ha. Over the last two decades, India's forest cover has shown a depletion of 235 km^2 per year [19].

3 Relevance of Geo-spatial Technologies

The introduction of modern geospatial technologies such as Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) has proved very efficient in surveying, identifying, classifying, mapping, monitoring, characterization, and tracking changes in the composition, extent, and distribution of various types of earth resources, both renewable and non-renewable, living and non-living in nature. The first step towards accomplishing the sustainable resource development plan is assessing natural resource availability and condition. Four basic steps involved in assessing the natural resources are [14].

Mapping: by acquiring of thematic and quantitative baseline data (current or historical) in geographic format.

Measuring: by quantifying and documenting the properties of phenomena.

Modelling: by characterising a system under investigation through exact quantitative input–output relationships, and simulating its current, past, or future behaviour.

Monitoring: regular monitoring of the conditions through the recording of shifts or changes in natural events and human activities.

4 Geo-informatics as an Emerging Science

Geo-informatics refers to the use of information technology to manage and analyze earth resources. Geospatial technologies viz. Remote sensing technology, Geographic Information System (GIS), Global Positioning System, and simulation models are being efficiently used for their application in various disciplines of natural resource management. The combination of these technologies allows for the acquisition of high-resolution real-time data via remote sensing, data management and analysis via GIS, and geo-referencing of ground truth data via GPS, as well as the integration of all data into an information system and the use of the information for a specific purpose. The essential feature that distinguishes geo-informatics from other disciplines of information technology is that all input data is geo-coded, that is, it has a 3-D address and is linked to a specific location on the earth's surface. However, the amalgamation of such technologies in combination with various other analytical approaches is always desirable as it would produce better information which would enhance our understanding of natural resource management.

5 Remote Sensing Technology

Remote sensing is the process of identifying the physical characteristics of an area by measuring its reflected or emitted radiation without coming in contact with that area. Different objects reflect or emit different amount of energy in different wavelength bands of electro-magnetic spectrum based on their structural, chemical and physical properties and then the sensors measure the amount of energy reflected from that object. The process of remote sensing involves following steps (Fig. 1):

Source of illumination.
Radiation and the atmosphere.
Interaction with the target.
Energy recorded and converted by the sensor.
Reception and processing.
Interpretation and analysis.
Application.

Remote sensing delivers multi-spectral, multi-sensor, and multi-temporal data, allowing for the development of accurate, timely, and cost-effective natural resource

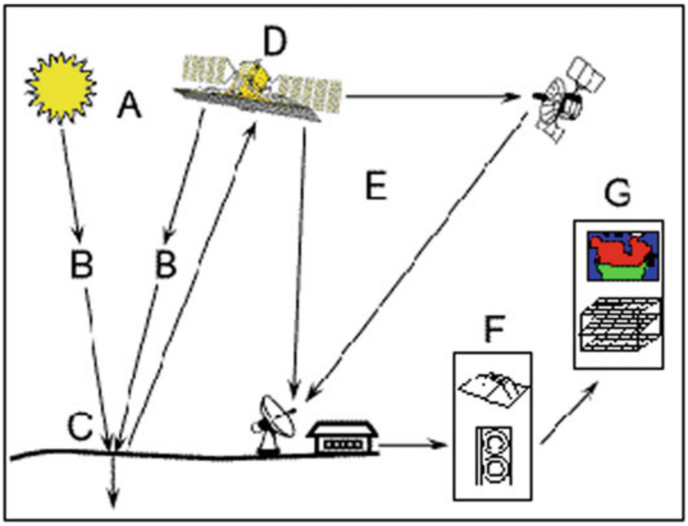

Fig. 1 The process involved in remote sensing

information. Based on source of energy remote sensing is classified in active remote sensing and passive remote sensing.

5.1 Active Remote Sensing

Active remote sensing involves active sensors and these sensors possess their own source of illumination. They illuminate the target with their own energy and then measure the reflected radiation from the target. Examples include LIDAR, RADAR.

5.2 Passive Remote Sensing

Passive remote sensing involves passive sensors and these sensors don't possess their own source of illumination. Here an external source of illumination (solar energy) is present which illuminates the target and after that the passive sensor measures the reflected radiation from the target.

Remote sensing sensors are further classified into optical, thermal, and microwave remote sensing based on the wavelength range the sensors are sensitive to.

5.3 Optical Remote Sensing

Optical remote sensing detects solar energy **reflected** from targets on the ground using visible, near-infrared, and short-wave infrared sensors (0.3–3 μ) to create images of the earth's surface.

5.4 Thermal Remote Sensing

Sensing radiation **emitted** by solids, liquids, and gases in the thermal infrared part of the spectrum (3–100 μ), where thermal emission dominates reflected sun energy, is used for thermal remote sensing.

5.5 Microwave Remote Sensing

The remote sensing using **microwave** spectrum (1 mm–1 m) is called microwave remote sensing. Optical remote sensing data available from IRS, Landsat, etc. faces limitations of data availability during intense cloud cover seasons. Microwave remote sensing through satellites like RADARSAT, SENTINEL-1, etc. have added advantage; has all weather capability, day and night observing capability and soil depth penetration capability to certain extent.

5.6 Aerial Photography

The original form of remote sensing is aerial photography and it remains the most widely used method. Aerial photographs are images captured by a camera mounted on an aeroplane flying over the terrain at a predetermined height, depending on the scale of aerial photography and the camera's focal length. The overlap between successive images is typically 50–65%, which is required for stereoscopic viewing and analysis of stereo-pairs (Fig. 2). With the help of stereoscope one can see the 3-D view of the aerial photograph. Aerial remote sensing is being widely used for natural resource management by various research institutes e.g. Survey of India.

5.7 Satellite Remote Sensing

The advent of satellite remote sensing can be marked form the launch of TIROS-1 i.e. Television and Infrared Observation Satellite which was operated by NOAA

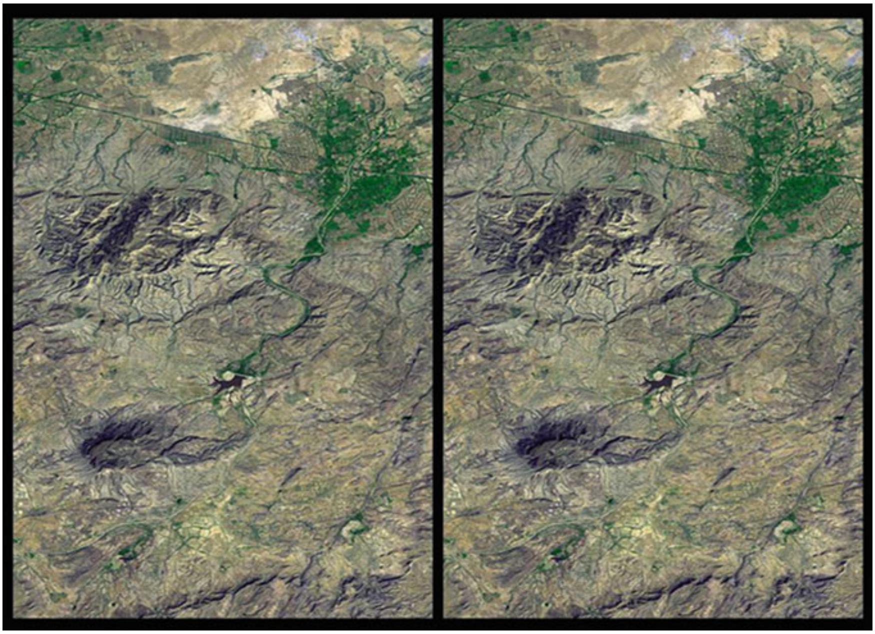

Fig. 2 STRM stereo pair of Northwest region of Bhuj (Image courtesy NASA/JPL/NIMA)

(National Oceanic and Atmospheric Administration) in 1960 which was carrying a single band TV camera. Since then the launching of numerous satellites (Landsat, SPOT, IRS) have increased the usefulness of satellite imagery for inventory and monitoring of Indian natural resources.

5.8 Geographic Information System (GIS)

A computer based information system that enables data acquisition, modeling, manipulation, analysis, presentation, and dissemination of spatially referenced data. Spatially referenced data can be in two forms; Spatial (x, y, or latitude, longitude of tube wells) as well as non-spatial (owner, status, wee id, meteorological parameters, socio-economic data). GIS can organize spatial data as type (point, line or polygon), feature (one particular point, line, area) and theme (collection of similar features of same type). Different components of GIS are hardware, software, data, people and procedure. Further its functionality involves: ***Data encoding, Data retrieval, Data Analysis, Data Storage, Data Display***. The GIS have been utilized to integrate spatial data on various resource themes and to construct an alternate development plan that includes site-specific primary production activities. Through the rule-based decision capabilities of the GIS package, the suitability of various combinations of land factors such as soil, groundwater quality, slope, landform, land use/land cover, and so on, can be linked to primary production activities.

5.9 Global Positioning System (GPS)

The Global Positioning System is a satellite-based navigation system made up of a network of 24 satellites placed into orbit at an altitude of 12,200 km by the U.S. Department of Defense which continuously transmit information to the receiver present at earth surface. Those satellites are positioned in such a way that at least four to five minimum satellites are visible and they all move in six orbits. The working of GPS is based on "distance". Each GPS satellite is equipped with an atomic clock and broadcasts data indicating its position and time. The operations of all GPS satellites are synchronised such that these repeating signals are broadcast at the same time. The GPS satellites' distance can be calculated by calculating the time it takes for their signals to reach the receiver. When the receiver calculates the distance between at least four GPS satellites, it can determine its three-dimensional position. It works on the principal of triangulation. Its various components include space segment (constellation of satellites), control segment (ground station) and user segment (users, GPS receivers). GPS is an all-weather, real time, continuously available, economic and very precise positioning technique that labels it perfectly suitable for monitoring natural resources.

5.9.1 National (Natural) Resources Information System (NRIS)

The Department of Space launched this programme to support National Natural Resources Management System (NNRMS) in decision making. Its goal is to provide decision-makers with information on natural resources such as land, water, forests, minerals, and soils and socioeconomic data such as demographics, amenities, and infrastructure. NRIS is being implemented nationally by Department of Space in collaboration with several institutions like ISRO, State Remote Sensing Centres and some private entrepreneurs are collaborating for that purpose.

5.9.2 Needs of RS and GIS for Natural Resource Management

Any nation's socio-economic, and cultural sustainability is largely determined by its land and water resources [11]. These natural resources are crucial to a nation's economy because they provide critical jobs, serve as a source of raw materials for numerous businesses, provide food and money, and provide medicine and energy. The aesthetic splendour of natural resources has always been viewed as a cultural expression of a nation.

However, understanding how to utilise these resources in a sustainable manner is critical for nations to ensure that their advantages are enjoyed by current and future generations. This is because if these resources are not used effectively and efficiently, they will be depleted. Because of the world's ever-increasing population, the world's resources are currently being overstretched [31]. As a consequence of this population explosion, forest cover has declined globally due to human encroachment. This has resulted in an increase in human-wildlife conflict and the development of desert-like conditions. Finally, the depletion of natural resources has resulted in an increase in the cost of living, changes in weather patterns, and a decrease in the economic, social, and cultural benefits accrued as a result of their utilisation.

Due to these restraints, it is critical to ensure that all these resources are managed appropriately. To attain this goal, a variety of management strategies in the field of natural resource management have been developed. Some have proven successful, while others have failed to produce the expected results. However, with the current trend in information technology advancement, natural resource management teams are emphasizing the use of remote sensing and GIS technologies in natural resource management. Remote sensing technology has become increasingly popular over the years for use in a variety of natural resource management disciplines. Remote sensing has become the ideal data source for large-scale applications and studies due to the availability of remotely sensed data from multiple sensors on various platforms with a wide variety of spatial, temporal, radiometric, and multispectral resolutions. Remote sensing data is currently used as input data for a variety of environmental process modelling applications [20]. The combined use of GIS, remotely sensed data, and GPS will empower researchers, planner, and natural resource managers of conservation organizations, government agencies, and industry to develop eco-friendly and novel management plans for the variety of natural resources management and its' applications [17, 23]. It has the potential to monitor changes in land cover, forest density, coastal morphology, reef status, and biodiversity on islands, even if they are located in remote locations.

6 Monitoring of Natural Resource Management by RS and GIS

6.1 Monitoring of Agriculture

The proliferative potential of using remote sensing platforms to gather real-time assessments of the agricultural landscape has received more attention. Precision agriculture is a farming method that encourages different management approaches within a field depending on the conditions. This method is based on new tools and information sources made available by modern technology. Seelan et al. [28] listed the remote sensing, geographic information systems (GIS), global positioning system (GPS), yield monitoring devices, soil, plant, and insect sensors, and variable rate technologies for input applicators as examples. Satellite remote sensing has been widely used and regarded as a potent and effective method for identifying land use and land cover change when combined with geographic information systems (GIS). It offers reasonable multi-spectral and multi-temporal data and transforms it into meaningful information for analysing and monitoring agricultural growth pattern. Change detection and database creation require a flexible environment for storing, analysing, and displaying digital data, which GIS technology delivers. Satellite imaging has been used to track distinct land cover categories using spectral classification and to estimate land surface biophysical parameters using linear connections with spectral reflectance or indices.

6.2 Monitoring of Soil

Standard soil examination and interpretation methods are time-consuming and costly, hence kriging and its variants have become generally acknowledged as an important spatial interpolation tool in land resource surveys [12]. Predictive soil mapping techniques have been developed in this frame of reference as geographic information system (GIS) and remote sensing technology have advanced. In situ point assessments of soil quality can be used in a regression analysis with extensive and comprehensive satellite-derived indices, and the correlation can be upscaled to larger spatial areas.

6.3 Monitoring of Crop-Irrigation Demand and Crop Modelling

Agriculture is the world's largest water consumer, consuming more than 70% of all fresh water. As a result, irrigation water plays a crucial role in enhancing land production. Land surface evapotranspiration (ET) is among the key components of the water balance that causes water loss [21], and it is important for environmental applications such as irrigation water use optimization, irrigation system performance, crop water deficit, and so on. In many arid and semi-arid growing regions, inadequate irrigation timing and water application are universal problems hindering agriculture production. In light of these issues, remote sensing technology has evolved as a useful tool for monitoring irrigated areas across a wide range of climatic conditions and locales over the previous few decades. By monitoring plant water status, measuring evapotranspiration rates, and estimating crop coefficients, it aids in determining when and how much to irrigate. Irrigation water policymakers have been very interested in the effective use of surface water and the monitoring of consumptive use of water using remote sensing techniques.

It is possible to combine crop models and remote sensing in order to evaluate yield variables using remote sensed data for each time step in model simulations, allowing us to fill in the missing model parameters during field scale recalibration. Furthermore, obtaining data from crop models at the field scale enables for the transfer of results from the field to the regional scale [24]. Wiegand et al. [33] and Delécolle et al. [8], for example, have proposed a number of methods for combining remote sensing data with crop models. A method is to use remote sensing to estimate LAI (leaf area index) data to calibrate crop models. The other option is to estimate the eventual yield early in the growing season; however, this strategy requires a lot of remote sensing data to employ in crop models. Baret et al. [5] used assimilation methodologies to combine remote sensing data with crop models to provide stress assessment. Crop and soil models combined with GIS can be used to identify methane emissions from fields [16], and GIS and crop models can be used to estimate world food production and the effects of global warming. With remote sensing, there are numerous strategies to reduce crop model uncertainty. One option is to use remote sensing photographs to classify agricultural fields and crop types, and then select crop models to use with this classification based on soil input data. Crop growth indicators that can be linked with crop models can also be estimated via remote sensing.

6.4 Monitoring of Water Resource Management

Water is a resource that is necessary for human survival. The availability of fresh water for human consumption has decreased over time, while the demand from a growing population has increased. In this environment, there is a pressing need to monitor and better understand its use, as this will give data that will aid in the creation of effective water management plans and infrastructure. This is especially important in areas where the amount of available water is restricted. For sustainable water resource management, understanding the complex water system necessitates a holistic approach that integrates concepts and ideas from other disciplines. Field research provides the first steps toward fully understanding the water cycle's many activities. However, political decisions are taken at the regional to national level, thus it is critical to upscale field scale studies to the regional or national level in a reasonable manner. Hydrological models are commonly employed for this, although they frequently face data scarcity or a lack of high-quality input data. Remote sensing technologies would then be a viable tool to combine with models in order to obtain continuous input data in data-scarce areas. Several Earth Observation (EO) based sensors launched from sophisticated satellites give continuous global observations on diverse hydrological components, which are critical input data for hydrological modelling. Satellite capture has filled in data gaps caused by a lack of on-the-ground monitoring of water resources around the world. Satellite products and advanced computational techniques for water management can thus play a key role in water resources' current and future management. The satellite remote sensing for hydrological applications includes, but not limited to rainfall (Global Precipitation Measurements (GPM) and Tropical Rainfall Measuring Mission (TRMM); Soil moisture (Soil

Moisture Active Passive (SMAP) and Soil Moisture Ocean Salinity (SMOS); Actual Evapotranspiration (Surface Energy Balance System); Mapping Evapotranspiration with Internalized Calibration (METRIC) and Surface Energy Balance Algorithm for Land (SEBAL); Groundwater level monitoring by Gravity Recovery and Climate Experiment (GRACE) [18, 30]. Water bodies such as rivers, lakes, dams, and reservoirs can be mapped in 3D using satellite data and GIS. It is possible to generate spatial maps of water availability. The relevant authorities can use the information to identify the sites or regions that require effective protection and management, and decisions can be made regarding the sustainable management of natural resources in the identified regions.

6.5 Monitoring of Water Quality

Water quality must be monitored on a regular basis in order to manage and improve the quality for human consumption. Water quality is currently assessed using in-situ measurements and laboratory analysis of water samples. Although these measurements are accurate for a specific point in time and space, they do not provide the spatial or temporal perspective of water quality required for accurate assessment or management of water bodies [7]. Furthermore, they are time-consuming and expensive, and they cannot meet the needs of regional or national monitoring. Water quality parameters (such as suspended sediments (turbidity), chlorophyll, and temperature) can be monitored using remote sensing techniques. Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information required to monitor changes in water quality parameters in order to develop management practises to improve water quality. Remote sensing was also used to estimate chlorophyll concentrations in temporal and spatial using empirical relationships with radiance or reflectance [27]. To predict the water quality for several years, empirical relationships (algorithms) between the concentration of suspended sediments and radiance or reflectance for a specific date and site were developed [26].

6.6 Monitoring of Forest Management and Wildlife Habitat

Forests are an essential part of our ecosystem; they have an impact on human lives in a variety of ways. However, despite their importance, the world forest has been diminishing at an alarming rate. Forest cover can be renewed through sustainable management because it is a renewable resource. A forest manager can generate information about forest cover, types of forest present within an area of interest, human encroachment extent into forest land/protected areas, encroachment of desert-like conditions, and so on, utilising remote sensing data and GIS tools. This information is essential for the formulation of forest management plans and in the decision-making process to guarantee that appropriate policies are in place to control and govern how forest resources are used. Remote sensing data can also be used to assess the appropriateness and state of sites/forest areas for a certain type of wildlife using multi criteria analysis.

6.7 Monitoring of Natural Disaster

Natural calamities such as flooding, earthquakes, volcanic eruptions, and landslides necessitate large amounts of multi-temporal spatial data. Satellite remote sensing is an effective tool in this context because it provides information over huge areas and at short time intervals that can be used in multiple phases of disaster management, such as prevention, readiness, relief, reconstruction, early warning, and monitoring. GIS techniques and remote sensing are necessary to handle large geographic data sets and have thus gained prominence in disaster management [32].

7 Conclusions

The availability and conservation of natural resources such as land and water determine a country's social, cultural, and economic stability and growth. These resources are important in measuring specific criteria because they play a significant role in creating employment, in the growth of a country, in the provision of food and other critical raw materials, as well as medicine and energy. It is critical for countries to recognise that the management and sustainable development of natural resources is critical for the survival of life on the planet. As the rate of integration of nature and technology increases, Information Technology (IT) is becoming a hotspot for monitoring of natural resources across the globe. IT is being utilised extensively to monitor, investigate, and understand our natural resources, particularly those that are finite. A lot of emphasis is being laid on various geospatial technologies, which the scientists, researchers and policymakers can retrieve, generate, store, analyze, disseminate useful information and can make sound decisions for natural resource management and sustainable development. These essential techniques serve as a foundation for making sound judgments about long-term growth. Combining these essential techniques and data simplifies mapping the spatial and temporal extent of natural resources, which aids in developing scientific and site-specific management plans to ensure the long-term viability of these precious resources.

References

1. Articlelibrary (2021) What are the different types of natural resources produced in India? https://www.yourarticlelibrary.com/economics/what-are-the-different-types-of-natural-resources-produced-in-india/2683

2. Ashraf M, Athar HR, Harris PJ, Kwon TR (2008) Some prospective strategies for improving crop salt tolerance. Adv Agron 97:45–110
3. Bajaj A, Singh S P and Nayak D (2021) Groundwater governance and interplay of policies in India. In: Water management and water governance. Springer, Cham, pp 505–522
4. Bardhan D, Tewari SK (2010) An investigation into land use dynamics in India and land under-utilisation. Indian J Agric Econ 65:658–678
5. Baret F, Houlès V, Guerif M (2007) Quantification of plant stress using remote sensing observations and crop models: the case of nitrogen management. J Exp Bot 58:869–880
6. Burrough PA (1993) Soil variability: a late 20th century view. Soils Fert 56:529–562
7. Das S, Kaur S, Jutla A (2021) Earth observations based assessment of impact of COVID-19 lockdown on surface water quality of Buddha Nala, Punjab. India Water 13:1363
8. Delécolle R, Maas SJ, Guerif M, Baret F (1992) Remote sensing and crop production models: present trends. ISPRS J Photogramm Remote Sens 47:145–161
9. Dhawan V (2017) Water and agriculture in India: background paper for the South Asia expert panel during the global forum for food and agriculture (GFFA) 2017
10. FSI (2019) State of forest report 2019. https://www.fsi.nic.in/forest-report-2019
11. Harahsheh H (2001) Development of environmental GIS database and its application to desertification study in middle east. Doctoral dissertation, Chiba University, Chiba
12. Hengl T, Heuvelink GBM, Stein A (2004) A generic framework for spatial prediction of soil variables based on regression-kriging. Geoderma 120:75–93
13. ICAR (2019) Vision 2050. https://icar-nrri.in/wp-content/uploads/2019/08/ebook_crrivision2050_final_16Jan13.pdf
14. Kala AK, Kumar M (2021) Role of geospatial technologies in natural resource management. Clim Impacts Sustain Natl Resour Manag 19:19–34
15. Kingra PK, Majumder D, Singh SP (2016) Application of remote sensing and GIS in agriculture and natural resource management under changing climatic conditions. Agric Res J 53:295–330
16. Kumar N, Yamaç SS, Velmurugan A (2015) Applications of remote sensing and GIS in natural resource management. J Andam Sci Assoc 20:1–6
17. Kumar S, Patel NR, Sarkar A, Dadhwal VK (2013) Geo-spatial approach of agro-climatic suitability of soybean in rainfed agroecosystem. J Indian Soc Remote Sens 41:609–618
18. Liu Z, Ostrenga D, Teng W, Kempler S (2012) Tropical rainfall measuring mission (TRMM) precipitation data and services for research and applications. Bull Am Meteor Soc 93:1317–1325
19. Malik DP, Dhanda S (2003) Status, trends and demand for forest products in India. Fuel 241:1–81
20. Melesse A, Wang X (2007) Impervious surface area dynamics and storm runoff response. Remote Sens Imperv Surf 19:369–384
21. Michailidis A, Mattas K, Tzouramani I, Karamouzis D (2009) A socioeconomic valuation of an irrigation system project based on real option analysis approach. Water Res Manag 23:1989–1919
22. OECD (2012) OECD environmental outlook to 2050. OECD Publishing. https://doi.org/10.1787/9789264122246-en
23. Philipson P, Lindell T (2003) Can coral reefs be monitored from space? Ambio 32:586–593
24. Priya S, Shibasaki R (2001) National spatial crop yield simulation using GIS-based crop production model. Ecol Model 136:113–129
25. Rao DP (2000) Role of remote sensing and geographic information system in sustainable development. Int Arch Photogram Remote Sens 33:1231–1251
26. Ritchie JC, Cooper CM (1991) An algorithm for using landsat MSS for estimating surface suspended sediments. Water Resour Bull 27:373–379
27. Ritchie JC, Schiebe FR, Cooper CM, Harrington JA Jr (1994) Chlorophyll measurements in the presence of suspended sediment using broad band spectral sensors aboard satellites. J Freshw Ecol 9:197–206
28. Seelan SK, Laguette S, Casady GM, Seielstad GA (2003) Remote sensing applications for precision agriculture: a learning community approach. Remote Sens Environ 88:157–169

29. Sekhri S (2012) Sustaining groundwater: role of policy reforms in promoting conservation in India. India Policy Forum 2012–2013(149):149–187
30. Sun AY (2013) Predicting groundwater level changes using GRACE data. Water Resour Res 49:5900–5912
31. Swe M (2005) Application of GIS and remote sensing in Myanmar. Retrieved on 5th October 2012 from http://www.aprsaf.org/data/aprsaf12_data/day2/eo/5_APRSAF-12MS.pdf
32. Van Westen CJ (2000) Remote sensing for natural disaster management. Int Arch Photogram Remote Sens 33:1609–1617
33. Wiegand CL, Richardson AJ, Jackson RD, Pinter PJ, Aase JK, Smika DE, Lautenschlager LF, McMurtrey JE (1986) Development of agrometeorological crop model inputs from remotely sensed information. IEEE Trans Geosci Remote Sens 1:90–98
34. WWAP (2017) The United Nations world water development report 2017. http://www.indiaenvironmentportal.org.in/files/file/World%20Water%20Development%20Report%202017.pdf
35. Yadav S, Modi P, Dave A, Vijapura A, Patel D and Patel M (2020) Effect of abiotic stress on crops. In: Hasanuzzaman M, Fujita M, Teixeira Filho MCM, Nogueira TAR, Galindo FS (eds) Sustainable crop production. Intech Open, London, UK

Climate Change: Its Impact on Land Degradation and Plant Nutrients Dynamics

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Abstract Climate change is the most dangerous threat that mankind has ever faced. Climate is the pivotal component in any agricultural production system as it affects cultivation directly and indirectly. It has very crucial imprints on bio-geogenic cycles in soil as all three types of soil processes (physical, chemical and biological) are controlled by the prevailing climatic conditions of a particular location. A change in climate throughout the globe are creating several challenges in many ways. Extreme weather events like cyclones, floods, and drought have become more frequent, affecting crop production globally and posing a danger to food security. Agriculturally dependent and highly populated countries like India are extremely vulnerable to climate change. The altered soil environment as influenced by climate change is altering nutrient cycles and causing degradation. According to Desertification and Land Degradation Atlas of India (https://vedas.sac.gov.in/vedas/downloads/atlas/DSM/Desertification_Atlas_2016_SAC_ISRO.pdf. Assessed 23 Sept 2021, 2016), about 29.32% of India's total geographical area (96.4 Mha) is currently undergoing desertification due to climate change. The problem of soil nutritional imbalance and decline in ecosystem services is the most challenging issue. The alteration in the soil environment manipulates soil fertility status and often impacts negatively on the production of various crops. Different nutrients show different and unique responses to climate change. Increased CO_2 conc. in soil often increase the available P content however, the same situation Our discussion in this chapter has focused on land degradation and soil nutrient dynamics as a result of climate change as both of them are equally important from the food and ecological sustainability viewpoint.

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_9

Keywords Climate change · Land degradation · Macronutrients · India · Agriculture · Food · Sustainability · Climate-smart agriculture

1 Climate Change

Once a prediction, climate change has now become a reality for mankind , and its impacts are evident globally. Earth's ecosystems have been greatly reshaped or are in the process of being altered by climate change, one of the world's most pressing concerns today. Climate is typically defined as an area's average weather conditions, or its distribution of those conditions, over a long period [1]. Any change in climate is termed climate change. According to Inter-Governmental Panel on Climate Change (IPCC), a deviation from the mean values of climatic variables is termed as climate change. The climate of our planet is changing since its existence however the rapidity in recent years is the prime concern for human civilization. After the industrial revolution, the atmosphere's chemical composition had changed significantly due to the enhanced emission of greenhouse gases like CO_2, CH_4, N_2O etc., from vehicles, electric appliances, and industries. A study revealed that CO_2 concentration in the atmosphere enhanced from 280 ppm in 1780 to 400 ppm in 2016 [2]. With models predicting a CO_2 concentration of 550 $\mu L\ L^{-1}$ by mid-century and 800 $\mu L\ L^{-1}$ by the end, the CO_2 concentration is set to increase exponentially over the next couple of centuries [3]. The greenhouse effect is a process by which thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases and re-radiated in all directions. Since part of this re-radiation is back towards the surface and the lower atmosphere, it results in an elevation of the average temperature above what it would be in the absence of the gases. Among the various greenhouse gases, the per cent contribution is maximum for CO_2 however, CH_4 and N_2O have much higher global warming potential (21 and 310 times of CO_2, respectively) and thus a very small increase in the amount of those gases impacts heavily. Over the years, rapid deforestation and unscientific agricultural practices worsened the situation. Rapid industrialization and urbanization through deforestation and mechanization of various sectors across the globe are impacting climate in a disastrous way. In order to maintain the natural process of the carbon (C) cycle, forests must act as a sink for CO_2, but an increasing rate of deforestation (mainly for agriculture and industrial development) has put a strain on the natural process. With the enhanced greenhouse effect, the earth's mean temperature got enhanced by 0.74 °C in the last century (IPCC). IPCC also projected a 1.5 °C increase in atmospheric temperature from the pre-industrial era will likely to be observed by 2050. Another major impact of climate change can be observed in the form of irregularity in rainfall distribution. Devasterous drought and floods are becoming common phenomena in recent years, aggravating the degradation of cultivable lands across the globe. As a consequence of anthropogenic activity and climate change, land degradation is influencing the lives of 1.5 billion people. Fifteen billion tons of fertile soil are lost yearly due to these activities [4]. An estimated quarter of land areas across the globe are now classified as degraded, according to the Global Assessment of Land Degradation and Improvement (GLADA). It is expected that over the course of this century there will be nearly two billion people affected by total water scarcity and that close to 65% will suffer from partial water scarcity. The intensity and frequency of tropical cyclones are also rising as a result of climate change. Additionally, some parts of the world (like the Mediterranean) are expected to become drier, but others (like the Northern Hemisphere high latitudes) may become wetter. Globally, the trend towards drying is expected [5].

Agricultural production is very well correlated with climatic variables. The demand for food and drinking water is increasing in exponential trends with the rise in the global population. The increase in atmospheric CO_2 was initially predicted to increase crop production as a result of C fertilization [6]. In the same way, some experiments have shown that crop yields could increase from 379 to 500 ppm by 10–20% for C_3 crops, and 0–10% for C_4 crops, but the products' quality would not improve. This threatens food safety. An increase in rainfall intensity is causing huge losses of nutrients from the fertile lands throughout the world leaving them barren for cultivation. As a result of extreme weather conditions such as droughts, cyclones and cloud bursts, crop failures are on the rise [7]. The inundation of cultivable land is accelerating due to the rise of sea level as an effect of global warming [8]. Winds at high speeds cause crop lodging, especially in cereals when they are in the ripening stage [9]. Drought during the midseason reduces yields of various crops as most of them reach critical stages, especially in rainfed cropping systems [10, 11]. In some cultivable areas, rising temperatures may affect crop productivity in the long run due to increased evapotranspiration and reduced soil moisture and quality [12]. Climate change may facilitate the uncontrolled expansion of some pests. A warmer winter may allow pests to survive, meaning disease incidence may increase [13].

2 Impacts of Climate Change

The impacts of climate change are ubiquitous for all creatures including human beings. Along with the economic losses, it possesses a great threat to food security for all living species across the globe. In this regard, degradation and desertification of cultivable lands are the most challenging issues in almost every nation on this planet. The up rise in sea level is inundating agricultural lands of the coastal areas in various countries. Decrease in rainfall, increase in aridity are making the fertile soil barren in different parts of the globe. On the other hand, devastating climatic calamities are becoming more frequent, incurring hefty losses in the food production systems and other sectors. Studying the impacts of climate change on soil is very important from the point of view of food security. Furthermore, soils serve as media for crops to grow and provide a variety of ecosystem services (ESs). Even though soil has a high buffer capacity, climate change has imprinted impacts on the most valuable yet free natural resource [14–19]. Understanding the impacts is essential for formulating mitigation and adaptation strategies [20]. In this light, we are going to discuss land degradation and soil nutrient dynamics as influenced by climate change in detail in this chapter.

2.1 Climate Change and Land Degradation

In recent years, land degradation has been regarded as one of the world's major problems because it reduces a particular land's ability to produce benefits by using it according to a specific form of land management [21]. However, there is no single definition of land degradation, but rather it refers to how the land resources (soil, water, vegetation, rocks, air, climate, relief) have been impacted negatively by human activity. Approximately 25% of the global land area is affected by land degradation, including changes in soil quality due to erosion, physical and chemical alteration, and reduction in biological productivity [22]. Land degradation and desertification have been estimated to lead to a global loss of ecosystem services between US$ 6.3 and 10.6 trillion a year (IUCN). A degraded soil provides fewer ESs important to humans and beneficial to nature [23]. Enhanced livestock grazing, over-cultivation, deforestation, and urbanization are combinedly deteriorating the cultivable lands (WHO). It is evident from various literature that climate change is acting as a catalyst in the rapid degradation of lands, worldwide. Various land use and management practices and events such as droughts, heavy rainfall, and forest fires may contribute to or exacerbate land degradation. The process is posing an immense threat to global food security [24]. As the global mean surface temperature increases with respect to preindustrial levels, increasing permafrost thawing, environmental degradation (soil erosion, vegetation loss, wildfires), and food security (crop yield and food supply instability) are all affected. Various indicators are being used for accessing and quantifying land degradation as defining land productivity with a single measure is impossible.

2.1.1 Types of Land Degradation

The causes of land degradation can be broadly classified into anthropogenic and natural. Most of the natural causes of land degradation are the results of climatic variability which is also directly impacted by human activities. The causal agents are water, wind, heat, livestock grazing, deforestation, etc. Rainfall and surface runoff water cause soil erosion, resulting in soil loss. Water erosion removes the fertile top layer of soil and makes it barren and is the most predominant form of degradation and occurs in almost all types of agroclimatic regions. Water erosion is of four types namely (a) splash erosion (detachment of soil particles and breaking of aggregates due to the action of raindrops) (b) sheet erosion (removal of the top layer of soil as muddy surface flow) (c) rill erosion (small channel erosion) (d) gully erosion (large channel erosion). Rill and gully formation arise problems to crop production. Water erosion not only degrades land but also cause eutrophication in natural water bodies through nutrient enrichment. Water erosion causes the siltation of water bodies, which increases flood risks, especially in wet months. For all global dynamics scenarios, climate projections indicate that the hydrological cycle will intensify, which may lead to an increased rate of water erosion throughout the globe (+30 to +66%) [25] (see Fig. 1).

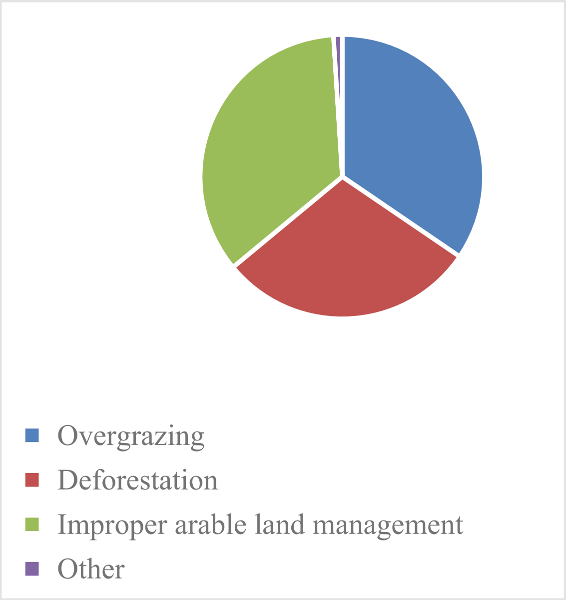

Fig. 1 Contribution of various processes on global soil degradation (*Source* [26])

Wind erosion is a major problem in arid and semi-arid regions and is the prominent land degrading agent in those areas. The stripping away of nutrient-rich top soil through wind erosion declines the fertility of croplands. This type of degradation is more prevalent in drier periods than other times of the year and depends upon the aridity of the climate, soil texture and structure, moisture content of soil and vegetation cover. Reduction in vegetation cover, overgrazing of grasslands, intensive tillage are some factors that accelerate wind erosion. Suspension, saltation, and soil creep are three transporting methods by which wind erosion occurs very specifically and intensively [27]. Agricultural practices also play a crucial role in contributing to the process of wind erosion. A conventional tillage system is 2.5 times more susceptible to wind erosion than a conventional tillage system. Due to the rapid change in climate and a majority of the world experiencing an increase in drought. The wind-driven soil erosion process is estimated to be the cause of land degradation for nearly 28% of the global land area (ESDAC). Approximately 16% of India's total geographical area (TGA) is affected by severe wind erosion, while 32% of the TGA is affected by moderate wind erosion [28].

Another form of land degradation is salinization. Accumulation and encrustation of salts on soil surface occur with increased evaporation and reduced rainfall. This type of land degradation is a common process where mean annual evapotranspiration exceeds mean annual precipitation. Capillary action causes groundwater to rise to the soil surface along with salts, which are then evaporated with time, leaving salts behind [29]. However, in irrigated land, salinity can be caused by excess irrigation and the use of fertilizers and other chemicals [30]. The mean annual temperature (both atmospheric and soil) is increasing as a result of global warming. The higher the temperature, the more rapid evaporation occurs, causing salt to accumulate faster on the soil's surface [17]. Salt-affected soil are not suitable for agricultural practices due to the high osmotic pressure of soil solution [31].

Forest helps in reducing the impact of raindrops on soil through their dense canopy and reduces the soil erosion through their dense root networks [32]. By shedding their leaves, which contain many nutrients, forests play a significant role in maintaining soil fertility [33]. It plays a significant role in nutrient cycling through the soil systems. The root systems draw nutrients from a deeper level and put them on the surface through the shredding of leaves. Besides, forests are great sinks of C and play a very crucial role in buffering atmospheric CO_2. The combined carbon content of vegetation (450–680 Gt C) and soil (1500–2000 Gt C) is much higher than that of the atmosphere (830 Gt C) (IUCN). Thus, the destruction of forests releases an enormous amount of C in the atmosphere, which greatly threatens our existence. In addition to supporting a multi-dimensional ecosystem, forests also promote the socio-economic condition of that region. Rapid deforestation due to forest fire, industrial expansion, jhum cultivation is breaking the harmony. A reduction in soil cover increases the chance of soil erosion through wind, water, or both.

Increased burning of fossil fuel and industrial emissions are increasing the concentration of NO_X and SO_X gases in the atmosphere. These gases react with water vapour under appropriate conditions form mineral acids like sulfuric acid and nitric acid and come down to earth as acid rain. Acid rain destroys vegetation, and makes the soil acidic and barren, deteriorates water bodies and weakens buildings. However, soil acidification is primarily caused due to the injudicious application of acid-forming fertilizers [34]. Secondary causes of soil acidity are due to the acidic parent material, leaching of bases due to high rainfall, decomposition of organic matter and root exudates [35]. Toxicity of Fe and Al and deficiency of major nutrients occur in crops grown on low pH soils [36]. The change in soil pH also impacts the microorganism-driven processes like mineralization, nitrification and nitrogen fixation. All the negative impacts of acidification ultimately lead to the declination of land productivity. The global percentage of acidic soils is nearly 40%, with the proportion still growing [37]. In total, approximately 6.98 M ha of land are affected by acid soils, equating to about 9.4% of India's land area [28].

A land degradation problem, with close to 30% of its geographical area already affected, is one of India's most burning environmental issues [38]. In addition, nearly every state in India has experienced an increase in degraded land in the past 15 years, with the fastest growth occurring in the biodiverse northeast. The total area of degraded land is more than twice its largest state, Rajasthan. Most of the degraded

Table 1 Status of land degradation in India (*Source* Desertification and Land Degradation Atlas of India)

Process of land degradation	Area (mha)	Direction of change	Change from previous estimation (mha)
Water erosion	36.10	Increased	0.49
Vegetation depletion	29.30	Increased	1.02
Wind erosion	18.23	Decreased	0.12
Salinity	3.67	Decreased	0.34
Frost shattering	3.34	Increased	0.23
Rocky/barren	1.89	Increased	0.01
Water logging	0.65	Increased	0.05
Others	3.22	Increased	0.53
Total	96.40	Increased	1.87

lands are mostly farmland or forestland. They provide the best defense against global warming. The problem of land degradation is mostly in the form of water erosion and occurs mostly during the monsoon months. The acreage of various types of land degradation in the country and their trends are enlisted in Table 1.

In addition to directly impacting degradation processes, climate change also plays a secondary role in threatening human civilization. In the face of global climate change, cloud bursts, mudflows, and cyclones have increased in frequency and cost lives as well as impacted social and economic development (Fig. 2). There are various and numerous adjustment and adaptation costs incurred with the impacts of climate change [40]. As discussed earlier, agriculture is the most vulnerable sector to land degradation. The ESs that soil provides are often undervalued and taken for granted and this approach is aggravating the process of land degradation along with climate change.

2.2 Impacts on Plant Nutrients

Plants take up almost all nutrients from soil and soil physical, chemical and biological environment play a pivotal role in their availability. The soil environment is, on the other hand, is impacted by climatic phenomenons. Several scientific investigations found that different forms of climate change are impacting the dynamics of those nutrient cycles. Plant nutrients are broadly classified as Fig. 3. Nitrogen is the prime macronutrient required for the growth and development of macro as well as microorganisms. Nitrogen is an integral part of genetic materials, proteins, enzymes and constitutes 1.5% of the plant body. Plants mostly take up nitrogen in NO_3^- and NH_4^+ form. The anionic uptakable form is susceptible to leaching and denitrification loss [41] whereas, the cationic form is prone to volatilization loss [42]. A majority of N is present in organic form in soil and their availability is dependent

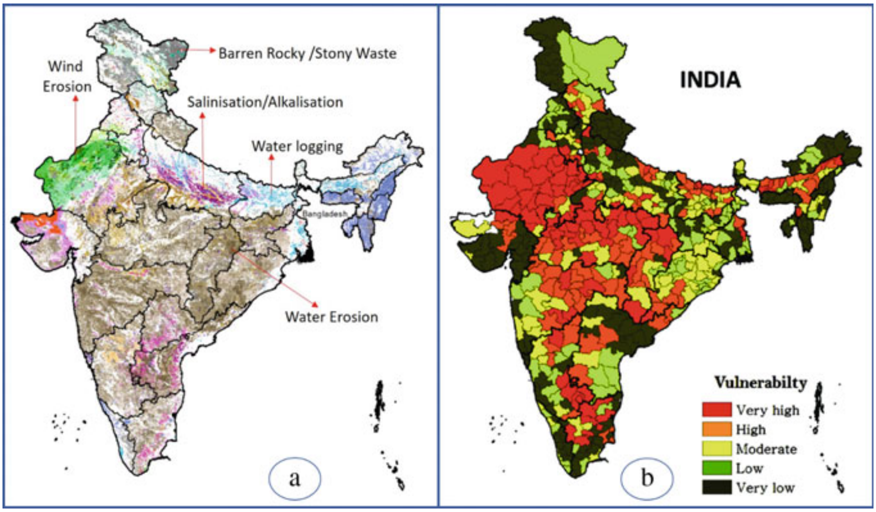

Fig. 2 Impact of climate change on **a** land degradation (adapted from ISRO) and **b** vulnerability of crop production (adapted from [39])

on the mineralization process [43]. Nitrogen is supplied through various fertilizers however, leguminous crops and some specific diazotrophic microorganisms fixes atmospheric N_2 gas with the help of nitrogenase enzyme. The nitrogen cycle very much relies on the interactive impacts of climatic parameters especially temperature, rainfall and CO_2 concentration. The rise in temperature could impact soil N availability by stimulating microbial activity [44]. The rate of the mineralization reactions almost gets doubled with a 10 increase in temperature [45]. However, the impact of elevated temperature on different enzymes of the N cycle varied widely from season to season and in between different ecosystems [46]. Beier et al. [47] observed that the impact is much greater in the cold months than at any other year. A change in pattern and distribution of rainfall also impacts various processes. A high-intensity rainfall often creates an anaerobic situation in the plough layer as the excessive water gets logged on the surface. Denitrification and leaching of nitrates are the major losses under excessive rainfall [48]. On the other hand, scarcity of rainfall reduces the rate of conversion of organic-N into plant uptake able inorganic forms [49]. Carbon augmentation under elevated CO_2 has been reported to stimulate either microbial N immobilization or mineralization due to a priming effect based on the limits of C or N in microbial communities, as well as the C/N ratio of the decomposing substrate [19, 50, 51]. As soil C/N ratio increases due to CO_2 enrichment, decomposing organisms in the soil require more N, making it harder for N to be mineralized [6]. Under fluctuating rainfall conditions accompanied by enhanced soil temperature, the rate of N mineralization was enhanced in temperate climatic conditions. An increase in temperature accompanied by rainfall variability changes soil microbial community structure [52]. Nitrogen uptake and accumulation in the plant body was also significantly altered under higher CO_2 conditions. Some scientists reported that in C_3 plants like wheat and Arabidopsis, an elevated atmospheric CO_2 reduces N assimilation by inhibiting the conversion of NO_3^- to NH_4^+, affecting overall growth [53, 54]. However, Andrews et al. [2] reported a contradictory result of having no impact of elevated CO_2 on NO_3^- assimilation of aforementioned crops. N fertilization inhibits symbiotic N_2 fixation, but elevated CO_2 may partially offset this effect, decreasing the duration of N_2-fixation in such environments [55]. Various studies also revealed the positive impacts of higher soil CO_2 conc. on the enzymatic activity of nitrogenase as well as the whole nodulation process [56–60].

Phosphorus is referred to as the energy currency as it is a formative element of energy-rich compounds like ATPs, NADPs [61]. Besides its role in supplying energy, it is also present in genetic materials like DNAs and RNAs [62]. However, the very reactive element is limited by various soil components due to its fixation and adsorptions [63]. Phosphorus in the soil is present as $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-} however, primary orthophosphate ($H_2PO_4^{-)}$ is the most preferred form by the plants [64]. A major portion of soil phosphorus is present as inorganic form [65]. The availability of phosphorus is very much dependent on the physicochemical properties of the soil. pH is the prime controller of P availability in cultivable soils. Besides pH, the amount of iron, aluminium oxide, and hydroxide in low pH and quantity of $CaCO_3$ regulates its availability directly [66, 67]. Nature and quantity of organic matter present in a particular soil also impact P availability in a particular soil [66]. Thus, an alteration in the soil condition impacts the equilibria of reactions controlling

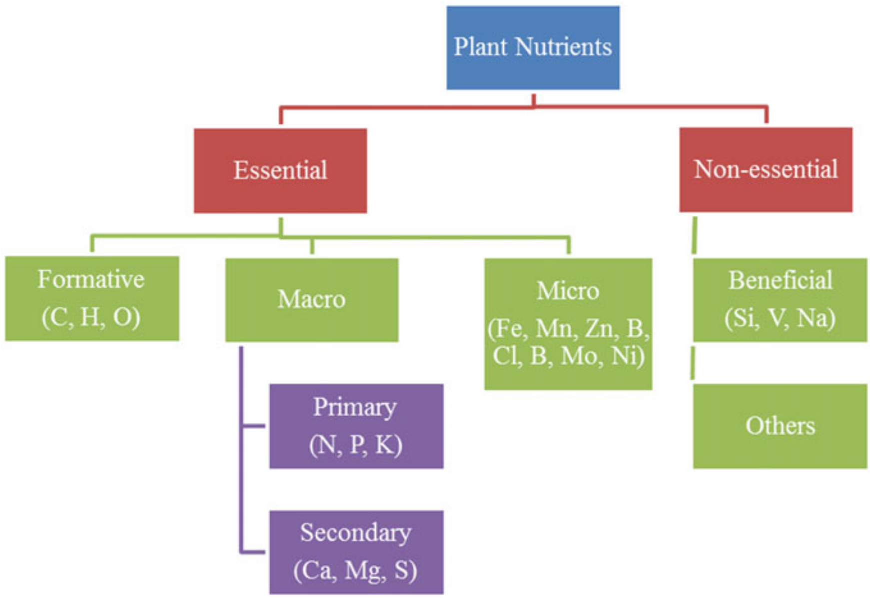

Fig. 3 Classification of plant nutrients

the distribution and accessibility of soil P. An increase in mean annual temperature and precipitation significantly reduces the available P content [68]. An increment in sand fraction accompanied by a reduction in primary P mineral and organic P pool takes place under high rainfall conditions might be the reason behind such results. However, a drop in redox condition due to poor aeration in high rainfall areas helps reducing the sesquioxides and release the bound P from their surfaces [69, 70]. An elevated CO_2 promotes the formation of carbonic acid in soil solution and releases fixed P through dissolution, ligand exchange and other mechanisms [71]. As a result, increased availability of belowground carbon under elevated CO_2 may lead to greater mineralization and availability of P from the soil mineral fraction [72]. Various scientists also reported an enhancement in mycorrhizal activity and secretion of different root enzymes under such conditions [73–76]. The amount and composition of root exudates are also likely to change under elevated CO_2, due to the changes in carbon fluxes along the glycolytic pathway and the tricarboxylic acid cycle [3]. Additionally, these root exudates may be responsible for mobilizing phosphorus from sparingly soluble phosphate complexes, altering the rhizosphere's biochemical environment, and modifying the microbial activity [77]. Due to the impact of climate change, some regions which experience an increase in winter rainfall, will observe increased phosphite concentrations due to chemical reduction of phosphate in saturated soils due to a decrease in redox potential. In light of the strong correlation between highly anaerobic conditions and phosphine gas production, climate change is more likely to increase phosphine production as soils become waterlogged [78]. An increase in the risk related to eutrophication is likely to occur as a result of climate change [79]. Studies revealed that P fertilizer use efficiency and total P uptake of wheat were significantly and positively impacted in increased CO_2 conditions [80]. By changing root morphology and increasing rooting depth, elevated CO_2 alters P acquisition in various crops [3]. A stimulated uptake of P by crop plants as a result of enhanced photosynthesis and growth in elevated CO_2 conditions has also been reported [3].

Researches related to the impact of climate change on the potassium nutrition of crops are very limited. However, the metallic primary macronutrient plays a significant role in the functionality of various phytoenzymes and also regulates various other physiological functions [81–83]. The master cation also imparts biotic and abiotic stress resistance and involves in the regulation of the stomatal opening. With the increase in climatic abnormality, the importance of potassium is growing more than ever [84]. Climate change is increasing the area under aridity across the globe. Potassium affects the water use efficiency of crops. On the other hand, a lack of water availability has been found to negatively affect plants' ability to take up K, thereby reducing the activity of aquaporins. An increase in CEC of soil under elevated CO_2 conditions also enhances cationic secondary macronutrients i.e., calcium and magnesium [72]. A major portion of potentially available S persists in the soil as an organic form. A change in microbial population structure under the influence of climate change is impacting the S cycle across the globe.

In addition to influencing essential nutrients, climate change also impacts beneficial nutrients. Increasing aridification leads to a shift in the species of Se in soils, resulting in more oxidized species which are weakly bound to soils and are more prone to leaching in precipitation events [85]. The drying of soil may increase Se mobility, but at the same time decrease its transportation [86]. Aridification also accelerates the solonization process as the exchange sites prefer the monovalent cations. Therefore, climate change affects almost all essential plant nutrients, which necessitates more intensive and multidimensional research in this area. Until now, most of the research centred around the impacts of changing climate on primary and secondary micronutrients, its impact on micronutrients and soil enzymes is still lacking globally.

3 The Indian Scenario

The impacts of climate change are expected to be harsher on tropical countries than others as most of the tropical nations are developing ones [87]. India is not an exception being a developing nation and country of tropics and subtropics. Since marginal farmers make up the majority of the farming community and rainfed agriculture is the dominant mode of agriculture in the country, the crop production system is highly sensitive to climatic changes. The southwest monsoon which occurs between June to September each year plays the most significant role as most of the countries grain production (except wheat) occurs during that period and any delay or early arrival or withdrawal causes indispensable losses. On the other hand, western disturbances are the main determining whether event that impacts the wheat cultivation of the north-western parts of the country. A change in any climatic factor heavily impacts the crops and the soil they are grown on since the former invariably affect them. Furthermore, climate change has a significant passive impact on agricultural land use patterns in India because of changes in soil organic matter, availability of irrigation water, frequency and intensity of seasonal droughts and floods, erosion, pest populations, inundation of coastal land, and availability of required energy.

Impacts of climate change are evidently visible in various sectors of the country. Several scientists conducted research to measure the impacts and tried to project a future based on observation and analysis. Compared to the last 100 years, Rupa Kumar et al. reported a temperature increase of 0.4–0.6 °C in India in 2002. According to [88], rainfall decreased in most parts of central and northern India during both the southwest and northeast monsoon seasons. On the other hand, peninsular India, particularly the rice-growing regions, tended to increase rainfall [89]. Despite no change in total rainfall received, a region-to-region variation was recorded with an increase of 10–12% in some regions and a decrease of 6–8% in others [90]. Rainfall patterns and the number of rainy days are also getting altered due to the irregularity in climatic behaviour. A rise of 0.4–2 mm in sea level was recorded across the 7517 km long coastline of the country [90]. However, another report by World Bank reveals that the whole country became drier as the average monsoon rainfall was significantly decreased from 1950 and a predicted 2 °C rise will make the summer monsoon completely unpredictable. Additionally, groundwater deficiency and enhanced soil salinity in various parts of the country are recorded.

3.1 Effect on Indian Agriculture

The risk of climate change in a country where 52% of the entire population is directly involved in farming as either farmers or farm labourers is extremely high. About 2/3rd of Indian agriculture is rainfed and even the irrigated one is also dependent on rain to maintain the water level in their water sources. Maximum and minimum temperature, intensity and quantity of precipitation, duration of sunlight hours, wind speed, relative humidity are the key weather parameters that determine the yield of numerous crops grown in different parts of the country throughout the year. Also, the incidence of pests and diseases is highly dependent on the weather. Climate change imparts a long-term change in the weather attributes that is implacably associated with crop production systems. Various researches in India were conducted to study the impact of some projected atmospheric conditions on soil and crop characteristics. Kant et al. [91] reported an atmospheric CO_2 level of 600 μmol mol^{-1} increased all C fractions in a *Typic Haplustept* soil in all fractions of C (maximum increase of 49% in dissolved organic C pool and a minimum increase of 0.83% in carbohydrate C pool). They also reported that microbial activity in soil was significantly increased at the crown root initiation stage of wheat and decreased gradually thereafter. In their study, Saha et al. [92] reported that an increase of 200 μmol mol^{-1} in ambient CO_2 levels resulted in a 3.2-fold increase in soil microbial biomass C and a significant increase in FDA and dehydrogenase activity. Kumar and Swarup [93] found a decline in Available-P content under an elevated CO_2 condition (650 ppm compared to a reference of 385 ppm) at various stages of wheat grown in a *Typic Haplustept* soil. Manna et al. [94] observed an elevated level of CO_2 (580 μmol mol^{-1}) significantly enhanced alkaline phosphatase activity and microbial biomass carbon in the rice-growing inceptisol of IARI, New Delhi. In 2013, Bhattacharyya et al. studied the impacts of elevated CO_2 and temperature on *Aeric Endoaquept* soil using rice as the test crop.

Additionally, studies were conducted from the 1990s to quantify the effects of climate change on yields of various crops. Hundal and Kaur projected the decline in yield of groundnut using PNUTGRO model as early as in 1996. They reported an 8.7, 23.2 and 36.2% reduction in groundnut yield as a result of 1, 2 and 3 °C temperature increase, respectively. A temperature increase of 1 °C caused a 6% drop in rice yield in Kerala, according to Saseendran et al. [95]. Sahoo [96] found that CO_2 concentration is positively and temperature is negatively correlated with maize yield. The benefit of increased ambient CO_2 to 700 ppm is negated by only a 0.6 °C increase in temperature. Lal et al. [97] reported that an increase of 3 °C in atmospheric temperature entirely negates the positive impact of enhanced CO_2. Furthermore, he found that a 10% drop in daily rainfall decreases grain yield by 32%. In a phytotron experiment on wheat grown in an inceptisol of subtropical India, Kumar et al. [80] reported that under elevated temperature and CO_2 conditions, grain and stem yield was significantly decreased despite the increase in leaf and root dry weight. Rao et al. [98] observed that changes in per cent yield of crops are directly proportional to the change in summer monsoon anomaly. A value of Indian summer monsoon rainfall

(ISMR) anomaly value of −20 incurred a −12.44% change in crop production. On the other hand, a positive change of ISMR value of 20 over normal effects a 7% increase in crop yield. Milesi et al. [99] noted a decline in the food grain production during the kharif season from 1.61 mt/year of the period of 1966–67 to 1991 to 0.7 mt/year during 1990–91 to 2005–06. A study on vulnerability analysis by the Indian Council of Agricultural Research (ICAR) reported that 19% and 35% of 573 rural districts of the country are under the category of very high risk and high risk, respectively [100]. National Innovations in Climate Resilient Agriculture, a project initiated by ICAR, predicted due to climate change a 2.5 and 7% reduction in rainfed and irrigated rice yield by 2050 (Ministry of Agriculture and Farmers Welfare, GoI) [101]. A 6–25% and 18–23% reduction in yield of wheat and maize was also projected. However, the authority projected a 25% increase in chickpea in the context of climate change.

4 Adaptation and Mitigation Strategies

Our existence's survival depends upon the endeavour of present and future generations. Combating climate change is a multidimensional approach involving various stakeholders all across the globe. To support the ever-increasing global population, combat against climate change is necessary. From the food security point, mitigation and adaptation strategies can be broadly categorized into two. i.e., (1) practices that minimize the factors fuelling climate change and (2) practices that minimize its hazardous impacts on agriculture Climate change can be managed by employing management practices that reduce the negative impact of a changing environment like increasing or decreasing precipitation and temperatures, or other extreme weather conditions.

Deforestation and our dependency on fossil fuels should be minimized on an immediate basis and to capture the released carbon from the atmosphere, afforestation is a must. Adoption of practises like conservation agriculture (CA) reduces the release of C from soils along with the decline in cost of cultivation. It demands less time and labour, minimum labour and machinery requirements compared to conventional agriculture [102]. Conservation agriculture also reduces sedimentation in downstream due to soil stabilization and erosion protection and promotes soil fertility and functionality. Alongside the long-term yield increase, CA minimizes the year on year yield fluctuations and hence assures food security. The minimum soil disturbance during CA helps sequester C by barring soil organic C oxidation. The proliferation of the native macro and microorganisms enables nutrient cycling and maintains the process of organic matter mineralization. By adopting CA, the two important sustainability goals can be achieved as long as the initial costs of machinery and skills can be managed. Another new concept of climate-resilient cultivation is carbon farming which includes all agricultural practices that focus on capturing CO_2 from the atmosphere into the soil or in various plant parts.

Anthropogenic global warming is largely contributed by agriculture, and reducing agricultural emissions, particularly CH_4 and N_2O, could reduce climate change [103].

The global food production systems contribute about 21–37% of annual emissions [26]. Apart from the aforesaid gases, CO_2 emissions from agricultural and associated activities are counted as indirect pollutants. The use of fossil fuels in the forms of diesel (largely), kerosine and petrol in machinery are the chief contributing sources of the later ones. Therefore, the adoption of climate-smart agriculture is necessary to mitigate climate change. The concept of climate-smart agriculture revolves around three main components of sustainable development: improving the productivity and income of agricultural systems; constructing and adapting resistance to climate change; and decline in emissions of various greenhouse gases. The main concept of climate-smart agriculture is a way to transform and reorient current agricultural methods to meet the new realities of climate change. Therefore, more investments towards climate-smart agriculture enhance the sustainability of human civilization with food security.

Biostimulants can be a magnificent tool in combating anthropogenic climate change and sustaining agricultural productivity. A plant stimulant (PB) is a substance that makes soil nutrients more available to plants by improving plant efficiency, speeding up the degradation of organic material in soil, and increasing soil humification [12, 104]. In addition to improving crop productivity and quality, PBs can increase nutrient availability in soil, improve nutrient access efficiency in plants, and promote soil degradation and humification [12]. Various types of biostimulants benefit crop production in numerous ways. Microbial derived PBs like *Trichoderma koningii* and arbuscular mycorrhizal fungi improve the uptake of P, Mg, Fe, Zn, Mn (from 20.8 to 97.4%) in crops like lettuce under water deficit conditions [105]. Rhizophagus intraradices and Funneliformis mosseae promote the healthy growth of tomato crops by manipulating the expressions of some specific genes under the scarcity of available water in the soil [106]. Seaweed-derived PBs like extracts of *Ascophyllum nodosum* helps tomato and some grassy crops in sustaining drought conditions [107, 108]. The negative impact of soil salinity on crops can also be minimized by applying extractants derived from various PBs.

Restoration of degraded forests and reduction in jhum cultivation helps not only in capturing atmospheric CO_2 but also in maintaining and recreating ecological balance. Bastin et al. [109] estimate that 10 years of global CO_2 emission and 205 billion tonnes of C can be captured by planting 1.2 trillion trees. Tropical forest alone contributes 60% of photosynthesis and reduces a significant amount of C from the atmosphere [110]. The increment of forest cover is directly related to soil conservation as the deep and dense roots helps to bind the soil and protect it against erosion. Trees inside and outside forests play a significant role in providing environmental and social benefits along with their contribution to food security across the globe [111]. In this regard, agroforestry can serve as a powerful tool to balance food production and environmental sustainability. An 11-year-old agri-silviculture system of an arid region has an average C storage capacity of 26 t/ha [112]. Besides, trees help in the nutrient and water cycle to maintain the climatic phenomenon. By afforesting degraded land and taking advantage of atmospheric CO_2 fertilization, adversity can be turned into an opportunity. Another major way to maintain the production sustainability of agricultural sectors is the identification and development of suitable varieties and crops for a particular region. Varieties with efficient water use efficiency, having the ability to withstand biotic and abiotic stress are definitely going to be valuable tools to maintain food availability. Optimization and efficient use of agricultural inputs like fertilizer, amendments, and irrigation are required to be adapted. Integrated nutrient management with minimum environmental footprints should be practiced. Thus, only the intergovernmental agreements are insufficient to achieve targets, a holistic cooperation between environmentalists, the general public, and farming communities should be undertaken.

5 Conclusion

Human existence depends on our ability to cooperate equally with nature, which is our greatest ally in combating climate change. Agriculture is the backbone of human civilization and climate change is making serious imprints on the global production systems. The projected yield decline in various crops by several models is clearly indicating a food crisis to the ever-increasing population worldwide. Understanding the impacts of climate change on land degradation and plant nutrient dynamics are essential to make strategies and policies to mitigate and/or minimize the hazard. In this aspect, various studies were conducted in various corners of the world through simulating the future impacts. However, most of those observations are based on short term data. Long term observations are required to check the validity and conformity of the data generated till now. Wholistic experiments to find out the impacts of climate change on soil processes (physical, chemical and biological) are required for such heterogeneous and highly complex systems. Assessments are also lagging due to the high costs incurred and the unavailability of infrastructures in developing nations like India. Nationally taken steps are not enough to solve a global problem like climate change. Therefore, more robust research and policies must be introduced by international organizations like UNEP, WHO and FAO to secure the food availability for upcoming days.

References

1. Zalta EN (2007) The Stanford encyclopedia of philosophy (Summer 2007 Edition)
2. Andrews M, Condron LM, Kemp PD, Topping JF, Lindsey K, Hodge S, Raven JA (2019) Elevated CO_2 effects on nitrogen assimilation and growth of C3 vascular plants are similar regardless of N-form assimilated. J Exp Bot 70:683–690
3. Jin J, Tang C, Sale P (2015) The impact of elevated carbon dioxide on the phosphorus nutrition of plants: a review. Ann Bot 116:987–999
4. Arora NK (2019) Impact of climate change on agriculture production and its sustainable solutions
5. Cook BI, Smerdon JE, Seager R, Coats S (2014) Global warming and 21st century drying. Clim Dyn 43:2607–2627

6. Brevik EC (2013) The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agriculture 3:398–417
7. Jena PP (2018) Climate change and its worst effect on coastal Odisha: an overview of its impact in Jagatsinghpur district. IOSR-JHSS 23:1–15
8. Snoussi M, Ouchani T, Niazi S (2008) Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: the case of the Mediterranean eastern zone. Estuar Coast Shelf Sci 77:206–213
9. Niu L, Feng S, Ru Z, Li G, Zhang Z, Wang Z (2012) Rapid determination of single-stalk and population lodging resistance strengths and an assessment of the stem lodging wind speeds for winter wheat. Field Crops Res 139:1–8
10. Debaeke P, Aboudrare A (2004) Adaptation of crop management to water-limited environments. Eur J Agron 21:433–446
11. Lal B, Gautam P, Panda BB, Raja R, Singh T, Tripathi R, Shahid M, Nayak AK (2017) Crop and varietal diversification of rainfed rice based cropping systems for higher productivity and profitability in Eastern India. PLoS ONE 12:e0175709
12. Del Buono D (2021) Can biostimulants be used to mitigate the effect of anthropogenic climate change on agriculture? It is time to respond. Sci Total Environ 751:141763
13. Prasad BVG, Chakravorty S (2015) Effects of climate change on vegetable cultivation-a review. Nat Environ Pollut Technol 14
14. Nearing MA, Pruski FF, O'neal MR (2004) Expected climate change impacts on soil erosion rates: a review. J Soil Water Conserv 59:43–50
15. Grillakis MG (2019) Increase in severe and extreme soil moisture droughts for Europe under climate change. Sci Total Environ 660:1245–1255
16. Jansson JK, Hofmockel KS (2020) Soil microbiomes and climate change. Nat Rev Microbiol 18:35–46
17. Corwin DL (2021) Climate change impacts on soil salinity in agricultural areas. Eur J Soil Sci 72:842–862
18. Ramesh M, Rajeshkumar L (2021) Technological advances in analyzing of soil chemistry. In: Inamuddin, Ahamed MI, Boddula R, Altalhi T (eds) Applied soil chemistry, Wiley, pp 61–78
19. Zak DR, Pregitzer KS, King JS, Holmes WE (2000) Elevated atmospheric CO_2, fine roots and the response of soil microorganisms: a review and hypothesis. New Phytol 147:201–222
20. Wang XJ, Zhang JY, Shahid S, Guan EH, Wu YX, Gao J, He RM (2016) Adaptation to climate change impacts on water demand. Mitig Adapt Strateg Glob Chang 21:81–99
21. Kumar R, Das AJ (2014) Climate change and its impact on land degradation: imperative need to focus. J Climatol Weather Forecast
22. Webb NP, Marshall NA, Stringer LC, Reed MS, Chappell A, Herrick JE (2017) Land degradation and climate change: building climate resilience in agriculture. Front Ecol Environ 15:450–459
23. Lal R (2012) Climate change and soil degradation mitigation by sustainable management of soils and other natural resources. Agric Res 1:199–212
24. Diamond J (2005) Collapse: how societies choose to fail or succeed. Viking, New York
25. Borrelli P, Robinson DA, Panagos P, Lugato E, Yang JE, Alewell C, Wuepper D, Montanarella L, Ballabio C (2020) Land use and climate change impacts on global soil erosion by water (2015–2070). PNAS 117:21994–22001
26. Mbow C, Rosenzweig C, Barioni LG, Benton TG, Herrero M, Krishnapillai M, Liwenga E, Pradhan P, Rivera-Ferre MG, Sapkota T, Tubiello FN (2019) Food security. In: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change (IPCC), Geneva https://www.ipcc.ch/site/assets/uploads/2019/11/08_Chapter-5.pdf
27. SAC I (2016) Desertification and land degradation atlas of India (Based on IRS AWiFS data of 2011–13 and 2003–05). Ahmedabad: Space Applications Centre, ISRO, Ahmedabad, India, 219

28. Maji AK, Reddy GO, Sarkar D (2010) Degraded and Wastelands of India: status and spatial distribution
29. Mohamed NN (2016) Management of salt-affected soils in the Nile Delta. In: Negm AM (ed) The Nile Delta. Springer, Cham, pp 265–295
30. Bilgili AV, Yeşilnacar İ, Akihiko K, Nagano T, Aydemir A, Hızlı HS, Bilgili A (2018) Post-irrigation degradation of land and environmental resources in the Harran plain, Southeastern Turkey. Environ Monit Assess 190:1–14
31. Rengasamy P (2020) Salt-affected soils: sustainable agriculture. In: Fath BD, Jørgensen SE, Cole M (eds) Managing soils and terrestrial systems. CRC Press, Boca Raton, pp 83–92
32. Yan Y, Zhen H, Zhai X, Li J, Hu W, Ding C, Qi Z, Qiao B, Li H, Liu X, Zhang X (2021) The role of vegetation on earth bunds in mitigating soil erosion in Mollisols region of Northeast China. CATENA 196:104927
33. Ge X, Zeng L, Xiao W, Huang Z, Geng X, Tan B (2013) Effect of litter substrate quality and soil nutrients on forest litter decomposition: a review. Acta Ecol Sin 33:102–108
34. Weldeslassie T, Naz H, Singh B, Oves M (2018) Chemical contaminants for soil, air and aquatic ecosystem. In: Oves M, Khan MZ, Ismail IMI (eds) Modern age environmental problems and their remediation. Springer, Cham, pp 1–22
35. Yirga C, Erkossa T, Agegnehu G (2019) Soil acidity management
36. Rahman M, Lee SH, Ji HC, Kabir AH, Jones CS, Lee KW (2018) Importance of mineral nutrition for mitigating aluminum toxicity in plants on acidic soils: current status and opportunities. Int J Mol Sci 19:3073
37. Bian M, Zhou M, Sun D, Li C (2013) Molecular approaches unravel the mechanism of acid soil tolerance in plants. Crop J 1:91–104
38. Desertification and Land Degradation Atlas of India (2016) https://vedas.sac.gov.in/vedas/downloads/atlas/DSM/Desertification_Atlas_2016_SAC_ISRO.pdf. Assessed 23 Sept 2021
39. Sehgal VK, Singh MR, Jain N, Pathak H (2017) Climate change and variability: mapping vulnerability of agriculture using geospatial technologies. In: Belavadi VV, Nataraja Karaba N, Gangadharappa NR (eds) Agriculture under climate change: threats, strategies and policies. Allied Publishers Pvt Ltd., New Delhi, India, pp 74–79
40. Diaz D, Moore F (2017) Quantifying the economic risks of climate change. Nat Clim Chang 7:774–782
41. Nielsen RL (2006) N loss mechanisms and nitrogen use efficiency. Purdue nitrogen management workshops. Purdue University West Lafayette, Indiana, US, pp 1–5
42. Rochette P, Angers DA, Chantigny MH, MacDonald JD, Bissonnette N, Bertrand N (2009) Ammonia volatilization following surface application of urea to tilled and no-till soils: a laboratory comparison. Soil Tillage Res 103:310–315
43. Mengel K (1996) Turnover of organic nitrogen in soils and its availability to crops. Plant Soil 181:83–93
44. Pendall E, Bridgham S, Hanson PJ, Hungate B, Kicklighter DW, Johnson DW, Law BE, Luo Y, Megonigal JP, Olsrud M, Ryan MG (2004) Below-ground process responses to elevated CO_2 and temperature: a discussion of observations, measurement methods, and models. New Phytol 162:311–322
45. Jackson LE, Calderon FJ, Steenwerth KL, Scow KM, Rolston DE (2003) Responses of soil microbial processes and community structure to tillage events and implications for soil quality. Geoderma 114:305–317
46. Gu C, Riley WJ (2010) Combined effects of short term rainfall patterns and soil texture on soil nitrogen cycling—a modeling analysis. J Contam Hydrol 112:141–154
47. Beier C, Emmett BA, Peñuelas J, Schmidt IK, Tietema A, Estiarte M, Gundersen P, Llorens L, Riis-Nielsen T, Sowerby A, Gorissen A (2008) Carbon and nitrogen cycles in European ecosystems respond differently to global warming. Sci Total Environ 407:692–697
48. Broadbent FE, Clark F (1965) Denitrification. Soil Nitrogen 10:344–359
49. Deenik J (2006) Nitrogen mineralization potential in important agricultural soils of Hawai'i.
50. Hodge A, Robinson D, Fitter A (2000) Are microorganisms more effective than plants at competing for nitrogen? Trends Plant Sci 5:304–308

51. Blagodatskaya E, Kuzyakov Y (2008) Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: critical review. Biol Fertil Soils 45:115–131
52. Ma LN, Lü XT, Liu Y, Guo JX, Zhang NY, Yang JQ, Wang RZ (2011) The effects of warming and nitrogen addition on soil nitrogen cycling in a temperate grassland, northeastern China. PLoS ONE 6:e27645
53. Bloom AJ (2015) Photorespiration and nitrate assimilation: a major intersection between plant carbon and nitrogen. Photosynth Res 123:117–128
54. Rubio-Asensio JS, Bloom AJ (2017) Inorganic nitrogen form: a major player in wheat and Arabidopsis responses to elevated CO_2. J Exp Bot 68:2611–2625
55. Thomas RB, Van Bloem SJ, Schlesinger WH (2006) Climate change and symbiotic nitrogen fixation in agroecosystems. Agroecosystems in a changing climate. CRC Press, Boca Raton, Florida, pp 85–116
56. Sa TM, Israel DW (1991) Energy status and functioning of phosphorus-deficient soybean nodules. Plant Physiol 97:928–935
57. Temperton VM, Grayston SJ, Jackson G, Barton CVM, Millard P, Jarvis PG (2003) Effects of elevated carbon dioxide concentration on growth and nitrogen fixation in *Alnus glutinosa* in a long-term field experiment. Tree Physiol 23:1051–1059
58. Thomas RB, Bashkin MA, Richter DD (2000) Nitrogen inhibition of nodulation and N_2 fixation of a tropical N_2-fixing tree (*Gliricidia sepium*) grown in elevated atmospheric CO_2. New Phytol 145:233–243
59. Lee TD, Reich PB, Tjoelker MG (2003) Legume presence increases photosynthesis and N concentrations of co-occurring non-fixers but does not modulate their responsiveness to carbon dioxide enrichment. Oecologia 137:22–31
60. De Luis I, Irigoyen JJ, Sánchez-Díaz M (1999) Elevated CO_2 enhances plant growth in droughted N_2-fixing alfalfa without improving water status. Physiol Plant 107:84–89
61. Martin WF (2020) Older than genes: the acetyl CoA pathway and origins. Front Microbiol 11:817
62. Elser JJ (2012) Phosphorus: a limiting nutrient for humanity? Curr Opin Biotechnol 23:833–838
63. Hemwall JB (1957) The fixation of phosphorus by soils. In: Norman AG (ed) Advances in agronomy. Academic Press, pp 95–112
64. Young RD, Westfall DG, Colliver GW (1985) Production, marketing, and use of phosphorus fertilizers. Fertilizer technology and use 323–376.
65. Dalai RC (1977) Soil organic phosphorus. Adv Agron 29:83–117
66. Fink JR, Inda AV, Tiecher T, Barrón V (2016) Iron oxides and organic matter on soil phosphorus availability. Cienc Agrotecnol 40:369–379
67. Afif E, Matar A, Torrent J (1993) Availability of phosphate applied to calcareous soils of West Asia and North Africa. Soil Sci Soc Am J 57:756–760
68. Hou E, Chen C, Luo Y, Zhou G, Kuang Y, Zhang Y, Heenan M, Lu X, Wen D (2018) Effects of climate on soil phosphorus cycle and availability in natural terrestrial ecosystems. Glob Chang Biol 24:3344–3356
69. Shaheen SM, Wang J, Baumann K, Ahmed AA, Hsu LC, Liu YT, Wang SL, Kühn O, Leinweber P, Rinklebe J (2021) Stepwise redox changes alter the speciation and mobilization of phosphorus in hydromorphic soils. Chemosphere 132652
70. Patrick Jr WH, Mahapatra IC (1968) Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. In: Advances in agronomy. Academic Press, pp 323–359
71. Van Cappellen P, Charlet L, Stumm W, Wersin P (1993) A surface complexation model of the carbonate mineral-aqueous solution interface. Geochim Cosmochim Acta 57:3505–3518
72. Chatterjee D, Saha S (2018) Response of soil properties and soil microbial communities to the projected climate change. In: Bal SK, Mukherjee J, Choudhury BU, Dhawan AK (eds) Advances in Crop Environment Interaction. Springer, Singapore, pp 87–136
73. Read DJ, Leake JR, Perez-Moreno J (2004) Mycorrhizal fungi as drivers of ecosystem processes in heathland and boreal forest biomes. Can J Bot 82:1243–1263

