Asraful Alam · Rukhsana *Editors*

Climate Change, Agriculture and Society

Approaches Toward Sustainability

Springer

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Preface

Agriculture is not only sensitive to climate change; it is also one of the major drivers of climate change. Understanding climate change over time and adapting management practices to achieve a good harvest is a challenge for the growth of the agricultural sector as a whole. The climate sensitivity of agriculture is uncertain, as there are regional variations in rainfall, temperature, crop and crop systems, soils, and management systems. The inter-annual changes in temperature and precipitation were much greater than the predicted changes in temperature and precipitation. Predicted Climate Change Increasing climate variability can increase crop damage. Different crops respond differently to the fact that global warming will have a complex effect. Tropical regions are more dependent on agriculture because 75% of the world's population lives in tropical regions and agriculture is the main occupation of two-thirds of these people. Low levels of technology, a wide range of pests, diseases, and weeds, land degradation, uneven land distribution and rapid population growth, and any impact on tropical agriculture will affect their livelihoods.

This volume discusses emerging contexts of climate change, agricultural transformation, and its adaptation at local and worldwide perspective, as well as contemporary technological advances. Climate change, resilience in relation to agriculture and livelihoods, and multi-dimensionality of various approaches are clearly taken into account by providing studies and perspectives on various methods and scales based from natural science to social science frameworks. It is an archived work of selected papers that are interdisciplinary, covering climate change, agriculture vulnerability, disaster impact, productivity efficiency, food security, livelihood resilience, land degradation, sustainability in terms of plan and perform for transformation, sustainability and adaptation, including philosophy, change, and economics, as well as the natural sciences. This volume addresses the Sustainable Development Goals to reduce the negative impacts on agricultural productivity brought on by climate change and its adaptation, and disaster risk reduction in developing and developed nations. Some of the assessed challenges include soil erosion, change in land use, natural resource mismanagement, crop productivity decline, and economic stagnation. This book discusses the important issues surrounding the production and consumption of food in the past and present periods, agriculture, livelihood, climate change, disaster risk management, and society. All of these are endangered, significant challenges to livelihood sustainability. The book has been arranged into three broad parts; each part will cover a set of articles dealing with a particular issue of the Climate change, Agriculture and Society: Approach towards sustainability. This volume supposedly attracts attention of the students, researchers, academician, policymakers, and other inquisitive readers interested in different aspects of climate change, agriculture, livelihood, and sustainability, particularly in the local as well as global context.

Debapriya Poddar, Tapash Mandal, and Dr. Jayanta Das (Siliguri & Birbhum, West Bengal, India) looked into the "Spatio-Temporal Changes of Rainfall Pattern Under Changing Climate in West Bengal, India" (Chap. 2). In this chapter, they try to assess the inconsistent nature of the annual and seasonal rainfall of West Bengal. The 110 years (1901–2010) data of 18 meteorological stations of West Bengal are used in this study. The nonparametric Mann-Kendall (MK), Modified Mann-Kendall (mMK), and Sen's slope estimator (Q) are used to detect the trend and magnitude of the trend. Furthermore, the sub-trends of the data series are estimated using the innovative trend analysis (ITA) method. The percent bias (P_{BIAS}) method is also used to compare the second half with the first half of the data series. The results of the ITA showed that Alipore (2.64) and Balurghat ($Q = -2.17$) had a maximum increasing and a decreasing trend in the annual rainfall. On the seasonal, summer (56%) and post-monsoon (100%) seasons are dominated by increasing trends, while decreasing trends dominate monsoon (61%) and winter (56%) seasons. The results of the MK/mMK and P_{BIAS}, more or less similar to the ITA, confirm its reliability for trend detection. The findings of this study can provide a proper way to develop future projects, as it can clarify the reliable information about the rainfall variability throughout the year and can also afford a power of sustain for water resources and agricultural development.

Chapter 3 entitled "Evaluating Apiculture as a Sustainable Livelihood Option in the Wake of Climate Change: West Bengal, India" by Dr. Anindya Basu and Sanghamitra Purkait (Diamond Harbour, India) is another important contribution of this book. This study focuses on the effect of changing climate on honey production in West Bengal by comparing the production details of varieties of associated crops during the years of 2010–2018. This chapter wishes to confirm how sustainable this apiculture industry will be in the wake of climate change.

The work of Juan Luis Hernández-Pérez and Deysi Ofelmina Jérez-Ramírez (Mexico), "The Impacts of Drought Disasters on Mexican Agriculture: An Interpretation from the Perspective of the Political Economy of Disasters" (Chap. 4), addresses that the effects of droughts are not only due to natural causes but also due to social, economic, and political factors associated with an uneven agricultural development process and also explains the impacts caused by droughts in Mexican agriculture, and the third is to analyze the institutional context of disaster risk management in the country.

Part II of the book combines the description and analysis of three chapters (Chaps. 5–7) relating to *Extreme Climatic Events: Impacts and Adaptation Issues in Agrarian Environment*. Chapter 5, "Smallholder Livestock Farmers' Animal Health

Management Practices in South Africa", contributed by Maziya, M, Tirivanhu, P, Kajombo, R. J. and Gumede, N. A. (Pretoria, South Africa), their aim of the study aims to investigate the animal healthcare management practices adopted by smallholder livestock farmers in South Africa. Combinations of multi-stage and stratified sampling techniques were used to select 591 farmers across five provinces in South Africa. The results revealed that farmers employed various primary animal healthcare practices to prevent diseases. The degree of uptake of the different primary animal healthcare practices differed across the five provinces. In general, dipping, vaccination, and deworming were the most used disease-preventative measures while disinfection, isolation, and restricted access were the least used disease-preventative measures.

"Identification of Spatio-Temporal Extent of Agricultural Drought Using Geospatial Techniques: A Case Study of Chhatna Block, Bankura District, West Bengal, India" (Chap. 6). In the study by Asraful Alam, Pradip Patra, Arijit Ghosh, and Lakshminarayan Satpati (Serampore, Purulia, Kolkata, India), they work on the spatiotemporal variation in agricultural drought identification; for this work, they measure the moisture surplus and deficit of the soil to crop, using Standardized Precipitation Index (SPI) 6 with the help of monthly precipitation of 116 years data. Then, multispectral band ratios have been performed to examine vegetation density and vegetation health to assess drought conditions over the study area, and seasonal Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) have been calculated to derive three other indices: Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI). For this paper, four years (1990, 2000, 2010, and 2017) have been chosen to know the VHI of the study area; out of four years, two are the worst drought years (2000 and 2010).

Chapter 7 is the study of "Climate Change and Agriculture: Understanding Short-Term Impact of Climate Change in Selected Crop Production in West Bengal" and was carried out by Parama Bannerj and Radhika Bhanja (Kolkata, India) based on both primary and secondary data. This chapter focuses on the Indian state of West Bengal and presents findings from a study and analyzes the impact of weather change on agricultural productivity in the short run and subsequently that of climate change in the long run.

Part III of this book focused on the *Agriculture Under Changing Climate*, and it includes Chaps. 8–10. Prabal Barua, Abhijit Mitra, Anisa Mitra, and Saeid Eslamian (Bangladesh, India, and Iran) study (Chap. 8) of "Resilience of Farmers in Response to Salinity Intrusion Problem in Agricultural Fields of Coastal Region of Bangladesh" tries to explore the saline water intrusion and soil quality and fertility status of agriculture fields and also adaptation practices by the farmer communities in the study areas of south-eastern coast of Bangladesh. The present study reveals that surface water salinity was found high in everywhere and soil quality was alarming here. Soil pH was strongly acidic and soil color was black and blackish, brown, and reddish but soil temperature was optimum for particular vegetable growth. Salinity level in agriculture field was also very strong. Soil fertility status was moderate because sand and clay dominating soil structure, sandy loam and silt loam leading soil texture, and soil bulk density (g/cm^3) were moderate. Besides, the authors also discover some indigenous knowledge-based adaptation and coping practices of the farmers for reducing the impact of climate change in the study areas. Salinity intrusion problem in the agriculture field is responsible for low production and economic loss for the farmers of the study areas. Farmers are trying to cope with some crop innovation techniques for adopting with changing climatic circumstances. This book chapter will help to demonstrate adaptation practices by the farmers for reducing the salinity level of agriculture field which will be effective in the climate change vulnerable area of other parts of the country and worldwide while the area was affected by salinization problem.

"The Ecological Significance to Maintain Rice Cropping Areas in the Rice Bowls of Kerala for Sustaining Food Security Under the Purview of Climate Change" (Chap. 9) has been carried out by Dhanya. P. and K. Jayarajan (Tamil Nadu, India). This study was an endeavor to understand the significance of sustaining rice cultivation in the rice bowl, Palakkad not only for food and livelihood security, but also for preserving ecosystem services. The state has about 300,000 rice growers. This study also explores the outcomes from Crop Simulation model DSSAT on the projected rice yield for Palakkad region under changing climatic scenarios. It also tries to find out the best suitable rice variety for the rice belts of under changed climatic conditions. The yield of Uma and Jyothi—two major ruling varieties—may be reduced by—14.4 and—21.8 %, respectively, by 2100 for Palakkad Region. Compared to current rice productivity in the rice belts of Kerala, future rice yield due to climate change with medium emission scenario of IPCC is projected to reduce during mid-century (2021–2050) and end-century (2071–2100) period. Unless there is efficient planning to provide smarter adaptive actions, it would affect local food security and livelihood security of the farmers. There is a need to have lab-to-land transfer of temperature drought and flood-tolerant seed varieties in the rice belts of Kerala to tackle climate change impacts and widening demand-supply gaps. However, the ecosystem services that these rice paddy wetland provide in maintaining ecosystems and biodiversity, flood water control, surface and ground water conservations, and aesthetic value to Kerala—Gods own country—are invaluable.

"Crop Diversification: An Adaptive Option for Climate Change Resilience in West Bengal" (Chap. 10), authored by Rukhsana (Kolkata, India), is another important contribution of this book. This study focused on the diversity of crop in context of climate change resilience in a coastal state of West Bengal of India. The region of crop diversification (HI) was developed to detect diverse agricultural impacts in West Bengal. Some districts in West Bengal have been cited as effective traditional systems of farming, lack of technology, average holding size, and low diversification of per capita income. The expansion of crop diversification depends on improvement in production risk through technical assistance, quality input supply, insurance cover, and the existence of modern storage-processing centers in the region. It is found that agricultural sector is gradually moving toward higher value crops in agro-climatic zone of West Bengal and its districts.

The work of Dr. Rashmi Rai and Dr. Lakshmypriya K. (Bengaluru, India) on "Unraveling the Interplay Between Indian Agricultural Sector, Food Security, and Farms Bill: Key to Sustainable Development Goals" (Chap. 11) attempts to analyze the poor food security and what strategies will contribute to the SDG goals to reduce hunger worldwide. It elucidates a variety of obstacles and opportunities for successful, sustainable, and resilient agriculture. It also covers topics such as the recent agricultural bill and its long-term implications for our growth and a few important takeaways that could help us get closer to our objectives, mainly through the application of technology.

Part IV of the book contains four chapters and shows the *Farmers Perceptions of Climate Change and Adaptation Strategy*. It is the study by Ankit Singh, Anju Singh, Sateesh Karwariya, Govind Pandey, Shruti Kanga, and Suraj Kumar Singh (Mumbai, Gandhinagar, Gorakhpur, Jaipur, India) on "Correlation Between Volumetric Loading Rate and Removal Efficiency of Bio-chemical Oxygen Demand and Chemical Oxygen Demand for Waste Water Treatment by Improved Bio-tower Technology in Ganga River Basin (India)" (Chap. 12); in this chapter, the comparison of volumetric loading rate and removal efficiency of BOD and COD of two wastewater treatment plants were obtained. The chosen WWTPs covered different regions in Allahabad city on the bank of Ganga River. The obtained correlation between BOD and COD will help in evaluating the treatment processes, which in turn leads to improve the performance of these two plants.

Chapter 13 is entitled "Site Suitability in Water Harvesting Management Using Remote Sensing Data and GIS Techniques: A Case Study of Sulaymaniyah Province, Iraq", authored by Shaho Noori, Redvan Ghasemlounia, and Abbas Mohammed Noori (Istanbul, Turkey and Kirkuk, Baghdad, Iraq). They discuss the issues of identifying appropriate sites for rainwater harvesting in the Sulaymaniyah province, Iraqi Kurdistan region. These processes have been done by using remote sensing, Geographic Information System (GIS) techniques, and multi-criteria decision-making (MCDM). Analytical hierarchy process (AHP) model has been used to find out suitable locations for water harvesting. The criteria considered were runoff, slope, soil type, land cover, and drainage density. Each factor was assigned to its weight depending on its effect. Based on the findings, the average region that is outstanding and very well suited for water collection is 32% of the whole area. The model that has been applied in the current study is extremely significant and supportive for water resource management.

Rajalakshmi D., Dhanya Praveen, Jagannathan R., and Geethalakshmi V. (Delhi and Tamil Nadu, India) authored "Futuristic Climate Change Impacts on Rice and Groundnut Production Over Tamil Nadu State, South India" (Chap. 14). This chapter discusses the research findings and reviews regarding the futuristic climate change on two major crops, rice and groundnut of Tamil Nadu state in India. The future impact assessments and adaptations for the crops, rice and groundnut projections, for future decades are explicitly discussed using the crop simulation models output by various researchers. The crop yield predictions based on the outputs from the crop simulation models indicated that the yield of these crops decreases due to the increase in temperature, but when we consider the carbon dioxide fertilization effect, the declining yield for both the crops showed a minimizing trend. Sowing date adjustments is one of the agronomic adaptations to offset negative impacts. The increasing trend for some decades despite the increase in temperature was due to the nature of the C3 crops that has high carbon dioxide compensation point. After assessing the impact, this review also focuses on the existing and suggested adaptation strategies proposed for climate resilience. This information can assist the decision-makers in selecting appropriate and climate smart strategies to ensure food security, minimizing climate risks and sustainable agriculture development in the futuristic climate.

Part V of the book combines the description and analysis of four chapters (Chaps. 15–18) relating to *Sustainable Adaptive Options to Combat Global Warming and Climate Change*. Chapter 15 is the study of "Assessment of Soil Suitability for Sunflower Cultivation in Sagar Island, India" and was carried out by Sabir Hossain Molla and Rukhsana (Kolkata, India) based on secondary sources of data. This chapter provides an important method to evaluate the suitability of soil for sunflower (Helianthus annuus, L.) cultivation in the coastal saline agro-ecological environment of Sagar Island, based on the essential soil quality requirements such as soil texture, soil pH, electrical conductivity (E.C), organic content, soil depth, nitrogen (N), phosphorus (P), and potassium (K). To generate suitability map layers using weighted sum overlay techniques in the ArcGIS 10.5 platform, an analytical hierarchical procedure (AHP) has been used to rank the various suitability factors. The entire Island has been classified into four suitable classes, namely 'highly suitable (S1)', moderately suitable (S2)', marginally suitable (S3)', and not suitable (N)' areas. Accordingly, more than 80% of the study area were found to be highly (54.48%) and moderately (30.03%) suitable for sunflower crop production. Overall, the findings revealed that the soil fertility of the study area has a huge potentiality for the sunflower crop. Therefore, the present research provided information at the local level that could be used by farmers to select cropping patterns and suitability.

Asraful Alam, Nilanjana Ghosal, Amir Khan, and Lakshminarayan Satpati (Serampore and Kolkata) work on the "Agricultural Bill 2020 in India: Agricultural Policy and Transition to Sustainable Agriculture and Self-reliance" (Chap. 16) and try to discuss the newly introduced agricultural bills by discussing their strength and weakness, also after understating the new agricultural bills to find out the main reason behind the recent ongoing farmer's protest toward the new farm bills, and third, to link the present agricultural policy with the sustainable agriculture and self-reliance. It is observed that the newly introduced agricultural policy has created much confusion among the farmers of our country. Thus, it is suggested that the Government of India should clarify all the fears and confusions of the farmers and guide them well about the new agricultural bills to achieve self-sustainability and self-reliance in the agricultural sector.

Chapter 17 is the study of "Urban Heat Island (UHI) Resilience Plan in Varying Climatic Conditions Using Geospatial Approach: A Case Study of Rajkot City" and was carried out by Mit J. Kotecha, Shruti Kanga, Sagar K. Pankhaniya, Sneha Agrawal, and Gowhar Meraj, Suraj Kumar Singh (Gujrat, J&K, and Jaipur, India). In this study, the Land Surface Temperature and Ambient Air Temperature of Rajkot city were assessed. They derived isotherm for Rajkot city for three locations: Madhapar chowk, Trikon Baug, and Atika industrial areas having different typologies. The discrepancy between LST and Ambient air temperature has been found out. Some environmental factors such as carbon dioxide and carbon monoxide, which contribute to the UHI effect, were analyzed for these locations. From the analysis, UHI's resilient strategies, effectiveness, and resilience were established to help provide recommendations for applying resilient strategies. The four central resilient systems are integrating reduction and response of UHI for existing policies and programs, strengthening and building green infrastructure, alleviating cool roofs, and creating cool road infrastructure.

"Identifying Suitable Sites for Alternative Agriculture in Drought-Prone Akarsa Watershed, West Bengal" (Chap. 18), is authored by Ujjal Senapati, Shrinwantu Raha, Tapan Kumar Das, and Shasanka Kumar Gayen (Cooch Behar, India). This research chapter is designed to identify the alternative agricultural sites with the help of Analytic Hierarchy Process (AHP) and weighted overlay technique. To do this, nine parameters are selected which are distance from settlements, proximity to ponds, slope, ground water, drainage density, land use-land cover (LULC), distance from roads, distance from vegetations, and distance from drainage.

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Kolkata, India

Dr. Asraful Alam
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Asraful Alam is an Assistant Professor and HoD at the Department of Geography, Serampore Girls' College, University of Calcutta, West Bengal, India. He received his M.A. and Ph.D. degrees in Geography from Aligarh Muslim University, Aligarh and Aliah University, Kolkata, India respectively and also completed PG Diploma in Remote Sensing and GIS. Dr. Alam completes his Post Doctorate (PDF) from Department of Geography, University of Calcutta, Kolkata, India. Earlier he was an Assistant Coordinator in PG Department of Geography, Calcutta Women's College, University of Calcutta, Kolkata, India. His research interests include Climatology, Health Geography, Population Geography, Agricultural Geography and Remote Sensing and GIS and Developmental Studies. He has contributed various research papers published in various reputed national and international journals and edited book volumes. He has authored jointly edited books entitled "Habitat, Ecology and Ekistics: Case Studies of Human-Environment Interactions in India", "Agriculture, Food and Nutrition Security: Case Study of Availability and Sustainability in India", "Agriculture, Environment and Sustainable Development: Experiences and Case Studies", "Life and Living through Newer Spectrum of Geography", and "Self-Reliance (Atmanirbhar) and Sustainable Resource Management in India". He was a convener in the National Seminar on Self-reliance (Atmanirbhar), Sustainable Development and Environment 25th and 26th March 2022 Sponsored by Indian Council of Social Science Research (ICSSR) organized by Department of Geography, Serampore Girls' College. Dr. Alam has served as a reviewer for many International journals (GeoJournal, Journal of the Indian Society of Remote Sensing, SN Social Sciences, Applied Geomatics, Frontiers in Geochemistry, Asia Pacific Journal of Public Health, Environment, Development and Sustainability, Journal of Public Affairs, Applied water science and BMC Public Health etc.). Dr. Alam has served as an Editorial Board Member in peer-reviewed International Journal of PLOS One, Earth Science, Scientific Journal of Health Science Research and Frontiers in Geochemistry.

Rukhsana is currently serving as an Assistant Professor in Department of Geography at Aliah University, Kolkata. She obtained her doctoral degree in Geography from Aligarh Muslim University. Dr. Rukhsana has published more than 40 research papers in reputed journals and four books at national and international levels. Dr. Rukhsana has presented a number of research papers and she was also conferred with the International Young Geographer Award. She has attended XXV FIG International Congress 2014, Malaysia, and ICGGS-2018, Bangkok, Thailand. She has supervised four Ph.D. students. Her research interests include agriculture, urban population, environment and development in geography. She has supervised four scholars leading to the award of Ph.D. degrees in Geography. Dr. Rukhsana has successfully completed one major research project sponsored by ICSSR, New Delhi. She has been the Head of the Department of Geography at Aliah University.

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Part I
Global warming and Climate Change: Vulnerability in Agricultural Sectors

Chapter 1
Climate Change Impact, Agriculture, and Society: An Overview

Asraful Alam and Rukhsana

Abstract Primary economic activity, notably agriculture, is heavily reliant on the environment and weather; therefore, climate change has a significant impact on this sector. It is crucial to recognize and give priority to the regions and communities that are mostly at risk at the subnational level as the effects of climate change continue to worsen and put strain on the agricultural sectors and livelihoods of many industrialized and developing countries. This overview provides some basic information about current understanding on agriculture, climate change, and society. It introduces the concepts of agriculture and climate change and conceptualizes the part of books part. This chapter reviews the relevant literature to the effects of climate change on agricultural productivity and aims to provide a global-scale overview of all relevant impacts, to inform a wider assessment of the climate risks to global agriculture and society specially in developing nation. While farmers are often flexible in dealing with weather variability from time to time, there is still a high degree of adaptation to the local climate in the form of established infrastructure, local agricultural practice, and personal skill. Therefore, climate change can be expected to affect agriculture, potentially threatening established aspects of the agricultural system but also providing opportunities for improvement.

Keywords Agriculture · Climate change · Society · Adaptation issues · Vulnerability

1.1 Introduction

Climate change and its effects on the global ecosystem and human life in numerous ways, such as energy and food security, flood and drought frequency, water resource management, and transportation systems, are currently the most important topics of

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discussion (Mukhopadhyay et al., 2016; Ramos, 2001; Mandal et al., 2021). The natural system of the planet has been substantially impacted by population growth and resource use due to economic development, which is straining the ecosystem on a worldwide scale (Paul et al., 2021). The global average sea level rose by 0.20 [0.15–0.25] m during 1901 and 2018 (Masson-Delmotte et al., 2021). The basic underpinnings of human livelihood are threatened by environmental deterioration, and as a result, poor people will be obliged to use natural resources for survival (Rukhsana et al., 2021b). Inappropriate land use, fast urbanization, and deforestation cause climatic change during an industrial revolution. In addition to harming human health, global warming has disastrous effects on agricultural production and food security. Because their output stability depends on the availability of water, climatic factors, and physiographic characteristics of the land, agricultural sectors become the most imbalanced sectors. In agricultural landscapes, the interaction between human activity and natural processes is crucial for development and enhancing adaptive ability in response to climate change (Farina, 1998). The agricultural sector is being severely impacted by climate change, which is disastrous for agricultural production, food security, and livelihood security and underscores the need for a shift to sustainable development (Lobell et al., 2011). Climate change is anticipated to significantly rise in the near future, particularly in emerging countries (IPCC, 2018; Rukhsana et al., 2021a). Crop productivity, production, water quality, resources, and moisture content are all impacted by weather variability, irregularity, and the abrupt onset of natural calamities like floods, droughts, cyclones, etc. (Tang et al., 2008).

In developing world, where smallholders account for a sizeable amount of GDP in the primary sector, agricultural growth is crucial for reducing poverty and generating jobs (Alam & Hasan, 2018).

The Nobel Prize winner Svante Arrhenius (1859–1927) predicted more than a century ago that a doubling of atmospheric CO_2 concentration would result in a temperature increase of approximately + 5–6 °C (Arrhenius, 1896). Surprisingly, his rough estimate is greater but not significantly different from the + 2.0–4.5 °C rise currently anticipated by the Intergovernmental Panel on Climate Change (IPCC, 2007a). Collectively, his estimates with prior research indicating that the use of fossil fuels may drastically change the amount of carbon dioxide in the atmosphere (Högbom, 1894). Ultimately, Arrhenius was the first to foresee the prospect of anthropogenic global warming (Weart, 2008). Homo sapiens, anatomically modern humans, have lived on the planet for almost 300,000 years (Stringer & Galway-Witham, 2017). Climate variations and the availability of food resources coming from the many different plants and animals on which humans depended directly affected the growth and decline of human populations. During the Holocene, a geological age that started around 12,000 years ago, human life on earth and our place within that web of life underwent significant change. In certain regions of the world, a higher reliance on wild grains has been made possible by an unparalleled triad of climate stability and mild temperatures. Agriculture and expansive state societies were the results of this rising dependency over the following several thousand years (Gowdy & Krall, 2014). Sedentary agriculture only took a few thousand years to spread and take over in the Middle East, South Asia, China, and Mesoamerica. By the beginning of the Common Era (CE) 2000 years ago, agriculture had caused the global human population to increase from 4 to 6 million to over 200 million people in that comparatively short amount of time (Biraben, 2003). Compared to more developed nations, developing nations are frequently thought to be more susceptible to the effects of climate change (Smit et al., 2001), with unequal distribution of the harmful effects of climate change being blamed to the developing world's poor potential for adaptation. The capacity for adaptation of a society or an individual may be closely related to vulnerability (Few, 2003).

One of the sector's most susceptible to the upcoming climate change is agriculture. Weather and climate continue to play a significant role in determining agricultural output throughout the majority of the world despite the technological advancements made in the second half of the twentieth century, such as the Green Revolution. The potential for agricultural production is anticipated to be significantly impacted by the predicted changes in temperature and rainfall patterns, as well as the effects these changes will have on water availability, pests, disease, and extreme weather events. Despite the possibility that global warming could marginally increase crop production in the short term (before 2030), according to literature on the economics of climate change, it will eventually have a negative impact over the longer term (Bruinsma, 2003; IPCC, 2007b). There are several ways that the climate might impact agriculture. A number of significant factors, including rainfall, temperature, soil moisture, and carbon dioxide (CO_2) concentration, affect agricultural productivity (Challinor et al., 2005). Like, the modelling studies described in previous IPCC reports show that crop yields in temperate regions are likely to gain from moderate to medium increases in mean temperature (1–3 °C), coupled with accompanying CO_2 increases and rainfall changes. However, mild temperature rises (1–2 °C) are predicted to have a detrimental effect on main crop yields in low-latitude locations. Any region would experience negative effects from warming of greater than 3 °C (IPCC, 2007b). Even though there have been many major worldwide improvements and significant advancements in food production, the shocking degree of world hunger has not decreased. More than 820 million people experience daily hunger, a number that has been gradually rising over the last three years, and 2 billion people suffer malnutrition, food insecurity, and malnutrition, according to the most recent State of Food Security and Nutrition (Alam & Ghosal, 2021).

1.2 Climate Change and Vulnerability in Agricultural Sectors

Due to its extensive reliance on temperature and weather conditions, agriculture is the sector most vulnerable to climate change. A major threat to food security and rural livelihoods, particularly in developing nations, is climate change, which has the greatest impact on the agricultural sector because of its reliance on weather and climate conditions. The majority of people live in developing countries, which are the most populous and where agriculture accounts for the majority of livelihoods. As a result, it is crucial to identify and give priority to the subnational sectors and communities that are most vulnerable to the effects of climate change (Paul et al., 2021). The purpose of this study is to create a replication strategy that gives local climate change and data restrictions a higher priority than the vulnerabilities of agricultural and rural livelihoods. The direct effects of climate change on agricultural productivity, including temperature rise, variable rainfall, and extreme weather events, make agriculture one of the most sensitive economic sectors (Mendelsohn & Dinar, 2009).

Fussel (2007) claims that assessments of climate-related vulnerability are based on the features of the vulnerable system, which include physical, economic, and social aspects. Through changes in the global average temperature and precipitation, climate change will have a significant influence on people and ecosystems in the next decades. In the past two decades, a rising volume of research has identified climate change as the top environmental concern and examined the vulnerability and biodiversity loss. The degree to which a system is vulnerable to or unable to withstand negative consequences of climate change, particularly climate variability and extremes, is known as vulnerability (IPCC, 2001). Vulnerability in the context of climate change is defined by the IPCC (2007a) as "the extent to which a system is sensitive to, and unable to cope with, detrimental effects of climate change, including climate variability and extremes". A system's sensitivity and adaptive capacity, as well as the type, severity, and rate of climatic change and variation to which it is exposed, determine its level of vulnerability. As a result, agricultural vulnerability to climate change can be explained, for instance, in terms of exposure to high temperatures, the sensitivity of crop yields to those temperatures, and the capacity of farmers to adapt to the effects of this exposure and sensitivity, such as by sowing crop varieties that are more heat-resistant or switching to a different kind of crop.