74. Lagomarsino A, Moscatelli MC, Hoosbeek MR, De Angelis P, Grego S (2008) Assessment of soil nitrogen and phosphorous availability under elevated CO_2 and N-fertilization in a short rotation poplar plantation. Plant soil 308:131–147
75. Chatterjee D, Datta SC, Manjaiah KM (2014) Fractions, uptake and fixation capacity of phosphorus and potassium in three contrasting soil orders. J Soil Sci Plant Nutr 14:640–656
76. Chatterjee D, Datta SC, Manjaiah KM (2015) Effect of citric acid treatment on release of phosphorus, aluminium and iron from three dissimilar soils of India. Arch Agron Soil Sci 61:105–117
77. Shen J, Yuan L, Zhang J, Li H, Bai Z, Chen X, Zhang W, Zhang F (2011) Phosphorus dynamics: from soil to plant. Plant Physiol 156:997–1005
78. Geng J, Jin X, Wang Q, Niu X, Wang X, Edwards M, Glindemann D (2005) Matrix bound phosphine formation and depletion in eutrophic lake sediment fermentation—simulation of different environmental factors. Anaerobe 11:273–279
79. Schoumans OF, Bouraoui F, Kabbe C, Oenema O, van Dijk KC (2015) Phosphorus management in Europe in a changing world. Ambio 44:180–192
80. Kumar M, Swarup A, Patra AK, Chandrakala JU, Manjaiah KM (2012) Effect of elevated CO_2 and temperature on phosphorus efficiency of wheat grown in an Inceptisol of subtropical India. Plant Soil Environ 58:230–235
81. Wang M, Zheng Q, Shen Q, Guo S (2013) The critical role of potassium in plant stress response. Int J Mol Sci 14:7370–7390
82. Wu H, Zhang X, Giraldo JP, Shabala S (2018) It is not all about sodium: revealing tissue specificity and signalling roles of potassium in plant responses to salt stress. Plant Soil 431:1–17
83. Gao X, Zhang S, Zhao X, Wu Q (2018) Potassium-induced plant resistance against soybean cyst nematode via root exudation of phenolic acids and plant pathogen-related genes. PLoS ONE 13:e0200903
84. Sardans J, Peñuelas J (2015) Potassium: a neglected nutrient in global change. Glob Ecol 24:261–275
85. Feinberg A, Stenke A, Peter T, Hinckley ELS, Driscoll CT, Winkel LH (2021) Reductions in the deposition of sulfur and selenium to agricultural soils pose risk of future nutrient deficiencies. Commun Earth Environ 2:1–8
86. Jones GD, Droz B, Greve P, Gottschalk P, Poffet D, McGrath SP, Seneviratne SI, Smith P, Winkel LH (2017) Selenium deficiency risk predicted to increase under future climate change. PNAS 114:2848–2853
87. Trenberth KE (2018) Climate change caused by human activities is happening and it already has major consequences. J Energy Nat Resour Law 36:463–481
88. Annamalai H, Hamilton K, Sperber KR (2007) The South Asian summer monsoon and its relationship with ENSO in the IPCC AR4 simulations. J Clim 20:1071–1092
89. Gupta A, Pathak H (2016) Climate change and agriculture in India.
90. Jayaraman T (2011) Climate change and agriculture: a review article with special reference to India. Rev Agrar Stud 1
91. Kant PC, Bhadraray S, Purakayastha TJ, Jain V, Pal M, Datta SC (2007) Active carbon-pools in rhizosphere of wheat (*Triticum aestivum* L.) grown under elevated atmospheric carbon dioxide concentration in a Typic Haplustept in sub-tropical India. Environ Pollut 147:273–281
92. Saha S, Chakraborty D, Pal M, Nagarajan S (2011) Impact of elevated CO_2 on utilization of soil moisture and associated soil biophysical parameters in pigeon pea (*Cajanus cajan* L.). Agric Ecosyst Environ 142:213–221
93. Kumar M, Swarup A (2012) Impact of elevated atmospheric CO_2 and temperature on plant-available phosphorus (A value) in soil-assessment using 32P tracer technique. J Indian Soc Soil Sci 60:312–316
94. Manna S, Singh N, Singh VP (2013) Effect of elevated CO_2 on degradation of azoxystrobin and soil microbial activity in rice soil. Environ Monit Assess 185:2951–2960
95. Saseendran SA, Singh KK, Rathore LS, Singh SV, Sinha SK (2000) Effects of climate change on rice production in the tropical humid climate of Kerala, India. Clim Change 44:495–514

96. Sahoo SK (1999) Simulating growth and yield of maize in different agro-climatic regions. M.Sc. thesis (unpublished), Indian Agricultural Research Institute, New Delhi; as cited in Mall, Singh, Gupta, Srinivasan and Rathore (2006)
97. Lal M, Singh KK, Srinivasan G, Rathore LS, Naidu D, Tripathi CN (1999) Growth and yield responses of soybean in Madhya Pradesh, India to climate variability and change. Agric For Meteorol 93:53–70
98. Rao GGSN (2008) Impacts of long-term climate change on Indian agriculture. Presentation at ICRISAT workshop, 7–9 May. http://www.icrisat.org/what-we-do/impi/inception-workshop/16-long-term-changes-crida.pdf. Assessed 2 Oct 2021
99. Milesi C, Samanta A, Hashimoto H, Kumar KK, Ganguly S, Thenkabail PS, Srivastava AN, Nemani RR, Myneni RB (2010) Decadal variations in NDVI and food production in India. Remote Sens 2:758–776
100. Rama Rao CA, Raju BMK, Adlul Islam SR, AVM R, KV RC (2019) Risk and vulnerability assessment of Indian agriculture to climate change
101. Ministry of Agriculture & Farmers Welfare (Government of India) (2021) Effect of climate change on agriculture. https://pib.gov.in/PressReleasePage.aspx?PRID=1696468. Assessed 1 Nov 2021
102. Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32:25–48
103. Lynch J, Cain M, Frame D, Pierrehumbert R (2021) Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO_2-emitting sectors. Front Sustain Food Syst 4:518039
104. Caradonia F, Battaglia V, Righi L, Pascali G, La Torre A (2019) Plant biostimulant regulatory framework: prospects in Europe and current situation at international level. J Plant Growth Regul 38:438–448
105. Saia S, Colla G, Raimondi G, Di Stasio E, Cardarelli M, Bonini P, Vitaglione P, De Pascale S, Rouphael Y (2019) An endophytic fungi-based biostimulant modulated lettuce yield, physiological and functional quality responses to both moderate and severe water limitation. Sci Hortic 256:108595
106. Chitarra W, Pagliarani C, Maserti B, Lumini E, Siciliano I, Cascone P, Schubert A, Gambino G, Balestrini R, Guerrieri E (2016) Insights on the impact of arbuscular mycorrhizal symbiosis on tomato tolerance to water stress. Plant Physiol
107. Elansary HO, Mahmoud EA, El-Ansary DO, Mattar MA (2019) Effects of water stress and modern biostimulants on growth and quality characteristics of mint. Agronomy 10:6
108. Martynenko A, Shotton K, Astatkie T, Petrash G, Fowler C, Neily W, Critchley AT (2016) Thermal imaging of soybean response to drought stress: the effect of Ascophyllum nodosum seaweed extract. Springerplus 5:1393
109. Bastin JF, Finegold Y, Garcia C, Mollicon D, Rezende M, Routh D, Zohner CM, Crowther TW (2019) The global tree restoration potential. Science 365:76–79
110. Mitchard ET (2018) The tropical forest carbon cycle and climate change. Nature 559:527–534
111. Mbow C, Van Noordwijk M, Luedeling E, Neufeldt H, Minang PA, Kowero G (2014) Agroforestry solutions to address food security and climate change challenges in Africa. Curr Opin Environ Sustain 6:61–67
112. Toppo P, Raj A (2018) Role of agroforestry in climate change mitigation. J pharmacogn phytochem 7:241–243
113. World Health Organization (WHO) (2021) https://www.who.int/news-room/q-a-detail/climate-change-land-degradation-and-desertification#:~:text=Land%20degradation%20is%20caused%20by,of%20soils%20and%20land%20utility.&text=Desertification%20is%20a%20form%20of,which%20fertile%20land%20becomes%20desert. Assessed 20 Sept 2021
114. International Union for Conservation of Nature (IUCN) (2021) https://www.iucn.org/resources/issues-briefs/land-degradation-and-climate-change. Assessed on 26 Aug 2021
115. European Soil Data Centre (ESDAC) (2021) https://esdac.jrc.ec.europa.eu/themes/wind-erosion. Assessed 30 Sept 2021

116. Rupa Kumar K, Krishna Kumar K, Ashrit RG, Patwardhan SK, Pant GB (2002) Climate change in India: observations and model projections. Climate change and India: issues, concerns and opportunities. Tata McGraw-Hill Publishing Company Limited, New Delhi
117. World Bank (2013) India: climate change impacts India: climate change impacts (https://worldbank.org). Assessed 1 Nov 2021
118. Bhattacharyya P, Roy KS, Neogi S, Dash PK, Nayak AK, Mohanty S, Baig MJ, Sarkar RK, Rao KS (2013) Impact of elevated CO_2 and temperature on soil C and N dynamics in relation to CH_4 and N_2O emissions from tropical flooded rice (*Oryza sativa* L.). Sci Total Environ 461:601–611
119. Indian Space Research Organization (ISRO) (2021) https://www.isro.gov.in/earth-observation/land-degradation. Assessed 1 Nov 2021

Climate Change and Its Impact on Soil Carbon Storage: An Indian Perspective

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Abstract The augmented anthropogenic activities have markedly contributed to climate change over the last few decades, becoming an alarming concern. In India, 0.62 °C increase in average annual temperature has been observed over the past 100 years. Though the increment in mean annual temperature has been noted slower than the global average (0.80 °C/100 years), the impacts are significantly being felt both directly and indirectly. Soil degradation in India has been noticed as one of the notable detrimental outcome of climate change. It indicates decline in capacity of soil to support and to provide services to the ecosystem while desertification is actually a sub-set of soil degradation that implies abatement in quality and functions of soil, especially in arid climate. A significant area of 96.4 m ha, around 30% of total geographical area of India (328.72 m ha), is currently considered an area with degraded soils. Twenty-six (26) out of 30 states of the country exhibited rise in degraded lands (in 2011–13) as compared to the previous decade (2003–05)

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_10

representing a total rise of 0.57% (which is 1.87 m ha in area) across the country. Therefore, the aim of this chapter is to convey sound understandings of land quality and soil C status of India for better implementation of mitigation strategies to combat the adverse impact of climate change.

Keywords Climate change · Soil degradation · Soil carbon content · Management practices · Monitoring and mitigation strategies

1 Introduction

Change in the state of climate over time both due to natural variability and anthropogenic activities could be referred to as climate change [74]. Rise in concentration of heat-trapping gases like carbon di-oxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) causes greenhouse effect which ultimately leads to climate change through abrupt alteration in surface temperature, precipitation, sea level etc. Highest contribution to global greenhouse gases (GHGs) emissions was noted in case of electricity and heat production through fossil fuel burning (25%) followed by emissions from by agriculture, forestry and other land-uses (24%), industries (21%), transport (14%), buildings (6%) and from other energy sectors (10%) [76]. Therefore, extenuation of emissions of such gases is badly needed to reduce the detrimental effect of global warming as well as climate change. Soil plays a pivotal role in global carbon cycle and also is related with climate through nitrogen (N) and hydrologic cycle [98]. Globally, soil acts as a large sink of C [109, 143, 151], that stores about 1408 Pg of organic C [10] considering a depth of up to 1 m which is about 3 times greater C than the atmospheric pool of C [76, 151]. So, any alteration in climate could significantly influence those cycles, especially the C cycle. According to [91] SOC stocks with long turnover times are significantly sensitive to temperature and mineralize rapidly with a rise in temperature, which might be the reason behind lower SOC stocks in warmer climates compared to colder climates [100]. Rainfall is another determinant for SOC build-up and abrupt alterations in precipitation patterns due to climate change is becoming a serious concern nowadays [68, 142]. However, through judicious agricultural management practices, loss of soil C and GHG emissions of GHGs could be prevented as agriculture, forestry and other land-uses store about 11.2 Gt CO_2 yr^{-1} which is almost 29% of total antrhopogenic CO_2 emissions [77]. Therefore, it is necessary to have a comprehensive idea regarding relationship between climate and soil C. Estimation of present status of soil C stock and future prediction by using simulation models is also needed to devise rational action plans to mitigate climate change and achieve sustainability through sequestering C in soil for a longer period of time.

2 Climate Change: The Indian Scenario

Various researches on rise in surface temperature as a result of climate change have been performed across India in last two decades [80, 92, 133, 146], but very few considered significant trend in rainfall on a national basis [80, 93, 95, 162]. According to the report of the [175], in the time period of 1901–2007 an increase of 0.56 °C in average annual temperature has been noted in India which is expected to rise by 1.7–2 °C and 3.5–4.3 °C by the end of 2030s and 2100 respectively. According to the data published by [57], 0.62 °C increase in average annual temperature has been recorded over the past 100 years. Though the increment in mean annual temperature has been noted slower than the global average (0.80 °C/100 years), the impacts are significantly being felt both directly and indirectly. [94] also predicted India will experience a temperature change of 2.33–4.78 °C with a doubling of CO_2 concentrations by the end of twenty-first century. As an obvious result of rise in temperature, the country would suffer more frequent heatwaves. It has already been noticed that, between 1985 and 2009, southern and western part of India experiences 50% more heatwaves compared to the previous 25 years [117]. As warm air is capable of holding more moisture than cool air, rise in air and oceanic temperature would ultimately result in frequent and heavy rainfall. In addition, rapid melting of glaciers would facilitate extreme floods [154]. Roxy et al. [147] observed about three times more severe rainfall between 1950 and 2015. Along with such detrimental events, combined effect of ocean expansion and melting ice sheets leads to rise in sea level which would submerge a large area under coastal zone and mangrove forests that acts as an effective sink of atmospheric C [167]. In the time period of 1993–2012, an average annual rise of 5 mm has been observed in Bay of Bengal [167]. A significant area of 96.4 m ha, around 30% of total geographical area of India (328.72 m ha), is currently considered an area with degraded soils [148]. Twenty-six (26) out of 30 states of the country exhibited rise in degraded lands (in 2011–13) as compared to the previous decade (2003–05) representing a total rise of 0.57% (which is 1.87 m ha in area) across the country. Through locally suitable judicious management practices, reclamation of such degraded lands could also be possible through improving soil C stocks. Therefore, climate change can affect the Indian agriculture either directly by hampering production due to disrupted rainfall, higher temperature and rise in CO_2 concentration or by affecting soil processes especially altering the mineralization rate of soil C. Therefore, proper understanding of soil-climate interrelationship is a prerequisite to monitor the dynamics of soil C as well as to take necessary actions to maintain a balance to achieve sustainability.

3 Impact of Climate Change on Soil Carbon

Gradual increase in temperature imparts a harmful impact on SOC stocks as it hastens the mineralization rate of stored C [114]. Several researchers noted that temperature increase causes reduction in SOC stocks in soils due to enhanced decomposition rate and emission of CO_2 [2, 98, 101, 131]. Abatement of both the C:N ratio and SOM contents have been observed in regions under warmer temperature over the cooler regions [73, 134]. According to [27] rise in temperature as result of global warming might cause emission of CO2 to the atmosphere through SOC mineralization which ultimately hastens the process of global warming which in turn degrade the SOC stocks. The rise in CO2 due to global warming and climate change enhances photosynthetic rates and plants' water-use efficiency, which in turn raises organic matter deposition in soil [21]. Hence, soil OM acts as both driver and product of climate change. Changes in soil temperature due to climate change imparts significant effect on soil moisture regime. Notable reduction in SOC stock as result of decrease in soil moisture regime due to droughts has been greatly observed [101]. However, drought induced reduction in SOC stock also decline CO_2 flux and reduces the cycling of labile pools of soil C [48]. Peatlands cover only around 350 M ha area of the globe but store about 450 Pg of C [101]. Considering the depth up to 3 m Peatlands and permafrost (stores around 1024 Pg C) in a combined way contribute around 38.9% (1474 Pg) of the global SOC stock [101]. Therefore, rise in temperature due to global warming and climate change may cause drastic changes in global soil C stock due to thermal mineralization soil C [86, 90]. Climate change also responsible for augmented chances of both water- and wind-driven erosions which facilitate movement and loss of a large proportion of soil C [40, 127, 178]. Based on such situations proper agronomic management practices could significantly influence the erosional hazards [125, 132]. Therefore, sound understanding of influence of climate change on soil C stocks, monitoring the soil C dynamics and based on that recommendation of proper management practices are of great concern.

4 Status of Soil Carbon Stocks of India and Impact of Climate Change

4.1 Status of Carbon Stocks in Indian Soil

Since 1990s a range of techniques such as soil survey and inventory, process-based modelling, digital soil mapping etc. These have been used in India to estimate the SOC status up to 100 cm depth [8, 17, 25, 63, 159] and a range of 21 to 27 Pg of SOC stock has been obtained in Indian soils (Table 1). In India, [83] performed the first-ever study on SOC under different forests and agricultural lands as affected by various climatic conditions and cultivation practices. It might not a direct study of SOC stocks in Indian soil but was the first ever furnished report depicting the impact of climate on soil C of India. Gupta and Rao [63] first ever reported the soil C storage of India as 24.3 Pg of SOC stock based on the 48 soil series conserving an average soil depth range of 44 to 186 cm. Bhattacharyya et al. [17] and Velayutham et al. [168] delivered the first comprehensive report on soil C storage of India with clear demarcation of SOC, soil inorganic carbon (SIC) and total carbon (TC) which were significantly useful for developing a notable number of mapping schemes [15]. By using coupled Climate-C cycle global circulation model [43] provided an estimation of 6.5–8.5 Pg of C stock in Indian soil. The soil C mapping of [15] exhibited a C stock of 24.04 and 29.92 Pg in Indian soil considering soil depths of up to 100 and 150 cm respectively. According to them, considering a soil depth up to 30 cm, contributions of semi-arid (116.4 Mha) and sub-humid (105.0 Mha) regions is the most which is about 56% of total SOC stock of Indian soil whereas the Himalayan region that constitutes around 19% of total geographical area of India contributes around 33% of total SOC stocks of Indian soil. [8] used process-based dynamic land ecosystem model and reported 20.5–23.4 Pg of SOC stock in Indian soil and as per their soil C map majority of the estimated C stock were stored in forest soils forest soils of north-eastern, northern India and in some pockets of southern India. [159] used random forest-based digital mapping technique to estimate India's soil C storage. Based on 1198 soil samples collected from different soils, agro-ecological zones, topography, and land-uses across the India they reported an estimation of 22.72 Pg of SOC stock up to 100 cm depth from soil surface. They also noted greater SOC stock in Western Ghats and coastal plains regions compared to arid and semi-arid regions. Humid tropical climate with a hyperthermic temperature regime, winter months and high rainfall might be the reason behind the improvement in sequestering soil C in the corresponding region indicating significant impact of climate on degree of soil C sequestration [169]. [159] recorded maximum SOC density in case of plantation (25.3 kg m^{-2}) followed by forests (13.99 kg m^{-2}) and agricultural land-use (5.85–6.74 kg m^{-2}) considering the depth of 100 cm. On the other hand, according to their findings 80% of the total SOC stock of India. That was noted in case of forests (9.38 Pg) and mono- and double-cropped lands (8.81 Pg). Which is almost in conformity with the findings of [8] reported an estimate of 11.0–11.8 and 3.9–7.8 Pg SOC stock in case of forests and croplands respectively (Table 11.1).

Table 1 Estimation of soil carbon stocks of India by different researches

Study year	Studied depth (cm)	SOC (Pg)	SIC (Pg)	References
1993	–	24.40–26.50	–	[25]
1994	44–186	24.30	–	[63]
2000	0–100	47.50	–	[168]
2008	0–100	24.04	22.46	[15]
2008	0–150	29.92	33.98	[15]
2015	0–100	20.5–23.40	–	[8]
2016	0–100	22.72	12.83	[159]

4.2 Predictions on Changes in SOC Stocks of India

An appreciable number of model based predictions have been performed in the last decade to know the present status and fate of Indian Soil C storage in future. Most of such experiments indicated negative impact of climate change on C stocks in soils of India. A major proportion of Indian soils are not that rich in terms of soil C content [9] which are again very sensitive to temperature alteration [27]. [43] used HadCM3LC model under the IS92a emissions scenario, and predicted a decrease of 2.07 Pg by the end of the twentieth century and a further decrease of by 0.11 Pg by the end of the twenty-first century from the baseline value of total SOC stock of India in 1860s i.e., 8.62 Pg. Under the same scenario and using same HadCM3LC model coupled with RothC model [43] predicted a reduction of 1.22 Pg by the end of 2000s and an additional decline of 0.63 Pg C by 2100 from the baseline Indian soil C stock data. Around 32% decline in SOC stock over a 5-year period was noted by [108] as a result of rapid increase in soil temperature and drying. The rate of such negative changes were observed faster and more prominent even than the changes due to intensive tillage and soil disturbances [108]. [16] studied soil C dynamics up to 30 cm depth in the Indo-Gangetic plains of India through an empirical IPCC method along with Global Environment Facility Soil Organic Carbon (GEFSOC) model and predicted 0.05 Pg C reduction by the end of 2030 from the base data of 0.96 Pg C in recorded in 1967due to alteration in land-uses as well as climate. The same GEFSOC model in combination with Century model reported 0.283 Pg decline in total SOC stock considering 30 cm depth by 2000 and further reduction of 0.35 Pg C by 2030 from the base data of 1.61 Pg C recorded in 1967 [16]. [8] used a process-based dynamic land ecosystem model and predicted a decrease of 0.78 Pg C in total SOC stock in India from 1901 to 2010. The most of this reduction was due to climate change induced as a result of increment in temperature and frequent occurrences of severe drought since 1950s. In the Indian Himalayan region from the baseline data of 2010, around 11.6–19.2% and 9.62–16.9% reduction in total SOC stock by 2099 was predicted by [64] under A2 and B2 climate change scenario respectively. Therefore, the emerging threat of negative impact of climate change on India's soil C stocks should be considered a great matter of concern, especially for the sake of food security, productivity and long-term sustainability. Hence, effective assessment of present C storage in soil, future prediction and based on that planning and implementation of appropriate management strategies is highly needed.

5 Importance and Approaches to Monitor Changes in Soil Carbon

In earlier days computational, statistical or regression approaches based on different long-term data of different sites were used to predict the SOC stocks in future but those were not capable of monitoring dynamic changes rather assumed constant rates in case of SOC changes which was not realistic [44]. Over time, many empirical and process-based models with varying utility and complexity have been developed to quantify and monitor soil C in various situations considering different types of available data [32] (Table 2). Such model helps to understand SOC dynamics by preparing a timeline of changes in SOC of a concerned area and providing future predictions. *Empirical Models* are generally constructed through observations and experimental data following a definite principle that can measure the value of dependable variable by hypothesizing relations between dependant and independent variables but could not explain the nature of such relationships. A notable number of empirical models have been developed to measure the soil C stock over the last few decades. [69] estimated GHG emissions of GHGs associated with crop production and livestock products by devising the cool farm tool, a complete model constructed with several empirical equations. Another notable empirical motel is the IPCC Tier 1 method given by [75], which is capable of measuring the alterations in soil C stocks. On the other hand *Process Based Models* deal with processes associated in transformation of energy or matter. In simple words, such models monitor and characterize decay rates, generally expressed by first- order rate kinetics in case of soil C and its pools [137]. One of the popular process based model is Rothamsted Carbon (RothC) model that provides simulation for C only, especially the turnover of the organic carbon (OC) mostly in surface soils [22, 56, 124]. The major input data that are required to run the model are: monthly input of plant residues (t C ha^{-1}), decomposability of the input plant materials, clay content (%), monthly soil cover (whether soil is bare or vegetated), monthly input of farmyard manure (t C ha^{-1}) (if any), monthly precipitation (cm), monthly air temperature (°C), and potential evapotranspiration (mm). DeNitrification-DeComposition (DNDC) model is another widely used process-based model developed in 1992 by [107] for predicting C and N dynamics in biogeochemical cycles based on agro-ecosystems of USA. Environmental Policy Integrated Climate (EPIC) model is another effective model that can depict climate's impact on soil C dynamics and crop development and could be operated on a daily basis and perform simulations for larger regions of area up to 100 ha. Initially in India, empirical computation approach outlined by the [78] have been used to estimate SOC stock and its changes. However, in later stage a number of studies have been performed by several researches using process based models delivered better understanding of soil C dynamics and impact of climate change on SOC stocks of India. In the 2000–2020 an appreciable number of studies have been made using a process-based model based on the first order kinetics of soil C decay [8, 16, 43, 64, 159]. The most commonly used process based models in various emission scenarios in India are mainly Century, Roth-C and DNDC models [171]. Such models are further coupled with the GCM model, which acts as a powerful tool to determine the climate change impact on SOC dynamics (Table 2) [51]. However, the reports and predictions on a national level regarding the influence of climate change on soil inorganic carbon (SIC) stock is very limited for India.

Table 2 Various models used in soil C stock estimation and prediction, their origin and development authority

Name of the model	Origin	Persons/institute involved
RothC	UK	[81, 82]
CENTURY	USA	[121, 135, 136]
DNDC	USA	[107]
APSIM	Australia	[119]
SOMM	USA	[24]
ECOSYS	Canada	[60]
Two-composition model	China	[182]
DAYCENT	USA	[61, 62]
DSSAT	USA	[85]
EPIC	USA	[79]
SOCRATES	USA & Australia	[58]

6 Management Practices to Sequester Soil Carbon to Mitigate Climate Change

6.1 Conservation Agriculture

Conservation agriculture (CA) could be broadly defined as "an approach to manage agricultural ecosystems for enhanced and sustained productivity, improved returns, and food security while preserving and enhancing the resource base and the environment" [42]. The three main principles of this sustainable model are as follows (Fig. 1):

(i) Minimal soil disturbance following zero/no-tillage
(ii) Sequential diversification of crops through rotations
(iii) Permanent soil covers either through crop residue retention or growing cover crops.

Conservation agriculture could be considered as a potential sustainable option for a number of emerging problems of climate change, viz., degradation of lands, loss of soil carbon, reduction in crop yield and productivity, soil erosion, lowering of water table and even rise in input costs (Fig. 1) [113, 120]. Moreover, conservation agriculture could be adapted in varieties of agro-ecological zones that would support food security in developing countries, especially of a notable number of smallholder residents [28, 150]. Reduction in land degradation, improvement in soil structure and build-up in soil carbon status could be significantly achieved through conservation agriculture [29, 46, 88, 89, 99] as tillage plays a pivotal role in mineralization of soil organic matters [115]. Greater rate of decomposition in case of conventional farming as compared to conservation agriculture might be due to break-down of soil aggregates, augmented soil aeration and temperature which facilitates microbial attacks on

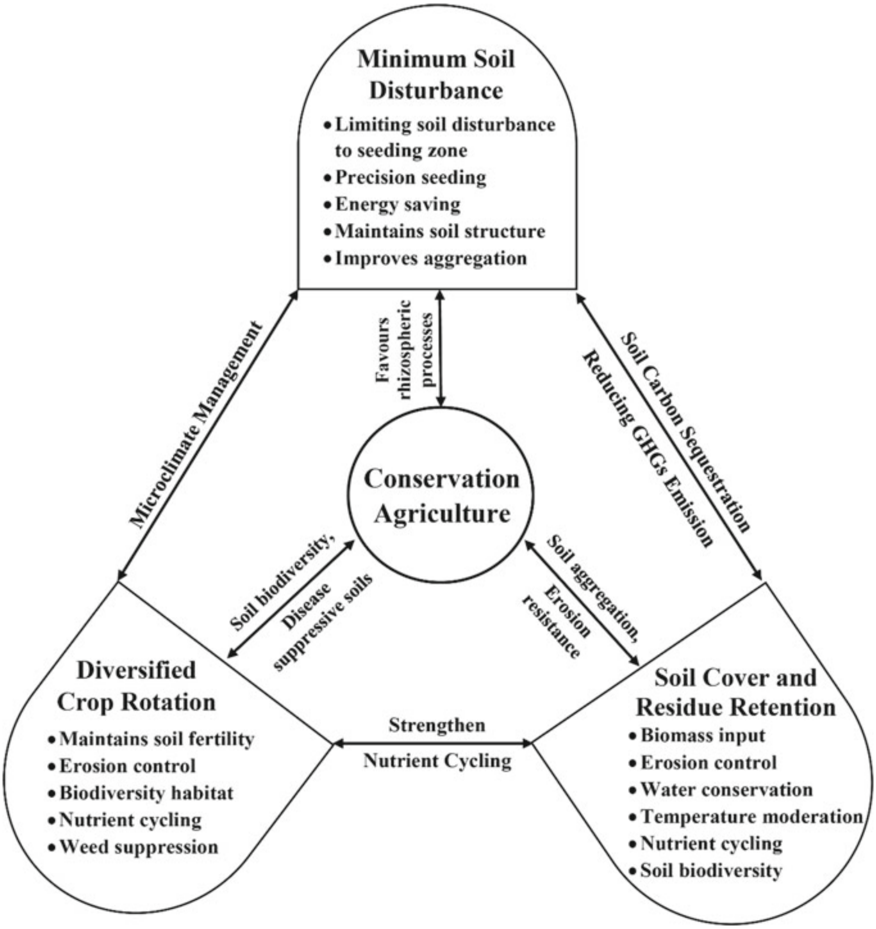

Fig. 1 Principles of conservation agriculture and their inter-relations

SOM resulting in rapid mineralization [6]. In case of conservation agriculture, stratification of SOC in relatively less-disturbed top soil enhances soil stability [14, 23, 29, 39, 113, 114, 164]. As a result, compared to conventional farming, conservation agriculture has been proved significantly effective in mitigating soil erosion which prevents translocation of a large amount of soil carbon [40, 155, 178]. Even retention of crop residues of previous seasons also prevents disruption of soil [144]. Year-long surface cover under conservation agriculture imparts improved aggregation and proliferation of beneficial structure forming soil organisms [19, 122]. which is usually further augmented diversified rotation of crops practised under conservation agriculture [139]. That ultimately provides significant resistance towards physical weathering by protecting the top soil from detachments [34, 54]. Greater proportion of labile fraction of soil carbon in the surface soils under minimum soil disturbance helps in microbial activity, ultimately enhancing soil aggregation (Ball et al. 2005). Again, conservation agriculture indulge in abundance of fungal hyphae in surface soils leading to an improved soil structure through improving soil aggregation [3]. In most cases, conservation agriculture could be found efficient enough to improve water use efficiency, soil biological activities and control soil temperature [67, 163]. Therefore, conservation agriculture could be considered as one of the promising agricultural management practice to establish a sustainable balance between crop productivity, healthy economy and maintenance of climate [41, 42, 52].

6.2 Biochar Application

Production of large amount of crop residues is a notable problem around the globe. Annual generation of around 2.8 and 3.6 Gt of residues from cereal crops and 27 food crops have been recorded globally [18]. India generates about 435.98 million tonnes of agricultural residues of which 313.62 mt remains excess. A significant of which (around 16%) is burned which in turn causes emissions of CO_2 and facilitates the greenhouse effect [126, 161]. Application of biochar could be an effective option to solve this problem as the agricultural wastes like crop residues, feedstocks, poultry litters, dairy manure and even sewage sludge are used to produce biochar through controlled pyrolysis [158]. Biochar is fine grained, porous, C rich by-product produced by thermal decomposition of organic materials under controlled temperature and limited or in absence of oxygen [4, 105]. For being rich in C, nitrogen (N) and sulfur (S) and due to its particular physical properties, viz., higher surface area and water holding capacity due to porous structure, many soil scientists recommend its application as effective soil amendment [18, 116].

In recent years, biochar is becoming popular to mitigate climate change for its significant C neutralization and sequestering potential [35, 50, 112, 176, 181]. Notable enhancement in quality of soil along with significant accretion in soil C content has been found in the findings of several researchers [38, 96, 104, 177]. An increase in SOC of around 23% under biochar treatment was noted by Jones et al. (2012) in their 3 years long field experiment. In 2018, El-Naggar et al. observed an increase of 5–56% in soil C under biochar application while 8–93% rise was observed by Haefele et al. (2011). [37], in their current research exhibited 77 and 44% enhancement in total C in soils treated with biochars produced from the residues of rice straw, *Miscanthus sacchariflorus*, and *Maesopsis eminii,* having higher proportions of stable C compounds with aromatic structures [183].

Properties of biochars vary with the variations of several factors such as pyrolysis processes, pyrolysis time, temperature of heating, nature of organic matter used etc. [20]. Temperature of heating is a vital determinant of C sequestering potential of biochar. Higher heating temperature enhances the proportion of recalcitrant aromatic C compounds, promoting longer stability and build-up of C in soil [141, 176]. Interaction with manures, composts and other organic amendments and aeration also play important roles in controlling the magnitude of CO_2 emission [84].

However, rational application of biochar is necessary as excess of it could hamper soil productivity through excessive rise in soil carbon sink. Therefore, evaluation of crop response to various rates of biochar treatments is necessary to get a sustainable soil system for the long run.

6.3 Organic Farming

Organic farming could be considered a potential agricultural practice to significantly sequester SOC particularly under croplands due to the addition of greater amount of organic matter inputs under this practice [49, 156]. However, quality of residues used as organic input is also a determining factor for magnitude of C build-up in soils [47, 145]. Apart from significant C capturing in soil organic farming also improves soil structure, nutrient availability, plant-water relations and makes the entire system resilient to climate change [5, 129, 138, 165]. In an organic farming system, [49] found addition of external C input was about 92% which was only about 27% under conventional trial. [106] run a meta-analysis, studied 68 data sets from 32 publications and found around an average of 2.2% increase in SOC build-up as a result of conversion conventional farming into organic one. A decline of 15% in SOC under conventional farming was observed in case of a 21 years long trial in Switzerland while organic system with greater livestock density resulted in better SOC stability in that time period [45]. Incorporating organic strategies like mulching, cover crops and crop rotation in conventional farming also exhibited a slight increase in SOC stock [173]. However, according to some scientists, applying manures is not the effective process to capture atmospheric C into the soil as it indicates transfer of C from one site to another site [128, 140]. Again, despite of being considered as an efficient practice to sequester C in soil, less disturbance of soil or no-tillage could not be followed easily under organic farming due to restriction in use of herbicides to control weeds [115]. Lower yields of crops are another drawback of organic farming and should be considered an issue for further advancements to secure ever-increasing food demand worldwide [152]. Therefore, implication of such strategies should be made in a balanced way so that both the soil C content, nutrient availability to the plants and crop yield could be maintained [31].

6.4 Cropping System and Land-Use Planning

Crop-rotation and land-uses are key determinants of magnitude of soil C build-up. Through proper inclusion of a particular crop in an existing cropping system significant changes could be made in terms of soil C content. In a report of 10 years simulation model report, around 7.2% greater SOC build-up was noted under wheat-wheat crop rotation compared to wheat-chickpea rotation [53]. Chickpea contributes around 47% lower biomass incorporation in soil than wheat, which might be the reason behind augmented soil C storage under wheat-wheat system. [26] observed no significant effect on SOC due to the incorporation of chickpea in wheat based cropping system while [71] found such changes significant due to the incorporation of chickpea in soil as green manure. In China, slow decomposition of SOC was noted under the soybean-corn break cropping system but it was not found much effective to elevate the SOC level to a significant level less biomass input in to the soil through soybean [166]. [149] observed highest SOC content under rice–wheat cropping system both in Alfisols and Inceptisols of north-western India which was much higher than the traditional maize-wheat cropping system. [13] in their 25 years long observation noted a significant increase of 2.9 to 4 g kg^{-1} in SOC stock as result of inclusion of rice cultivation in wheat system trather than inclusion of any other cereal crops like maize or millets. [111] also found the enrichment in SOC stocks under double-cropped rice system in sub-tropical climate of Eastern India. This might be due to puddled anaerobic condition that reduces the microbial activity and oxidation of SOC under rice cultivation. Again, rice contains higher amount of lignin and polyphenol that are resistant to oxidation. Therefore, incorporation of crop residues in to the soil having recalcitrant long chained carbon compound is another vital reason for better C stabilization in soils under rice cultivation.

Along with alteration in cropping systems, changes in land uses also potentially affects soil C. According to [70] during 1700–1990, a loss of 25 Pg C from soil to atmosphere was only due to changes in land-uses, especially due to conversion of forestlands into arable lands or grasslands [55, 179]. In sub-tropical China, [153] found the changes in SOC due to alteration in land-uses in surface soils and up to a depth of 20 to 100 cm. Deforestation and transformation of forests into agricultural fields release about 2 Pg C $year^{-1}$ [98]. Therefore, reforestation and preservation of forest would be promising strategies to protect the terrestrial pools of carbon. Conservation of lowlands and marginal lands into forests can also improve soil carbon [66]. Larea area, lower oxidative decomposition due to lesser decomposition, less thermal decomposition due to prolonged shed and incorporation of large quantity of residues having recalcitrant carbon compounds could be the reason behind better sequestration of C under forests [72, 97, 157]. Agro-forestry is another effective strategy to enhance soil C sequestration in terms of land-use management [30, 123].

6.5 Growing Bioenergy Crops

Nowadays researches on efficiencies of bioenergy crops to offset GHGs emissions are becoming popular [170, 172] . Plants usually grown in marginal lands with higher biomass and energy potential capable of producing bioenergy could be defined as bioenergy crops or plants. In a broader aspect, bioenergy crops could be grouped in (1) *First Generation (1G) Bioenergy Crops:* food crops like wheat, sugarcane, corn, sugar beet etc. fall under this group, and (2) *Second Generation (2G) Bioenergy Crops:* perennial crops like switchgrass *(Panicum virgatum),* miscantus (*Miscanthus giganteus*), *Jatropha curcas*, *Salix herbacea*, *Pennisetum purpureum*, *Andropogan gerardii* etc. that are grown dedicatedly for the production of biofuel. In mid-western USA significant sequestration of SOC was observed under Miscanthus and Switchgrass cultivation [174] as because of greater accumulation of recalcitrant C compounds in soils due to deep root systems of cultivated 2G crops [110]. Reduction in microbial activity and mineralization as well as decomposition of organic matter due to greater C:N ratio of Miscanthus and Switchgrass biomass is another plausible reason for better C build-up [87], but this could result in reduction in available soil N also, especially in case of soils deficient in N [118]. [65] in their meta-analysis exhibited around 2.7% increase in SOC due to conversion of arable lands to lands with cultivation of perennial grasses. A number of researchers also observed higher C capturing potential of *Jatropha curcas* as compared to 1G bioenergy crops (e.g. sugarcane, corn etc.) also grown for consumption purpose [1, 11, 160]. Grandy and Robertson [59] also noted greater C sequestration rate under cultivation of perennial crops over annual crops cultivation. But, optimum inputs and management practices along with type of crops also play vital roles in soil C management [33, 102]. As for example, proper application of nitrogenous fertilizers imparts a notable influence on maintaining GHGs balance under Miscantus cultivation [12, 130]. Therefore, along with efficient maintenance of GHGs balance and soil C contents cultivation of bioenergy crops also improve degraded lands and improves livelihoods of rural people by providing employment [103].

6.6 Other General Sustainable Practices

Along with the strategies discussed above, some other sustainable general measures capable enough to supress GHGs mitigation and to mitigate climate change are:

Growing cover crops during off-season instead of keeping the land fallow would ultimately reduce the C mineralization by lowering thermal decomposition and adding OM in soils through leaf-litter fall, root decomposition and deposition of root exudates.

Afforestation of agriculturally marginal soil and growing of plant species containing resistant aromatic C compounds especially in degraded lands.

Reducing methane (CH_4) emission from rice field and capturing CH_4 emitted from landfills is another important measure. Selection of suitable rice variety and proper management strategies are necessary in this regard. Alternate wetting–drying and mid-season drainage could be promising practices to check CH_4 emission and SOC build-up under rice cultivation [180] .

Integrating livestock farming with crop production would be another profitable option where excess crop residues could be used as feed for livestock which ultimately will reduce the magnitude of C emission due to burning of excess crop residues. On the other hand livestock wastes could be used for manure and biogas preparation which could be again utilized for agricultural benefits.

Upgrading the machineries and equipment used in farms and transport is another simple step towards abatement of pollution and mitigating climate change.

Increasing dependency on renewable energy sources like solar and wind power from farm level to large production level would also bring significant changes towards a sustainable greener future.

7 Limitations, Future Outlook and Policy Implications

Soil is a major sink as well as source of atmospheric C. Hence, through proper management practices effective control of detrimental effects of climate change could be possible and along with that food security and biodiversity could also be secured. But to adapt such practices, several limitations are also there. Here, some of such limitations and solutions to overcome those are discussed below.

Lack of knowledge, farmer expertise and extension services is a notable limitation in several part of the world. Locally suitable, relevant and credible information are of utmost importance to overcome the knowledge gaps. Agricultural technicians and extension personnel with clear concepts are greatly needed to create interest and awareness among farmers. Sound understanding regarding the relation between climate, soil C sequestration and even activities of soil biota is also required.

Preparation of soil C maps of various agro-climatic regions is needed to know the current status, future prediction and potential of soil to sequester C. For such case, large-scale field trials and simulation models should be considered to know current C stocks and the implication of most suitable management practices for that particular region. Monitoring soil C contents at certain intervals is crucial to know the efficiencies of management practices recommended for a particular site.

For a specific region, standardization of SOC sequestration rates under different recommended management practices is also needed for precise evaluation of the progress. Management strategies that facilitate the build-up of recalcitrant carbon should be more encouraged to store C in soil for a longer period.

Region-wise cost-effectiveness of different management strategies should be calculated to implement relevant policies for that region.

Researches on unconventional but effective strategies such as, bioenergy plantation, biochar application etc. should be encouraged so that along with soil C sequestration and climate-change mitigation, reclamation of degraded and marginal lands could also be executed.

Local manufacturing and supply of advanced instruments and machineries that causes less pollution and effective for less soil disturbances during land preparation, seeding and harvesting would also be a significant effort to store soil C and mitigate climate change.

Burning of residues is another harmful practice among farmers. Government should take active steps to encourage farmers not no burn the crop residues. Knowledges regarding economic use of crop residues should be disseminated among farmers through skilled technical and extension personnel.

Reformation of policies that supports sustainable agriculture through agricultural development along with natural resource conservation policies would be another positive step. Removal of subsidies for agricultural practices that causes degradation of natural resources would also be effective.

Market development for environment-friendly certified products in an extensive manner would encourage farmers to perform eco-friendlier sustainable practices.

8 Conclusions

Climate change also influences mineralization of soil carbon and its pools which in turn hastens the process of climate change and ultimately facilitate the land degradation in a cyclic manner. Therefore, along with controlled anthropogenic activities, stabilizing carbon in soil would be an effective option to mitigate land degradation or to attain land degradation neutrality and could be a promising one to limit the global warming to 2 °C. In this chapter, along with India's current status and changes in soil carbon content and soil quality, effective management practices have also been discussed. Reforestation, conservation agriculture, organic farming and integrated nutrient management, soil/water conservation, application of biochar, planting bioenergy crops could be considered. As some of those promising practices that are efficient in improving land quality through rise in soil carbon stock which in turn reduces the terrestrial GHGs emissions as well. However, continuous monitoring and research is needed using modern approaches like remote sensing and simulation models to predict the future situation based on which strategic policies could be employed.

Despite the lower elevation rate in average annual temperature (0.62 °C/100 years) compared to the global average (0.80 °C/100 years), the significant impacts of climate change are already being felt in India. Land degradation in India could be identified as one of the detrimental outcome of climate change and loss of soil C plays a pivotal role in this case. Vulnerability of soil C stocks towards climate change has been observed since last two decades in India. Though, an appreciable number of researches have been performed by several researchers regarding the present status and future prediction of C storage of Indian soils, further sequential timely monitoring on local and national levels should be undertaken to develop effective action plans. Base on the results of such continuous monitoring adaptation of efficient management practices including conservation agriculture, optimum use of fertilizer and organic farming, application of biochar, proper land-use management, growing bioenergy crops in marginal lands etc. could offset the effects of climate change through augmentation of soil C storage. However, a considerable number of limitations are also there in order to adapt such changes which could be overcome through effective policy making.

References

1. Abhilash PC, Srivastava P, Jamil S, Singh N (2011) Revisited Jatropha curcas an oil plant of multiple benefits: Critical research needs and prospects for the future. Environ Sci and Pollut Res 18(1):127–131. https://doi.org/10.1007/s11356-010-0400-5
2. Allen DE, Singh BP, Dalal RC (2011) Soil health indicators under climate change: A review of current knowledge. In: Singh BP et al (eds) Soil Health and Climate Change, Soil Biology 29. Springer-Verlag, Berlin, Heidelberg, pp 25–45
3. Alvarez CR, Alvarez R (2000) Short-term effects of tillage systems on active soil microbial biomass. Biol Fert Soils 31:157–161
4. Amonette J, Joseph S (2009) Characteristics of biochar: micro-chemical properties. In: Lehmann J, Joseph S (eds) Biochar for environmental management: science and technology. Earth Scan, London, pp 33–52
5. Azeez G (2009) Soil carbon and organic farming. Retrieved December 12, 2010, from http://www.soilassociation.org
6. Balesdent J, Chenu C, Balabane M (2000) Relationship of soil organic matter dynamics to physical protection and tillage. Soil Till Res 53:215–230
7. Ball BC, Scott A, Parker JP (1999) Field N_2O, CO_2 and CH_4 fluxes in relation to tillage, compaction and soil quality in Scotland. Soil Till Res 53:29–39
8. Banger K, Tian H, Tao B, Lu C, Ren W, Yang J (2015) Magnitude, spatiotemporal patterns, and controls for SOC stocks in India during 1901–2010. Soil Sci Soc Am J 79:864–875
9. Banger K, Toor GS, Biswas A, Sidhu SS, Sudhir K (2010) SOC fractions after 16-years of applications of fertilizers and organic manure in a Typic Rhodalfs in semi-arid tropics. Nutr Cycl Agroecosyst 86:391–399
10. Batjes NH (2016) Harmonized soil property values for broad-scale modelling (WISE30sec) with estimates of global soil carbon stocks. Geoderma 269:61–68
11. Behera SK, Srivastava P, Tripathi R, Singh JP, Singh N (2010) Evaluation of plant performance of *Jatropha curcas* L. under different agro-practices for optimizing biomass: a case study. Biomass Bioenergy 34(1):30–41. https://doi.org/10.1016/j.biombioe.2009.09.008
12. Behnke GD, David MB, Voigt TB (2012) Greenhouse gas emissions, nitrate leaching, and biomass yields from production of Miscanthus giganteus in Illinois, USA. BioEnergy Res 5(4):801–813. https://doi.org/10.1007/s12155-012-9191-5
13. Benbi DK, Brar JS (2009) A 25-yar record of carbon sequestration and soil properties in intensive agriculture. Agron Sust Dev 29:257–265
14. Benbi DK, Senapati N (2010) Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice-wheat systems in northwest India. Nutr Cycl Agroecosyst 87:233–247
15. Bhattacharyya T, Pal DK, Chandran P, Ray SK, Mandal C, Telpande B (2008) Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. Curr Sci 95:482–484
16. Bhattacharyya T, Pal DK, Easter M, Batjes NH, Milne E, Gajbhiye KS, Chandran P, Ray SK, Mandal C, Paustian K, Williams S, Killian K, Coleman K, Falloon P, Powlson DS (2007) Modelled SOC stocks and changes in the Indo-Gangetic Plains, India from 1980 to 2030. Agric Ecosyst Environ 122:84–94
17. Bhattacharyya T, Pal DK, Velayutham M, Chandran P, Mandal C (2000) Total carbon stock in Indian soils: Issues, priorities and management. Special Publication of the International Seminar on Land Resource Management for Food, Employment and Environment Security (ICLRM). Soil Conservation Society of India, New Delhi, pp 1–46
18. Bhattacharyya P, Dash PK, Swain CK, Nayak AK, Chatterjee D, Padhy SR, Saha R, Barman D (2018) Carbon Dynamics in Soil-Plant- Environment System on Climate Change Perspective: Special Reference to Rice. In: Bal SK et al. (eds) Advances in Crop Environment Interaction, Springer Nature Singapore. pp 3–24
19. Blanco-Canqui H, Lal R (2008) Principles of soil conservation and management. Springer, Dordrecht

20. Brewer CE, Schmidt-Rohr K, Satrio JA, Brown RC (2009) Characterization of biochar from fast pyrolysis and gasification systems. Environ Prog Sustain Energy 28(3):386–396. https://doi.org/10.1002/ep.10378
21. Brinkman R, Sombroek W (1999) The effects of global change on soil conditions in relation to plant growth and food production. In: Global Climate Change and Agricultural Production, Bazzaz F, Sombroek W (eds) Food and Agriculture Organization of the United Nations, John Wiley and Sons: Rome, Italy, pp 49–63
22. Cagnarini C, Renella G, Mayer J, Hirte J, Schulin R, Costerousse B, Marta AD, Orlandini S, Menichetti L (2019) Multi-objective calibration of RothC using measured carbon stocks and auxiliary data of a long-term experiment in Switzerland. European J Soil Sci 70:361–377. https://doi.org/10.1111/ejss.12802
23. Causarano HJ, Franzluebbers AJ, Shaw JN, Reeves DW, Raper RL, Wood CW (2008) Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain. Soil Sci Soc Am J 72:221–230
24. Chertov OG, Komarov AS (1997) SOMM: A model of soil organic matter dynamics. Ecol Model 94(2–3):177–189
25. Dadhwal VK, Nayak SR (1993) A preliminary estimate of biogeochemical cycle of carbon for India. Sci Cult 59:9–13
26. Dalal RC, Strong WM, Weston EJ, Cooper JE, Lehane KJ, King AJ, Chichen CJ (1995) Sustaining productivity of a Vertisol at Warra, Queensland, with fertilisers, no-tillage, or legumes 1.Organic matter status. Austr J Exp Agric 35:903–913. https://doi.org/10.1071/EA9950903
27. Davidson EA, Janssens IA (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440:165–173
28. Derpsch R, Friedrich T (2009) Global overview of conservation agriculture adoption. In: Lead Papers 4th World Congress on Conservation Agriculture. World Congress on Conservation agriculture, New Delhi, India
29. Dhaliwal SS, Naresh RK, Gupta RK, Panwar AS, Mahajan NC, Singh R, Mandal A (2020) Effect of tillage and straw return on carbon footprints, soil organic carbon fractions and soil microbial community in different textured soils under rice–wheat rotation: a review. Rev Environ Sci Biotechnol 19:103–115. https://doi.org/10.1007/s11157-019-09520-1
30. Dhaliwal SS, Naresh RK, Walia MK, Gupta RK, Agniva M, Rajveer S (2019) Long-term effects of intensive rice–wheat and agroforestry based cropping systems on build-up of nutrients and budgets in alluvial soils of Punjab. Arch Agron Soil Sci, India. https://doi.org/10.1080/03650340.2019.1614564
31. Dhaliwal SS, Sharma Vivek, Mandal A, Naresh RK, Verma G (2021) Improving Soil micronutrient availability under organic farming. In: Meena VS, Meena SK, Rakshit A, Stanley J, Shrinivasarao Ch. (eds.), Advances in Organic Farming. Elsevier, Oxford, UK. https://doi.org/10.1016/B978-0-12-822358-1.00002-X
32. Dondini M, Hastings A, Saiz G, Jones MB, Smith P (2009) The potential of Miscanthus to sequester carbon in soils: comparing field measurements in Carlow. Ireland to model predictions. GCB Bioenergy 1(6):413–425
33. Drewer J, Finch JW, Lloyd CR, Baggs EM, Skiba U (2012) How do soil emissions of N2O, CH4 and CO2 from perennial bioenergy crops differ from arable annual crops? GCB Bioenergy 4(4):408–419. https://doi.org/10.1111/j.1757-1707.2011.01136.x
34. Durán Zuazo VH, Rodríguez Pleguezuelo CR (2008) Soil-erosion and runoff prevention by plant covers. A review. Agron Sustain Dev 28:65–86. https://doi.org/10.1051/agro:2007062
35. El-Naggar A, El-Naggar AH, Shaheen SM, Sarkar B, Chang SX, Tsang DCW, Rinklebe J, Ok YS (2019) Biochar composition-dependent impacts on soil nutrient release, carbon mineralization, and potential environmental risk: A review. J Environ Manage 241:458–467. https://doi.org/10.1016/j.jenvman.2019.02.044
36. El-Naggar A, Lee SS, Awad YM, Yang X, Ryu C, Rizwan M, Rinklebe J, Tsang DCW, Ok YS (2018) Influence of soil properties and feedstocks on biochar potential for carbon mineralization and improvement of infertile soils. Geoderma 332:100–108. https://doi.org/10.1016/j.geoderma.2018.06.017

37. El-Naggar A, Lee MH, Hur J, Lee YH, Igalavithana AD, Shaheen SM, Ryu C, Rinklebe J, Tsang DCW, Ok YS (2020) Biochar-induced metal immobilization and soil biogeochemical process: An integrated mechanistic approach. Sci Total Environ 698:134112. https://doi.org/10.1016/j.scitotenv.2019.134112.
38. El-Naggar A, Lee SS, Rinklebe J, Farooq M, Song H, Sarmah AK, Zimmerman A, Ahmad M, Shaheen SM, Ok YS (2019) Biochar application to low fertility soils: A review of current status, and future prospects. Geoderma 337:536–554. https://doi.org/10.1016/j.geoderma.2018.09.034
39. Elliott ET (1986) Aggregate structure and carbon, nitrogen and phosphorus in native and cultivated soils. Soil Sci Soc Am J 50:627–633
40. Erhart E, Hartl W (2009) Soil protection through organic farming: a review. In: Lichtfouse E (ed) Organic farming, pest control and remediation of soil pollutants. Springer, Dordrecht, pp 203–226
41. FAO (2011) The State of food and agriculture. Women in agriculture. Closing the gender gap for development. Food and Agriculture Organisation of the United Nations, Rome, 2.
42. FAO (2014) What is conservation agriculture? FAO CA website. http://www.fao.org/ag/ca/1a.html.
43. Falloon P, Jones CD, Cerri CE, Al-Adamat R, Kamoni P, Bhattacharyya T, Easter M, Paustian K, Killian K, Coleman K, Milne E (2007) Climate change and its impact on soil and vegetation carbon storage in Kenya, Jordan, India and Brazil. Agric Ecosyst Environ 122:114–124
44. Falloon P, Smith P, Szabo J, Pasztor L (2002) Comparison of approaches for estimating carbon sequestration at the regional scale. Soil Use Manage 18:164–174
45. Fließbach A, Oberholzer HR, Gunst L, Meader P (2007) Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric Ecosyst Environ 118(1–4):273–284. https://doi.org/10.1016/j.agee.2006.05.022
46. Franzluebbers AJ (2010) Achieving Soil Organic Carbon Sequestration with Conservation Agricultural Systems in the Southeastern United States. Soil Sci Soc Am J 74:347–357. https://doi.org/10.2136/sssaj2009.0079
47. Friedel JK (2000) The effect of farming system on labile fractions of organic matter in calcariepileptic regosols. J Plant Nutr Soil Sci 163(1):41–45
48. Garten C, Classen A, Norby R (2009) Soil moisture surpasses elevated co2 and temperature as a control on soil carbon dynamics in a multi-factor climate change experiment. Plant Soil 319:85–94
49. Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, Buchmann N, Meader P, Stolze M, Smith P, El-Hage Scialabba N, Niggli U (2012) Enhanced top soil carbon stocks under organic farming. PNAS USA 109(44):18226–18231. https://doi.org/10.1073/pnas.1209429109
50. Gaunt J, Lehmann J (2008) Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. Environ Sci Technol 42(11):4152–4158. https://doi.org/10.1021/es071361i
51. Ghosh S, Majumder PP (2008) Statistical downscaling of GCM simulation to streamflow using relevance vector machine. Adv Water Resour 31(1):132–146
52. Giller KE, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: the heretic's view. Field Crops Res 114(1):23–34
53. Godde CM, Thorburn PJ, Biggs JS, Meier EA (2016) Understanding the Impacts of Soil, Climate, and Farming Practices on Soil Organic Carbon Sequestration: A Simulation Study in Australia. Frontiers Plant Sci 7:661. https://doi.org/10.3389/fpls.2016.00661
54. Goebes P, Seitz S, Geißler C, Lassu T, Peters P, Seeger M, Nadrowski K, Scholten T (2014) Momentum or kinetic energy—how do substrate properties influence the calculation of rainfall erosivity? J Hydrol 517:310–316. https://doi.org/10.1016/j.jhydrol.2014.05.031
55. Gosling P, van der Gast C, Bending GD (2017) Converting highly productive arable cropland in Europe to grassland: –a poor candidate for carbon sequestration. Sci Rep 7:10493. https://doi.org/10.1038/s41598-017-11083-6
56. Gottschalk P, Smith JU, Wattenbach M, Bellarby J, Stehfest E, Arnell N et al (2012) How will organic carbon stocks in mineral soils evolve under future climate? Global projections

using RothC for a range of climate change scenarios. Biogeosciences 9:3151–3171. https://doi.org/10.5194/bg-9-3151-2012
57. Government of India (2021) 'Statement on climate of India during 2020'. Press release, 4 January. https://reliefweb.int/sites/reliefweb.int/files/resources/Statement_of_Climate_of_India-2020.pdf
58. Grace PR, Ladd JN, Robertson GP, Gage SH (2006) SOCRATES—A simple model for predicting longterm changes in soil organic carbon in terrestrial ecosystems. Soil Biology Biochemistry 238:1172–1176. https://doi.org/10.1016/j.soilbio.2005.09.013
59. Grandy AS, Robertson GP (2007) Land-use intensity effects on soil organic carbon accumulation rates and mechanisms. Ecosystems 10(1):59–73. https://doi.org/10.1007/s10021-006-9010-y
60. Grant RF (1997) Changes in soil organic matter under different tillage and rotation: Mathematical modeling in ecosystems. Soil Sci Soc Am J 61:1159–1175. https://doi.org/10.2136/sssaj1997.03615995006100040023x
61. Del Grosso SJ, Parton WJ, Mosier AR, Hartman MD, Brenner J, Ojima DS, Schimel DS (2001) Simulated interaction of carbon dynamics and nitrogen trace gas fluxes using the DAYCENT model. In: Schaffer M, Ma L, Hansen LS (eds) Modeling Carbon and Nitrogen Dynamics for Soil Management. CRC Press, Boca Raton, Florida, pp 303–332
62. Del Grosso S, Parton W, Mosier AR, Holland EA, Pendall E, Schimel DS, Ojima DS (2005) Modeling soil CO_2 emissions from ecosystems. Biogeochemistry 73:71–91. https://doi.org/10.1007/s10533-004-0898-z
63. Gupta RK, Rao DLN (1994) Potential of wastelands for sequestering carbon by reforestation. Curr Sci 66(5):378–380
64. Gupta S (2015) Simulating Climate Change Impact on Soil Erosion and Carbon Sequestration. Ph.D thesis. Andhra University, Visakhapatnam, India
65. Harris ZM, Spake R, Taylor G (2015) Land use change to bioenergy: A meta-analysis of soil carbon and GHG emissions. Biomass Bioenergy 82:27–39. https://doi.org/10.1016/j.biombioe.2015.05.008
66. Harrison AF, Howard PJA, Howard DM, Howard DC, Hornung M (1995) Carbon storage in forest soils. Forestry 68:335–348
67. Henneron L, Bernard L, Hedde M, Pelosi C, Villenave C, Chenu C, Bertrand M, Girardin C, Blanchart E (2015) Fourteen years of evidence for positive effects of conservation agriculture and organic farming on soil life. Agron Sustain Dev 35:169–181. https://doi.org/10.1007/s13593-014-0215-8
68. Heviaa GG, Buschiazzoa DE, Heppera EN (2003) Organic matter in size fractions of soils of the semiarid Argentina. Effects of climate, soil texture and management. Geoderma 116:265–277
69. Hillier J, Walter C, Malin D, Garcia-Suarez T, Mila-i-Canals L, Smith P (2011) A farm-focused calculator for emissions from crop and livestock production. Environ Model Software 26(9):1070–1078
70. Houghton RA, Hackler JL, Lawrence KT (1999) The U.S. carbon budget: contributions from land-use change. Science 285:574–578
71. Hoyle FC, Baldock JA, Murphy DV (2011) Soil organic carbon – role in rainfed farming systems. In: Tow P, Cooper I, Partridge I, Birch C (eds) Dordrecht Rainfed Farming Systems, Springer, pp 339–361. https://doi.org/10.1007/978-1-4020-9132-2
72. Huang A, Clinton PW, Davis MR, Yang Y (2011) Impacts of plantation forest management on soil organic matter quality. J Soil Sediment 11:1309–1316
73. Hunt JR, Celestina C, Kirkegaard JA (2020) The realities of climate change, conservation agriculture and soil carbon sequestration. Glob Change Biol 26:3188–3189
74. IPCC (2018) In: Matthews JBR (eds) Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea , Shukla PR, Pirani A, Moufouma-Okia

W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (eds)].
75. IPCC (2006) Agriculture, forestry and other land use. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds) IPCC Guidelines for National Greenhouse Gas Inventories. National Greenhouse Gas Inventories Programme (vol. 4). IGES, Japan
76. IPCC (2014) Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press
77. IPCC (2019) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge University Press, Cambridge, UK
78. IPCC (1997) Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reporting Instructions (vol. 1); Workbook (vol. 2); Reference Manual (vol. 3). Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency, Paris
79. Izaurralde RC, Williams JR, McGill WB, Rosenberg NJ, Quiroga Jakas MC (2006) Simulating soil C dynamics with EPIC: model description and testing against long-term data. Ecol Model 192:362–384. https://doi.org/10.1016/j.ecolmodel.2005.07.010
80. Jain SK, Kumar V (2012) Trend analysis of rainfall and temperature data for India. Curr Sci 102(1):37–49
81. Jenkinson DS (1990) The turnover of organic carbon and nitrogen in soil. Phil Trans Royal Soc London Series B: Biol Sci 329(1255):361–368
82. Jenkinson DS, Rayner JH (1977) The turnover of soil organic matter in some of the Rothamsted classical experiments. Soil Sci 123(5):298–305
83. Jenny H, Raychaudhuri SP (1960) Effect of Climate and Cultivation on Nitrogen and Organic Matter Reserves in Indian Soils. ICAR, New Delhi, India, p 126
84. Jien SH, Wang CC, Lee CH, Lee TY (2015) Stabilization of organic matter by biochar application in compost-amended soils with contrasting pH values and textures. Sustainability 7(10):13317–13333. https://doi.org/10.3390/su71013317
85. Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, Ritchie JT (2003) The DSSAT cropping system model. Eur J Agron 18:235–265. https://doi.org/10.1016/S1161-0301(02)00107-7
86. Jones C, Mcconnell C, Coleman K, Cox P, Falloon P, Jenkinson D, Powlson D (2005) Global climate change and soil carbon stocks; predictions from two contrasting models for the turnover of organic carbon in soil. Global Change Biol 11:154–166
87. Jordan N, Boody G, Broussard W, Glover JD, Keeney D, McCown BH, McIsaac G, Muller M, Murray H, Neal J, Pansing C, Turner RE, Warner K, Wyse D (2007) Sustainable development of the agricultural bio-economy. Science (New York, N.Y.) 316(5831):1570–1571. https://doi.org/10.1126/science.1141700
88. Kassam A, Derpsch R, Friedrich T (2020) Development of Conservation Agriculture systems globally. In: Kassam A (eds) Advances in Conservation Agriculture Volume 1: Systems and Science, Burleigh Dodds Science Publishing, Cambridge, UK. https://doi.org/10.19103/AS.2019.0048.02
89. Kay BD, VandenBygaart AJ (2002) Conservation tillage and depth stratification of porosity and soil organic matter. Soil Till Res 66:107–118
90. Keller J, White J, Bridgham S, Pastor J (2004) Climate change effects on carbon and nitrogen mineralization in peatlands through changes in soil quality. Global Change Biol 10:1053–1064
91. Knorr W, Prentice IC, House JI, Holland EA (2005) Long-term sensitivity of soil carbon turnover to warming. Nature 433:298–301
92. Kothawale DR, Munot AA, Krishna Kumar K (2010) Surface air temperature variability over India during 1901–2007, and its association with ENSO. Climate Res 42:89–104
93. Kripalani RH, Kulkarni A, Sabade SS, Khandekar ML (2003) Indian monsoon variability in a global warming scenarios. Nat Hazards 29(2):189–206

94. Kumar R, Gautam J (2014) Climate change and its impact on agricultural productivity in India. Climatol Weather Forecasting 2(1):1–3
95. Kumar V, Jain SK, Singh Y (2010) Analysis of long-term rainfall trends in India. Hydrol Sci J 55:484–496
96. Laird DA (2008) The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. Agronomy J 100(1):178–181. https://doi.org/10.2134/agrojnl2007.0161
97. Lal R (2005) Forest soils and carbon sequestration. For Ecol Manag 220:242–258
98. Lal R (2013) Soil carbon management and climate change. Carbon Management 4(4):439–462. https://doi.org/10.4155/cmt.13.31
99. Lal R (2015) Sequestering carbon and increasing productivity by conservation agriculture. J Soil Water Conserv 70(3):55A-62A. https://doi.org/10.2489/jswc.70.3.55A
100. Lal R, Follett RF, Stewart BA, Kimble JM (2007) Soil carbon sequestration to mitigate climate change and advance food security. Soil Sci 172(12):943–956
101. Lal R (2019) Climate Change and the Global Soil Carbon Stocks. In: Lal R, Stewart BA (eds) Advances in Soil Science: Soil and Climate. CRC Press, NW, USA, Taylor and Francis Group., pp 419–426
102. Lal R (2004) The potential of carbon sequestration in soil of south Asia. Proceeding of the 13th International Organisation Conference on Soil Conservation, ISCO 2004. Paper No 134
103. Lal R (2008) Carbon sequestration. Phil Trans Royal Soc London. Series B: Biol Sci. 363(1492):815–830. https://doi.org/10.1098/rstb.2007.2185
104. Lehmann J, Rondon M (2005) Bio-char soil management on highly-weathered soils in the humid tropics. In: Uphoff N (eds) Biological approaches to sustainable soil systems. CRC Press, Boca Raton
105. Lehmann J, Czimczik C, Laird D, Sohi S (2009) Stability of biochar in the soil. In: Lehmann J, Joseph S (eds), Biochar for environmental management: Science and Technology. Earthscan. pp. 183–205
106. Leifeld J, Fuhrer J (2010) Organic farming and soil carbon sequestration: What do we really know about the benefits? Ambio 39(8):585–599. https://doi.org/10.1007/s13280-010-0082-8
107. Li C, Frolking S, Frolking TA (1992) A model of nitrous oxide evolution from soil driven by rainfall events: 1. Model structure and sensitivity. J Geophys Res: Atmospheres. 97(D9):9759–9776. https://doi.org/10.1029/92JD00509
108. Link SO, Smith JL, Halverson JJ, Bolton H (2003) A reciprocal transplant experiment within a climatic gradient in a semiarid shrub-steppe ecosystem: Effects on bunchgrass growth and reproduction, soil. Glob Change Biol 9:1097–1105
109. Lorenz K, Lal R, Shipitalo MJ (2006) Stabilization organic carbon in chemically separated pools in no-till and meadows soils in Northern Appalachia. Geoderma 137:205–211
110. Ma Z, Wood CW, Bransby DI (2000) Soil management on soil C sequestration by switchgrass. Biomass Bioenergy 18(6):469–477. https://doi.org/10.1016/S0961-9534(00)00013-1
111. Mandal B, Majumder B, Adhya TK, Bandyopadhyay PK, Gangopadhyay A, Sarkar D, Kundu MC, Gupta-Choudhury S, Hazra GC, Kundu S, Samantaray RN, Misra AK (2008) Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. Global Change Biol 14:2139–2151. https://doi.org/10.1111/j.1365-2486.2008.01627.x
112. Mandal Agniva, Majumder A, Dhaliwal SS, Toor AS, Mani PK, Naresh RK, Gupta RK, Mitran T (2020) Impact of agricultural management practices on soil carbon sequestration and its monitoring through simulation models and remote sensing techniques: a review. Crit Rev Environ Sci Technol. https://doi.org/10.1080/10643389.2020.1811590
113. Mandal A, Mani PK (2020) Conservation Techniques for Modern Agriculture. SATSA Mukhapatra-Ann Tech Issue 24:24–45
114. Mandal Agniva, Toor AS, Dhaliwal SS (2020) Assessment of sequestered organic carbon and Its pools under different agricultural land-uses in the semi-arid soils of south-western Punjab. India. J Soil Sci Plant Nutr 20(1):259–273. https://doi.org/10.1007/s42729-019-00137-5
115. Mandal Agniva, Dhaliwal SS, Mani PK, Toor AS (2021) Conservation agricultural practices under organic farming. In: Meena VS, Meena SK, Rakshit A, Stanley J, Shrinivasarao Ch.