According to the IPCC's fourth assessment report, there is no longer any doubt about the climate change system's warning, as is now clear from measurements of increasing sea levels, melting snow and ice throughout most of the world, and global air and ocean temperatures. In contrast to developed countries, developing countries suffer negative effects (Stern, 2006). For example, one in 19 people in the developing world experienced climatic distress on an annual basis from 2000 to 2004 (Watson, 2007), and flooding also had a negative impact on the lives of 68 million people in East Asia and 40 million people in South Asia (Watson, 2007). More than 14 million people died in India, 7 million in Bangladesh, and more than 1000 people died throughout South Asia in Asia in 2007. The IPCC predicts that climate change will affect agricultural productivity in both good and negative ways (IPCC, 2007a). Consequently, these climate calamities make people's livelihoods in India more sensitive because they are already susceptible to the standard issues of poverty, food security, etc. There is a claim that India is especially susceptible to the predicted effects of climate change due to its high population density, limited capacity for adaptation, and numerous distinctive and priceless ecosystems (including coral reef, expansive deltaic regions with rich biodiversity, desert ecosystem, Himalaya ecosystem, coastal ecosystem, etc.) as well as extensive low-altitude agricultural activities (Roy, 2007). There are 360 million undernourished and 300 million poor people in India, making it the country with the highest rate of hunger and deprivation in the whole globe. Food supply sustainability is turning to become a crucial problem. Food grain production has grown slowly, actually declining from 1996 to 2008. Instead of the 3.5% annual growth rate attained in 1980, it climbed by just 1.2% per year, from 199 to 230 million tonnes.

1.3 Agriculture Under Changing Climatic and Society

The consequences of high temperatures are already having an impact on people's ability to work, which has significant ramifications for non-mechanized subsistence farming. Climate change is also already having an impact on the population's health issues. Global rural labour capacity decreased by more than 5% between 2000 and 2016 (Watts et al., 2015). Due to climate change, the regions of the world with the largest crop yield losses are also those that are most at risk from undernutrition (Watts et al., 2017).

In addition to being vulnerable to climate change, agriculture is one of the main contributors to it. A problem for the expansion of the agricultural sector as a whole is comprehending how the climate changes over time and modifying management techniques to produce a successful yield. Considering the geographical variations in rainfall, temperature, crops and crop systems, soils, and management practices, it is unclear how sensitive agriculture is to climate change. The actual temperature and precipitation fluctuations between years were substantially larger than those that were anticipated. Climate Change Projection Crop damage may grow as climatic variability rises. The complicated effects of global warming will have a diverse impact on various crops. Because 75% of the world's population resides in tropical areas and 2/3 of them make their living via agriculture, these areas are more dependent on it. Their way of life will be impacted by low levels of technology, a large variety of pests, diseases, and weeds, land degradation, uneven land distribution, and rapid population expansion. The six largest crops of the world—rice, wheat, corn, sorghum, soybeans, and barley—grow on 40% of the cropland, provide 55% of the calories from non-meat sources, and make up more than 70% of animal feed. Therefore, any influence on this crop will have a negative impact on food security (Alam & Satpati, 2021).

The long-term mean climate state has a significant impact on the nature of agriculture and farming practices in any given location; the infrastructure and experience of the local farming communities are typically appropriate to specific farming techniques and to a specific group of crops that are known to be productive underneath the current climate. In some circumstances, the best style of farming may alter as a result of mean climatic shifts away from existing conditions, requiring modifications to current methods in order to sustain production. Rising temperatures during the growing season can have a massive impact on agricultural output, farm incomes, and food security (Battisti & Naylor, 2009). The suitability and productivity of crops are expected to rise and extend northward in mid- and high latitudes, specifically for grains and cool-season seed crops (Tuck et al., 2006). Maize, sunflower, and soya bean crops, which are common in Southern Europe, might also be feasible further north and at higher elevations (Hildén et al., 2005). Expected significant increases in potential agricultural area for the next century in regions like with the Russian Federation, due to prolonged planting windows and generally more suitable growing conditions under climate, totalling to a 64% rise over 245 million hectares by the 2080s. Though these effects might be mitigated by technological advancement, by the 2050s, the aggregate wheat production might grow by 37–101%. Climate change can affect food supply, access to food, and food quality. Even moderate degrees of climate change may not necessarily benefit agriculture without adaptation by farmers because a rise in the mean seasonal temperature can advance the harvest season of many present crop varieties (IPCC, 2007a; Watson, 2007).

1.4 Climate Resilience and Adaptation Strategy in Agriculture Sector

A new approach to agricultural management called climate-resilient agriculture (CRA) aims to development (Duque-Acevedo et al., 2020). For example, using organic fertilizer instead of chemical fertilizer, and pesticide, results in a positive and significant effect on food production and soil health and decreases carbon emission for long-term higher productivity also reduce hunger and poverty in the face of climate change by adhering to the principles of sustainable and farm incomes under climate variability. Climate-resilient agriculture (CRA) is an approach that includes sustainably using existing natural resources through crop and livestock production systems (Koondhar et al., 2021). In the face of climate change, this strategy lessens hunger and poverty for future generations. Especially when done sustainably, CRA methods have the power to change the situation and maintain agricultural productivity on a local, national, and international scale. Climate-resilient practices lead to improved access to and use of technology, open trade policies, higher use of resource conservation methods, and increased crop and livestock tolerance to climatic stress. The majority of nations have been experiencing crises as a result of natural disasters and armed conflicts, but food security is negatively impacted by insufficient food supplies, volatility in the price of staple foods, a high demand for agrofuels, and abrupt weather changes.

Long-term adaptations involve significant structural modifications to overcome adversity, such as adjustments to land use to maximize production under new conditions, use of new technology, new land management approaches, and water-use efficiency-related techniques.

According to Reilly and Schimmelpfennig (1999), "seasonal variations and sowing dates; different variety or species; water supply and irrigation system; other inputs (fertilizer, tillage methods, grain drying, other field activities); new crop varieties; forest fire control, promotion of agroforestry, adaptive management with compatible species, and silvicultural practises" are all examples of the "other inputs" (FAO, 2005). The following are examples of possible responses: "reducing the risk to food security; recognizing current vulnerabilities; modifying agricultural research goals; preserving genetic resources and intellectual property rights; enhancing agricultural extension and communication systems; adjusting commodities and trade policies; increasing training and education; and identification and promotion of (micro-) climatic benefits and environmental services of trees and flora" (FAO, 2005).

Nations all across the world face hazards brought on by the climate, but developing nations are especially at risk due to their inadequate capacity for adaptation and strong reliance on industries that are sensitive to the climate, including agriculture. In East Africa (EA) and South Asia (SA), climate change has had a negative impact on agricultural production, and this is only predicted to get worse in the future. The average daily temperature in South Africa is expected to rise to close to 1.5–2 °C (Chevuturi et al., 2018). As the remaining bastions of world poverty with significant populations and recent economic growth, EA and SA are particularly vulnerable to climate-induced threats. In the light of this, adaptation is essential to protect agricultural production and lessen the negative effects of climate change on farmers' livelihoods. Along with mitigation strategies, adaptation to climate change is seen as a critical component in the fight against global warming. The definition of adaptation, a complicated, multifaceted, and multi-scale process, is "adjustments to behaviour or economic systems that lessen vulnerability of society in the face of scarcity or dangerous environmental change" (Adger et al., 2003). The adaptation reactions have been categorized based on the scale at which they occur; purpose, timing in relation to the climate stress, length, form/type, and impact; purpose, timing in relation to the climate stress, length, form/type, and impact; and purpose, timing in relation to the climate stress, length, form/type, and impact (Agrawal & Perrin, 2008; Bryant et al., 2000; Heltberg et al., 2009). Even though many adaptation choices are presently being used, more adaptation options than those being used now are needed to lessen future impacts (UNFCCC, 2007). Due to the diversity and complexity of farming methods and farmers' livelihoods, the effects of climate change on smallholder farms will be regionally specific and challenging to assess. Documenting local knowledge, attitudes, and practices can help with the problem of comprehending climate change consequences at the farm level.

1.5 Adaptive Options to Combat Climate Change for Agriculture Sustainability

Future food availability may be affected by increased storm severity and frequency, drought and flooding, changed hydrological cycles, and precipitation variability. We still do not fully understand the possible effects of irrigated agriculture versus rain-fed agriculture. Chronic food issues already exist in the underdeveloped countries. Yet another big obstacle that must be overcome is climate change. Even if the world's food supply may not be in danger, those who are least equipped to handle it will probably suffer additional negative effects (WRI, 2005). Anthropogenic global warming might damage 11% of arable land in developing nations, resulting in a drop in cereal production in up to 65 countries and a 16% fall in agricultural GDP (FAO Committee on Food Security, Report of 31st Session, 2005).

Planned adaptation and independent adaptation are the two basic categories of adaptation. A farmer might alter crops or employ various harvest and planting/sowing dates as an example of autonomous adaptation in response to shifting weather patterns. Planned adaptation measures are deliberate policy choices or response tactics, frequently multisectoral in scope, with the intention of changing the agricultural system's capacity to adapt or enabling particular adaptations. The planned selection and distribution of crops throughout various agroclimatic zones, the replacement of existing crops with new ones, and resource substitution brought on by scarcity are a few examples (Easterling, 1996).

Climate change adaptation and mitigation in agriculture should be tailored to the specific situation in question. Crop producers should think about their region's climate peculiarities, agricultural potential and needs, and the cost of applicable technologies when planning how to adapt to changing weather circumstances. Crop growers and experts alike are very concerned about agriculture and climate change adaptation. To help farmers, botanists are developing species that are more resilient to extremes in temperature and water availability. Ecologists support efficient soil management by minimizing resource depletion, encouraging carbon sequestration, protecting the environment, avoiding chemical applications, and lowering hazardous emissions (Easterling et al., 2007).

Aligning the scales (spatial, temporal, and sectoral) and accuracy of the information with the scope and character of the decision, however, is particularly crucial. For instance, if there is a strong correlation between local climatic patterns and anticipated climate changes, farmers may be able to adapt to short-term climate change by considering these trends, or they may do so by using climate forecasting at time periods ranging from daily to inter-annual. Given the considerable uncertainty at the finer spatial and temporal scales at which their decisions are made, farmers may find minimal use in long-term climate projections. On the other hand, general trends at bigger time and spatial dimensions that may be more accurately anticipated using current climate models may be very helpful as input (White et al., 2006). Understanding how short-term response methods may link to long-term alternatives may be a substantial benefit of adaptation research. This will help to ensure that, at the very least, management and/or policy decisions made over the next one to three decades do not jeopardize the capacity to deal with potentially more significant impacts later in the century.

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Chapter 2
Spatio-Temporal Changes of Rainfall Pattern Under Changing Climate in West Bengal, India

Debapriya Poddar, Tapash Mandal, and Jayanta Das

Abstract The study of rainfall variability is essential to the environmental researcher as it influences the agricultural-based economy like West Bengal. The primary aim of this research paper is to assess the inconsistent nature of the annual and seasonal rainfall of West Bengal. The 110 years (1901–2010) data of 18 meteorological stations of West Bengal are used in this study. The nonparametric Mann–Kendall (MK), modified Mann–Kendall (mMK), and Sen's slope estimator (Q) are used to detect the trend and magnitude of the trend. Furthermore, the sub-trends of the data series are estimated using the innovative trend analysis (ITA) method. The percent bias (P_{BIAS}) method is also used to compare the second half with the first half of the data series. The results of the ITA showed Alipore (2.64) and Balurghat ($Q = -2.17$) had a maximum increasing and a decreasing trend in the annual rainfall. On the seasonal, summer (56%) and post-monsoon (100%) seasons are dominated by increasing trends, while decreasing trends dominate monsoon (61%) and winter (56%) seasons. The results of the MK/mMK and $P_{BIAS,}$ more or less similar to the ITA, confirm its reliability for trend detection. The findings of this study can provide a proper way to develop future projects, as it can clarify the reliable information about the rainfall variability throughout the year and can also afford a power of sustain for water resources and agricultural development.

Keywords Rainfall · ITA · MK/mMK · Climate change · Agricultural development

2.1 Introduction

Climate change is an alarming environmental issue in the modern age, responsible for changing the different climatic parameters such as precipitation, temperature,

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humidity, and evapotranspiration (Ahmad et al., 2018; Chen et al., 2017). Such changes have been expanded throughout the world uninterruptedly (Lee & Dang, 2020; Al Mamun et al., 2023). According to the Intergovernmental Panel on Climate Change 2012 (IPCC), climate change is a principal cause of rising extreme weather indices in several parts of the world. Precipitation is one of the essential meteorological variables affected by climate change. The changing precipitation scenario alters numerous crucial sectors of the economy, such as agriculture, irrigation, and transport (Lee & Dang, 2020). It also influences the flood and drought events, generates a considerable difference between the water supply and water requirement, eventually affecting the entire hydrological system at global and local scales (Jain et al., 2013; Wu et al., 2013). However, the spatial and temporal consistency of rainfall widely varies worldwide (Sa'adi et al., 2019), predominantly affecting the spatial distribution of water resources (Dore, 2005; Wu & Qiana, 2017; Alam et al., 2023). India receives about 80% of annual precipitation from the South Asian summer monsoon (Sravani et al., 2021). But the changing nature of the environment is vastly hindering agricultural production and water resources management systems, which is immensely affecting the agricultural-based economy of India (Gosain et al., 2006; Kalra et al., 2008; Lal, 2000; Lee & Dang, 2020; Mukherjee, 2017; Pal et al., 2015; Patle & Libang, 2014). Hence, some essential and accurate information concerning long-term precipitation trends is necessary to get an idea about any region's water resources (Sun et al., 2018).

Numerous studies have been conducted on rainfall variability at regional, national, and global scales using parametric and nonparametric approaches (e.g., Mann–Kendall test, Sen's slope estimator, Spearman's rho, linear regression, etc.) (Pingale et al., 2014). Most of the studies based on MK or mMK test revealed rainfall in India show both positive and negative trends for monthly, seasonally, and annually (Bhutiyani et al., 2010; Gadgil et al., 2007; Joshi & Kumar, 2006; Kumar & Jain, 2011; Mondal et al., 2012; Mandal et al., 2021a, b). The methods used in these studies are generally for trend detection, and it requires some assumptions regarding the data, such as independence from autocorrelation and normality distribution (Singh et al., 2021). To overcome this problem, Şen (2012) has proposed a newly trend analysis technique, i.e., innovative trend analysis (ITA), which many researchers have used successfully in their area of study (Ay & Kisi, 2015; Cui et al., 2017; Kisi & Ay, 2014; Saplıoğlu et al., 2014). This new method can analyze the different time series data by identifying sub-trends from the graphical representation, which is impossible in the MK test (Kisi & Ay, 2014; Wu & Qian, 2017). In addition, the ITA method has universal contextually compared to MK or mMK test (Mandal et al., 2021).

West Bengal is India's most popular agricultural-based state. The livelihood pattern of most of the people of West Bengal relies on an agro-based economy. So, timely occurrences of adequate rainwater are significant for the inhabitants as proper growth of crops entirely depends on rainwater. However, the state's agricultural system is hampered regularly due to its divergence rainfall. The irrigation facility is also directly or indirectly dependent on sufficient rainwater. According to Pal et al. (2015), the entire state experienced varied and inadequate rainfall, which utterly affects agricultural production. Similarly, the tea industry of the Dooars region is threatened by the massive changes in precipitation and temperature as such industries near the Darjeeling district have been struck by the increased temperature and decreased rainfall in the last 20 years (Mallik & Ghosh, 2021). On the other hand, as it is situated in the adjacent vicinity of the Bay of Bengal, it experiences tremendous low pressure arise from this ocean, creating heavy rainfall and producing extreme floods, especially in the Sundarbans region (Nandargi & Barman, 2018). Therefore, the present study on the long-term variation of precipitation and its trends in West Bengal will be most significant for forecasting climatological disasters (flood and droughts) and water resources management (Ghosh et al., 2009).

The principal aim of the present work is to find out the spatial and temporal variation of rainfall trends (1901–2010) at annual and seasonal scales using MK, mMK, and Sen's slope estimator. Additionally, the ITA method has been used to analyze the rainfall characteristics with its sub-trend of the data series. The ITA has also been used to justify the results of the MK or mMK test. P_{BIAS} identifies the percentage of increasing and decreasing trends of the second half of the entire period concerning the first half. Therefore, the present study exhibited the potentiality of comprehensive statistics to better understand the rainfall distribution patterns over space and time.

2.2 Materials and Methods

2.2.1 Study Area

West Bengal situated between 21º31′ and 27º13′14″ north latitudes and 85º45′20″ and 89º53′ east longitudes having a unique landscape with heterogeneous relief features. The northern part is enclosed with the mountain ranges. In contrast, the western segment is covered with the plateau region, while the broad plain is situated in the central part. On the other hand, the coastal area with a deltaic formation is concentrated in the southern section of West Bengal. The countries of Bangladesh delimit it in the eastern region, Nepal and Bhutan in the north-eastern segment, and the Indian states of Odisha existed in the southward's direction, Jharkhand, Bihar occupied the western section, Sikkim and Assam situated in the northeast corner of the West Bengal (Fig. 2.1). Based on the latitudinal extension, the northern province of West Bengal confines in the temperate belt due to the Tropic of Cancer passing 6 km north of Nabadwip. The southern segment lies in the tropical belt. But this part obtains an ample amount of rainfall as the prevailing marine climate decreased the extreme hot condition. Excluding the mountainous belt of Darjeeling and Jalpaiguri, the whole state experiences a tropical monsoon with warm wet weather. Besides this, the western part of West Bengal, characterized by the plateau region, has practiced significantly less rainfall and temperature variation. On the other hand, marine effects in the coastal area have experienced a moderate and pleasant climate.

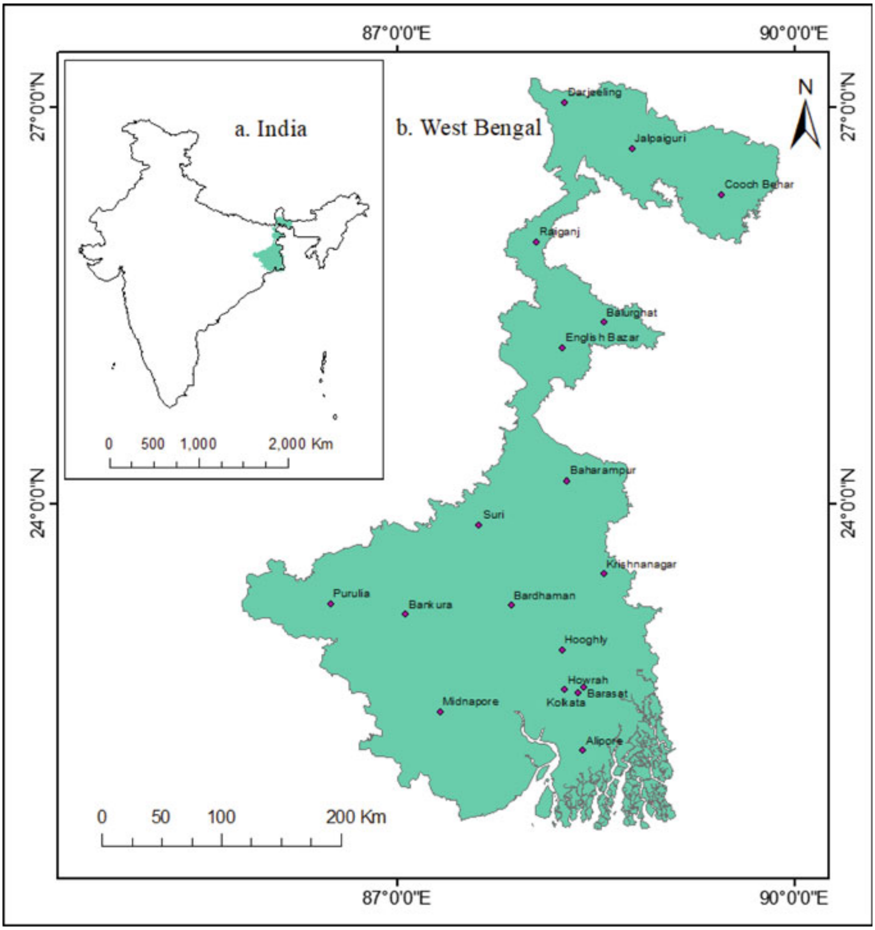

Fig. 2.1 Study area **a** India, **b** West Bengal with rain gauge stations

2.2.2 Data Sources

The present research work applied three popular trend analysis statistics (MK, mMK, and Sen's slope estimator) and the autocorrelation function to identify the inconsistency in the precipitation trends from 1901 to 2010. Moreover, the ITA method was also used to examine the variant precipitation at 18 climatological stations throughout the state and compare its consequences with MK, mMK, and Sen's slope estimator test. On the other hand, the exclusive method of Percent Bias is also used to detect the percentage of the inconsistency of the second half of the entire series in relation to the first half. For the above analysis, the required data of 18 meteorological stations of West Bengal for the year 1901–2010 have been taken from the India-water portal.

2.2.3 Autocorrelation Function

In 1999, Von Storch and Navarra recommended that, at first, the entire series should be pre-whitened to reject the serial relationship from the series. After that, the MK test should be applied. These research works integrate this proposal in both the MK test and Sen's slope estimator test.

The trends of sample data which are probably significant (m_1, m_2, … m_n) are examined with the subsequent measures:

(1) At first calculate the lag-1 serial correlation coefficient, which is represented by P_1. The given equation evaluated the lag-1 serial correlation coefficient of sample data of m_i

$$P_1 = \frac{\sum_{i=1}^{N-1}\left(M_i - \overline{M}\right)\left(M_{i+1} - \overline{M}\right)}{\sum_{i=1}^{N}\left(M - \overline{M}\right)}, \quad (2.1)$$

$$E(m_i) = \frac{1}{n}\sum_{i=1}^{\mathrm{n}} m_i. \quad (2.2)$$

In the above equation, $E(m_i)$ denotes the sample data with the mean value and n represented as the sample size.

(2) If the result of P_1 is characterized with a non-significant trend at a 5% level; subsequently, the statistical test of MK test and Sen's slope estimator is used.

(3) If the result of P_1 is characterized with the significant trend, then at first apply the MK and Sen's slope estimator test; afterward, the time series of 'pre-whitened' might be acquired by $(m_2 - p_1 m_1, m_3 - p_1 m_2, \ldots, m_n - p_1 m_{n-1})$

The natures of the test have highly influenced the significance level of the critical value of p_1, whether it may one-tailed test or a two-tailed test. In a one-tailed test, the alternative hypothesis is usually that the true p_1 is more significant than '0'. But in the case of a two-tailed test, the alternative hypothesis is that the true p_1 is different from '0' (zero), with no particular positive or negative result. By the following formula, the limits of the probability of an independent series for p_1 can be presented (Anderson, 1942) as

$$p_1 = \begin{cases} \frac{-1+1.645\sqrt{n-2}}{n-1}, & \text{one tailed test} \\ \frac{-1\pm1.96\sqrt{n-2}}{n-1}, & \text{two tailed test} \end{cases}, \quad (2.3)$$

where

n denotes the sample size.

The one-tailed test is most appropriate if there are several causes to assume positive autocorrelation—otherwise, the two-tailed examination is considered more suitable.

2.2.4 Method of Innovative Trend Analysis (ITA)

In 2012, Sen offered a newly statistical test of trend analysis, i.e., innovative trend analysis. This method splits an entire series into equal two fragments, independently arranged in rising order. Afterward, the first sub-series (X_i) is sited on the horizontal (X) axis, and the second sub-series (Y_i) is sited on the vertical (Y) axis in a Cartesian coordinate system which is two-dimensional. The actual nature of these two concerns sub-series specifies with no trend. On the other hand, the dots of the scatter plot diagram establish on a 1:1 line (45°). The points positioned on the upward side of the 1:1 line demonstrated that the time series had experienced a rising trend. In contrast, the opposite part of the points placed under the 1:1 line indicates a decreasing order of trend. The different absolute values of y and x positioned at the horizontal and vertical axis represent the distance from the 1:1 line (Şen, 2014). Thus, it can conduct to measure the trend of any time series. And the average disparity indicated the general trend. On the other hand, the average variation must standardize as it compares the trends of two sequences with varying magnitude. In favor of direct comparison, the chief task is to multiply 10 with the indicator to achieve a similar result of the MK test and Sen's slope estimator. Subsequently, the indicator of ITA is expressed as follows:

$$\beta = \frac{1}{n}\sum_{i=1}^{n}\frac{10(Y_i - X_i)}{\mu}, \tag{2.4}$$

where β symbolizes a trend indicator with the positive value specify a trend of increasing order, and the negative value indicated the trend with decreasing order. On the other hand, the total number of observations of all sub-series expresses by n. X_i and Y_i represent as the mean value of the observed data in the first sub-series and second sub-series. The symbol μ is the average of the first sub-series.

2.2.5 Mann–Kendall (MK) Test

Kendall (1938); Kendall and Gibbons (1975) and Mann (1945) invented the nonparametric statistics of the MK (Mann–Kendall) test. This technique is more suitable and well recognized in identifying the trends pattern in the meteorological and hydrological time series (Chaouche et al., 2010; Cui et al., 2017; Das et al., 2020a, b, c). In this test, H_0 denotes the null hypothesis, representing the independent nature of the data, and haphazardly distributes as it has no significant trend. And $H_{1,}$ another hypothesis, has the monotonous trend. The statistical test k is equated

$$k = \sum_{s=1}^{n-1}\sum_{r=s+1}^{n}\mathrm{sign}(x_r - x_s), \tag{2.5}$$

where nth value denotes the number of total observations, x_s and x_r are the sth and rth ($r > s$) observations in the time series. On the other hand, sign $(x_r - x_s)$ denotes the sign function explained as follows:

$$\begin{aligned} \mathrm{Sign}(x_r - x_s) &= +1 \text{ if } x_r - x_s > 0 \\ &= 0 \text{ if } x_r - x_s = 0 \\ &= -1 \text{ if } x_r - x_s < 0 \end{aligned} \tag{2.6}$$

When the nth value is higher than ten (10), then the distribution of k has experienced an average trend (Kendall & Gibbons, 1975). The formula of VAR(S), i.e., the variance of S, is

$$\mathrm{VAR(S)} = \frac{1}{18}\left\{N(N-1)(2N+5) - \sum_{l=1}^{g} G_l(G_l-1)(2G_l+5)\right\}. \tag{2.7}$$

The above equation N denotes the number of groups of tied, G_l means as some ties of extent l. The statistic K as the standard regular test applies for perceived a significant trend which is represented as

$$\tau = \frac{K}{D}, \tag{2.8}$$

where

$$D = \sqrt{\frac{1}{2}N(N-1) - \frac{1}{2}\sum_{l=1}^{g} G_l(G_l-1)}\sqrt{\frac{1}{2}N(N-1)}. \tag{2.9}$$

The assessment of (K) and VAR(S) applies to computed the suitable measurement of Z is implemented when $n > 10$ (Gilbert, 1987)

$$Z = \begin{cases} \frac{K-1}{\sqrt{\mathrm{VAR}(S)}}, & \text{if } K > 0 \\ 0, & \text{if } K = 0 \\ \frac{K+1}{\sqrt{\mathrm{VAR}(S)}}, & \text{if } K < 0 \end{cases}. \tag{2.10}$$

The standardized Z value follows a normal distribution and also characterizes by the variance of '1' and the average of '0'. It has been used to determine the significant trend level (Das et al., 2019).

2.2.6 Modified Mann–Kendall Test

The modified MK (mMK) test is applied when the autocorrelation coefficient of the given data is significant at lag-1 to avoid the serial dependency in the concerned series (Basak et al., 2021; Das et al., 2021a). The VAR(S) can evaluate with the help of the given formula:

$$\mathrm{VAR}(S) = \left(\frac{N(N-1)(2N+5)}{18}\right), \left(\frac{N}{N_e^*}\right) \tag{2.11}$$

For autocorrelated data, the correlation factor $\left(\frac{N}{N_e^*}\right)$ is fix as follows:

$$\left(\frac{N}{N_e^*}\right) = 1 + \left(\frac{2}{N^3 - 3N^2 + 2N}\right) \sum_{j=1}^{N-1}(N-f)(N-f-1)(N-f-2)p_e(f). \tag{2.12}$$

$p_e(f)$ signifies the autocorrelation between observational ranks, which can access as follows:

$$p_e(f) = 2\sin\left(\frac{\pi}{6}p_e(f)\right). \tag{2.13}$$

2.2.7 Sen's Estimator Method

This nonparametric test (Sen, 1968) is generally applied to perceive the magnitudes of the trend pattern of the time series data. It also uses it to compute the changes that happen per unit time. The trend slope has increased or decreased appearances in the seasonal and annual time series (Das and Bhattacharya, 2018). With the help of the following equation, the slope of N can be first evaluated.

$$Q_i = \frac{x_r - x_s}{r - s}, \quad i = 1, 2, \ldots N, \quad r > s, \tag{2.14}$$

x_r and x_s symbolize the data's values at time r and s ($r > s$) from the above equation. A positive Q_i value stands for a rising trend, whereas a negative Q_i value stands for a declining trend.