(eds) Advances in Organic Farming. Elsevier, Oxford, UK. https://doi.org/10.1016/B978-0-12-822358-1.00014-6
116. Masek O (2009) Biochar production technologies. http://www.geos.ed.ac.uk/sccs/biochar/documents/BiocharLaunch-OMasek.pdf
117. Mazdiyasni O, AghaKouchak A, Davis SJ et al (2017) Increasing probability of mortality during Indian heat waves. Science 3(6):e1700066. https://doi.org/10.1126/sciadv.1700066
118. McIsaac GF, David MB, Corey A (2010) Miscanthus and switchgrass production in Central Illinois: Impacts on hydrology and inorganic nitrogen leaching. J Environ Quality 39(5):1790–1799. https://doi.org/10.2134/jeq2009.0497
119. Mccown RL, Hammer GL, Hargreaves JNG, Holzworth D, Huth NI (1995) APSIM: An agricultural production system simulation model for operational research. Math Comput Simul 39:225–231. https://doi.org/10.1016/0378-4754(95)00063-2
120. Meena RS, Meena VS, Meena SK, Verma JP (2015) The needs of healthy soils for a healthy world. J Cleaner Prod 102:560–561
121. Metherell AK (1993) CENTURY Soil organic matter model environment. Technical Documentation Agroecosystem.
122. Mikha MM, Rice CW (2004) Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Sci Soc Am J 68:809–816. https://doi.org/10.2136/sssaj2004.8090
123. Montagnini F, Nair PKR (2004) Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforestry Syst 61–62(1–3):281–295
124. Morais TG, Silva C, Jebari A, A´lvaro-Fuentes J, Domingos T, Teixeira RFM (2018) A proposal for using process- based soil models for land use Life cycle impact assessment: Application to Alentejo, Portugal. J Cleaner Prod 192:864–876. https://doi.org/10.1016/j.jclepro.2018.05.061
125. Mullan D (2013) Soil erosion under the impacts of future climate change: Assessing the statistical significance of future changes and the potential on-site and off-site problems. CATENA 109:234–246
126. Murali S, Shrivastava R, Saxena M (2010) Greenhouse gas emissions from open field burning of agricultural residues in India. J Environ Sci Engg 52(4):277–284
127. Nearing M, Pruski F, O'neal M (2004) Expected climate change impacts on soil erosion rates: A review. J Soil Water Conserv 59:43–50
128. Niggli U, Fließbach A, Hepperly P, Scialabba N (2009) Low greenhouse gas agriculture: Mitigation and adaptation potential of sustainable farming systems. Rev. 2. http://www.ifr.ac.uk/waste/Reports/LowGreenhouseGasAgriculture.pdf.
129. Niggli U, Fließbach A, Schmid H, Kasterine A (2007) Organic farming and climate change. Geneva: International Trade Center UNCTAD/WTO. Retrieved December 9, 2010 from http://www.ifoam.org.
130. Nikiema PR, Rothstein DE, Miller RO (2012) Initial greenhouse gas emissions and nitrogen leaching losses associated with converting pastureland to short-rotation woody bioenergy crops in northern Michigan, USA. Biomass Bioenergy 39:413–426. https://doi.org/10.1016/j.biombioe.2012.01.037
131. Nuttall JG (2007) Climate change—Identifying the impacts on soil and soil health. Department of Primary Industries, Future Farming Systems Research Division, Victoria.
132. O'Neal M, Nearing M, Vining R, Southworth J, Pfeifer R (2005) Climate change impacts on soil erosion in Midwest United States with changes in crop management. CATENA 61:165–184
133. Pai DS, Smitha A, Ramanathan AN (2013) Long term climatology and trends of heat waves over India during the recent 50 years (1961–2010). Mausam 64(4):585–604
134. Pareek N (2017) Climate change impact on soils: adaptation and mitigation. MOJ Eco Environ Sci 2(3):136–139. https://doi.org/10.15406/mojes.2017.02.00026
135. Parton WJ, Schimel DS, Cole CV, Ojima DS (1987) Analysis of factors controlling soil organic matter levels in Great Plains Grasslands. Soil Sci Soc Am J 51(5):1173–1179
136. Parton WJ, Scurlock JMO, Ojima DS, Gilmanov TG, Scholes RJ, Schimel DS, Kamnalrut A (1993) Observations and modelling of biomass and soil organic matter dynamics for the grassland biome worldwide. Global Biogeochem Cycles 7(4):785–809

137. Paustian K (1994) Modelling soil biology and biochemical processes for sustainable agriculture research. In: Pankhurst CE, Doube BM, Gupta VVSR, Grace PR (eds) Soil Biota: Management in Sustainable Farming Systems. CSIRO, Australia, pp 182–193
138. Pimentel D, Hepperly P, Hanson J, Douds D, Seidel R (2005) Environmental, energetic and economic comparisons of organic and conventional farming systems. Bioscience 55(7):573–582. https://doi.org/10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2
139. Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, van Gestel N, Six J, Venterea RT, van Kessel C (2015) Productivity limits and potentials of the principles of conservation agriculture. Nature 517:365–368. https://doi.org/10.1038/nature13809
140. Powlson DS, Gregory PJ, Whalley WR, Quinton JN, Hopkins DW, Whitmore AP, Hirsch PR, Goulding KW (2011) Soil management in relation to sustainable agriculture and ecosystem services. Food Policy 36:S72–S87. https://doi.org/10.1016/j.foodpol.2010.11.025
141. Qayyum MF, Steffens D, Reisenauer HP, Schubert S (2014) Biochars influence differential distribution and chemical composition of soil organic matter. Plant Soil Environ 60:337–343
142. Quideau SA, Chadwick QA, Benesi A, Graham RC, Anderson MA (2001) A direct link between forest vegetation type and soil organic matter composition. Geoderma 104:41–60
143. Quideau SA, Graham RC, Chadwick OA, Wood HB (1998) Organic carbon sequestration under chaparral and pine after four decades of soil development. Geoderma 83:227–242
144. Ranaivoson L, Naudin K, Ripoche A, Affholder F, Rabeharisoa L, Corbeels M (2017) Agro-ecological functions of crop residues under conservation agriculture. A review. Agron Sustain Dev 37:1189. https://doi.org/10.1007/s13593-017-0432-z
145. Raupp J, Oltmanns M (2006) Soil properties, crop yield and quality with farmyard manure with and without biodynamic preparations and with inorganic fertilizers. In: Raupp J, Pekrun C, Oltmanns M, Keopke U (eds) Long-term field experiments in organic farming (pp. 135–155). International Society of Organic Agriculture Research (ISOFAR)
146. Rohini P, Rajeevan M, Srivastava AK (2016) On the variability and increasing trends of heat waves over India. Scientific Rep 6:26153. https://doi.org/10.1038/srep26153
147. Roxy MK, Ghosh S, Pathak A et al. (2017) 'A threefold rise in widespread extreme rain events over central India'. Nature Commun 8(708). https://doi.org/10.1038/s41467-017-00744-9
148. SAC-ISRO: Space Application Centre-Indian Space Research Organisation (2016) Desertification and Land Degradation Atlas of India. Department of Space, Government of India, Ahmedabad – 380 015, India
149. Saha D, Kukal SS, Sharma P, Sharma BD (2014) Profile distribution of carbon fractions under long-term rice-wheat and maize-wheat production in alfisols and inceptisols of NW India. Land Degradation and Development. 10.1002./LDR.2299
150. Sayre K (2000) Effects of tillage, crop residue retention and nitrogen management on the performance of bed-planted, furrow irrigated spring wheat in northwest Mexico. In: 15th Conference of the International Soil Tillage Research Organization, 2–7 July, 2000, Fort Worth; Texas, USA
151. Scharlemann JPW, Tanner EVJ, Hiederer R, Kapos V (2014) Global soil carbon: understanding and managing the largest terrestrial carbon pool. Carbon Management 5(1):81–91. https://doi.org/10.4155/CMT.13.77
152. Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485(7397):229–232. https://doi.org/10.1038/nature11069
153. Sheng H, Zhou P, Zhang Y, Kuzyakov Y, Zhou Q, Ge T, Wang C (2015) Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. Soil Biol Biochemistry 88:148–157
154. Singh D, Horton DE, Tsiang M et al (2014) 'Severe precipitation in Northern India in June 2013: causes, historical context, and changes in probability'. Bull Am Meteorological Soc 95(9):S58–S61. https://deeptis47.github.io/papers/Singh2014a.pdf
155. Six J, Paustian K, Elliott ET, Combrink C (2000) Soil structure and organic matter I. distribution of aggregate-size classes and aggregate-associated carbon. Soil Sci Soc Am J 64:681–689. https://doi.org/10.2136/sssaj2000.642681x

156. Smith P (2005) An overview of the permanence of soil organic carbon stocks: Influence of direct human-induced, indirect and natural effects. Eur J Soil Sci 56(5):673–680. https://doi.org/10.1111/j.1365-2389.2005.00708.x
157. Smith P (2008) Land use change and soil organic carbon dynamics. Nutr Cycl Agroecosyst 81:169–178
158. Sohi S, Krull E, Lopez-Capel E, Bol R (2010) A review of biochar and its use and function in soil. Adv Agron 105:47–82
159. Sreenivas K, Dadhwal VK, Suresh K, Harsha SG, Mitran T, Sujatha G, Suresh JRG, Fyzee MA, Ravisankar T (2016) Digital organic and inorganic carbon mapping of India. Geoderma 269:160–173
160. Srivastava P, Behera SK, Gupta J, Jamil S, Singh N, Sharma YK (2011) Growth performance, variability in yield traits and oil content of selected accessions of Jatropha carcus L. Growing in a large scale plantation site. Biomass Bioenergy. 10.101/j.biombioe.2011.60.008
161. Streets D, Yarber K, Woo J, Carmichael G (2003) Biomass burning in Asia: annual and seasonal estimates and atmospheric emissions. Global Biogeochem Cycles 17(4):1099
162. Thapliyal V, Kulshrestha SM (1991) Climate changes and trends over India. Mausam 42:333–338
163. Thierfelder C, Wall PC (2009) Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Till Res 105:217–227
164. Tisdall JM, Oades JM (1982) Organic carbon and water stable aggregates in soils. J Soil Sci 33:141–163
165. Tizio A, di Lagomarsino A, Moscatelli MC, Marinari S, Mancinelli SGR (2008) The effects of system management on soil carbon dynamics. Lucrari Stiintifice –Universitatea de Stiinte Agronomice si Medicina Veterinara Bucuresti. Seria B, Horticulture 51:645–650
166. Tong Y, Liu J, Li X, Sun J, Herzberger A, Wei D, Zhang W, Dou Z, Zhang F (2017) Cropping System Conversion led to Organic Carbon Change in China's Mollisols Regions. Scientific Rep 7:18064. https://doi.org/10.1038/s41598-017-18270-5
167. Unnikrishnan AS, Nidheesh AG, Lengaigne M (2015) Sea-level-rise trends off the Indian coasts during the last two decades. Curr Sci 108(5):966–971
168. Velayutham M, Pal DK, Bhattacharyya T (2000) Organic carbon stock in soils of India. In: Climate G (ed) Lal R, Kimble JM, aStewart BA. Change and Tropical Ecosystems. Lewis Publishers, Boca Raton, FL, pp 71–96
169. Venkanna K, Mandal UK, Raju AS, Sharma KL, Adake RV, Pushpanjali RB, Masane RN, Venkatravamma K, Babu BP (2014) Carbon stocks in major soil types and land-use systems in semiarid tropical region of southern India. Curr Sci 106(4):604–611
170. Verlinden MS, Broeckx LS, Zona D, Berhongaray G, De Groote T, Camino Serrano M, Janssens IA, Ceulemans R (2013) Net ecosystem production and carbon balance of an SRC poplar plantation during its first rotation. Biomass Bioenergy 56:412–422
171. Viaud V, Angers DA, Walter C (2010) Towards land scape-scale modelling of soil organic matter dynamics in agro ecosystems. Soil Sci Soc Am J 74(6):1–14
172. Wang S, Hastings A, Wang S, Sunnenberg G, Tallis MJ, Casella E, Taylor S, Alexander P, Cisowska I, Lovett A, Taylor G, Firth S, Moran D, Morison J, Smith P (2014) The potential for bioenergy crops to contribute to GB heat and electricity demands. GCB Bioenergy 6(2):136–141. https://doi.org/10.1111/gcbb.12123
173. Wells T, Chan KY, Cornish PE (2000) Impact of different conventional and alternative farming systems on soil quality. Agric Ecosyst Environ 80(1–2):47–60. https://doi.org/10.1016/S0167-8809(00)00133-X
174. Woo DK, Quijano JC, Kumar P, Chaoka S, Bernacchi CJ (2014) Threshold dynamics in soil carbon storage for bioenergy crops. Environ Sci Technol 48(20):12090–12098. https://doi.org/10.1021/es5023762
175. World Bank (2017) Climate Change Knowledge Portal Data Source: http://sdwebx.worldbank.org.
176. Xie T, Sadasivam BY, Asce SM, Reddy KR, Asce F, Wang C, Spokas K (2016) Review of the effects of biochar amendment on soil properties and carbon sequestration. J Hazardous Toxic Radioactive Waste 20(1):04015013. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000293

177. Yuan JH, Xu RK, Zhang H (2011) The forms of alkalis in the biochar produced from crop residues at different temperatures. Bioresource Technol 102(3):3488–3497. https://doi.org/10.1016/j.biortech.2010.11.018
178. Zhang G, Chan K, Oates A, Heenan D, Huang G (2007) Relationship between soil structure and runoff/soil loss after 24 years of conservation tillage. Soil Till Res 92:122–128. https://doi.org/10.1016/j.still.2006.01.006
179. Zhang T, Wang Y, Wang X, Wang Q, Han J (2009) Organic carbon and nitrogen stocks in reed meadow soils converted to alfalfa fields. Soil Till Res 105:143–148
180. Zhang L, Zhuang Q, He Y, Liu Y, Yu D, Zhao Q, Shi X, Xing S, Wang G (2016) Toward optimal soil organic carbon sequestration with effects of agricultural management practices and climate change in Tai-Lake paddy soils of China. Geoderma 275:28–39. https://doi.org/10.1016/j.geoderma.2016.04.001
181. Zhao X, Wang JW, Xu HJ, Zhou CJ, Wang SQ, Xin GX (2014) Effects of crop-straw biochar on crop growth and soil fertility over a wheat-millet rotation in soils of China. Soil Use Manage 30(3):311–319. https://doi.org/10.1111/sum.12124
182. Zhongpei L, Xiaoju W (1998) Simulation of soil organic carbon dynamic after changing landuse pattern in hilly red soil region. Chinese J Appl Ecol 4.
183. Zhu LX, Xiao Q, Shen YF, Li SQ (2017) Effects of biochar and maize straw on the short-term carbon and nitrogen dynamics in a cultivated silty loam in China. Environ Science Pollut Res 24(1):1019–1029. https://doi.org/10.1007/s11356-016-7829-0

Potential Impacts of Climate Change on the Sustainability of Crop Production in the West Bengal, India

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Abstract Since the earth's creation, there has been a constant shift in the climate. Over the past ten years, there has been a lot of political and scientific interest in climate change. Even though the earth's climate has always had distinct hot and cold

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cycles, these changes have been seen to happen relatively swiftly over the past 150–200 years everywhere on Earth. In order to address the worldwide concern about food and fibre for the growing people from inadequate soil resources, soil seems to be more significant for current human cultures than ever before. Climate change is putting the world's food security in jeopardy. Countries like India are more defenceless as a result of the harsh tropical environment and the poor adaptation of small and marginal farmers. Agriculture is most likely to be significantly impacted by the direct and indirect effects of climate change on crops, soil flora and fauna, animals, and pests. Despite being a slow-moving process with relatively small changes in temperature and precipitation over a long period of time, climate change has an impact on a number of soil processes, including soil fertility, soil structure, and stability, nutrient availability, top soil water holding capacity, and erosion. Changes in soil moisture conditions, an increase in soil temperature, and a rise in CO_2 levels are all anticipated climate change effect on soils. Depending on the processes and characteristics of the soil that are crucial for recovering soil fertility and production, the consequences of global climate change are expected to differ. Heat waves and rising CO_2 levels are the primary indicators of climate change. In conclusion, increased output frequently causes the soil to accumulate more carbon, which raises the level of organic matter.

Keywords Climate · Food security · Soil fertility · Temperature · Productivity

1 Introduction

Rough climate change this century has had an impact on global agriculture and its sustainability. By 2080, it is anticipated that agricultural production would have decreased globally by between 3 and 16%, as well as by an average of 10–25% in India and other emerging nations [108]. In India, agriculture plays vital role in the economic sector for feeding 1.35 billion people of the nation by providing 15% of Gross Domestic Products (GDP) of the total population [159]. As populations are growing in a geometric progression whereas food production increased in arithmetic progression, the food requirement will also grow up soon, while cultivable areas will likely remain at current levels in the climate change scenario. Add to this, share of agriculture in GDP will continue to decline, as other sectors grow faster, at an absolute level the agriculture economy will increase. Food security for India is to be more concern from the context of availability to feed the large and growing population as well as balanced nutrition and affordability. Hence, containing food inflation will continue to be a key imperative over the coming years. This, coupled with need to sustainable agricultural practices for enhancing farm income, inevitably leads to the challenge of improving the overall efficiency of farming i.e., reduce input cost and increase output per unit of area. By 2050, food production must rise by 60% to accommodate the enormous demands of the world's 10 billion inhabitants. Approximately 2 billion people worldwide now experience vitamin deficiencies [173, 174]. Currently, the effects of climate change impose pressure on all facets of food security, making it challenging to attain food security [111]. Globally, the consequences of climate change on food production, price, availability, consumption, and use continue to have a detrimental influence on food security [111]. The part of food security that is most specifically focused on food production Numerous studies have demonstrated that using cutting-edge, environmentally friendly, and sustainable technology may increase food production [163]. Sustainable agricultural production is seriously threatened by a variety of problems, such as climate change, resource depletion, biodiversity loss, unpredictable food costs, and structural diet changes [163]. In climate-sensitive sector, agriculture is impacted by both climate change and variability. Despite the fact that they are greatly influenced by certain geographic regions, crops, and how flexible and adaptive the agriculture production system is [164]. It is anticipated that the worldwide agricultural production system would change due to the shifting climatic condition. Previous research has established that the current crop fluctuation is mostly caused by climate change [3, 52, 120]. One of the major sources of global greenhouse gas emissions (GHGs) is the agricultural production sector, which accounts for 19–29% of GHC emissions [133]. Therefore, the scientific community has made genuine efforts to develop new climate smartfarming technologies for improved climatic adaptability. Reduced tillage, crop establishment techniques, nutrient and irrigation management, residue incorporation, water and nutrient use efficiency, lowering greenhouse gas emissions, etc. are just a few of the options currently available to stop the detrimental effects of climate change on agricultural systems [79]. But because they are less widely used, these climate smart technologies have a relatively low acceptance [172]. For instance, during the past 40 years, just 12% of Indian farmers have adopted innovative water management practises [110]. Climate smart technologies must be put into practise to address the aforementioned problems, and they primarily rely on three strategies:—(i) adoption: through increasing resistance to adverse weather and climate change (ii) Increasing agricultural output and per capita income while maintaining food security (iii) mitigation: lowering GHG emissions and/or increasing carbon sequestration [170]. Climate smart technologies are systematic activities taken by farmers, researchers, enterprises, the public sector, and politicians to improve the efficacy of agricultural production systems and farmers' capacity to adapt [83].

2 Climate Change Impact on the Agriculture System of West Bengal, India

2.1 Impacts on Agricultural Productivity

The two main issues facing mankind in the twenty-first century are climate change and food security. By the end of 2050, the world population is projected to be above 9 billion (see the 10 billion forecast above), and food consumption is predicted to increase by 85% [41]. Increased frequency of droughts, strong rainstorms, temperature changes, salinity shifts, and insect pest assaults on crucial food crops pose major threats to the agriculture industry [32, 60]. According to the FAO, land use and agriculture were responsible for 20% of all GHG emissions. Changes in rainfall patterns, more frequent drought and dry spells, rising sea levels, rising temperatures, and unpredictability of temperature all have a detrimental influence on agriculture production (Fig. 1). Zhao et al. [178] constructed a number of simulation models and analysed the yield data from 46 research publications and 48 places throughout the world to ascertain how the production of four crops was influenced by the rising temperatures. With each degree that the average global temperature rises, he got to the conclusion that the output of wheat, rice, maize, and soybeans will fall, respectively by 6.0%, 3.2%, 7.4%, and 3.1% (GMT). The impact of temperature may be either good or detrimental depending on the area. Temperature increases typically have an impact on how crops develop phonologically [155], on how effectively plants use water and nitrogen [158], on how long plants spend in their vegetative and reproductive growth stages (Wan et al. 2008), on how many grains are produced, and on how long the grain-filling period lasts [86]. One of the indirect effects of climate change is the rapid expansion of insects and pests that decimate critical crops [32]. China, the US, and France, the three nations that produce the most grains globally, are coping with significant crop pest infestations and accompanying production declines [144]. This is accurate since rising temperatures and more precipitation encourage some pest species to multiply and spread.

2.2 Impact on Food Security

For the millions of people who depend on agriculture for their livelihood and way of life in developing nations, climate change poses major risks [79]. Extreme weather events like droughts, floods, and cyclones will unavoidably become more frequent and severe in the near future as a result of the rapidly changing global climate and its effects on the amount of GHGs in the atmosphere. This will alter seasonal changes and mean temperature swings [18]. Nitrous oxide levels increased dramatically after the green revolution as a result of the usage of synthetic fertilisers in agricultural outputs. Agricultural techniques such as lowland paddy cultivation and ruminant husbandry are also largely to blame for the rise in methane levels in the atmosphere [164]. Given that the nation depends on climate-sensitive industries like agriculture, forestry, and fisheries for a living, a significant portion of the Indian population is exposed to the effects of climate change [75]. India's existing food security issue must be resolved immediately in order to prevent it from becoming more severe owing to climate change, since above one-third of our people is anticipated to live in poverty and half of all children are malnourished in some fashion [31]. Crop yields in India and West Bengal are unfavourably affected due to natural calamities like high or low rainfall [82], erratic temperatures and humidity [146] and emerging as national threat to food security. This might have a substantial influence on India's agricultural

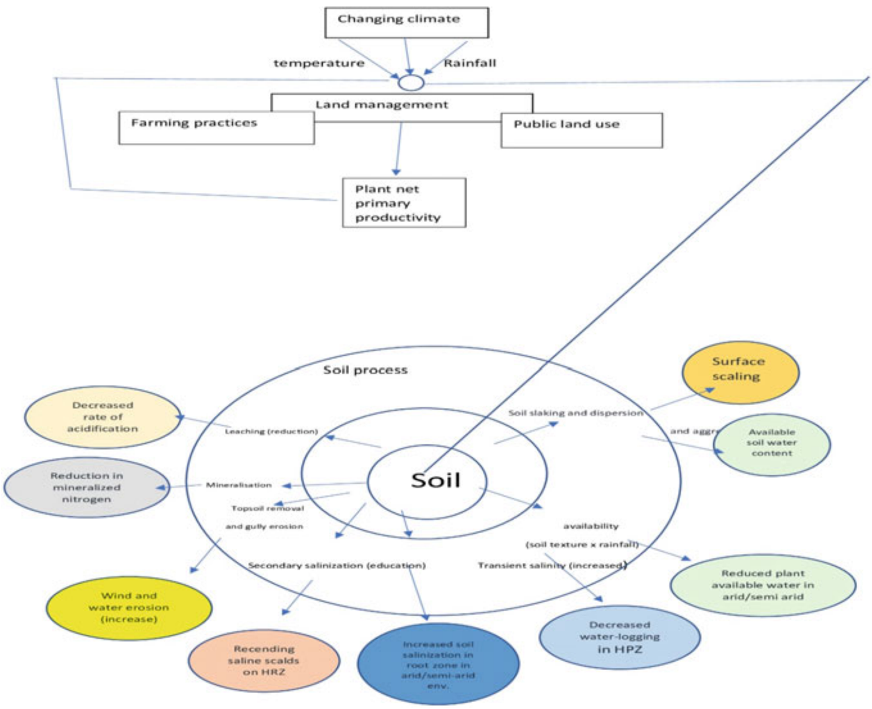

Fig. 1 Impacts of climate change on soil processes diagrammatically represented

productivity and food security [34]. It is generally known that the production and quality of food and beverage crops, medicinal herbs, dairy products, and fish are all impacted by climate change [49]. According to estimates, the impact of weather changes in the different places for example a cereal crops can range from up to 35% for rice, 20% for wheat, 50% for sorghum, 13% for barley, and 60% for maize, based on places [111].

A complex and nuanced concept, food security must include a variety of elements, including food production, distribution, quality, purchasing power, and the sustainability of the entire process. Among the businesses that climate change affects are agriculture, forestry, fisheries, and aquaculture. Significant social and economic consequences may also result, including decreased income, reduced livelihoods, interruptions to business, and detrimental impacts on one's health [24]. However, the severity of the climatic shock and the underlying vulnerabilities have an impact on how climate change manifests itself. According to the Food and Agriculture Organization, the total effect of climate change on food security is influenced by societal and biophysical vulnerabilities [24]. India and West Bengal's decadal progress rates between 2001 and 2011 were 17.7% and 13.8%, respectively, compared to 21.34% and 17.77% between 1991 and 2001. This is despite the fact that the production rate of cereals, pulses, and other food products decreased from 2.9% to 0.93% during the same period [143]. This is a significant subject of worry, and immediate measures based on climate change technology must be taken to improve food grain production in order to keep pace with population increase. The amount of arable land per person fell along with the population growth from 0.48 ha in 1950 to 0.15 ha in 2000, and 0.08 ha by 2020 [91]. Every year, climate change in India has an estimated 4–9% impact on agriculture, which will cause the GDP to decline by 1.5% [118]. According to predictions from The World Bank, yields of rice and wheat are predicted to decline by 6–10% by 2030 [118]. The four summer months (June, July, August, and September) account for 80–85% of West Bengal's annual rainfall, with the winter months seeing a considerable deficit [128]. The area is renowned for its intense rainstorms and frequent catastrophic weather events that are caused by the climate. Therefore, climate-related catastrophes like floods have been the primary cause of problems in rural areas [128]. There are a number of signs that West Bengal's climate has been shifting recently. For instance, the lowest daytime temperature has significantly increased over the past 37 years [47], and The maximum and lowest temperatures in West Bengal have increased over the previous 100 years, according to the Berkley Earth climate study [11]. Additionally, precipitation in various agroclimatic zones has gradually changed, and the state's land mass has seen an increase in high-intensity tropical storms [129]. The three primary stable crops of West Bengal, rice, wheat, and maize, have been shown to be most impacted by the shift in climatic circumstances [24]. This will cause instability in the production of crops and have an impact on the prices of crucial agricultural commodities. Additionally, in recent years, West Bengal's core area has seen lengthier heatwaves (Govt. of West Bengal 2018). Instability in water supplies and foods generated from rivers is a result of these weather changes' effects on ecosystem services to humans and agricultural enterprises [26]. In West Bengal, there are several intrastate, interstate, and international water challenges (with the neighbouring countries Nepal and Bangladesh). Unfortunately, because there aren't enough practical solutions or strong political will, the problem is becoming worse. Numerous committees in charge of certain rivers have been unable to address the problems due to a lack of timely and effective decision-making, which has had an effect on the farmers in the participating states [76].

2.2.1 Current Adoption Strategies

Because of climate change, the number of cultivable lands per person is declining, which puts further strain on the impoverished rural agricultural communities [112, 126]. Food affordability for disadvantaged groups in a sufficient amount and quality is therefore a problem, in addition to food availability. The question of whether increased food production can sustainably meet the needs of the expanding population must now be addressed. To lessen the farming community's susceptibility and sustainably increase agricultural production with little harm to the environment, a long-term sustainable plan is required [149]. The Indian Council for Agricultural Research (ICAR) launched a network project in 2011 called National Innovations in Climate Resilient Agriculture in order to comprehend the effects of climate change and develop adaptation and mitigation strategies to address the challenges posed by climate change to agricultural systems. http://www.nicra-icar.in/nicrarevised/ (NICRA) (2016) (2016) Srinivasa et al. The study's themes include management of natural resources, fisheries, animals, and crops.

The main aim of the project was

(a) Enhancing agricultural adaptability through strategic research on mitigation and adaptation measures;
(b) Evaluating and displaying appropriate technology in practise;
(c) Building the skills of scientists and other interested parties in climate-resilient agriculture and
(d) Making policy framework strategies for wider implementation.

The expected outputs from the research are

(a) Selection of location specific climate stress tolerance with potential livestock breeds and crop genotypes;
(b) Demonstration of existing best climate resilience practices for vulnerable districts all over the country;
(c) Strengthening key institutes infrastructure development for research on climate change; and
(d) Wider scale research on climatic research in the country and help farmers to cope with changing climate conditions [61].

To address the negative impacts of climatic changes on yield, the following points may focus on:

(a) Emerging flood-drought- and pest-resistant and tolerant crop varieties;
(b) Improve various techniques of water and soil conservation;
(c) Strengthening stakeholders regarding climate resilient agriculture;
(d) Ensuring that farmers receive financial assistance so they may invest in and put effective climate-smart technology into practise.
(e) Utilization of improved GIS-based, web-enabled natural resource planning;
(f) Periodical risk and susceptibility assessment and forecast.

2.3 Agricultural Conservation

Reduced soil disturbance, permanent organic soil cover to decrease soil erosion, and crop diversification are the three central principles. According to the FAO, conservation agriculture minimises the chance of total crop failure in unfavourable or unpredictable weather and improves erosion management, soil quality, water storage, profit, and net farm income [40]. Ineffective and needless tillage techniques cause soil erosion and degradation, which lower soil productivity and organic carbon levels.

Attention has been drawn to conservation agriculture as a method for environmental sustainability and mitigation and adaptation for the production of healthy, safe food [141]. Conservation agriculture can save up to 40% more time and energy than traditional farming [12]. In the global perspective, adoption of conservation agriculture is still at a standstill [27] and west Bengal context. A vast area of agro-ecosystems that are supplied by rain were overlooked during the Green Revolution, which contributed to bettering India's food security.

Conservation agriculture has emerged in West Bengal as a fresh paradigm for accomplishing the goals of sustainable agriculture. In order to manage land for sustainable agricultural production and safeguard soil and water resources at the same time, this method was developed. Conservation agriculture is often built on three fundamental principles: keeping a continuous vegetative cover or protection over the soil's surface; avoiding or lowering tillage to create the least amount of soil disturbance; and rotating crops in various ways. Unpredictable rainfall patterns, stresses (both biotic and abiotic), and reliance on traditional farming methods has resulted in lower crop intensities and inadequate yields [112]. Inadequate food production has resulted in the tribal people of the nation's suffering from chronic malnutrition as a result of their complete reliance on farming for both a living and food consumption [112]. Districts in West Bengal including Birbhum, Bakura, and Purulia are likely to be more affected.

2.4 Natural Resource Management

The largest reduction in detrimental effects of changing climatic circumstances on agricultural productivity has occurred in rain-fed farming systems, but irrigation also plays major roles in this process [14]. The varying levels of rainfall have already had an effect on the river systems. India's capacity to do extensive irrigation has been a key factor in the country's agricultural success and historical food security. Despite the fact that climate change has significantly impacted the hydrological development of large river irrigation systems, the anticipated increase in rainfall variability, which includes longer dry spells, would increase the need for irrigation even if total precipitation during the growing season remains constant.

The groundwater resources being rapidly depleted as a result of excessive, unsustainable extraction. In India, it is anticipated that groundwater use in irrigation would exceed 50%, compared to a global average of roughly 40%. In reality, between 60 and 80% of the irrigation water in several Indian regions comes from the earth [33]. Even though irrigation is done using surface water, groundwater is still important, especially if there are ongoing water shortages. Thus, the necessity for groundwater to enable irrigation management will rise due to climate change [109]. India's groundwater irrigation infrastructure is still very badly organized technically despite the growing deficit. For instance, just 3% of India's 8.5 million irrigation well owners employed drip or spray irrigation, while 88% used open canals to completely drench their crops in water.

The majority of farmers in West Bengal have physical access to groundwater, although pumping expenses are very high due to the lack of mechanization [44, 81]. In order to achieve sustainable food security and better the lives of West Bengal's primarily rural poor, it is imperative to identify and evaluate technologies to strengthen cropping system production in a way that is environmentally sustainable, while increasing crop yields and cropping system yield and lowering labour, water, and energy requirements [63]. The deployment of water-saving techniques that increase crop output while lowering the environmental consequences of food production may be part of an effective cropping system management strategy. These actions should be taken as part of climate change adaptation strategies:

(a) Considering the needs to be established for both surface- and groundwater utilisation.
(b) Reduction of waste increased water gathering capacity and faster storage refuelling.
(c) To make these reservoirs more sustainable, make sure that the rates of groundwater withdrawal and natural recharging are equivalent.
(d) Lining water conveyance lines to cut down on outflow losses.
(e) By using the right storage, you may increase your water carrying capacity from season to season.
(f) Improved bore well management for rotational irrigation, canal lining, and sluice control.
(g) Beginning an investigation of the use of sewage and industrial effluent to reduce the requirement for freshwater.
(h) Effective departmental synchronisation for governance.
(i) When choosing crops, times for planting, arrangements, and input management, the meteorological department is actively involved.
(j) Increased rice intensification, machine installation, and alternating wetting and drying [101].

2.5 Climate-Smart Crop

The ability of the current system to familiarize to alteration will based on climate-related factors and measures. How well crops can adapt to the demands made on environment by a changing climate will determine their potential. Climate-smart agriculture and horticulture can both be useful answers. Utilizing modelling methods for effect assessments for various horticulture crops will be appropriate when developing adaptation and modification strategies. The specific agro-ecological region should adopt the modern climate-smart crops that can endure high temperature, frost, and additional moisture stress circumstances. Each crop's production method should take into account improved water usage effectiveness and climate adaptation. More over 65% of Indians use ice as their primary diet, making up 40% of the country's total output of food grains and providing nourishment and a means of livelihood to a sizeable percentage of the rural population [73]. West Bengal is the state that produces the most rice in India, with an estimated 5.4 million acres and a production capacity of 14.7 million tonnes. In the state, there is a 2.7 t/ha production rate [121].

Rice-based agricultural practises are constantly creating issues with environmental sustainability because of their significant contribution to India's greenhouse gas (GHG) emissions, which are the second highest in the world [65]. Yadav et al. [175], The generation of 95.2 million tonnes of CO_2eq GHGs from rice cultivation in India alone in 2016 accounted for almost 70.3% and 18.6%, respectively, of total CO_2eq GHG emissions from rice fields globally and in South-East Asia. This is an important issue that has to be addressed. Among the most important adaption techniques are major crop management strategies like raising crops off the ground to defend these from extreme soil moisture was caused [92]. Research utilising CRISPR genome editing technologies has improved the capacity to aim and alter agricultural genes for the development of superior varieties with improved productivity and resilience to difficult climatic conditions such as drought, flood, diseases (fungal and insect), high temperatures, and low humidity. India has made great advancements in CRISPR technology, and more should be done to enhance and promote in country [94, 117, 150]. The International Rice Research Institute in the Philippines is actively receiving funds from the Bill and Melinda Gates Foundation to do joint work on these crops [156]. CRISPR genome editing technologies are presently widely used in the horticulture and fishing industries. The most recent improvements in gene editing methods have been demonstrated in farmed fish (Labeorohita, often known as rohu) and bananas (rasthali) in several experiments conducted in India [25, 74].

3 Climate Change Effects on Soil Processes and Properties

The consequences of global climate change have a substantial influence on both soils and the functions that the soils perform. A rise in soil temperature, a change in soil moisture content, and an increase in CO_2 levels are projected to be the main effects of climate change. Temperature and CO_2 level raises are expected to have the most effects on soil processes and soil characteristics as a result of climate change. These elements are essential for restoring the productivity and output of the soil. Table 1 is an example of how soil qualities are severely impacted by climate change. C and N are the two primary components of soil organic matter [17]. The ability of organic matter to store water, exchange cations, develop and sustain structures, and distribute nutrients has an effect on the soil ecosystem [19, 20] (Fig. 1).

Studies by Gorissen et al. [50] and predict that increased global temperatures will have a detrimental effect on how much carbon is delivered to the soil [167]. This will lead to a optimistic response circle in the worldwide carbon sequence and a reduction in soil organic carbon. In an analysis of the soils of a semi-arid steppe. This was far speedy than the decreases in soil carbon that increasing tillage has been shown to cause (Table 1) and [113]. Another modeling research predicted that the North Central United States' soil organic C levels will decrease by 2.0–11.5% by 2100 in comparison to 1990 levels [51]. Nikliska et al. [103] determined the

Table 1 Impacts of climate change on soil

Climatic factors	Impacts
Rise in temperature	Increases soil compactness Decreases soil porosity Increases CO_2 discharge from soil Decrease of soil fertility Salinization of soil Reduction of water retention capacity Reduction of soil organic C Enhances soil microbial activity Increases ammonia volatilization Stimulation of nutrient acquisition Increases rhizospheric temperature Increase the soil erosion Loss of soil organic matter
Decreased rainfall	Increases salt content Possibility of occurring drought Soil moisture deficit Reduces nutrient acquisition capacity of root system Possibility of occurring drought
Increase in atmospheric CO_2	Increase soil fungal population Enhances the soil microbial activity 3. Increases soil C availability
Heavy and intensive rainfall	Increases leaching of basic cations Soil acidification Increases possibility of soil erosion Increases leaching of basic cations Loss of soil nutrients, especially N Loss of N through denitrification Toxicities of Fe, Mn, Al, and B Reduces soil CEC Destruction of soil aggregate

amount of humus exhalation in samples from European Scots pine stands at higher temperatures [48, 59, 123].

The mineralization phase of the plant's N-feeding process is crucial [10, 39]. As a result, it makes sense to assume that decreased N mineralization will result in lower soil N levels that are accessible to plants, which will have a detrimental effect on plant development. According to Holland [56], N limitation of CO_2 fed plants is similar to the results reported by Hungate et al. [59], but higher soil temperatures boost N availability, leading to more terrestrial C absorption than would be expected based on those results. Studies by Norby and Luo [104], Joshi et al. [68], and Reich et al. [122] suggest that higher temperatures encourage N mineralization, which may be beneficial for plant development. However, according to an et al warming experiment, N mobilization increased in the first year but decreased in the second [4, 119, 147, 177].

Favis-Mortlock et al. [42] reported that 10% upsurge in winter precipitation might result in an annual increase in soil erosion of up to 150%. Li et al. [85] was reported water erosion will change from 5 to 195% for normal tillage and from 26 to 77% for conservation tillage.

3.1 Effects on Soil Physical Properties

The physical properties of the soil, such as its texture, bulk density, particle density, porosity, structure, and pore-size distribution, have an impact on its hydrological features (such as water retention and hydraulic conductivity). In the end, these elements regulate the soil profile's temperature, air content, and water content [55]. Through the chemical and biological processes of the soil, including adsorption, water, heat, and mass transfer, nutrient delivery, biological activity, etc., the physical characteristics of the soil have a significant influence on soil fertility [58]. There is an inverse relationship between soil properties and climate change susceptibility. Variations in climatic factors, such as seasonal temperature changes or precipitation intensities, which have an effect on the soil's water regime, have a substantial impact on the soil's hydro-physical properties [58]. Salinization, decreased water and nutrient availability, changed C and N dynamics, and a decline in soil biodiversity are all seriously threatened by the rise in temperature and CO_2 concentration, changes in rainfall patterns, and their interactions with climate change. According to Mills et al. low soil moisture stress is well documented to damage soil processes, which in turn affect plant yield [96]. The following important soil properties have a direct impact on soil fertility as a result of climate change.

3.2 Effects on Soil Texture

Despite being a reasonably permanent soil feature, soil texture greatly affects soil qualities and regulates how susceptible soil is to climatic circumstances. Clay soils that are shrinking and swelling are sensitive to climate change if there are more frequent cycles of wetting and drying since this practise significantly encourages the formation of soil fractures. Since water escapes the soil's filtering function and flows directly to porous surfaces or pours through them when these fissures form quickly, more nutrients are lost from the soil and neighbouring water sources get contaminated [62, 127]. This behavior could worsen if longer and more frequent droughts are followed by more intense precipitation. The seasonal soil moisture regime is significantly influenced by regional climate variations and the modifications in capillary water transport from groundwater to the root zone that occur from those variations. It is believed that silt soils are more vulnerable to climate change than clay soils, independent of plant cover, groundwater effect, and regional temperature change [15]. The primary determinant of how soil will react to local climate change is its texture.

3.3 Effects on Soil Structure

As a result of large changes in precipitation patterns and temperature increases brought on by climate change, the intricate processes of slaking, dispersion, mechanical disturbance, and compaction influence soil structure (type, spatial distribution, and aggregate stability of soil) [125]. Heavy rainfall, surface runoff, and water filtration during thunderstorms all have an immediate effect on soil structure due to their aggregate-destructive nature [145, 161]. Because the type and quality of organic matter in soil affect the type and quality of the structure, a decrease in its levels in the soil causes a decrease in the stability of the soil aggregate, a reduction in infiltration rates, and an increase in susceptibility to compaction, runoff, and erosion [71]. Due to the vulnerability of soil macrofauna and microorganisms to the impacts of the changing environment, climate change may indirectly alter soil biological function and soil structure Singh et al. [145].

3.4 Effects on Soil Salinization

Due to human activities like industrialization, urban and rural growth, intensive agriculture, excessive energy use, as well as natural occurrences, the atmosphere's gas composition has undergone dramatic changes during the previous 150–200 years. Temperature rises cause a surge in evapo-transpiration, whereas drops in precipitation cause a drop in the potential for salt leaching [30, 135, 136]. As a result of the rapid warming of the atmosphere, glaciers may melt, sea levels may rise quickly, there may be excessive rain after floods, and agricultural regions may get submerged as a result. The melting of glaciers on earth may cause sea levels to rise by 3 mm annually as a result of thermal expansion [162], which might hasten the salinization of groundwater and agricultural regions. The impact is more pronounced and may significantly influence the processes of soil formation, degradation, and water holding capacity in dry and semiarid situations. The soil may progressively deteriorate and become more vulnerable to wind and water erosion, leading to salinization and alkalinization. Salt dynamics, which exacerbates the effects of climate change on soil salinization, is the most vulnerable indication of climate change of all indicators [135, 136]. On the main factors contributing to salinization, wind deposition, and salt buildup, climate change is projected to have an effect. Due to changes in the overall environment, this increase in salinization has been worse more lately, notably in the previous 20–30 years [106].

3.5 Effects on Nutrient Cycle in Soil

The nutrient cycle, especially nitrogen, which is closely linked to the water and carbon cycles, is an essential aspect of soil fertility. Thus, factors affecting the carbon cycle and water eventually affect the availability of nutrients in soil. Climate change has a significant impact on the N cycle, which is closely connected to the soil organic carbon cycle [90], as well as possibly on other plant-available nutrient cycles like those for P and S. Climate change also causes temperatures to rise, unpredictable precipitation, and atmospheric N deposition. At higher temperatures, the organic matter in the soil could decay more quickly. The geographical variability in microbial respiration, or soil CO_2 emission, is found to be positively correlated with soil pH and fine root mass [124]. Many places of the world may become hotter and drier as a result of climate change. Additionally, it may increase the acidity of the soil and mess with the way that bacteria, plants, and animals live in communities. However, by examining the impacts of climate on soil microbial activity and soil characteristics, Smith et al. [148] came to the conclusion that a predicted rise in temperature and decrease in precipitation over the next century will result in an increase in soil pH and a decrease in soil electrical conductivity. As a result, the nitrification potential diminishes and the ammonium concentration increases. Manure slurries are reduced by ammonia volatilization, which occurs when soil pH increases and may be problematic for eutrophication and acidification of the soil. The rise in temperature brought on by climate change may increase ammonia volatilization, which might aggravate N pollution, according to Van der Stelt et al. [160].

The carbon and nitrogen cycles of the global climate system are thought to be completely dependent on soil. In environments with high ozone levels and rising temperatures brought on by climate change, there may be less plant growth. According to Kirkham [80], soil organic levels are reported to decrease with increased atmospheric CO_2 levels because of increased microbial activity, and emission of greater amounts of CO_2 occurs at the time of degradation of plant tissues under rising atmospheric CO_2 [22]. Therefore, increased soil C turnover may result from increased CO_2 levels rather than increased soil C sequestration [36]. Increased CO_2 discharge from soils to the atmosphere as a result of rising global temperatures causes reduced soil organic C, which has a favorable response effect on the global C cycle [50, 167]. It was discovered that soil heat and drying reduced soil carbon by 32% over five years, a decline that was far faster than that caused by increasing tillage [87].

3.6 Nutrient Transformation in Soil

The biological conversion between the organic and inorganic pools in soil may be significantly influenced by changes in moisture and temperature brought on by global climate change. Increased soil microbial activity may result from warmer temperatures, which may cause more nitrogen and phosphorus to be released from organic matter in accessible forms [21, 172]. According to several research, soil warming may increase the inorganic pools of N and P in soil by speeding up the processes of ammonification, nitrification, and P mineralization [102, 134]. Rustad et al. [130], The adsorption and desorption processes might potentially be accelerated by an increase in temperature. According to Macrae et al., altered precipitation patterns that result in a decline in the water table increase the depth of the unsaturated zone and raise the quantity of oxygen in the dry soil, which enhances the availability of plant nutrients through the oxidation of organic matter [89].

3.7 Effects on Soil Nitrogen and Phosphorus

According to strong evidence [29, 70, 169], chemical pollutants such heavy metals harm the N and P cycle mostly by preventing the microbial activity needed for these processes. But the concurrent occurrence has hardly ever been mentioned. The eutrophication of lakes and coastal rivers brought on by soil runoff transporting N and P nutrients can be connected to significant consequences of climate change, such as higher temperatures, increased precipitation, and soil erosion (Moss and Company 2011). According to Sardans et al. [132], a prolonged examination (May 2004 to April 2005) in the Mediterranean shrubland revealed a decrease in the activity of soil enzymes such urease, protease, and glucosidase, which may further affect the N cycle in soil. For instance, according to these experts, a 5–1 °C rise in soil temperature may cause an abundance of NO_3^- species but a deficiency in NH_4^+ species. Similar interference from drought was induced on soil enzymes, but neither the net gain nor loss of N in the soil was determined [13]. On the other hand, the nitrification, nitrification, leaching, acidification, and mineralization of organic matter of soil processes may be influenced by the deposition of air NO_x and N_2O [97]. If the speciation and availability of nitrogen in the soil have an immediate effect on the mobility of contaminants, it is uncertain. However, the process associated to N directly affects the accumulation of N in plants [43]. According to several studies [88, 157, 171], the addition of nitrogen, which encourages the development and dominance of specific grass kinds, is associated with both a loss of species variety and an increase in soil acidity. These two changes in soil pH and the decline in biodiversity have an effect on heavy metal mobility as well as the biologically mediated breakdown or transformation of chemical pollutants. As an illustration, van Breemen and van Dijk showed that excessive atmospheric N deposition may result in soil acidification, which makes some contaminants more accessible to the biological receptors present in soil (such Al^{3+}). Extreme weather patterns may amplify soil erosion-induced P runoff. For instance, a 3.3–16.5% increase in P runoff was seen in northern temperate coastal locations during the winter [66] due to more precipitation and colder temperatures. The destiny of pollutants already existing at the point of soil erosion can also be affected, in addition to the nutrient pollution caused by such discharge. For instance, the presence of HPO_4^2 combined with other anions such as SO_4^2, CO_3^2, and OH leads in the immobilization of metal(loid)s in soils polluted with a high concentration of heavy metal(loid) ions [57, 100, 105].

According to McGowen et al. [95], metal(loid)-P precipitates have been found to lessen the leaching of Cd, Pb, and Zn. However, under P-limiting circumstances, iron plaque develops in agricultural soil (such as paddy soil), immobilizing heavy metals (such as Cd) [138]. The effects of temperature-induced soil acidification, which increases the quantity of metals accessible to the plant-root system, are felt by this metal-binding complex [138]. It also affects how metals are taken up by plants, including how they travel from the root to the shoot and how they are disseminated throughout the systems of the shoots.

3.8 Effects on Soil Erosion

By the other hand, additional contaminants may be transferred outside of the parental soils due to increased surface runoff and erosion brought on by more powerful and frequent storms, floods, and rains. Runoff from contaminated soils can carry dioxins, heavy metal(loid), cyanide, hydrophobic organics, ammonium, and hydrocarbons to uncontaminated water and soil, according to research by Anawar [6], Jesus et al. [67], Serpa et al. [137], Boxall et al. [16]. For example, strong rainfall events promote the transport of herbicides from arable land to aquatic ecosystems with surface runoff and erosion [137]. On the other side, crop harvesting and soil tilling can result in the release of pollutants from soils that are linked to soil particles, such as steroids, pesticides, and polycyclic aromatic hydrocarbons [180]. The discharge of contaminants during these processes may be made worse by the hotter and drier summers brought on by climate change. In mining sites, increased pollutant runoff or stoppage of mining operations may result from potential damage to hydraulic infrastructure such as dams, ditches, spillways, and holding ponds during intense rainfall and flooding events [5].

3.9 Climate Change Effects on Salinity

One effect of climate change on this sort of land is that soil salinity on coastal agricultural land has grown from 1 to 33% during a 25-year period as a result of sea level rise [116]. The rise in sea level, which is brought on by the melting of glaciers and ice sheets as well as the thermal expansion of sea water, is linked to the acceleration of global warming. Using a hydrodynamic model, Bhuiyan and Dutta [13] showed a thorough comprehension of the potential implications of sea level rise. Flooding and salinization are two effects of sea level rise that have an impact on water availability. The salinity of both surface water and groundwater rises with the sea level due to saltwater intrusion.

Agriculture soils in semi-arid coastal locations are more salinous, especially in dry parts of the world [53, 72, 114]. Since more than 10 years ago, there have been more frequent droughts and stronger rainstorms than typical due to changes in weather patterns [9]. The major causes of the salinity of the root zone were water rising upward in sites with shallow water tables and coastal regions with sea water intrusion. Changes in temperature and precipitation have more noticeable impacts on soil salinity. In one study, Bannari and Al-Ali [10] examined how long-term effects of higher temperatures and less precipitation for 30 years correlated favorably with increased soil salinity in arid landscape because there was less salt over leaching in the soil using Thematic Mapper (TM), Thematic Mapper Plus (ETM+), and Operational Land Imager data from Landsat sensors (OLI). Over the past 25 years, the salinity of coastal agricultural areas grew from 1 to 33% [116].

According to the FAO [39], 397 Mha of agricultural land in the globe have been harmed by salinity, while 434 Mha have been destroyed by sodicity [93, 139]. Excessive salinity has an influence on 50% of the world's planted and irrigated agricultural area [46, 179]. A 10% annual rate of salinization of agricultural lands is caused by three primary factors: irrigation with salinized water, a dearth of precipitation, and excessive evapotranspiration. By the year 2050, all arable land on the planet would have become salinized [64]. It has been made clear that the expansion of salt-affected arable lands poses a severe danger to global food security. 6% of all farmed land worldwide is lost to soil salinization, and this percentage is increasing by 1–2% year. This results in considerable output losses for crops including the staple grains maize, rice, and wheat [99]. Salt accumulates on the soil's surface with high evapo-transpiration rates [8, 98]. Under these circumstances, most subsurface water utilized for agriculture turns brackish and has a high concentration of soluble salt ions like Na^+ and Cl and a low concentration of K^+, Ca^{2+}, and NO_3 ions [2, 99]. These ions cause "oxidative stress," which decreases metabolic activity, and "hyper ionic salt stress," which generates "reactive oxygen species" (ROS), which lowers agricultural output [23, 38].

3.9.1 Salinity's Effects on Crop Physiology

Salinity harms plants in two separate ways: osmotic stress and ion toxicity. Because Na^+ and Cl are absorbed, there is a brief negative effect that reduces the osmotic potential between the soil solution and the roots and limits water availability [1]. Second, ion toxicity caused by excessive Na^+, Cl, or $SO_2{}^4$, $SO_4{}^{2-}$ concentrations reduces the efficiency with which nutrients are absorbed [154]. Electrical conductivity (EC), a gauge of a plant's susceptibility to salt stress, and sodium chloride (NaCl) toxicity are strongly related [63]. Beyond 2 dSm1, crop tolerance declines, however certain plants can still thrive at 8 dSm1. Growth and yield are significantly impacted over this point. Figure 2 lists the detrimental consequences of salinity on crop shape, physiology, and yield. Poor germination occurs when seeds are planted in salinity [158]. Salinity impacts seedling emergence and reduces endogenous phytohormone levels [35]. If seeds are sown during the first salinity phase, further stages of shoot growth will be harmed [37, 166]. The yield will eventually be affected, even if seedlings are strong and continue to grow normally throughout the second salinity phase. Numerous physiological processes in plants are impacted by salinity, for example, reduced stomatal conductivity limits the capacity for C-fixation, interferes with the catalytic activities of C-fixing enzymes, and degrades pigments essential for photosynthetic processes [107]. Plants grown in salty soil have shown a significant decrease in shoot and root biomass [45, 69] (Fig. 2).

Studies have shown that the production of Triticum aestivum was decreased by up to 65% in the presence of salt (10 mM NaCl) [78, 140]. By lowering K, Ca, and Mg absorption, high salt concentrations disrupted stomatal conductance and transpiration rate [77, 152], iron (Fe) is an essential metal activator (co-factor) of numerous antioxidant enzymes that helps to control plant life-sustaining activities including photosynthesis and chloroplast production [142]. Iron is lacking in saline sodic soil, according to Rabhi et al. [115]. Such soil caused interveinal chlorosis and reduced yields in plants [84]. In salty settings, the chloride ion (Cl) predominates, and its uptake is inversely linked. In reaction to salt, crops often suffer a decrease in nitrate uptake as well as an increase in Cl absorption [54, 70, 131, 168, 176].

Salinity causes a secondary stress known as oxidative stress, which produces ROS, which is made up of O_2, OH, and H_2O_2 [7, 28, 165]. ROS are typically present in the chloroplast, mitochondria, and peroxisome as a side consequence of aerobic metabolism. As a result of their increased production, lipid peroxidation occurs,

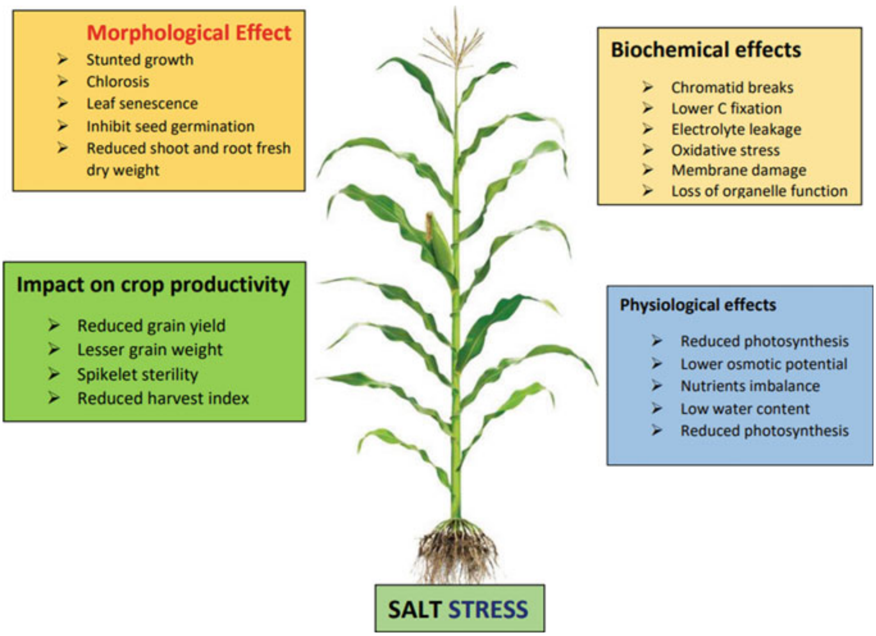

Fig. 2 Effects of salt stress on the biochemistry, physiology, and production of crops

which lowers enzyme activity, hinders photosynthesis, decreases membrane permeability, oxidizes lipids, destroys nucleic acids, and triggers programmed cell death [7, 97, 151, 153]. Due to the extreme salinity of the water, plants such as Brassica napus and Triticum aestivum that were cultivated in saline circumstances displayed low development and yield.

4 Conclusion

The effects of global climate change are expected to change soil physical parameters like texture, structure, bulk density, porosity, nutrient retention, etc., affecting the soil fertility through which it may cause salinization of the soil, reduce nutrient and water availability, alter C and N dynamics, and reduce soil biodiversity. The chemical properties of soil, such as pH, salinity, cation exchange capacity, nutrient cycle, and acquisition, are most affected negatively by climate change. The nitrogen and carbon cycles of the soil are strongly linked to its physical, chemical, and biological features, which in turn balance soil fertility. The variation in the decomposition rate of soil organic matter affects the majority of soil functions, such as pH, cation exchange capacity, water and nutrient retention, and soil structure.

References

1. Abbasi H, Jamil M, Haq A, Ali S, Ahmad R, MaliK Z (2016) Salt stress manifestation on plants, mechanism of salt tolerance and potassium role in alleviating it: a review. Zemdirbyste-Agricul 103:229–238. https://doi.org/10.13080/z-a.2016.103.030
2. Abro SA, Mahar AR, Talpur KH (2007) Effective use of brackish water on saline-sodic soils for rice and wheat production. Pak J Bot 39:2601–2606
3. Aggarwal PK, Jarvis A, Campbell BM, Zougmoré RB, Khatri-Chhetri, Vermeulen SJ, Loboguerrero A, Sebastian LS, Kinyangi J, Bonilla-Findji O, Radeny M, Recha J, Martinez-Baron D, Ramirez-Villegas J, Huyer S, Thornton P, Wollenberg E, Hansen J, Alvarez-Toro P, Aguilar-Ariza A, Arango-Londoño D, Patiño-Bravo V, Rivera O, Ouedraogo M, Tan Yen B (2018) The climate-smart village approach: framework of an integrative strategy for scaling up adaptation options in agriculture. Ecol Soc 23(1):14
4. An Y, Wan S, Zhou X, Subedar AA, Wallace LA, Luo Y (2005) Plant nitrogen concentration, use efficiency, and contents in a tallgrass prairie ecosystem under experimental warming. Glob Change Biol 11:1733–1744
5. Anawar HM (2013) Impact of climate change on acid mine drainage generation and contaminant transport in water ecosystems of semi-arid and arid mining areas. Phys Chem Earth Parts A/B/C 58:13–21
6. Anawar HM (2015) Sustainable rehabilitation of mining waste and acid mine drainage using geochemistry, mine type, mineralogy, texture, ore extraction and climate knowledge. J Environ Manag 158:111–121
7. Apel K, Hirt H (2004) Reactive oxygen species: metabolism, oxidative stress, and signal transduction. Annu Rev Plant Biol 55:373–399. https://doi.org/10.1146/annurev.arplant.55.031903.141701

8. Ashraf MY, Akhtar K, Sarwar G, Ashraf M (2002) Evaluation of arid and semi-arid ecotypes of guar (Cyamopsis tetragonoloba L.) for salinity (NaCl) tolerance. J Arid Environ 52:473–482. https://doi.org/10.1006/jare.2002.1017
9. Ayanlade A, Radeny M, Morton JF, Muchaba T (2018) Rainfall variability and drought characteristics in two agro-climatic zones: an assessment of climate change challenges in Africa. Sci Total Environ 630:728–737. https://doi.org/10.1016/j.scitotenv.2018.02.196
10. Bannari A, Al-Ali ZM (2020) Assessing climate change impact on soil salinity dynamics between 1987–2017 in arid landscape using Landsat TM, ETM+ and OLI data. Remote Sens 12:2794. https://doi.org/10.3390/rs12172794
11. Berkeley Earth (2019) http://www.berkeleyearth.org.data. Accessed on 17 July 2022
12. Bharti C, Ahmed B, Maurya A (2021) A review on conservation agriculture (CA) and sustainable food production. J Ext Syst 37(1):22–27
13. Bhuiyan M, Dutta D (2012) Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh. Estuarine Coast Shelf Sci 96:219–227. https://doi.org/10.1016/j.ecss.2011.11.005
14. Birthal PS, Negi DS, Kumar S, Agarwal S, Suresh A, Khan MT (2014) How sensitive is Indian agriculture to climate change? India J Agric Econ 69(4):474–487
15. Bormann H (2012) Assessing the soil texture-specific sensitivity of simulated soil moisture to projected climate change by SVAT modelling. Geoderma 185–186:73–83
16. Boxall ABA, Hardy A, Beulke S, Boucard T, Burgin L, Falloon PD, Haygarth PM, Hutchinson T, Kovats RS, Leonardi G et al (2009) Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. Environ Health Perspect 117:508–514
17. Brady NC, Weil RR (2008) The nature and properties of soils, 14th ed. Pearson Prentice Hall, Upper Saddle River, NJ, USA
18. Brammer H (2016) Floods, cyclones, drought and climate change in Bangladesh: a reality check. Int J Environ Stud 73(6):865–886
19. Brevik EC (2013) An introduction to soil science basics. In: Brevik EC, Burgess LC (eds) Soils and human health. CRC Press, Boca Raton, FL, USA, pp 3–28
20. Brevik EC (2009) Soil health and productivity. In: Verheye W (ed) Soils, plant growth and crop production. Encyclopedia of life support systems (EOLSS), Developed under the Auspices of the UNESCO, EOLSS Publishers: Oxford, UK. http://www.eolss.net. Accessed on 10 May 2013
21. Brown RD, Braaten RO (1998) Spatial and temporal variability of Canadian monthly snow depths, carbon balance of Arctic tundra ecosystems. Bioscience 55:408–415
22. Carney KM, Hungate BA, Drake BG, Megonigal JP (2007) Altered soil microbial community at elevated CO_2 leads to loss of soil carbon. Biol Sci 104(12):4990–4995
23. Caverzan A, Casassola A, Brammer SP (2016) Antioxidant responses of wheat plants under stress. Genet Mol Biol 39:1–6. https://doi.org/10.1590/1678-4685-GMB-2015-0109
24. Chakrabarty M (2016) Climate change and food security in India. Observer Research Foundation (ORF), New Delhi, India
25. Chakrapani V, Patra SK, Panda RP, Rasal KD, Jayasankar P, Barman HK (2016) Establishing targeted carp TLR22 gene disruption via homologous recombination using CRISPR/Cas9. Dev Comp Immunol 61:242–247. Change Biol 17:1394–1407
26. Chapagain PS, Ghimire M, Shrestha S (2019) Status of natural springs in the Melamchi region of the Nepal Himalayas in the context of climate change. Environ Dev Sustain 21(1):263–280
27. Chatterjee R, Acharya SK, Biswas A, Mandal A, Biswas T, Das S, Mandal B (2021) Conservation agriculture in new alluvial agro-ecology: differential perception and adoption. J Rural Stud 88:14–27
28. Chawla S, Jain S, Jain V (2013) Salinity induced oxidative stress and antioxidant system in salt-tolerant and salt-sensitive cultivars of rice (Oryza sativa L.). J Plant Biochem Biotechnol 22:27–34. https://doi.org/10.1007/s13562-012-0107-4
29. Chen J, Zhou HC, Pan Y, Shyla FS, Tam NF-Y (2016) Effects of polybrominated diphenyl ethers and plant species on nitrification, denitrification and anammox in mangrove soils. Sci Total Environ 553:60–70

30. De Paz JM, Viscontia F, Molina MJ, Ingelmo F, Martinez D, Sanchezb J (2012) Prediction of the effects of climate change on the soil salinity of an irrigated area under Mediterranean conditions. J Environ Manag 95:53783
31. Dev SM, Sharma AN (2010) Food security in India: performance, challenges and policies
32. Dhankher OP, Foyer CH (2018) Climate resilient crops for improving global food security and safety. Plant Cell Environ 41:877–884. https://doi.org/10.1111/pce.13207
33. Dhawan V (2017) Water and agriculture in India—Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture (GFFA). German Asia-Pacific Business Association, German Agri-Business alliance, TERI. https://www.oav.de/fileadmin/user_upload/5_Publikationen/5_Studien/170118_Study_Water_Agriculture_India.pdf. Accessed on 7 July 2022
34. Duchenne-Moutien RA, Neetoo H (2021) Climate change and emerging food safety issues: a review. J Food Prot 84(11):1884–1897
35. Egamberdieva D, Kucharova Z (2009) Selection for root colonising bacteria stimulating wheat growth in saline soils. Biol Fertil Soils 45:563–571. https://doi.org/10.1007/s00374-009-0366-y
36. Eglin T, Ciasis P, Piao SL, Barré P, Belassen V, Cadule P, Chenu C, Gasser T, Reichstein M, Smith (2011) Overview on response of global soil carbon pools to climate and land-use changes
37. El Sayed HESA (2011) Influence of salinity stress on growth parameters, photosynthetic activity and cytological studies of Zea mays, L. plant using hydrogel polymer. Agric Biol J Am 2:907–920. https://doi.org/10.5251/abjna.2011.2.6.907.920
38. El-Hendawy SE, Hu Y, Yakout GM, Awad AM, Hafiz SE, Schmidhalter U (2005) Evaluating salt tolerance of wheat genotypes using multiple parameters. Eur J Agron 22:243–253. https://doi.org/10.1016/j.eja.2004.03.002
39. FAO (2008) Land and plant nutrition management service. htpp://www.fao.org/ag/agl/agll/spush. Accessed 17 September 2020
40. FAO (2019) Conservation agriculture. http://www.fao.org/conservation-agriculture/overview/what-is-conservation-agriculture/en/. Accessed on 7 July 2022
41. FAO F (2017) The future of food and agriculture–trends and challenges. New York, NY
42. FAOSTAT (2018) Statistical databases and data-sets of the food and agriculture. Organization of the United Nations. http://faostat.fao.org. Accessed on 7 July 2022
43. FOG K (1988) The effect of added nitrogen on the rate of decomposition of organic matter. Biol Rev 63:433–462
44. Gathala MK, Timsina J, Islam MS, Krupnik TJ, Bose TR, Islam N, Rahman MM, Hossain MI, Harun-Rashid AR, Ghosh AK, Hasan MMK, Khayer MA, Islam MZ, Tiwari TP, McDonald AJ (2016) Productivity, profitability, and energetics: a multi-criteria and multi-location assessment of farmers' tillage and crop establishment options in intensively cultivated environments of South Asia. Field Crops Res 186:32–46
45. Genc Y, Taylor J, Lyons GH, Li Y, Cheong J, Appelbee M et al (2019) Bread wheat with high salinity and sodicity tolerance. Front Plant Sci 10:1280. https://doi.org/10.3389/fpls.2019.01280
46. Gengmao Z, Yu H, Xing S, Shihui L, Quanmei S, Changhai W (2015) Salinity stress increases secondary metabolites and enzyme activity in safflower. Indust Crops Prod 64:175–181. https://doi.org/10.1016/j.indcrop.2014.10.058
47. Ghosh M, Ghosal S (2021) Climate change vulnerability of rural households in flood-prone areas of Himalayan foothills, West Bengal, India. Environ Dev Sustain 23(2):2570–2595
48. Gill RA, Polley HW, Johnson HB, Anderson LJ, Maherali H, Jackson RB (2002) Nonlinear grassland responses to past and future atmospheric CO_2. Nature 417:279–282
49. GoI (2018) National action plan on climate change. Prime Minister's Council on Climate Change, Ministry of Environment, Forest, and Climate Change, Government of India, New Delhi. Accessed on 6 July, 2022
50. Gorissen A, Tietema A, Joosten NN, Estiarte M, Peñuelas J, Sowerby A, Emmett BA, Beier C (2004) Climate change affects carbon allocation to the soil in shrublands. Ecosystems 7:650–661

51. Grace PR, Colunga-Garcia M, Gage SH, Robertson GP, Safir GR (2006) The potential impact of agricultural management and climate change on soil organic carbon of the north central region of the United States. Ecosystems 9:816–827
52. Harikrishna YV, Naberia S, Pradhan S, Hansdah P (2019) Agro-economic impact of climate resilient practices on farmers in Anantapur District of Andhra Pradesh. Indian J Ext Educ 55(4):91–95
53. Hashem A, Alqarawi AA, Radhakrishnan R, Al-Arjani ABF, Aldehaish HA, Egamberdieva D et al (2018) Arbuscular mycorrhizal fungi regulate the oxidative system, hormones and ionic equilibrium to trigger salt stress tolerance in Cucumis sativus L. Saudi J Biol Sci 25:1102–1114. https://doi.org/10.1016/j.sjbs.2018.03.009
54. Hassan TU, Bano A, Naz I (2017) Alleviation of heavy metals toxicity by the application of plant growth promoting rhizobacteria and effects on wheat grown in saline sodic field. Int J Phytoremed 19:522–529. https://doi.org/10.1080/15226514.2016.1267696
55. Hillel D (1973) Soil and physical principles and processes, 3rd ed. Academic Press, New York
56. Holland EA (2011) The Role of soils and biogeochemistry in the climate and earth system. In: Sauer TJ, Norman JM, Sivakumar MVK (eds) Sustaining soil productivity in response to global climate change: science, policy, and ethics. Wiley, Oxford, UK, pp 155–168
57. Hong CO, Lee DK, Chung DY, Kim PJ (2007) Liming effects on cadmium stabilization in upland soil affected by gold mining activity. Arch Environ Contam Toxicol 52:496–502
58. Horel A, Lichner L, Alaoui A, Czachor H, Nagy V, Tóth E (2014) Transport of iodide in structured clay-loam soil under maize during irrigation experiments analyzed using HYDRUS model. Biologia 69:1531–1538
59. Hungate BA, Dukes JS, Shaw MR, Luo Y, Field CB (2003) Nitrogen and climate change. Science 302:1512–1513
60. Hussain HA, Men S, Hussain S, Chen Y, Ali S, Zhang S et al (2019) Interactive effects of drought and heat stresses on morpho-physiological attributes, yield, nutrient uptake and oxidative status in maize hybrids. Sci Rep 9:1–12. https://doi.org/10.1038/s41598-019-40362-7
61. ICAR (2018) National innovations in climate resilient agriculture. http://www.nicra-icar.in/nicrarevised/index.php/home1. Accessed on 6 July 2022
62. IPCC (2007) Summary for policymakers. In: Climate change 2007: impacts, adaptation and vulnerability
63. Isla R, Aragüés R (2010) Yield and plant ion concentrations in maize (Zea mays L.) subject to diurnal and nocturnal saline sprinkler irrigations. Field Crops Res 116:175–183. https://doi.org/10.1016/j.fcr.2009.12.008
64. Jamil A, Riaz S, Ashraf M, Foolad MR (2011) Gene expression profiling of plants under salt stress. CRC Crit Rev Plant Sci 30:435–458. https://doi.org/10.1080/07352689.2011.605739
65. Jat ML, Dagar JC, Sapkota TB, Govaerts B, Ridaura SL, Saharawat YS, Sharma RK, Tetarwal JP, Jat RK, Hobbs H, Stirling C (2016) Chapter three climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia and Latin America. Adv Agron 137:127–235. https://doi.org/10.1016/bs.agron.2015.12.005
66. Jeppesen E, Kronvang B, Meerhoff M, Søndergaard M, Hansen KM, Andersen HE, Lauridsen TL, Liboriussen L, Beklioglu M, Özen A et al (2009) Climate change effects on runoff, catchment phosphorus loading and lake ecological state, and potential adaptations. J Environ Qual 38:1930–1941
67. Jesus JM, Danko AS, Fiúza A, Borges M-T (2015) Phytoremediation of salt-affected soils: a review of processes, applicability, and the impact of climate change. Environ Sci Pollut Res 22:6511–6525
68. Joshi AB, Vann DR, Johnson AH (2005) Litter quality and climate decouple nitrogen mineralization and productivity in Chilean temperate rainforests. Soil Sci Soc Am J 70:153–162
69. Kalhoro NA, Rajpar I, Kalhoro SA, Ali A, Raza S, Ahmed M et al (2016) Effect of salts stress on the growth and yield of wheat (Triticum aestivum L.). Am J Plant Sci 7:2257. https://doi.org/10.4236/ajps.2016.715199

70. Kanagaraj G, Desingh R (2017) Salinity influences physiological traits of seven Sesame (Sesamum indicum L.) varieties. J Sci Agri 1:188–196. https://doi.org/10.25081/jsa.2017.v1.59
71. Karmakar R, Das I, Dutta D, Rakshit A (2016) Potential effects of climate change on soil properties: a review
72. Kasim WA, Osman ME, Omar MN, El-Daim IAA, Bejai S, Meijer J (2013) Control of drought stress in wheat using plant-growth-promoting bacteria. J Plant Growth Regul 32:122–130. https://doi.org/10.1007/s00344-012-9283-7
73. Kasliwal R (2021) The new green revolution: a just transition to climate-smart crops. ORF Issue Brief 433:8–9
74. Kaur N, Alok A, Shivani, Kaur N, Pandey P, Awasthi P, Tiwari S (2018) CRISPR/Cas9-mediated efficient editing in phytoenedesaturase (PDS) demonstrates precise manipulation in banana cv. Rasthali genome. Funct Integr Genom 18(1):89–99
75. Kaushik G, Sharma KC (2015) Climate change and rural livelihoods-adaptation and vulnerability in Rajasthan. Global NEST J 17(1):41–49
76. Kelkar N (2016) Digging our rivers' graves. Dams, Rivers, People Newsl 14:1–6
77. Keutgen AJ, Pawelzi KE (2009) Impacts of NaCl stress on plant growth and mineral nutrient assimilation in two cultivars of strawberry. Environ Exp Bot 65:170–176. https://doi.org/10.1016/j.envexpbot.2008.08.002
78. Khan MA, Hussain N, Abid M, Imran T (2004) Screening of wheat (Triticum aestivum L.) cultivars for saline conditions under irrigated arid environment. J Res 11:471–477
79. Khatri-Chhetri A, Aryal JP, Sapkota TB, Khurana R (2016) Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. Curr Sci 110(7):1251–1256
80. Kirkham MB (2011) Elevated carbon dioxide. CRC Press, Boca Raton, FL
81. Krupnik TJ, Schulthess U, Ahmed ZU, McDonald AJ (2017) Sustainable crop intensification through surface water irrigation in Bangladesh? A geospatial assessment of landscape-scale production potential. Land Use Policy 60:206–222
82. Kulkarni A, Sabin TP, Chowdary JS, Rao KK, Priya P, Gandhi N, Bhaskar P, Buri VK, Sabade SS, Pai DS, Ashok K (2020) Precipitation changes in India. In: Assessment of climate change over the Indian Region. Springer, Singapore, pp 47–72
83. Kumar S, Thombare P, Kale P (2019) Climate smart agriculture: Challenges, implications, innovations for achieving food and nutrition security. Agric Food e-Newsl 1(9):267–271
84. Lan P, Li W, Wen TN, Shiau JY, Wu YC, Lin W et al (2011) iTRAQ protein profile analysis of Arabidopsis roots reveals new aspects critical for iron homeostasis. Plant Physiol 155:821–834. https://doi.org/10.1104/pp.110.169508
85. Li Z, Lui W-Z, Zhang X-C, Zheng F-L (2011) Assessing the site-specific impacts of climate change on hydrology, soil erosion, and crop yields in the Loess Plateau of China. Clim Change 105:223–242
86. Lin Y, Feng Z, Wu W, Yang Y, Zhou Y, Xu C (2017) Potential impacts of climate change and adaptation on maize in northeast China. Agron J 109:1476–1490. https://doi.org/10.2134/agronj2016.05.0275
87. Link SO, Smith JL, Halverson JJ, Bolton H Jr (2003) A reciprocal transplant experiment within a climatic gradient in a semiarid shrub-steppe ecosystem: effects on bunchgrass growth and reproduction, soil carbon, and soil nitrogen. Global Change Biol 9(7):1097–1105. https://doi.org/10.1046/j.1365-2486.2003.00647.x
88. Lu X, Mao Q, Gilliam FS, Luo Y, Mo J (2014) Nitrogen deposition contributes to soil acidification in tropical ecosystems. Glob Chang Biol 20:3790–3801
89. Macrae ML, Devito KJ, Strack M, Waddington JM (2013) Effect of water table drawdown on peatland nutrient dynamics: implications for climate change. Biogeochemistry 112:661–676. https://doi.org/10.1007/s10533-012-9730-3
90. Magdoff F, Weil RR (eds) Soil organic matter in sustainable agriculture. CRC Press, Boca
91. Mai NC (2022) Measuring and mapping food security status of Rajasthan, India: a district-level analysis

92. Malhotra SK (2017) Horticultural crops and climate change: a review. Indian J Agric Sci 87(1):12–22
93. Martinez-Beltran J (2005) Overview of salinity problems in the world and FAO strategies to address the problem. In: Managing saline soils and water: science, technology and social issues. Proceedings of the international salinity forum, Riverside, CA
94. Mazumdar S, Quick WP, Bandyopadhyay A (2016) CRISPR-Cas9 mediated genome editing in rice, advancements and future possibilities. Indian J Plant Physiol 21(4):437–445
95. McGowen SL, Basta NT, Brown GO (2001) Use of diammonium phosphate to reduce heavy metal solubility and transport in smelter-contaminated soil. J Environ Qual 30:493–500
96. Mills RTE, Gavazov KS, Spiegelberger T, Johnson D, Buttler A (2014) Diminished soil functions occur under simulated climate change in a sup-alpine pasture, but heterotrophic temperature sensitivity indicates microbial resilience. Sci Total Environ 473–474:465–472. https://doi.org/10.1016/j.scitotenv.2013.12.071
97. Mishra S, Jha AB, Dubey RS (2011) Arsenite treatment induces oxidative stress, upregulates antioxidant system, and causes phytochelatin synthesis in rice seedlings. Protoplasma 248:565–577. https://doi.org/10.1007/s00709-010-0210-0
98. Munns R (2002) Comparative physiology of salt and water stress. Plant Cell Environ 25:239–250. https://doi.org/10.1046/j.0016-8025.2001.00808.x
99. Munns R, Tester M (2008) Mechanisms of salinity tolerance. Annu Rev Plant Biol 59:651–681. https://doi.org/10.1146/annurev.arplant.59.032607.092911
100. Naidu R, Kookana RS, Sumner ME, Harter RD, Tiller KG (1997) Cadmium sorption and transport in variable charge soils: a review. J Environ Qual 26:602–617
101. Naresh KS, Aggarwal PK, Swaroopa Rani DN, Saxena R, Chauhan N, Jain S (2014) Vulnerability of wheat production to climate change in India. Clim Res 59(173–187):5–187
102. Natali SM, Schuur EA, Trucco C, Hicks Pries CE, Crummer KG, Baron Lopez AF (2011) Effects of experimental warming of air, soil and permafrost on carbon balance in Alaskan tundra. Glob Change Biol 17(3):1394–1407
103. Niklińska M, Maryański M, Laskowski R (1999) Effect of temperature on humus respiration rate and nitrogen mineralization: implications for global climate change. Biogeochemistry 44:239–257
104. Norby RJ, Luo Y (2004) Evaluating ecosystem responses to rising atmospheric CO_2 and global warming in a multi-factor world. New Phytol 162:281–293
105. Ok YS, Oh S-E, Ahmad M, Hyun S, Kim K-R, Moon DH, Lee SS, Lim KJ, Jeon W-T, Yang JE (2010) Effects of natural and calcined oyster shells on Cd and Pb immobilization in contaminated soils. Environ Earth Sci 61:1301–1308
106. Okur B, Örçen N (2020) Soil salinization and climate change. In: Prasad MNV, Pietrzykowski M (eds) Climate change and soil interactions
107. Omoto E, Taniguchi M, Mayake H (2012) Adaptation responses in C4 photosynthesis of maize under salinity. J Plant Physiol 169:469–477. https://doi.org/10.1016/j.jplph.2011.11.009
108. Pal BD, Joshi PK, Tyagi NK (2019) Two-way association between agriculture and climate change. In: Climate smart agriculture in South Asia. Springer, Singapore, pp 1–16
109. Palanisami K, Kakumanu KR, Khanna M, Aggarwal PK (2013) Climate change and food security of India: adaptation strategies for the irrigation sector. World Agric 3:20–26
110. Palanisami K, Kumar DS, Malik RPS, Raman S, Kar G, Monhan K (2015) Managing water management research: analysis of four decades of research and outreach programmes in India. Econ Pol Wkly I(26&27):33–43
111. Porter JR, Xie L, Challinor AJ, Cochrane K et al (2014). Food security and food production systems. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge/New York, pp 485–533