Sen's slope estimator test has broadly applied in hydrological time series and meteorological time series (Tabari & Marofi, 2011; Yue & Hashino, 2003).

2.2.8 Percent Bias

In the present study, the percent bias method is used to determine the percentage change in rainfall between the first and second half of the time series, (Mandal et al., 2021b; Das et al., 2021b).

$$\text{PBIAS} = 100 - \sum_{i-1}^{n} \frac{Y_i}{X_i} \times 100, \quad (2.15)$$

where (PBIAS) represents Percent bias, n represents the entire length of individual sub-series; X_i and Y_i are signified as the value of observed data in the first and second sub-series, respectively, with a positive score indicating an inclining trend and negative score indicating a declining trend in respect of first sub-series.

2.3 Results and Discussion

2.3.1 Exploratory Statistics

The study area has experienced a varying mean annual rainfall of 1281.60–2420.10 mm with a mean value of 1595.31 mm during the hydrological period of 1901–2010. The highest mean rainfall is observed at Jalpaiguri (2420.10 mm ± 17.61), higher than the state's average rainfall. In contrast, the lowest mean rainfall is found at Purulia (1281.60 mm ± 23.24). The mean annual rainfall of 28% of the stations has exceeded the state's average annual rainfall. The study area has a sharp gradient from the west to the north-eastern region with an increasing trend. (Table 2.1). Moreover, the standard deviations (SD) of annual rainfall varied from 210.14 mm (Krishnanagar) to 429.33 mm (Raiganj), whereas coefficient of variation (CV) values range from 14.61 mm (Krishnanagar) to 29.80 mm (Raiganj station). The CV slope represents a sharp gradient from the eastern part to the western part of West Bengal with an increasing trend.

2.3.2 Autocorrelation Effect on Rainfall

Autocorrelation plots for the seasonal and annual rainfall distribution of 18 weather stations have been presented in Fig. 2.2. The analysis is conducted to check the randomness and periodicity among the rainfall time series. From the analysis, it is found that both positive and negative serial correlations characterize the annual and seasonal rainfall except post-monsoon. At the same time, the post-monsoonal rainfall has experienced only positive serial correlations (Fig. 2.2e). Additionally, the

Table 2.1 Descriptive statistics of the annual rainfall of West Bengal

Stations	Lat	Long	Mean	SD	CV	Skewness	Kurtosis
Bankura	23.16	87.06	1412.50	212.85	15.07	0.57	1.09
Bardhaman	23.23	87.86	1415.37	217.99	15.40	0.67	0.72
Suri	23.84	87.62	1387.00	233.56	16.84	0.56	0.46
Cooch Behar	26.34	89.45	2172.21	346.75	15.96	1.07	2.20
Balurghat	25.37	88.56	1484.00	225.57	15.20	−0.13	−0.21
Darjeeling	27.04	88.26	2156.30	359.48	16.67	1.09	2.54
Howrah	22.60	88.26	1601.10	269.65	16.84	0.45	−0.11
Hooghly	22.90	88.25	1526.90	254.69	16.68	0.55	0.11
Jalpaiguri	26.68	88.77	2420.10	426.21	17.61	1.45	3.34
Kolkata	22.57	88.36	1585.70	273.37	17.24	0.54	−0.01
English Bazar	25.18	88.25	1382.99	210.45	15.22	0.14	−0.22
Midnapore	22.43	87.32	1578.73	241.93	15.32	0.50	0.28
Baharampur	24.18	88.28	1401.53	215.53	15.38	0.36	0.22
Krishnanagar	23.47	88.56	1438.45	210.14	14.61	0.38	0.58
Barasat	22.62	88.40	1601.60	265.13	16.55	0.42	−0.17
Purulia	23.25	86.50	1281.60	297.84	23.24	−1.91	8.11
Alipore	22.14	88.40	1428.80	270.26	18.92	0.56	0.24
Raiganj	25.98	88.05	1440.70	429.33	29.80	−2.34	5.84

Krishnanagar for annual rainfall and Darjeeling for post-monsoon rainfall showed the weakest and strongest serial correlations in the study period. On the other hand, entire stations have no evidence of the significant negative serial correlations seasonally. Surprisingly, all the stations except for Kolkata have experienced a significant positive serial correlation in the post-monsoon season (Fig. 2.2e). Similarly, Cooch Behar in the monsoon season and Jalpaiguri in the winter have experienced a significant positive serial correlation (Fig. 2.2d, b).

2.3.3 Annual and Seasonal Trend by ITA

Analysis of annual and seasonal precipitation trends using ITA is presented in Figs. 2.3 and 2.4a. The results obtained from ITA showed more than 50% of the stations had a decreasing trend. The decreasing trends are observed in the Bankura, Bardhaman, Suri, Darjeeling, Balurghat, English Bazar, Baharampur, Purulia, and Raiganj weather stations distributed over the whole West Bengal. At the same time, Cooch Behar, Howrah, Hooghly, Jalpaiguri, Kolkata, Midnapore, Krishnanagar, and Barasat showed an increasing trend. This rising trend has occurred from north to

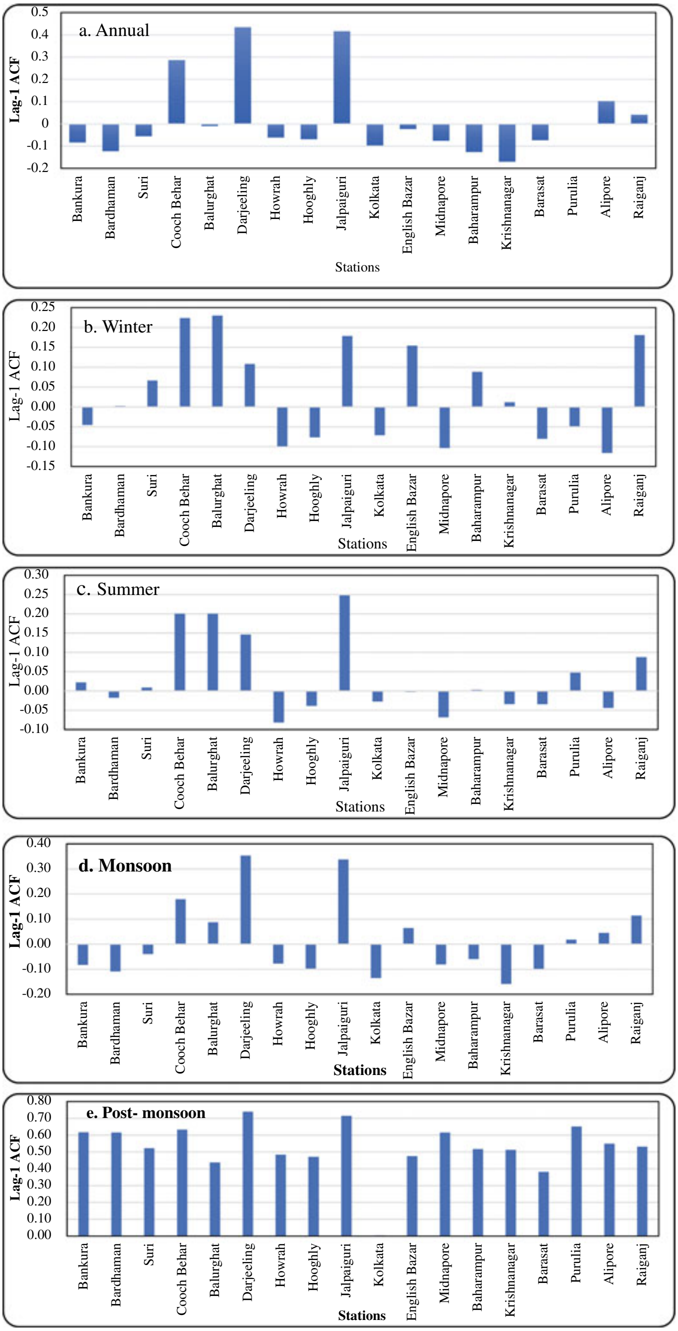

Fig. 2.2 Lag-1 autocorrelation function of the stations **a** annual rainfall, **b** winter rainfall, **c** summer rainfall, **d** monsoonal rainfall, and **e** post-monsoonal rainfall

southward to the Murshidabad station and from the south to north direction up to Krishna Nagar and Birbhum (Fig. 2.4a.).

On the other hand, the summer season showed a decreasing trend of 4.44% of the stations covering the Middle East to the southwest part of West Bengal. In contrast, the remaining stations have acquired an increasing trend with the slope direction

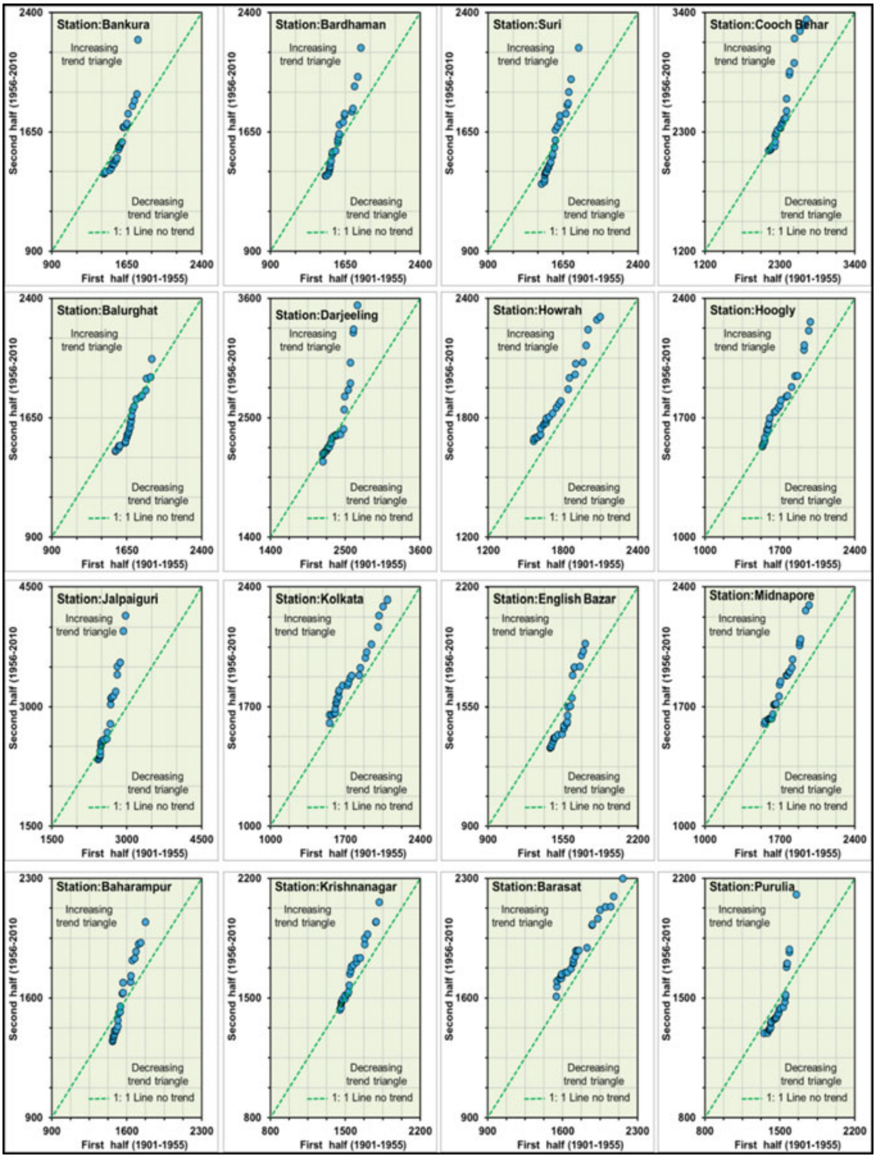

Fig. 2.3 ITA of the annual rainfall of the selected stations

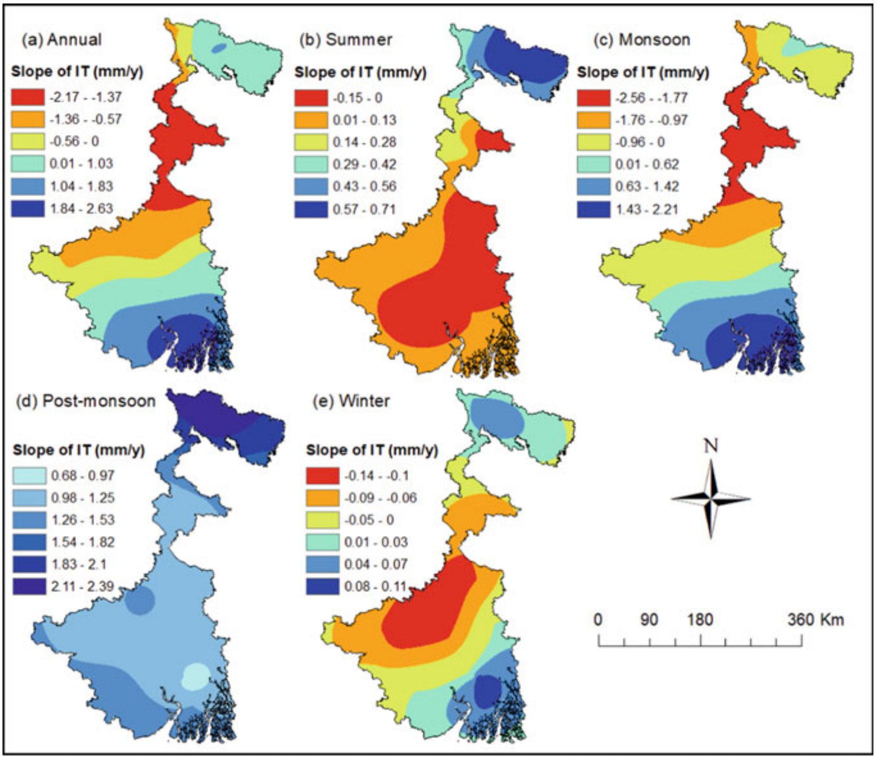

Fig. 2.4 Spatial distribution of slope of the ITA **a** annual, **b** summer, **c** monsoon, **d** post-monsoon, and **e** winter

from north to south. In the monsoon period, about 39% of stations obtained a rising trend with the gradient from north to the south except the central part, which ultimately practiced a declining trend. However, the Cooch Behar is considered a trendless station in the monsoon season. The post-monsoon season has experienced an increasing trend, which is the source of the flood in West Bengal. In addition, more than half (55.55%) of the stations in the winter season have shown a decreasing trend. In all season except for post-monsoon, Bardhaman, Balurghat, and Baharampur have shown a decreasing trend, whereas Cooch Behar, Jalpaiguri, Kolkata, and Alipore, showed no decreasing trend in all seasons, positioned in the extreme north and southern segment. Conversely, Darjeeling is the only weather station with a decreasing trend in the monsoon and the annual rainfall series. In contrast, Howrah showed a decreasing trend only in the summer season. Furthermore, the descending trend is observed over Hooghly and Midnapore weather stations in the summer and winter seasons, respectively. At the same time, a similar result receives by Krishna Nagar in the summer, monsoon, and winter series, and Barasat in only the summer season (Fig. 2.4).

2.3.4 Annual and Seasonal Trend by MK/mMK Test

Table 2.2 and Figs. 2.5, 2.6 represent the result of the annual and seasonal rainfall trends, using the MK, mMK, and Sen's slope estimator. From the annual rainfall trend, it is found that about 27.8% of weather stations are statistically significant ($P < 0.05$). However, the significant decreasing (80%) trends are dominated the study area for annual rainfall. Only one station, i.e., Alipore, has experienced a significant increasing trend, located in the southern segment of this state. Significant decreasing tendencies have been observed in the central part of West Bengal. Raiganj has experienced a maximum rate of decreasing trend (− 3.1 mm/year). This negative trend has also been gradually increased toward southern and northern West Bengal (Fig. 2.5a). Mukherjee (2017) and Pal et al. (2015) have also found the same consequence in their research regarding the significant rising trend of West Bengal.

The distributional pattern of rainfall at different seasons has also been experienced wide variation. Such as out of 18 stations, three (16.66%) stations in summer, five (27.8%) in monsoon, and one (5.55%) in post-monsoon season, are statistically significant at a 5% significant level. Significant ($P < 0.05$) positive trend in the summer season has been noticed in Cooch Behar, Darjeeling, and Jalpaiguri, situated in the northern part of the study area. Whereas, in the post-monsoon season, only English Bazar in Malda district showed a significant increasing trend. On the other hand, in the monsoon season, a significant ($P < 0.05$) positive trend has been observed at Alipore, located in the southern part of West Bengal. Still, a significantly decreasing trend at a 0.05% significant level has been found at four stations of Balurghat, English Bazar, Baharampur, and Raiganj. The English Bazar of Malda district has obtained the highest decreasing trend and the rate of − 1.88 mm/year (Fig. 2.6).

2.4 Percent Bias

P_{BIAS} is the most recently introduced method that divided the entire rainfall series of 110 years into two sub-series, i.e., the first series extended from 1901 to 1955 and the second series extended from 1956 to 2010. It represents the percentage of inconsistent nature of the rainfall of the second series in comparison with the first series. The results of the P_{BIAS} show that about 44.44% of stations of annual rainfall have experienced an increasing trend, located mainly in the southern and extreme northern parts. However, the rest of the stations have acquired a declining trend. The most robust decreasing trend in the second half has been noticed at the station of Balurghat (Fig. 2.7). Besides this, in the summer season, seven meteorological stations, situated in the southern and Middle Eastern part of West Bengal, have attained a decreasing trend in the second half concerning the first half. At the same time, the rest of the stations have shown an increasing trend, with the maximum in Jalpaiguri and the minimum in Bankura (Fig. 2.7).

Table 2.2 Results of the MK, mMK test statistics *Z*, Sen's slope estimators *Q* for annual and seasonal rainfall time series (1901–2010)

Season	Annual		Summer		Monsoon		Post-monsoon		Winter	
Statistics	*Z*	*Q*	*Z*	*Q*	*Z*	*Q*	*Z*	*Q*	*Z*	*Q*
Bankura	−0.28	−0.21	0.26	0.051	−0.28	−0.184	1.22	0.175	−0.71	−0.055
Bardhaman	−0.86	−0.52	−0.09	−0.019	−1.11	−0.652	1.49	0.247	−1.07	−0.086
Suri	−1.25	−0.883	0.7	0.128	−1.86	−1.143	1.92	0.339	−1.39	−0.12
Cooch Behar	1.35	1.206	2.67*	0.872	0.83	0.632	1.21	0.25	1.06	0.054
Balurghat	−2.23*	−1.54	−0.37	−0.06	−2.84*	−1.81	1.91	0.36	−0.92	−0.05
Darjeeling	0.91	0.89	2.12*	0.58	0.47	0.64	0.66	0.14	0.33	0.02
Howrah	1.22	1.03	−0.59	−0.13	1.02	0.72	1.79	0.51	−1.16	−0.1
Hooghly	−0.02	−0.02	−0.44	−0.1	0.04	0.03	1.43	0.32	−1.04	−0.09
Jalpaiguri	1.57	1.92	2.98*	0.93	1.28	1.26	0.35	0.07	1.23	0.06
Kolkata	1.64	1.18	−0.29	−0.06	1.92	1.19	0.91	0.16	0.17	0
English Bazar	−1.9	−1.22	0.93	0.16	−3.06*	−1.88	2.30*	0.43	−1.14	−0.06
Midnapore	1.48	1.1	0.13	0.03	1.45	0.82	1.37	0.32	−0.99	−0.09
Baharampur	−2.15*	−1.45	−0.8	−0.16	−2.20*	−1.45	1.78	0.33	−1.78	−0.12
Krishnanagar	0.06	0.05	−0.39	−0.11	−0.15	−0.07	1.54	0.27	0.29	0.02
Barasat	1.47	1.12	0.23	0.04	1.11	0.82	1.41	0.39	0.32	0.03
Purulia	−2.18*	−1.52	0.69	0.11	−1.03	−0.65	0.87	0.12	−1.62	−0.16
Alipore	3.35*	2.63	0.54	0.12	3.03*	1.98	1.89	0.51	0.3	0.03
Raiganj	−3.90*	−3.1	0.73	0.13	−2.62*	−1.52	0.96	0.16	−0.41	−0.02

Z, normalized test statistics; Q, Sen's slope per decade
*Statistically significant trends at the 5% significant level

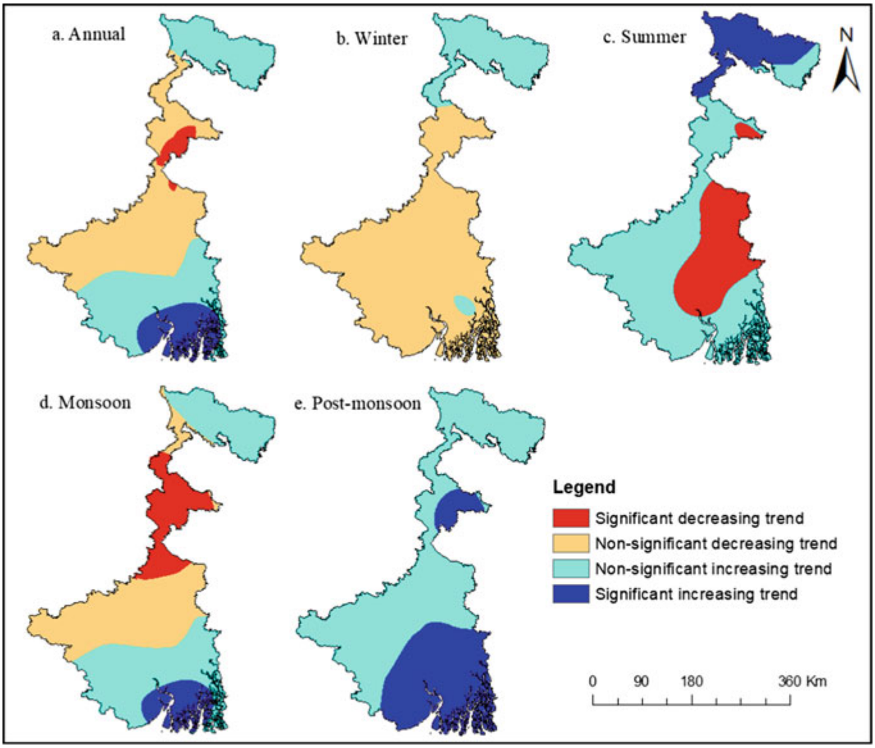

Fig. 2.5 Spatial distribution of trend of different stations **a** annual rainfall, **b** winter rainfall, **c** summer rainfall, **d** monsoonal rainfall, and **e** post-monsoonal rainfall

2.5 Comparisons Between the Trend Analysis Methods

The reliability of the recently introduced ITA method is estimated by comparing its result with the result of Z statistic, i.e., MK/mMK, and Sen's slope for annual and seasonal rainfall, is presented in Fig. 2.8. The comparative assessment of these three methods has been conducted by quadrantal analysis. Figure 2.8a, b shows the scattered plots of ITA slope and the Z statistics of MK/mMK and ITA and Sen's slope. These two scatter plots represent the maximum points (97%) drop inside the first and third quadrants. From this, it is identified that the general agreement has prevailed in these three methods. The remaining 3% points fall in the 4th quadrants, showing a discrepancy in the rainfall trend, revealing insignificant magnitudes. The results show a robust statistical relationship between the ITA slope and the Z of MK/mMK and ITA slope with Sen's slope. Therefore, the reliability of these three methods of trend identification affirms that the ITA is more efficient and dependable as it can easily evaluate the trend of the hydrological and meteorological time series data at low, medium, and high values through the diagrammatical presentations (Wu & Qian, 2017).

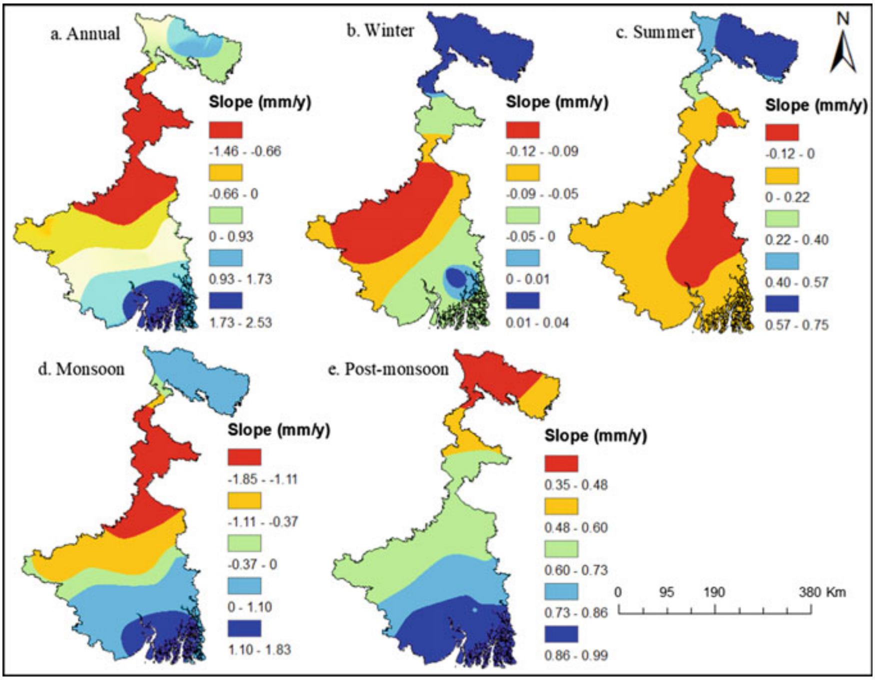

Fig. 2.6 Magnitude of change of different stations **a** annual rainfall, **b** winter rainfall, **c** summer rainfall, **d** monsoon rainfall, and **e** post-monsoon rainfall

2.6 Discussion

The present work investigates the inconsistent nature of rainfall on the annual and seasonal scale over West Bengal. The state is situated adjacent to the vicinity of the Bay of Bengal, experiencing great vagaries in the monsoonal and annual rainfall. Hence, the state's climate is affected by wet monsoonal air streams blow from the south to the southeast Bay of Bengal during the monsoon season. So, West Bengal's water resources entirely depend on the summer monsoon precipitation, which carries the moisture from the Bay of Bengal and the Arabian Sea. This season the mountainous region and foothills of the Himalayas and the Sundarbans of West Bengal received more rainwater. The low pressure over the southern part of West Bengal is responsible for heavy rainfall, causing massive floods in the Sundarbans region (Nandargi & Barman, 2018). Also, the middle part of the state is characterized by the flood-prone area, which is the primary source of agricultural practices. Although, the quantity of summer monsoon rainfall decreased due to high temperatures throughout the state due to the summer solstice. Recently, West Bengal has suffered from the declining trend of monsoonal rainfall and the inclining trend of post-monsoonal rainfall (Pal et al., 2015; Mukherjee, 2017).