112. Pradhan A, Chan C, Roul PK, Halbrendt J, Sipes B (2018) Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: a transdisciplinary approach. Agric Syst 163:27–35
113. Price DT, Peng CH, Apps MJ, Halliwell DH (1999) Simulating effects of climate change on boreal ecosystem carbon pools in central Canada. J Biogeogr 26:1237–1248
114. Qadir M, Oster JD, Schubert S, Noble AD, Sahrawat KL (2007) Phytoremediation of sodic and saline-sodic soils. Adv Agron 96:197–247. https://doi.org/10.1016/S0065-2113(07)96006-X
115. Rabhi M, Talbi O, Atia A, Abdelly C, Smaoui A (2008) Selection of a halophyte that could be used in the bioreclamation of salt-affected soils in arid and semi-arid regions. In: Abdelly C, Öztürk M, Ashraf M, Grignon C (eds) Biosaline agriculture and high salinity tolerance, BirKhäuser, Basel, pp 241–246. https://doi.org/10.1007/978-3-7643-8554-5_22
116. Rahman AKMM, Ahmed KM, Butler AP, Hoque MA (2018) Influence of surface geology and micro-scale land use on the shallow subsurface salinity in deltaic coastal areas: a case from southwest Bangladesh. Environ Earth Sci 77:423. https://doi.org/10.1007/s12665-018-7594-0
117. Rani R, Yadav P, Barbadikar KM, Baliyan N, Malhotra EV, Singh BK et al (2016) CRISPR/Cas9: a promising way to exploit genetic variation in plants. Biotechnolnol Lett 38(12):1991–2006
118. Rattani V (2018) Coping with climate change: an analysis of India's national action plan on climate change. Centre for Science and Environment, New Delhi.
119. Ravi S, Breshears DD, Huxman TE, D'Odorico P (2010) Land degradation in drylands: interactions among hydraulic-aeolian erosion and vegetation dynamics. Geomorphology 116:236–245
120. Ray DK, Gerber JS, MacDonald GK, West PC (2015) Climate variation explains a third of global crop yield variability. Nat Commun 6:5989
121. Ray K, Hasan SS, Goswami R (2018) Techno-economic and environmental assessment of different rice-based cropping systems in an inceptisol of West Bengal, India. J Clean Prod 205:350–363
122. Reich PB, Hobbie SE, Lee T, Ellsworth DS, West JB, Tilman D, Knops JM, Naeem S, Trost J (2006) Nitrogen limitation constrains sustainability of ecosystem response to CO_2. Nature 440:922–925
123. Reich PB, Hungate BA, Luo Y (2006) Carbon-nitrogen interactions in terrestrial ecosystems in response to rising atmospheric carbon dioxide. Annu Rev Ecol Evol Syst 37:611–636
124. Reth S, Reichstein M, Falge E (2005) The effect of soil water content, soil temperature, soil pH-value and the root mass on soil CO_2 efflux – A modified model. Plant Soil 268:21–33
125. Reubens B, Poesen J, Danjon F, Geudens G, Muys B (2007) The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. Trees 21:385–402
126. Roul PK, Pradhan A, Ray P, Mishra KN, Dash SN, Chan C (2015) Influence of maize-based conservation agricultural production systems (CAPS) on crop yield, profit and soil fertility in rainfed uplands of Odisha, India in conservation agriculture. In: Chan C, Fantle-Lepczyk K (eds) Subsistence farming: case studies from South Asia and beyond. CABI, Wallingford, UK, pp 95–108
127. Rounsevell M, Evans SP, Bullock P (1999) Climate change and agricultural soils: impacts and adaptation. Clim Change 43:683–709
128. Roy S (2011) Flood hazards in Jalpaiguri District. Unpublished PhD.Thesis, Department of Applied Geography, University of North Bengal, Siliguri
129. Rudra K, Mukherjee S, Mukhopadhayay UK, Gupta D (2017) State of environmental report: West Bengal. Saraswaty Press, Kolkata
130. Rustad LE, Campbell J, Marion G, Norby R, Mitchell M, Hartley A, Cornelissen J, Gurevitch J (2001) A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia 126(4):543–562. https://doi.org/10.1007/s004420000544

131. Sadale AN, Karadge BA (2013) Effect of salinity and water stress on nitrogen metabolism in Sesbania grandiflora (L.) Poir. Bioinfolet-A Q J Life Sci 10:814–818
132. Sardans J, Peñuelas J, Estiarte M (2008) Changes in soil enzymes related to C and N cycle and in soil C and N content under prolonged warming and drought in a mediterranean shrubland. Appl Soil Ecol 39:223–235
133. Sarkar S, Padaria RN, Das S, Das B, Biswas G, Roy D, Sarkar A (2022) Conceptualizing and validating a framework of climate smart village in flood affected ecosystem of West Bengal. Indian J Ext Educ 58(2):1–7
134. Schimel JP, Bilbrough C, Welker JM (2004) Increased snow depth affects microbial activity and nitrogen mineralization in two Arctic tundra communities. Soil Biol Biochem 36(2):217–227
135. Schofield RV, Kirkby MJ (2003) Application of salinization indicators and initial development of sensitivity indicates microbial resilience. Sci Total Environ 473:465–472
136. Schofield RV, Kirkby MJ (2003) Application of salinization indicators and initial development of potential global soil salinization scenario under climatic change. Glob Biogeochem Cycles 17(3):1078. https://doi.org/10.1029/2002GB001935,2003
137. Serpa D, Nunes JP, Keizer JJ, Abrantes N (2017) Impacts of climate and land use changes on the water quality of a small Mediterranean catchment with intensive viticulture. Environ Pollut 224:454–465
138. Seshadri B, Bolan N, Wijesekara H, Kunhikrishnan A, Thangarajan R, Qi F, Matheyarasu R, Rocco C, Mbene K, Naidu R (2016) Phosphorus–cadmium interactions in paddy soils. Geoderma 270:43–59
139. Setia R, Gottschalk P, Smith P, Marschner P, Baldock J, Setia D et al (2013) Soil salinity decreases global soil organic carbon stocks. Sci Total Environ 465:267–272. https://doi.org/10.1016/j.scitotenv.2012.08.028
140. Shafi M, Bakhat J, Khan MJ, Khan MA, Anwar S (2010) Effect of salinity on yield and ion accumulation of wheat genotypes. Pak J Bot 42:4113–4121
141. Sharma BC, Kumar R, Slathia PS, Puniya R, Vaid A (2022) Evaluation of refresher training programme on conservation agriculture practices. Indian J Ext Educ 58(1):49–52
142. Sharma P, Jha AB, Dubey RS, Pessarakli M (2012) Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. J Bot 2012:217037. https://doi.org/10.1155/2012/217037
143. Shiferaw B, Sahoo A, Sika G, Ghosh J (2016) A CGE analysis of the implications of technological change in Indian agriculture
144. Shrestha S (2019) Effects of climate change in agricultural insect pest. Acta Sci Agric 3:74–80. https://doi.org/10.31080/ASAG.2019.03.0727
145. Singh BP, Cowie AL, Chan KY (eds) (2011) Soil health and climate change, soil biology. Springer
146. Singh N, Sharma DP, Chand H (2016) Impact of climate change on apple production in India: a review. Current World Environ 11(1):251
147. Sivakumar MVK (2011) Climate and land degradation. In: Sauer TJ, Norman JM, Sivakumar MVK (eds) Sustaining soil productivity in response to global climate change: science, policy, and ethics. Wiley, Oxford, UK, pp 141–154
148. Smith JL, Halvorson JJ, Bolton H Jr (2002) Soil properties and microbial activity across a 500 m elevation gradient in a semi-arid environment. Soil Biol Biochem 34(11):1749–1757. https://doi.org/10.1016/S0038-0717(02)00162-1
149. Spiegal S, Bestelmeyer BT, Archer DW, Augustine DJ, Boughton EH, Boughton RK, Cavigelli MA, Clark PE, Derner JD, Duncan EW, Hapeman CJ (2018) Evaluating strategies for sustainable intensification of US agriculture through the long-term agroecosystem research network. Environ Res Lett 13(3):034031
150. Srivastava D, Shamim M, Kumar M, Mishra A, Pandey P, Kumar D et al (2017) Current status of conventional and molecular interventions for blast resistance in rice. Rice Sci 24(6):299–321

151. Srivastava S, Dubey RS (2011) Manganese-excess induces oxidative stress, lowers the pool of antioxidants and elevates activities of Key antioxidative enzymes in rice seedlings. Plant Growth Regul 64:1–16. https://doi.org/10.1007/s10725-010-9526-1
152. Sumer A (2004) Evidence of sodium toxicity for the vegetative growth of maize during the first phase of salt stress. J Appl Bot 78:135–139
153. Tanou G, Molassiotis A, Diamantidis G (2009) Induction of reactive oxygen species and necrotic death-like destruction in strawberry leaves by salinity. Environ Exp Bot 65:270–281. https://doi.org/10.1016/j.envexpbot.2008.09.005
154. Tavakkoli E, Fatehi F, Coventry S, Rengasamy P, McDonald GK (2011) Additive effects of Na^+ and Cl^- ions on barley growth under salinity stress. J Exp Bot 62:2189–2203. https://doi.org/10.1093/jxb/erq422
155. Teller AS (2016) Moving the conversation on climate change and inequality to the local: socio-ecological vulnerability in agricultural Tanzania. Sociol Dev 2:25–50. https://doi.org/10.1525/sod.2016.2.1.25
156. Temple J (2017) Reinventing source: rice for a world transformed by climate change. MIT Technology. https://www.technologyreview.com/s/604213/reinventing-rice-for-a-world-transformed-by-climate-change/. Accessed on 7 July 2022
157. Thurston JM, Williams E, Johnston A (1976) Modern developments in an experiment on permanent grassland started in 1856: effects of fertilisers and lime on botanical composition and crop and soil analyses. Ann Agron (Fr) 27:1043–1082
158. Ullah A, Bano A (2019) Role of PGPR in the reclamation and revegetation of saline land. Pak J Bot 51:27–35. https://doi.org/10.30848/PJB2019-1(43)
159. Umamaheswari S, Sreeram S, Kritika N, Prasanth DJ (2019) Biot: blockchain based IoT for agriculture. In: 2019 11th international conference on advanced computing (ICoAC). IEEE, pp 324–327
160. Van der Stelt B, Temminghoff EJM, Van Vliet PCJ, Van Riemsdijk WH (2007) Volatilization of ammonia from manure as affected by manure additives, temperature and mixing. Bioresour Technol 98(18):3449–3455
161. Várallyay G (2010) The impact of climate change on soils and on their water management. Agron
162. Vengosh V (2005) Salinization and saline environments. Ben Gurion University of the Negev, Beer
163. Venkatramanan V (2017) Climate change and food security. UGC ePGPathshala. http://epgp.inflibnet.ac.in/epgpdata/uploads/epgp_content/S000017GE/P001781/M025271/ET/1512451985Module36,VVRamanan,ClimateChangeandFoodSecurity.pdf. Accessed on 7th July 2022
164. Venkatramanan V, Shah S (2019) Climate smart agriculture technologies for environmental management: the intersection of sustainability, resilience, wellbeing and development. In: Sustainable green technologies for environmental management. Springer, Singapore, pp 29–51
165. Voothuluru P, Sharp RE (2012) Apoplastic hydrogen peroxide in the growth zone of the maize primary root under water stress. Increased levels are specific to the apical region of growth maintenance. J Exp Bot 64:1223–1233. https://doi.org/10.1093/jxb/ers277
166. Wakeel A, Sümer A, Hanstein S, Yan F, Schubert S (2011) In vitro effect of different Na^+/K^+ ratios on plasma membrane H^+-ATPase activity in maize and sugar beet shoot. Plant Physiol Biochem 49:341–345. https://doi.org/10.1016/j.plaphy.2011.01.006
167. Wan Y, Lin E, Xiong W, Li Y, Guo L (2011) Modeling the impact of climate change on soil organic carbon stock in upland soils in the 21st century in China. Agric Ecosyst Environ 141(1):23–31. https://doi.org/10.1016/j.agee.2011.02.004
168. Wang CJ, Yang W, Wang C, Gu C, Niu DD, Liu HX et al (2012) Induction of drought tolerance in cucumber plants by a consortium of three plant growth-promoting rhizobacterium strains. PLoS ONE 7:e52565. https://doi.org/10.1371/journal.pone.0052565
169. Wang Y, Shi J, Wang H, Lin Q, Chen X, Chen Y (2007) The influence of soil heavy metals pollution on soil microbial biomass, enzyme activity, and community composition near a

copper smelter. Ecotoxicol Environ Saf 67(1):75–81. https://doi.org/10.1016/j.ecoenv.2006.03.007

170. Wassmann R, Villanueva J, Khounthavong M, Okumu BO, Vo TBT, Sander BO (2019) Adaptation, mitigation and food security: multi-criteria ranking system for climate-smart agriculture technologies illustrated for rainfed rice in Laos. Glob Food Sec 23:33–40
171. Wedin DA, Tilman D (1996) Influence of nitrogen loading and species composition on the carbon balance of grasslands. Science 274:1720–1723
172. Westermann O, Förch W, Thornton PK (2015) Reaching more farmers: innovative approaches to scaling up climate smart agriculture. CCAFS Working Paper no. 135. CGIAR research program on climate change, agriculture and food security CCAFS, Copenhagen, Denmark. www.ccafs.cgiar.org. Accessed on 7th July 2022
173. World Bank (2015) Future of food: shaping a climate-smart global food system. World Bank, Washington, DC. Accessed on 6 July 2022
174. World Bank (2016) World Bank Group climate change action plan. Washington: IBRD. Accessed on 6 July 2022
175. Yadav GS, Lal R, Meena RS, Datta M, Babu S, Das A, Layek J, Saha P (2017) Energy budgeting for designing sustainable and environmentally clean/safer cropping systems for rainfed rice fallow lands in India. J Clean Prod 158:29–37
176. Yu Y, Xu T, Li X, Tang J, Ma D, Li Z et al (2016) NaCl-induced changes of ion homeostasis and nitrogen metabolism in two sweet potato (Ipomoea batatas L.) cultivars exhibit different salt tolerance at adventitious root stage. Environ Exp Bot 129:23–36. https://doi.org/10.1016/j.envexpbot.2015.12
177. Zhang XC, Nearing MA, Garbrecht JD, Steiner JL (2004) Downscaling monthly forecasts to simulate impacts of climate change on soil erosion and wheat production. Soil Sci Soc Am J 68:1376–1385
178. Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y et al (2017) Temperature increase reduces global yields of major crops in four independent estimates. Proc Natl Acad Sci 114:9326–9331. https://doi.org/10.1073/pnas
179. Zhu JK (2001) Plant salt tolerance. Trends Plant Sci 6:66–71. https://doi.org/10.1016/S1360-1385(00)01838-0
180. Zobeck TM, Van Pelt RS (2006) Wind-induced dust generation and transport mechanics on a bare agricultural field. J Hazard Mater 132:26–38

Potential Impacts of Climate Change on the Sustainability of Crop Production: A Case in India

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Abstract One of the biggest environmental problems of the twenty-first century is climate change, which is defined as long-term changes. Climate change is defined as a shift in the climate's state that lasts for at least a few decades and can be detected by changes in the mean or the variable nature of its properties. Water and solar energy, which are required for plant growth, are the natural resource foundation for food production. As a result, climate change can effect agriculture productivity in two ways. Firstly, changes in rainfall/precipitation, temperature, and CO_2 levels directly impact plant growth, development, and yield. Secondly, snow melt, irrigation availability, soil organic matter, seasonal droughts and floods, among other factors, may significantly impact agricultural land use. Rainfall controls the availability of water and dictates when to plant. Crop growth is controlled by temperature, while pest and disease incidence is controlled by duration and relative humidity. Photosynthetic productivity is influenced by radiation. Wet and dry spells profoundly impact the physiology of standing crops, resulting in product losses. All of these developments would have a significant impact on India's agricultural production. The

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_12

present chapter focuses on the impact of changing climate on India's crop production sustainability.

Keywords Climate change · Rainfall · Temperature · Weather · Yield reduction

1 Introduction

Climate change is a shift in the climate's statement that may be seen in the structure's flexibility and durability, which can last decades or more. Internal and external causes may contribute to climate change [1]. Changes in solar radiation and volcanoes are external forces that naturally occur and provide diversity in the climate system. Other external changes, such as those induced by human activities in the atmosphere. Food production is reliant on water and sun energy as natural resources. Climate change is a long-term climate change that includes normal temperatures and rainfall. Diversity in weather events results in climate change, this type of change alarms food production, sea-level rise contaminates freshwater reservoirs and increases the risk of catastrophic floods [2].

Climate change defined by how the weather fluctuates yearly, either above or below the long-term value. There is a close relationship between climate and food production [3]. Food production depends on the natural resources of water and solar energy. Therefore, climate change affects agricultural production in two techniques. All of this impact on the crop development and yield due to variations in rain water, and other climate elements [4]. However, modern agriculture uses management techniques, fertilizers, pest control, etc. and increases the yield of food crops. Increasing the use of fertilizers, modern irrigation systems, etc. helps to reduce dependence only on the weather. Therefore, the final product i.e. food items in any one year depends

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on a variety of man-made and natural materials [5]. The overall amount of rainfall received every year is a significant factor among all natural factors. Crop productivity is also influenced by differences in rainfall distribution over a year. For example, a single period of heavy rain, such as in 1979, might affect crop production in India by around 17%. There are various indirect effects on crop production. For example, evapotranspiration levels, which are radiation, temperature, air, humidity, and humidity, determine irrigation schedules. Similarly, the temperature and humidity combination determine insect pests and pathogens' growth rate and development. These indirect effects of climate change have great economic power when combined with modern farm management. Including climate and weather information in the management system for better crop production is challenging due to the dynamic and complex interaction between climate and agricultural production systems [4]. Rain, solar radiation, atmospheric temperature, humidity, and air are common components that determine the weather. All of these have their importance for healthy plant life.

2 Concept of Climate Change

To understand climate change, first of all, you need to be aware of the differences between climate and climate.

- The temperature, precipitation, humidity, wind, and clouds that we experience in space at a specific time and location are referred to as weather.
- The average weather in the area over a lengthy period (30–50 years) is called climate.
- Climate change is a shift in the area's typical weather patterns. This could be a change in the amount of rainfall the area receives on a yearly basis, or a change in the mild local temperature for a specific month or season.

3 What Causes Climate Change?

Earth's equilibrium changes (the amount of energy from the sun entering the earth (and its atmosphere)—the energy released into the atmosphere is a fundamental cause of climate change). Human activities have added a vast amount of greenhouse gases (GHG) to Earth's atmosphere since Industrial Modernization began 200 years ago. Instead of releasing solar energy and heat back into space, these GHGs serve as heat sinks (or blankets or car windows) to absorb it. High temperatures shut down when GHG levels are too high, and global temperatures climb beyond the range of natural changeability. There are a variety of GHGs, each with a unique ability to trap heat (known as "global warming") and play a unique role in space life. Because many GHGs have extra consequences, particularly on human well-being, they are frequently referred to as "climate active pollutants" [6].

Carbon dioxide (CO_2) is a GHG that causes global warming. Combined, those three processes produce more than 80% of the CO_2 emissions that go into the atmosphere [7]. Some other important GHGs include methane, nitrous oxide, carbon black, and other fluorinated gases. These gases emit less CO_2, but they also absorb more heat from the environment than CO_2. The capacity to absorb heat is measured by the potential for global warming (GWP). CO_2, like most prevalent and plentiful greenhouse gases, has a GWP of 1, hence it is used to compare all other GHG warming potential. Climate change, which humans mainly cause, has piqued the interest of all agronomists in recent years. CO_2 is required for green plant growth. The high CO_2 content in the atmosphere will boost photosynthetic processes, crop growth, and agricultural production without raising crop transpiration water demands [8].

On the contrary, expected climate warming could negatively affect agriculture, partially antagonistic to the positive direct greenhouse gas effects. Models predict that the world temperature can rise by 1–3.5 °C by 2100. Forests, deserts, rangelands, sand, and other untapped ecosystems could face new climatic disorders. Consequently, some flora and fauna species can face extinction. Different elements of the planet can face different types of effects (detrimental or beneficial) of temperature change. Studies of the ascertained changes in surfaces temperature over the Indian region are reviewed by Pant et al. [9]. The all-India mean annual surface temperature derived from seventy-three stations across India shows vital warming of 0.4 °C per hundred years, equivalent to the world mean trend of 0.3 °C per hundred years [10]. This increase is due to the contribution of the post-monsoon and winter seasons, there is hardly any trend within the monsoon season temperature. Of the seventy-three stations accustomed to derive the all India average, thirty stations show a big warming trend whereas six show a cooling trend. A comparison of the trends in rainfall and temperature within the belt north of 20 on wherever most models predict a rise shows that the eastern sector exhibits a decreasing trend whereas the western an increasing one, though neither is significant at the majority of the stations.

Crop yields are generally affected by changes in rainfall, greenhouse gas CO_2 concentration, and temperature. Increased rainfall and CO_2 concentrations normally result in an increase in yield, while in the tropics, the impact of rising temperatures is frequently the opposite. As a result, if both rainfall and temperature rise, it's vital to determine if the impact of higher rainfall and CO_2 can outweigh the impact of increased temperature and evapotranspiration over certain locations and crops.

4 Why Short-Lived Climate Pollutants Matter

Impacts of the SLCP occurred shortly, whereas the total impacts from greenhouse gas are going to be undergone later. We must always try for carbon-free transportation and energy systems, to keep the environment, suitable for human habitation. On the other hand, reduced emissions of short-lived climatic pollutants could "buy time" while we work to make the shift.

Reducing global SLCP levels significantly by 2030 will:

- Decrease the global rate of sea-level rise by 20% by 2050
- Cut global warming in half, by 2050, or 0.6 °C, and by 1.4 °C by 2100
- 2.4 million premature deaths globally every year are going to be Checked
- Recover health, particularly for deprived communities
- Many methods to cut back SLCP even have immediate health advantages, such as:
  - Reduce hospitalization related to air pollution
  - Promotion of meat consumption reduction
  - Strict emission restrictions, particularly for diesel cars
  - Clean household stoves in developing countries.

5 Five Critical Global Environmental Changes Due to Climate Change

5.1 Increasing Temperature of the Earth's Surface and the Oceans

Since 1957, the globe has been warming at a pace of 0.13 °C per decade, nearly twice as fast as the rate of temperature rise over the previous century.

5.2 Alterations in the Global Water Cycle ('Hydrologic' Cycle)

Over the last 100 years, there have been shifts in total annual rainfall across the country, with some places facing extended drought and others seeing an increase in yearly rainfall. Storms become more frequent and intense as the atmosphere warms and can hold more water vapour.

5.3 Declining Glaciers and Snowpack

Around the globe, nearly every glacier is melting and falling in size, volume, and size. Billions of people depend on glaciers and meltwater is thus crushed.

5.4 Sea Level Rise

Warmer waters expand, increasing the volume of water in the sea, causing sea-level rise. Sea-level rise is also influenced by melting glaciers and tropical ice.

5.5 Ocean Acidification

The oceans absorb about 25% of CO_2 into the atmosphere, resulting in acidic saltwater.

6 Potential Impacts of Climate Change on Agriculture in India

Agriculture is the sole source of income for half of India's population. Agriculture and related industries make for 15.4% of India's GDP [11]. Farming techniques include choosing a crop suited to the climate, soil type, and available resources, among other factors. As a result, agriculture and production are completely reliant on climatic circumstances [12, 13]. Temperature, rainfall, and sun radiation all impact the agricultural ecosystem, including the livestock, agriculture, and hydrological sectors. According to an international assessment, crop production would decline by 10–40% by 2100 (https://icar.org.in/node/1738). Around 70% of the population of South Asia still lives in pastoral areas, and 75% of them are poor [14]. Improving agricultural output is critical for ensuring food security and national security, particularly for the poorest people, such as small and medium-scale farmers.

Depending on local climate change and weather variability, land use, and management, the consequences of ecological change on crop productivity might be progressive or devastating. It is important to remember that the region's sustainability in terms of crop production, as well as agronomic processes mitigating impacts and other ecosystem services such as soil protection, cleaning, and recycling of water, is important for biodiversity conservation. Climate change and agriculture are interdependent processes, both occurring around the world. Agriculture is at risk of climate change. High temperatures often reduce crop yields; may increase the spread of weeds and pests. Changes in rainfall patterns make it possible for temporary crop failures and to reduce crop production over the long term. Overall, the consequences of climate change on agriculture are likely to be unfavourable, posing a danger to global food security. Climate change will induce crop failure on the most essential crops in underdeveloped countries. The majority of the population in South Asia will be affected. Climate change will affect irrigation crops in all regions, but irrigated crops in South Asia will decline dramatically. The most significant crops—rice, wheat, maize, and soybeans—will increase as a result of climate change. High feed prices contribute to high meat prices, while climate change is expected to slow meat growth. In India, the effects of climate change on agriculture are being further exacerbated by previously thought, especially wheat if a 1 °C temperature rises in areas such as Punjab, UP, and Haryana could be a loss of about several million tons annually, in addition, production from crops such as rice, sorghum, maize can be reduced by up to 10%. Yield reduction may be due to a reduction in the growing season, a decrease in water availability when water is not harvested properly. Climate change impacts biodiversity, which in turn impacts agricultural production, which is especially crucial for small and medium-sized farmers in India. Poor people, particularly those living in low-productivity agricultural areas, rely mostly on a range of natural genes.

Climate variation has a greater impact on local climate change than it does on global climate change. Since 1880, the average worldwide temperature has climbed 0.83 °C. As a result, any evaluation should be carried out independently by identifying each place. It's also worth noting that not all effects of climate change are negative; knowing the possible favourable benefits of CO_2 on plant development and enhancing water usage efficiency can have positive effects on the crop.

7 Projected Impact of Climate Change on Indian Agriculture

When CO_2 levels rise to 550 ppm, rice, wheat, legumes, and oilseed yields increase by 10–20%.

Wheat, soybeans, and mustard [*Brassica juncea* (L) Czernj. Cosson], nuts (*Arachis hypogaea* L) and potatoes (*Solanum tuberosum* L) yields may be reduced by 3–7% if the temperature is raised by 1 °C.

Most agricultural productivity will decline slightly by 2020, but by 10–40% by 2100.

Important impact on the food quality of basmati rice–wheat etc.

Perhaps some improvement in the harvest of chickpea (Cicer arietinum L), winter (Rabi) Maize, sorghum [*Sorghum bicolor* (L) Moench], and barley and coconut (*Cocos nucifera* L.) on the west coast.

Reduced initial damage has resulted in little losses of potatoes, mustard, and vegetables in northwest India.

Droughts and floods are expected to worsen, causing production swings.

Significant effects on microbes, viruses, and insects.

Fish spawning, migration, and harvesting are anticipated to be affected by rising sea and river water temperatures.

Increasing the amount of water, housing, and energy that animals require.

Heat stress in animals; consequences for reproduction.

Inequality in the food trade as a result of favourable effects on Europe and North America but negative ones on us.

8 Effect of Climate Change on Crop Production

Increased CO_2 levels aid the growth and output of C_3 plants in the atmosphere. On the other hand, increased temperature can shorten plant duration, increase plant respiration rate, influence plant–insect balance, accelerate nutrient mineralization in the soil, lower fertiliser efficiency, and increase evapotranspiration things. All of this can significantly affect crop yields over a long period. Increased CO_2 levels are projected to result in increased crop yields and, as a result, will aid in mitigating the detrimental consequences of future global warming. The effects of climate change will alter crop production areas on a worldwide scale. Global warming will lengthen the growing season in medium to high temperatures, allowing for early spring planting, ripening, and harvesting and the ability to complete two more harvest cycles simultaneously. Reduced production in hot locations due to heat tension; damage to crops, soil erosion, and the ability to cultivate land due to heavy rains; and land degradation due to increasing drought are all potential implications of climate change on agriculture. Crop simulation models, influenced by future weather patterns derived from global circulation models, imply that diminishing agricultural production would be exacerbated in tropical regions, where food supply is still scarce.

Although certain benefits may be dependent on crop and regional growth, the overall impact on agriculture is projected to be negative, posing a danger to global food security. Crop-to-crop variations exist. Cotton, for example, can withstand extreme heat and dryness thanks to its vertical taproots. It is, nevertheless, extremely sensitive to water supply, particularly during flowering and wall development. Rising temperatures favor the growth of cotton plants at temperatures exceeding 32. A moderate increase in air CO_2 and favor the development of Cotton plants [15]. Generally, the grain cereals will be severely affected. According to Aggarwal [16], a 1 °C increase in air temperature and a 1 °C increase in CO_2 concentration can result in a very minor decline in wheat yield in India. Adaptability measures like shifting planting dates and cultivars are also acceptable. However, if no adaptive mechanism is implemented, wheat production loss might reach 6 million tonnes. A further increase in 5C could result in a loss of up to 27.5 million tonnes of wheat production. Rice yields can be lowered by 6% for every 1 °C increase in temperature [17]. However, this is not the same as pulses. They are left to compete with the input responsive cereals. In addition, pulses are heavily planted under marginal lands. Although the severity of abiotic and biotic pressure is stronger in this fragile and lowly productive soil, there are claims that climate change will have a minor impact on legumes due to increased nitrogen fixation linked with higher CO_2 levels [18]. Plants that produce oil will have the same impact. Pests and diseases that are emerging as a result of life-threatening weather will have a terrible impact on output.

Most cereal productivity would suffer as a result of rising temperatures and decreasing water availability, particularly in the Indo Gangetic plain. The consequences and sensitivity to climate change differ depending on the code's model. Rice is sensitive to extreme temperatures during pollination, while cotton is sensitive to hot temperatures during the advancement of the boll. Wheat and small grains are responsive to the least event occurring, cold snap throughout flowering and water stress; soybeans are susceptible to water stress and extremely temperatures; and rice is vulnerable to high temperature changes during pollination. Even with the favourable effect of increasing CO_2 in the future, severe water shortages mixed with heat stress could have a negative impact on wheat and rice output in India.

8.1 Climate Change Effects on Photos, Thesis, C_3, and C_4 Plants

Weather conditions have a direct and indirect impact on photosynthesis. Although light absorption is temperature independent, the subsequent stages in converting light to chemical energy react to temperatures in a variety of ways. Increasing CO_2 may enhance the process of photosynthesis especially in C_3 plants. This may increase in high temperatures and under conditions of water stress. C_4 plants do not respond significantly to CO_2 emissions because they have a CO_2 concentrating mechanism (PEP carboxylase). Other than CO_2, the temperature can affect photosynthesis [19]. However, the rising level of CO_2 will not lead to an increase in ecosystem productivity, and any potential increase in production should be considered in the context of the many eco-climate changes expected due to climate change. Changes in mean midnight temperatures, soil nutrient availability, pest survival and distribution, water resources and irrigation availability, spatial and temporal rainfall variability, drought and flood frequency and intensity, and soil erosion, for example, all have direct or indirect effects on yield [20]. Similarly, when atmospheric CO_2 levels are high, the rate of transpiration increases [21].

In general, temperature changes significantly affect crop phonology. A 2 °C increase in mean temperature resulted in a significant fall in the grained yield of C_3 plants like rice, while yields of wheat, soybean, mustard, peanut, and potato are predicted to reduce by 3–7% for every 1 °C increase in temperature [22]. The decrease may have influenced the phonological patterns in C_3 plant production. Despite the unfavourable impacts of high temperatures on leaf photosynthesis, the ideal temperature for photosynthesis net is expected to rise as CO_2 emissions rise. CO_2 driven increases in agricultural yields are far more likely in warmer than cooler conditions, according to several research.

As a result, global warming may significantly impact net photosynthesis. Temperature is a major determinant of crop distribution and production, with significant implications for physical activity on both a local and a transient scale. On the other hand, temperature responses for individual physiological processes do not always correlate with growth, because the latter is an amalgamation of temperature effects on total metabolism [23].

CO_2 is required for plant growth since it is the photosynthesis substrate. CO_2 is absorbed by plants through their leaves' stomatal pores. Transpiration occurs at the same time. The essential phenomena of plan productivity are the trade-off between

CO_2 gain and water loss [24]. Some plants use C_4 carbon fixation to get around this problem. Higher CO_2 levels in the atmosphere are projected to improve photosynthetic efficiency and, as a result, the total rate of plant growth in C_3 plants. Due to higher levels of CO_2 absorption and stronger stomatal resistance to water loss, C_4 species, particularly dicots, require less water than C_3 species at current CO_2 levels [25]. C_3 species would be more competitive than C_4 species in the event of drought and increased CO_2. Low stomatal conduction in C_4 plants at any given CO_2 level results in a drop in respiratory rate and a higher leaf temperature in C_4 plants, hence the higher temperature is linked to the damage to C_4 plants in the same location. Given the stronger average promotion of high CO_2 growth in C_3 species, increased CO_2 increases leaf size, which should increase sleep temperature during heat stress more in C_3 than C_4 habitats.

8.2 Climate Exchange Outcomes on Soils

Organic matter availability, temperature regimes, hydrology, and variations in evapotranspiration capacity are some potential changes in soil growing characteristics that may occur due to global climate change. The effects of climate change on soil properties are numerous. Rainfall quantity, intensity, timing, and type impact soil formation; daily and seasonal temperature fluctuations impact moisture effectiveness, dynamic rates of biological activity and chemical reactions, and vegetation types.

Soil moisture pressure will be driven by stepped evaporation from the topsoil and the plants' rapid transpiration. A changing climate may also affect mineral soil's workability and susceptibility to erosion, compaction, and diminished water retention capacity. In regions with heavier winter rainfall, a few soils may be more susceptible to corrosion. Mini soil physical qualities are derived from a variety of chemical and biological processes, and can be further influenced by weather panorama positions and land use. Soil available water and distribution may also react quickly to climate change, particularly to variable and high-intensity rainfall or drought events, and thus control strategies, such as cover crop planting, conservation tillage, and organic matter incorporation, can be counted on to keep or even improve water infiltration and available water in soil, which can help alleviate the effects of extreme rainfall and drought events.

8.3 Climate Change Effect on Insect Pest

Increased temperatures caused by climate change can have a variety of effects on crop insect populations. The interaction between the insect pest and their host plant is changing as a result of climate change. Global warming additionally changes the flowering time in temperate areas, mainly to the incumbent of latest insects and achieving a pest repute of non-pest insects. This leads to the large pests shifts in due route of time concerning change in the climate.

Added peers of insects in temperate climates due to greater than before temperature might also compel insecticide application to preserve population below the economic damage threshold. CO_2 appears to have an indirect effect on bugs, with detrimental effects on insects resulting from changes in the host crop. Exposure to extreme CO_2 levels boosts plant photosynthesis, increasing above-ground biomass, leaf area, yield, carbon, and the C:N ratio. These changes may increase the attractiveness of food for herbivorous insects, which may have a variety of effects on insect herbivore performance. The effects of CO_2 on nutritional quality and secondary metabolites off the host plant will modify the insect-host plant interaction. Plants are more susceptible to pest damage as a result of both direct and indirect effects of moisture stress, particularly in the early stages of plant growth. A few insects are rain-sensitive, and severe rains kill or eradicate them from vegetation. Drought-stressed tillering cereals diminish the reproductive capability of overwintering aphids, hence lower winter rainfall should result in lower aphid development rates.

8.4 Climate Change Effects on Disease

Increases in temperature, UV radiation, and relative humidity may make natural plant products, ento-pathogenic viruses, fungus, bacteria, and nematodes, as well as synthetic pesticides, less effective, with natural plant products suffering the most.

8.5 Climate Change Effects on Weeds

Climate change could result in the spread of tropical and subtropical weed species in temperate regions, as well as an increase in the number of temperate weed species that are now hampered by cold temperatures at high latitudes. Alterations in rainfall patterns will lead to variations in water availability, which will lead to weed changes. Species and cultural factors influence drought responses to agricultural circumstances. Any condition that raises the crop's environmental stress may make insects and plants more susceptible to pathogen assault, reducing the crop's capacity to compete with weeds. Rising temperatures substantially impact agriculture in general, crop weed competition in particular, and weed management. It has been suggested that weeds of transient origin are particularly responsive to slight temperature rises, and there have been multiple occurrences of considerable weed growth in response to rising temperatures [26].

9 Sector-Wise Effects of Climate Change in Agriculture

9.1 Field Crops

Crop yields in South Asian countries are expected to fall by 30% by the middle of the twenty-first century. Rainfall and temperature variations will have a greater impact on North Indian states and Bangladesh [27]. That is, in India, a 1.50 C increase in temperature and a 2 mm decrease in rainfall reduced paddy yields by 3–15%. [14]. Climate change may cause crop yields and production to differ from region to region. Normal agricultural yields in Pakistan are predicted to fall by 50%, according to the Meteorological Office (the United Kingdom's National Weather Service). Under optimum hydrologic circumstances, corn production in European countries is predicted to increase by 25% (Fig. 1).

9.2 Horticulture

High respiratory damage occurs in vegetable crops as a result of extreme high temperatures caused by climate change. High temperatures during flowering have been shown to significantly impair the fruiting stage of navel oranges (Davies 1986). High temperatures have an effect on the flowers or blossoms of garden plants, which burn,

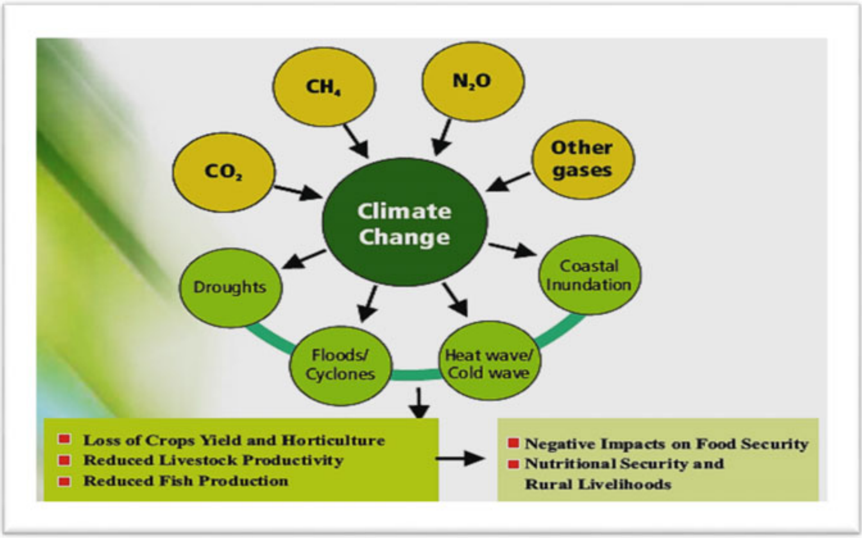

Fig. 1 Causes and impact of climate change on agriculture and allied sectors (*Source* Srinivasa et al. [28])

as well as fruits and vegetables. In litchi orchards, temperature pressures during the ripening period induce fruit burns and cracks [29]. Lack of moisture causes sunburn and cracking in fruits including cherries, apricots, and apples. Floods have wreaked havoc on most food crops, particularly tomatoes.

9.3 Livestock, Poultry and Fishery Sectors

Climate change has an impact on the productivity, reproduction, health, and adaptability of cattle, poultry, and fisheries. Pereira et al. [30] found that high temperatures cause physiological changes in the body of the animal, such as an increase in respiration rate (>70–80 per minute), blood flow, and body temperature (>102.5° F). Diseases, a lack of seedlings, heat stress, and breeding procedures contribute to Bangladesh's enormous economic losses due to lower cow productivity [31]. Uneven weather variations have a direct impact on animal output by 58% and reproduction by 63.3% [32]. Heat stress is more common in dairy breeds than in meat types. Higher milk producing breeds are more sensitive to heat stress because of increased metabolic heat production, low milk producing animals are more resistant to heat stress because of lower metabolic heat output [33]. Increasing the temperature and temperature-humidity indicator outside the essential threshold level reduces dry matter intake and milk yield. It also has an effect on the animal's physiology [34]. Floods and cyclones wrecked large-scale agricultural production in southern and central Mozambique in 2009–10, resulting in cattle, infrastructure, and food loss [35]. Poultry are particularly vulnerable to temperature-related issues, particularly heat stress. Chronic heat stress causes endocrinological changes in broiler hens that increase lipid buildup, inhibit lipolysis, and induce amino acid catabolism [36].

The amount of poultry consumed will decrease due to heat stress [37], resulting in decreased body weight, reduced egg production and meat quality, reduced egg shell thickness and increased egg breaking rate [38]. Heat stress reduces egg shells' strength, weight, ash content, and thickness [39]. Rising environmental temperatures may boost fish growth and development seasonally, but it increases the risk of the population living outside in the heat tolerance zone [40]. Fish mortality and distribution will be affected by a 1 °C temperature increase [41]. The shift in the mating season of Indian major carp to fish hatcheries in West Bengal and Orissa from June to March was caused by a temperature increase from 0.37 to 0.67 C (DARE/ICAR Annual Report, 2008–09).

9.4 Economic Losses of Climate Change in Agriculture

The agricultural sector is very vulnerable to climate change and is expected to suffer significant economic losses worldwide. According to the United Nations Office for Disaster Risk Reduction (UNISDR), the disaster-affected nations experienced a direct economic loss of US 29 2908 billion from 1998 to 2017. Climate-related disasters are responsible for 77% of all damage. Climate change's effects on agriculture have become more specific in recent years. According to the Economic Survey of the Government of India (2018), climate change has resulted in an annual loss of US $9.9–10 billion.

9.5 Agro-techniques for Adaptation to Climate Change

"Adapting to or profiting from environmental or social stimuli in reaction to actual or expected stimuli and their consequences or effects on environmental, social, or economic systems," according to the IPCC [42, 43]. "Possibilities linked with in both the creation and evaluation of impacts and vulnerabilities, as well as response options, adaptation to the climate change debate is critical.

9.6 Primary and Secondary Tillage Practices

Planting cover crops and green manure crops can help prevent future loss of soil organic matter, moisture, erosion, and nutrient loss due to climate change. This low-tech agricultural method could also be a viable option.

9.7 Choice of Crops and Cultivars

Introduce or select resilient varieties/hybrids/composites for climate change (Fig. 2). Long-season varieties can be selected to provide a stable yield under more variable conditions.

9.8 Relocation of Crops in Alternative Areas

The effects of climate change vary across crops and regions. More suitable crops and areas need to be identified and relocated to unsuitable areas for climate change/variability.

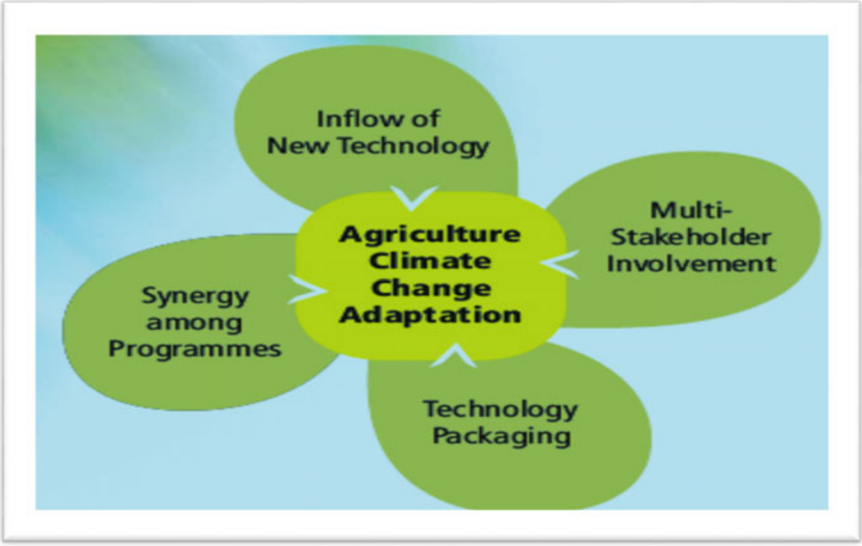

Fig. 2 Key strategies essential for climate change adaptation in the agriculture sector (*Source* Srinivasa et al. [28])

9.9 Resilient Cropping System

The advantages include (a) maintaining and improving soil fertility as crops deplete soil fertility, (b) improved crop growth as crops may provide mutual support to each other, such as reducing lodging, enhancing winter survival, or even acting as windbreaks to enlarge growth, and (c) disease spread reduction. The more plant species there are and the longer it takes before the soil is reseeded with the same crop, the more disease problems are likely to occur (see Fig. 3).

Effective crop-growing season, which is calculated from long-term rainfall data analysis, is used to determine the various cropping systems, including mono-cropping, intercropping, and double-cropping. The All India Coordinated Research Project for Dryland Agriculture (AICRPDA) conducted research on intercropping systems (ICSs) and found that additive series were more successful than replacement series in various seasonal drought situations, with multiple benefits including higher output and returns, spread labour peaks, soil fertility maintenance (with legume inclusion), and production stability. When seasonal rainfall was above normal, optimum production was obtained. When rainfall was normal, relatively high values of land equivalent ratios were achieved; and when rainfall was low, one of the two crops yielded reasonably, giving insurance against weather aberrations [44].

Furthermore, the ICSs have discovered that, due to soil moisture replenishment, the rainy (Kharif) season is more suitable to intercropping than the rabi season in India's wet production systems. Pigeon pea performed better as a foundation crop or intercrop, particularly in intercropping systems based on sorghum, cotton, and pearl

Fig. 3 Schematic diagram of the overall strategy of climate change adaptation with the implementation of various technological interventions (*Source* Srinivasa et al. [28])

millet [45]. The diversity of cropping systems, which is tied to rain-fed agriculture and influences the socio-economic conditions of the agricultural community, has been one of the most important aspects of Indian agriculture. Double cropping is possible in areas with sufficient rainfall (usually more than 750 mm) and a soil moisture storage capacity of more than 150 mm. Rainwater collected in agricultural ponds for the development of winter crops can also be used for double cropping. One of the two crops could be a 60–70-day crop (generally a legume), while the other could be a 110–120-day crop (usually cereal).

9.10 Seed Rates and Spacing

Seed rates and row spacing must be changed to cope with situations such as delayed and early season dryness, which need re-sowing. Plant populations may be modified based on crop water needs and water-use efficiency, which can be seen in early-season rainfall.

9.11 Contingency Crop Planning

Contingency crop planning is putting in place a strategy for switching crops or making other decisions based on the current rainfall condition and soil moisture status in a specific area [46]. Due to extended dry spells after seeding at the regular commencement of the monsoon, the crops endure agricultural drought at various stages. During the rainy season (July to September), a seasonal drought causes crop failure. Early-season dryness is most often caused by a delayed beginning of monsoon or a lengthy dry period shortly after the rainy season begins. Mid-season drought is caused by a lack of soil moisture availability between two successive rainfall events during the crop-growing cycle. As the crop matures, so does its impact. At each stage, the length and intensity of the dry situation. Droughts that occur late in the season or towards the end of the monsoon season are more likely to occur in years with a late start or inadequate monsoon activity. The early monsoon withdrawal causes early-season droughts in July, mid-season droughts in August, and terminal droughts in September, all of which have varied consequences on plant growth and output. Contingency crop planning refers to a technique for picking crops based on rainfall and moisture levels during any agricultural growing season.

9.12 High Intense Rainfall Events

Preventing seed germination and collecting produce are two stage-recommended practises throughout the time of crop maturity. In the event of inconvenient rains during the vegetative stage, contingency measures include: draining excess water as soon as possible, applying 20 kg N + 10 kg K/acre (0.4 ha) after draining excess water, applying 50 kg urea + 50 kg mutate of potash (MOP)/acre (0.4 ha) after draining excess water, gap-filling either with accessible nursery or by piercing the tillers from the existing hills in rice, weed control, and appropriate plant.

High intense rainfall events generally occurred due to the following events:

Floods: The type of material (sand or silt) deposited during floods has an impact on crop/field management. Early sand exclusion or ploughing in of sand (depending on the degree of deposit) to assist rabi crops or Kharif are examples of ameliorative treatments in sand-deposited agricultural fields/fallows. An early rabi crop strategy is recommended in existing cultivated regions and current fallow lands in the silt deposit Indo-Gangetic plains. Other efforts include emptying stagnant water and bolstering agricultural bunds, among others. In diara (flood-prone land regions), different agricultural plans for receding scenarios are included. Flooding is common in rice-growing areas, resulting in the loss of nurseries as well as the strengthening of include alternate losses of nurseries, delayed transplantation, or damage to previously transplanted fields. To avoid losing the season, community nurseries are recommending boosting scheduled bushenings, transplanting in damaged fields and transplanting new areas, or direct seeding depending on seed availability. Spraying a salt solution on the submerged crop at maturity or on harvested produce to prevent early germination are two further methods.

Heatwave: Heat-tolerant cultivars, light, regular watering, foliar spraying with thiourea or KNO_3 at appropriate distances, and other interventions are suggested.

Cold wave: Cold-tolerant types should be used, light watering should be done often, and smoking should be done at night, among other things.

Frost: Frost-tolerant varieties are sought, planting schedules are adjusted to avoid sensitive phases falling during frost periods, young plants are thatched, and ground cover such as shelterbelts and shade trees is employed to reduce heat loss, among other things.

Cyclones: In high-risk locations, forestry windbreaks or shelterbelts, as well as the cultivation of storm-resistant crops, are recommended (e.g. ginger and pineapple). Other methods include field drainage, staking and propping of plantation crops, and washing and drying of harvested field crops.

Hailstorm: Anti-hail guns and anti-hail nets have been suggested as possible solutions. To prevent further fungal infection, spray 0.1% carbendazim on the affected area.

9.13 Nutrient Management

It's unsafe to rely solely on basal soil application of nutrients in arid and semi-arid locations where dry spells and droughts are prevalent. It is preferable to supply roughly 50–60% of the nutrients by a basal application and the rest through a foliar spray. Plants are unable to acquire an appropriate quantity of nutrients when soil moisture is scarce, which has detrimental consequences for their general health, particularly their growth and grain quality. As a result, it is beneficial to provide chosen plants with nutrients, either with or without plant development agents, in order to help stressed plants recover quickly. For example, Pulses, are grown without fertilisers or irrigation under rainfed and rice fallow environments, and their yields are low. Foliar fertiliser treatment can be used to boost their yield. Pulses also have a shorter duration between the maximal vegetative and reproductive stages. Foliar nutrition is a superior technique in the nutritional management of pulses to avoid any of these issues. A foliar spray of 2% diammonium phosphate (DAP) was applied in rainfed and rice fallow pulses.

9.14 Weed Management

Another important endeavour is timely weed control. Stale seedbed method, manipulation of sowing time so that ecological conditions for weed seed germination are not favourable, mulching, crop diversification, selection of acceptable crop varieties as well as planting of weed-smothering crops, land levelling, conservation tillage, and efficient weed-management strategies are examples of different types of measures.

9.15 Water Management

Conservation of water for irrigation while drought conditions persist, as well as drainage of excess water from agricultural land during flooding, should be prioritised. To keep water levels in aquifers stable, rainwater harvesting and other water-saving activities should be used. In drought-prone nations and tropical climates, reusing waste water should be encouraged. Because agricultural productivity depends on water availability, advancements in runoff control and irrigation technologies will be critical.

9.16 Mitigation Strategies

Mitigation refers to efforts to reduce or eliminate greenhouse gas emissions. Climate change mitigation is the reduction of human-caused (anthropogenic) greenhouse gas emissions (GHGs). Carbon sink capability can also aid with mitigation, such as through reforestation. The following agro-techniques must be applied to combat climate change.

9.17 Crop Management

Intensively maintained croplands provide several chances to implement strategies that minimize net GHG emissions. The following, partially overlapping types of farmland management mitigation practices: Increased soil carbon storage can be achieved by enhanced agronomic methods that increase yields and create greater carbon residual inputs. These are some examples of unethical behaviour. Improved crop varieties are one example; other farming practises that use less fertiliser can also reduce emissions per hectare. These 'catch' or 'cover' crops offer carbon to soils while also absorbing plant-available Nun used by the preceding crop, minimising N_2O emissions. Methane emissions from rice. Intermittent flooding has been proposed in many studies as a technique to reduce CH_4 emissions. In all irrigated rice regions across the country, by transitioning from the current technique of water management to intermittent floods. It is possible that the amount of CH_4 emitted by irrigated rice fields could be lowered by 40%. In the case of intermittent floods, however, the N_2O N fluxes may increase by 6%. The upscaling research for India has so revealed the challenge of GHG reduction. When intermittent floods repressed CO emissions, N_2O emissions increased. Because N_2O has a higher global warming potential (GWP), the benefits of lowering CH_4 and CO_2 fluxes are offset by increased N_2O. Total carbon equivalent emissions from irrigated rice-growing areas of the country fell from 41.1 Tg C to 36.2 Tg C in a year as a result of intermittent irrigation in lice. Rice direct seeding (DSR) and rice intensification (SRI) are two promising methods for reducing methane emissions. Methane is generated when the soil is constantly submerged in water, as in the case of conventional puddled transplanted rice. Methane emissions are reduced when rice is grown as an aerobic crop because DSR and SRI crops do not require continuous soil submersion. When compared to the traditional puddled transplanted rice farming method, DSR and SRI methods have a considerable potential to lower GWP (by around 35–75%).

9.18 Nutrient Management

Site-specific nutrient management, slow-release nitrogenous fertilisers, and nitrification inhibitors such as coated calcium carbide and dicyandiamide are the most effective management options for lowering nitrous oxide emissions. Using a leaf colour chart (LCC) can reduce nitrous oxide and greenhouse gas emissions by 11–14%. Crops do not always absorb nitrogen efficiently from fertilisers, manures, biosolids, and other nitrogen sources. Improved N-use efficiency can reduce N_2O emissions and indirectly reduce GHG emissions from fertiliser. That lead to N_2O formation; placing N more precisely into the soil to make it more reachable to crop roots; or avoiding N application Climate change can be mitigated with the help of the INM and SSNM. Greater rice yields and hence increased net CO_2 assimilation, as well as a 30–40% increase in nitrogen utilisation efficiency, are instances of proven technology. This gives an excellent opportunity to reduce greenhouse gas emissions linked with nitrogen fertiliser use in rice systems. Better CO_2 concentrations may create thermal stress in many rice production systems in the future, but they will also allow for larger yields in settings when temperatures are not over threshold levels. As a result, prudent fertiliser use, a crucial component of the SSNM strategy, has a twofold benefit: it lowers GHG emissions while increasing yields in high CO_2 settings. In rice fields, the use of hydroquinone, a urea inhibitor, and dicyandiamide (DCD), a nitrification inhibitor, in combination with urea, is an effective way to reduce N_2O and CH_4.

9.19 Soil Carbon Management Strategies

It is crucial to manage soil organic carbon to maintain soil resilience to climate change. So soil carbon sequestration is a significant way to over come the climate change increased soil organic carbon (SOC) storage can help to slow climate change. Management techniques should be kept in place to ensure a positive net carbon transfer from the atmosphere to the soil. Soil sink capacity is reduced during the conversion of natural to agricultural ecosystems, as well as the drainage of wetlands, due to extensive tillage of soils and burning or removal of crop residue. Conversion to restorative land use and adoption management methods should be implemented to enrich the SOC pool. As a result, effective land use and management techniques must be maintained to promote both carbon storage in soil and other environmental services. This is an important strategy for climate moderation as well as improving rainfed system provisioning services.

Many long term experiment were started long back in India to enhance carbon sequestration and also for better productivity of different agro eco regions of the country. Appropriate land use and best management practices are found to increase carbon stock in rainfed situations. However, the exact sink capacity depends on prior SOM level and kind of land use system, climate, profile characteristics and the management practices implemented. Drylands have the obvious potential to play a significant role in climate mitigation while also providing significant co-benefits. Changes in dryland management practises can help increase carbon sequestration. Though dryland ecosystems have less carbon storage potential per unit area than moist tropical ecosystems, the prospect for carbon sequestration in dryland agriculture is enormous. On agricultural soils, the usual rate of SOC sequestration is 200–500 kg C/ha/year. Better management approaches increase carbon sequestration in soils. Crop residues as surface mulch, complex crop rotations and various farming systems, and integrated nutrient management (INM) strategies for recycling biosolids and other co-products are examples of these activities. Improving soil organic matter and biological nitrogen fixation through promoting soil fertility through integrated nutrient management.

SSNM (site-specific nutrient management) is a promising solution for climate change mitigation. Because it uses less inorganic fertilizer, SSNM increases agricultural productivity and helps mitigate climate change. The judicious application of inorganic fertiliser is a key component of the SSNM approach, as it has two benefits: it reduces greenhouse gas emissions while also improving yields under high CO_2 levels in the atmosphere. Cropping intensity is increased and both active and passive pools of SOC are maintained through crop rotation with winter cover crops.

9.20 Crop Residue Management and Carbon Sequestration

Crop residues are the primary source of soil carbon, accounting for roughly 40% of total biomass on a dry weight basis. Crop residue is the biomass that remains in the field after grains and other valuable commodities have been harvested. Shoots, leaves, cobs, husk, and other above-ground components of agricultural wastes include shoots, leaves, cobs, and husk. Crop residues' ability to sequester carbon in soils could be a valuable asset in the fight against climate change and greenhouse gas emissions. The total input of crop residues that remain on the surface or are incorporated into the soil determines the concentration of organic C in the surface soil (0–15 cm). Farmers typically burn crop wastes such as pigeon pea and cotton stalks rather than reusing them. Therefore, shredding of crop residues is to be mechanised. Crop residues will decompose more easily and quickly in the soil or in vermicompost pits as a result of this.

Crop residue application to soil can be done in situ or ex situ in a variety of ways. Because agricultural leftovers and animal dung are correctly utilised directly into the soil with no nutrient loss, the in situ approach is the most efficient method of recycling organic residues. Crop residue application increases infiltration rate, improves soil characteristics, increases soil organic matter, encourages earthworm activity, and improves soil structure, resulting in a greater yield after four to seven years. Permanent crop cover with crop residue recycling is a prerequisite and key feature of conservation agriculture. Existing crop leftovers, however, cause agricultural swing problems. However, utilising machines such as the ziro till seed cum fertiliser drill or planters such as the happy seeder turbo seeder and rotary disc drill can assist to mitigate the issue. These devices are extremely effective at managing crop leftovers for moisture and nutrient conservation, as well as weed control and soil temperature regulation. Soil organic carbon is increased and carbon sequestration is aided by crop residue retention and nutrient application. Surface residues gradually decompose, improving soil organic matter status, biological activity, and diversity, and contributing to overall soil quality improvement. The C:N ratio in plant leftovers determines how quickly organic matter decomposes. C:N is the most commonly used criterion for determining the quality of residue. The legume's nitrogen source is critical for carbon sequestration regulation. Biomass carbon inputs as crop residue enhanced soil organic carbon and stock by a large amount each year.

9.21 Conservation Agriculture and Carbon Sequestration

The carbon sequestration in soil by adopting various agricultural practices broadly known as conservation agriculture and using this method may mitigate global climate change. There are mainly 3 basic principles up conservation agriculture. These three basic principles are minimum soil disturbance; coop residue cover end diversified crop rotation preferably with legumes. By combining information of carbon and nitrogen cycling in agriculture and summarising the impact of tillage, residue management, and crop rotation on soil organic carbon stock, the potential impact of conservation agriculture's own carbon sequestration can be better understood. Conventional tillage and erosion are the primary drivers of soil organic carbon loss. By lowering soil disturbance, shortening fallow times, and including cover crops into the rotation cycle, soil can store carbon when converted from plough till to no-till or conservation tillage. In dry and semi-arid environments, eliminating summer fallowing and replacing it with no-till with residue mulching improves soil structure, enhances filtration capacity, and lowers bulk density. However, the benefits of no-till on soil organic carbon sequestration may vary depending on the soil/site, and improvements in soil organic carbon may be inconsistent in fine-textured and poorly drained soil.

Growing cover crops in a rotation cycle greatly enhances the benefits of conservation tillage for soil organic carbon sequestration. Growing a leguminous cover crop improves biodiversity, residue quality, and the soil organic carbon pool. A high-biodiversity environment may absorb and sequester more carbon than a low-biodiversity ecosystem. The soil carbon sequestration is boosted by conservation agricultural system. Carbon sequestration in soil can be aided by increasing carbon inputs while reducing production. Soil organic carbon in conservation agriculture ranged between 0.31 and 0.45%, which is somewhat higher than in conventional agriculture (0.29–0.42%). Reduced tillage combined with crop residue retention raises soil organic carbon levels. Crop leftovers are a source of organic matter, and when degraded, they enhance the storage of soil organic carbon, hence removing them diminishes soil organic carbon greatly. Continuous application of manure and fertiliser in tropical Indian soils has shown that balanced fertilisation increased soil organic carbon and MBC. The higher amount of C mobilised in microbial biomass shows that soil organic matter supplies more labile C in conservation agricultural systems than in conventional systems. As a result, conservation agriculture likely provides a steady source of organic C to support the microbial community, as opposed to a conventional system, where each tillage event causes a temporary flush of microbial activity, resulting in large losses of C as CO_2. Although, due to high temperatures, tropical regions cannot trap carbon in soil. In some cropping systems, correct management approaches, particularly conservation agriculture, increase reasonable amounts of carbon sequestration, particularly in areas with heavy rainfall [47].

9.22 Bio-char and Carbon Sequestration

When added to soil, biochar, a carbon-rich, fine-grained, porous byproduct of the pyrolysis process, improves soil fertility and increases soil carbon sequestration, among other environmental advantages [48]. The use of biochar in soil is seen as a novel way to create a significant, long-term, and considerable sink for atmospheric carbon dioxide in the terrestrial environment. It is thought to be a novel method of carbon sequestration in the terrestrial ecosystem. In India, annual biochar production is over 309 million tonnes, which may offset roughly half of carbon emissions (292 Tg C/year) by using biochar produced from fossil fuels [49].

Significant amounts of crop leftovers are produced in the Indo Gangetic plains of India from rice wheat cropping systems, and if these residues can be pyrolised, 50% of the carbon in biomass is returned to soil as biochar, increasing soil fertility and crop yields through carbon sequestration. When biochar is put to soil, it can permanently raise the carbon content of the soil and provide a carbon sink for CO_2 in the atmosphere. Essentially, it lowers atmospheric carbon dioxide by sequestering carbon that would otherwise be used to develop plants and other organic things in the earth. Biochar has the ability to trap huge amounts of carbon from the atmosphere. Bing conventional carbon capture and storage, new technologies are proposed for reducing carbon emission from coal fired power station, sequestration of biochar removes carbon from the atmosphere.

9.23 *Agroforestry Systems in Carbon Sequestration*

To achieve the ecological and economic interaction of the various components in order to maximise productivity per unit area and time, woody perennials are introduced with crops, pastures, and livestock. The addition of trees to agricultural landscapes can boost system productivity by providing possibilities to produce carbon (C) sinks. Sequestration of carbon in agroforestry systems can be classified into two types: above-ground and below-ground plant components. The agroforestry system, which shape and environmental and socioeconomic conditions largely govern function, contributes significantly to carbon sequestration. In agroforestry, tree species and system management play a role in increasing carbon storage. The incorporation of carbon into plant matter is known as above-ground (vegetation) carbon sequestration.

The quantity of carbon sequestered in each section varies substantially based on a variety of parameters such as agro-climatic area, system type, site quality, historical land usage, and so on. The rates of above-ground carbon sequestration in some of the world's largest agroforestry systems range from 0.29 to 15.2 mg/ha/year. Agroforestry systems on fertile humid sites have a larger carbon sequestration potential than those on arid semi-arid and degraded sites, while tropical agroforestry systems have a higher sequestration potential than temperate agroforestry systems in general. Significant carbon is trapped in below-ground tree parts, with a portion of it added to the soil each year, contributing to soil carbon.

The tree-based systems also largely contribute significant amount of litter to the soil every year, which helps to increase the soil carbon. Different land use management with a higher potential to sequester carbon can enhance the carbon stocks in an ecosystem by removing atmosphere CO_2. The type of freshly stored carbon, changes in land use management, the ecosystem's inherent biological production, and the kind and thickness of soil all affect how quickly carbon is accumulated and released [50]. The carbon stored in soil in agroforestry systems ranges from 30 to 300 mg C/ha up to a depth of one metre, and the land conversion from worthless crops and grassland to agroforestry can result in a greater rate of carbon deposition that is to the tune of 3 tonnes/ha/year [51].

Carbon sequestration in agroforestry systems is determined by the quantity and quality of biomass contributed by trees and soil factors such as soil structure and aggregation. There is a 6.07 t/ha/year increase in soil carbon in a poplar system, and in sandy clay, higher carbon content was reported in the 0–30 cm depth compared to loamy sand. Carbon stock ranged from 8.5 to 15.2 mg C/ha in the upper 40 cm soil layer, which contained around 69% of soil carbon in the profile. Mixing agroforestry with crop fields is viable for increasing C sequestration in soils. Many types of agroforestry systems are common in India, and the following are the carbon sequestration rates recorded from these systems.

Agri-silviculture systems: Several sections of India have long practised agri-silvicultural systems. These systems can be classified into two groups. The first is farmers who plant trees in and around their fields where they grow food crops, and the second is farmers who plant trees in private holdings in diverse spatial arrangements where the main product is the tree, with the help of huge corporations. The tree can be cultivated in a variety of densities and spacing on boundaries or in the field.

Silvo-pasture systems: It is the practise of combining the growth of trees with the production of pastures and cattle. Many different silvo pastoral systems are practised in India. Scattered trees on pastures, plantation crops mixed with pastures, live fences, fodder banks, windbreaks and shelterbelts, and hedgerow intercropping on pastures are all examples of silvopastoral methods. Trees un silvopastoral systems provide protein-rich feed when grass is scarce or indigestible. In the Himalayan foothills and Rajasthan, there are several types of traditional silvopastoral systems, some of which are subsistence and migratory. These mechanisms help to sequester carbon.

9.24 Economic Impact of Climate Change and Climate-Smart Agriculture Technologies

Despite the fact that climate change has few good benefits, global warming is a major harmful effect. Temperatures above 30 °C have net negative consequences, and temperatures exceeding 70 °C can result in severe loss. In 2015, the global social cost of carbon emissions is anticipated to be USD 29/tC (tonnes of carbon), rising at a rate of 2% per year [52]. If adequate climate change mitigation techniques can be implemented, the net economic growth of Solomon Island's fishery sector will also increase. Climate change will also have a negative impact on agricultural markets, resulting in a 0.26% drop in world GDP [53]. In a quadratic progression, both market and non-market losses have increased. If the average world temperature rises 1 °C, it is expected to cost 1.2% of GDP [54]. If future mitigation initiatives follow the adaption of previous strategies, global income is expected to drop by 23% by 2100, widening the income inequality gap [55]. Global economic growth is expected to slow by 0.28% annually [56].

10 Impact of National Programmes and Policies

10.1 Impact of Irrigation Policies

Groundwater resources have been created in South Asian countries over the last 20 years. The average productivity of wheat, paddy, corn, and peanuts has increased to 2.97 Mt/ha from 2.32 Mt/ha. Irrigation policies have enhanced the resources for food as well as reduced the emission of greenhouse gases (GHGs) to a greater extent by avoiding the conversion of forest land to cropland. Among different types of irrigation processes, the Micro type irrigation smart technology has increased productivity to a greater extent which is almost triple time than the previous and saves water and energy too. In Indian agriculture for water utilization strategy "More crop per drop" is a very important message. Policies like MGNREGA and PMSKY (Prime Minister Krishi Sinchayee Yojana) significantly affected the country's conservation and utilization of groundwater. These irrigation programmes and policies has positive impact in both field crops and horticultural crops.

10.2 Impact of Fertilizer Policies

South Asian countries have seen a fast increase in fertiliser consumption. The application of fertiliser has enhanced crop production and crop productivity in India. Due to the proper application of fertilizer, the production and productivity of the crop have been increased from the same piece of land, so the grain production has also been increased, saving a million hectares of forest land from conversion into cropland. The government's Soil Health Card objective has increased production and need-based nutrient application, as well as enhanced soil health. India plays a key role in climate change adaptation. The government has enacted legislation to minimise fertiliser input costs, enhance nutrient usage efficiency, and reduce GHG emissions from fertiliser nutrient sources. Neem-coated urea was introduced by India.

10.3 Agroforestry Policy

The Government of India's forestry and agroforestry policies plays a critical role in climate adaptation and mitigation. The area under agroforestry is on an upward trend towards more carbon fixation and reduced GHGs. Aside from environmental services, including a price mechanism would help to stabilise the livelihoods of India's agroforestry producers. Through its network, ICAR supported location-specific agroforestry species identification and associated technology.

10.4 Livestock, Poultry and Fishery Sector Policies

In order to combat animal diseases, develop genetic resources, implement scientific and improved management practises, increase production and abundance of healthy feed and fodder, develop processing and marketing facilities, and increase the productivity and profitability of livestock and fisheries enterprises, the Department of Agriculture and Allied Industries has been collaborating with state governments. In 2017–18, 176.3 million metric tonnes of milk were produced, up to 132.4 million metric tonnes in 2012–13. Several livestock-related measures contributed to India's overall development. In the financial year 2017–18, India's total fish production was anticipated to be around 12.61 million metric tonnes. Similar initiatives were taken to improve the poultry sector's administration and development.

10.5 Contingency Plans and Resilient Model Villages

ICAR's agriculture contingency plans and climate-resilient villages have the following main effects:

(a) A large-scale effective awareness was produced from multiple hierarchies and capacity building to roughly million stakeholders involved in resilient agriculture through various workshops, village institutions, interface meetings, field visits, and so on.
(b) Seed systems and agricultural machinery are available through Custom Hiring Centres for timely sowing and farm operations.
(c) In Madhya Pradesh, for example, essential technology were adopted for resilient agriculture, while crops in Andhra Pradesh were preserved using rain gun-based lifesaving irrigation.
(d) Drought years in the region (2014, 2015, 2016) resulted in a 6–9% reduction in sowing area. ICAR built a total of 151 resilient communities, which were then reproduced in state government programmes. Village carbon balances were improved by offsetting GHG emissions through the implementation of climate-resilient villages. The implementation of climate-resilient villages was a ground-up innovation involving multi-stakeholder participation, significant technical support, scientific knowledge flow, and regular monitoring.

10.6 Insurance Policies

Farmers' financial conditions have been improved by the implementation of insurance policies that lessen anguish and recompense for readiness. Under the Prime Minister Crop Insurance Scheme various chances have been provided to develop the farm insurance.

10.7 Agriculture and Rural Development Ministries Aggregated

In 2019 the Govt. of India bring two important ministers. They are the ministers of agriculture and rural development which are regulated or headed by a single minister and by combining these two ministries it is possible to implement climate change at ground level and it is expected to strengthen this thing further in India.

11 Conclusions

Providing food and nutrition security for the world's growing population has put a strain on agriculture, which is deteriorating further as a result of climate change. According to many studies, climate change is expected to reduce agricultural productivity in the coming years. Several mitigation and adaption strategies have been developed to mitigate the negative effects of climate change on agricultural sustainability. Climate change-related economic losses can be addressed using those methods at both the local and macro levels. However, in order to be effective, these mitigation and adaptation strategies must be planned at the regional or local level. Mitigation and adaptation planning is complicated by the fact that the future of climate change and its consequences is very unpredictable. This necessitates the development of climate-resilient technology based on a regional multidisciplinary approach. Farmers must be educated about various climate-smart technologies and climate-resilient cultivars must be produced. Climate change, its origins, and consequences are among science and technology's most rapidly changing topics. India is a tropical country whose agriculture sector is being impacted by climate change. Agriculture and sub-sectors employ over 70% of the Indian population directly or indirectly. Climate adaptation and mitigation measures can aid them in combating climate change's detrimental effects on agriculture.