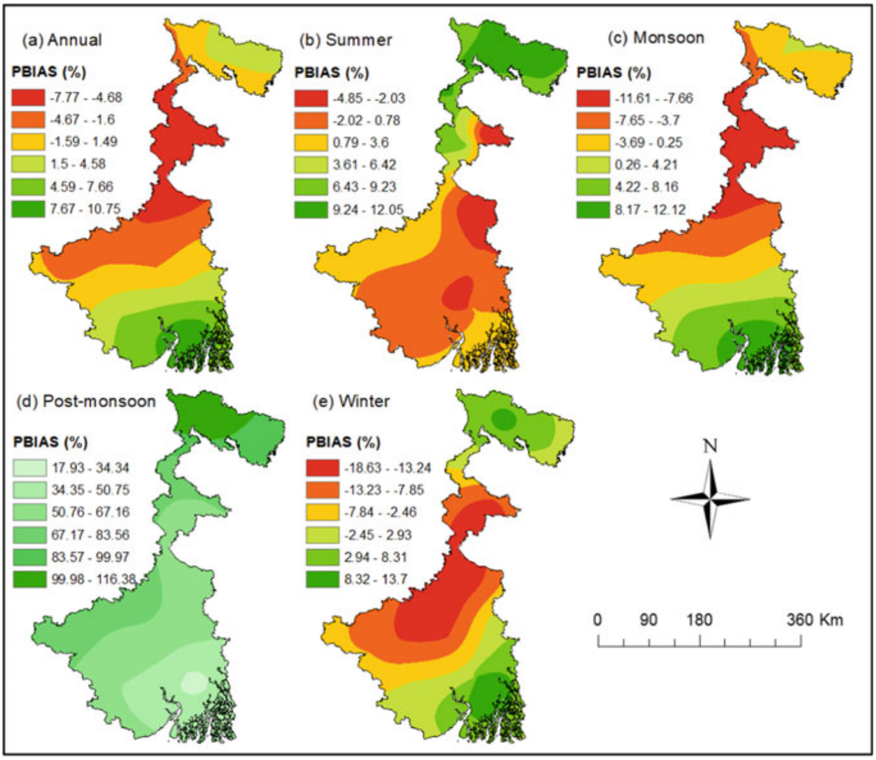

Fig. 2.7 Spatial distribution of P_{BIAS} of **a** annual, **b** summer, **c** monsoon, **d** post-monsoon, and **e** winter

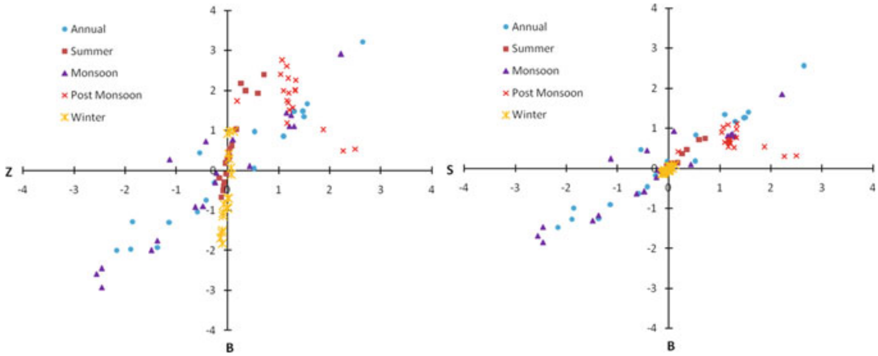

Fig. 2.8 Comparison of **a** *Z* statistic and innovative trend and **b** Sen's slope and innovative trend

Most of the stations of North Bengal experienced an inclining trend in the pre-monsoon period, whereas most of all stations in South Bengal have shown the opposite result. Therefore, it is clear that North Bengal is more suitable for boro cultivation than South Bengal. However, it is impossible without the use of an irrigation facility. The Malda district has shown an insignificant declining trend in the annual rainfall, representing a curious rain incidence. Therefore, agricultural activities suffered from an inadequate water supply; however, the agricultural lands are transformed into mango orchards due to their suitable environmental condition (Mukherjee, 2017). Likewise, the increasing rainfall trend in the post-monsoon in the study area apart from North Bengal has become anxiety for the flood prospects and crop defeat. Therefore, the agricultural land is facing water staging, and hence, the pre-harvested crops become damaged. The declined rainfall throughout the post-monsoonal series has affected the harvest of Kharif crops as it causes a severe loss of yield. Such an unpredictable trend is very much consideration for the economy of the entire West Bengal. According to Mukherjee (2017), the economy of West Bengal is purely agro-based, and rice is considered the principal crop.

2.7 Conclusion

The present work has investigated the inconsistent nature of annual and seasonal rainfall of West Bengal using ITA, MK/mMK, percent bias, and Sen's slope. The study also assessed the ITA's reliability by comparing its result with the Z statistic of MK/mMK and Sen's slope estimator. By analyzing the rainfall trend using the method mentioned above, it can be said that all the methods are more or less the same in terms of finding the significant trend. On the other hand, the climate changes impact has been significantly noticed in the study area's annual and seasonal rainfall pattern. Therefore, measuring future water accessibility at diverse spatio-temporal scales is obligatory as water demand is continuously increasing due to increasing population and agricultural and industrial purposes. The findings of this study provide a proper way to develop future projects as it explained the rainfall variability accurately, which can support many engineers and practitioners to construct the desirable infrastructures for managing the vulnerable conditions of floods and droughts hazards. Moreover, understanding the rainfall variability is also very effective for agricultural production. It will also help the local water management authorities to construct a wise and rational plan to satisfy and overcome all the challenges in the state in the context of rainfall change.

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Chapter 3
Evaluating Apiculture as a Sustainable Livelihood Option in the Wake of Climate Change: West Bengal, India

Anindya Basu and Sanghamitra Purkait

Abstract At present, climate change is an actual global threat affecting the bio-network and agricultural production adversely. Apiculture sector is part of agriculture which helps in maintaining ecological balance through pollination services rendered by the honey bees. In West Bengal, the state ranking second in honey production nationally, beekeepers from different districts, perusing modernized apiculture, migrate seasonally every year for collecting honey. This study evaluates the effect of changing climate on honey production in West Bengal by comparing the production details of varieties of associated crops during the years from 2010 to 2018. The paper wishes to confirm how sustainable this apiculture industry will be in the wake of climate change. A primary survey was also conducted on the beekeepers of West Bengal ($n = 339$) passing through the five "honey-flow" districts (South 24 Parganas, North 24 Parganas, Maldah, North Dinajpur, and South Dinajpur) to know their perception about climate change and its resultant impact on honey production. Simple statistical tools have been applied here for data analysis. To find out the changes in climatic condition, time-series analysis has been done over the years (1999–2020) based on linear trend model. To assess the perception of the beekeepers, Likert 5-point scale is applied and along with a SWOT analysis. Compound annual growth rate analysis used to find out the change of production of honey and associated crops establishes that apiculture fared as a more stable sector than other agriculture and horticulture alternatives during the selected timeframe. The study also revealed that flexible approach of the modern beekeeping in West Bengal involving variety of forage ensures the livelihood sustainability.

Keywords Climate change · Apiculture · Pollination · Honey flow · Perception · SWOT

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3.1 Introduction

The interaction between increasing human population and oscillating agricultural production is complex, but with efficient agricultural policies and strategies, adequate yields can be achieved to meet the growing demands (Tilman et al., 2011). Climate is the primary important factor for agricultural production. Climate change directly influences on food production over the world. The Club of Rome Report officially confirmed that the global warming as an international issue in 1972. The production of final yield can reduce by the increasing of the mean seasonal temperature (IPCC, 2007). Increasing atmospheric CO_2 concentrations directly effect on the growth rate of crop plants and weeds (Mall et al., 2017). It was highlighted in World Bank Climate-Smart Agriculture Report, 2021 that approximately 690 million people (8.9% of the world population) were suffering from hunger (World Bank, 2021) and this crisis will get further deepened with extreme vulnerability of this sector to climate change.

With the climatic variability—increasing temperature, irregular rainfall, frequent extreme weather events there are shifts in agroecosystem boundaries, lowering of yields, invasion of pests making the situation critical (FAO, 2021). Average of 30% crop yields decrease is expected by mid-twenty-first century in South Asian countries. North Indian states and Bangladesh are highly susceptible due to erratic changes in rainfall and temperature (World Bank, 2008). Any change in rainfall trend affects agriculture severely and Indian agriculture since ancient periods depended greatly on monsoon rains. There have been several instances where climate-induced production failures have happened—the changes of the pre-monsoon season have great impacts on the wheat production of the Indo-Gangetic Plain (Mahato, 2014). The production of rice suffered 40% due to five times severe droughts in one year in the states of Jharkhand, Odisha, and Chhattisgarh (Pandey et al., 2007). Ahluwalia and Malhotra (2006) showed that in India, due to increase of 1.5 °C temperature the rainfall decreases 2 mm and production of rice also reduced (by 3–5%).

To adapt to this, substantial investment needs to be made in farming and agricultural practices (Fraser et al., 2008) and besides emphasis on complementary avenues like animal husbandry, pisciculture, apiculture is also required. The diversity in flora provides additional prospects for the growth of beekeeping industry, hinting at the close relation between agriculture and apiculture. Both have a kind of symbiotic relationship, apiculture sector plays an important part in increasing the productivity of agricultural/horticultural crops, by giving pollination services and on the other hand from the flowering plants the honey bees gather the natural honey. Apiculture is the science and culture of honey bees and their management. On the basis of the latest production data of 2019 derived from FAO, average annual production of honey worldwide was about 1.85 million metric tonnes. China holds the first position with 444 thousand metric tonnes, followed by Turkey, Canada, Argentina, Iran, USA, Ukraine, and India in spite of having huge potential have slipped to eight position with 67 thousand metric tonnes (Statista, 2020). India ranks ninth in share of export value of honey and is the only country within top-ten who has suffered a decline in the growth of export value (Tridge, 2021). This production and export figures indicate that India has not been able to harness its full potential in apiculture and may be the climate change has also played its part in this. Though agricultural variations have influenced the quantity and quality of honey produced to some extent barring few cases like West Bengal where apiculture production has maintained its upwards trend in the wake of climate change. West Bengal is playing leading position for honey production in India (The Indian Blog, 2020). Modem beekeeping has come a long way from the traditional clay pots, log hives, bamboo baskets, and wooden boxes to movable frame, beehive based on the principle of bee spacing invented by Langsthroth in 1851 (Nicolaidis, 1955). By employing little investment in terms of locally available resources and skills, apiculture gives nutritive and medicinal products through tapping of natural materials like nectar and pollen of plants that were being wasted in forests and farms usually for not attending by any pollinator. In rural areas, beekeeping can be experienced as an extra source of income for rural people and it can be positively applied in poverty-alleviating schemes (Lietaer, 2009). Apiculture acts a vital part for developing the socio-economic condition of the residents of the rural areas by employing little investment in terms of locally available resources and skills (Joni, 2004). Beekeeping not only can help the people for improvement of sustainable livelihoods system but also for equilibrium of the environmental biodiversity (Makerere University, 2001).

Apiculture, which helps in pollination, an important activity in maintaining ecological system assisting in 76% of global crop production (Klein et al., 2007) also helps to give an answer to climate change through a resilient, adaptive nature of its functioning. The main thrust area of the study is to evaluate the effect of changing climate on honey production by comparing the production details of varieties of crops and honey across a time frame. The perception study of the beekeepers is an integral part of the study which establishes how apiculture is viewed as a sustainable livelihood option for socio-economic development addressing climate change.

3.2 Literature Review

Mathauda et al. (2000) investigated the effects of temperature on rice production in the Punjab by using the CERES RICE simulation model between 1970 and 1990. They categorized the weather scenario by five different conditions ranging from normal to extreme warm for the simulation modelling which projected that increasing temperature decreases the production of rice and also negatively affects other rice ascriptions such as biomass, crop duration, and straw yield. Aydinalp and Cresser (2008) in their research paper focused about the probable geographical impacts of climatic change on agriculture sector, not only the changing trends of crops but also economic significances of these changes of possible crop. This study also reviewed the effects of global warming on agriculture and the participation of farmers' adaptations in answering to climate change, probable effects of local agricultural systems, and also the changing designs of food production and values. The effects of climate change on honey bees at different levels were studied by Le Conte and Navajas (2008) and opined that climate change had direct influence on honey bee behaviour and physiology. Authors analysed that climate change can alter the quality of the floral environment and increase or reduce colony harvesting capacity, highlighted the great genetic capacity of honey bees to adapt to the changing conditions and advised to modify beekeeping approaches accordingly. Basak (2009) has analysed climate change impacts on Boro rice production in Bangladesh by using simulation model, which showed both increasing temperature and drop in minimum temperature adversely affected the production. Gornall et al. (2010) reviewed literature relevant to the impacts of climate change on global productivity of agricultural by an extensive variety of methods. This paper showed all relevant impacts, rather than concentrating on exact regions or methods, as the purpose of this assessment was to have a wider assessment of the risks to global food security.

According to Delgado et al (2012), climate change has impacts on services honey bees including honey production. This study is based on the comparison between contemporary and historical production of honey. This study revealed average decrease of total production of honey including changeability, over time, with present crops, and intended honey harvests at the municipality level by using beekeeping census data for the period 1998–2005. Study revealed that there was expected average reduction of harvested honey, including variability, over time. There produced honey was used as starting point to compare the behaviour of collective of four spatially explicit models that were established to forecast the production of honey. Schweitzer et al. (2013) pointed out that rainfall has direct negative impacts in honey production through the reduction of honey bees foraging activities (it prevents honey bees to go out the beehives and to fly) and also the dilution and/or the washing of nectar also occurs hampering the production. Agrawal (2014) in her paper studied the future scenarios of the apiculture industry and the policy changes that are required for the same. She tried to reason out the change of relative status of major honey-producing countries in international level and compared their competitive ability in honey export market. Abou-Shaara (2016) discussed about the possible differences in weather in Egypt during near future and also predicted that the increasing temperature may create major problems on apiculture sector specifically during summer in Egypt. This study rooted for using of Italian Carniolan honey bees for future beekeeping as they are more resistant to thermal stress. Ali and Jabeen (2017) revealed that the honey production and income of the honey producers decreased by 50% during the period of study in Zambia, compared with the normal rainy season and also said that lack of finance from banks and micro-finance institutions was the main challenge of the honey producers in using the new methods of production. Kumar and Joy (2017) discussed about the production issues and marketing problems of honey. The study revealed that beekeepers faced many difficulties due to globalization. It reported that this agro-based industry does not require any specific raw material like other industries and the raw materials in the form of nectar and pollen from flowers is freely available in nature, so only intent and expertise is needed to harness it; providing employment opportunity to many. Dutta (2018) made a comparative study among three agro-climatic zones (ACZ) of West Bengal taking into account topographical form, soil condition, land use, and its effect on economic condition of those ACZ of West Bengal. Rao et al. (2019) in their article discussed that global climate change, its causes and impacts are one of the most emerging issues in science and technology domain, and India is no exception. About 70% of the Indian population is directly or indirectly associated with agriculture and sub-sectors, and major Sustainability Development Goals (SDGs) are expected to be met from this sector. But the increasing global temperature and associated climate change is disrupting to achieve the desired goal. They pointed out that the beekeepers expressed several consequences which affect their bees as well as honey production like damage of collections, insufficiency of nectar, pollen and decline in pollination due to change in climate. Vercelli et al. (2021) addressed the issue of climate change effects on honey bees and beekeeping in Italy from the point of view of the beekeepers. The issues like weakening of colonies; scarcity of nectar, pollen; decrease in production; intensive transhumance; greater infestation by varroa; decline in pollination have come up but solutions like depending on different species, providing supplemental sugar feeding, controlling varroa have helped the beekeepers to cope with the climatic stresses and limit the adversities.