References

1. Asamoah EF, Beaumont LJ, Maina JM (2021) Climate and land-use changes reduce the benefits of terrestrial protected areas. Nat Clim Chang 11:1105–1110. https://doi.org/10.1038/s41558-021-01223-2
2. FAO (2011) Climate change, water and food security, FAO water reports
3. Seneviratne SI, Nicholls N, Easterling D, Goodess CM et al (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp 109–230
4. Raza A, Razzaq A, Mehmood S, Zou X, Zhang X, Lv Y, Xu J (2019) Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. Plants 8(2):34. https://doi.org/10.3390/plants8020034
5. Levidow L, Zaccaria D, Maia R, Vivas E, Todorovic M, Scardigno A (2014) Improving water-efficient irrigation: prospects and difficulties of innovative practices. Agric Water Manag 146:84–94. https://doi.org/10.1016/j.agwat.2014.07.012
6. McMichael AJ et al (2000) The sustainability transition: a new challenge (editorial). Bull World Health Organ 78:1067
7. FAO (2014) Agriculture, forestry and other land use emissions by sources and removals by sinks climate, energy and tenure division, FAO
8. Goudrian J, Unsworth MH (1990) Implications of increasing carbon dioxide and climate change for agricultural productivity and water resources. In: Impact of carbon dioxide, trace cases and

climate change on global agriculture. american society of agronomy (ASA) special publication no. 53. ASA, Madison, WI, USA, pp 111–130
9. Pant GB, Rupa Kumar K, Parthasarathy B (1993) Observed variation in rainfall and surface temperature over India. In: Global warming: concern for tomorrow (Lal M (ed)). Tata McGraw-Hill, pp 71–91
10. Hingane LS, Rupa Kumar K, Ramana Murty BV (1985) Long-term trends of surface air temperatures in India. J Climatol 5:521–528
11. OECD (2017) Working with change: systems approaches to public sector challenges
12. Bal SK, Minhas PS (2017) Atmospheric stressors: challengesand coping strategies, In: Minhas PS et al (eds) Abiotic stress management for resilient agriculture. Springers Nature Singapore Pte. Ltd., pp 9–50. https://doi.org/10.1007/978-981-10-5744-1_2 (2) (PDF) Challenges and Opportunities in Weather Based Crop Insurance in India. Available from: https://www.researchgate.net/publication/333389271_Challenges_and_Opportunities_in_Weather_Based_Crop_Insurance_in_India#fullTextFileContent [accessed Aug 25 2023]
13. Slinivasarao C, Deshpande AA, Venkateswarlu B, I-al R, Singh AK, Kundu S, Vittal KPR, Mishra PK, Prasad JVNS, Mandal UK, Sharma KL (2012) Grain yield and carbon sequestnuion potential of post monscx•n sorghum culuvation in Vertisols in the semi-arid tropics of central India. Geodenna 175–176:90–97
14. Ahluwalia VK, Malhotra S (2006) Environmental science. Anne Books India, New Delhi
15. Ton (2011) International trade centre (ITC). Cotton and climate change: impacts and options to mitigate and adapt. ITC, Geneva
16. Aggarwal PK (2009) Global climate change and indian agriculture: case studies from the Indian council of agricultural research network pmiect. ICAR, New Delhi, p 148
17. Saseendran ASK, Singh KK, Rathore LS, Singh SV, Sinha SK (2000) Effects of climate change on rice production in the tropical hunud climate of Kerala, India. Clim Chang 44:495–514
18. Bahl PN (2015) Climate change and pulses: approaches to combat its impact. Agric Res 4(2):103–108
19. Kirschbaum MUF (2004) Direct and indirect climate change effects on photosynthesis and transpiration. Plant Biol 6:242–253
20. Mall R, Singh R, Gupta A, Srinivasan G, Rathore L (2006) Impact of climate change on Indian agriculture: a review. Clim Change 74:225–231
21. Stanhil G, Cohen S (2001) Global dimming: a review of the evidence for a wide spread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences. Agric For Meteorol 107:255–278
22. Dagar JC, Singh AK, Singh R, Arunachalum A (2012) Climate change vis-a-vis Indian agriculture. Ann Agric Res New Ser 33(4):189–203
23. Bowes G (1993) Facing the inevitable: plants and increasing atmospheric CO_2. Annu Rev Plant Physiol Plant Mol Biol 44:309–332
24. Sage RF, Kubien DS (2007) The temperature response of C_3 and C_4 photosynthesis. Plant Cell Environtnent 30:1086–1106
25. Lara MV, Andreo CS (2011) C_4 plants adaptation to high levels of CO_2 and to drought environments, Abiotic stress in plants-mechanisms and adaptations (ArunShanker (ed)). ISBN: 978-953-307394-1. InTech, http://www.intechopen.com/books/abiotic-stress-in-plantsmechanismsandadaptations/c4plantsadaptationtohighlevelsofCO2andtodroughtenvironments
26. Patterson IT (1995) Weeds in a changing climate. Sciences 43:685–701
27. World Bank (2008) World Bank's approach to climate change in South Asia: an overview. Bank Information Center. www.bicusa.org
28. Srinivasa Rao C, Prasad RS, Mohapatra T (2019) Climate change and Indian agriculture: impacts, coping strategies, programmes and policy. Technical bulletin/policy document 2019. Indian Council of Agricultural Research, Ministry of Agriculture and Farmers' Welfare and Ministry of Environment, Forestry and Climate Change, Government of India, New Delhi, p 25
29. Kumar R, Kumar KK (2007) Managing physiological disorders in litchi. Indian Hortic 52(1):22–24

30. Pereira AMF, Baccari F Jr, Titto EAL, Almeida JAA (2008) Effect of thermal stress on physiological parameters, feed intake and plasma thyroid hormones concentration in Alentejana, Mertolenga, Frisian and Limousine cattle breeds. Int J Biochem 52:199–208
31. Chowdhury QM, Monzur K (2016) Impact of climate change on livestock in bangladesh: a review of what we know and what we need to know. Am J Agric Sci Eng Technol 3(2):18–25–via e-palli. http://ajaset.e-palli.com/wpcontent/uploads/2013/12/impactof-climate-change-on-livestock-inbangladesh-a-review-of-what-weknow-and-what-we-need-toknow.pdf
32. Singh SK, Meena HR, Kolekar DV, Singh YP (2012) Climate change impacts on livestock and adaptation strategies to sustain livestock production. J Vet Adv 2(7):407412
33. Dash S, Chakravarty AK, Singh A, Upadhyay A, Singh M, Yousuf S (2016) Effect of heat stress on reproductive performances of dairy cattle and buffaloes: a review. Vet World 9(3):235–244
34. West JW (2003) Effect of heat stress on production in dairy cattle. J Dairy Sci 86:21312144
35. Musemwa L, Muchenje V, Mushunje A, Zhou L (2012) The impact of climate change on livestock production amongst the resource-poor farmers of third world countries: a review. Asian J Agric Rural Dev 2(4):621–631
36. Geraert PA, Padilha JC, Guillaumin S (1996) Metabolic and endocrine changes induced by chronic heat exposure in broiler chickens: growth performance, body composition and energy retention. Br J Nutr 75:195–204
37. Deng W, Dong XF, Tong JM, Zhang Q (2012) The probiotic Bacillus licheniformis ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens. Poult Sci 91:575–582
38. Lin H, Mertens K, Kemps B, Govaerts T, De Ketelaere B, De Baerdemaeker J, Decuypere E, Buyse J (2004) New approach of testing the effect of heat stress on eggshell quality: mechanical and material properties of eggshell and membrane. Br Poult Sci 45:476–482
39. Miller PC, Sunde ML (1975) The effects of precise constant and cyclic environmental on shell quality and other performance factors with Leghorn pullets. Poult Sci 54:36–46
40. Morgan I, McDonald DG, Wood CM (2001) The cost of living for freshwater fish in a warmer, more polluted world. Glob Change Biol 7:345–355
41. Vivekanandan E, Ratheesan K, Manjusha U, Remya R, Ambrose TV (2009) Temporal changes in the climatic and oceanographic variables off Kerala. In: Vivekanandan E et al (eds) Marine ecosystems challenges and opportunities. Book of Abstracts, Marine Biological Association of India, Cochin, pp 260–261
42. IPCC (2001) Impacts, adaptations and vulnerability of climate change: contribution of working group Il to the third intergovernmental panel on climate change (Mc Canhy JJ, Canjiani OF, Leary NA, Dokken DJ, White KS (eds)). Cambridge University Press. Cambridge, UK
43. IPCC (2001) Climate change: the scientific basis, p 881. Contribution of working group I to the third assessment report of the international panel on climate change (Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Mskell K, Johnson CA (eds)). Cambridge University Press, Cambridge, UK
44. Ravindra Chary G, Venkateswarlu B, Sharma SK, Mishra JS, Rana DS, Ganesh Kute. (2012). Agronomic research in dryland f•Mning in India: an oseniew. Indian J Agron 57 (3rd IAC special issue):157–167
45. AICRPDA (2003) Annual reports 1971–2001. Eldo scope electronic document. All India coordinated research project for dryland agriculture (AICRPDA), central research institute for dryland agriculture (CRIDA), Hyderabad, India, p 6357
46. Venkateswarlu B, Singh AK, Prasad YG, Ravindra Chary G, Srinivasa R, Rao KV, Ramana DBV, Rao VUM (2011) District level contingency plans for weather aberrations in India. Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad, Andhra Pradesh India, p 136
47. Srinivasarao C, Vankateswarlu B, Lal R, Singh AK, Kundu Vittal KRR, Balaguruvaiah G, Vijaya Shankar Babu M, Ravindra Chary G, Prasadbabu MBB, Yellamanda Reddy T (2012) Soil carbon sequestration and agronomic productivity of an alfisol for a groundnut-based system in a semiarid environment in southern India. Eumpean J Agron 43:40–48
48. Lehmann J (2007) A handful of carbon. Nature 447:143–144

49. Lal R (2005) World cop residues production and implication of its use as a biofuel. Environ Int 31:575–586
50. Watson D (2000) Mood and Temperament. New York: Guilford Press
51. Nair PKR, Nair VD, Kumar BM, Showalter J (2010) Carbon sequestration in agroforestry systems. Adv Agron 108:237–307. https://doi.org/10.1016/S0065-2113(10)08005-3
52. Tol RSJ (2012) On the uncertainty about the total economic impact of climate change. Environ Res Econ 53:97–116
53. Costinot A, Donaldson D, Smith C (2016) Evolving comparative advantage and the impact of climate change in agricultural markets: evidence from 1.7 million fields around the world. J Pol Econ 124:20–25
54. Hsiang S, Kopp R, Jina A, Rising J, Delgado M, Mohan S, Rasmussen DJ, Muir-Wood R, Wilson P, Oppenheimer M et al (2017) Estimating economic damage from climate change in the United States. Science 356:1362–1369
55. Burke M, Hsiang SM, Miguel E (2015) Global non-linear effect of temperature on economic production. Nature 527:235–239
56. Carleton TA, Hsiang SM (2016) Social and economic impacts of climate. Science 353:9837
57. Ciscar JC, Iglesias A, Feyen L, Szabo L, Regemorter DV, Amelung B, Nicholls R, Watkiss P, Christensen OB, Dankers R et al (2011) Physical and economic consequences of climate change in Europe. Proc Natl Acad Sci USA 108:2678–2683
58. IPCC (2006) IPCC guidelines for national gas inventories. http://www.ipcc.nggip.iges.or.jp
59. Li CS, Frolking S, Frolking TA (1992) A model of nitrous-oxide evolution from soil driven by rainfall events. 2. Model applications. J Geophys Res-Atmos 97(9):9777–83
60. Olivier JG, Schure KM, Peters JAHW (2017) Trends in global CO_2 and total greenhouse gas emissions. PBL Neth Environ Assess Agency 5
61. Srinivasarao C, Venkateswarlu B, Lal R, Singh AK, Kundu S, Vittal KPR, Sharma SK, Sharma RA, Jain MP, Rasåndra Chary G (2012) Sustaining agronomic prcxiuctivity and quality of a Vertisolic soil (Vertisol) under soybean-safflower croppmg system in semi-arid central India. Can J Soil Sci 92(5):771–785

Elucidating Revival Measures to Extenuate Expanse of Fallow Lands and Climate Change: An Empirical Analysis of Jharkhand

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Abstract Various natural and human activities, institutional, socio-economic, weather and climate-related factors-govern the use of cultivable land in developing countries. No doubt, for all practical purposes, supply of land is fixed. Increasing human population and economic growth has undoubtedly led to increased demand of land for different competing purposes. To achieve maximum possible boot from scarcely available land resources and with the view to remove non-comparability of earlier five-fold land-classification, a nine-fold land use classification was recommended by 'the Technical Committee on Agricultural Statistics' (Set up in 1948 by the Ministry of Food and Agriculture, Government of India (GOI). It encompassed: (i) Forests, (ii) Land put to non-agricultural uses, (iii) Barren and unculturable land, (iv) Permanent Pastures and other grazing land, (v) Miscellaneous tree crops and groves not included in the net area sown (NAS), (vi) Culturable waste, (vii) Fallow land other than current fallows, (viii) Current fallows and (ix) NAS. The Problem: During the 70 years' period of 1950–51 to 2020–21, particularly during 1950–51 to 2012–13, an increase of about 43% was evident in area under current fallows in India, that increased from 10.68 million hectares(ha) to 15.28 mha. Mono-cropped rice cultivation under rainfed conditions—has remained one of the essential characteristics of Jharkhand. Occurrences of frequent droughts at intervals, low rain fall, long dry spells during crop season and rise in temperature-engender indifferent attitudes among rural people towards agriculture. Further, declines of about 41.68 and 12.25% in 'annual' and 'monsoon rainfalls' during 18 years' period of 2002 to 2020 (as compared to base-year figure) in Jharkhand, besides 9–10 districts declared as drought affected almost every year at an average-clearly point out towards climate

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_13

change in the region over the period. The effect of climate change can be seen in an increase of 0.13% of area under 'fallow land category' during 22 years' period of 1996 to 2018 (2.34% and 2.47%) respectively. Overall, as per data upto 2016, the percentage of 'total fallow land to total geographical area' was 32.1 in Jharkhand. Out of the total geographical area of 79.70 lakh ha, total fallow land was estimated at 25,58,957 ha. In view of contended and evident extent of fallow land, fluctuations with decline in rainfall and, a number of districts faced with drought like situation every year in Jharkhand—this paper seeks to examine the following.

Keywords Net Area Sown (NAS) · Fallow land · Climate change · Current fallow · Agro-climatic zone · Total cropped area (TCA)

1 Introduction

The land of Jharkhand is known for its natural resources, which includes flora, fauna, water and mineral resources. As mentioned in the 'India State of Forest Report, 2019', forest cover in the state was 23,611 square kilometres (sq. kms), which is 29.62% of its total geographical area. With 77% of its population dependent on agriculture, this sector is the main source of livelihood for the rural people of Jharkhand. About 77% of the population depended on it. However, fluctuations in agricultural production, which had remained common in the state, has affected the farmers by shaking their confidence regarding assured profitable returns. The state witnessed fall in agricultural production during 2017–18 to 2018–19 [1–5]. Declines in production of Kharif and rabi crops were witnessed in the year 2018–19 compared to 2017–18. Total cropped area (TCA) and production of paddy had declined to 1,338 thousand hectares (ha) and 2991 thousand tonnes in 2019–20 from 1,735,000 ha and 5109 thousand tonnes respectively in 2017–18. Such fall in agricultural production and fluctuations can be attributed to deficit rainfalls during particular years, which could be as result of climate change as one of the responsible factors [5–13].

Objectives: (i) To delineate broad characteristics of different 'agro-climatic zones' of the state, (ii) Elicit rainfall trend and climatic effects, (iii Analyze irrigation and extent of fallow lands of households, (iv) Go into reasons for leaving land fallow and (v) Suggest observation-based Action Points.

1.1 Fallow Land and Climate Change: Observed Outlook

Global community is faced with climate change, which is one of the conspicuously visible challenges. Epitomized erratic behavior in regard to climate does indicate natural climate variability prevailing in Jharkhand. High climate sensitivity, vulnerability, and low adaptive capacity have made the situation more precarious.

1.2 Agriculture Sector and Climate Change

Created in the year 2000 by the bifurcation of the hilly plateau regions of the erstwhile state of Bihar, Jharkhand with an area of 79,714 Sq. Kms. was home to 3.3 crore people by the end of 2013. Jharkhand is predominantly an agrarian state with 80% of its population dependent on agriculture and allied activities. As per 1st advance estimate of the Directorate of Agriculture, Government of Jharkhand—total area under Kharif and rabi crops (during the year 2019–20) was 24.96 lakh ha. Broadly, the state can be categorized under three agro-climatic zones, viz: (i) Central and North Eastern Plateau sub zone (ii) Western Plateau sub zone and (iii) South-Eastern Plateau sub-zone. Output of 'the Agriculture, forestry and fishing sector' constituted 14.5% of 'the Gross State Value Added (GSVA)' of the state in the year 2019–20, but its contribution to state's growth rate was disproportionately low—at11.1% in the year. This had been because of a low growth in crop production, i.e.; a major constituent of this sector, and almost stagnant livestock production [14–19].

In case of inadequate rainfall, farm production falls sharply. It is so because agriculture is heavily dependent on rain. In Jharkhand (as per the data of 2004–05), only 43% of land was cultivated whereas at all-India level, 76% of the total cultivable area is under net sown area (NSA). Cropping intensity (CI) in the state was 117%. The per capita net sown area (PCNSA) was 0.083 ha, which is quite low compared to 'per capita land holding', which is estimated to be 0.14 ha [1]. One of the other disconcerting factors for farmers being indifferent from 'crop growing activities' is that in Jharkhand, area under fallow land increased by 0.13% from 1996 to 2018. So, it must be a matter of concern for all. As far the term 'fallow land' is concerned, these are the lands used for cultivation, but have been left un-cropped for one or more seasons, but not less than one year. Area under the fallow land category was 2.34% in 1996, 5.21% in 2007 and 2.47% in 2018.

1.3 Climate Change: Indian Perspective

Changes in global temperature and precipitation that result due to natural or human factors over a long period of time-refer to variation as properties of the climate system. Distribution and quality of natural resources can be insanitary due to climate change. It affects people's livelihood security and has become a serious environmental concern. Greenhouse gases (GHGs) present in the environment—is the prime reason of climate change. These threats have to be discreetly reduced—by delving existing potential of expanding areas under plants, tree and vegetative cover. Using fossil fuel and land use change has led to an increase of CO_2 concentration at a global level, resulting in climate change [20–25]. Global warming is the biggest example of the said climatic changes which is the rise in average temperatures of the areas near the earth's surface and oceans in recent decades. With their limited capacity and resources, developing countries are the ones facing the biggest challenge. Observations of the Inter-Governmental Panel on Climate Change (IGPCC) indicate that rising temperatures and extreme weather events could impact agricultural growth. India in recent years has observed more frequent and intense extreme weather events. Regions like coastal areas, Indo-Gangetic plains, and the drought and flood-prone regions of the country have been identified as risk-prone due to the impact of climate change. In 2007, about 17.6% of the GHGs emissions were from agricultural activities with enteric fermentation (63.4%), agricultural soils (13.0%), manure management (2.4%) and burning of crop residues (2.0%) being the major contributors. Farmers need to be apprised of and encouraged for adopting 'less carbon-intensive farming practices (LCIFPs)'. For achieving the goals of greater resilience in production systems, food security and guiding national planning for low carbon development, quantification and reduction of GHGs from agriculture is fundamental.

1.4 Challenges of Agricultural Sector: Statement of the Problem

According to Concept note of the first meeting of 'the Task Force on Agricultural Development' held on 6th April, 2015 and based on discussions, paddy/rice covered approximately 70% of the state's area during the Kharif season. During the Rabi season, majority of these areas remained fallow which lead CI to the level of 116% only, as the irrigation potentials created, were only 12% of the cropped area. It did not only hollow 'the already poor economic conditions of resource less farmers' and other rural people, but adversely affected their health related status. It can be a fact to daze that 'mono-cropped rice cultivation under rainfed conditions' is Jharkhand's unique and obfuscating characteristics. Occurrences of frequent drought at intervals, low rainfall, long dry spells during crop season and rise in temperature—can be taken as direct or indirect effects of climate changes in the region. Some of these climatic changes have caused the farmers to shift towards crops like pulses, oilseeds and cereals (namely Ragi and Jowar) which have low water requirements.

In yet another distracting way, a glance at 19 years' annual rainfall data (2002–2020) clearly reveals fluctuating trend, particularly during the last three years of 2018–2020, when the decline in average annual rainfall as compared to initial year's (2002) had remained upto 34.42%. Fluctuating and decreased rainfall had resulted in more than 9 districts (at an average) declared drought affected in the state (DES, GoJ). Further, the percentage of 'total fallow land' to 'total geographical area' in Jharkhand was 32.1 (as per 2016 data) which shows the impact of climate change on 'extent of fallow land' in the state. In the above backdrop, it will be desirable to confide in and delineate dynamics of fallow land, and the constraints of the agricultural sector as a result of confounding climate change. With the above 'Nature-Contorting events' in view, the paper has been prepared with the following objectives.

1.5 Objectives of the Paper

(i) To delineate broad characteristics of different ‘agro-climatic zones of the state,
(ii) Elicit rainfall trend and climatic effects,
(iii) Analyze irrigation and extent of fallow lands of households,
(iv) Go into reasons for leaving land fallow, and
(v) Suggest observation-based Action Points.

2 State-of-the-Art Review

In case of India (in general) and the state of Jharkhand (in particular), autonomous adaptation to climate change cannot be expected. Even if it was possible, it would not be sufficient to offset losses from climate change. Special attention to economic impacts of climate change and its consequences in developing countries—was paid in ‘the Stern Review’. Expressing concern for distracting negative effects of climate change, the Report cleared the fact of developing economies being more vulnerable than industrialized ones, where more severe projected climate changes will affect weaker economies. Extreme climatic events, such as droughts, always pose a significant threat to achieving sustainable development in agriculture, and thereby to agriculture-based livelihoods. The threat is more pronounced in developing countries like India, where agriculture still engages about half of the workforce. A widespread severe drought may cause a ‘gasping situation of food production decline, aggravate food insecurity, exacerbate rural poverty and lend to the depletion of productive assets.

Good potential in agriculture, particularly in tropics, was estimated by the IPCC [2]. It was in regard to mitigating GHG emissions. While intending to understand and assess ‘climate change and challenges to sustainable development’, Research Unit of Rajya-Sabha Secretariat presented impact of climate change (CC) as witnessed in recent times. In India, agriculture can be affected in different ways due to CC. No doubt, it is educed fact that with large part arable lands in India being rainfed, agricultural productivity depends on rainfall. Its patterns and would be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shift in its timings. No doubt, adaptation to climate change is paramount, alongside a fast mitigation response. To devise a planned or policy-driven adaptation can be another solution, which would require the Researchers, policy-makers and the government to come up with region-specific policy recommendations. Perception is a necessary pre-requisite for adaptation. Whether farmers are adapting agricultural practices to climate change that has been adding to the threat of fallow land, barren land and unculturable wastelands, depends on where they perceive it or not. However, this is not always enough for adaption. It is important how a farmer perceives the risks associated with climate change. Several studies have emphasised that risk-perceptions are important for motivating adaptation decisions.

Describing germane relationship and scored effects of CC on rice producers and consumers in India. Auffhammer et al. presented that rice yields of nearly 6% higher on an average would have been achieved had it not been for more frequent droughts, warmer nights and lower rainfall. This would have increased the cumulative harvest during 1966–2002 by an amount roughly equal to 1/5th of the increase caused by better farming technologies. This was also equivalent to rice consumption of an additional 30 million people yearly [3]. While examining India's flustering large proportion of agricultural area being rainfed [4] noted that in regard to India, it can be exemplified that despite over 56% of its total agricultural area being under rainfed conditions, India's agricultural sector feeds about 17.2% of the global population with only 9% of world's arable land. 'Intergovernmental Panel on Climate Change Draft' invariably noted that climate change can aggravate, which is land degradation processes—through increase in rainfall intensity, flooding, heat stress, drought frequency and severity, dry spells, wind etc., with outcomes being modulated by land management [26–30].

Rao et al. [5] in their ICAR Policy paper entitled: "Climate Change and Indian Agriculture: Impacts, Coping Strategies, Programmes and Policy"—brought out observed facts that emission of enormous quantities of GHGs from different sources has led to increasing global temperature. It is one of the significant reasons for CC and its adverse effect. Activities of all the existing lives and survival of all other living creatures on the planet—are pushed to disquieting conditions due to extreme temperature and its erratic events, which are the means of severe damage or loss. Averring the need of not ignoring semi-natural systems, which is possibly accounted for half of the global soil erosion by water, Borrelli et al. [6] found that soil and environmental degradation and sustainable source of major biogenic GHG emissions were main drivers of prevailing agricultural systems. No doubt, these factors have directly or indirectly, but adversely affected the climate and environment (as a whole). Above 'review of literatures' helps to follow as outcome that factors, like: poor possibility of adaptation to climate change, extreme climatic events, occurrences of severe droughts, fluctuations in rainfall, heat-stress, emission of green house gases (GHGs), etc., need to be routed or atleast made less severe. These can be done by undertaking 'climate-sensitive development(CSD)','region-specific agricultural practices (RSAPs)' and emphasizing social forestry to reduce the adverse effects of GHGs.

3 Materials and Methods

With both secondary and primary data both forming the basis, 'tabular' and 'percentage analysis' have been used as statistical tools' besides Compound Annual Growth Rate (CAGR), average rating and standard deviation (SD) of ratings. At the first stage of sampling, total fallow land, as a percentage of total land reported, was kept at least 2.00%. Further, at the second stage, the districts with highest fallow land and lowest fallow land were selected from those districts, which came under the criteria. At the third stage of sampling, Ranchi district (from out of the districts with highest fallow land i.e.; 1,70,709 hectares) and Ramgarh district with 47,577 ha of total fallow land (from out of the class of districts with lowest fallow land)—were selected for in depth study. At the fourth sampling stage, two blocks have been selected based on the average of fallow land (for the recent year, for which the data was available) from each of the selected districts. The two blocks with highest fallow land have been selected. Having followed this criterion, Kanke and Namkum blocks under Ranchi district and Gola and Patratu blocks under Ramgarh district, have been selected. At the fifth sampling stage, two villages/village clusters have been randomly selected from each of the selected blocks. The villages selected in Ranchi district are: (i) Pattagain and (ii) Chama-Barhu (under Kanke block) and (i) Garke and (ii) Plandu (in Namkum block). Villages selected from Gola and Patratu blocks under Ramgarh district were; (i) Rola and (ii) Baman-Sangatu (under Gola block), and (i) Armadag and (ii) Jumra (under Patratu block).

At the sixth sampling stage, 15 farmers from each of the villages/village clusters who had left the land fallow over a year/current fallow have been surveyed. Thus, the total sample was (2 villages × 2 blocks × 15 Hhs × 2 districts = 120).

Apart from the household survey across farmers, who had left land fallow, a village questionnaire had also been administered with the village headman/progressive village elder(s), who were competent to provide the required information containing a total of 35 information (Table 1). Multi-stage random sampling method has been followed. At the first stage, total fallow land as percentage of total land reported was kept at 2% at least. At the second stage, from out of those districts, which came under the criteria, the districts with highest area under fallow land (Ranchi) and lowest fallow land (Ramgarh) were selected. At the third sampling stage, two blocks (with highest fallow lands, data for which was available for the recent year) from the selected districts have been chosen. Thus, Kanke and Namkum blocks (under Ranchi district) and Gola and Patratu blocks (under Ramgarh district) were selected. For the fourth sampling stage, two villages/village clusters have been randomly selected from each of the selected blocks. As per suggested methodology given by the coordinator, i.e. 'IEG, New Delhi' for the state of Jharkhand, the criteria of minimum 10 ha of 'current fallow land' and 15 farm HHs, who had left land current fallow, were considered. At the fifth sampling stage, 15 farmers (who had left land fallow over a year) each of the village/cluster of villages have been surveyed. Thus, total sample size being (2 villages × 2 blocks × 15 HHs × 2districts = 20). Besides simple tabular and percentage methods, Compound annual growth rate (CAGR) and ranking methods have been used as statistical tools. Primary survey data revisited in 2019. In regard to some specific characteristics of agro-climatic zones—zones-IV, V and VI falling under 'agro-climatic region-VII'—occupied 1,042 thousand ha, 771.8 thousand ha and 389.1 thousand ha of cropped are respectively percentage of irrigated area was highest in sub-zone—V followed by sub-zones IV and VI (9.65, 6.58 and 4.54) respectively. Some of the common but significantly visible characteristics were (i) erratic and uneven distribution of rainfall, (ii) low water retention capacity and (iii) Poor Soil fertility (Tables 3 and 4).

Table 1 Selected districts and blocks along with number of farmers

State	Districts	Blocks	No. of farmers surveyed
Jharkhand	District-I Ranchi	Block-I, Kanke	$15 \times 2V = 30$
		Block-II, Namkum	$15 \times 2V = 30$
	District-II Ramgarh	Block-I, Gola	$15 \times 2V = 30$
		Block-II, Patratu	$15 \times 2V = 30$
	Total Sample		$= 120$

3.1 Rainfall Trend and Climatic Effects

Rainfall is the primary source of water, and is of great importance for the economies of the nation and the state of Jharkhand as well. It is especially significant and every time highly desired for its agricultural sector. It is highly variable over space and time, leading to flood and drought every year in one or the other parts of the country and different states. It is to be noted here that in Jharkhand, out of the 18 years' period of 2002 to 2020, for 11 years, there had been declines in rainfall. During 9 different years, 9 to 24 districts (out of the total 24) had been declared drought affected. Suppose data of monsoon rainfall during the 19 years' period of 2002 to 2020 is taken into consideration. In that case, a 12.25% decline could be seen in the year 2020 as compared to initial year (Table 4). As a result of it, the menace and extent of fallow land including: (i) Current fallow, (ii) other fallow, (iii) Barren lands, (iv) Non-agricultural use and (v) Culturable Waste lands had been estimated at 51.58% of Jharkhand's total geographical area of 7.97 million hectares (MHAs) Thus, about 42.81% of the total geographical area being not suitable for 'crop-raising purposes' or fallow will certainly expose the climatic factors to worsen further, if 'interception factors' are not neutralized by discreet measures. To extenuate the adverse impacts/effects of climate change (as a result of declining rainfalls and increasing 'non-agricultural land areas'), there is a need to understand the reasons and explore measures for revival of fallow land in Jharkhand.

As far annual rainfall in Jharkhand is concerned, except significant variation means declines during the years 2004, 2006, 2010, 2011, 2013, 2016, 2018 and 2020, it had remained more or less similar during the 18 years' long period of 2002 to 2020. In the year 2002, the actual annual rainfall was 1,270.9 mm. In 2017 also, it maintained the level of 1,264.0 mms. But, during the years 2004, 2006, 2010, 2011, 2013, 2014 and 2018, the state experienced declines with 1148.2 mms, 1000.4 mms, 970.61 mms, 806.1mms, 1102mms, 1085.6mms, 896 mms and 738.69 mms respectively (Table 4). The delineation of monsoon rainfall in Jharkhand based on data in the table reveals a spirit extinguishing scenario in the form of quite lower recorded rainfalls during the years 2003 to 2006, 2010, 2011, 2013, 2014, 2015, 2018, 2019 and 2020. During these years, monsoon rainfalls were 959.8 mms, 818.3 mms, 928.4mms, 819 mms, 793.7 mms, 648.1 mms, 938.5 mms, 884.5 mms, 930.1 mms, 784 mms, 865.6 mms and 899.2 mms respectively (Table 4). Frequently varying and quite lower rainfalls in different years have led to a very high number of districts declared drought-affected by the State Government. Numbers of drought affected districts in the state were as high as 24, 24, 22, 22, 20 and 15 in the years 2010, 2011, 2006, 2016, 2005 and 204 respectively. It is to be noted here that total number of districts in Jharkhand is 24 (Table 4).

4 Reference Period

Primary survey was conducted in last quarter of 2016. Data were revisited in 2019.

5 Results and Discussion

5.1 Broad Characteristics: Administrative and Agro-climatic Zones

Jharkhand comprised: 24 districts, 36 sub-divisions. 263 development blocks, 4,402 g Panchayats, 2076 clusters. 32,615 villages/1,400 Wards and 228 small and medium towns (Table 2).

The state comes under 'Agro-Climate Region-VII' of India, i.e. Eastern Plateau and Hills Region. This Region is further divided into three sub-zones, namely; (i) Central and North-Eastern Plateau Zone (Sub-Zone-IV) (ii) Western Plateau Zone (Sub-Zone-V) and (iii) South-Eastern Zone (sub-Zone-VI)—(Table 3).

Table 2 Administrative set-up: Jharkhand

District	24
Sub-district	36
Development blocks	263
Panchayat	4,402
Clusters	2,076
Village/wards	32,615/1,400
Small and medium towns	228
Urban local bodies	39
(a) Municipal corporations	3
(b) Nagar parishad	14
(c) Nagar panchayt	19
(d) Notified area	2
(e) Cantonment board	1

Source "Annual Plan (2016–17)" Department of Planning-Cum-Finance, Government of Jharkhand

Table 3 Agro-climatic division with broad characteristics (Jharkhand)

Region/zones Region-VII	Agro-climatic regions	Districts	Cropped area in (000 hectares)	% irrigated area	Characteristics
Zone-I Sub-Zone-IV	Central and North-Eastern Plateau	Chatra, Koderma, Hazaribagh, Bokaro, Dhanbad, Giridih, Deoghar, Dumka, Pakur, Godda, Sahebganj	1,042.0	6.58	(a) Uneven and erratic distribution of rainfall, (b) coarse textured soils. (c) Crust formation on the soil surface, low water retention capacity of soil. (d) Lack of safe disposal run off and drying of the tanks
Zone-II Sub-Zone-V	Western Plateau	Garhwa, Palamau, Lohardagga, Gumla and Ranchi	771.8	9.65	(a) Uneven and erratic distribution of rainfall. (b) Low water retention capacity of the soil
Zone-III Sub-Zone-VI	South-Eastern Plateau	East Singhbhum and West Singhbhum	389.1	4.54	(a) Uneven distribution of rainfall. (b) Low water holding capacity, (c) eroded soil (d) shallow soil depth (e) poor soil fertility

Source "Economic Survey (2007–08", Government of Jharkhand)

In regard to some specific characteristics of agro-climatic zones—zones-IV, V and VI falling under 'agro-climatic region-VII'—occupied 1,042 thousand ha, 771.8 thousand ha and 389.1 thousand ha of cropped are respectively percentage of irrigated area was highest in sub-zone-V followed by sub-zones IV and VI (9.65, 6.58 and 4.54) respectively. Some of the common but significantly visible characteristics were (i) erratic and uneven distribution of rainfall, (ii) low water retention capacity and (iii) Poor Soil fertility (Table 3).

Table 4 Rainfall and other factors associated with trends and variability for the State Jharkhand

Year	Annual rainfall (in mm)	Monsoon rainfall (in mm)	No. of districts declared drought affected
2002	1270.9	1024.7	00
2003	1094.9	959.8	22
2004	1148.2	818.3	15
2005	1163.3	928.4	20
2006	1000.4	819.0	22
2007	1436.3	1267.0	00
2008	1476.4	1271.3	00
2009	1270.0	1166.4	00
2010	970.6	793.7	24
2011	806.1	648.1	24
2012	1274.7	1160.6	00
2013	1102.0	938.5	00
2014	1253.6	844.5	00
2015	1156.6	930.1	00
2016	1085.6	941.9	22
2017	1264.0	1107.0	00
2018	896.0	784.0	NA
2019	–	865.6	09
2020	738.69 (41.88)	899.2 (12.25)	11

Figures in bracket show percentage declines in Annual and Monsoon rainfalls in 2020 over 2002
Sources (i) www.imd.gov.in/rainfall (ii) DES, Govt. of Jharkhand 2015 and Ranchi, (iii) DAC, GoI, 2nd November, (iv) 'Economic Survey (2020–21)', Jharkhand).

5.2 *Extent of Fallow Land in the State*

As per data available till December, 2016, out of the total geographical area of 79.70 lakh hectares (ha), 15.32 lakh ha (19.22%) fell under current fallow, and 25,58,957 ha (i.e.; 32.11%) land areas were estimated to be total fallow land (Table 5). As far areas under 'total fallow' are concerned, districts of Gumla, Ranchi, West Singhbhum, East Singhbhum and Khunti etc. were faced. It is highest proportion to total geographical areas of the respective districts. Areas under total fallow lands in these districts were: 172,510 ha, 170,709 ha, 167,869 ha, 160,013 ha, 157,140 ha, 149,918 ha, 128,287 ha, 121,704 ha, 117,707 ha, 115,623 ha, 113,538 ha and 104,751 ha) respectively. Areas under total fallow lands in the remaining 12 districts of the state-were less than 1 lakh hectares. In regard to 'percentages of total fallow land to total geographical areas, Deoghar, Pakur, Sahibganj, Khunti and Godda districts were (48.3, 42.8, 41.9, 40.1 and 40) respectively.

Table 5 District wise area under fallow and selection of districts (area in ha)

District	Total area	Current fallow	Total fallow	% of total fallow land to total geog. area
State total	7,970,075	1,531,626.6	2,558,957	32.1
Gumla	534,318	108,687.6	172,510	32.3
Ranchi	497,306	103,241	170,709	34.3
West Singhbhum	567,769	91,055	167,869	29.6
Giridih	493,248	95,619.8	160,013	32.4
Palamu	460,431	97,579.6	157,140	34.1
Dumka	377,523	104,508.4	149,918	39.7
Hazaribagh	431,315	73,323.4	128,287	29.7
Garhwa	428,826	65,047.4	121,704	28.4
Deoghar	243,695	76,370	117,707	48.3
Simdega	379,434	67,274.2	115,623	30.5
East Singhbhum	556,697	72,285.4	113,538	20.4
Khunti	261,088	54,348.8	104,752	40.1
Chatara	382,050	45,889.4	98,873	25.9
Latehar	383,490	57,569.8	95,726	25.0
Godda	231,842	69,711.8	92,785	40.0
Bokaro	288,992	47,822	90,503	31.3
Sahibganj	198,780	45,592	83,267	41.9
Dhanbad	204,161	52,146.8	78,518	38.5
Pakur	180,557	46,390.8	77,276	42.8
Jamatara	180,704	39,515	67,697	37.5
Lohardaga	153,621	30,940.2	50,453	32.8
Kodarma	156,999	30,844.2	49,235	31.4
Ramgarh	139,998	25,698.8	47,577	34.0
Saraikela	237,231	30,165.2	47,276	19.9

5.3 Land Use Pattern

It is interesting to note that during the 14 years' period of 2001–02 to 2014–15, the state of Jharkhand witnessed an increase of 2,11,427 ha in its area under fallow lands other than current fallows (Table 6). This is the point of prime anxiety for the state.

Concluding, it is stimulating to note here that 14.07% of the total reported area was under 'fallow lands other than current fallow' and 17.38% were under 'current fallows' categories in the year 2014–15. Both the types of fallows comprised 31.46% of the total reported area in 2014–15. In the year 2001–02, areas under the two types of fallow lands taken together accounted for 29.60%. It means there was an increase of 1.86% in 'areas under fallow other than current fallows' and 'current fallows'

Table 6 Land use pattern of the state (in ha)

Year	Reporting area for land utilization statistics	Forests	Area under non-agricultural use	Barren and un-cultural land	Net area sown	Other unculti-vated land excluding Fallow land	Land under misc. Tree crops and groves not included in net sown	Cultural waste land	Fallow lands other than current fallows	Current fallows
2001–02	7,970,075	2,239,481	758,512	564,113	1,521,946	527,028	83,298	334,037	910,365 (11.42)	1,448,630 (18.18)
2002–03	7,970,075	2,239,481	758,512	564,113	1,535,946	527,028	83,298	334,037	910,365	1,434,630
2003–04	7,970,075	2,239,481	758,512	564,113	1,565,475	527,028	83,298	334,037	901,137	1,414,329
2004–05	7,970,075	2,239,481	754,508	4,164,513	1,475,922	525,975	83,328	332,955	968,579	1,441,097
2005–06	7,970,075	2,239,481	756,908	564,113	1,405,860	525,975	83,328	332,955	1,026,726	1,450,612
2006–07	7,970,075	2,239,481	757,515	564,113	1,503,565	536,904	93,177	334,037	966,476	1,402,021
2007–08	7,970,074	2,239,481	754,480	564,113	1,535,764	535,539	93,177	332,671	912,796	1,427,901
2008–09	7,970,074	2,239,481	763,555	568,686	1,503,980	538,893	93,334	335,868	961,781	1,393,698
2009–10	7,970,075	2,239,481	763,722	568,699	1,250,366	538,912	93,345	335,873	1,045,043	1,563,852
2010–11	7,970,075	2,239,481	763,722	568,699	1,085,366	538,912	93,345	335,873	1,045,043	1,728,852
2011–12	7,970,075	2,239,481	775,334	563,648	1,249,901	563,537	99,414	343,361	1,046,561	1,531,613
2012–13	7,970,075	2,239,481	709,548	571,878	1,405,985	564,841	101,985	349,236	1,038,224	1,440,118
2013–14	7,970,075	2,239,481	705,788	568,009	1,383,585	564,940	98,260	352,871	1,063,146	1,445,126
2014–15	7,970,075	2,239,481	705,788	568,009	1,384,515	564,940	98,260	352,871	1,121,792 (14.07)	1,385,550 (17.38)

Figure in parenthesis shows % of 'areas under particular category' to 'reported area for Land Utilization Statistics' in respective Years)
Source Jharkhand Economic Survey (2016–17), Planning-cum-Finance Department, Govt. of Jharkhand

(taken together) to total reported area for land utilization during the 13 years' period of 2001–02 to 2014–15 (Table 6).

5.3.1 Land Irrigation and Others

In this section, attempt has been made to analyse and explain farm class wise and district wise land irrigation and other features of sampled farm households. The description focuses on aspects related to: (i) total area irrigated, (ii) percentage of irrigated area, (iii) area under food grains, and; (iv) area under fruits and vegetables. Having analysed on all sampled farmers' level, it is observed that percentages of irrigated area were 100 in the two districts, namely: Ranchi and Ramgarh, at overall level. Total irrigated areas in districts I (Ranchi) and II (Ramgarh) and at overall level, were estimated at 32.65 acres, 33.22 acres and 65.87 acres respectively. Much larger proportions of land were found to have been occupied by food grains in the two surveyed districts (97.37% and 95.83%) respectively. Across the farm size, larger percentages of irrigated areas were viewed in cases of marginal farm households of District-I and at overall level, of the same classand in regard to small farms of district-II (50.38, 45.65 and 59.00) respectively. Very small areas under fruits and vegetables were found to have been devoted by marginal, small and medium farm households of both the districts (2.70%, 3.41%, 0.99% meant for district-I and 4.02% and 4.32% in district-II) respectively. At overall level, marginal, small and medium farm households devoted 96.73, 95.91 and 99.01% areas under food grains and remaining meager proportions of land to fruits and vegetables (Table 7).

5.3.2 The Extent of Fallow Land

Efforts have been made to make out in this section about block wise extent of fallow land in the surveyed districts. i.e.; in Ranchi and Ramgarh. Exercises have been made to find out the data/aspects related to (i) area of fallow land, (ii) percentage of total land, (iii) number of households owning wells, (iv) number of wells, (v) area irrigated per well (vi) average number of well per household, and; (vii) average number of tractors. A glance on data helps to comprehend that surveyed farm households of Namkum block under Ranchi district had highest percentage to total land (80.66) closely followed by Gola and Patratu blocks of Ramgarh district (79.67% and 76.69%) respectively. Area irrigated per well was found to be the largest in Patratu block (1.39 acres). Average number of tractor was also found to be maximum again in Patratu block (0.07) equally followed by the remaining three blocks, i.e., Kanke, Namkum and Gola (0.03). Areas of fallow lands owned by the surveyed farm households of Kanke, Namkum, Gola and Patratu blocks were estimated at 49.50 acres, 43.58 acres, 49.45 acresand 67.77 acresrespectively (Table 8). It is to be noted that none of the sampled farm households possessed any un-culturable land area.

Table 7 Land Irrigation and others

Districts	Particulars	Farm-size categories				
		Marginal farmers	Small farmers	Medium farmers	Large farmers	All sampled farmers
District I	Total irrigated area (acre)	16.45	6.00	10.20	–	32.65
	% of irrigated area	50.38	18.38	31.24	–	100.00
	Area under food grains	83.00 (97.30)	24.63 (96.59)	15.05 (99.01)	–	122.68 (97.37)
	Area under fruits and vegetables	2.30 (2.70)	0.87 (3.41)	0.15 (0.99)	–	3.32 (2.63)
District II	Total irrigated area (acre)	13.62	19.60	–	–	33.22
	% of irrigated area	41.00	59.00	–	–	100.00
	Area under food grains	73.56 (95.98)	70.61 (95.68)	–	–	144.17 (95.83)
	Area under fruits and vegetables	3.08 (4.02)	3.19 (4.32)	–	–	6.27 (4.17)
State	Total irrigated area (Acre)	30.07	25.60	10.20	–	65.87
	% of irrigated area	45.65	38.86	15.49	–	100.00
	Area under food grains	156.65 (96.73)	95.24 (95.91)	15.05 (99.01)	–	266.94 (96.56)
	Area under fruits and vegetables	5.38 (3.27)	4.06 (4.09)	0.15 (0.99)	–	9.59 (3.44)

Source Primary Survey. *Note* Figures in parentheses show percentages of respective total

5.3.3 Fallow Land of Households

In this section, efforts have been made to calculate and mention data-based facts to support farm class and district-wise descriptions regarding fallow land of households (Hhs). It discusses: (i) number, (ii) total owned land, (iii) fallow land related area, average area and percentage of total owned land. The data provide sufficient ground to impart obtained facts that at overall level (taking all categories together), percentage of fallow land to total owned land was 74.09 in district-I, i.e., Ranchi and 77.89 in district-II, i.e., Ramgarh. Across the farm size, marginal farm households owned

Table 8 The extent of fallow land (area in acre)

Districts/ blocks	Total owned land	Fallow land	Percentage of fallow land to total land	No of households owning wells	No. of wells	Area irrigated per well	Average no of well per household	Average of tractor
Ranchi Block I (Kanke)	71.70	49.50	69.04	–	–	–	–	0.03
Block II (Namkum)	54.03	43.58	80.66	–	–	–	–	0.03
Ramgarh Block III (Gola)	62.07	49.45	79.67	1	1	0.78	0.03	0.03
Block IV (Patratu)	88.37	67.77	76.69	2	2	1.39	0.07	0.07

Source Primary Survey

highest proportions of fallow to total owned land in both the districts (80.71% and 82.19%) in districts-I and II respectively. While marginal sampled farm households in both the districts owned larger areas (85.3 acres and 76.46 acres), largest total fallow lands were also reported in case of marginal households itself (68.85 acres and 62.84 acres) respectively. Percentage of fallow land to total owned land by medium farm households of Ranchi district was 32.89 as sample households of Ramgarh did not have medium and large categories of farm households. In regard to average area of fallow land, small farm households of both the districts were ahead (2.44 acres and 2.36 acres) respectively. At overall level, these were 1.56 acres and 1.95 acres for districts-I and II respectively (Table 9).

5.3.4 Extent of Fallow Land: Social Category-Wise

In this section of the chapter/paper, attempt has been made to analyse and describe social category wise and district wise extent of fallow land. The components discussed in the preceding section have been analysed in regard to: (a) other backward class (OBC), (b) Scheduled Tribe (ST), (c) Scheduled Caste (SC), and; (d) All Categories (district wise). No sampled farm households belonged to general category in both the districts. District-I did not have other backward class (OBC). No surveyed farm households belonged to SC also in either of the districts. Percentages of fallow land out of the total owned land by the ST households in Districts-I and II were 74.09 and 77.54 respectively. On overall level, these were found as 74.09 and 77.89 respectively. In regard to district-II, OBC farm Households possessed 16.15 acres of fallow land, average size of fallow land was estimated at 1.79 acres and percentage of fallow land to total owned land was 81.15. Areas of fallow land owned by all social categories of farm households in districts I and II were estimated at 93.35 acres and

Table 9 Fallow land of households (area in acre)

Farm-size categories	District I					District II				
	No. farms	Total owned land	Fallow land			No. farms	Total owned land	Fallow land		
			Area	Average area	% of total owned land			Area	Average area	% of total owned land
Marginal farmers	49	85.3	68.85	1.40	80.71	37	76.46	62.84	1.70	82.19
Small farmers	8	25.5	19.5	2.44	76.47	23	73.80	54.2	2.36	73.44
Medium Farmer	3	15.2	5.00	1.67	32.89	–	0.00	0.00	0.00	0.00
Large farmers	–	–	–	–	–	–	–	–	–	–
All categories	60	126.00	93.35	1.56	74.09	60	150.26	117.04	1.95	77.89

Source: Primary Survey

117.04 acres, averages of fallow land being 1.54 acres and 1.95 acres respectively (Table 10).

Table 10 Extent of fallow land by social category (area in acre)

	District I					District II				
Categories	No. farms	Total owned land	Fallow land			No. farms	Total owned land	Fallow land		
			Area	Average area	% of total owned land			Area	Average area	% of total owned land
General	–	–	–	–	–	–	–	–	–	–
Other backward castes	–	–	–	–	–	9	20.15	16.15	1.79	81.15
Scheduled tribes	60	126.00	93.35	1.56	74.09	51	130.11	100.89	1.98	77.54
Scheduled castes	–	–	–	–	–	–	–	–	–	–
All categories	60	126.00	93.35	1.54	74.09	60	150.26	117.04	1.95	77.89

Source Primary Survey

5.3.5 Social Farm Class Wise Fallow Land Scenario

In this section of the paper, attempt has been made to illuminate on extents of fallow land left fallow by surveyed farmers belonging to different social groups and land holding classes in both the districts. The extents have been analysed in terms of percentages of fallow lands to 'total owned land' by respective categories/groups of farm households. Percentage of total land areas owned by ST category of farmers in district-I, i.e., Ranchi that was left fallow after the Kharif crop-was 100 and 86.20% of the respondents belonging to same social group in district-II, i.e., Ramgarh. In district-I, 73.75 and 20.89% of land areas were found fallow in case of marginal and small farm households, whereas in district-II, the same were 53.69% and 46.31% respectively. Areas under main crop, i.e., paddy were very high in district-I and II (76.15% and 72.06%) respectively, the production potential of which was limited, as a result of significantly larger unirrigated areas (i.e.,74.09% and 77.92%) in districts-I and II respectively.

These extents of land areas left fallow by different social and farm size groups of surveyed households are percentages of fallow land to 'total fallow land area' by all farm size groups of farmers surveyed in the particular districts. Irrigated areas in both the districts were quite insufficient (25.91% and 22.08%) respectively. Overall percentage of irrigated land area (having taken both the districts together) was found at 23.83 (Table 11).

Table 11 Fallow land % of households in different social and farm size categories

Indicators	District-I	District-2	Overall
Social group (% of Fallow land)			
SC	–	–	–
ST	100.00	86.20	07.68
OBC	–	13.80	92.32
General	–	–	–
All	100.00	100.00	100.00
Farm size wise			
Marginal	73.75	53.69	62.59
Small	20.89	46.31	35.03
Medium	05.36	–	02.38
Large	–	–	–
All	100.00	100.00	100.00
Irrigation			
Irrigated	25.91	22.08	23.83
Un irrigated[a]	74.09	77.92	76.17
Main crop (Paddy)	76.15	72.06	73.92

Source Primary Survey
[a] % of Irrigated displays the land area left fallow

On overall level (i.e., taking both the districts together), OBC households were found to have owned maximum percentage of fallow land (92.32). In regard to farm size wise criteria and irrigation fronts, larger concentrations of fallow land on overall level, were viewed in case of marginal households (62.59%) and inunirrigated area (76.17%) respectively.

5.3.6 Reasons for Land Left Fallow

In this section of the paper, attempt has been made to consciously find out the reasons or factors responsible for leaving land fallow by surveyed farmers. A well-determined and given list of reasons for leaving land fallow in the study area-had been enumerated and analysed by using: (i) average rating, and; (ii) standard deviation (SD) of the ratings. Prudent analysis suggests that lack of assured irrigation was rated as one of the most prominent reasons for leaving land fallow with average rating of 4.46 and standard deviation (SD) of 55. The next important reasons were lack of watershed or similar efforts. Which could recharge groundwater (1.98) with SD of 44, surface runoff (1.96) with SD 42, no access to easy credit (1.92) with SD 30. It is moved to other occupations (particularly during the rabi season), which were more profitable' (1.90) with SD 61.00. Apart from the above described reasons, some other factors responsible for leaving land fallow were: land is not suitable for cultivation (1.81) with SD-48, land set apart for conversion into non-agricultural purposes (1.80) with SD 63 and close to mountain/forest (1.79) with SD 42. Uncertainty of rainfall can also not be underestimated and ignored (1.51) with SD 75.00 as one of the stronger reasons (Table 12).

It is to be noted here that the reasons for leaving land fallow have been measured on scale of 1 to 5 with 1 being not at all a reason to 5 being one of the major and strongest reasons. All the 26 listed reasons captured through the questionnaire have been rated on this scale.

5.4 A Final Comment

As the Zone-I, Sub-Zone-IV, under 'agro-climatic region-VII' means Central and North-Eastern Plateau Region with 51.90% of the total geographical area. It-is the most significant one, so there is stronger need to gear it up with allied activities. This Sub-Zone comprises 11 districts, namely: Chatra, Koderma, Hazaribagh, Bokaro, Dhanbad, Deoghar, Dumka, Giridih, Godda, Pakur and Sahebganj. But, the irony of this zone/region is that only 6.58% of its total cropped area is irrigated. Apart from this limitation, it is constrained with some 'inefficacious characteristics' noted hereunder: (a) Uneven and erratic distribution of rainfall, (b) Coarse textured soils, (c) Crust formation on the soil surface, (d) low water retention capacity of the soil, (e) Lack of safe disposal runoff and (f) drying of the tanks. One of the significant factors that contributes in attenuating 'agrarian economy of Jharkhand' is that rice covers

Table 12 Reasons for land left fallow

S. no	Regions for leaving land fallow	Average rating	Standard deviation of the ratings
a.	Land is not suitable for cultivation	1.81	48.00
b.	Land set apart for conversion into non-agricultural purposes	1.80	63.00
c.	Not able to recover costs in farming/low profit	1.48	77.00
d.	Lack of assured irrigation	4.46	55.00
e.	Moved into other occupations which are more profitable	1.90	61.00
f.	Providing grazing lands for the cattle	1.70	60.00
g.	To conserve moisture and prepared land for next crops	1.77	53.00
h.	Labor is not available for cultivation	1.73	49.00
i.	High yield volatility in the previous years	1.68	61.00
j.	Lack of assured market for the produce	1.73	49.00
k.	High price volatility in the previous years	1.62	65.00
l.	High production cost/lack of resources	1.78	56.00
m.	Lack of agricultural extension	1.20	64.00
n.	No access to credit	1.92	30.00
o.	Surface runoff	1.96	42.00
p.	Lack of watershed or similar efforts which could recharge ground water	1.98	44.00
q.	Water logging	1.55	68.00
r.	Uncertainty in rainfall	1.51	75.00
s.	Issues related to land entitlement	1.21	46.00
t.	Lack of expertise/experience in cultivation	1.42	71.00
u.	Shocks in personal life (like accident or death of a member)	1.43	75.00
v.	Low fertility of soil and lack of Interest in cultivate in unfavorable season	1.56	57.00
w.	Lack of plough/tractor/Farm Yard Manure (FYM)	1.30	69.00
x.	Weed infected	1.45	44.00

(continued)

Table 12 (continued)

S. no	Regions for leaving land fallow	Average rating	Standard deviation of the ratings
y.	Close to mountain/forest	1.79	42.00
z.	Left land fallow for crop rotation	1.25	54.00

Source Primary Survey

approximately 70% of the area in the state and a big proportion of this area remains fallow during the rabi season. This has led to cropping intensity level of 116% only as the irrigation potential of only 12% of the cropped area has been created so far. In view of the higher percentage of fallow land to total land owned by the surveyed farmers, emphasis on some other 'allied agricultural activities' equally needs to be given. The observed and conspicuous climate, fallow land and soil-texture related weaknesses do strongly provide logic and ground for laying on the Animal Husbandry Sector in the region. Animal husbandry is an important 'Knotting means' of integrated farming in Jharkhand. 80% of the cultivators of the state earned their livelihood by depending on Animal husbandry. The Animal husbandry sector contributes about 30–40% of the income of farmers. So, in view of the limitations, threats and weaknesses prevailing in the agricultural sector (i.e.; crop growing enterprises), a circumspect strategy for promoting and strengthening the animal husbandry sector may be considered and designed for Jharkhand.

As far reasons for leaving land fallow are concerned: (i) lack of assured irrigation, (ii) lack of watershed or similar devices, which could recharge ground water, (iii) Surface runoff, (iv) no access to credit, (v) moved to other occupations, which were more profitable, (vi) land was not suitable for cultivation, (vii) land set apart for conversion to non-agricultural purposes and (viii) close to mountains/forests—were reported to be prominent ones (with average ratings of: 4.46, 1.98, 1.96, 1.92, 1.90, 1.81, 1.80 and 1.79) respectively. So, to reduce the intensity of these distracting factors, there is a need to excogitate such suitable mechanism and measures that could lead to reduction in fallow land, resulting from frequent declines and fluctuations in rainfall and drought situations. Observation and scientific study-based suggestions and possible measures must be consciously contrived to sustain agricultural production. Besides, preparation of data-base on climate change in selected locations; and development of 'area/region-specific models' for population dynamics may also form part of our efforts—to reduce ill-effects of climate change (CC).

5.5 Recommendations

In view of larger proportion of current and permanent fallow, barren/wasteland and uncultivable wasteland in Jharkhand, allied agricultural activities (particularly Animal Husbandry enterprises, poultry, Piggery, fisheries), should be specifically promoted in the state in place of only undertaking crop-raising activities, particularly in mono-cropped areas.

5.5.1 Short-term Measures

(a) Desirous farmers should be given crossbred milch animals on subsidies.
(b) Logically desired enhancement in prices of animal products should be announced, which may be able to extricate the people engaged in Animal husbandry from poverty trap.
(c) Research Faculties of Colleges of Forestry, State Agricultural Universities, WALMI (wherever in operations), and state level/regional centres/institutions. That undertake research studies related to economic problems of agriculture sector—may be assigned additional tasks of exploring such undulated areas in hilly and mountain regions. Where significant proportions of allocated assistances may be utilized under the recently approved NMOOP. In such regions/ areas of Jharkhand, and other states, pulses and oilseeds can be largely grown by the farmers.

5.5.2 Medium-term Measures

(a) A countrywide assessment is needed that urgently maps risks based on the changes in climate. Any kind of development (particularly to be undertaken for reducing area under fallow land—by using suitable cropping pattern and/ adopting allied agricultural activities) should be planned based on an evaluation of these risks—whether this is a public infrastructure, or even a farm household.
(b) Serious thinking is required on what may be allowed to remain in India's portfolio of priorities, while greening the nation and the economy.
(c) Needs are there for clear identification of climate-risk and embedding this in
(d) For maintaining the interest of crop-growers (farmers) in agricultural activities, and with the view to counter the food insecurity related threats prevailing in 'very insecure' and'extremely insecure districts'-dairying, poultry, piggery, goatery, bee-keeping-like activities need to be promoted.
(e) Allied agricultural activities may be specifically emphasised and promoted in two districts of Zone-III (East Singhbhum and West Singhbhum), where percentage of irrigated area to total cropped area is the lowest, i.e., 4.54 only.
(f) Farmers of Jharkhand (in particular), and India (in general), should be made aware of the alarming threats of climate change and negative effects of increasing fallow, barren and unculturable waste lands. They may be convinced to undertake allied enterprises in such land areas.

5.5.3 Long-term Provident Measures

(a) A well-reliable, duly surveyed data bank need to be contemplated/formed (at Gram Panchayat and Block levels)—for obtaining data of land use pattern (that may be revisited after every two years).
(b) One Data Bank/Data House, like the Directorate of Economics and Statistics mandated at the national and State levels (having reliable data sources and transparency with scope for revisiting the published data)-should be strengthened and expanded. Multiplicity of data sources creates confusion in chalking out any effective, concrete, real policy. There are often some variations/differences in published agricultural data from different sources.
(c) Emphasis should be given on development and expansion of areas under green fodder.
(d) With a view to enhance productivities of milch and other animals, installation of manufacturing units by using new techniques like: (i) Complete Feed Block, (ii) Urea treated straw block, (iii) Urea Mollases Block, (iv) By-pass protein, (v) By-pass fat, etc.—may be done in remote village areas in good number.
(e) By making efforts to reduce the number of 'undesirably long channel of middlemen', commission agents and brokers in the Marketing Channel—'exploitation free and profit-providing markets' should be established in nearby peripheries.
(f) If some possibility of expanding irrigation facilities is there, then it should be complemented by steps like: (i) Water-Saving technologies and (ii) Agronomic practices, such as Direct-seeding, alternate wet and dry irrigation, laser land leveling, lining and regular cleaning of field channels, improved tillage, etc.
(g) Climate change is posing a big challenge to the human race. With the view to reduce the dismaying effects of climate change, a comprehensive "State Action Plan on Climate Change (SAPCC)" has been formulated by an interdepartmental team, which covered, besides knowledge management on climate change, all relevant sectors, such as: Forestry, Agriculture, Health, Industries, Mining, Energy, Urban Transport and Water Resources. No doubt, the plan also incorporates 'Civil Society Inputs'.

What is then desired, SAPCC meant for Jharkhand has to be geared up and needs to be advised for cogitating on grass-root level inputs submitted/obtained by 'AERCs'/AERUs, SIRDs, and other Centres of Excellence, SAMETI, BAU, Kanke, Ranchi. SAPCC should prefer to work on suggested steps for countering adverse effects of climate change without delay.

Above steps (if taken up seriously and in planned way), will certainly bring cheerfulness among farmers and rural households—by making the state self-sufficient in agricultural production by bridging several critical gaps in agriculture and allied sectors.

5.6 Conclusion

At overall level, marginal, Small and medium farm HHs devoted 96.73, 95.71 and 99.01% areas under food grains and remaining meagre proportions of lands to fruits and vegetables. Percentages of 'fallow lands to total land' owned by the surveyed HHs of blocks-I andII, i.e.; Kanke and Namkum in Ranchi district and blocks-III and IV, i.e.; Gola and Patratu in Ramgarh district were 49.50, 43.58, 49.45 and 67.77 respectively. Highest percentages of fallow lands out of the total land areas owned by marginal farmers of Ranchi (D-1) and Ramgarh districts (D-2) were visible 80.71 and 82.19 respectively. Social category-wise extent of fallow land data establishes OBCs' to have owned highest percentage of fallow land to total owned land (81.15) in D-2. It was followed by STs (77.54). It was 74.09% in D-1 in case of STs. Out of the land area left fallow by sample HHs, larger percentages of unirrigated land were found in D-2 (77.92). In D-1, it was 74.09. 'Lack of assured irrigation' was rated as one of the most prominent reasons for 'leaving land fallow' with average rating of 4.46. Besides above Observed problems, opportunity, way forward, short, medium and long-terms 'prudent and possible action points (PPAPs)' like sections form part of the paper/chapter.

References

1. "Jharkhand – Action Plan on Climate Change", Government of Jharkhand, Ranchi, 2014.
2. IPCC-Climate Change and Land (Summary for Policy Makers) WG-I, WG-II, WG-III, WMO, UNEP-Approved Draft, August 07, 2019
3. FAO of the United Nations (2017) Food Outlook Biannual report on global food markets. FAO, Rome, www.fao.org/3/i8080en/I8o8oEN.pdf
4. Goyal MK, Surampalli RY (2018) Impact of climate change on water resources in India. J Environ Eng 114(7). https://doi.org/10.1061/(asce)ee.1943-7870.0001394
5. Rao CS, Prasad RS, Mohapatra T (2019) Climate change and indian agriculture : impacts, coping strategies,programmes and policy. ICAR policy paper p 31
6. Borrelli PR, Robinson DA, Panagos P, Lugato E, Yang JE, Alewell C, Wuepper D, Montanarella L, Ballabio C (2020) Land use and climate change impacts on global soil erosion by Water (2015–2070). PNAS (Proc Natl Acad Sci USA)
7. "Jharkhand Economic Survey (2019–20)", Planning-Cum-Finance Department, 'Centre for Fiscal Studies', Govt. of Jharkhand
8. 1st Advance Estimates, 2019–20 "Directorate of Agriculture, Govt. of Jharkhand
9. Directorate of Statistics and Evaluation, PDD, GoJ and Bihar, 2004–05
10. Maurya C, Sharma VN (2020) Land use/land cover change detection in Auranga River Basin—Jharkhand. NGJI, Int Peer Rev J, NGSI-BHU 66(1):51–58
11. Comment On the Concept Note On Agriculture-NITI-Aayog, https://www.niti.gov.in
12. SANDRP "Monsoon 2019; State wise Rainfall"
13. Dr. Sinha RK (2017) Dynamics and revival of fallow land in Jharkhand. AERC for Bihar & Jharkhand, TMBU-Research Study No. 43
14. Turral H (2011) FAO water reports 36. In climate change, water and food security. FAO of the United Nations, Rome
15. Auffhammer M, Ramanathan V, Vincent JR (2012) Climate change, the monsoon, and rice yield in India. Climate Change 111:411–424. https://doi.org/10.1007/310584-011-0208-4

16. State of Indian Agriculture (2015–16), DES, DAC & FW, Ministry of Agriculture & Farmers Welfare, Government of India, May 19th, 2016, pp 17–19 & 59–62
17. The Hindu Business Line, May 3, 2018, p 4
18. Dalwai A (2017) Doubling of farmers' income: agricultural growth and farmers welfare, Kurukshetra, vol 65, no 8, June 2017, pp 5–14
19. Birthal P-N, Digvijay S-K, Tajuddin Md, Agrawal S (2015) Is Indian agriculture becoming resilient to droughts? Evidence from rice production. Policy Brief (41), NIAE & PR, New Delhi-110012, February 2015
20. Tripathi A, Mishra AK (2017) Farmers need more help to adapt to climate change, Econ Polit Wkly LII(24):53–59
21. Prof. Chand R, Transforming agriculture for farmers' Prosperity, Ibid:15–17
22. Food security Atlas of rural Jharkhand (2008) UN World Food Programme. Institute for Human Development, New Delhi-110002
23. Annual Plan (2016–17) Department of planning cum-finance. Government of Jharkhand
24. Road Map for Doubling Income in Five Years (2016–2021) Deptt. of 'agriculture, animal husbandry and co-operation'. Govt. of Jharkhand
25. Directorate of Economics and Statistics, Govt. of Jharkhand (2017)
26. Moharir et al. (2020) Evaluation of analytical methods to study aquifer properties with pumping test in Deccan basalt region of the Morna River basin in Akola District of Maharashtra in India. Groundw Hydrol (2020). https://doi.org/10.5772/intechopen.84632
27. Pande CB (2020) Sustainable watershed development planning. In: Sustainable watershed development. SpringerBriefs in Water Science and Technology. Springer, Cham. https://doi.org/10.1007/978-3-030-47244-3_4
28. Pande CB, Moharir KN, Singh SK et al (2022) Groundwater flow modeling in the basaltic hard rock area of Maharashtra, India. Appl Water Sci 12:12 (2022). https://doi.org/10.1007/s13201-021-01525-y
29. Pande CB, Kadam SA, Jayaraman R, Gorantiwar S, Shinde M (2022) Prediction of soil chemical properties using multispectral satellite images and wavelet transforms methods. J Saudi Soc Agric Sci 21(1):21–28
30. Mishra AP, Khali H, Singh S, Pande CB, Singh R, Chaurasia SK (2021) An assessment of in-situ water quality parameters and its variation with Landsat 8 level 1 surface reflectance datasets Int J Environ Anal Chem, pp 1–23
31. "Climate Change: Challenges to Sustainable Development of India", Research Unit (LAR-RDIS), RajyaSabha Secretariat, New Delhi, October 2008.

Potential Impact of Changing Climate on the Sustainability of Potato (*Solanum Tuberosum* L.) Production in India

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Abstract Potatoes are a large commercial crop and the world's most consumed non-cereal food crop. The crop thrives in cool, but not frosty weather. Potatoes are a cool-season vegetable. Climate change is a serious issue that has the potential to impact the way we produce and handle food. Potato production systems will undoubtedly

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need to adapt to the consequences of climate change and control greenhouse gas emissions and energy from arable land. Frost free and heat free period is essentially required for potato in some critical growth stages. Climate change may alter the climatic condition of a region which may result in drastic yield reduction There is a key differential between locations where potato is grown in a relatively frost-free time and areas where potato is produced in a relatively frost-free period when assessing the effects of climate change on potato and areas where potato is grown in a moderately heat-free period. Higher day temperatures can make some areas unsuitable for potato production due to lower tuber yields and quality. Temperature fluctuations outside of 5–30 °C can severely limit tuber growth and yield. The rate of warming in the last 50 years has been twice that of the previous century. The temperature rises and increases in atmospheric CO_2 levels occur concurrently under future climate change and global warming scenarios. If CO_2 levels rise to 550 ppm, temperature rises are expected to be 3 °C, with a 13.72% drop in potato production by 2050. Drought, salinity, frost, flooding, and erratic unseasonal weather will negatively impact potato production. It has the potential to reduce seed tuber production, as well as have an impact on the storage facility and potato processing industries. As a result, quantifying regional vulnerability and assessing its impact is critical for developing early warning disease forecasting systems and breeding heat, drought, salinity, and disease-resistant cultivars.

Keywords Climate change · Greenhouse gas · Temperature · Drought · Crops

1 Introduction

On a worldwide basis, climate change is having a significant impact on agricultural productivity. Climate change is defined as a long-term change in temperature and typical weather patterns in a location beyond the average atmospheric condition caused by both natural and artificial factors such as volcanic activity, the orbit of the Earth's revolution, and crustal movements, as well as an increase in greenhouse gas and aerosol concentrations. Climate change, an average global temperature increase, has emerged as a key issue that will result in substantial future world changes. In reaction to changes in temperature and precipitation patterns, climate change increases the frequency and intensity of floods, droughts, heat waves, typhoons, and hurricanes. Worldwide, climate change considerably impacts agricultural productivity [43]. Climate change is projected to influence India, too [49]. By 2030, temperatures are anticipated to climb by up to 0.5 °C, causing more harsh weather and rainy days [62]. People are becoming more aware of the weather and the effects of climate

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change. If people are unaware of climate change, it will weaken or decrease rural incomes, food security, water storage, and increase the incidence of pests and diseases [55, 56, 67, 75, 80]. Globally speaking India is the world's second-largest producer of potatoes. It is an irrigated crop grown during the winter season, with the Indo-Gangetic plains (IGP) accounting for nearly 85% of the crop's 1.8 million hectares in India. West Bengal and Bihar are the two major Eastern Indo-Gangetic Plains (IGP) states. In India, Uttar Pradesh is the largest producer of potatoes, followed by West Bengal. Potato production is expected to be around 53.69 million tonnes, up from 48.56 million tonnes in 2019–20. India covers 2.13 million hectares for potato production, with annual output reaching nearly 44 million tonnes and an average yield of 20.5 tonnes per hectare [23]. The United Nations estimated in 2017 that the Indian population will increase by 19% by 2050, posing a significant challenge for the production of all food crops, including potatoes, to meet the country's future demand. Climate change is expected to shorten the duration of potato cropping in West Bengal's Indo-Gangetic plains (IGP). In future climates, evapotranspiration (ET) is expected to increase while water use efficiency (WUE) for potato yield is expected to decrease due to lower threshold temperatures for yield reduction than ET. It has been discovered that the upper threshold for ET decrease is 23 °C, whereas the upper threshold for WUE is 15 °C. The optimal temperatures for tuber yield are 17 °C, and thus a decrease in water use efficiency (WUE) in future climates is detectable. Climate change is expected to reduce potato yields in the IGP region by 2.5, 6, and 11% in 2020 (2010–2039), 2050 (2040–2069), and 2080 (2070–2099), respectively.

Rice, mustard, jute, wheat, and a few pulses have significantly contributed to agricultural research on the Gangetic plains of Bengal. Potato is a relative newcomer to this sector. Environmental elements such as temperature, sun radiation, and day length play a major role in the growth of the potato plant and its tubers. The potato feeds on the top layer of the soil. The root system is usually restricted to the top layers of soil (up to 30 cm). As a result, the nutritional content of the uppermost layers of the soil mostly controls the growth of haulm and tuber. Soil temperature affects the uptake of nutrients and water from the top soil layer. After the tuber is planted, potato buds begin to grow, which is mostly reliant on temperature. At 15 °C or higher, the apical sprout grows quicker, limiting the growth of the other buds [33]. Many buds continue to grow for prolonged periods due to climate change and unfavourable conditions. The dominating sprout is maintained by storing the tuber at a favorable and unfavorable temperature. Potato agriculture is mostly limited to a few areas dispersed along both banks of the Ganges in West Bengal's Gangetic plains. In the current scenario, the Leaf Area Index has significantly dropped as the cumulative maximum and lowest air temperatures have increased. The incidence of late blight in potato, the most deadly disease in West Bengal, is determined by rainfall and relative humidity, both of which are significant and destructive variables. Rainfall helps to reduce soil temperature and hydrolysis of starch respiratory losses from potato tubers, resulting in higher potato yields. Monsoon rains arrive late and stay late, making it difficult to prepare potato fields. The temperature does not drop even in December. Climate change is causing rising temperatures and CO_2 levels in the atmosphere, and both are predicted to rise at the same time in future climate change and global warming scenarios. Temperature rises of 3 °C are projected if CO_2 levels are elevated to 550 ppm, with a 13.72% reduction in potato yield by 2050. Potato output will be harmed by drought, salinity, frost, flooding, unpredictable unseasonal rains, and other conditions. It has the potential to diminish seed tuber output while also affecting the potato storage and processing businesses. As a result, evaluating regional susceptibility and assessing its impact is crucial for developing early warning disease forecasting systems, and breeding heat, drought, salinity, and disease resistant cultivars. The negative effect of climate change on potato productivity can be mitigated to some extent by changing the planting date and/or selecting suitable varieties, which may reduce the yield reduction from 9.7 to 7.1% in 2055.

2 General Observations on the Extreme Events of Weather Conditions on Potato

- Unwanted rain during the winter season at the time of planting affects the plant's emergence as well as tuber yield.
- Flooding in the crop field caused by heavy rain during the crop season reduces crop yield.
- Heavy rain at the time of harvesting causes potato rot.
- Cloudy skies and early rain during the cropping season increase the attack of blight disease in potatoes, resulting in a lower yield.
- Relatively warmer winters in 2008 reduced tuber yield in West Bengal, Uttar Pradesh, and Bihar.

3 Climate Change Impacts on Potato Production in India

Climate-related temperature, precipitation patterns, and circular factors such as high intensity and prevalence of pests and conditions all have an impact on potato output. Although climate change forecasts for Indian agriculture are still questionable, some experts anticipate that excessive rains will negatively influence the country [55, 56]. Despite this, due to India's size, there are regional variations in how climate change affects potato production.

Temperatures are not predicted to rise in northern provinces like as Punjab and western Uttar Pradesh, where the current average is the lowest minimum temperature, and some writers predict an increase in rainfall; as a result, potato farming in the region could be profitable. In Punjab, however, farmers employ groundwater sources in addition to the monsoon for irrigation, and there is evidence of over-exploitation of these resources [8]. In addition, rising groundwater depletion may restrict the benefits of rain. Rising temperatures and late blight could wreak havoc in southern states like as Gujarat and Karnataka, where temperatures are already high [78].

Punjab is getting warmer, but rain is on its way, which is great news for potato farmers. Late blight, as well as other pests and illnesses, will be more difficult to combat. A similar pattern would emerge in western Uttar Pradesh. Temperatures are forecast to rise in other parts of the country, putting potato production in peril. This will be especially true in Karnataka, where growing potatoes will become a high-risk endeavour. Minimum temperatures in Bihar are approaching the maximum limit for a number of grain and transplanting varieties [36], [83]. Rising temperatures in Punjab may be compensated for by increased CO_2 levels in the environment, resulting in steady potato yields overall [25]. Another issue related to climate change is dwindling rainfall. Rainfall-dependent areas, such as IGP, will be impacted. The states most affected by the increased pressure of low humidity induced by falling rainfall include Bihar and Eastern Uttar Pradesh, Gujarat, and Karnataka, whereas West Bengal and West Uttar Pradesh are predicted to benefit from monsoon rains [35, 48, 55, 56, 83]. A significant dependency on rainfall and a high drought sensitivity in the Northwest Peninsula (which includes Punjab and Gujarat). Guhathakurta and Rajivan [35], on the other hand, expected increasing rainfall in those states, while Mohanty et al. confirmed that rainfall levels in Gujarat have increased [59]. Our research area's comparatively wealthy states have fewer constraints, such as better market access, increased rural electrification, and a lower share of marginal farmers, and are thus better prepared to adapt to climate change [69]. During the Kharif season, most of Karnataka's northern districts are predicted to see more drought, while the Rabi season is likely to see more dryness in the eastern districts [7]. The conditions (e.g., greater temperatures, more variable rainfall) change as the climate changes, allowing germ density and disease severity to rise [31]. In the case of late blight, climate change may increase or reduce the ideal duration of disease development. For example, the number of good days in Punjab is projected to rise, while the number of suitable days in West Bengal is expected to fall [25, 54]. The Indo-Gangetic plains in India account for over 85% of total potato farming land (1.8 MHa). The crop is grown as an irrigated crop throughout the winter season. Climate change would cut potato yield by 2.5, 6, and 11% in the Indo-Gangetic plains by 2020 (2010–2039), 2050 (2040–2069), and 2080 (2070–2099), according to an experiment conducted by Naresh Kumar et al. [61]. Several techniques can be implemented to address this issue, such as shifting crop planting dates, which will boost tuber output by 6% in 2020. In the same way, enhanced potato cultivars can be utilised in addition to nitrogen to boost potato yield by 8% in 2020 and about 5% by 2050.

Climate change caused by global warming has the potential to increase potato production in Punjab, Haryana, and western and central Uttar Pradesh by 3.46–7.11% by 2030. However, potato production in West Bengal and the plateau region may fall by 4–16%. If proper strategies or management are not implemented, potato production in India may decrease by 3.16% and 13.72% in the years 2020 and 2050, respectively, due to climate change and global warming. Potato production is expected to fall by 23–32% by 2050 as a result of climate change and global warming. Dua [25] conducted a simulation study for 13 different locations in Punjab using the WOFOST crop growth model. According to the findings, an increase in temperature will reduce the productivity of potato varieties such as KufriBadshah from +11.6% (Amritsar) to −10% (Fatehgarh) in 2020, KufriJyoti from +11.6% to −11.6%, and KufriPukhraj from +12% to −11.5%. If the CO_2 concentration is increased, potato productivity will increase by 3.9–4.5%, depending on the production area and potato variety. Potato varieties may decrease production from 17.9 to 22% if the temperature rises further until 2055. When changes in temperature and carbon dioxide concentration are combined, potato production will be unaffected in 2020 compared to the baseline scenario; however, potato production of various cultivars in Punjab will decrease in the range of 2.62–5.3% until 2055. Venkateswarlu and Rao used the INFOCROP-POTATO model to investigate the effects of global climate change on potato production in India. According to the study's findings, potato production will decrease by 2.61% and 15.32% respectively by the years 2020 and 2050 if proper measures are not taken. However, due to climate change, potato production in Punjab, Haryana, and Western Uttar Pradesh may increase by 7.11% and 3.46% in 2020 and 2050, respectively, while potato production in the rest of India will decrease by 0.52–16.59% and 0.69–46.51% in 2020 and 2050, respectively. Singh et al. (year) demonstrated in his experiments that increasing the CO_2 concentration by 550 ppm and increasing the temperature by 10 °C increases potato production by 11.1%, but increasing the temperature to 30 °C has the opposite effect, reducing potato production by 13.7%. If CO_2 concentrations rise to 550 ppm, the temperature rises to 3 °C, reducing potato production by 13.72% by 2050. Severe climatic conditions such as drought, frost, flooding, salinity, unseasonal rain, and many other climate changes caused by global warming will negatively impact potato production in India. It will reduce seed tuber production and impact storage facilities and industries related to potato processing.

There is a growing consensus that changes in temperature, precipitation, and atmospheric CO_2 levels can have a negative impact on potato production. These effects are difficult to quantify and depend on various assumptions, and the land suitable for potato cultivation will be greatly impacted. Climate change will have different effects on different agro-ecological regions. Some of the regions will have a negative impact on potato cultivation, while others will have a positive impact.

Climate change will, directly and indirectly, affect potato cultivation, affecting food security and livelihood. Changes in agroecological conditions of regions are among the direct impacts, while changes in economic growth and farmer income distribution are among the indirect impacts. The problem will worsen as the quality and quantity of available cropland begins dwindle. Some cropland areas will also suffer from various types of land degradation and soil salinity issues [39].

3.1 Impact of Higher CO_2 Level and Temperature on Potato

According to the Intergovernmental Panel on Climate Change [40], atmospheric carbon dioxide (CO_2) concentrations have increased from roughly 280 parts per million before the industrial revolution to around 360 parts per million now. Higher

CO_2 levels should, in theory, enhance photosynthesis in some plants. This is particularly true for C_3 plants like potatoes, because increasing CO_2 suppresses photorespiration. When atmospheric CO_2 level is higher, Rubisco, the principal enzyme in C_3 plant for CO_2 fixation, fixes more CO_2 and reacts less with O_2, resulting in increased photosynthesis and encouraging growth and production [4]. It has the potential, on the other side, to reduce crop duration. Potatoes may be cultivated in a range of climates, but they do best in milder ones. Increased temperature caused by increased CO_2 concentration results in a decrease in tuber yield, owing to increased respiration rates. At high temperatures (over 170 °C; [81], tuberization reduces. Reynolds and Ewing [70]. Potato is also frost-sensitive, thus it suffers when the temperature dips below 0 °C [38]. Assimilation and CO_2 concentration have a positive relationship. Total biomass grew by 27–66% when CO_2 concentrations were increased from 360 to 720 parts per million [18, 24, 37, 58, 65], [87]. Tuber yield increased from 32 to 85%. [19, 28, 92].

For every 100 ppm rise in CO_2 content, the increase in tuber production is expected to be around 10% [58]. These beneficial impacts are: ascribed to a 10–40% increase in photosynthesis [18, 44, 65, 73, 89]. Young leaves showed the greatest improvement in photosynthesis [44, 89]. This is due to a phenomenon known as photosynthetic acclimation. It occurs later in the growth season, especially in older leaves [50, 73, 89]. There are racial disparities in how people react to increased CO_2 levels [65]. Under increasing CO_2, the number of tubers remained unaltered, but mean tuber weight rose mostly due to an increase in the number of cells in the tuber. Tubers without affecting the volume of the cells [17, 18, 24]. However, there has been a rise in the number of tubers [19, 58]. When CO_2 levels are high, evapotranspiration (ET) is reduced, resulting in water savings of 12–14% [65]. Increased CO_2 concentration promotes tuber start and blooming [58], but accelerates leaf withering [58, 86]. Reduced chlorophyll content in leaves, especially later in the growth season after tuber start, is one of the few detrimental impacts of high CO_2 concentration [11, 50].

Potatoes are a temperature-sensitive crop. Cumulative maximum and lowest temperatures have a substantial impact on potato growth rate. The leaf area index decreased dramatically as the cumulative maximum and minimum temperatures rose. As the temperature rises throughout the growing season of the crop year after year, the greenhouse effect will reduce potato output in dry and semi-arid regions compared to northern India. Temperature and CO_2 levels in the atmosphere rise in lockstep, and CO_2 enrichment does not appear to compensate for the negative effects of increasing temperatures on tuber yields. The potato crop yield varies with temperature variations and is somewhat dependent on the current temperature in that location. Reduced tuber initiation and growth, reduced starch partitioning to tubers, physiological damage to tubers (e.g. brown patches), shortened/non-existent tuber dormancy, and tuber sprouting too early are all detrimental consequences of temperatures exceeding 30 °C on potato output. They will limit the crop's output by reducing the number and tuber of the potato crop. As a result, areas where the temperature is close to the maximum temperature for the potato crop will undoubtedly suffer in the future. The yield of the crop has been lowered. The growth and development of the potato crop is hampered in tropical areas by high temperatures. Potato crop growth is impossible at temperatures below 2 °C and impossible at temperatures beyond 30 °C [88]. The optimal (16–25 °C), lowest (0–7 °C), and maximum (40 °C) temperatures for net photosynthesis are presented [45]. Tuberization of potatoes requires a chilly night temperature [15, 21, 46]. Although high temperatures reduce photosynthesis in potatoes [46], tuberization and the partitioning of photosynthates to tuber [71]. Under high temperatures, the radiation use efficiency (RUE) is lowered [3]. Tuber number and size are reduced when the temperature is too high [26]. High temperatures cause aberrant morphological changes in the plant, such as white yellow spots and smaller leaves and leaflets, lowering the LAI [26, 29], as well as a reduction in tuber quantity and size [26, 29, 67]. Long day conditions and high temperatures, prevalent in the spring season in Punjab state on India's plains, encourage leaf growth and increased tuber processing quality [57]. Potato tuberization requires a cold night temperature, which is disrupted by even modestly high temperatures [26, 46]. Temperature had the greatest impact on tuber start [32].

3.2 Temperature and CO_2 Interaction Effect on Potato

As a result of the current global warming situation, temperature and CO_2 levels are becoming increasingly intertwined. This will be a source of concern in the following days, and it will have economic implications in terms of crop growth, output, and quality. The impact of rising CO_2 and temperature on potato output in India was assessed using the INFOCROP-POTATO simulation model [76, 77] without adjustments and assuming that the area under the crop remains constant at current levels in future climatic scenarios (1.2 m ha). Experiments have shown that a 550 ppm rise in CO_2 content will boost potato yield by 11.12% However, the future climatic scenario for India suggests that if CO_2 concentrations rise by 550 ppm, temperature rises by 30° [40], reducing potato output by 13.72% by 2050. The 1 °C increase in temperature is projected to be connected with just 400 ppm of CO_2 in 2020 [40], resulting in a 3.16% decrease in potato yield.

3.3 Elevated Precipitation Due to Increased Temperature and Its Impact on Potato

Rainfall in India and extreme rainfall events are expected to increase steadily in the future. By the 2030s, mean warming over India is anticipated to be in the range of 1.7–2.0 °C, and 3.3–4.8 °C by the 2080s, compared to pre-industrial times. As a result, precipitation over India is projected to rise by 4–5% significantly in comparison to 1961–1990, between the 2030s and 2080s, the annual growth rate will be 6–14%. Increased precipitation will result in a delayed monsoon and undesired rains throughout the winter season, delaying crop planting and inviting several crop diseases. The effects of climate change are diverse in different sections of the nation. Extreme occurrences are more likely to hit western Rajasthan, southern Gujarat, Madhya Pradesh, Maharashtra, northern Karnataka, northern Andhra Pradesh, and southern Bihar [55, 56]. Wheat, soybean, mustard, peanut, and potato yields are predicted to fall by 3–7% for every 1 °C increase in temperature [2]. High rainfall may have a deleterious effect on tuber bulking, but it also has a beneficial effect in that it reduces the need for irrigation water, lowering the cost of cultivation. The presence of moisture in the soil also inhibits the hydrolysis of the starch in the tuber, resulting in a reduction in respiration loss and an increase in yield, despite the increased moisture content in the soil being a challenge during crop harvesting.

3.4 The Impact of Increased CO_2 Levels and Temperatures on Soil and Water Availability, as Well as the Consequences for Potato

The soil carbon and nitrogen stocks are substantially negative and positively connected to the ratio of mean annual precipitation to potential evapotranspiration, meaning that they are equally vulnerable to rising temperatures and decreasing water availability. Acidic soils with pH levels ranging from 5.0 to 6.5 are ideal for growing potatoes. As a result of rising temperatures and lower precipitation, water quality is deteriorating day by day. Soil acidity in north east India could develop further under a business-as-usual scenario, due to rising temperatures and CO_2 concentrations in the atmosphere. Repeated experimental observations of increased CO_2 creation in soil as a result of greater root and soil microbial respiration in rising CO_2 environments tend to confirm this notion. CO_2 can exacerbate carbonic acid leaching and thus exacerbate the already severe problem of soil acidity in north east India [47].

Because climate change occurs often and swiftly, it has an impact on the ecosystem, particularly the soil system. Soil formation is impacted by a variety of soil forming elements and processes such as gas exchange, temperature, solar radiation, and other factors that are directly influenced by climate change [14]. Changes in global climate have an impact on soil erosion rates, which are determined by rainfall intensity and total number of wet days. Soil erosion affects soil fertility and water availability, which is a primary factor causing a fall in agricultural output and degrading environmental quality. The quantity and intensity of rainfall directly influence soil erosion, which fluctuates as the amount and intensity of rainfall changes [64, 90]. Soil deterioration is mostly caused by water erosion (82.6 Mha), followed by chemical degradation (24.7 Mha). There are 5.34 billion tonnes (Gt) of soil in the world degraded at a rate of 16.3 t ha^{-1} yr^{-1} on average in India. Temperature rises will enhance potential evapo-transpiration while decreasing surface runoff, infiltration, water storage, and groundwater recharge, especially if there is little precipitation. Climate change poses a danger to potato availability, access, and use owing to changes in climatic factors such as temperature, precipitation, CO_2, and so on. It is also predicted that soil salinity would rise in many parts of the world, reducing the appropriateness of potato farming on such soils. Furthermore, changes in environmental conditions may affect the availability of water for this vital crop's production.

According to the IPCC Working Group II report and a few other worldwide studies [1], crop production in India might drop by 10–14% by the year 2080–2100. This would result in more frequent heat waves, floods, droughts, cyclones, and glaciers' slow retreat, resulting in increased food production instability [1]. Looking at this statistic on temperature changes through time, it appears that the classifications of land suitability in terms of climatic region, with specific reference to mean temperature during the growing season, will continue to shift, and areas classified as very appropriate may become less so up to 2080, moderately appropriate will shift to marginally suitable class, while marginally suitable class will transition to unsuitable class.

4 Impact of Maximum and Minimum Temperature on Growth Parameter

The influence of cumulative minimum and maximum temperatures on LAI is nearly identical, with 36.4% of the variance in LAI explained by changes in cumulative minimum temperature. The CGR is inversely proportional to the cumulative maximum temperature, meaning that when the cumulative maximum temperature rises, the CGR rises up to a certain point. The fluctuation in cumulative maximum temperature might account for 32.3% of the variance in CGR of potatoes. When the cumulative maximum and lowest temperatures approached 350 and 150 °C, respectively, the CGR dropped considerably. Temperature has a significant impact on respiration [5]. Solar radiation, temperature, LAI, canopy design, and single leaf photosynthetic rate all influence canopy photosynthesis [52]. Potatoes are mostly farmed in north India during the winter months, when there is little rain. However, owing to the effects of global warming, the temperature is expected to rise the most in northern India, affecting potato output directly or indirectly. Today, we may witness unpredictable weather conditions such as unseasonal rain, floods, and icing, all of which impact crop development and productivity.

5 Indirect Effects of Climate Change and Global Warming

5.1 Drought

The shallow root structure of the potato need optimal water delivery. The potato plant's roots are usually 40–50 cm deep [10]. Potato tuber beginning is quite susceptible to dryness, and drought under this scenario will result in a drop in tuber output.

As a function of development stage (DS) and root:shoot ratio, drought stress impacts dry matter partitioning to root, shoot, leaf, and stem. Drought reduces dry matter production, resulting in an increase in the root:shoot ratio, indicating that root development is favoured. Drought-stricken plants' roots are also often thinner. Both reactions allow drought-stricken plants to better use the existing soil moisture [91]. Under drought stress, tuber initiation and maturity are accelerated [10].

5.2 Salinity

Despite low residual sodium carbonate (RSC) levels, potato is particularly vulnerable to salt and irrigation with saline water [79].

5.3 Frost

Potatoes have a high level of frost sensitivity. When the temperature drops below 2 °C for 2–3 nights in a row, foliage is reported to be completely gone. It will take about 4–5 h. Even one night of exposure to temperatures below 1 °C can cause 50% leaf loss. The timing of frost in relation to the crop's growth stage determines the crop's yield loss. The degree of agricultural yield loss is also determined by when the frost occurs; for example, if the frost occurs 80–90 days after planting (DAP). The yield loss will be 10–15%, however if it occurs 50–60 days after planting (DAP), the yield loss will be 30–50%.

5.4 Flooding

Even a few days of flooding during the active vegetative phase has an impact on growth and productivity. Flooding during harvest affects physical appearance and marketable quality due to rotting and rupture of tuber lenticels, whereas flooding before emergence diminishes emergence due to rotting seed tubers and the production of soil crusts. Erratic Rainfall that is out of the ordinary. Rainfall of even 10–15 mm during or immediately after planting hastens emergence due to the formation of a soil crust, delaying planting and reducing yield. Rains during the active vegetative period can worsen late blight disease.

5.5 Production of Seed Tuber

The use of disease-free, high-quality seed tubers as planting material in a vegetatively propagated potato crop is of particular importance. When tuber is utilised as seed material, it contains several fungal, bacterial, and viral pathogens that induce disease infestation in subsequent generations of the crop, resulting in a loss in crop production. Seed tubers, in particular, account for half of the cost of inputs in potato cultivation, and seed quality significantly impacts the cropping operation's profitability. Aphids and other vectors disseminate viral diseases that induce rapid degradation of planting materials in the potato crop. The 'seed plot approach' was developed to produce seed tubers in normally aphid-free seasons in the plains during the winters and terminating vines by dehaulming before the aphid population reaches a threshold, preventing viral disease infection. For every 1 °C increase in mean temperature, the arrival of the potato peach aphid (Myzuspersicae) is claimed to accelerate by two weeks, and population expansion is connected to highest temperature and lowest relative humidity [12]. Aphids have appeared earlier and in greater numbers as a result of climate change and global warming. The population is expected to reduce the amount of time that seed tubers are free of aphids, lowering seed tuber quality and quantity, and reducing potato output in India. In certain locations, warming may completely destroy seed tuber production, while in others, it will increase the cost of herbicides and insecticides, as well as the cost of seed, resulting in a drop in profitability.

5.6 Storage

Potato harvesting in India's plains corresponds with the start of the scorching summer season. To keep the tuber from decaying and losing weight, it is kept in the refrigerator. The tuber is kept in cold storage until the end of October, when it is harvested for eating. The potato may be kept in farm storage for up to 80 days in certain areas with chilly meteorological conditions. The operating cost of the potato grew while it was held in cold storage; as a result, the market cost of the potato as well as the seed cost of the potato increased. A greater number of cold storage facilities should be available around the region of production and consumption to keep the manufacturing, storage, and supply chains running efficiently, especially during the summer months (March–October).

5.7 Industry of Potato Processing

Potato tubers kept in cold storage at 4 °C are not suitable for processing because of a rise in decreasing sugar content in the stored potato, which is not viewed as a desirable attribute for many processed commodities. Potato tubers are kept in low-temperature storage at 10 °C or in farm country warehouses for processing. Tubers stored in low-temperature and remote storage, on the other hand, sprout and lose weight once the dormancy is broken, making them unsuitable for processing. As a result of global warming, the 'time window' of accessible potato appropriate for processing will be decreased, raising the expense of chemically treating tubers to avoid sprouting. In terms of raw material supply, this has ramifications for the potato processing industry's long-term viability.

6 Effect of Elevated CO_2 on Disease of Potato:

CO_2 levels that are too high can affect the host and the pathogen in various ways. The faster growth of leaves and stems in plants grown in high CO_2 environments has been related to thicker canopies and more humidity, both of which favour disease (www.Climate-and-forming.org). Increased CO_2 levels (400–700 ppm) and/or ozone levels (ambient or two-fold ambient) impacted the susceptibility of potato plants infected with P. infestans, according to Osswald et al. [66]. The most important conclusion was that raising CO_2 made the sensitive potato cultivar 'Indira' far more resistant to P. infestans, whereas ozone had no effect. The impact of N-fertilization in combination with CO_2-treatment on potato resistance to P. infestans was also investigated because CO_2 caused a rise in resistance linked to an increased C/N-ratio in potato leaves. The lower C/N ratio, which was generated by higher N concentrations, lowered resistance to P. infestans. Similarly, Plessl et al. [68] discovered that after exposure to 700 ppm CO_2, the potato cultivar Indira, which was vulnerable to P. infestans under normal conditions, developed resistance. Ywa et al. [93] discovered that tomato plants planted at higher CO_2 levels were more resistant to Phytophthera root rot. Higher CO_2 increased the pathogen load of C3 grass, possibly due to increased leaf lifetime and photosynthetic rate.

7 Effect of Elevated Temperature on Disease of Potato

Temperature and exposure time are crucial factors in understanding the impact of climate change on disease severity. Changes in temperature have resulted in the emergence of novel disease races that are currently inactive but may become pandemic in nature in the future. Temperature changes directly impact a pathogen's capacity to infect, reproduce, disperse, survive, and other important phases of its life cycle. When soil temperatures rise, several soil-borne illnesses may become more common. Pathogens will follow their hosts if climate change causes a progressive shift in farming zones. In the epidemiology of the disease, the susceptible host is critical. Epidemiological factors have a significant impact on climate change. At higher temperatures, P. infestans had a short incubation time, with the shortest Incubation

Period (IP) occurring at 28 °C [9]. According to Mizubuti and Fry, with increasing temperature, IP reduced exponentially but Lesion Area (LA) increased exponentially (1998). Indirect germination (5–10 zoospore/sporangium) is favoured at temperatures below 20 °C, with an ideal of 1213 °C, whereas direct germination (5–10 zoospore/sporangium) is favoured at temperatures above 20 °C, with an optimum of 24 °C (one sporangium gives rise to a germ tube). Even at ideal temperatures, direct germination is typically much lower than indirect germination [20, 34].

Late blight's destructive capacity may alter abnormally in India as well as the rest of the world as the climate changes. Previously, late blight was not a serious problem in Punjab, Haryana, and parts of Uttar Pradesh due to sub-optimal temperature regimes in December and January. The sickness epidemic was exacerbated by increased temperature mixed with high RH. Such scenarios have occurred during warmer years, such as 1997–98 and 2006–07, when average crop losses in this region neared 40%. The severity of late blight has lately grown as a result of increased rainfall during advanced stages of crop growth. Under the current climate, states like Madhya Pradesh, Gujarat, and Central Uttar Pradesh, which are comparably less affected by late blight, may see regular outbreaks of the disease.

8 Effect of Rainfall/High Humidity on the Disease of Potato

When rainfall and high humidity increase at the same time, disease outbreaks in potatoes such as late blight (Potato infestans) become more likely, especially when extended growing seasons are combined. In Upper Great Lakes region of the US, the late blight of potato causes huge loss of the yield of potato due to this reason economic loss occurs this thing happens when there is an increase in precipitation as well as number of rainy days' increases. In India, the Lahaul valley of Himachal Pradesh, which had previously been free of late blight due to a lack of precipitation, has suddenly been hit by late blight as a result of rainfall [75]. Summers that are hotter and drier, as they are predicted to be in the UK, may lessen the importance of late blight, while early disease onset may negate this benefit. An empirical climate disease model has suggested that with the increase in temperature by 1 °C with the decrease in the amount of precipitation by 30% will reduce the chances of Late blight of potato in Germany by 16% from the current scenario. With the rise in temperature in India's North-Western plains, late blight attacks are anticipated to grow. The disease is expected to decline in the Eastern Plains, especially West Bengal. With the increase in temperature and decrease in precipitation, hilly locations may have a shorter late blight assault.

9 Climate Change Effect on Rainfall:

Precipitation is influenced directly by global warming. Increased temperature leads to increased evaporation and, as a result, surface drying, increasing the severity and duration of the drought. The ability of air to store water increases by about 7% as the temperature rises by 1 °C. (This causes an increase in atmospheric water vapour, according to the Clausius-Clapeyron (C–C) equation.) Additionally, every decade, global warming produces a 0.14 °F increase in mean sea surface temperature (https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature). With increased moisture, extratropical rain or snow storms produce more powerful precipitation episodes, which leads to more storms (Fig. 1).

In India, the highest rainfall in June was received in 2008 (445.8 mm), and the highest rainfall in July was received in 2007 (638 mm), while the highest rainfall in August was received in 1996 (494.7 mm), and the highest rainfall in September was received in 1995 (482.2 mm). The years 1990 and 1999 saw the highest annual rainfall of 2384.5 mm and the maximum southwest monsoon rainfall of 1814.2 mm, respectively (IMD). Southwest monsoon rainfall (June–September) accounts for 77% of yearly rainfall in India. And West Bengal receives the most rain in July (30% of SW monsoon rainfall), followed by August (26% of SW monsoon rainfall) (IMD). Due to climate change, monsoons begin with modest rainfall but end with increasing rainfall, with torrential rains triggering fatal floods in many states. The number of days with heavy rainfall has increased as a result of climate change, making weather forecasting more difficult.

The monsoon in India retreated several days later than usual in 2019. The monsoon usually withdraws from extreme northwest India, i.e. west Rajasthan, on September 1 and from the entire nation by September 15. Because of various circumstances, the

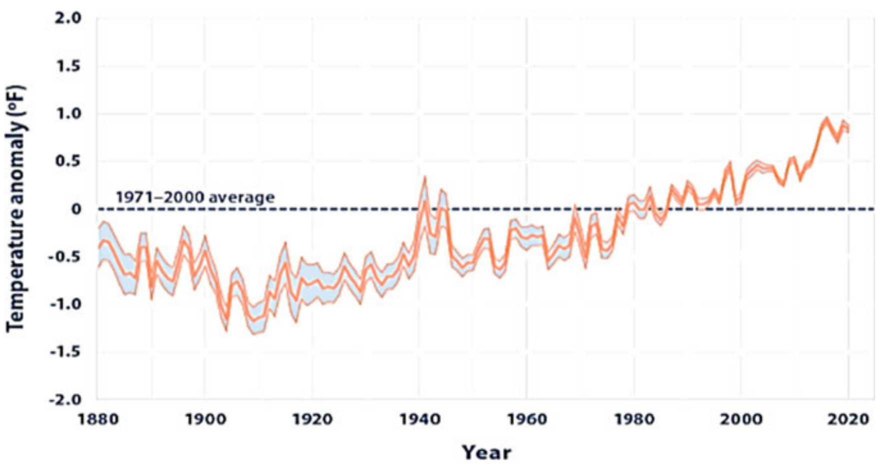

Fig. 1 Average global sea surface temperature (1880–2020). *Source* NOAA [63]

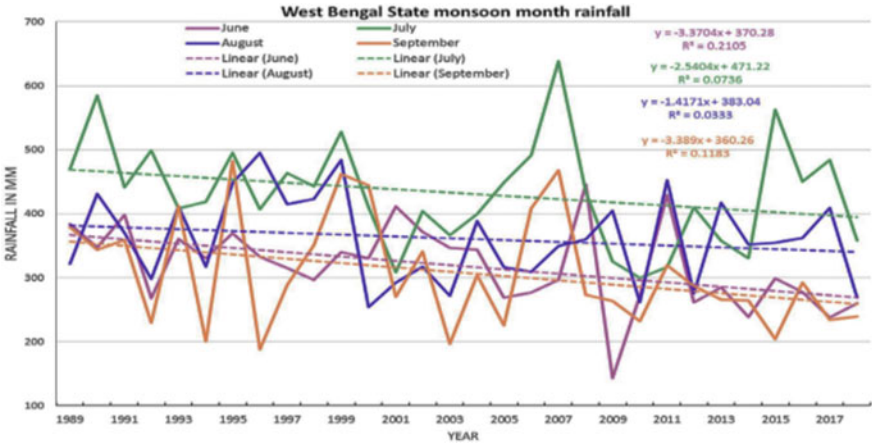

Fig. 2 Annual rainfall trend over the years in whole India. *Source* Exploratory data analysis on Indian rainfall (1901–2017)

monsoon has been very active in September. One key element is that low-pressure systems that developed over the Bay of Bengal proceeded towards Rajasthan, causing an east–west-directed low-pressure zone. The monsoon was able to continue for a long time as a result of this (https://medium.com/@vighneshutamse/analysis-on-indian-rainfall-1901-2017-49224557278c).

The graphical representation of rainfall for last 100 years has been presented in Fig. 2.

In West Bengal, the monthly rainfall in June and seasonal and annual rainfall indicate a substantial declining trend, whereas the remaining months show no such pattern (Fig. 3).

Due to climate change variation of rainfall and associate factors over West Bengal has been presented below (Figs. 4, 5, 6 and 7, Table 1): (from 1989 to 2018)

Heavy rainfall days have increased significantly during the year in the districts of Alipurduar, Bankura, Birbhum, Jalpaiguri, Purulia, PurbaMidnapore, Pashchim-Midnapore, North 24 Parganas, South 24 Parganas, and Kalimpong. High rainfall days have decreased significantly in the Malda, Nadia, Birbhum, and Murshidabad districts.

(From 1989 to 2018) There has been a notable increase in the number of rainy days in the districts of Kalimpong, Jalpaiguri, PaschimMidnapore, PaschimBurdhman, PurbaBurdhman, Bankura, and Nadia during the months of June to September. Rainy days have decreased significantly in Cooch Behar, Malda, Hoogly, PurbaMidnapore, and Murshidabad districts. The number of rainy days in Purulia, Kalimpong, Jalpaiguri, PaschimMidnapore, PaschimBurdhman, PurbaBurdhman, and Nadia

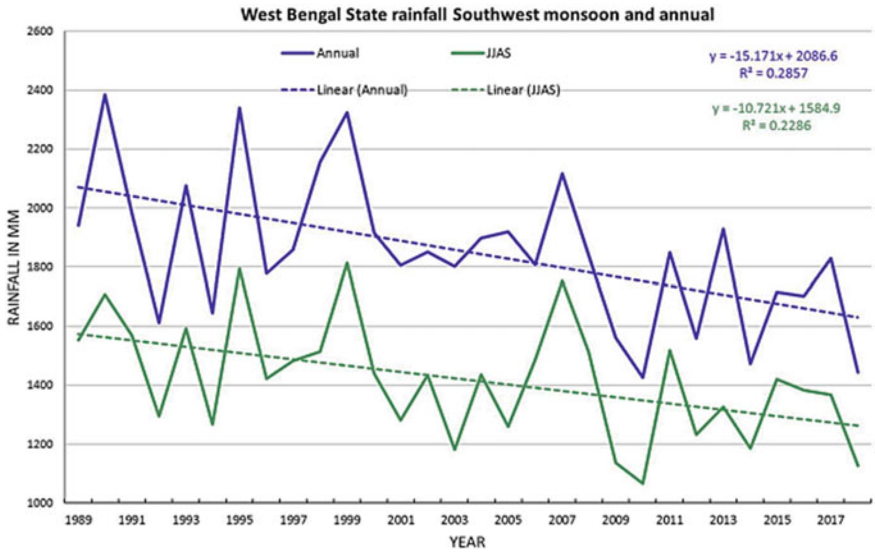

Fig. 3 Variation of rainfall in West Bengal in different year. *Source* Observed rainfall variability and changes over West Bengal state

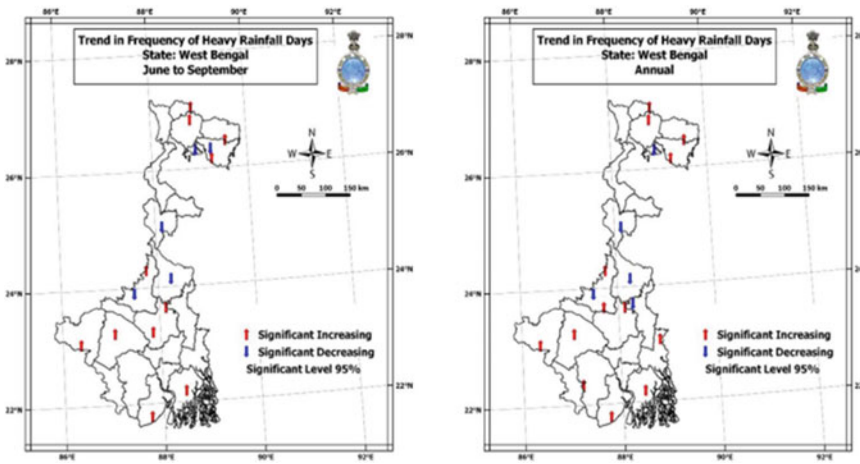

Fig. 4 Trend in frequency of heavy rainfall days over West Bengal. *Source* Observed rainfall variability and changes over West Bengal state

districts has increased significantly over the year. Rainy days have decreased significantly in the districts of Cooch Behar, Malda, Hoogly, PurbaMidnapore, Darjeeling, Birbhum, DakshinDinajpur, and Murshidabad.

Mean rainfall amount with respect to month and year and corresponding CV% in WB has been given in Table 1.

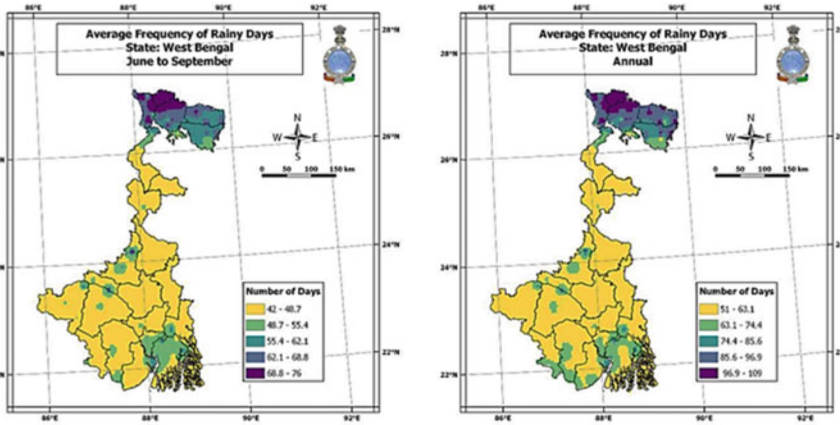

Fig. 5 Average frequency of rainy days over West Bengal. *Source* Observed rainfall variability and changes over West Bengal state

Table 1 The state's mean rainfall (mm) and coefficient of variation for monsoon months, the southwest monsoon season, and the annual

	June	July	August	September	JJAS	Annual
Mean	318	431.8	361.1	307.7	1418.7	1851.4
cv	20.3	19.1	18.9	28.2	13.9	13.5

Source Observed rainfall variability and changes over West Bengal state

CV% of annual and seasonal rainfall for different districts of WB has been diagrammatically presented in Fig. 6.

Almost all 26 districts, with the exception of Uttar Dinajpur, Darjeeling, Jhargram, and Hoogly, see a considerable rise in dry days from June to September. Almost all districts, with the exception of Uttar Dinajpur, Jhargram, and DakshinDinajpur, see a considerable increase in dry days during the year. However, in the districts of Birbhum and Murshidabad, the number of dry days has decreased significantly (Fig. 7).

10 Climate Change Effect on Water Resources

India now has a water stress of 1,588 cubic metres of water per person per year (India-WRIS, 2012), which is higher than 1000 cubic metres per year and qualifies the country as a water-scarce country. India now has 18% of the world's population, yet it only has 4% of the world's renewable water resources. Only roughly half of the accessible water sources are useable. There will be tremendous strain on our current water resources as a result of population expansion and the predicted rise in demand for water resources, particularly to meet the country's food demands. More

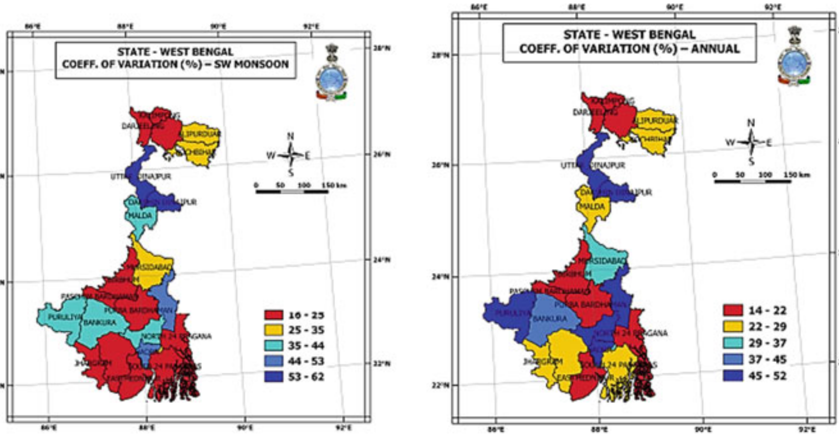

Fig. 6 CV% of annual and seasonal rainfall for different districts of WB. *Source* Observed rainfall variability and changes over West Bengal state

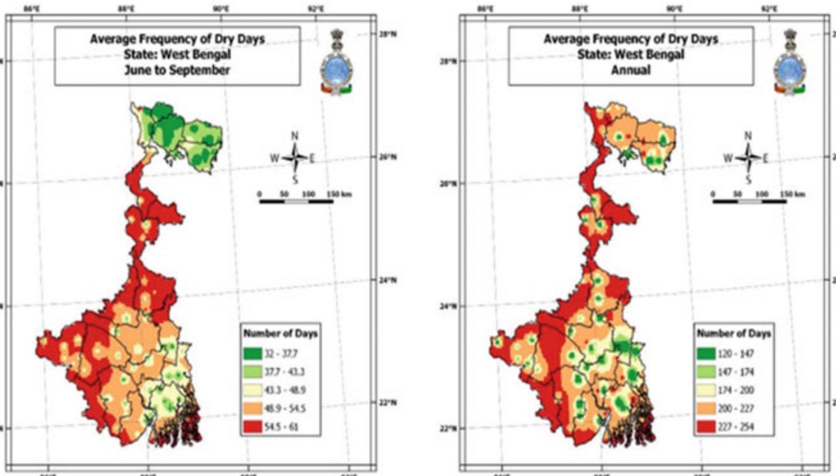

Fig. 7 Average frequency of dry days over West Bengal. *Source* Observed rainfall variability and changes over West Bengal state

than 54% of the country is now experiencing acute water scarcity. Adopting proper conservation standards, encouraging replenishment, sustainable management, and preserving the quality of current resources are all critical steps in preventing future water shortages in our nation. Apart from conservation, the reuse and recycling of current water resources and the creation of new water resources to satisfy future demands should be prioritised.

10.1 Surface Water Sources

The Central Water Commission divides India's surface water resources into 12 main districts and eight composite basins (CWC). Various government agencies (e.g., CGWB, NCIWRDP, ISRO, India–WRIS) create classifications. Surface water provides 37% of irrigation demands, with 29% coming from canals, 4% from higher tanks, and some from other sources. To understand water loss, these figures must be compared to the overall irrigation efficiency of canals, which is 38–40%. [22]. Canal irrigation is widespread in India's northern and northwestern plains, whereas tank irrigation, one of the most popular and long-lasting irrigation technologies, is common on the peninsula's rocky terrain.

11 Potential Impacts of Climate Change

The increased frequency of climatic extremes projected as a result of global warming [60] may further diminish the capacity of usable surface water sources. High-intensity precipitation within the catchment regions of storage reservoirs exceeds their capacity, causing shutters to open, resulting in higher flows downstream of rivers and water waste. Flood-prone areas such as Kerala, Chennai, Gujarat, Hyderabad, Uttarakhand, and others are examples of surface water being squandered without being able to retain and maintain it for future use, particularly during droughts. Flash floods are caused by excessive temporal precipitation variability in urban and rural locations. L lengthy droughts mostly affect the south Indian basins, with seasonal flow adding to the water stress in these areas.

GCMs (global climate models) were used to forecast future weather anomalies over a period of time. Despite a forecast rise in precipitation practically everywhere on the planet, even in parched places, all representatives oppose it. The expected temperature in Himalayan and Sub-Himalayan regions and northern India in general shows a better growth. Another significant hazard to the floor water resource is pollution from both point and non-point sources. Climate change contributes significantly to the deterioration of pollutants in water resources. Floods in cities can cause sewage and industrial waste to mingle with surface water sources. The high degree of groundwater extraction in Rajasthan and Gujarat has resulted in uranium contamination of groundwater. Because of the decreasing water levels in such aquifers, the uranium-rich granite undergoes oxidation, resulting in uranium contamination of the groundwater [82].

Snow and glacier melt play a critical role in improving water resources in Himalayan rivers. Glacier melt is significant because it delivers a significant amount of water mostly during drought years and a little amount of water at times during flood years, balancing and sustaining water availability in the basin [55, 56]. Since the mid-nineteenth century, glaciers in Himalayan areas have been retreating and demonstrating negative mass stability, and the rate of loss has doubled in recent years due to temperature rises, according to a large body of evidence [13].

12 Groundwater Resources

Groundwater resources are mainly used by the agricultural sector for up to 90% of the groundwater draft, leaving the remaining 10% for domestic and industrial use. Groundwater serves 62% of irrigation needs, 85% of rural water supply systems, and 45% of urban water supply systems [16].

13 Potential Impacts of Climate Change

Climate change affects soil moisture, groundwater recharge, and groundwater level in various places by changing climatic extremes' frequency. As the world's population grows, so does the demand for ground water, which limits the real recharge time of aquifers and worsens water levels [55, 56]. The north-west and north-central parts of India experience low-intensity rainfall due to El Nino, which negatively impacts recharging alluvial aquifers. Southern India, on the other hand, receives high-intensity precipitation due to the Atlantic Ocean's warm sea surface temperature, which favours groundwater recharging [6].

On the recent fluctuations in groundwater levels, there is a wealth of information accessible. The analyses based on the Gravity Recovery and Climate Experiment Mission (GRACE) data between 2002 and 2008 produced some contradictory conclusions. Some studies exaggerated depletion rates in north-west India, estimating them to be 17.7 4.5 BCM/year on average [72], which is higher than the Ministry of Water Resources' estimate of 13.2 BCM/year. Long et al. [53] validated GRACE's overestimation of groundwater depletion in north-west India, and he recalculated the depletion to 140.4 BCM/year, in line with Ministry of Water Resources statistics. The high rate of groundwater abstraction for agriculture in Northern India's Gangetic basin causes resource depletion at a rate of 549 km^3/year from 2002 to 2008 [84]. The study by Asoka et al. discovered a 1–2 cm/year increase in storage level in southern India from 2002 to 2008 [6]. During the same time span, however, the storage level in northern India fell at a rate of 2 cm/year. Their research also discovered that groundwater withdrawal increases when there is a lack of precipitation in India.

According to Asoka et al. climate change is more significant than manmade factors in determining a region's groundwater table [6]. About 40% of the land area in the north Indian plains and Saurashtra region is irrigated by groundwater; positive precipitation trends have resulted in an increase in groundwater table in the Saurashtra region, In the north Indian plains, negative precipitation patterns have resulted in a drop in groundwater table.

14 Effect on Agriculture

The agricultural sector consumes the majority of the country's water resources, accounting for around 83% of total accessible water resources. Sprinkler and drip irrigation systems have an impact on irrigation efficiency. India's Water Resources in a Changing Climate: An overview irrigation system, as well as the total removal of flood irrigation, is crucial for reducing the expanding needs of the agriculture sector. The government's 'per drop, more produce' project is a praiseworthy attempt to improve water efficiency. To minimise groundwater consumption for irrigation, effective and efficient irrigation technology must be implemented by water regulations that incentivize conservation measures such as water price and de-subsidizing pumping costs [30]. Irrigation penetration in the nation is now less than 50%. More penetration is unavoidable in order to secure food security in the face of climate change. Increased irrigation penetration will quadruple water demand for agriculture at current irrigation efficiency. For developing countries like India, obtaining high water and land productivity is critical to ensuring future food security. We must evaluate variables such as green and blue water and their proportional participation in our agricultural goods and agro-exports to optimise water consumption [27]. Water demand is increased by inefficient irrigation practises and an unscientific cropping pattern adopted in the country, where water-intensive crops are produced in critically challenged areas. Since the green revolution, paddy cropping in northern India has resulted in the indiscriminate draining of groundwater resources in the north Indian plains. India is a net water exporter, meaning that it exports water-intensive crops while importing less water-intensive products, increasing the amount of virtual water in our economy. Water-intensive crops such as cotton, rice, sugar, and soybean are exported, resulting in a net water export of 1% of total available water per year [22].

15 Future Projections

India's population is expected to reach 1.7 billion people by 2050, as the country changes from an agrarian to a service-oriented economy, the demand for water resources is likely to skyrocket. Rapid urbanisation and industrialisation not only strain food security but also increase demand for water resources, exacerbating the problem. India's water consumption is estimated to increase by more than 70% by 2025, and the country is expected to face serious water scarcity by 2050. The rate of groundwater depletion is at an alarming level and the harsh reality of our country's water crisis is being observed under uncertain and variable precipitation caused by climate change, inefficient irrigation water use. On the one hand, water demand is rapidly increasing while water quality is getting degraded.

According to recent estimates, at least 21 Indian towns may have zero groundwater levels by 2020, and over 40% of Indians may not have enough water to drink by 2030 [74]. Our available resources are both insufficient in quantity and quality. India is ranked 120th out of 122 nations in terms of water quality by the United Nations. Only 20% of municipal and industrial water in India is treated, resulting in 70% of the supply being polluted [42].

16 Conclusion

Global warming directly impacts agricultural output, and it has now become a severe challenge for our country in terms of food security. The planting period will vary due to global warming, and the crop's maturity will be delayed. The location of potato production will alter as a result of global warming. In many parts of India, agricultural output will decline in smaller quantities, which will be difficult to notice now but would result in a big loss in the future. Shifting planting time or location is more difficult at lower elevations, and global warming may have a substantial negative influence in these places.

Climate change and global warming will majorly impact India's potato growth storey, affecting all part of the perishable vegetatively propagated crop, including seed multiplication, storage, marketing, and processing. Unless adequate adaptation strategies are developed and implemented in a timely manner, potato growth estimates in India may be halted or even reversed due to future climate change scenarios.

17 Recommendation

Recommendations for addressing the impacts of global warming on potato production in India in the context of a research paper could include:

Assessment of Climate Change Vulnerability: Conduct comprehensive assessments to identify the regions and specific potato-growing areas in India that are most vulnerable to the impacts of global warming. This will help prioritize adaptation strategies and allocate resources effectively.

Development of Climate-Resilient Varieties: Invest in research and breeding programs to develop and promote climate-resilient potato varieties that can withstand higher temperatures, changes in precipitation patterns, and emerging pests and diseases. These varieties should have improved heat and drought tolerance, shorter maturity periods, and high yield potential.

Implementation of Climate-Smart Practices: Promote the adoption of climate-smart agricultural practices among potato farmers, such as precision farming, improved irrigation techniques, and conservation agriculture. These practices can enhance resource-use efficiency, water management, and soil health, reducing the vulnerability of potato crops to climate change.

By implementing these recommendations, India can mitigate the adverse impacts of global warming on potato production, ensure food security, and sustain the livelihoods of potato farmers.

References

1. Aggarwal PK (2008) Climate change: implications for Indian agriculture. In Lal SS, Govindakrishnan PM, Dua VK, Singh JF, Pandey K (eds) Impact assessment of climate change for research priority planning in horticultural crops. Central Potato Research Institute, Shimla, pp 1–10. Retrieved August 17, 2016, from http://krishikosh.egranth.ac.in/bitstream/1/2054278/1/CPRI034.pdf
2. Aggarwal PK (2009) Global climate change and Indian agriculture: case studies from ICAR network project. Indian Council of Agricultural Research
3. Allen EJ, Scott RK (1992) Principles of agronomy and their application in the potato industry. In: Harris PM (ed) The potato crop. The scientific basis for improvement. Chapman and Hall, London, pp 816–881. https://doi.org/10.1007/978-94011-2340-2_17
4. Allen LH Jr, Prasad PV (2004) Crop responses to elevated carbon dioxide. Encycl Plant Crop Sci 346–348
5. Akita S (1993) Respiration: variation and potential for manipulation. In: International crop science I. Crop Science Society of America
6. Asoka A, Wada Y, Fishman R, Mishra V (2018) Strong linkage between precipitation intensity and monsoon season groundwater recharge in India. Am Geophys Union. https://doi.org/10.1029/2018GL078466
7. Bangalore Climate Change Initiative – Karnataka (BCCI-K) (2011) Karnataka climate change action plan – final report. Website. http://www.lse.ac.uk/asiaResearchCentre/_files/KarnatakaCCactionPlanFinal.pdf. Accessed on 06 November 2018
8. Baweja S, Aggarwal R, Brar M (2017) Groundwater depletion in Punjab, India. In: Lal R (ed) Encyclopedia of soil science, 3rd ed, pp 5. https://doi.org/10.1081/E-ESS3-120052901
9. Becktell MC, Daughtrey ML, Fry WE (2005) Temperature and leaf wetness requirements for pathogen establishment, incubation period, and sporulation of Phytophthorainfestans on Petunia × hybrida. Plant Dis 89(9):975–979. https://doi.org/10.1094/PD-89-0975
10. Beukema HP, Van der Zaag DE (1990) Introduction to potato production. Pudoc, Wageningen
11. Bindi M, Hacour A, Vandermeiren K, Craigon J, Ojanpera K, Selldén G, Fibbi L et al (2002) Chlorophyll concentration of potatoes grown under elevated carbon dioxide and/or ozone concentrations. Eur J Agron 17(4):319–335. https://doi.org/10.1016/S1161-0301(02)00069-2
12. Biswas MK, De BK, Nath PS, Mohasin M (2004) Influence of different weather factors on the population build up of vectors of potato virus. Ann Plant Prot Sci 12(2):352–355
13. Bolch T, Kulkarni A, Kääb A, Huggel C, Paul F, Cogley JG, Frey H, Kargel JS, Fujita K, Scheel M et al (2012) The state and fate of Himalayan glaciers. Science (80):336, 310–314
14. Brevik EC (2012) Soil and climate change: gas fluxes and soil processes. Soil Horizons 53. Retrieved August 04, 2016, from https://www.researchgate.net/publication/262260059_Soils_and_Climate_Change_Gas_Fluxes_and_Soil_Processes
15. Burt RL (1964) Influence of short periods of low temperature on tuber initiation in the potato. Eur Potato J 7(4):197–208. https://doi.org/10.1007/BF02368251
16. CGWB (2014) Dynamic groundwater resources of India (As on March 31st 2011). Cent. Gr. Water Board Minist. Water Resour. River Dev. Ganga Rejuvenation Gov. India 299
17. Chen CT, Setter TL (2003) Response of potato tuber cell division and growth to shade and elevated CO_2. Ann Bot 91(3):373–381. https://doi.org/10.1093/aob/mcg031. PMID:12547690
18. Collins WB (1976) Effect of carbon dioxide enrichment on growth of the potato plant. HortScience 11:467–469

19. Craigon J, Fangmeier A, Jones M, Donnelly A, Bindi M, De Temmerman L, Ojanpera K et al (2002) Growth and marketable-yield responses of potato to increased CO_2 and ozone. Eur J Agron 17(4):273–289. https://doi.org/10.1016/S1161-0301(02)00066-7
20. Crosier W (1934) Studies in the biology of phytophthorainfestans (Mont.) De Bary. Cornell Univ. Exp. Stn. Memoir, 155
21. Cutter EG (1992) Structure and development of the potato plant. In: Harris PM (ed) The potato crop. The scientific basis for improvement. Chapman and Hall, London, pp 65–161. https://doi.org/10.1007/978-94-011-2340-2_3
22. Dhavan V (2017) Water and agriculture in India background paper for the South Asia expert panel during the global forum for food and agriculture
23. Directorate of Economics and Statistics (2017) Agricultural statistics at a glance 2016. Ministry of Agriculture and Farmers Welfare, Government of India, p 226. http://eands.dacnet.nic.in/PDF/Glance-2016.pdf. Accessed on 06 November 2018
24. Donnelly A, Craigon J, Black CR, Colls JJ, Landon G (2001) Elevated CO_2 increases biomass and tuber yield in potato even at high ozone concentrations. New Phytol 149(2):265–274. https://doi.org/10.1046/j.1469-8137.2001.00015.x
25. Dua VK (2017) Impact of climate change on potato: current scenario and adaptation strategies. In: Pandey NK, Chakrabarti SK, Singh B, Kumar Tiwari J, Buckseth T (eds) Summer school on recent advances in crop improvement, production and post-harvest technology in potato research (18th July–07th August, 2017). ICAR-Central Potato Research Institute, Shimla-171001, H.P., India, pp 48–52
26. Ewing EE (1997) Potato. In: Wien HC (ed) The physiology of vegetable crops. CAB International, Wallingford, UK, pp 295–344
27. Falkenmark M (2006) The new blue and green water paradigm: breaking new ground for water resources planning and management. J Water Resour Plan Manag 132:129–132
28. Finnan JM, Donnelly A, Burke JI, Jones MB (2002) The effects of elevated concentrations of carbon dioxide and ozone on potato (Solanumtuberosum L.) yield. Agric Ecosyst Environ 88(1):11–22. 10.1016/ S0167-8809(01)00158-X
29. Fleisher DH, Timlin DJ, Reddy VR (2006) Temperature influence on potato leaf and branch distribution and on canopy photosynthetic rate. Agron J 98:1442–1452
30. Fishman RM, Siegfried T, Raj P, Modi V, Lall U (2011) Over-extraction from shallow bedrock versus deep alluvial aquifers: reliability versus sustainability considerations for India's groundwater irrigation. Water Resour Res 47:1–15. https://doi.org/10.1029/2011WR010617
31. Gautam HR, Bhardwaj ML, Kumar R (2013) Climate change and its impact on plant diseases. Curr Sci 105(12):1685–1691
32. Ghosh SC, Asanuma K, Kusutani A, Toyota M (2000) Effect of temperature at different growth stages on nonstructural carbohydrate, nitrate reductase activity and yield of potato (Solanumtuberosum).[Japan]. Environ Control Biol 38:197–206. https://doi.org/10.2525/ecb1963.38.197
33. Goodwin PB (1967) The control of branch growth in potato tubers. II. The pattern of sprout growth. J Exp Bot 18(1):87–89. https://doi.org/10.1093/jxb/18.1.87
34. Goodwin SB, Cohen BA, Fry WE (1994) Panglobal distribution of a single clonal lineage of the Irish potato famine fungus. Proc Natl Acad Sci USA 91(24):11591–11595. https://doi.org/10.1073/pnas.91.24.11591. PMID:7972108
35. Guhathakurta P, Rajeevan M (2008) Trends in rainfall pattern over India. Int J Climatol 28:1453–1469
36. Haris AA, Chhabra V, Bhatt BP, Sikka AK (2015) Yield and duration of potato crop in Bihar under projected climate scenarios. J Agrometeorol 17(1):67–73
37. Heagle AS, Miller JE, Pursley WA (2003) Growth and yield responses of potato to mixtures of carbon dioxide and ozone. J Environ Qual 32(5):1603–1610. https://doi.org/10.2134/jeq2003.1603. PMID:14535300
38. Hijmans RJ (2003) The effect of climate change on global potato production. Am J Potato Res 80:271–280

39. IPCC (2001) Third assessment report of the intergovernmental panel on climate change. WMO, UNEP
40. IPCC (2007) Climate change 2007, the physical science basis. In: Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averut KB, Miller HL et al (eds) Contribution of working group – I to the fourth assessment report of the IPCC. Cambridge University Press
41. IMD report: https://imdpune.gov.in/hydrology/rainfall%20variability%20page/wbengal_final.pdf
42. Iyer SP, Singh SUP, Kumar SJ, Kumar SN, Saran SG (2018) The composite water management index
43. Kang Y, Khan S, Ma X (2009) Climate change impacts on crop yield, crop water productivity and food security – a review. Prog Nat Sci 19:1665–1674
44. Katny MAC, Hoffmann TG, Schrier AA, Fangmeier A, Jager HJ (2005) Increase of photosynthesis and starch in potato under elevated CO_2 is dependent on leaf age. J Plant Physiol 162(4):429–438. https://doi.org/10.1016/j.jplph.2004.07.005. PMID:15900885
45. Kooman PL, Haverkort AJ (1995) Modelling development and growth of the potato crop influenced by temperature and daylength: Lintul-Potato. In: Haverkort AJ, MacKerron DKL (eds) Potato ecology and modelling of crops under conditions limiting growth. Kluwer Academic Publishers, Dordrecht, pp 41–60. https://doi.org/10.1007/978-94-011-0051-9_3
46. Ku G, Edwards E, Tanner CB (1977) Effects of light, carbon dioxide and temperature on photosynthesis, oxygen inhibition of photosynthesis and transpiration in Solanumtuberosum. Plant Physiol 59(5):868–872. https://doi.org/10.1104/pp.59.5.868. PMID:16659958
47. Kumar M (2011) North East India: soil and water management imperatives for food security in a changing climate? Curr Sci 101:1119
48. Kumar N, Kumar Singh A, Aggarwal PK, Rao VUM, Venkateswarlu B (eds) (2012) Climate change and Indian agriculture: impact, adaptation and vulnerability – salient achievements from ICAR network project. IARI Publication, p 32
49. Kumar SN, Govindakrishnan PM, Swarooparani DN, Ch, Nitin, Surabhi J, Aggarwal PK (2015) Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India. Int J Plant Prod 9(1):151–170
50. Lawson T, Craigon J, Tulloch AM, Black CR, Colls JJ, Landon G (2001) Photosynthetic responses to elevated CO_2 and O_3 in field-grown potato (Solanumtuberosum). J Plant Physiol 158(3):309–323. https://doi.org/10.1078/01761617-00105
51. Link. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature; https://medium.com/@vighneshutamse/analysis-on-indian-rainfall-1901-2017-49224557278c)
52. Loomis RS, Connor DJ (1992) Crop ecology: productivity and management in agricultural systems. Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/CBO9781139170161
53. Long D, Chen X, Scanlon BR, Wada Y, Hong Y, Singh VP, Chen Y, Wang C, Han Z, Yang W (2016) Have GRACE satellites overestimated groundwater depletion in the Northwest India Aquifer ? Nat Publ Gr 1–11. https://doi.org/10.1038/srep24398
54. Luck J, Asaduzzaman M, Banerjee S, Bhattacharya I, Coughlan K, Chakraborty A, Debnath GC, De Boer RF, Dutta S, Griffiths W, Hossain D, Huda S (2012) The effects of climate change on potato production and potato late blight in the Asia-Pacific region
55. Mall RK, Gupta A, Singh R, Singh RR, Rathore LS (2006) Water resources and climate change: an Indian perspective. Curr Sci 90:1610–1626
56. Mall RK, Singh R, Gupta A, Srinivasan G, Rathore LS (2006) Impact of climate change on Indian agriculture: a review. Clim Change 78:445–478
57. Marwaha RS, Sandhu SK (2002) Yield, growth components and processing quality of potatoes as influenced by crop maturity under short and long days. Adv Horticult Sci 16:47–52
58. Miglietta F, Magliulo V, Bindi M, Cerio L, Vaccari FP, Loduca V, Peressotti A (1998) Free air CO_2 enrichment of potato (Solanumtuberosum L.), development, growth and yield. Glob Change Biol 4(2):163–172. https://doi.org/10.1046/j.1365-2486.1998.00120.x

59. Mohanty M, Ray K, Chakravarthy K (2015) Analysis of increasing heavy rainfall activity over Western India, Particularly Gujarat State, in the Past Decade. In: Ray K, Mohapatra M, Bandyopadhyay BK, Rathore LS (eds) High impact weather events over SAARC region. Springer Ltd. Publisher, New Delhi, pp 259–276. Website. https://www.springer.com/la/book/9783319102160. Accessed on 06 November 2018
60. Mukherjee S, Aadhar S, Stone D, Mishra V (2018) Increase in extreme precipitation events under anthropogenic warming in India. Weather Clim Extrem 1–9. https://doi.org/10.1016/j.wace.2018.03.005
61. Naresh Kumar S, Aggarwal PK, Swarooparani DN, Saxena R, Ch, Nitin, Surabhi J (2014) Vulnerability of wheat production to climate change in India. ClimRes. https://doi.org/10.3354/cr01212.(35)
62. National Intelligence Council (NIC) (2009) India: the impact of climate change to 2030. A commissioned research report. NIC 2009-03D, April 2009. https://www.dni.gov/files/documents/climate2030_india.pdf. Accessed on 06 November 2018
63. NOAA (National Oceanic and Atmospheric Administration) (2021) Extended reconstructed sea surface temperature (ERSST.v5). National Centers for Environmental Information. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst. Accessed February 2021
64. Nearing MA (2001) Potential changes in rainfall erosivity in the U.S. with climate change during the 21st century. J Soil Water Conserv 56:229–232
65. Olivo N, Martinez CA, Oliva MA (2002) The photosynthetic response to elevated CO_2 in high altitude potato species (Solanumcurtilobum). Photosynthetica 40(2):309–313. https://doi.org/10.1023/A:1021370429699
66. Osswald WF, Fleischmann F, Heiser I (2006) Investigations on the effect of ozone, elevated CO_2 and nitrogen fertilization on host-parasite interactions. Summa Phytopathol 32S:S111–S113
67. Peet MM, Wolfe DW (2000) Crop ecosystem responses to climate change: vegetable crops. In Reddy KR, Hodges HF (eds) Climate change and global crop production. CAB International, pp 213–243. https://doi.org/10.1079/9780851994390.0213
68. Plessl M, Elstner EF, Rennenberg H, Habermeyer J, Heiser I (2007) Influence of elevated CO_2 and ozone concentrations on late blight resistance and growth of potato plants. Environ Exp Bot 60(3):447–457. https://doi.org/10.1016/j.envexpbot.2007.01.003
69. Rama Rao CA, Raju BMK, Subba Rao AVM, Rao KV, Rao VUM, Kausalya R, Venkateswarlu B, Sikka AK (2013) Atlas on vulnerability of Indian agriculture to climate change. Central Research Institute for Dryland Agriculture, Hyderabad, p 116
70. Reynolds MP, Ewing EE (1989) Effects of high air and soil temperature stress on growth and tuberization in solanumtuberosum. Ann Bot 64(3):241–247. http://aob.oxfordjournals.org/content/64/3/241.short
71. Reynolds MP, Ewing EE, Owens TG (1990) Photosynthesis at high temperature in tuber bearing Solanum species. Plant Physiol 93(2):791–797. https://doi.org/10.1104/pp.93.2.791. PMID:16667538
72. Rodell M, Velicogna I, Famiglietti JS (2009) Satellite-based estimates of groundwater depletion in India. Nature 460:999–1002
73. Schapendonk AHCM, van Oijen N, Dijkstra P, Pot CS, Jordi WJRM, Stoopen GM (2000) Effects of elevated CO_2 concentration on photosynthetic acclimation and productivity of two potato cultivars grown in open-top chambers. Aust J Plant Physiol 27:1119–1130
74. Shukla A (2017) Alarming: 21 Indian cities will run out of water by 2030. Bus. World
75. Singh BP, Rana RK (2013) Potato for food and nutritional security in India. Indian Farm 63(7):37–44
76. Singh JP, Govindakrishnan PM, Lal SS, Aggarwal PK (2005) Increasing the efficiency of agronomy experiments in potato using INFOCROP-POTATO model. Potato Res 48(3–4):131–152. https://doi.org/10.1007/BF02742372
77. Singh JP, Govindakrishnan PM, Lal SS, Aggarwal PK (2008) Infocrop Potato a model for simulating growth and yield of potato in the sub-tropics. Central Potato Research Institute, Shimla

78. Singh JP, Lal SS (2009) Climate change and potato production in India. In: ISPRS archives XXXVIII-8/W3 workshop proceedings: impact of climate change on agriculture, pp 115–117
79. Singh JP, Trehan SP (1993) A case study of soil and irrigation water related constraints in potato crop production: cause and correction. In: National seminar on ‘developments in soil science, 58th annual convention, Dehradun
80. Sparks AH, Forbes GA, Hijmans RJ, Garrett KA (2014) Climate change may have limited effect on global risk of potato late blight. Glob Change Biol 20:3621–3631. https://doi.org/10.1111/gcb.12587
81. Stol W, de Koning GHJ, Haverkort AJ, Kooman PL, van Keulen H, Penning de Vries FWT (1991) Agro-ecological characterization for potato production. A simulation study at the request of the international potato center (CIP), Lima, Peru. CABO-DLO, Report 155
82. Supriya L (2018) Excess uranium in Gujarat, Rajasthan’s groundwater poses grave health risks. Bus. Stand
83. Tesfaye K, Aggarwal PK, Mequanint F, Shirsath PB, Stirling CM, Khatri-Chhetri A, Rahut DB (2017) Climate variability and change in Bihar, India: challenges and opportunities for sustainable crop production. Sustainability 9:22
84. Tiwari VM, Wahr J, Swenson S (2009) Dwindling groundwater resources in northern India, from satellite gravity observations. Geophys Res Lett 36:1–5. https://doi.org/10.1029/2009GL039401
85. United Nations, Department of Economic and Social Affairs, Population Division (2017) World population prospects: the 2017 revision, key findings and advance tables. ESA/P/WP/248
86. Vaccari FP, Miglietta F, Giuntoli A, Magliulo V, Cerio L, Bindi M (2001) Free air CO_2 enrichment of potato (Solanumtuberosum L.). Photosynthetic capacity of leaves. Italian J Agron 5:3–10
87. Van de Geijn SC, Dijkstra P (1995) Physiological effects of changes in atmospheric carbon dioxide concentration and temperature on growth and water relations of crop plants. In: Haverkort AJ, MacKerron DKL (eds) Potato ecology and modelling of crops under conditions limiting growth. Kluwer Academic Publishers, Dordrecht, pp 89–100. https://doi.org/10.1007/978-94-011-0051-9_6
88. Van Keulen H, Stol W (1995) Agro-ecological zonation for potato production. In: Haverkort AJ, MacKerron DKL (eds) Potato ecology and modelling of crops under conditions limiting growth. Kluwer Academic Publishers, Dordrecht, pp 357–372. https://doi.org/10.1007/978-94-011-0051-9_23
89. Vandermeiren K, Black C, Lawson T, Casanova MA, Ojanpera K (2002) Photosynthetic and stomatal responses of potatoes grown under elevated CO_2 and/or O_3 - results from the European CHIP-programme. Eur J Agron 17(4):337–352. https://doi.org/10.1016/S1161-0301(02)00070-9
90. Varallyay G (2007) Potential impacts of climate change on agro-ecosystems. Rev Agric Conspec Sci 72:1–8
91. Vos J (1995) Nitrogen and the growth of potato crops. In: Haverkort AJ, MacKerron DKL (eds) Potato ecology and modelling of crops under conditions limiting growth. Kluwer Academic Publishers, Dordrecht, pp 115–128. https://doi.org/10.1007/97894-011-0051-9_8
92. Wheeler RM, Tibbitts TW, Fitzpatrick AH (1991) Carbon dioxide effects on potato growth under different photoperiods and irradiance. Crop Sci 31(5):1209–1213. https://doi.org/10.2135/cropsci1991.0011183X003100050026x. PMID:11537629
93. Ywa NS, Walling L, McCool PM (1995) Influence of elevated CO_2 on disease development and induction of PR proteins in tomato roots by phytophthoraparasitica. Plant Physiol 85(Suppl):113. Retrieved November 4, 2015, from http://www.climateandforming.org

Building Climate Resilient Agriculture in the Indian State of Assam in Foot Hill Himalayas

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Abstract The farming system of Assam is principaly characterized by rice based mono cropping by small and marginal farmers and is essentially dependent on rain and greatly influenced by type of soil, crops, and socioeconomic condition of the farmers. Farmers of the state are relatively resource-poor with low adaptive capacity; therefore, weather aberrations make rainfed agriculture of the state highly vulnerable, risk-prone and often unprofitable and thus impacting their livelihoods. The threat to agricultural production in the state has already been reported due to rise in ambient temperature, reduction in the availability of water for irrigation, degradation of soil health, the emergence of new pests and disease complex along with the increased frequency of extreme weather events like high-intensity rainfall events, flood, drought, etc. The innate problem of floods and seasonal drought in the state causes widespread destruction of the crop fields along with causing a huge loss of the vast fertile cultivated land areas permanently. These problems are likely to be aggravated in the future due to an increase in rainfall variability driven by climate change. Since the occurrence of such weather aberrations may not be sudden and

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_15

some regions may often encounter a definite type of weather aberrations, management of these aberrations can be planned effectively with the available technologies and farmers' wisdom. The effects of such weather aberrations can largely be counteracted in many situations, if not eliminated by adopting improved soil, water, crop, and pest management strategies even with the hostile impact of climate change. Preparation and implementation of real-time crop contingencies are important to respond to weather aberrations in different stages like preparedness, real-time response, relief and rehabilitation. Moreover, identification of various adaptation strategies including climate-resilient crops and cultivars, rainwater harvesting and recycling, efficient energy management through farm mechanization, dissemination of weather information and weather-based agro advisories to farmers on a real-time basis, post-harvest processing, marketing, identification, evaluation of ingenious technological are important deliberations as an benchmark for initiating agriculture resilient to climate change in Assam.

Keywords Agro-met advisory · Alternate crops and varieties · Climate Change · Custom hiring center flood · Dry spells

1 Introduction

One of the prime challenge faced by world community today is the climate change. It has impacted throughout the world which has been experienced through the changes in not only in temperature but also in other climatic changes, viz., the rainfall, retreating of ice cap, melting glaciers, pattern of atmospheric circulation, rise in sea level and the overall ecosystem change. One of the most severeimplications of climate change is the increase in extreme weather events. It is indeed responsible for the increased frequency of destructive weather events like heavy rainfall incidents, pronounced heat or cold waves, cyclones, drought, flood, etc. all over the globe The rises in global temperature coupled with undesirable changes in rainfall patterns lead to the occurrence of drought and flood which is responsible for the shortening of the growing season, damaging standing crops, increasing insects, pests, and diseases, and in turn reducing agricultural productivity [2, 5, 7, 12, 13, 24]. According to [10] the current temperature of the earth surface is 0.89 °C above the period of industrialisation level which may rise by 1.0 to 3.7 °C by 2081–2100. In India, an increasing trend of temperature at the order of 0.60 °C during the last 112 years [21] and an increase in heavy rainfall events [8] have been documented. The country is also witnessed with increased frequency of droughts, cyclones, hailstorms, etc. during the past decade indicating increased variability of climate. Analysis of long term data (1951 to 2010) revealed that there is an increase in mean temperature and decrease in mean annual rainfall in the state by 0.01 °C/year and 2.96 mm/year, respectively [21]. The increasing trend of temperatures and decreasing trend of annual and seasonal rainfall along with the increasing frequency of heavy rainfall events, flash flood and seasonal drought in the recent past might be a reflection of increasing climatic variability in the state of Assam [15]. According to India Meteorological Department (IMD), the temperature in the state may increase by 1.7 to 2.0 °C during 2021 to 2050 and the extreme rainfall events, drought weeks and floods are likely to increase by 5 to 38%, >75% and >25% respectively, with respect to the baseline year [4]. Deka et al. [6] observed decreasing pattern of monsoon and total annual rainfall with a corresponding increase in rainfall deficit years in Assam starting from 2001 onwards in both the valleys of the Brahmaputra and the Barak rivers in north and south of the state of Assam In the north bank plain zone of Assam, increased variability in amount and distribution of rainfall has also been observed in recent years along with an increase in numbers of wet spellsand dry spells driven flash floods and seasonal droughts, respectively [14]. The probability of occurrence of two wet weeks consecutively with 40 mm rainfall was observed at 10 weeks during Sali season in Assam [23]. However, the area has been drought prone and it was observed that agricultural drought was as long as 4 weeks during Kharif and 11 weeks during *rabi* season.

2 Materials and Methods

The NICRA project is being implemented in Chamua village of Lakhimpur district, situated in the North Bank Plain zone of Assam. The village lies in 27°02′18″ N latitude and longitude of 93°52′46″ E with varying altitude of 83 to 90 m from mean sea level. An area of 133 ha is cultivated in the village, which is entirely rainfed. The village receives on an average 1987 mm of annual rainfall out of which an average of 1375.3 mm falls during Kharif (June–September). The soils of the village are *Inceptisols* (sandy loam to silty clay loamy) The pH ranges from 4.65 to 6.38. Organic matter of the soil varies from 0.34 to 3.03%. The available nitrogen and Potassium are in the range of 275–540 kg ha^{-1} and 138–330 kg ha^{-1}, respectively. The range of available phosphorus is 21.4–54.0 kg ha^{-1}, which falls in the range of low to medium. The soil is characterised with acidic, high fixation of phosphorus, deficiency in micronutrients, toxicity of iron, high intensity rainfall during kharif and periodic soil moisture stress during winter seasons,.

The common farming practice was monocropping till recent past, when 90% of total cultivable land was occupied by only winter rice. With the newer interventions, presently the village farmers have been encouraged to undertake diversification of. crops. As a result area under rapeseed, potato, tomato, black gram, green gram, turmeric, ginger, maize and vegetables have been considerably increased. Predominantly the farmers of the village are small and marginal and only 14.5% of them belong to medium category. Apparent drought is the major weather aberration in Chamua village. Ground water table of the village is very low reached at just 6 m and contaminated with both Arsenic (10 ppb) and iron (14.2 ppm). The village has different weather related problems like Dry spells and occurrence of flash flood during winter rice season and scanty rainfall during *Rabi* season is a charaecteristic feature of the village. The availability of different land situations comprising of many natural ponds in the village provide ample scope for rain water harvesting.

Since 2012–13, the NICRA programme has also being implemented in a village named *Gankdoloni* in *Dhalpur* block of Lakhimpur district, Assam. The village lies in latitude and longitude of 26°55′33″ N and 93°52′17″ E, respectively. Similar pattern of rainfall like Chamua village was also observed in Ganakdoloni.. area total of 75 farm families reside in the village having an area of 66 ha under cultivation. Majority of the farmers are either small or marginal and only eight are medium. within contrast to Chamua no contamination of Arsenic is found in the village. Ground water table is shallow. The village is characterised by chronically affected flood. Almost every year the village is affected by on an average 3–5 flash floods of one to two weeks duration during winter rice season., During *Rabi* season owing to scanty rainfall, soil moisture deficit is a common problem in the village. The scope for crop diversification has been limited in the village owing to low lying land situation. The winter rice (*Sali* rice) grown in the village chronically suffer from flash flood every year. The distress in agriculture forces migration of agricultural labour from the village.

3 Impact of Climate Change on Agriculture

The anthropogenic change in climate is the prime challenge in sustainability of agriculture worldwide. Over the next decades it is likely to be increased owing to increasing negative impact of climate change in crop production.. Presumably agricultural production in higher latitude may be increased due to increase in temperature. On the other hand some dry areas be benefited due to more rainfall. However, millions of people of the world depend on rainfed agriculture or natural ecosystems for their livelihood. According to [11], extreme climatic events may become more frequent for the farming community in days to come. Climate change is likely to put additional stress on our agricultural systems and will act as ‘risk multiplier’ [9]. Increased temperatures is likely to adversely affect crop growth rate, reduce crop duration, production. This will also adversely impact on increased rate of evapotranspiration and decreased efficiency of fertilizer use. Greater evapotranspiration, soil moisture deficit, higher mineralization, and increased in soil temperature will have negative impact on soil health. In extreme cased high temperatures associated with drought may lead to agriculture in some places almost impossible. Temperatures is crucial for the growth of pests and diseases. As such, survival and distribution of pests is likely to be affected. With increased temperature in an area of higher relative humidity in the state of Assam, the disease–pest scenario will be much impacted. There is, thus, the likelihood of increased ranges of pests in a warmer environment of Assam. Some insects or diseases may become Prevalent of some insects and pathogents will change in different areas. In some areas previously unknown or less important species will become dominant. Change of a minor pest or disease to a major one or vice versa is likely to happen. In the tropical and subtropical world climate change is likely to put negative impact through increased vulnerability to droughts and other weather extremities [26]. Indian agriculture may further be worsened by increased water scarcity, drought, t floods and declining soil carbon due to incread temperature and precipitation [1, 14].

4 Climate Change Impact—Assam Situation

The economy of Assam is primarily dependent on agriculture. More than 87% of the population of the state lives in rural areas which contributes 17% to the GDP of the state. The dominance of small and marginal farmers (83.1%), rain-dependent agriculture (81.5%), small and fragmented land holding, poor mechanization, poor socio-economic conditions of the farmers, poor rural and marketing infrastructure, withdrawal of labour from agriculture sectors etc. along with weather aberrations make the agriculture of the state more vulnerable to the climate change. Rice dominates the state's agriculture and is cultivated almost entirely as rainfed. The monocrop farming of state is often affected by several weather constraints mainly Flood and drought often affect severely the rice crop in the state. The flooding pattern has been very typical in the state due to the increase in high intensity-rainfall. Agriculture in the state, thus, has become uncertain and full of risks. Flash flood during the monsoon season is very frequent causing extensive damage to the rice based cropping system of Assam. The fluctuations in rainfall in past several years indicated a higher likelihood of not only heavy floods but also of short drought spells challenging future of agriculture in the state of Assam [6, 14]. In recent years there has been frequent intermittent dry spells experienced during the *Sali* rice-growing season causing extensive damage to the rice crop in the state. Shift in rainfall behavior has been observed in the state. Annual and monsoon rainfall has decreased with coherent decrease of June–October monthly rainfall and significant increased rainfall variability in June, September, and October. Quick drainage through the close river networks, loose alluvial soil having poor water retention capacity leads to water deficit with characteristic agricultural drought of varying duration ranging from one week to more in the rarrow valley of North Bank of Brahmaputra [15]. The impacts of intermittent dry spells during winter rice growing season in recent years in Lakhimpur district of Assam is presented in Table 1.

5 Building Climate Resilient Agriculture in Assam

The innate problem of flash floods and the occurrence of multiple dry spells during crop growing in Assam is likely to be accelerated in future due to increased rainfall variability as a result of climate change. Weather aberrations are likely to make the rainfed agriculture of the state most vulnerable, risk-prone, and unprofitable. The resource poor, small farmers having poor adaptive capacity are to suffer most. Appropriate mitigation and adaptation strategies are the need of the hour to deal with

Table 1 Effect of intermittent dry spells of different stages of growth of *Sali* rice in Chamua village, Lakhimpur

Year	Vulnerability	Crop growth stages affected
2001	Dry spells	Tillering, PI and grain filling
2005	Dry spells during Sept/Oct	-do-
2006	Dry spells (Aug/Sept/Oct)	-do-
2009	Dry spells (early and late season)	Sowing, transplanting, tillering, PI and grain filling
2011	The onset of monsoon was delayed, midseason and terminal drought—weed/insect/disease	Sowing, tillering, PI and grain filing
2012	Heavy rainfall up to mid-October, thereafter no rainfall up to May2013	Tillering and PI; *rabi* crops
2013	Delayed onset of monsoon, terminal dry spells, very less rainfall during *rabi*	Sowing and grain filing
2014	Delayed onset, Terminal dry spells, less rainfall in *rabi*	Sowing and grain filing
2015	Terminal dry spells	Grain filling stage

Source [15]

the situation. Attempt should be made so that agriculture can be resilient to such adversities owing to climate change. Mitigation of climate change has been aleways important. However, mitigation can solve the impact of climate change at most to 40% in agriculture only [20]. The other option in order to reduce vulnerability and enhance the resilience of the agricultural system to climate change is to undertake adaptation strategies for the climate change events. The climate variability can very well be managed through adaptation strategy through improved technologies and indigenous knowledge system. In this article, important adaptations strategies for building climate-resilient agriculture in Assam are discussed.

5.1 Contingency Crop Planning

The occurrence of weather aberrations may not be sudden and some regions may often encounter a definite type of weather aberration, so their management can be planned properly. The effect of weather aberrations can largely be counteracted in many situations, if not eliminated with contingency crop planning. Contingency crop planning refers to implementing a plan for making alternate crop or cultivar choices and measures need to be taken in tune with the actual rainfall situation (excess or deficit) and soils in a given location. The contingency crop planning includes contingency measure, which may be related to technologies applied to land, soil, water, crop, approaches of institutional and policy-based that are implemented based on real-time weather patterns during crop period [25]. The unusual weather situations like excess pre-monsoon showers, high intensity rainfall, delayed onset of monsoon, early mid and terminal drought have become common in the state in recent years. Flash flood during monsoon season, intermittent dry spells during rice growing seasons, prolonged dry spell during post-monsoon and winter season, are being experienced very frequently. As a result crop productivity has suffered badly. The characteristic feature of the state is that both flood and drought has become a simultaneous problem. Therefore, appropriate contingency measures have to be sorted out with critical observation into the cropping system *vis a vis* observed climatic variables Both drought and flood cause loss in livestock and fish productivity, so appropriate location-specific measures should be taken to reduce the adverse impact on livestock and the fishery sector which is the major source of livelihood of farmers of our state. Therefore, contingency crop plans should be prepared to tackle abnormal weather situations and thereby uphold the production of the crop, fish, and animal/animal products.

Agricultural contingency plans consist of four phases: preparedness, real-time response, relief, and rehabilitation. Preparedness is a set of measures that converts vulnerable system to resilient one and the system is now capable to cope with the abnormal weather condition. Some rice varieties (like Ranjit Sub-1 and Bahadur Sub-1) can tolerate submergence up to 15 days, so these submergence tolerant varieties should be transplanted in flash flood-affected areas of Assam as a measure of preparedness. Initial preparedness is the must-do agricultural practices like selecting appropriate crops and cultivars based on land situations make available seeds of suitable crop/varieties through seed bank, seed treatments, need-based fertilizers application, and pest-diseases management, rainwater management, make availability of suitable farm implements, etc. Real-time response is the planning for response and recovery during and after the occurrence of the crisis. Immediate response to reduce losses to standing crops can be achieved through midterm corrections such as draining out excess water from the crop field, gap filing through re-transplanting, re-sowing, life-saving irrigation, soil and foliar application of chemicals, etc. The relief means the measures to be taken to meet the immediate requirements of victims of weather aberrations. Raising community nursery, supply seed or seedlings in the doorstep of farmers of the affected area, arrangement for spraying of chemicals for controlling pests and diseases, creating awareness and organizing need-based training programme, etc. during or after the crisis are some examples relief. Rehabilitation is the act of restoring the system into its original state after the destruction of the system by a weather hazard. Suppose the cropping system of a large area is damaged entirely by an extreme weather event. In that case, the affected farmers need outside physical, material, financial, and psychological support. When the heavy flood destroys the Salipaddy in a large area, resource farmers of the area cannot do any agricultural activities in the next crop season. In such a situation, they need help from outside to raise the next crop. The local authority in support of state and national government should help the farmers by supplying seed, fertilizers, diesel, farm machinery, and implements, etc. for restoration farming in the affected area.

Assam Agricultural University has already prepared Agricultural Contingency Crop Plans for all the districts of Assam in collaboration with India Council of Agricultural Research (ICAR). The district's agricultural contingency plans are available in the public domain (https://agricoop.nic.in/en/divisiontype/horticulture) for public use. These contingency plans are useful tools for effectively managing weather aberrations and building climate-resilient agriculture in an area.

5.2 Management of Flood

Floods are the recurrent phenomenon in Assam which causes widespread damage to winter or Salirice. However, it is imperative to identify improved technologies to cope with such extreme events and enhance the adaptive capacity of farmers. Introduction of short duration rice varieties suitable grown before and after the flood contributed immensely in increasing rice production in the flood-prone areas of Assam. Development of submergence tolerant rice varieties is another option for managing flood, as these varieties can tolerate submergence up to two weeks or more. Assam Agricultural University has developed some submergence tolerant rice varieties like Jalashree, Jalkunwari, Ranjit-1, Bahadur Sub-1, which are suitable for low land flash flood situations, however, these varieties cannot withstand submergence after attainment of panicle initiation stage.Ranjit-1, Bahadur Sub-1 can withstand 14–18 days of submergence with an average yield of 55 to 60 qt/ha. Moreover, some high yielding varieties like *Gitesh* and *Prafulla* are suitable for late planting with aged seedlings of 60–70 days. Varieties having staggering ability should be sown at normal sowing time, however, it can be a wait to receding of flood for transplanting**.** Some traditional photosensitive variety like *Manohar Sali* and *Andrew* Sali can be late transplanted with nagged seedlings after receding of the flood. Assam agricultural also developed some deep water rice varieties like *Padmanath, Panchanan, Panindra, Basudev, Padmapani,* etc. which can withstand water depth up to 2 m.

Flood damages of Salirice depend on the time of occurrence flood, flooding depth, and crop growth stages. Early season (June and July) flood generally affects the seedling and/or tillering stage, while mid (mid-August to mid-October) and late season (mid-September to mid-October) flood affect tillering and panicle initiation and development stages, respectively. Therefore, varietal resources must be properly utilized according to the situations that arise depending on the land situation (flooding depth), time of flood and crop growth stages (Table 2). The newly developed submergence tolerant varieties can tolerate upto two weeks of submergence during vegetative stage. However, the same variety can not tolerate it during reproductive stage (From panicle intitation onwards). Therefore, the submergence of rice fields at the panicle initiation stage caused total crop failure in these varieties. Under such a situation, although low yielder, traditional *bao* varieties (floating rice) can survive and give assured yield. This traditional knowledge could be an appropriate contingency measure under flood prone situation.

Under a situation of submergence for 7–15 days duration which continue up to the first week of October with a flooding depth of upto 1.5 m, the traditional *bao* varieties

Table 2 Contingency crop planning for the management of flood in *Sali* rice

Flooding situation	Must do technologies
If sowing is possible within 30th June	Sowing of long duration normal varieties like Ranjit, Bahadur, etc.
If sowing is not possible within 30 June due to stagnant water/recurrent flood	Sowing of medium duration varieties like Satyaranjan, Shraboni, etc.
If sowing is not possible up to 15 July	Sowing of short duration varieties like *Lachit* and *Chilarai*
If sowing is not possible up to 30 July	Sowing of very short duration varieties like Luit, Kapili and Kolong and Disang, Sowing can be continued up to first week September
Sowing in normal time (within June), but wait for transplanting up to receding of the flood up to the first week of September	Staggered Planting of varieties like *Prafulla* and *Gitesh* aged seedlings of 60–70 days
-do-	Planting traditional varieties like *Manohar Sali* and *Andrew Sali* with nagged seedlings
Low laying area often affected by a flash flood of 14 to 18 days durations	Submergences tolerant varieties like Ranjit Sub 1, Bahadur Sub-1, etc.
Low lying area with water stagnation for more than a month and with flooding depth of less than 1 m 3 to 4 m	Improved *baodhaan* like *Padumani, Panchanan*, etc. Traditional *bao* varieties like *kekua*, *maguri*, *Amona* etc.

can survive with acceptible yield [14]. These floating rice varieties can adapt under flash floods, occasional drought have stem elongation and kneeing ability to survive under deep water situation.

A traditional bao varities can survive with acceptabile grain yield under submergence with flooding depth of less than 1.5 m for 7 to 15 days up to the first week of October [14]. These floating rice cultivars have the stem lengthening and kneeing ability necessary to survive the situations of submergence in deep water situation (Table 3).

Table 3 Mean height, characteristics and mean yield of *bao* varieties grown at *Ganakdoloi* village of Lakhimpur during 2013 and 2014

Sl no	Name	Height (m)	Characteristics	Yield (Kg ha^{-1})
1	*Kekua*	2.2	Having both elongation and kneeing ability	2474
2	*Tulshi*	2.5–4.6	Having both elongation and kneeing ability. Having maximum elongation ability	2250
3	*Dhushuri*	2.0	Having elongation, keening and submergence ability	2719
4	*Maguri*	2.1	Having both elongation and kneeing ability	2567
6	*Rangabao*	2.5–3.5	Having both elongation and kneeing ability	1764

5.3 Management of Dry Spells

The impact of a dry spell on crop performance varies with The length of dry spells, land situations and the crop/varieties impacts on the performance of the crops. Crop/ varieties differe in terms of water requirements. Under the same level of dry spell a variety may behave differently to different land situations. Thus all these factors are highly interactive. Therefore, specific variety needs to be identified to cope with a specific land situation under a given dry spell. The adaptation strategies through sdoption of selected crop/varieties as a climate resilient contingency are discussed below.

5.4 Alternate Varieties and Agronomic Manipulation

The winter rice (Sali) is grown in varying land situations in Assam (Upland to low land). In spite having good amount of rainfall the winter rice is affected by several dry spells, which is much pronounced in the well drained uplands. Assam is known for a large array of diversity in rice varietal types. Thus, there exist the possibility of management of seasonal drought through the identification of appropriate traditional rice varieties under different land situations. Type of dry spells and critical crop growth stages of rice varieties are presented in Table 4.

A case study carried out by [15] clearly demonstrated the implication of dry spell on the performance of winter rice in the state The year 2011 experienced with a multiple dry spells and delayed onset of monsoon followed by a substantial reduction of rainfall from mid-August at the experimental village. Farmers could not sow the normal long duration rice varieties in time (before the third week of June). This resulted in poor crop performance. The affect was so severe that in some extreme cases, no panicle emergence was observed. It was observed that 40–100% yield reduction occurred in the most popular long duration variety, Ranjit (Table 5).

Table 4 Types of dry spells for which contingency planning is required [15]

Type of dry spells	Varieties of rice affected
Delayed onset of monsoon (beyond 21 June)	Long duration varieties with duration 150 or more
Early season drought (reduced rainfall in June/ July)	Transplanting and tillering stages of any varieties
Mid Season drought (educed rainfall in August/ September)	Tillering and Panicle Initiation stages any varieties
Terminal drought (reduced rainfall activities in September/October)	Reproductive stage of any varieties
Long dry spell (up to 10 weeks)	Crop failure, go for the alternate crop

Table 5 Characteristics of a few rice varieties suitable for the management of seasonal drought under different land situations [15]

Group of rice (duration in days)	Land situations	Name of rice varieties	Duration (days)	Average yield (Kg ha^{-1})
Short duration (90–120)	Upland	Dishang	90–100	3200
		Lachit	120	3500
		Kolong	90–100	3000
		Luit	90–100	3000
Medium duration (125–140)	Medium land	Bashundhora	130–133	4500
		Mohan	126–130	4100
		Mulagabhoru	130–135	4600
		TTB-404	130–135	5000
		Mohan	126–130	4100
Long duration (150–160)	Low land	Ranjit	150–155	5500–6000
		Gitesh	150–160	5000–5500
		Moniram	150–155	5400–6000

Plant's response to abiotic stresses is crop and cultivar specific. Generally, short-duration high yielding varieties can escape the terminal drought as these varieties could reach physiological maturity earlier which enabled escape of dry spells beyond mid-September. Similarly, terminal dry spells could be averted by medium-duration high-yielding varieties under medium land situation. Under same land situation farmers' varieties were suffered due to dry spells during the months of October and November. This resulted in substantial yield loss. Therefore, short and medium duration varieties could be a better contingency measure to avoid the terminal and mid season drought due to dry spells [15].

The long duration rice varieties, if sown before third week of June, are not generally by midseason or terminal dry spells [17]. However, owing to the delay of monsoon, if sowing is done beyond the third week of June they suffered from low-temperature stress (below 20 °C) during flowering (Fig. 1).This leads to substantial reduction in grain yield. This adverse affect of delayed onset of monsoon could be averted by completing sowing within the third week of June with the utilizing of harvested rainwater from the pre-monsoon sower [15].

5.5 *Alternate Crops and Crop Diversification*

In comparision to other crops we cultivation of rice require a much higher quantity of water. Therefore, it may be assumed that other alternative crops may perform better than rice under the similar land situation and same amount of rain water.

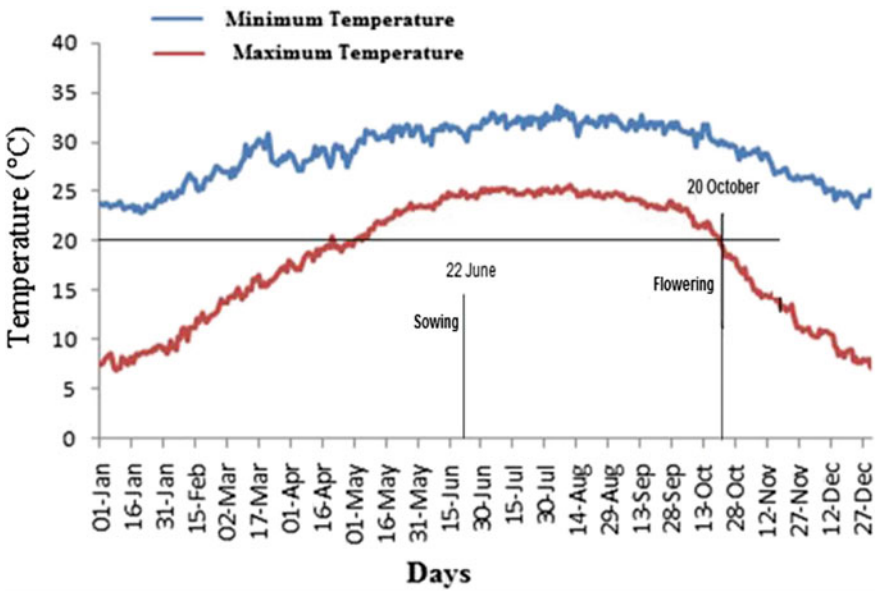


Fig. 1 Exposure of anthesis of long-duration sali rice varieties to low daily temperatures in North Bank Plains Zone of Assam, India

It was observed that rice yield was greatly reduced under all types of land situations in the years with multiple dry spells. It was worst under upland situation when preceeded by delayed onset of monsoon. Adoption of crop diversification with less water requiring crops, viz., sesame, ginger, turmeric, colocasia, green gram, black gram, summer vegetables etc. as contingency measures have been successful. Thus, the diversification with alternate crops was proved to be a good strategy for managing dry spells during both Kharif and Rabi seasons.. It was further proved benefitial in enhancing nutritional security, rural employment, income generation, poverty reduction and accelerating rural trade. Neog et al. [18] demonstrated that much higher income could be earned by the farmers from crop diversification than the monocropping with rice under upland situation (Table 6).

5.6 Multiple Cropping Systems

There is ample scope for adoption of more than one crop in a season in thestate. Crop productivity could be increased by changing from the conventional monocropping to double or triple cropping. The selection of crop/variety should be specific to land situation and the probable climatic variations and its effects. A number of profitable cropping systems identified through NICRA interventions under different land situations in participatory mode for Assam are presented in Table 7.

Table 6 Cropping intensity, yield, net income, Increase in net return and B:C ratio of different farmers from 2013 to 16

Farmer	Crops	CI (%)			Yield (Kg/ha)			Net income (Rs/ha)			Increase in net return (Rs/ha)			B:C ratio		
		2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16
Farmer-1	Rice, maize, chilli, potato, rapeseed, cabbage, cauliflower, brinjal	1.9	1.34	1.62	162,663	167,581	157,745	87,895	859,935	1,066,275	81,291	844,935	1,046,275	3.02	2.67	3.16
Farmer-2	Rice, maize, sugarcane, potato, rapeseed, pea	1.15	1.12	1.13	316,839	35,644	598,034	93,256	88,150	265,498	84,856	73,150	245,498	2.98	1.35	2.0

(continued)

Table 6 (continued)

Farmer	Crops	CI (%)			Yield (Kg/ha)			Net income (Rs/ha)			Increase in net return (Rs/ha)			B:C ratio		
		2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16
Farmer-3	Rice, maize, ridge gourd, cucumber ladies finger, potato, cabbage, cauliflower, knolkhol, rapeseed	2.10	2.06	2.08	114,100	98,453	129,747	109,898	490,897	811,610	101,498	475,897	791,610	2.25	2.22	2.71
Farmer-4	Maize, turmeric, colocasia, ridge gourd cucumber, bhindi, cow pea, green gram, sesame, potato, rapeseed, cabbage, brinjal	2.04	1.42	1.73	97,164	66,269	128,059	48,828	547,660	897,752	39,228	532,660	877,752	1.78	2.97	3.93

Table 7 Double cropping systems identified the different land situation of villageChamua, Lakhimpur, Assam [18]

S. no.	Land situation	1st crop (variety)	Second crop (variety)
1	Upland	*Sali*rice (short-duration varieties like dishang)	Rapeseed (TS-36/TS-38)
2	Upland	*Sali*rice (short duration varieties like dishang)	Potato (KufriJyoti/Pokhraj)
3	Mid land	*Sali*rice (medium duration varieties like TTB-404)	Rapeseed (JT-90–1) Potato (KufriJyoti/Pokhraj)
4	Low land (relay)	*Sali* rice (long-duration varieties like Ranjit, Gitesh, etc.)	Pea (as relay crop)
5	Up/mid/low land situation	Rice	Maize

Table 8 Performance of double cropping or relay cropping at NICRA village Chamua during 2014–15 and 2015–16 (pooled data)

Cropping system	Crops	REY (Kg/ha)	Net income (Rs)
	Rice + maize	15,050	110,075
	Rice + maize + pumpkin[a]	–	–
	Rice + rapeseed	7534	36,893
	Rice + potato	19,460	158,303
	Rice + pea**	–	–

[a]Yield of pea and pumpkin is not available

In all the above double cropping system, rice equivqllent yield along with net income was increased than the traditional monocropping. Rice + potato system was identified as the most profitable out of all the systems (Table 8).

5.7 Maize as a Climate-Resilient Crop

Maize is considered as a water-efficient crop owing to its deep and fibrous root system. The crop being a C_4 plant, has a higher level of adaptation under increased temperature and also elevated CO_2 concentration.. In this sense, maize may be considered as a climate resilient or climate neutral crop.. The crop could very well be grown in all type of soil in the studied village even during the driest period of the year during Rabi season after harvest of the winter rice..

6 Rainwater Harvesting and Recycling

The state of Assam belongs to a high rainfall zone where average rainfall is of 2100 mm. In spite of this, crops suffer from dry spells for a long span in the year, owing to irratic distribution of rainfall. More than 80% of the annual rainfall is received during the months, mid-March to end of September. However, the winter season of the state is virtually dry receiving only 0.83 to 3.6% of annual rainfall. Therefore, crops grown in the major part of the year particularly during Rabi, often suffer from moisture deficit.

In-situ rainwater management mitigates dry spells and increases the rainwater use efficiency, crop yield and benefit–cost ratio. Mulching is benefitial in management of dry spells. Apart from conserving moisture mulching has added advantage of manuring and enriching soil with organic matters. Locally available waste materials like rice straw, stubbles, water hyacinth, etc. can very well be utilised as mulching materials for crops like turmeric and ginger during Kharif and potato, tomato etc. During Rabi. Therefore as an alternate crop of rice under upland, farmers may be advised to take up turmeric and ginger cultivation with mulch cover. It has been observed that potato yield could be increased by 42.5% if the crop is grown under organic mulching. Under mulching it was also observed that plant height, LAI, bomass production and tuber development period were increased apart from the increase intuber yield [19]. Similarly, higher yield of tomato along with longer fruiting period was also observed [15, 18].

Though Assam has enormous water resources, the use of both surface and groundwater for irrigation is not enough. Moreover, the unevenrainfall distribution experienced over the year in the state resulted the crops suffering from agricultural drought due to dry spells. Because the state has a higher rainwater harvesting potential, harvesting, and recycling of rainwater perhaps one of the options to nullify the ill effect of seasonal droughts on crops. It was observed that The annual PET at Biswanath Chariali in the NBPZ of Assam has been observed to be 1138 mm, which is 887 mm less than the normal annual rainfall i.e. 1925 mm. On the other hand, from March to the end of October the difference between rainfall and PET is 935 mm in the same station (Fig. 2). Therefore, the station has a rainwater harvest potential of 887 and 935 mm for the year as a whole and from March to October, respectively.

The farm pond harvested rainwater during the pre-monsoon and monsoon months can efficiently be utilized to sow Sali rice and provide supplemental irrigation to both *Kharif* and *rabi* crops, respectively. In most part of the state, a good amount of rainfall generally receives during pre-monsoon months (March to May), which can be efficiently utilized after harvesting for nursery bed preparation of *Sali* rice. This is beneficial in situations like the delayed onset of monsoon, as the sowing of long duration rice cultivars can be completed in time. In a case study under NICRA, it was

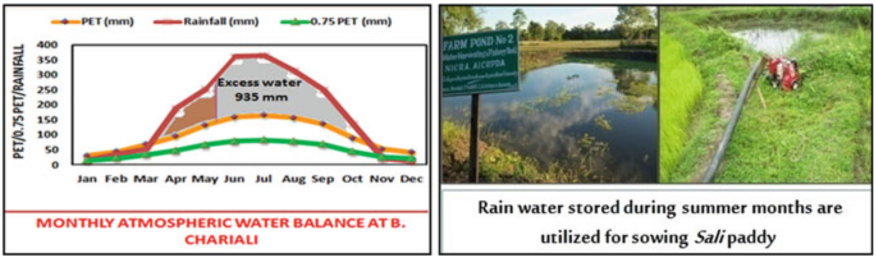


Fig. 2 Monthly potential evapotranspiration (PET) and monthly PET, rainfall and 75% of PET at Biswanath Chariali

realised that the harvested rainwater could be utilized for providing 1–2 supplemental irrigation to potato and rapeseed crops resulting in significant yield advantage [18].

7 Efficient Energy Use and Management Through the Establishment of Custom Hiring Center

Appropriate use of farm machinery and farm power is crucial for agricultural production, productivity and profitability. To reduce the impact of weather eccentricity farm operations needs to be done in a timely manner for which use of improved implements and machines are inevitable. For example, if a flood occurs in the month of June or July, our state's farmers have less time to sow or transplant *Sali* rice. In such a situation farmers cannot rely on animal power and traditional farm implements for early completion of farm operations. Thus, farm mechanization appears to be the key factor for building climate-resilient agriculture [25].

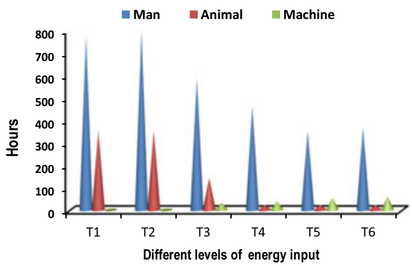
Farmers with limited resources could find relief by setting up a custom hiring centre with farmer-friendly farm equipments. Farm implements like cultivators, ploughs, rotavators, threshers, reapers, transplanters, water pumps, sprayers, and dusters, among others, would be very helpful to farmers if they were made available in a centre and provided to them in rental basis..

It will not only ensure to undertake timely farm operations but also help in taking up more than one crop. A model custom hiring centre was established under the NICRA project of BN College of Agriculture at Chamua village of Lakhimpur district of Assam in 2011 with the implements and machinery necessary for the rice-based cropping system of Assam (Table 9).

Reduction in human and animal hour requirement as a result of farm mechanisation was observed (Fig. 3). Thus, mechanization helped in a substantial reduction of the drudgery of humans and animals. Neog et al. [16] observed the use of energy in paddy cultivationwas reduced by 8–23% with the increased levels of mechanisation.

Table 9 Farm implements and machinery available at the custom hiring center of Chamua village

1. Cultivator and harrow	11. MB plough
2. Water lifting pump	12. Ridger seeder
3. Self-propelled Reaper	13. Sprayer
4. Thresher	14. Cultivator
5. Paddy weeder/wheel hoe	15. Disk plough
6. Drylandweeder	16. Power tiller
7. Rotavator	18. Manual fertilizer broadcaster
8. Seed-cum-fertilizer drill (manual)	19. Multi-crop seed drill
9. Power-operated duster	
10. Maize Sheller	



Energy level	Name of the energy level
T_1	Farmers' practice: No use of improved implement/machinery and fertilizer.
T_2	Use of fertilizer, but no use of improved implements/ machineries
T_3	Use of fertilizer + Cultivator + Rotavator + water lifting pump (WLP)
T_4	Use of fertilizer + Cultivator + Rotavator + WLP + Thresher
T_5	Use of fertilizer + Cultivator + Rotavator + WLP + Thresher + Reaper
T_6	Use of fertilizer + Cultivator + Rotavator + WLP Thresher + Reaper + Irrigation

Fig. 3 Human, animal, and machine hours required for different farm operations in the cultivation of *Sali* paddy under different levels of energy input

8 Alternate Land Use and Integrated Farming System

In building climate-resilient agriculture, alternate land use and the farming system can play a pivotal role. The state of assam is enriched with the traditional sustainable model of *Bari* system which could be a model of farming system in thestate. Integrated with other ancillary technologies like low cost polyhouse, biocompost and biofertilizer production, this system would provide the best model for building climate resilient agriculture. Traditionally the *bari* system significantly contributes to the hosehold income generation to the farming community. The *bari* system generally integrates all components of the farming system including crop, animal and fisheries. It is generally focused on the maintenance of the common hosehold requirements and use of internal farm resources. In the surrounding area of the farm family house, all the components are managed in an integrated manner. Among animals, cattle, goat, duck, poultry, pig, etc. And crops like arecanut, betel vine, fruits are common. A kitchen garden along with a farm pond with rearing of fishes are also the important parts of the system. A very intensive, multistoried integrated *bari* system of Assam has been identified as an important farming system contributing significantly in building climate-resilient agriculture.

According to a case study conducted in a village of Assam, 11.7% of the village's total land was covered by the homestead *Bari* system. In that village, each family had an average holding size of 0.12 ha, with fisheries accounting for 34.2, plantations for 31.6 and vegetables for 22.6% of the total. According to the study, the coconut and fishing systems had the highest benefit-cost (B:C) ratio of 6.0, while a local breed of cattle had the lowest B:C ratio of 1.2 [18]

Low-cost polyhouse based protected cultivation has been profitablein raising high-value crops and off-season vegetables which are otherwise not possible due to heavy rainfall during the rainy season. Moreover, poly houses advance the sowing of rabi crops like cabbage, cauliflower, tomato, etc. which is otherwise not possible due to heavy rainfall up to mid-October. Farmers are encouraged to strengthen the already existing integrated farming system in the village. Assistance was provided to ten groups of farmers to strengthen/take up an integrated farming system. Some groups are doing very well and many farmers adopted suggested farming systems like—Pigs + Duck + Fish + horticulture/rice; Duck + Fish + Horticulture/rice etc.

9 Other Interventions

9.1 Village Seed Bank

One of the adaptation strategy for bulding climate resilient agriculture could be the village seed bamnk. Seed bank provides reliable contingency in order to mitigate the situations arising out of extreme weather events. The establishment of village seed banks not only helps the small and marginal farmers for being self-reliant for seed supply but also helps in building seed production enterprises. As a contingency measures it should be ensured to store all types of seeds of crop/varieties needed to cope up different situations. Need based exchange and supply of seeds with other areas may also be practiced as and when necessary.

9.2 Agromet Advisory Services

Farmers are not satisfied only with the technical information on crop husbandry; they need all information related to their farm business for maximum income [22]. Weather information is one of the key inputs in agriculture. If accurate and timely weather information is provided to farmers, they can organize and activate their resources to reap the benefits of that information. Therefore, Agrometeorological Advisory Services (AAS) have been rendering by India Meteorological Department in collaboration with State Agricultural Universities with the objectives of helping farmers by providing weather information based agro advisories so that can make the most efficient use of resources. The AAS can be effectively used by the farmers for immediate adjustment of their operations and thereby could protect themselves from the probable losses due to adverse. Based on the reliable advisories farmers can plan the sowing, watering, disease pest management and even harvesting and post harvest operations. Growing uncertainties of weather and climate are impacting agriculture and impact will be more pronounced in the coming decades. Therefore, AAS has been gaining importance as it is capable to help out farmers to cope with the eventuality arising due to an increase in weather variability and climate change.

India Meteorological Department (IMD) launched the 'Integrated Agromet Advisory Service scheme in collaboration with state agricultural universities, which was renamed as '*Gramin Krishi Mausam Sewa*' (GKMS) in 2013. At present there are 130 Agromet Filed Units working under GKMS in different agroclimatic zones of India. Based on the medium-range forecast on temperatures, rainfall, relative humidity, wind speed and direction, cloudiness for next 5 days received from IMD, these field units prepare agromet advisory bulletins (AAB) for every district of their agroclimatic zone twice in a week (Tuesday and Friday) both in vernacular and English languages. AABs are prepared based on location-specific weather forecasts received from IMD. They include specific advice on field crops, horticultural crops, livestock, fisheries, etc., which farmers need to act upon. The district AABs generated by AMFUs are being disseminated to the farmers through mass media (radio, Print media and TV), internet, SMS, Whatsapp, personal contact, etc. India Met Department has recently developed a mobile application *Meghdoot App*, which allows farmers to access crop advisories along with weather forecasts within a user-friendly manner. A mechanism has also been developed to obtained feedback from for on quality weather forecast, relevance, and content of agromet advisories and effectiveness of the information dissemination system. Services rendering under GKMS project is very encouraging and there are many more success stories of efficient management of resources and abiotic and biotic stresses. The effort of the establishment of District Agromet Field Units (DAMU) in all KVKs of India for providing downscaled weather information and agromet advisories up to block level is going on. In Assam, presently 6 AMFU and 8 DAMU are working under Assam Agricultural University or ICAR.

10 Village Level Institutions, Crop Insurance, and Capacity Building

Village level institutions can play a very important role in identifying and facilitating the implementation of interventions related to climate-resilient agriculture by government agencies or NGOs. Various climate resilient interventions like renovations or establishment new farm ponds, crop, land, and soil-based interventions, establishing and efficient functioning of the custom hiring centre, creating village assets, etc. could be effectively implemented through the Village-level institutions may be helpful in implementing and managing different components of the climate resilient interventions like farm pond construction and renovation, custom horing centre, seed bank and decision making for farm operations. Moreover, it can help identify and evaluate farmers' wisdom of traditional knowledge, which may be proved the best climate-resilient technology for the locality.

Crop insurance is insurance insures farmers and crop producers against their loss of crops due to natural disasters, including hail drought and floods. There are two types of crop insurance:

Multiple peril crop insurance: This crop insurance extends financial coverage to the loss due to weather related factors viz., flood, drought etc.

Actual production history: This covers the losses arising out of wind, hail, insects, etc. Apart from this, losses due to lower yield and it compensates for the difference between the estimate and the real observed level of yield.

Crop revenue coverage: This type of insurance cover is based on not only the crop yield but also on the total revenue generated from the harvest. This also protects from the drop in price of produces.

Training and demonstration of climate-resilient technologies and operation of farm implements, exposure visits, sensitization meetings, animal vaccination camps, awareness programme harvest festivals, field day, etc. should be organized from time to time for capacity building of farmers which help in adaptation and implementation of climate-resilient technologies among them.

11 Conclusion and a Way Forward

Climate change is also realized in this part of the world and this the time for action, not to simply discuss it. It impacts people's livelihood and the impacts of ill effects are likely to increase in the future. The predominantly small farmer-oriented monocrop farming in Assam is often affected by floods and seasonal drought. However, the existing gap between the actual and potential yield of the crops can be reduced by adopting improved practices and adding adapted germplasm to the system despite the ill effect of climate change. Preparation and implementation of real-time crop contingencies are important to respond to weather aberrations in different stages like preparedness, real-time response, relief, and rehabilitation. Crop based adaptation strategies like alternate crops and varieties tolerant to submergence and seasonal drought, crops or varieties fitting into the new cropping system, crop diversification, manipulation of agronomic operations, alternate land use and farming system, etc. are to be identified and demonstrated among farmers. Water-based adaptation strategies like rainwater harvesting and recycling, in-situ moisture conservation, and improved water management practices can bring resilience to agriculture in the region. Efficient energy management through the establishment of a custom hiring centre is a must for resource-poor farmers of state so that they can complete their farm operations in time and within the very time available after the flood or drought. Strengthening the dissemination mechanism of weather information and related advisories to the end-user is important for better utilization of imputes and decrease loss due to weather hazards. Sometime weakness due to awful weather situations converts into the chance and such opportunities should never allow going away, but to be exploited. For instance increasing duration and frequency of flood due to climate enhances the chance of cultivation *bao* rice, red kernel *bao* rice has a good international market, so this opportunity should be exploited. Organizing awareness programme, training, harvest festival, field day and exposure visit, demonstration of climate-resilient technologies, make availability of farm implements and machinery through the establishment of custom hiring center, establishment of seed and seed fodder bank, etc. useful for capacity building and motivating farmers to adopt climate-resilient technologies.

References

1. Aggarwal PK, Kumar SN, Pathak H (2010) Impacts of climate change on growth and yield of rice and wheat in the Upper Ganga Basin. Worldwide Fund for Nature (WWF) and Indian Agricultural Research Institute (IARI), New Delhi
2. Ahenkan A, Chutab DN, Boon EK (2020) Mainstreaming climate change adaptation into pro-poor development initiatives: evidence from local economic development programmes in Ghana. Clim Dev. https://doi.org/10.1080/17565529.2020.1844611
3. Asfaw S, Branca G (2018) Introduction and overview. In: Lipper L, McCarthy Zilberman N, Asfaw S, Branca G (eds) Climate smart agriculture—building resilience to climate change. Springer, pp 3–12. https://doi.org/10.1007/978-3-319-61194-5
4. ASSAPCC (2015) Assam state action plan on climate change (2015–220). Department of Environment, Government of Assam. http://www.moef.gov.in/sites/default/files/Final%20draft%20ASAPCC%20document.pdf
5. Branca G, Arslan A, Paolantonio A, Cavatassi R, Grewer U, Cattaneo A, Lipper L, Hillier J, Vetter S (2012) Assessing the economic and mitigation benefits of climate-smart agriculture and its implications for political economy: a case study in Southern Africa. J Clean Prod 285:125161. https://doi.org/10.1016/j.jclepro.2020.125161
6. Deka RL, Mahanta C, Pathak H, Nath KK, Das S (2013) Trends and fluctuations of rainfall regime in the Brahmaputra and Barak basins of Assam, India. Theor Appl Climatol 114:61–71. https://doi.org/10.1007/s00704-012-0820-x
7. FAO (2013) Climate-smart agriculture sourcebook. Food and Agriculture Organization. http://www.fao.org/climate-smart-agriculturesourcebook/en/
8. Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, Xavier PK (2006) Increasing trend of extreme rain events over India in a warming environment. Science 314:1442–1445
9. https://cgspace.cgiar.org/handle/10947/5523
10. IPCC (2014) Summary for policy makers, climate change 2014: the physical science basis. In: Working group I contribution of the fifth assessment report of the united nations intergovernmental panel on climate change
11. IPCC (2013) Summary for policy makers, climate change 2013: the physical science basis. In: Working group I contribution of the fifth assessment report of the intergovernmental panel on climate change
12. Mensah H, Ahadzie DK, Takyi SA, Amponsah O (2020) Climate change resilience: lessons from local climate-smart agricultural practices in Ghana. Energy, Ecol Environ. https://doi.org/10.1007/s40974-020-00181-3
13. Muchuru S, Nhamo G (2019) A review of climate change adaptation measures in the African crop sector. Clim Dev 11(10):873–885. https://doi.org/10.1080/17565529.2019.1585319
14. Neog P, Sarma PK, Dutta S, Rajbongshi R, Deka RL, Baruah S, Sarma D, Sarma MK, Borah P, Chary GR, SrinivasRao C (2016) Building climate resilient agriculture through traditional

floating rice in flash flood affected areas of North Bank Plains Zone of Assam. Indian J Tradit Knowl 5(4):632–638

15. Neog P, Sarma PK, Saikia D, Borah P, Hazarika GN, Sarma MK, Sarma D, Chary GR, Rao CS (2019) Management of drought in Sali rice under increasing variability in the north Bank Plains Zone of Assam, North East India. Clim Change 158:473–484
16. Neog P, Sarmah K, Rajbongshi R, Kalita MK (2015) Development of weather based fore-warning models for Downy mildew and Alternaria blight diseases of Rapeseed (*Brassica campestris*) in North Bank Plain Zone of Assam. Mausam 66(2):217–224
17. Neog P, Sarma PK (2014) Sharing experiences of NICRA project implemented in Assam. In: Saikia U, Ramesh T, Ramkrushna GI, Krishnappa R, Rajkhowa DJ, Venkatesh A, Ngachan SV (eds) Natural resource management for enhancement adaptation and mitigation potential under changing climate. ICAR Research Complex for NE India, Meghalaya, India, pp 185–201
18. Neog P, Sarma PK, Borah P, Sarma D, Sarma MK, Borah R, Hazarika GN, Chary GR (2018) Climate resilient agriculture—experiences from NICRA implementation in North Bank Plains Zone of Assam. Research Bulletin (AAU/DR/18(BL)/229/2018–19), BN College of Agriculture, published by AICRPDA, Biswnath Chariali, Assam
19. Panging M, Neog P, Deka RL, Medhi K (2019) Assessment of performance of potato crop under modified microclimates in rice based cropping system of Upper Brahmaputra valley zone of Assam. J Agrometeorol 21(3):249–253
20. Pathak H, Aggarwal PK, Singh SD (2012) Climate change impact, adaptation and mitigation in agriculture: methodology for assessment and applications. Indian Agricultural Research Institute, New Delhi, 302
21. Rathore LS, Attri AD, Jaswal AK (2013) State level climate change trends in India. In: Meteorological Monograph. (ESSO/IMD/EMRC/02/2013). India Meteorological Department, Govt of India
22. Sarma K, Neog N, Rajbanshi R, Sarma A (2015) Verification and usability of medium range weather forecast for North Bank Plain Zone of Assam. Mausam 66(3):585–594
23. Sarmah K, Rajbongshi R, Neog P, Maibangsha M (2013) Rainfall probability analysis of Lakhimpur, Assam. J Agrometeorol 15(Special Issue-II):247–250
24. Senyolo MP, Long TB, Blok V, Omta O (2018) How the characteristics of innovations impact their adoption: an exploration of climate-smart agricultural innovations in South Africa. J Clean Prod 172:3825–3840. https://doi.org/10.1016/j.jclepro.2017.06.019
25. Srinivasarao C, Dixit S, Srinivas I, Sanjeeva Reddy B, Adake RV, Shailesh B (2013) Operationalization of custom hiring centres on farm implements in hundred villages in India. [Book] Central Research Institute for Dryland Agriculture, Hyderabad, pp 3–4
26. Wassmann R, Jagadish SVK, Heuer S, Ismail A, Redona E, Serraj R, Singh RK, Howell G, Pathak H, Sumfleth K, Donald LS (2009) Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. Adv Agron 101:59–122

Effect of Nutrient Management on Production Potential and Energy Budgeting of Soybean-Based Crop Sequences

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Abstract A field experiment was conducted during 2014–15 to 2015–16 at MPKV, Rahuri, Maharashtra to study the response of nutrient management on productivity and profitability of soybean based cropping systems. The productivity of crops viz., soybean, onion and potato in soybean-onion and soybean-potato cropping systems was higher when 125% GRDF and 125% RDF level was used as compared to other GRDF and RDF levels. The soybean-onion cropping system recorded higher soybean equivalent yield and energy out input ratio among the two cropping systems.

Keywords Soybean · Potato · Onion · Equivalent yield · Energy budget

1 Introduction

Soybean, an important oilseed and grain legume crop, needs special attention to overcome crisis in edible oil production in the country. It is also called as "Gold of Soil" . Soybean (*Glycine max* L. Merrill) with its 40–42% protein and 20–22% oil has already emerged as one of the major oilseed crop in India. In spite of its high yielding potential (4.5 t ha^{-1}), soybean productivity is much less in India (0.95 t ha^{-1}) than world average of 2.3 t ha^{-1}. In the country soybean cover an area of 10.84 mha with production of 14.68 mt and productivity of 1.36 t ha^{-1} [2]. Maharashtra ranks second in terms of production of soybean after Madhya Pradesh in the country with an area 3.22 mha, 4.67 mt production and productivity of 1.45 t ha^{-1} [3]. Constraint analyses have indicated that unbalanced nutrition is one of the important reasons for restricted growth in productivity [32].

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_16

The applications of general recommended dose of fertilizer assume a greater importance as these improves the soil fertility and productivity and bring down the mounting pressure on inorganic fertilizer. The use of GRDF not only pushes the production and profitability of field crops but also help in maintaining the fertility status of soil. India is the second most populous country in the world after China. The onion and potato, the most sustainable crops grown in Maharashtra, has radically improved the farming community [13, 18–22]. It is considered as exhaustive crops demanding heavy nutrition when grown as individual crop. Use of GRDF to *kharif* soybean crop and RDF to succeeding onion and potato in *rabi* season may prove a viable option for sustaining the productivity of soybean- based cropping system. The soybean-onion sequence cropping is one of the most popular practices followed by majority of farmers in semi arid regions of Maharashtra. However, soybean-potato also found profitable system in diversified cropping system than soybean-wheat. Soybean-onion and soybean-potato cropping system in rotation gives higher yield, greater income and maintain soil fertility. Most farmers grow soybean without fertilizer application and realize the legume crop's carry-over effect on the succeeding wheat crop [5].

Intensive cropping systems with high yielding improved crop varieties require a higher amount of nutrients as the system removes large amount of nutrients from the soil pool. Intensive cultivation and growing of exhaustive crops have made the soil deficient in macro as well as in micro nutrients. The success of any cropping system depends upon the appropriate management of resources including balanced use of manures and fertilizers. Chemical fertilizer increases the quantity of food produced but decreases its nutritional quality and also soil fertility over the years if used in imbalanced form [29]. However, the information about the manner in which these two crops would behave after soybean if they are grown in sequence is lacking. Hence, the nutrient management on a cropping system basis is the need of the hour to know the residual effect of *kharif* season GRDF to the succeeding crops. The nutrient management practices for soybean based cropping system of onion and potato is important to the farmers and community at large. The existing system of fertilizer application is based on nutrient requirement of the individual crop ignoring the carryover effect of the manure and fertilizer applied to preceding crop.

2 Material and Methods

Treatments under the present investigation were tested in soybean based cropping system during 2014–15 and 2015–16. The experiment was laid out in split plot design with three replications. Six combinations of two crop sequences (soybean-onion and soybean-potato) and three levels of GRDF viz., 75, 100 and 125% were the main plot treatments in *kharif* season replicated three times in randomized block design. During *rabi* season each main plot treatments of residual effect of GRDF levels was split into three sub plot treatments with three levels of recommended dose of fertilizer viz., 75, 100 and 125% to *rabi* season crops resulting in eighteen treatment combinations

Table 1 Grain yield of soybean as influenced by levels of GRDF

Treatments of GRDF	Grain yield (t ha^{-1})		
	2014	2015	Pooled mean
G_1: 75%	2.66	2.76	2.71
$G_{2.}$: 100%	3.22	3.41	3.32
G_3: 125%	3.24	3.48	3.36
SEm±	0.05	0.05	0.04
CD at 5%	0.15	0.14	0.12
Mean	3.04	3.22	3.13

replicated three times in split plot design. The gross plot size for soybean and onion was 3.60 m × 3.00 m; net plot size for soybean was 3.20 m × 2.40 m, for onion 3.00 m × 2.40 m and for potato 2.80 m × 1.80 m, respectively.

3 Results and Discussion

3.1 *Soybean Grain Yield (t ha^{-1})*

The data on soybean grain yield as influenced by different treatments during 2014, 2015 and pooled mean are presented in Table 1. The mean grain yield of soybean was 3.04, 3.29 and 3.13 t ha^{-1} during first year, second year and pooled mean respectively. In general, increase in % GRDF level from 75 to 125 increased the grain yield but significant increase was observed up to 100% GRDF. The application of 125% GRDF to soybean produced significantly higher grain yield of 3.24, 3.48 and 3.36 t ha^{-1} during 2014, 2015 and pooled mean basis, respectively than 75% GRDF (2.66,2.76 and 2.71 t ha^{-1}) and being at par with 100% GRDF (3.22, 3.41 and 3.32 t ha^{-1}). On an average the application of 125% GRDF and 100 GRDF level to soybean crop enhance the grain yield to the tune of 23.70 and 22.22% than 75% GRDF respectively on pooled mean basis. The higher values of yield attributes such as a number of pods and weight of seed $plant^{-1}$ were recorded with 125 and 100% GRDF level which in turn resulted in higher grain yields. The effect of integration of in organics and organic on harvest index i.e. partitioning of photosynthates between vegetative and reproductive organs was non-significant, indicating proportionate partitioning with increasing and decreasing supply of nitrogen.

3.2 *Onion Bulb Yield (t ha^{-1})*

The data pertaining to bulb yield of onion as influenced by different treatments during 2014–15, 2015–16 and on pooled mean basis, respectively are presented in Table 2.

The mean yield observed was 48.93, 50.30 and 49.62 t ha^{-1} during first year second years and pooled mean basis respectively. Onion bulb yield was significantly higher when it was raised in the treatments of residual effect of 125% GRDF (50.28, 51.94 and 51.11 t ha^{-1}) than 75% GRDF (47.16, 47.52 and 47.34 t ha^{-1}) however; it was statistically similar with the treatment receiving 100% GRDF (49.36, 51.46 and 50.41 t ha^{-1}) during *rabi* season 2014–15 and 2015–16, respectively. It appears that residual effect 125% GRDF enhance the bulb yield of onion to the tune of 7.96% than 75% GRDF levels on pooled mean. The application of 125% GRDF might have resulted in better supply of nutrients to the previous crop and after meeting its requirement some quantity have been left to the succeeding crop of onion. The GRDF show residual effect due to slow and gradual release of nutrients and thus might have improved the growth performance of onion. Increase in bulb yield was therefore due to significant increase in yield parameter. The results of experiment are quite in line with the findings of Gaud [8] in rice- mustard, Gawai and Pawar [9] in sorghum-chickpea, Gudadhe [12] in cotton-chickpea, Shanwad et al. [27] in maize-bengal gram who has recorded maximum yield on the residual fertility effect. The data in Table 2 showed that the crop applied with 125% RDF produced the highest bulb yield of 50.37, 50.94 and 50.65 t ha^{-1} during the year 2014–15, 2015–16 and on pooled mean basis respectively. All these values excelled significantly was recorded with 75% RDF level. On the other side the yield obtained under 100% RDF was at par with yield recorded 125% RDF during respective years and pooled mean basis except in the 2014–15. On an average RDF at 125% RDF level increased the bulb yield to the extent of 7.21, 2.90 and 5.32% over 75% level of RDF during the respective year and pooled mean basis. The second major nutrient phosphorous might have encouraged meristematic activity of plants resulting in increased plant height, number of leaves $plant^{-1}$ and leaf area. The potassium might have increased synthesis and translocation of photosynthates, which were further utilized in building up of new cells leading to better height, vigor and more number of leaves per plant. These results are similar to the findings of Ghanti and Sharangi [10], Prabhakar et al. [23], Choudhary et al. [7], Shinde et al. [28] who reported improvement in growth parameters with by application of RDF.

3.3 Potato Tuber Yield (t ha^{-1})

The data regarding the effect residual effect of GRDF of previous crop and RDF on total tuber yield are presented in Table 3. The mean tuber yield of potato was 28.78, 29.13 and 29.05 t ha^{-1} during first year, second year and pooled mean basis, respectively. It is evident from data that there was significant difference in tuber yield due to residual effect of GRDF treatments on tuber yield of potato. Among the different GRDF treatments 125% GRDF level recorded significantly maximum tuber yield (29.55, 29.71 and 29.61 t ha^{-1}) which was significantly higher over 75% GRDF level (27.14, 28.26 and 27.70 t ha^{-1}). However, it was found statistically at par with tuber yield recorded under treatment 100% GRDF level (29.64, 29.41 and 29.52

Table 2 Bulb yield of onion as influenced by different treatments

Treatments	Bulb yield (t ha^{-1})		
	2014–15	2015–16	Pooled
A. Residual effect of GRDF levels (*kharif* soybean)			
G_1: 75%	47.16	47.52	47.34
$G_{2.}$: 100%	49.36	51.46	50.41
G_3:125%	50.28	51.94	51.11
SEm±	0.54	0.41	0.47
CD at 5%	2.13	1.63	1.43
B. Direct effect of RDF levels (*rabi* onion)			
F_1: 75%	46.98	49.20	48.09
$F_{2.}$: 100%	49.45	50.78	50.11
F_3: 125%	50.37	50.94	50.65
SEm±	0.24	0.29	0.22
CD at 5%	0.74	0.90	0.66
Interaction A × B			
SEm±	0.41	0.50	0.57
CD at 5%	1.29	1.56	1.66
Mean	48.93	50.30	49.62

t ha^{-1}), respectively in first year, second year and pooled mean basis. The increase in tuber size in response to the residual effect of 125% GRDF could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthates which might have induced formation of tubers thereby, resulting in higher yields. These results are in accordance with Gaud [8] in rice- mustard, Gawai and Pawar [9] in sorghum-chickpea, Gudadhe [12] in cotton-chickpea, Shanwad et al. [27] in maize-bengal gram. The tuber yield differed significantly due to RDF treatments during both the years as well as on pooled mean basis. The data clearly showed that the RDF treatments of 125% RDF had significantly highest total tuber yield (29.59, 29.66 and 29.71 t ha^{-1}) over 75% RDF (27.66, 27.91 and 27.78 t ha^{-1}) and it was found statistically at par with yield obtained under treatment of 100% RDF (29.07, 30.01 and 29.54 t ha^{-1}), respectively in first year, second year and pooled mean basis. Nitrogen is the constituent of protoplasm and it is helpful for chlorophyll synthesis. It also helps to increase tuberization as well as bulking of tubers which would have resulted in higher production. Phosphorous and potassium increases the growth of shoots, tuber formation and development in potato. Thus, NPK application plays a key role in crop growth and development resulting in increased size of potato tubers which would have enhanced the total yield of potato. The results are conventionality with those reported by Amanullah et al. [1], Baishya et al. [4], Mozumder et al. [17], Sandhu et al. [25].

Table 3 Yield of potato tubers and haulm as influenced by different treatments

Treatments	Potato tuber yield (t ha^{-1})			Haulm yield (t ha^{-1})		
	2014–15	2015–16	Pooled mean	2014–15	2015–16	Pooled mean
A. Residual effect of GRDF levels (*kharif* soybean)						
G_1: 75%	27.14	28.26	27.70	0.76	0.94	0.85
$G_{2.}$: 100%	29.64	29.41	29.52	1.00	1.27	1.13
G_3: 125%	29.55	29.71	29.61	1.29	1.49	1.39
SEm±	0.21	0.22	0.24	0.11	0.07	0.06
CD at 5%	0.83	0.87	0.74	0.33	0.30	0.28
B. Direct effect of RDF levels (*rabi* potato)						
F_1: 75%	27.66	27.91	27.78	0.82	1.09	0.95
$F_{2.}$: 100%	29.07	30.01	29.54	1.06	1.24	1.15
F_3: 125%	29.59	29.66	29.71	1.18	1.37	1.28
SEm±	0.17	0.21	0.16	0.07	0.06	0.06
CD at 5%	0.54	0.65	0.49	0.23	0.19	0.18
Interaction A × B						
SEm±	0.30	0.37	0.41	0.13	0.11	0.15
CD at 5%	0.93	1.13	1.20	NS	NS	NS
Mean	28.78	29.13	29.05	1.02	1.23	1.13

3.4 System Productivity (t ha^{-1})

The data on system productivity of different cropping system were evaluated on the basis of soybean grain equivalent yield (SGEY) during both the years are presented in Table 4. The mean system productivity was 15.65, 15.62 and 15.63 t ha^{-1} during first year, second year and pooled mean basis respectively. The system productivity was influenced significantly due to different cropping systems during both the years. Among the cropping systems, soybean-onion cropping system recorded significantly higher system productivity (17.15, 16.69 and 16.92 t ha^{-1}) than soybean-potato cropping system (14.11, 14.46 and 14.28 t ha^{-1}) during first year, second year and pooled mean basis, respectively. The higher system productivity in soybean-onion cropping system was obtained due to higher onion yield, which directly reflected the increase in total system productivity. It was found that cropping sequence including legumes perform fairly well with regard to onion productivity introduction of legume crop in cropping system may have advantages well beyond the N addition through biological nitrogen fixation including nutrient recycling from deeper soil layer. Kushwah et al. [16] and Raskar [24] reported that the soybean-onion cropping system found suitable for diversification. The residual effect of GRDF levels on system productivity was influenced significantly during 2014–15, 2015–16 and pooled mean basis, respectively. The residual effect of 125% GRDF (6.25 t ha^{-1} FYM + 62.50 kg N + 93.75 kg P_2O_5 ha^{-1}) recorded significantly higher system productivity (16.17, 16.15 and 16.16 t ha^{-1}) than the residual effect 75% GRDF levels (3.75 t FYM + 37.5 kg N + 56.25 kg P_2O_5 ha^{-1}), however, it was at par with residual effect 100% GRDF level (5 t FYM + 50 kg N + 75 kg P_2O_5 ha^{-1}) during 2014–15 and 2015–16, respectively. [31] also revealed that the nutrients applied partly through organic manures and inorganic fertilizers to *Kharif* rice exhibits significant residual effects on the succeeding upland crop and hence the fertilization must be considered not only for individual crops but also for the cropping system as a whole. The application of 125% RDF to succeeding *rabi* season crops recorded significantly higher system productivity over the rest of the treatments during both years and pooled mean, respectively, except 100% RDF level where it was at par during second year and pooled mean basis respectively. These results corroborate findings of Gaud [8], Gudadhe [12], Senthivelu [26], Shanwad et al. [27] and Subehia and Sepehya [30].

3.5 Energy Studies

The soybean based cropping system was evaluated on the basis of input energy. Output energy, energy balance, energy output input ratio and energy balance per unit input during both years are presented in Table 5. The soybean-potato cropping system recorded significantly higher value of total energy output and balance during both years. While the soybean-onion cropping system compute significantly higher value of energy output input ratio (7.23 and 7.54) and energy balance per unit input (6.23 and 6.54) as compared to soybean-potato cropping system. These results are agreement with those reported by Jat et al. [14], Kumar et al. [15], Gudadhe et al. [11].

The residual effect of 125% GRDF level recorded significantly maximum value of output energy (268 and 279), energy balance (235 and 248), energy output input ratio (7.52 and 7.83) and energy balance per unit input (6.52 and 6.83) as compared to residual effect of 75% GRDF level. However, all these values were at par with residual effect of 100% GRDF level during 2014–15 and 2015–16, respectively. The residual effect of 100 and 125% GRDF increases the nutrient availability to *rabi* season crops, reflecting production of higher energy values. Similar results reported by Billore and Joshi [6].

Among the RDF levels the application of 125% RDF level recorded significantly maximum value of output energy (265 and 276), energy balance (227 and 239), energy output input ratio (7.37 and 7.63) and energy balance per unit input (6.37 and 6.63), which is compare to residual effect of 75% RDF level and at par with residual effect of 100% GRDF levels during 2014–15 and 2015–16, respectively. The residual effect of 100 and 125% RDF increases the nutrient availability to *rabi* season crops, reflecting production of higher energy values. Similar results reported by Gudadhe et al. [12], Jat et al. [14], Kumar et al. [15].

Table 4 Total system productivity (SGEY) of soybean based cropping system as influenced by different treatments

Treatments	Grain yield of soybean (t ha^{-1})		SGEY of *rabi* crops (t ha^{-1})		System productivity in term of SGEY (t ha^{-1})		
	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16	Pooled mean
A. Cropping systems							
S_1: Soybean-Onion	3.03	3.18	14.11	13.51	17.15	16.69	16.92
S_2: Soybean-Potato	3.05	3.25	11.07	11.20	14.11	14.46	14.28
SEm±	0.02	0.01	0.04	0.02	0.01	0.02	0.01
CD at 5%	NS	0.04	0.22	0.09	0.09	0.13	0.09
B. Residual effect of GRDF levels (*kharif* soybean)							
G_1: 75%	2.66	2.76	12.02	11.85	14.68	14.61	14.65
$G_{2.}$: 100%	3.22	3.41	12.82	12.55	16.04	15.96	16.00
G_3: 125%	3.23	3.48	12.93	12.67	16.17	16.15	16.16
SEm±	0.18	0.17	0.25	0.20	0.36	0.25	0.19
CD at 5%	0.59	0.57	0.82	0.65	1.16	0.81	0.57
C. Direct effect of RDF levels (*rabi* crops)							
F_1: 75%	3.03	3.13	12.10	12.01	15.12	15.14	15.13
$F_{2.}$: 100%	3.04	3.26	12.72	12.57	15.76	15.75	15.76
F_3: 125%	3.05	3.26	12.96	12.49	16.01	15.83	15.92
SEm±	0.06	0.05	0.05	0.06	0.07	0.08	0.05
CD at 5%	NS	NS	0.14	0.16	0.21	0.22	0.15
Interaction							
A × B	–	–	–	–	Sig	Sig	Sig
A × C	–	–	–	–	Sig	Sig	Sig
B × C	–	–	–	–	Sig	Sig	Sig
A × B × C	–	–	–	–	NS	NS	NS
Mean	3.06	3.25	12.59	12.37	15.65	15.62	15.63

Table 5 Energy balance of soybean based cropping systems as influenced by different treatments ($\times 10^3$ MJ ha^{-1})

Treatments	Input energy		Output energy		Energy balance		Energy output–input ratio		Energy balance per unit input	
	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16
A. Cropping system										
S_1: Soybean-Onion	30.26	30.26	219	228	189	198	7.23	7.54	6.23	6.54
S_2: Soybean-Potato	42.28	42.28	299	312	257	270	7.08	7.39	6.08	6.39
SEm±	–	–	0.47	0.47	0.47	0.47	0.01	0.02	0.01	0.02
CD at 5%	–	–	2.89	2.88	2.89	2.88	0.08	0.12	0.08	0.12
B. Residual effect of GRDF levels										
G_1: 75%	34.94	34.94	236	246	202	211	6.58	6.84	5.58	5.84
$G_{2.}$: 100%	36.27	36.27	268	279	231	243	7.48	7.72	6.48	6.72
G_3: 125%	37.61	37.61	273	285	235	248	7.52	7.83	6.52	6.83
SEm±	–	–	8.64	8.33	8.64	8.33	0.22	0.25	0.22	0.25
CD at 5%	–	–	28.19	27.16	28.18	27.16	0.73	0.82	0.73	0.82
C. Direct effect of RDF levels										
F_1: 75%	34.10	34.10	251	260	217	226	6.91	7.18	5.91	6.18
$F_{2.}$: 100%	36.27	36.27	260	275	224	237	7.19	7.58	6.19	6.58
F_3: 125%	38.44	38.44	265	276	227	239	7.37	7.63	6.37	6.63

(continued)

Table 5 (continued)

Treatments	Input energy		Output energy		Energy balance		Energy output–input ratio		Energy balance per unit input	
	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16	2014–15	2015–16
SEm±	–	–	2.58	2.24	2.58	2.24	0.07	0.06	0.07	0.06
CD at 5%	–	–	7.54	6.56	7.54	6.56	0.21	0.18	0.21	0.18
Interaction										
A × B	–	–	NS	NS	NS	NS	NS	NS	NS	NS
A × C	–	–	NS	NS	NS	NS	NS	NS	NS	NS
B × C	–	–	NS	NS	NS	NS	NS	NS	NS	NS
A × B × C	–	–	NS	NS	NS	NS	NS	NS	NS	NS
Mean	36.81	36.81	263	275	226	238	7.16	7.48	6.16	6.48

4 Conclusion

Based on the above results, it is concluded that the soybean-onion cropping system and combination of residual effect of 100% GRDF applied to preceding kharif season soybean. Direct application of 100% recommended dose of fertilizer to *rabi* season onion found highly remunerative and is the best option for higher productivity, profitability and energy budgeting.

References

1. Amanullah MM, Somasundaram E, Vaiyapuri K, Sathyamoorthi K (2007) Intercropping in cassava–a review. Agric Rev 28(3):179–187
2. Anonymous (2015) Annual report, ICAR National Research Centre for onion and garlic, Rajgurunagar, Pune, Maharashtra, India, pp 102–106
3. Anonymous (2015) All India estimates of food grain production, State of Indian Agriculture 2013–14, GOI, New Delhi, pp 186–191
4. Baishya LK, Kumar M, Ghosh M, Ghosh DC (2013) Effect of integrated nutrient management on growth, productivity and economics of rainfed potato in Meghalaya hills. Int J Agric Environ Biotechnol 6(1):69–77
5. Behera UK, Sharma AR, Pandey HN (2007) Sustaining productivity of wheat-soybean cropping system through integrated nutrient management practices on the Vertisols of central India. Plant Soil 297:185–199
6. Billore SD, Joshi OP (2004) Production potential and economic feasibility of soybean, Glycine max (L.) Merrill based cropping system. J Oilseed Res 21(1):55–57
7. Choudhary BS, Soni AK, Khaswan SL (2013) Growth, yield and quality of garlic as influenced by different nutrient management practices. Annu Agric Res New Ser 34(3):210–213
8. Gaud VV (2004) Production potential and economic feasibiity of rice based cropping system under integrated nutrient management. PhD thesis submitted to Navsari Agriculture Universaity, Navasri
9. Gawai PP, Pawar VS (2006) Inegrated nutrient management in sorghum (Sorghum bicolor)-chickpea (Cicer arietinum) cropping sequence under irrigated conditions. Indian J Agron 51(1):17–20
10. Ghanti S, Sharngi AB (2009) Effect of biofertilizer on growth, yield and quality of onion cv. Sukhsagar. J Crop Weed 5(1):120–130
11. Gudadhe N, Dhonde MB, Hirwe NA, Thete NM (2016) Crop energy balance study of cotton–chickpea cropping sequence under organic and inorganic fertilizer sources in western Maharashtra. Legum Res 39(1):79–85
12. Gudadhe NN (2008) Effectof integrated nutrient management system in cotton-chickpea cropping sequnence under irrigated conditions. PhD thesis submitted to M.P.K.V., Rauri (M.S.)
13. Gulhane VA et al. (2023) Correlation analysis of soil nutrients and prediction model through ISO cluster unsupervised classification with multispectral data. Multimed Tools Appl 82:2165–2184. https://doi.org/10.1007/s11042-022-13276-2
14. Jat HS, Meena LR, Mann JS, Chand R, Chander S, Sharma SC (2011) Relative efficiency of different cropping sequence in a farmers participatory research programme in semi-arid agro-ecosystem of Rajasthan. Indian J Agron 56(4):221–227
15. Kumar R, Singh VK, Sharma RP, Kumar A, Singh G (2012) Impact of nitrogen, phosphorus and potash and sulpher on productivity of rice-wheat system in sub-humid region. J Agric Phys 12(1):84–88
16. Kushwah SS, Singh OP, Gupta BS (2011) Evaluation of potato based crop sequences for crop diversification in malwa region of Madhy Pradesh. J Hortic Sci 6(2):166–168

17. Mozumder M, Banerjee H, Ray K, Paul T (2014) Evaluation of potato cultivars for productivity, nitrogen requirement and ecofriendly indices under different nitrogen levels. Indian J Agric Sci 59(2):327–335
18. Pande CB, Moharir KN (2023) Application of hyperspectral remote sensing role in precision farming and sustainable agriculture under climate change: a review. Clim Change Impacts Nat Resou Ecosyst Agric Syst. Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_21
19. Pande CB, Kadam SA, Rajesh J, Gorantiwar SD, Shinde MG (2023) Predication of sugarcane yield in the semi-arid region based on the sentinel-2 data using vegetation's indices and mathematical modeling. Clim Change Impacts Nat Resou Ecosyst Agric Syst. Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_12
20. Pande CB, Moharir KN, Varade A (2023) Water conservation structure as an unconventional method for improving sustainable use of irrigation water for soybean crop under rainfed climate condition. Clim Change Impacts Nat Resou Ecosyst Agricu Syst. Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_28
21. Pande CB, Moharir KN, Singh SK, Varade AM, Ahmed Elbeltagie SFR, Khadri PC (2021) Estimation of crop and forest biomass resources in a semi-arid region using satellite data and GIS. J Saudi Soc Agric Sci 20(5):302–311
22. Pande CB, Kadam SA, Jayaraman R, Gorantiwar S, Shinde M (2022) Prediction of soil chemical properties using multispectral satellite images and wavelet transforms methods. J Saudi Soc Agric Sci 21(1):21–28
23. Prabhakar M, Hebbar SS, Nair AK (2011) Effect of micro sprinkler fertigation on growth and yield of rabi onion. J Hortic Sci 6:66–68
24. Raskar BS (2012) Cropping system diversification/intensification under irrigated conditions. Research review committee report of IFSRP, MPKV, Rahuri, 2012
25. Sandhu AS, Sharma SP, Bhutani RD, Khurana SC (2014) Effects of planting date and fertilizer dose on plant growth attributes and nutrient uptake of potato (Solanum tubersoum L.). Int J Agric Sci 4(5):196–202
26. Senthivelu M, Padian BJ, Surya PACS (2009) Dry matter production and nutrient removal in wet seeded rice-cotton cropping sequence under irrigated nutrient management practices. Oryza 46(4):279–289
27. Shanwad UK, Kumar BNA, Hulihali UK, Survenshi A, Reddy M, Jalageri BR (2010) Integrated nutrient management in maize-bengal gram cropping system in Northen Karnataka. Res J Agric Sci 1(3):252–254
28. Shinde RN, Karanjikar PN, Gokhale DN (2015) Effect of different levels fertilizer and micronutrients on growth, yield and quality of soybean. J Crop Weed 11(1):213–215
29. Sinha KR, Aggarwal S, Chauhan K, Valani D (2010) The wonders of earthworms and its vermicompost in farm production: Charles Darwin's, friends of farmers, with potential to replace destructive chemical fertilizers from agriculture. Agric Sci 1(2):76–94
30. Subehia SK, Sepehya S (2012) Influence of long-term nitrogen substitution through organic on yield uptake and available nutrients in rice-wheat system in acidic soil. J Indian Soc Soil Sci 60(3):213–217
31. Thimmegowda S (2006) Effect of residual fertility and direct fertilization on kernel, protein and oil yield of peanut (Arachis hypogaea L.) grown in rice fallows. J Sci Food Agric 61(4):385–387
32. Tiwari A, Dwivedi AK, Dikshit PR (2002) Long term influence of organic and inorganic fertilization on soil fertility and productivity of soybean-wheat system in vertisol. J Indian Soc Soil Sci 50(4):472–475

Monitoring Agriculture Land Use and Land Cover Changes of Rahuri Region, (MS), India Using Remote Sensing and GIS Techniques

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Abstract The primary purpose of this research is to identify changes in agriculture and non-agricultural land over the years from 2015 to 2019 in the Rahuri region. The continued expansion of non-agricultural land (i.e. desert area, developed land, body of water, and forest land) and agricultural land has been reduced each year in the study area. Agricultural land is considered to have the highest variation in 2015 and 2019 (32,252.8 ha) and 27,343.2 ha, respectively. Therefore 5% of agricultural land has been reduced due to insufficient rainfall and dry spell conditions. However, non-agricultural land was increased in 2019 compared to 2015. The non-agricultural area was 78,810.8 ha and 73,901.2ha between 2019 and 2015 in the Rahuri region. These results can be helpful to land use policymakers, planners and water development agencies related to development investigators and implement the most suitable agricultural land and non-agricultural land using the choice of Rahuri region officials.

Keywords GIS · Change detection · Agriculture land · Remote sensing · Classification

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_17

1 Introduction

Land use categories and land coverage are critical to water and environmental management. Therefore, a traditional watershed basin with multiple types of land use (LU) can affect the water features in a watershed basin. The land cover indicates visible areas, such as tree-covered areas, inaccessible areas, farm areas, wetlands and open water; and land use records use the land for development, conservation, or mixed-use [10]. Land use and current coverage represent the environmental and social impacts of the local economy [35]. Agriculture has been the focus of many policies for sustainable growth in the country. The government has increased farm production and quality in the past two seasons by cultivating agriculture and practice implementation [36]. Currently, land degradation is a significant problem in the ecosystem and global food security [14]. Man-made activities have caused variations in land use. Still, nowadays, many climate changes such as heavy rainfall, air pollution, high temperatures, drought, crop production, food supply, environmental system, deforestation, and land developed mainly in the arid region [13, 18]. The value and impact of LULC as the basis for planning and sustainable development and natural resources management. Many such studies found that land use significantly impacts the work of socio-economic and environmental systems, with substantial compromises on sustainability, food safety, biodiversity and human and ecosystem socio-economic vulnerability. Although land-use change by land use does not necessarily mean land degradation, LULC changes are one of the world's most important drivers [19]. These activities affect a lot of geological and natural ecosystems, including biodiversity, water and the budget for radiation [9].

Remote sensing (RS) and geographic information system (GIS) are two technologies used to identify variations found in land use categories and land cover areas over a while [29–38]. Remote sensing technology is better information about the earth's view and natural resources, while many researchers have used these types of technologies to study natural resources and vegetation conditions [24, 26]. A land cover map should need several years to assess changes over time, and the resulting analysis helps planners understand the current landscape and emerging trends [39–42]. As per the maps, stakeholders can use such kinds of studies to plan crops and overcome the problems with increasing the cultivated land. It also enables management methods to be understood and evaluated before future implementation. Remote sensing is an effective tool in the agricultural sector, where digital data on multiple spectral wavebands is higher than field-based analyses at least twice [14]. Image classification has been used to monitor different land cover types or examine terrestrial structures between objects directly related to spectral or indices from satellite imagery [1, 17, 41]. The discovery of the change in land use and land cover identification and meaning is based on the collection of time-series data by remote sensing satellites [5, 36]. The aim and objectives are in the following order: 1. To prepare maps of agricultural and non-agricultural land use with satellite data of high resolution and classification techniques. 2. Changing the availability of agricultural and non-agricultural maps will be constructed based on RS and GIS technology. 3. In agriculture, non-agricultural land is calculated between 2015 and 2019. 4. This map to use maps can be helpful for agricultural planning and water development in the Rahuri area.

2 Study Area

The current study area is located in Rahuri in the Ahmednagar District (MS) region of India. The total area is 1058.58 sq. Km. The latitude and longitude in between 73°48′E and 19°36′N of the rahuri region. The highest elevation is 511 m above Sea Level. The highest elevation is 511 m above the Mean Sea Level. This area's population is three times the size of agricultural land. The primary source of income is agricultural land, considering the most crucial lesson for farmers and land use planning. Annual rainfall is 400 to 650 mm. Therefore, the most important crop is sugarcane and onions, especially in the rahui region. Mula Dam is being established locally. Mula is a highly developed canal system on agricultural land. Sugarcane and other crops depend on dam water and rainwater. During field research, basaltic rock has been found in the area. A map of the stud area is shown in Fig. 1.

3 Methodology

3.1 Data Collection

Satellite and field data sets are selected to study agriculture and non-agriculture land use classes analysis. Two separate days of Landsat-8 images are collected on the USGS (United States Geological Survey) website (www.earthexploer.com). Landsat-8 satellite data consists of 11 bands with a resolution of 30 m of 1–7 bands, 9 of which have a resolution of 30 m, 10 and 11 bands (thermal bands) (TIRS) with 100 m, band 8 (panchromatic) has a spatial resolution of 15 m. Two different days of images were used on 18/01/2015 and 28/01/2019, respectively. However, the secondary data added field research data for agricultural and non-agricultural groups to map for change. Data were collected as reference data points, used for image classification, and comprehensive assessment of category effects by Geographical Positioning System (GPS) 2015 and 2019 image surveys [24].

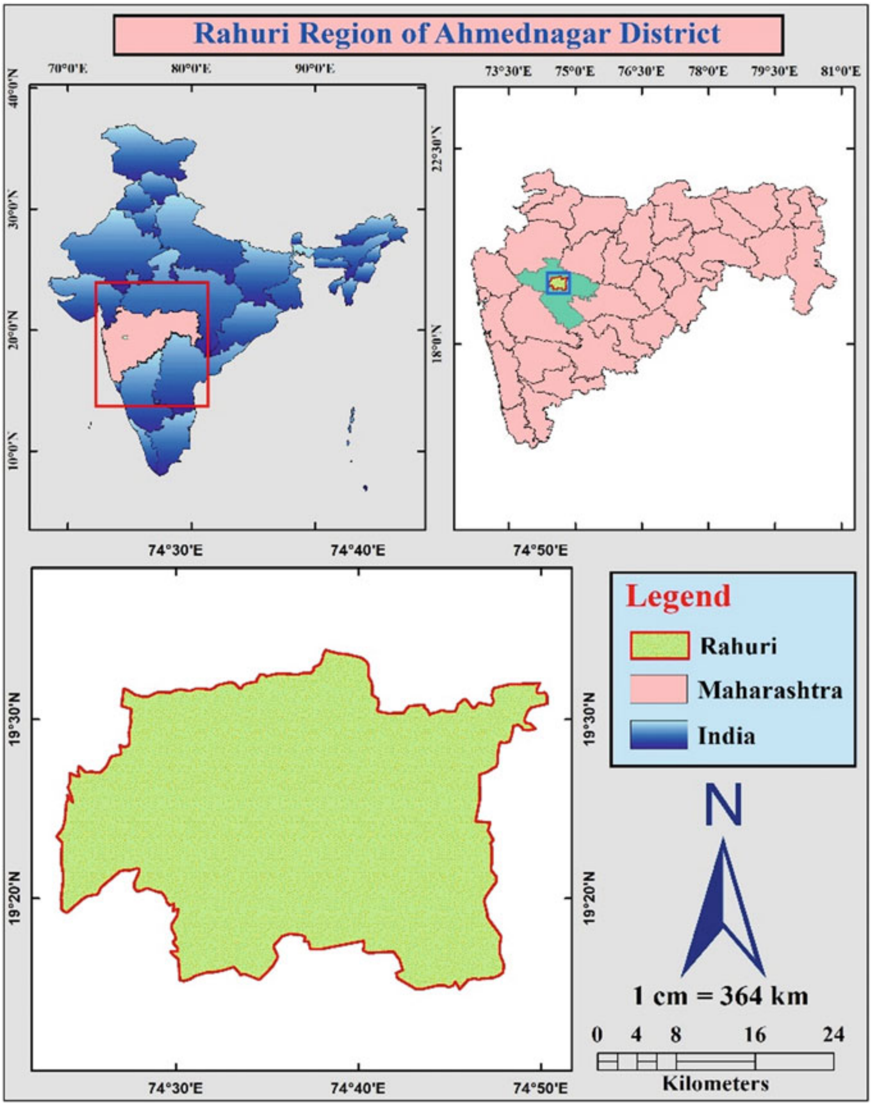

Fig. 1 Location map of the study area

3.2 *Image Pre-processing and Agriculture and Non-agriculture Class Change Detection*

ERDAS (Earth Resource Development Assessment System) imagine 2018v a layer of software stacks used to convert bands into a single system into image processing and create unobtrusive classification methods for satellite imagery. Satellite data was a combination of red, green, blue and near-infrared bands. The four bands used for land use classes were identified in this analysis by the ERDAS (Earth Resource Development Assessment System) software [12]. These satellite bands are transformed into a false integrated colour composite image. To collected images and process them by using Arc GIS 10.1, the resulting Rahuri shapefile is created in the description process. The cliff data was also projected into zone 43 N and displayed on the Universal Transverse Mercator (UTM) up to 30 m. Subsequently, provided pixel signatures to ERDAS (Earth Resource Development Assessment System) imagine 2018 was used for all Satellite Data. The entire Rahuri area is divided into two classes, meaning that agriculture and non-agricultural areas are described in Table 2. The polygons draw areas to represent each defined category, describing the slightest uncertainty between the national covers to be specified. High-resolution satellite images assist in identifying land use categories and the inclusion of signatures on satellite images. Unsupervised image classification of the highest probability algorithm was used for land agricultural and non-agricultural mapping studies between 2015 and 2019 (Fig. 2).

3.3 Image Processing

Image processing was processed using the ERDAS (Earth Resource Development Assessment System) 2018 software. The classes were identified by unsupervised classification of the study area. Unsupervised separation using types means consistently dispersing the interplanetary information and then clusters comprising the remaining pixels using minimum grade techniques. Unsupervised segregation continued based on the vector support process with the selected ERDAS (Earth Resource Development System) sigmoid model 2018 [40]. Landsat-8 data divided into two categories was agricultural and non-agricultural land in the study area.

3.4 Unsupervised Classification Method

Unsupervised segmentation is based on image processing software without sample classes provided by the user. Results (collection of pixels with standard features) Training sites are selected based on user information (test sets or input classes). Agricultural or arable land was marked in red, as shown below, after giving the image a false colour. Enable the Spatial Analyst Toolbar, load the clipped raster, click the Arc toolbox > Spatial Analyst Tool, and select the Iso cluster unsupervised classification. The input and output band are here, except for the segments taken [30]. Fifty categories are listed here. Additional images are reclassified by clicking on the Reclassify tool and collecting specific pixels at certain class values. In agriculture, red, pink, and brown pixels are divided into agricultural land with the references of

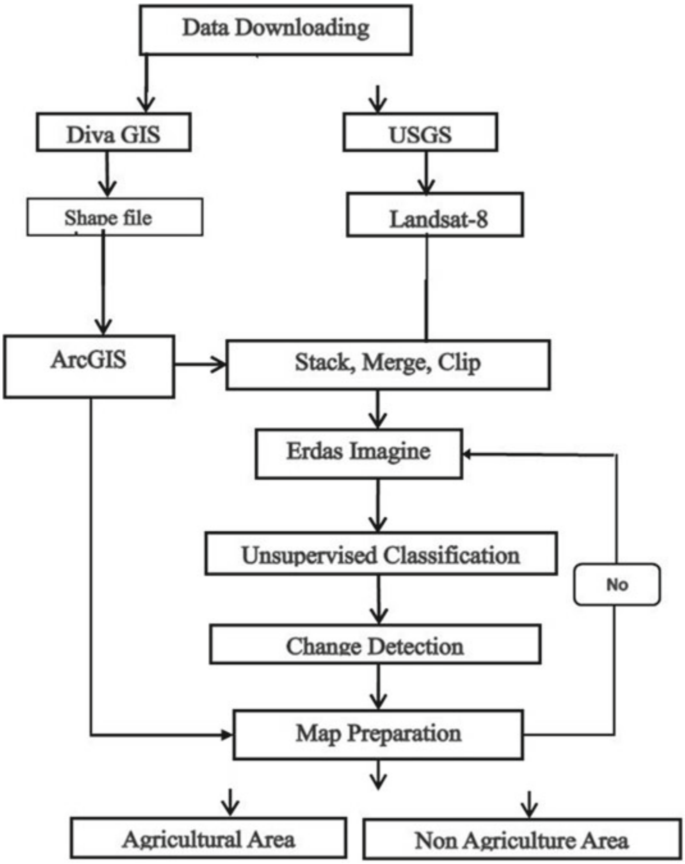

Fig. 2 Flow chart of methodology

training sample data (Fig. 3). All the classes were cross-verified by using ground truth information.

3.5 *Change Detection*

The change detection process is used to assess agricultural and non-agricultural land use classes with the ERDAS 2018 software change detection tool. All non-agriculture classes are combined for this study because we focus on agriculture and other agricultural lands such as built-up, water land, forest and other lands. This area wants to have such results for developing and monitoring the agricultural land class. This tool can easily identify the increase and decrease in a study area. Supports change detection between two unspecified dates (or more) (Fig. 4). After separating the adjusted

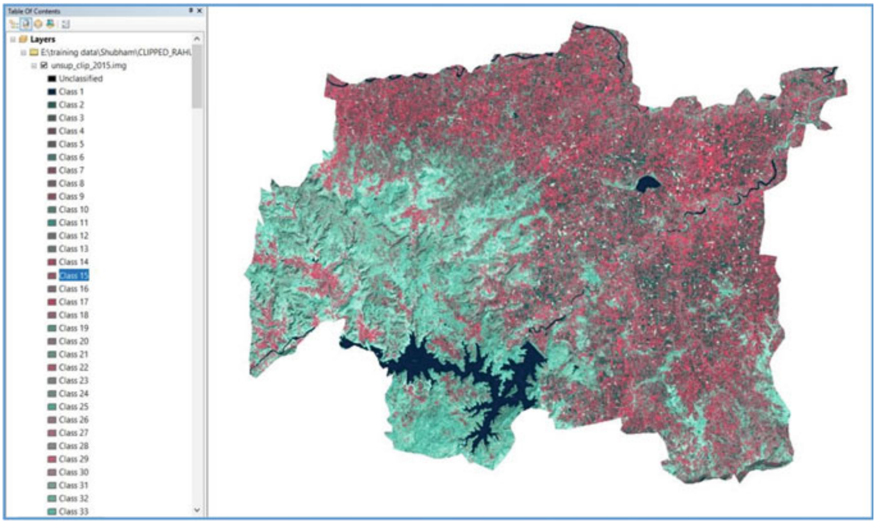

Fig. 3 Unsupervised classification in the years of 2019

images by two periods (2015 and 2019 years, respectively), the change results were compared and rated by land-use area from the study area change detection. The results were trained and validated with ground data and estimated the confusion matrix of 2015 and 2019 [25]. Adapt to various changes in the growth or decline of agriculture and non-agricultural lands. The classified images have been translated into Arc GIS 10.1 software for vectorization, measurement, and comparison of areas by dates.

3.6 Agriculture and Non-agriculture Land Use Mapping Analysis

The outcome of the agricultural and non-agricultural land use map is expected to provide information on the distribution of land use classrooms and the identification and measurement of non-agricultural land use variations for four years. In addition, to determine the number of changes from the agricultural and non-agricultural land class within the two distinct periods of 2015 and 2019, cross-tabulation analysis has been completed in the form of a pixel-by-pixel-based unsupervised classification method and remote sensing data [20].

3.7 Accuracy Assessment

Accuracy assessment means comparing classification with data from a field survey to assess the real world of the classification. In this analysis, the random sampling process examined the accuracy of the classified images that emerged. During the field survey, we have collected 60 points for the accuracy of non-agricultural land use categories. A vital difference found in the classification and location directly in the field survey and the accurate assessment was the unsupervised classification of agricultural land as non-agricultural land and wasteland failing agricultural land. Some of the rocks on the exposed threshold are also improperly classified as built land. Kappa's calculations, user and producer accuracy, were eliminated by the ERDAS Imagine software 2018v phase's accuracy process to create a computer-level accuracy class [11].

4 Results and Discussion

Rahuri region is one of the largest sugarcane crops in the Ahmednagar district of Maharashtra, India. Agricultural land is severely affected by human activities and climate change. In this view, the study is significant in the Rahuri region. Exposed agricultural and non-agricultural land goes up and down the learning area. Most of the land is under agriculture, and farmers have been farming the land three times a year. Satellite data and segmentation identify these land-use changes. LULC maps have been provided with relevant information on areas that reduce agricultural land and increase non-agricultural land use categories. Land use maps are updated from satellite imagery in 2015 and 2019. Significant changes in agriculture and non-agricultural land use have been made in the area. The various agricultural and non-agricultural land use categories include the two critical classes for 2015 and 2019 shown in Figs. 4 and 5. Land use and land distribution pattern have been identified through supervised classification. The results of agricultural and non-agricultural land use and classification maps for 2015 and 2019 are shown in Fig. 6, and a resulting map summary is shown in Table 1.

4.1 Agriculture and Non-agriculture Land-Use Scenario of Rahuri Region 2015

In 2015, the Rahuri area was closed to the agricultural area (30%) and, in particular, the non-agricultural area (60%) due to drought conditions, freshwater problems and arable land (Fig. 4 and Table 1). Much of the land is heavily irrigated in this area due to the Mula dam in the Rahuri region. In essence, agricultural land plays a vital role in producing sustainable crops in the learning environment. In the study areas,

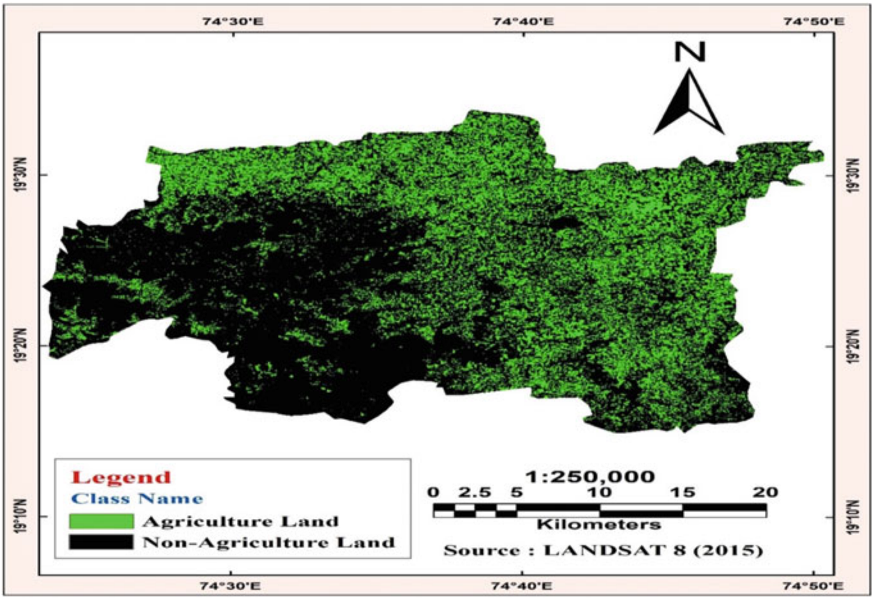

Fig. 4 Agriculture and non-agriculture land use map for the studied area in 2015

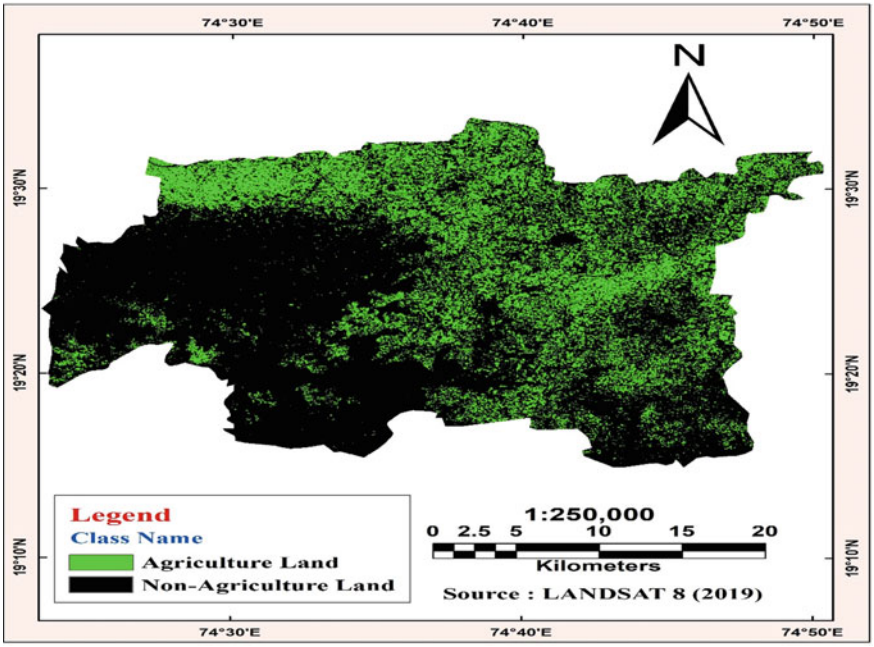

Fig. 5 Agriculture and non-agriculture land use/cover map for the studied area in 2019

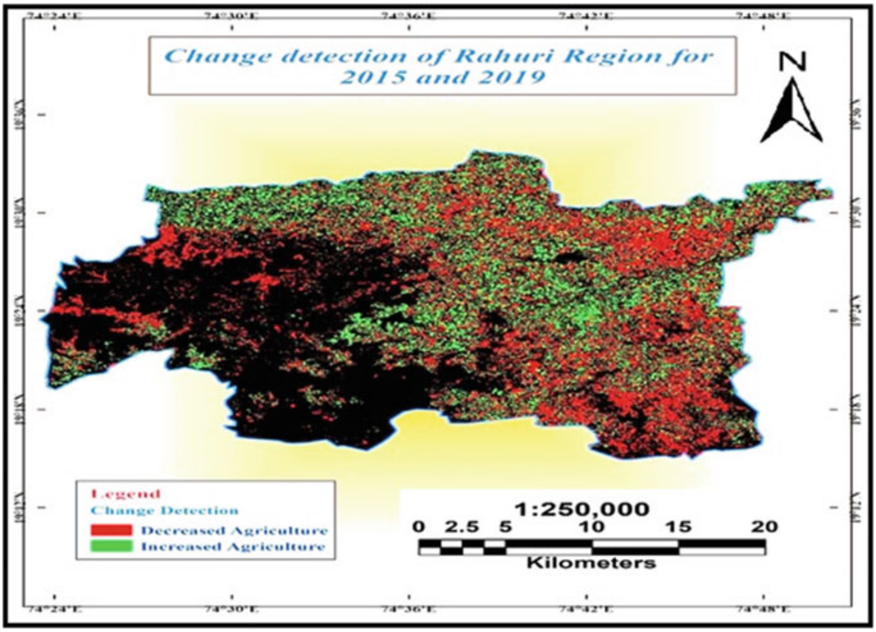

Fig. 6 Change detection map of Rahuri region from 2015 and 2019. **Note**: positive (+) sign denotes increase and negative (−) sign denotes a decrease of magnitude of LULC in different period frames.

Table 1 Category wise land use distribution of agriculture and non-agriculture area from 2015 and 2019

Land use classes	Land-use change from 2015 and 2019	
	Change area (ha)	Change percentage (%)
Agriculture land	−4909.6	4.62
In-agriculture land	4909.6	−4.62

Table 2 Details of accuracy assessment of 2015 and 2019

Classes	Producers accuracy (%)		User's accuracy (%)		Kappa coefficient (%)	
	Years					
	2015	2019	2015	2019	2015	2019
Agricultural land	90.23	91.67	93.87	92.54	94	95
Non-agriculture Land	94.50	95	97	93	94	96
Overall classification accuracy	97.54	96.3	95.54	94.2	93.54	92.6
Overall kappa statistics	94.32	96.32	97.32			

urbanization has an enormous population impact on land loss. The results showed that all stages of land use had changed dramatically [32].

4.2 Agriculture and Non-agriculture Land-Use Scenario of Rahuri Region 2019

In 2019, the study of agricultural and non-agricultural land was essential for developing a land-use policy. The 2019 map shows the decrease in agricultural land compared to 2015. By the end of 2019, built-up, wasteland, barren, and fallow land are increasing due to insufficient rainfall, climate change factors, land use policy, and man-made activities in the study area. In Fig. 5, agricultural land decreases by 4.62% and non-agricultural land increases by approximately 4.62% [32].

5 Discussion

5.1 Change Detection of Agriculture and Non-agriculture Analysis During the year of 2015 and 2019

Worldwide ecological processes, resulting in significant worldwide environmental challenges, have been impacted by changes in human utilisation (LULC) [15, 39]. Eighty-three per cent of the global terrestrial surface has approximated to have been influenced by the human footprint. In the last 50 years alone, LULC changes have degraded around 60% of ecosystem services. The change in LULC is perhaps the most prevalent socioeconomic force that drives ecosystem change and degradation. The Earth's landscape has been dramatically altered by deforestation, urban development, agriculture and other human activity [42]. Agriculture is now 38% of the world's ice-free land surface and is by zone the largest type of land cover [6]. Globally, the rate of agricultural expansion is falling. The effect is probable to be high in developing countries like India [24].

Land use classes in agriculture and non-agriculture are monitored, and the changes have been identified during 2015 and 2019. The detection of agriculture and non-agriculture land-use change was obtained through remote sensing software. Between 2015 and 2019, the prominent decline for area coverage has been observed in agriculture, and non-agriculture land use classes, whereas the area of non-agricultural land, i.e. Built-up, waste, fallow and barren land, increased (Table 1). The agricultural land is 32252.8 (ha) and 27,343.2 (ha) during 2015 and 2019. The agricultural land area has decreased by 4909.6 (ha) in the last four years. The non-agriculture area has increased by 4909.6 (ha) during 2015 and 2019 (Fig. 6). The changes in 2015 and 2019 agriculture were identified in maps as shown further. It significantly implies a massive decrease in agriculture in western and south-eastern parts of the

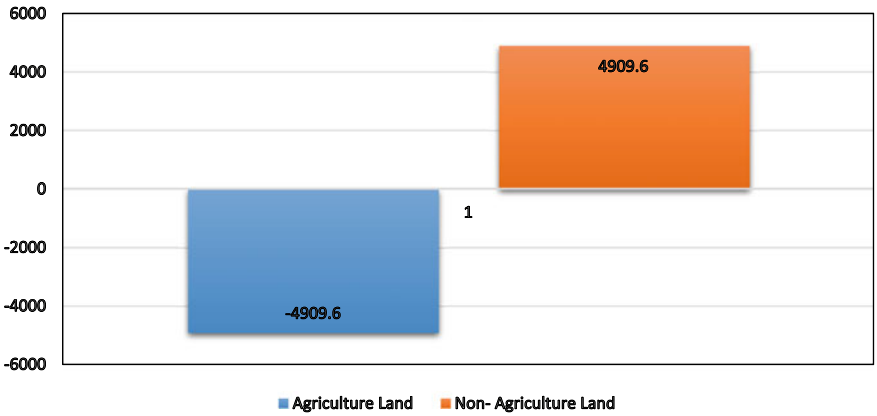

Fig. 7 Change detection of agriculture and non-agriculture land during years of 2015 and 2019

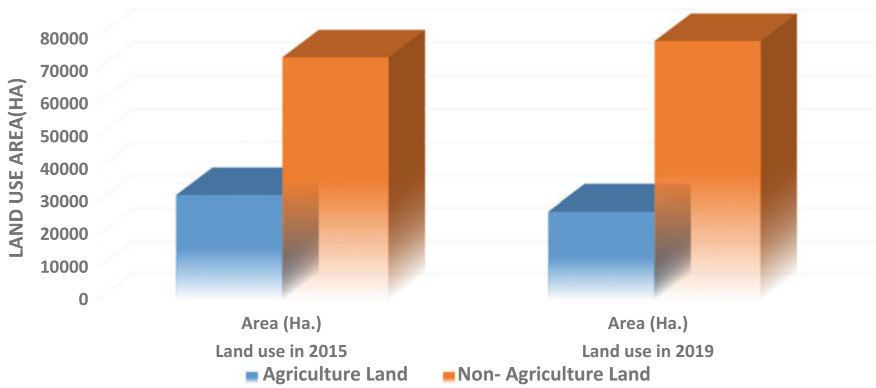

Fig. 8 Agriculture and non-agriculture land during years of 2015 and 2019

Rahuri region (Fig. 6). The detection of changes for the whole study period showed that the most significant changes. However had been made in the non-agriculture and farmland Rahuri region [31]. The current human activates, and drought conditions in the research area can be linked to these findings. But continuous efforts are still underway to increase non-agricultural territory and loss of highly cultivated land in the region of Rahuri (Figs. 7 and 8).

5.2 *Accuracy Assessment*

The uncertainty matrix or error matrix investigates three types of accuracy: user, producer, and machine accuracy (Table 1). Based on these types, calculated absolute

Table 3 Confusion matrix of 2015

Classes	Agricultural land	Non-agriculture land	Total
Agricultural land	570	634	1204
Non-agriculture Land	720	690	1410
Total	1290	1324	2614
Overall classification accuracy	Overall accuracy = (2470/2614) = **94.49**		

Table 4 Confusion matrix of 2019

Land use classes	Agricultural land	Non-agriculture land	Total
Agricultural land	590	657	1247
Non-agriculture land	780	710	1490
Total	1370	1367	3814
Overall classification accuracy	Overall accuracy = (3578/2614) = **93.81**		

accuracy and kappa statistics. Table 2 shows a summary of the 2015 and 2019 study area error matrix. The overall accuracy in 2015 and 2019 total classification rates were 97%, 95.54% and 93.54%, while in 2015 and 2019, the total Kappa values were 94.32%, 96.32% and 97.32%, respectively. These Kappa principles contained precise land use classification [21]. The confusion matrix of 2015 and 2019 were presented in Tables 3 and 4.

6 Conclusion

This study has examined and identified the diversity of agricultural and non-agricultural sectors in the Rahuri region of Maharashtra using sentinel-2 satellite data between 2015 and 2019. This study has shown that the most important category of agricultural land use in the Rahuri region and the second-largest land use category is forestry. This area is vital for farmers' points because the area is the highest sugarcane crop grown in the agricultural region. The non-agricultural underground study area increased by 74.25% (78,810.8 ha) And agricultural land decreased by 25.75% (27,343.2 ha) Compared to 2015 (Figs. 7 and 8). In the next five years, 5% of the land is converted to non-agricultural land due to water shortages, droughts, climate change and man-made activities. Agricultural land use has been significantly reduced due to the conversion of wasteland, fallow land, infertility, water bodies and residential land. Significant changes in the non-agricultural sectors were observed in the Rahuri region. Leading land use for forestry and agriculture is directly linked to the natural habitat of natural resources. In the final analysis, this data helps identify the limited resources and natural areas that can be identified as hot spots for conservation and restoration. Resource evaluation can also contribute to a greater understanding of outcomes, on the one hand, and strategic planning for the development of various projects in these resources. In this study, one of the most prominent technologies currently in the RS and GIS process used in space analysis is other standard mapping methods included. In addition, monitoring progress in a system that responds promptly to decision-making processes has suggested that permanent hearing aids should be collected, translated, and updated in the Rahuri area through agricultural and non-agricultural land-use changes. A robust natural resource management programme at the local level must be put in place to mitigate the harmful effects of degrading natural resources, based on the findings of the study results. The authors also recommend that a research programme be carried out in conjunction with climate variability to understand the impact of the LULC change on water resources.

Acknowledgements Nil

Conflict of Interest The authors declare no competing interests.

References

1. Aithal BH, Ramachandra TV (2016) Visualization of urban growth pattern in chennai using geoinformatics and spatial metrics. J Indian Soc Remote Sens 44(4):617–633
2. Chathuranika et al (2022) Implementation of water-saving agro-technologies and irrigation methods in agriculture of Uzbekistan on a large scale as an urgent issue. Sustain Water Resour Manag 8:155. https://doi.org/10.1007/s40899-022-00746-6
3. Ekanayake et al (2021) Regression-based prediction of power generation at samanalawewa hydropower plant in Sri Lanka using machine learning. Math Probl Eng Article ID 4913824 1–12. https://doi.org/10.1155/2021/4913824
4. El-Asmar HM, Hereher ME (2010) Change detection of the coastal zone east of the Nile Delta using remote sensing. Environ Earth Sci 2(1):43–59. https://doi.org/10.1007/s12665-010-0564-9
5. Elagouz MH, Abou-Shleel SM, Belal AA, El-Mohandes MAO (2020) Detection of land use/cover change in Egyptian Nile Delta using remote sensing. Egypt J Remote Sens Space Sci 23:57–62. https://doi.org/10.1016/j.ejrs.2018.10.004
6. FAO F (2011) The state of the world's land and water resources for food and agriculture (SOLAW)-Managing systems at risk. In: Food and Agriculture Organization of the United Nations
7. Gulhane VA, Rode SV et al (2022) Correlation analysis of soil nutrients and prediction model through ISO cluster unsupervised classification with multispectral data. Multimed Tools Appl https://doi.org/10.1007/s11042-022-13276-2
8. Gunathilake MB, Amaratunga YV, Perera A, Chathuranika IM, Gunathilake AS, Rathnayake U (2020) Evaluation of future climate and potential impact on streamflow in the upper nan river basin of Northern Thailand. Adv Meteorol 8881118
9. Guzha AC, Rufino MC, Okoth S, Jacobs S, Nobrega RLB (2018) Impacts of land use and land cover change on surface runoff, discharge and low flows: evidence from East Africa. J Hydrol: RegNal Stud 15:49–67
10. Islam MR, Hassan MZ (2011) Land use changing pattern and challenges for agricultural land: a study on Rajshahi District. J Life Earth Sci 6:69–74. https://doi.org/10.3329/jles.v6i0.9724

11. J.S. Rawat, M. Kumar, V. Biswas (2014) Land use/cover dynamics using multi-temporal satellite imagery: a case study of Haldwani Town area, district Nainital, Uttarakhand, India, Inter. J Geom Geosci 4(3):536–543
12. Kandpal R, Saizen I (2019) An evaluation of the relative urbanisation in peri-urban villages affected by industrialisation: the case study of Bhiwandi in the Mumbai Metropolitan Region, India. Spat Inf Res 27(2):137–149
13. Karimi H, Jafarnezhad J, Khaledi J et al (2018) Monitoring and prediction of land use/land cover changes using CA-Markov model: a case study of Ravansar County in Iran. Arab J Geosci 11:592. https://doi.org/10.1007/s12517-018-3940-5
14. Khalil AA, Essa YH, Hasaean MK (2014) Monitoring agricultural land degradation in Egypt using MODIS NDVI satellite images. Nat Sci 12(8):15–21, ISSN: 1545-0740, http://www.sciencepub.net/nature.
15. Klimanova O, Naumov A, Greenfeldt Y, Prado RB, Tretyachenko D (2018) Regional trends of land use and land cover transformation in Brazil in 2001–2012. Geogr Environ Sustain 10(4):98–116
16. Kumar S et al (2023) Land use and cover variations and problems associated with coastal climate in a part of Southern Tamil Nadu, India. Using remote sensing and GIS approach. Clim Change Impacts Nat Resour Ecosyst Agricul Syst Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_26
17. Lakshmi DSV, Thomas S (2018) Mapping of land use and land cover changes in chennai using gis and remote sensing, 17:12
18. Lambin EF (1997) Modelling and monitoring land cover change processes in tropical regions. Prog Phys Geogr 21:375–393. https://doi.org/10.1177/030913339702100303
19. Lambin EF, Meyfroidtb Hegazy P (2011) Global land use change, economic globalization, and the looming land scarcity. PNAS 108(9):3465–3472. https://doi.org/10.1073/pnas.1100480108.
20. Mahender Reddy D, Patode RS, Nagdeve MB, Satpute GU, Pande CB (2017) Land use mapping of the warkhed micro-watershed with geo-spatial technology. Contemp Res India J 7(3), ISSN 2231-2137
21. Mehta A, Sinha VK, Ayachit G (2012) Land use/land cover study using remote sensing and GIS in an arid environment Bull. Envi Sci Res 1(3–4):4–8
22. Mishra et al (2022) Assessment of water quality index using Analytic Hierarchy Process (AHP) and GIS: a case study of a struggling Asan River. Int J Environ Anal Chem 1–13. https://doi.org/10.1080/03067319.2022.203201500
23. Mohseni U et al (2023) Understanding the climate change and land use impact on streamflow in the present and future under CMIP6 climate scenarios for the Parvara Mula Basin, India. Water 15(9):1753. https://doi.org/10.3390/w15091753
24. Pande CB, Kanak N, Moharir KSFR, Patil S (2018) Study of land use classification in the arid region using multispectral satellite images. Appl Water Sci, Springer J 8(5):1–11. https://doi.org/10.1007/s13201-018-0764-0
25. Pande C, Moharir K (2014) Analysis of land use/land cover changes using remote sensing data and GIS techniques of Patur Taluka, Maharashtra, India. Int J Pure Appl Res Eng Technol 2(12):85–92, ISSN: 2319-507X
26. Pande CB, Moharir KN, Pande R (2018) Assessment of Morphometric and Hypsometric study for watershed development using spatial technology—a case study of Wardha river basin in the Maharashtra, India. Int J River Basin Manag, Taylors Fr J. https://doi.org/10.1080/15715124.2018.1505737
27. Pande CB (2022) Land use/land cover and change detection mapping in Rahuri watershed area (MS), India using the google earth engine and machine learning approach. Geocarto Int https://doi.org/10.1080/10106049.2022.2086622
28. Pande CB, Kadam SA, Jayaraman R, Gorantiwar S, Shinde M (2022) Prediction of soil chemical properties using multispectral satellite images and wavelet transforms methods. J Saudi Soc Agric Sci 21(1):21–28

29. Pande CB (2020) Watershed management and development. In: Sustainable watershed development. Springer briefs in Water Science and Technology. Springer, Cham. https://doi.org/10.1007/978-3-030-47244-3_2
30. Pande CB, Khadri SFR, Moharir KN, Patode RS (2018) Assessment of groundwater potential zonation of Mahesh River basin Akola and Buldhana districts, Maharashtra, India using remote sensing and GIS techniques. Sustain Water Resour Manag, Springer J 4:965–979. https://doi.org/10.1007/s40899-017-0193-5
31. Pande C (2014) Change detection in Land use/land cover in Akola taluka using remote sensing and GIS technique. Int J Res 1(8), ISSN 2348-6848
32. Patode RS, Nagdeve MB, Pande CB, Moharir KN (2017) Land use and land cover changes in devdari watershed Tq. Patur, Distt. Akola, of Vidarbha Region in Maharashtra. Trends Biosci J 10(8), ISSN: 0974-8431
33. Rajesh J, Pande CB (2023) Estimation of land surface temperature for Rahuri Taluka, Ahmednagar District (MS, India). Using remote sensing data and algorithm. Clim Change Impacts Nat Resour Ecosyst Agricul Syst Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_24
34. Rathnayake U (2015) Migrating storms and optimal control of urban sewer networks. Hydrology 2(4):230–241. https://doi.org/10.3390/hydrology2040230
35. Rawat JS, Kumar M (2015) Monitoring land use/cover change using remote sensing and GIS techniques: a case study of Hawalbagh block, district Almora, Uttarakhand, India Egypt. J Rem Sens Space Sci 18:77–84. https://doi.org/10.1016/j.ejrs.2015.02.002
36. Shalaby A, Moghanm FS (2015) Assessment of urban sprawl impact on the agricultural land in the Nile Delta of Egypt using remote sensing and digital soil map. Chin Geogra Sci 25:274–282. https://doi.org/10.1007/s11769-015-0748-z
37. Shinde S et al (2023) Flood impact and damage assessment based on the Sentitnel-1 SAR data using google earth engine. Clim Change Impacts Nat Resour Ecosyst Agricul Syst Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_20
38. Singh R et al (2023) Classification of vegetation types in the mountainous terrain using random forest machine learning technique. Clim Change Impacts Nat Resour Ecosyst Agricul Syst Springer, Cham. https://doi.org/10.1007/978-3-031-19059-9_27
39. Sleeter BM, Sohl TL, Bouchard MA, Reker RR, Soulard CE, Acevedo W, Zhu Z (2012) Scenarios of land use and land cover change in the conterminous United States: utilizing the special report on emission scenarios at Eco regional scales. Glob Environ Chang 22(4):896–914
40. Srivastava DK, Bhambhu L (2009) Data classification using support vector machine. J Theor App Info Tech 6:125–136. E-ISSN 1817–3195
41. Weng Q (2001) Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. J Environ Manage 64:273–284. https://doi.org/10.1006/jema.2001.0509
42. Wu J (2008) Land use changes: economic, social, and environmental impacts. Choices 23(316):6–10

Climate Effects of Sea Levels Rise Change on Vulnerability in the Coastal Area of Nagapattina in India

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Abstract Environmental change related to ocean level ascent (SLR) is one of the significant environmental issues of today. This report is about the ocean level ascent and its effects because of environmental change along the waterfront zone of Nagapattinam. The seaside immersion risk map was set up for this specific area as it was influenced by numerous twisters, flooding, storm flood, and tidal wave waves during the most recent decades. The outcomes were produced from different satellite information LANDSAT 8 (OLI) 2014 and Digital Elevation Model (DEM), combined with GIS overlay strategies, to decide the immersion zones along the beachfront area. Static immersion investigation uncovered that immersion will submerge a territory equivalent to 6.09 km^2 if the ocean level exceeds one meter. For a two-meter rise, the immersion will cover 11.15 km^2. Additionally, for 3, 4, and 5 m rise, 18.18 km^2, 24.86 km^2, and 30.71 km^2 will become submerged, respectively. 5 m run up the stature of immersion almost 3 towns and 11 towns expected will be seriously influenced.

Keywords Sea level rise · DEM · Inundation · Nagapattinam coast

1 Introduction

The ocean level ascent is the best predictor of environmental change than other barometrical variables. The softening of polar ice sheets and ice sheet dissolves because of an ascent in sea temperature are the immediate impact of barometrical temperature change. Different examinations were completed in the twentieth century, dependent

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_18

on the tidal information that is accessible. There are suggestions for utilizing tidal information since there will be a variety of tidal information on a territorial scale dependent on the number of tidal stations and area of tide measures which can't be connected all-inclusive. However, sufficient proof can clarify the increment in sea temperature and dissolving of polar ice, which can be identified with ocean level ascent. It is critical to include the Effective Sea level ascent known as the change in eustatic ocean level for delta surface, including the subsidence esteems and fluvial silt testimony. Hence viable ocean level ascent can clarify territorial varieties. A few examinations have demonstrated the appraisals of the potential effects for some created nations [2, 5, 20, 33], creating nations [1, 6, 8, 9, 31], or explicit territories of the world. Just scarcely any investigations, for example, Nicholls and Mimura [21], and Nicholls and Tol [22], have evaluated the effects of SLR on an incredible degree of local or world scale. As the conviction that human-initiated environmental change is expanded [28]. The appraisal of potential effects on distinguishing critical vulnerabilities and adjustment and relief needs turns out to be all the more squeezing. SLR and major coastal floods influence at the regional level, but Lichter and Felsenstein [14] put a lot of focus on analyzing the effect at the national level. Because SLR or coastline changes are not the same in all places, specific assessments are required for sensitive areas. Detailed local investigations will provide a comprehensive picture of the effects of SLR [10] and will help identify the effective implementation strategies to cope with climate risk. The visualization of flooding will enable us to understand the risk and provide important information for future strategy and decision-making [30]. Remote sensing (RS) and Geographical Information Systems (GIS) have been acknowledged as the best components for spatial decision-making at all levels, from regional to nation-wide, as well as quantifying spatial variation through time and the effect of SLR projections [7].

Although particularly sensitive to sea level fluctuations, coastal zones (areas less than 10 m above mean sea level) are ecologically diverse, wealthy, and productive [24, 32]. More than 600 million people call them home, 300 million of whom reside in areas susceptible to flooding. Coastal regions, which are home to 65% of the largest and numerous smaller cities in the world, are important economic engines for the entire world. According to Neumann et al. [19], if current trends continue, the coastal population will roughly double by 2060, and the coastal economy will expand even more, possibly by an order of magnitude. This will significantly increase the exposure of people and infrastructure to the risks associated with sea-level rise (SLR).

The destinations of this paper were to distinguish and measure the defenseless low-lying beachfront regions to the unfriendly impacts of ocean level ascent on the Nagapattinam seaside zone. Right now, evaluated the effects on the seaside angling towns, land use, touchy regions, and places of interest that are perhaps in danger. The outcomes from the investigation can be utilized to take arrangement choices and adjustment measures concerning environmental change and ocean level ascent issues.

2 Study Area Description

Nagapattinam taluk Tamil Nadu State of Southern India lies between Northern Latitude 10046′16″ and 79050′50″ Eastern Longitude. Nagapattinam is known for its rich strict legacy and shared concordance with the all-out populace of 282,784, according to 2011 registration. The male populace is around 139,917, and the female populace is 142,867, a number of houses hold right now 70,683. The zone gets precipitation affected by both southwest and upper east rain storm. A decent piece of the precipitation happens during escalated storms, mostly from twisters produced in the Bay of Bengal, particularly during the upper east rainstorm. The precipitation example of the region shows fascinating highlights, yearly precipitation, which is around 1500 mm, the southern piece of the region diminishes around 1100 mm towards the northern piece of the locale. The territory appreciates a sticky and tropical atmosphere with blistering summers, which are noteworthy to gentle winters and moderate to substantial precipitation. The temperature differs from 40.6 to 19.3 °C, with a sharp fall in night temperatures during rainstorm periods. The relative mugginess ranges from 70 to 77%, and it is high from October to November (Fig. 1).

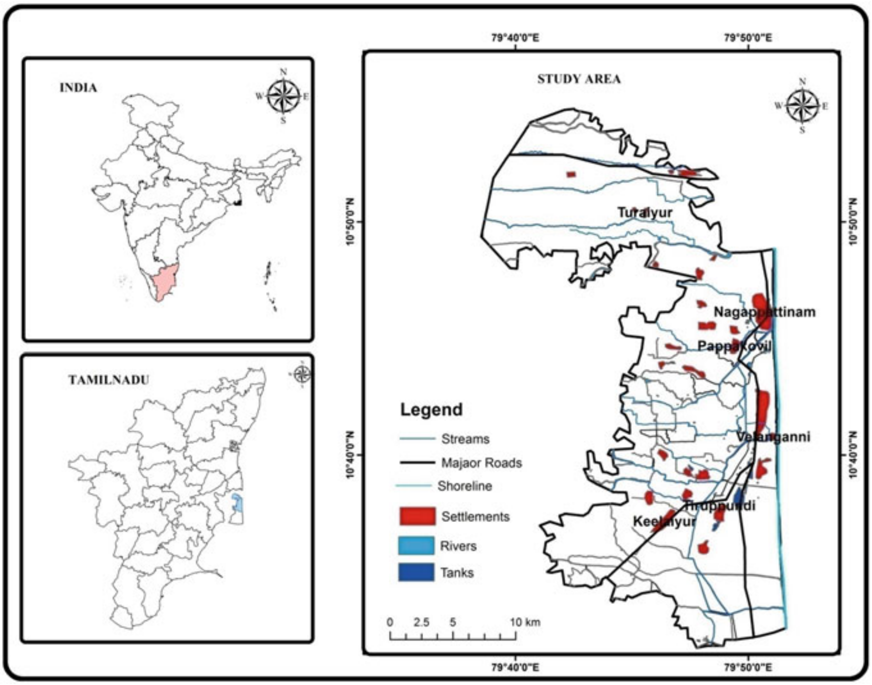

Fig. 1 Study area location map

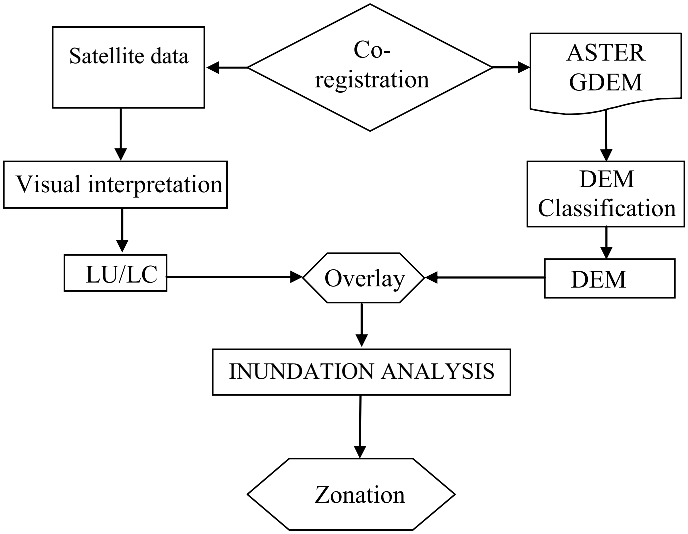

Fig. 2 Flow chart of methodology

3 Methodology

The seaside immersion and flood risks of Nagapattinam locale utilizing land use and land-spread (LULC) map was prepared from LANDSAT OLI 2014 information [27], computerized rise model (DEM) of ASTER GDEM. A seaside immersion map for the investigation regions was readied by overlaying these two informational collections [25, 26]. The adopted methodology is presented in Fig. 2.

4 Results and Discussion

4.1 Innundation Risk Analysis

The tidal immersion system is characterized as the recurrence, length, and profundity of water arriving at the plain of estuarine tidal swamps. The immersion system applies huge control over the swamp plain in the substance and physical properties of bog soils, going with changes in the natural network. These maps are a portrayal of immersion dependent on ASTER GDEM information. Immersion is accepted to happen at a consistent rise (Bathtub Model), and no different factors other than tidal height are utilized to decide water levels. The land surface rises to depend on information with a normal precision of 10 m; anyway, territories of substantial vegetation may have blunders surpassing that sum. India and other low-lying seaside districts far and wide from immersion, disintegration, and land misfortune impacts are too overwhelming to consider for beachfront directors.

Considering these realities, immersion maps were readied utilizing Spatial Analysis Module for five meters run-up, i.e., from 1 to 5 m, with an interim of 1 m. the Digital rise model (DEM) of the investigation region with a reference standard of the flow mean ocean level was used (Fig. 3). This DEM was readied utilizing ASTER GLOBAL DEM. The outcome shows that if the ocean level ascents by one meter, it will submerge a territory equivalent to 6.09 km^2. For two-meter rises, the immersion will cover 11.15 km^2. Likewise, 3, and 4, 5 m rise 18.17 km^2, 24.86 km^2, and 30.71 km^2 will be submerged individually. The immersion model using DEM helps in the distinguishing proof and evaluation of zones of submergence. A thought of land use is influenced is likewise required. Consequently, the spatial conveyance of the seaside immersion flood Hazards of Nagapattinam district was resolved to utilize a 5 m run-up just as from the characterization of advanced rise model DEM of ASTER DEM. By coordinating every one of these informational collections, appraisals of various land use classes that may influence various situations are immersion are distinguished (Fig. 4). Expecting the run-up stature of one meter, mud level, saline water stream, seashore edge, and Coastal plain is, for the most part, influenced. Moreover, the ethereal augmentation of land use classes settlement, salt influenced land, land with clean, and aquaculture and ranch are separate, 0.51, 0.13, 1.20, 1.05, 0.15 km^2 (Fig. 5). For the two-meter run-up tallness, seaside plain (6.94 m), seashore edge is generally influenced. The territory under submergence of settlements 1.12 km^2, River/Tank/Canal 0.38 km^2, Land with clean 3.40 km^2, Land without scour 2.75 km^2, aquaculture 1.28 km^2, estate 0.40 km^2 salt influenced land 0.17 km^2 separately (Fig. 6) (Tables 1 and 2).

On the off chance that we thought about a run up the tallness of three meters, seaside plain, seashore edge, salty water brooks are generally influenced by the immersion. The zone under submergence for cropland 0.01 km^2, settlement 2.16 km^2, land with scour 6.15 km^2, land without clean 4.72 km^2, aquaculture 1.42 km^2, estate 0.93 km^2, salt influenced land 0.19 km^2 individually. Under four-meter run-up tallness, immersion reaches out past the coastline table. What's more, significant land covers viz., Fallow land 0.06 km^2, settlements 3.20 km^2, River/Tank/Canal 0.65 km^2, land with scour 8.75 km^2, and land without clean 6.58 km^2, aquaculture 1.47 km^2, salt influenced land 0.21 km^2, and sandy territory 1.77 km^2, separately. For a run-up level of five meters. Harvest land 0.01 km^2, Fallow land 0.08 km^2, settlement 3.95 km^2, River/Tank/Canal 0.78 km^2, land with scour 11.25 km^2, and land without clean 8.12 km^2, aquaculture 1.48 km^2, salt influenced land 0.21 km^2, and sandy zone 1.94 km^2, separately (Table 3).

The populace that may get influenced because of immersion, overlay of coming about settlement layer with 5 m run up stature immersion map uncovers that 2.28 km^2 of settlements region will be submerged of the situation. Since the 2004 tidal wave is run up tallness was around 2.6–5.6 m [15] along the Tamil Nadu coast, the

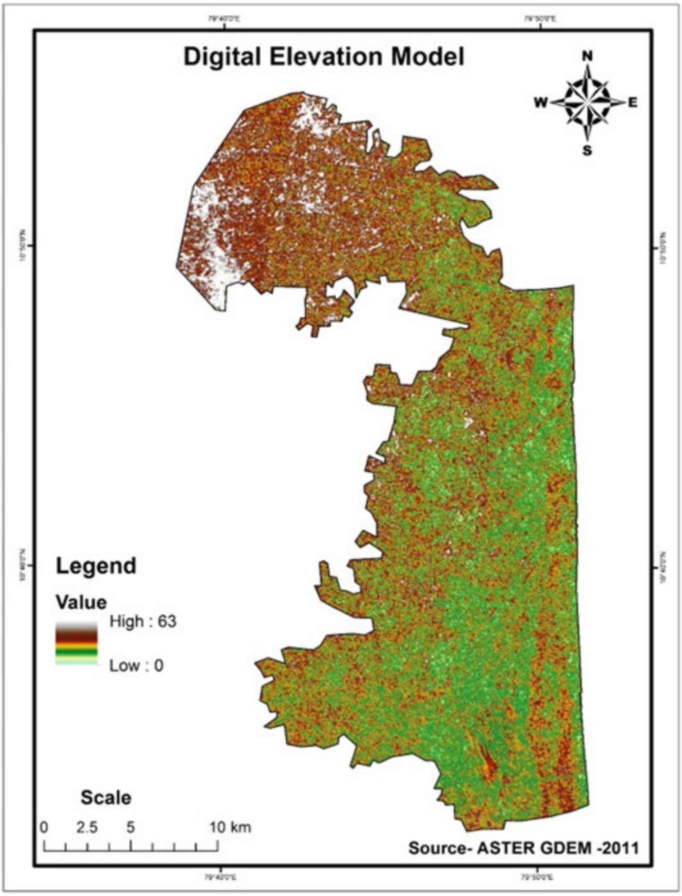

Fig. 3 Digital elevation model

whole settlements falling under this classification can be considered under profoundly helpless class.

5 Discussion

SLR in the twentieth century was primarily brought on by ocean temperature increases and mass depletion of glaciers and ice caps, generally called to as glaciers [11–13]. However, since 1990, the Greenland and Antarctic ice sheets (AIS and GrIS), which together have an ocean warming capacity of about 65 m, have accelerated their impact to SLR [3, 4]. The major lack of certainty in predictions of future SLR is the restricted ability to model the forthcoming evaporate dynamic nature of

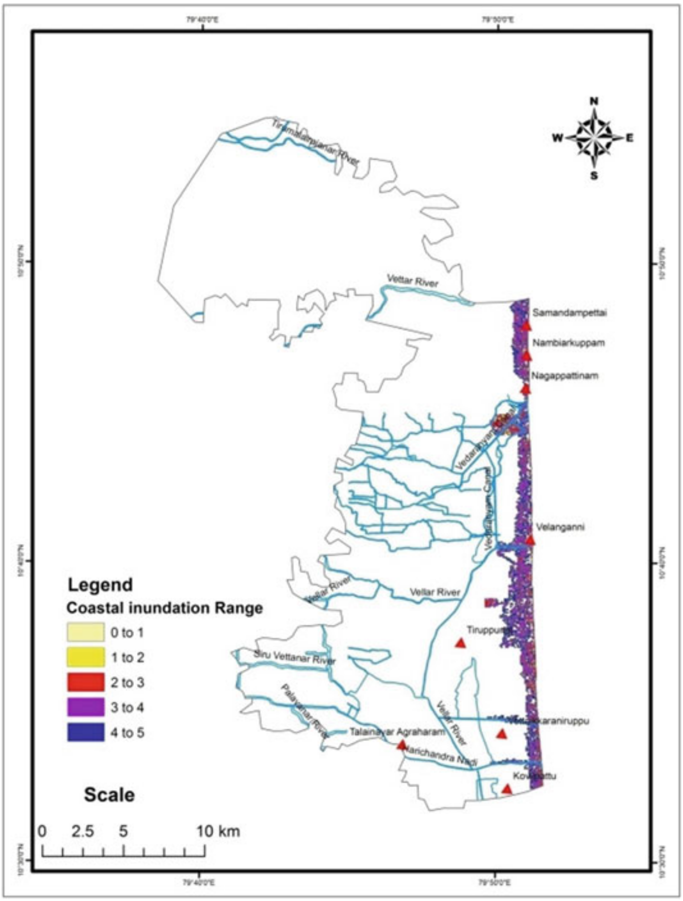

Fig. 4 Tidal inundation map (up to 5 m run up)

the AIS and GrIS, as emphasised in the most recent three evaluations reports of the International Panel on Climate Change (IPCC) [11, 12]. The reality that when both ice sheets are thought to have critical threshold at, or just above, 1.5–2.0 °C warming relative to the which was before epoch further confuses the quantification of risk [23, 29]. Remote sensing and GIS technology has been proved the land use and land cover features changes observed by various methods, which is affected by any disaster activities that time very fastly identified the land use and land cover features changes [16–18]. Nowadays sea level increases due to pollution and temperature rising due to climate changes of climatic parameters in the semi-arid region or costal area. In this chapter, we have created various the matics maps as per 1–5 m area buffer, which area more affected due to sea level rises.

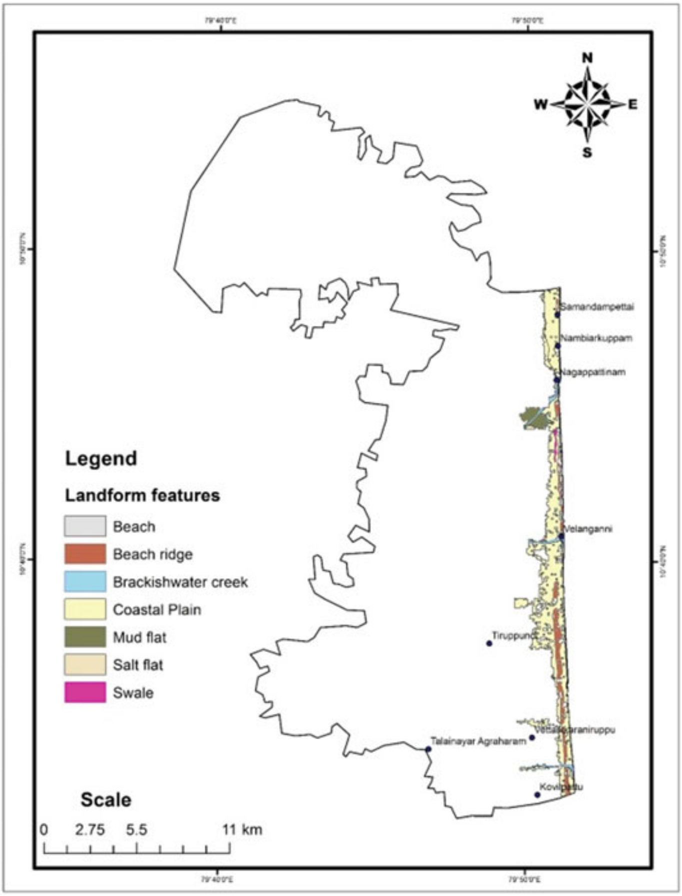

Fig. 5 Affected landform features under inundation for (up to 5 m run up)

6 Conclusion and Recommendation

The degree of the waterfront fields of Nagapattinam beachfront zones was recognized utilizing a computerized height model. Different investigations demonstrate that the waterfront locales of Nagapattinam, Tamil Nadu, along the East shore of India, are influenced via ocean level ascent. To approve this model, results show that if the sea level ascends by one meter, the zone will be submerged to 6.09 km^2. If there should be a two-meter rise, the immersion will cover around 11.15 km^2. Essentially, for 3, 4, and 5 m rise, 18.17 km^2, 24.86 km^2, and 30.71 km^2 regions will be submerged individually. The number of populace and houses in these towns and towns is 40, 450, and 163,631, dependent on the year 2011 statistics. The above outcomes on the immersion level now mirror the seriousness of the ground circumstance, and the need of great importance is that people, in general, know about the formative

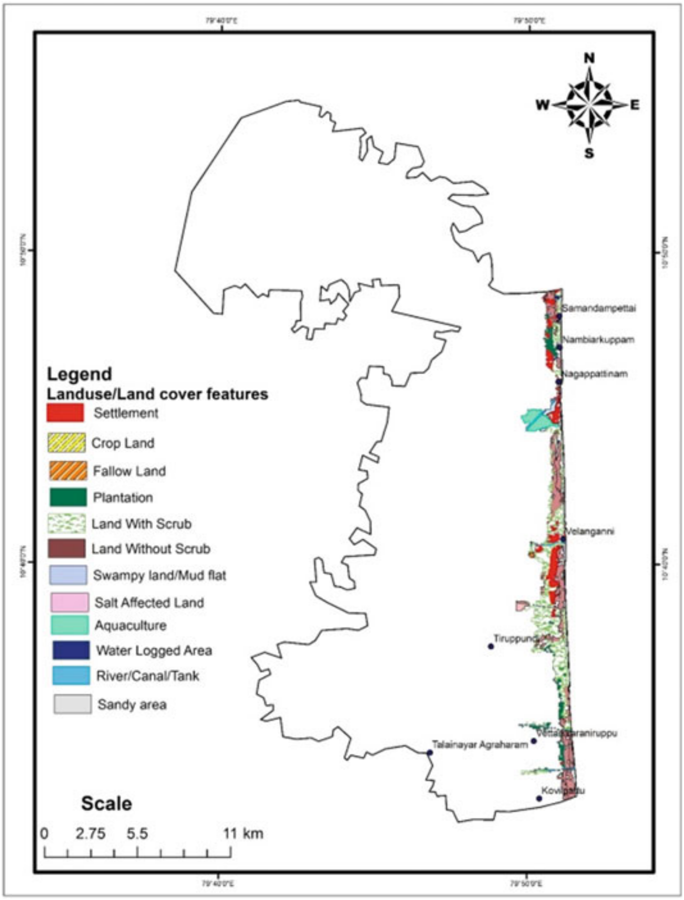

Fig. 6 Affected land use features under inundation for (up to 5 m run up)

Table 1 Areal extension of inundation (km^2) distance from the shore

Geomorphology	1 m	2 m	3 m	4 m	5 m
Coastal plain	3.36	6.94	12.09	17.14	21.49
Beach	0.13	0.18	0.26	0.34	0.44
Beach ridge	0.34	0.80	1.55	2.34	3.17
Brackish water creeks	0.35	0.54	0.66	0.78	0.87
Mud flat	0.97	1.14	1.25	1.27	1.27
Salt flat	0.12	0.14	0.16	0.17	0.18
Swale	0.07	0.09	0.13	0.17	0.19

Table 2 Areal extension of inundation (km^2) for different land use for 1 to 5 m run up

Landuse/land cover	1 m	2 m	3 m	4 m	5 m
Settlement	0.51	1.12	2.16	3.20	3.95
Cropland	0.00	0.00	0.01	0.01	0.01
Fallow land	0.00	0.02	0.05	0.06	0.08
Plantation	0.15	0.40	0.93	1.62	2.33
Land with scrub	1.59	3.40	6.15	8.75	11.25
Land without scrub	1.20	2.75	4.72	6.58	8.12
Swampy land/mudflat	0.22	0.28	0.36	0.38	0.39
Salt affected land	0.13	0.17	0.19	0.21	0.21
Aquaculture	1.05	1.28	1.42	1.47	1.48
Waterlogged area	0.04	0.08	0.12	0.16	0.17
River/tank/canal	0.25	0.38	0.50	0.65	0.78
Sandy area	0.95	1.27	1.56	1.77	1.94

Table 3 Localities and population expected to be affected for 1–5 m run up Height

S. no	Category	Location	Number of house hold	Total population
1	Municipality	Nagapattinam (M)	24,688	102,905
2	Municipality	Nagapattinam	462	1939
3	Rural	Vadakkupoigainallur	2610	10,826
4	Rural	Karuvalangadai	585	2309
5	Rural	Therkupoigainallur	1250	4731
6	Urban	Velankanni (TP)	2753	11,108
7	Rural	Prathabaramapuram	2603	10,124
8	Rural	Thirupoondi (East)	1533	5647
9	Rural	Vizhunthamavadi	1834	6608
10	Rural	Vettaikkaraniruppu	2102	7314
11	Rural	Kovilpathu	30	120
Total			40,450	163,631

exercises that might get influenced in the future. The outcomes likewise bolster the utilization of early forecast in the helpless waterfront districts anyplace in the World for assessment of immersion limits.

References

1. Adam KS (1995) Vulnerability assessment and coastal management program in the Benin coastal zone. In: Beukenkamp P (ed) Proceedings of WCC93. CZM management publication no. 4. National Institute for Coastal and Marine Management, The Hague, pp 489–501
2. Baarse G, Peerbolte EB, Bijlsma I (1994) Assessment of the vulnerability of the Netherlands to sea-level rise. In: O'Callahan J (ed) Global climate change and the rising challenge of the sea, proceedings of the 3rd IPCC CZMS workshop, Margarita Island, March 1992. NOAA, Silver Spring, pp 211–236
3. Bamber JL, Oppenheimer M, Kopp RE, Aspinall WP, Cooke RM (2019) Ice sheet contributions to future sea-level rise from structured expert judgment. Proc Natl Acad Sci USA 116:11195–11200. https://doi.org/10.1073/pnas.1817205116
4. Bamber JL, Westaway RM, Marzeion B, Wouters B (2018) The land ice contribution to sea level during the satellite era. Environ Res Lett 13:063008. https://doi.org/10.1088/1748-9326/aac2f0
5. Bijlsma L, Ehler CN, Klein RJT, Julshrestha SM, McLean RF, Mimura N (1996) Coastal zones and small islands. In: Watson RT, ZinyoweraMC, Moss RH (eds) Impacts, adaptations, and mitigation of climate change: scientific–technical analyses, environmental monitoring assessment. Cambridge University Press, Cambridge, pp 289–324
6. Dennis K, Niang-Diop I, Nicholls RJ (1995) Sea level rise and Senegal: potential impacts and consequences. J Coast Res 14:242–261
7. Ford M (2013) Shoreline changes interpreted from multitemporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. Remote Sens Environ 135:130–140. https://doi.org/10.1016/j.rse.2013.03.027
8. French GT, Awosika LF, Ibe CE (1995) Sea-level rise in Nigeria: potential impacts and consequences. J Coast Res 14:224–242
9. Han M, Hou J, Wu I (1995) Potential impacts of sea level rise on China's coastal environment and cities: a national assessment. J Coast Res 14:79–95
10. Hennecke WG, Greve CA, Cowell PJ, Thom BG (2004) GIS-based coastal behavior modeling and simulation of potential land and property loss: implications of sea-level rise at Collaroy/Narrabeen beach, Sydney (Australia). Coast Manag 32(4):449–470. https://doi.org/10.1080/08920750490487485
11. IPCC (2019) Polar regions. In: IPCC special report on the ocean and cryosphere in a changing climate. IPCC, Geneva
12. IPCC (2021) Climate change 2021: the physical science basis. In: Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge
13. Khanna P, Udayakumar (2014) Effects of sea level change on the vulnerable east coast of India. Res J Mar Sci 2(1):1–5. ISSN 2321-1296
14. Lichter M, Felsenstein D (2012) Assessing the costs of sea level rise and extreme flooding at the local level: a GIS-based approach. Ocean Coast Manag 59:47–62. https://doi.org/10.1016/j.ocecoaman.2011.12.020
15. Murthy KSR, Subrahmanyam AS, Murty GPS, Sarma KVLNS, Subrahmanyam V, Mohana-Rao K, Suneetha-Rani P, Anuradha A, Adilakshmi B, Sri-Devi T (2006) Factors guiding tsunami surge at the Nagapattinam-Cuddalore shelf, Tamil Nadu, east coast of India. Curr Sci 90(11):1535-P1538
16. Muthusankar G (2011) Un published PhD Thesis at Bharatahidasan University, Tiruchirappalli. Multi hazard risk assessment and management strategies for Nagapattinam Coastal zone, Tamil Nadu
17. Muthusankar G, Lakshumanan.C, Pradeep Kishore V, Sujitha SB, Jonathan MP (2013) Recognizing the inundation boundary along the southeast coast of India. In: 3rd Congreso Nacional de investigacion en cambio climatico, October 2013, UNAM, Mexico, pp 14–18

18. Natesan U, Parthasarathy A (2010) The potential impacts sea level rise along the coastal zone of Kanyakumari district in Tamil Nadu, India. J Cons 14:2017–2214. https://doi.org/10.1007/s11852-010-0103-6
19. Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ (2015) Future coastal population growth and exposure to sea-level rise and coastal flooding: a global assessment. PLoS One 10:e0118571. https://doi.org/10.1371/journal.pone.0118571
20. Ng WS, Mendelshon R (2005) The impact of sea level rise on Singapore. Environ Dev Econ 10(2):201–215
21. Nicholls RJ, Mimura N (1998) Regional issues raised by sea-level rise and their policy implications. Clim Res 11:5–18
22. Nicholls RJ, Tol RSJ (2006) Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. Philos Trans R Soc 364(1841):1073–1095
23. Noël B, van Kampenhout L, Lenaerts JTM, van de Berg WJ, and van den Broeke MR (2021) A 21st century warming threshold for sustained greenland ice sheet mass loss. Geophys Res Lett 48:e2020GL090471. https://doi.org/10.1029/2020GL090471
24. Oppenheimer M, Glavovic BC, Hinkel J, van de Wal R, Magnan AK, Abd-Elgawad A et al (2019) Sea level rise and implications for low-lying islands, coasts and communities. In: IPCC special report on the ocean and cryosphere in a changing climate, vol 126. IPCC, Geneva
25. Pande CB, Moharir KN, Singh SK, Varade AM, Ahmed Elbeltagie SFR, Khadri PC (2021) Estimation of crop and forest biomass resources in a semi-arid region using satellite data and GIS. J Saudi Soc Agric Sci 20(5):302–311
26. Pande CB, Moharir KN, Khadri SFR (2021) Assessment of land-use and land-cover changes in Pangari watershed area (MS), India, based on the remote sensing and GIS techniques. Appl Water Sci 11:96. https://doi.org/10.1007/s13201-021-01425-1
27. Pande CB, Moharir KN, Khadri SFR et al (2018) Study of land use classification in an arid region using multispectral satellite images. Appl Water Sci 8:123. https://doi.org/10.1007/s13201-018-0764-0
28. Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) (2007) Climate change 2007: the physical science basis, contribution of working group I to the fourth assessment report of the IPCC. Cambridge University Press, Cambridge
29. Thieler E, Hammar-Klose E (1999) National assessment of coastal vulnerability to future sea-level rise: preliminary results for the U.S. Atlantic coast. http://pubs.usgs.gov/of/of99-593/
30. Walsh KJE, Betts H, Church J, Pittock AB, McInnes KL, Jackett DR, McDougall TJ (2004) Using sea level rise projections for urban planning in Australia. J Coastal Res 20(2):586–598. https://doi.org/10.2112/1551-5036(2004)020[0586:USLRPF]2.0.CO;2
31. Warrick RA, Le Provost C, Meier MF, Oerlemans J, Woodworth PL (1996) Changes in sea level. In: Houghton JT, Meira Filho LG, Callander BA, Harris N, Klattenberg A, Maskell K (eds) Climate change 1995, the science of climate change. Cambridge University Press, Cambridge, pp 359–405
32. Wong PP, Losada IJ, Gattuso J-P, Hinkel J, Khattabi A, McInnes KL et al (2014) Coastal systems and low-lying areas. Clim Change 2104:361–409
33. Zeidler RB (1997) Climate change vulnerability and response strategies for the coastal zones of Poland. Clim Change 36:151–173

Conclusion

Conclusions

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Abstract The main attention of this chapter is to introduce and précis the important results and conclusions of this climate change impact on India. Climate change is a more important factor and impact on natural resource, agriculture and water etc. Now a day everywhere climate change is affected entire countries and changing the metrological parameters. The main purpose of this chapter is to update the state-of-the-art review in the book and to summarise the conclusions of the book chapters. Also, the chapter ends with some climate change policy and recommendations in India to help India to achieve sustainable development.

Keywords Climate · India · Sustainable · Policy

The main focus of this chapter is to discuss and summarize the major findings and conclusions of chapters of this book titled Climate Change Impact on Groundwater Resources—Human Health Risk Assessment in Arid and Semi-Arid Regions. Groundwater is a significant freshwater resource and provides essential freshwater supply, chiefly in dry regions where surface water availability is limited. However, groundwater problems are one of the most serious and complex technical problems in today's world. The main purpose of this book is to disseminate advanced technical knowledge to the technology community, and this book seeks to fill the research gap on groundwater resource sustainable management activities. In response to global warming (CO_2 & BC) inland ice melting, thermal expansion of ocean has increased global sea level. In the same line global sea level increase, North Indian

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C. B. Pande et al. (eds.), *Climate Change Impacts in India*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-42056-6_19

Ocean Sea level accelerated to 3.3 mm (1993–2017) per year with the rate 1.06–1.75 mm during 1874–2004. RCP 8.5 scenario, projected global sea level rise is almost 180 mm while in the North Indian Ocean it is 300 mm for data 1986–2005). Climate change will have impact on capitals, ecosystem, environment, disease and migration socio-economic, investments availability, commodity price, infrastructures, land restructuring, inter-and-intra national dealings and other large/small scale industries. A meaningful development has least transformation from agricultural to a non-agricultural economy and reduce agriculture dependency. Climate change and variability is equally important for the arid regions as for the semi-arid and humid regions. This chapter provides an appraisal of climate related studies reported from the arid regions involving a variety of weather variables and different statistical tests. It highlights limitations of the past climate studies performed for the arid regions, and includes a case study of an Indian arid region where trend and homogeneity of the monthly and annual rainfall is explored at 62 stations using multiple statistical tests. Pluvial events change nature due to climate change. Spatial prioritisation based on urban flood analysis of Agartala City has been spotted. To resolve the issue of urban flooding, sustainable strategic city drainage network planning is needed for making the plan. With Definiens' Cognition Network Technology, the basis is available to analyse images and texts from many different domains, and combine the information from heterogeneous sources to support decision makers. RS and GIS based alone cannot stand or predict the changes but the information collected by RS can be fed to different models to get real world simulation or result. Few agroclimatic concepts are: (a) the rhythmic variations in Indian rainfall, (b) the impact of rhythmic variations on agroclimatic variables, such as drought proneness, water availability in some Indian rivers, etc., (c) models that integrate soil–water-crop factors and (d) Crop-weather model related issues. Agriculture is highly sensitive to short-term changes in weather and seasonal, annual and long-term climate variations. It will ultimately affect availability, accessibility and stability of food supply, threatening the country's food security. In the face of changing climate, for managing agriculture and its resources accurate crop yield estimation and forecasting at regional and global scales is critical. Crop growth models can be used to properly simulate and predict the growth and development of crops at a single point scale under various biotic and abiotic stresses. Crop monitoring over a vast area can also benefit from satellite remote sensing. The availability and conservation of natural resources such as land and water determine a country's social, cultural, and economic stability and growth. These resources are important in measuring specific criteria because they play a significant role in creating employment, in the growth of a country, in the provision of food and other critical raw materials, as well as medicine and energy. Countries must recognise that the management and sustainable development of natural resources is critical for the survival of life on the planet. As the rate of integration of nature and technology increases, Information Technology (IT) is becoming a hotspot for monitoring of natural resources across the globe. Information technology is being utilised extensively to monitor, investigate, and understand our natural resources, particularly those that are finite. Human existence depends on our ability to cooperate equally with nature, which is our greatest ally in combating climate change. Agriculture is the backbone of human civilization and climate change is making serious imprints on the global production systems. The projected yield decline in various crops by several models is clearly indicating a food crisis to the ever-increasing population worldwide. Understanding the impacts of climate change on land degradation and plant nutrient dynamics are essential to make strategies and policies to mitigate and/or minimize the hazard. It is anticipated that the effects of global climate change will alter soil physical parameters such as texture, structure, bulk density, porosity, nutrient retention, etc., affecting the soil fertility through which it may cause soil salinization, reduce nutrient and water availability, alter C and N dynamics, and reduce soil biodiversity. Climate change's negative effects are mostly felt in the soil's chemical characteristics, such as pH, salinity, cation exchange capacity, nutrient cycle, and acquisition. Climate change is also realized in this part of the world and is the time for action, not simply to discuss it. It impacts people's livelihood and the impacts of ill effects are likely to increase in the future. The predominantly small farmer-oriented mono-crop farming in Assam is often affected by floods and seasonal drought. However, the existing gap between the actual and potential yield of the crops can be reduced by adopting improved practices and adding adapted germplasm to the system despite the ill effect of climate change. Organizing awareness programme, training, harvest festival, field day and exposure visit, demonstration of climate-resilient technologies. Make availability of farm implements and machinery through the establishment of custom hiring center, establishment of seed and seed fodder bank, etc. useful for capacity building and motivating farmers to adopt climate-resilient technologies.

1 Summary

Observed and Projected Global Climate: 1 °C global warming due to climate change is due to industrial revolt, alteration of atmospheric constituents and earth energy balance. Consequences of global warming are weather modification, extreme events, change of ecosystem and weather patterns, rise in sea surface temperature (SST) and its acidification, receding glaciers/snow, intensification of cyclone, heat wave increment etc. Upto twenty-first century global warming range will reach the range between 5 and 8 °C although emission is restricted or zero emission is implemented or follow Paris Agreement/Kyoto protocol in all scenarios climatic system will be accelerated.

Temperature Rise Over India: Average temperature over an Indian region is already raised by 0.7 °C according to the analysis of data series 1901–2018. In the RCP8.5 scenario, it is estimated that warmest day, coldest night and average temperature will further rise by 4.4 °C, 4.7 °C and 5.5 °C respectively and further increase in the frequencies of warm days/night, heat wave, heat stress in the twenty-first century and beyond.

Indian Ocean Warming: Markedly 1 °C increased in the sea surface temperature (SST) of Tropical Indian Ocean. This increased of SST is more than global mean

SST warming (0.7 °C). Also, increasing trend initiates in the upper level (700 hpa) during 1951–2015. Also, during past two decades increasing warming trend has already increased in an abrupt way.

Changes in Rainfall: From data 1951–2015, a noticeable decreased (6%) in the Indian Summer Monsoon (ISM) and same declining trend is observed over Indo-Gangetic plains, western ghats. Projected data as per climate model simulation analysis showed same rainfall trend.

From 1951–2015, aerosols offset precipitation and GHG warming declined precipitation in the Northern Hemisphere. 27% shifts of dry spell are analysed from data 1981–2011. In the worldwide level, it is projected that more intense wet spells and increased in the frequency of local precipitation will occur on the worldwide level. In the central India occurrence of daily extreme rainfall intensity has increased about 75% (150 mm/day) during 1950–2015. Under projection of global warming and reduction of aerosols, there will be increase in the daily rainfall extreme as well as in the variability and mean rainfall amount.

Droughts: Central India, SW coast, Peninsular India, NE-India showed more frequency and spatial scale of drought spells according to data 1951–2016 along with increased in its area by 1.3% per decade. Projected simulation data also exhibited the same results.

Sea Level Rise: In response to global warming (CO2 & BC) inland ice melting, thermal expansion of ocean has increased global sea level. In the same line global sea level increase, North Indian Ocean Sea level accelerated to 3.3 mm (1993–2017) per year with the rate 1.06–1.75 mm during 1874–2004. RCP 8.5 scenario, projected global sea level rise is almost 180 mm while in the North Indian Ocean it is 300 mm for data (1986–2005).

Tropical Cyclones: Analysis of data (1951–2018) showed that there will be considerable reduction in the occurrences of TCs over NIO basin but increase in the intensity of TCs during post-monsoon season and the same results are projected by the climate models. However, anthropogenic warming trend is not yet appeared.

Changes in the Himalayas: In Hind Kush Himalayas deteriorating snow, retreat glaciers and escalation of temperature about 1.3 °C as per studied years 1951–2014. However, Karakoram Himalayas have inverse effect i.e. more winter snowfall safeguard from melting of glaciers. In the twenty-first century, it is projected that Hind Kush Himalayas will face rise of temperature by 5.2 °C under RCP8.5 scenario.

Agriculture: Climatic changes and climatic variability have negative impact on soil, food and water. According to climate model output increased temperature, shortage of water resources and uncertain precipitation will decline yield production, soil moisture and water use efficiencies. This will restrict crop selection, sowing zones, soil deficiency, developing climate and water accessibility throughout the crop growth period. Higher latitudes will have less harmful effects than tropical areas.

To identify probable environmental limitations for agricultural production, alteration of crop calendars, cropping systems, market strategies (capital, labour, land, trade etc.), expansion of ecological information system, qualitative and quantitative universal databases acquisition its dissemination should be included in adaptation and mitigation. Extreme rainfall will weaken adaptation and mitigation capabilities for poorer especially residing in tropical belts, may permanent damage agricultural land and water resources. There will be threat of hunger by year 2080 and undernourished places will be more affected. Publishing farmer's awareness programme, climate-smart agriculture knowledge, implement disaster risk management should be executed in a very much keen and advance manner.

Energy and Water Resources Security: Water resources can undermine dominant form of hydro and thermal power generation which depends on adequate and fresh water supplies to maintain efficient functioning. Temperature increase will reduce water resources will cause major risk to thermal power generation, hydropower plants, physical damage from landslide, flash floods, glacial lake outbursts and other climatic hazards. Hence, these should be properly plan out with consideration of all climatological risk factors.

Climate Change: To face extreme weather, keep high GDP rate, poverty alleviation can be achieved by applying Carbon tax or international tradable emission permit and mitigation and adaptation strategy implementation. But mitigation may hinder due to asymmetric distribution between developing and developed countries as developed countries are not ready to bear bulk responsibility of their past emission. Climate change will have impact on capitals, ecosystem, environment, disease and migration socio-economic, investments availability, commodity price, infrastructures, land restructuring, inter-and-intra national dealings and other large/small scale industries. A meaningful development has least transformation from agricultural to a non-agricultural economy and reduce agriculture dependency.

Providing food and nutrition security for the world's growing population has put a strain on agriculture, which is deteriorating further as a result of climate change. According to many studies, climate change is expected to reduce agricultural productivity in the coming years. Several mitigation and adaption strategies have been developed to mitigate the negative effects of climate change on agricultural sustainability. Climate change-related economic losses can be addressed using those methods at both the local and macro levels. However, in order to be effective, these mitigation and adaptation strategies must be planned at the regional or local level. Mitigation and adaptation planning is complicated by the fact that the future of climate change and its consequences is very unpredictable. This necessitates the development of climate-resilient technology based on a regional multidisciplinary approach. Farmers must be educated about various climate-smart technologies and climate-resilient cultivars must be produced. Climate change, its origins, and consequences are among science and technology's most rapidly changing topics. India is a tropical country whose agriculture sector is being impacted by climate change. Agriculture and sub-sectors employ over 70% of the Indian population directly or indirectly. Climate adaptation and mitigation measures can aid them in combating climate change's detrimental effects on agriculture.

At overall level, marginal, Small and medium farm HHs devoted 96.73%, 95.71% and 99.01% areas under food grains and remaining meagre proportions of lands to fruits and vegetables. Percentages of 'fallow lands to total land' owned by the surveyed HHs of blocks-I and II, i.e.; Kanke and Namkum in Ranchi district and blocks-III & IV, i.e.; Gola and Patratu in Ramgarh district were 49.50, 43.58, 49.45 and 67.77 respectively. Highest percentages of fallow lands out of the total land areas owned by marginal farmers of Ranchi (D-1) and Ramgarh districts (D-2) were visible 80.71 and 82.19 respectively. Social category-wise extent of fallow land data establishes OBCs' to have owned highest percentage of fallow land to total owned land (81.15) in D-2. It was followed by STs (77.54). It was 74.09% in D-1 in case of STs. Out of the land area left fallow by sample HHs, larger percentages of unirrigated land were found in D-2 (77.92). In D-1, it was 74.09. 'Lack of assured irrigation' was rated as one of the most prominent reasons for 'leaving land fallow' with average rating of 4.46. Besides above Observed problems, opportunity, way forward, short, medium and long- terms 'prudent and possible action points (PPAPs)' like sections form part of the paper/chapter.