3.3 Objectives

The major objectives of the study are.

- To assess and compare the change in honey production with other associated agricultural and horticultural produces under changing climatic conditions (2010–2018).
- To conduct a perception study of the beekeepers about climate change and its impact on honey production to establish how apiculture is viewed as a sustainable livelihood option.

3.4 Study Area

Since West Bengal which ranks second in the national scenario of honey production and has diverse agro-climatic zones, it has been selected as the study area. On the basis of climate, soil and agricultural production West Bengal has been classified into six agro-climatic zones, namely the hill zone, Terai zone, old alluvial zone, new alluvial zone, red and laterite zone, and coastal and saline zone (Table 3.1). Apart from high diversity in natural vegetation, there is huge crop diversity too. There are various types of crops like food grains, oil seeds, vegetable, fruits, etc., in this state. Different food products grow in different agro-climatological zones and are impacted by different degrees of changing the weather parameter (State of Environment Report, 2016, West Bengal Pollution Control Board). The agriculture sector in West Bengal is characterized by the predominance of minor and bordering

Table 3.1 Outline of the study area based on agro-climatic zonation

Zone (under Indian agro-climatic region)	Districts covered	Soil type	Annual rainfall, maximum-minimum temperature
New alluvial zone	North 24 Parganas	Acidic to neutral	Temperature range: 15.6–35 °C Annual rainfall: 1200–1700 mm
Old alluvial zone	North Dinajpur, South Dinajpur, and Maldah	Mostly neutral, loamy in nature	Temperature range: 15.6–35 °C Annual rainfall: 1200–1700 mm
Saline coastal zone	24 South Parganas	Saline	Temperature range: 16–34 °C Annual rainfall: 1500–1700 mm

Source Environment Department, Government of West Bengal (2020)

agriculturalists (95.4%) who own 84% of the land with the per capita share of land being only 0.07 hectare (State of Environment Report West Bengal, 2016). So, even being a predominantly agricultural state, the landless cultivators often take resort to parallel income opportunities like horticulture, pisciculture, and apiculture as livelihoods.

As a study area whole of West Bengal has been covered, as it is difficult to spatially divide the apiculture sector in the state as the beekeepers are mobile and migratory in nature coving almost the whole district seasonally. But based on production the major honey-producing districts have been identified—Maldah, North Dinajpur, South Dinajpur, North 24 Parganas, and South 24 Parganas and are designated as the main honey-flow areas (Fig. 3.1). There honey-flow period generally extends from September to end of April of next year, when the temperature is moderate and rainfall is very scarce. Around sixty thousand beekeepers (Chaudhuri, 2020) from different districts of West Bengal migrate seasonally to these fields every year for honey collection. But the number of formally trained and registered beekeepers under the seven cooperative bodies is only around fifteen hundred as informed by the various Apiculture Cooperative Societies, of West Bengal. Mustard, mango, and litchi flowers are predominantly targeted for quality honey.

The state of West Bengal has consistently ranked second in the country during the phase 2016–2019 with positive compound annual growth rate (CAGR), while Uttar Pradesh leads the pack nationally (Table 3.2). Hence, modern beekeeping plays a vital role in West Bengal with positive growth rate indicating that apiculture has future sustainability.

3.5 Methodology

The entire paper is based on both primary and secondary sources of data. Secondary sources involve various reports, books, and journals relevant to this sector. This paper is based on a literature review and is explanatory in nature. Besides secondary data

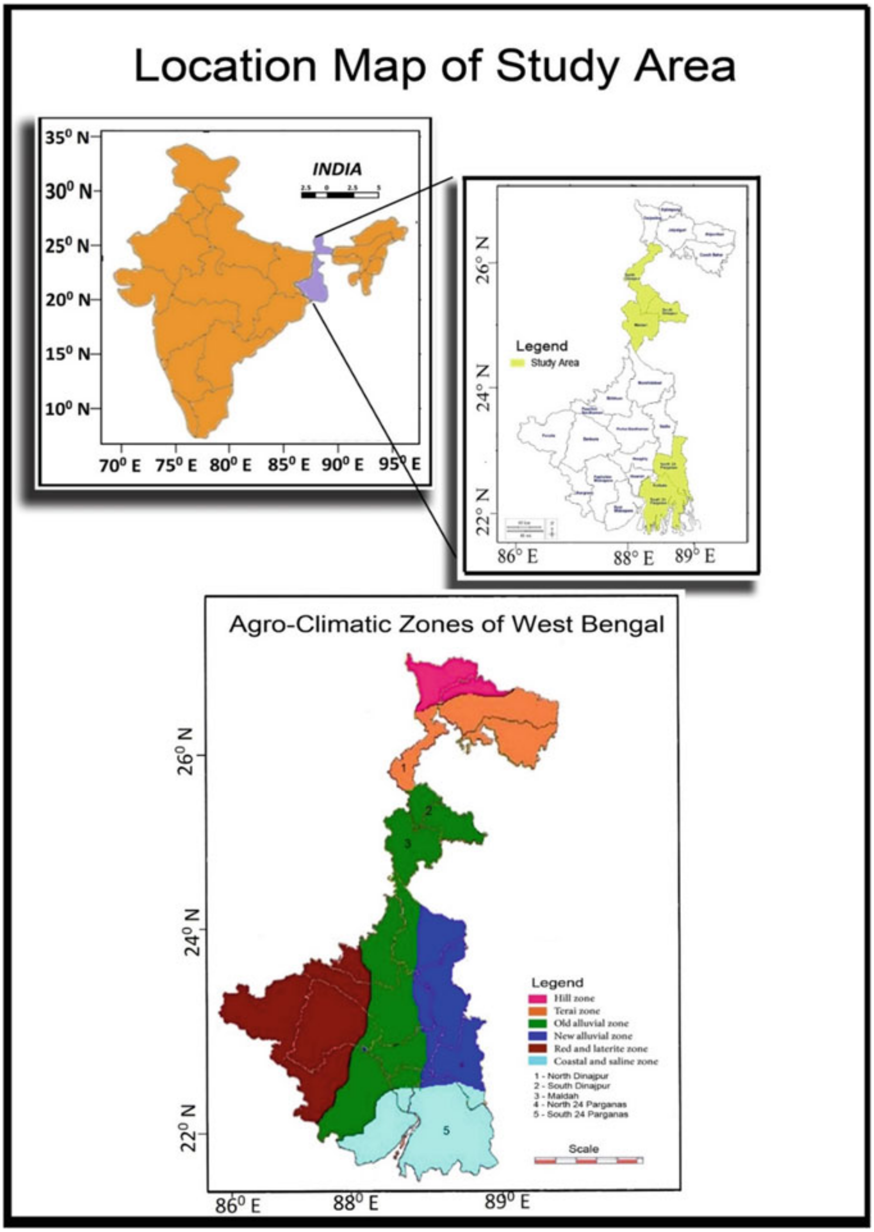

Fig. 3.1 Locating the study area (selected districts of West Bengal) on the basis of agro-climatic zonation and honey-flow region identification. *Data Source* Department of Agriculture, Government of West Bengal (2016)

Table 3.2 Status of honey production (in '000 tonnes) across India (2016–2019)

States	2016–2017	2017–2018	2018–2019	Mean	SD	CV (%)	CAGR (%)	Rank as per 2018–2019	Rank on mean
Uttar Pradesh	17	18.9	22	19.30	2.52	13.08	0.09	1	1
West Bengal	**15.8**	**16.5**	**18.5**	**16.93**	**1.40**	**8.27**	**0.05**	**2**	**2**
Punjab	15	15.5	16.5	15.67	0.76	4.88	0.03	3	3
Bihar	9	10	15	11.33	3.21	28.36	0.19	4	4
Rajasthan	6	8.5	10.5	8.33	2.25	27.06	0.21	5	5
Himachal Pradesh	5.2	5.5	6	5.57	0.40	7.26	0.05	6	6
Haryana	4	4.5	4.8	4.43	0.40	9.12	0.06	7	7
Uttarakhand	2.5	2.7	2.8	2.67	0.15	5.73	0.04	8	8
Madhya Pradesh	2.15	2.25	2.55	2.32	0.21	8.99	0.06	9	10
Karnataka	2	2.1	2.2	2.10	0.10	4.76	0.03	10	11
Kerala	2.7	3	2.2	2.63	0.40	15.35	−0.07	11	9
Jammu and Kashmir	1.15	2.1	2.2	1.82	0.58	31.90	0.24	12	14
Tamil Nadu	1.8	1.9	2.1	1.93	0.15	7.90	0.05	13	12
Andhra Pradesh	1.7	1.87	1.9	1.82	0.11	5.92	0.04	14	13
Maharashtra	1.5	1.65	1.7	1.62	0.10	6.44	0.04	15	15
Odisha	1.25	1.35	1.5	1.37	0.13	9.21	0.06	16	16
Jharkhand	1.25	1.35	1.5	1.37	0.13	9.21	0.06	17	16
Assam	1	1.2	1.25	1.15	0.13	11.50	0.08	18	18
Chhattisgarh	0.65	0.75	0.85	0.75	0.10	13.33	0.09	19	20
Telangana	0	0	0.76	0.25	0.44	173.21	*	20	24
Nagaland	0.45	0.55	0.7	0.57	0.13	22.21	0.16	21	21

(continued)

Table 3.2 (continued)

States	2016–2017	2017–2018	2018–2019	Mean	SD	CV (%)	CAGR (%)	Rank as per 2018–2019	Rank on mean
Gujrat	0.45	0.55	0.7	0.57	0.13	22.21	0.16	22	21
Sikkim	0.35	0.4	0.4	0.38	0.03	7.53	0.05	23	23
Manipur	0	0	0.35	0.12	0.20	173.21	*	24	27
Meghalaya	0.2	0.25	0.28	0.24	0.04	16.61	0.12	25	25
Mizoram	0.15	0.18	0.2	0.18	0.03	14.24	0.10	26	26
Tripura	0	0	0.18	0.06	0.10	173.21	*	27	28
Arunachal Pradesh	0	0	0.1	0.03	0.06	173.21	*	28	29
Others	1.3	1.5	0.28	1.03	0.65	63.73	−0.40	29	19
Total	94.55	105.05	120	106.53	12.79	12.01	0.08		

Source Agricultural and Processed Food Products Export Development Authority (APEDA) (2020) played an important part in identifying the changing climate (1999–2020) across the six agro-climatic zones on the basis of few weather components like mean maximum and minimum temperature (°C) and mean rainfall (mm) and on the basis of time-series analysis projection has been done for 10 and 20 years. A correlation between honey production in West Bengal with the climatic parameters has been done to find out the actual fact. Based on secondary data, this study had done the assessment of the honey production comparing it to other associated crops under the changing climatic conditions (2010–2018) using compound annual growth rate (CAGR) and year-on-year growth methods.

Primary survey was conducted involving the beekeepers following modern beekeeping methods. A questionnaire was prepared, including checklists, Likert Scale, and open-ended questions to ensure randomness and quantity of data. A total of 339 respondents have been surveyed covering the honey-flow zones of South 24 Parganas, North 24 Parganas, Maldah, North Dinajpur, and South Dinajpur districts, i.e. five districts. The snowball sampling method has been chosen as most of the beekeepers are very closely connected with each other. Likert 5-point scale is applied to judge the awareness of beekeepers about climate change and to analyse the perceptions of beekeepers about impact of climate change on honey production. On the basis of this personal interactions and focused group discussions, a strengths, weaknesses, opportunities, and threats (SWOT) analysis has been conducted to note whether climate change issues are matter of concern for the beekeepers.

3.6 Result and Discussion

3.6.1 Changing Weather and Honey Production Scenario

Apiculture has a long history, and the industry is in a continuous evolution. Honey hunting and thereafter fixed-comb hives of a range of types and sizes were used for primitive beekeeping that evidently continued over the centuries. Wild colonies were also captured and kept in primitive hives like log hives, clay pots or pitchers' hives, cylindrical jars hives, and basket hives in different parts of India. The adaptations of modern beekeeping techniques in world have motivated and triggered the development of modern beekeeping in India. India took many attempts to introduce modern beekeeping in different provinces of India. However, the first state to introduce the modern beekeeping in India is Bengal in 1882 (Suranarayana, 1994). Apis Cerana is known as the Asian hive bee because, like European bees, Apis Mellifera, it can be kept and managed inside a hive (Hilmi et al., 2011). But in West Bengal, keeping of these indigenous bees, Apis Cerana is declining. The beekeepers of West Bengal are more interested to keep Apis Mellifera bees. Though these native bees have various potential and adoptability to collect multifarious floral nectar in a climatically diverse state like West Bengal but for greater profits opt for the exotic ones. Honey hunting in Sunderban forests involves risk, uncertainty, and unscientific method; so, they are also presently opting to practice the modern beekeeping with the help of forest department, cooperative societies, or NGOs. This study includes only the modern beekeepers for the primary study.

As mentioned before, there are six types of agro-climatic zones in West Bengal and these regional variations providing floral diversities have helped to develop the bee-rearing activity and honey collection. To find out the changes in climatic condition time in these agro-climatic zones, time-series analysis spanning over 22 years (1999–2020) has been done based on considering linear trend model. Table 3.3 shows zone-wise trend equation (with origin at the mid-point of 2009 and 2010 and t unit = 1/2 year). Though not very pronounced but certain, it has noticed that there are certain changed in every zone of West Bengal.

Based on this, an estimation has been made how the climatic components are going to vary in the years to come, a span of 20 years, i.e. 2030 and 2040, assuming that the situation remains same. On the basis of the forecasting (Table 3.4), it can be said that in case of temperature (both mean maximum and minimum), a rising trend can be seen in all the zones excepting in old alluvium where mean maximum

Table 3.3 Time-series analysis (1999–2020) of few weather components across different agro-climatic zones of West Bengal

Linear trend	Weather components	Hill zone	Terai zone	Old alluvial zone	New alluvial zone	Laterite zone	Saline coastal zone	All West Bengal
Trend equation (with origin at the mid-point of 2009 and 2010 and t unit = 1/2 year)	Mean maximum temperature (°C)	$y = 15.42 + 0.01$ t	$y = 29.64 + 0.01$ t	$y = 33.27 - 0.004$ t	$y = 33.05 + 0.01$ t	$y = 32.73 + 0.01$ t	$y = 33.03 - 0.004$ t	$y = 29.52 + 0.01$ t
	Mean minimum temperature (°C)	$y = 8.77 + 0.02$ t	$y = 17.94 + 0.03$ t	$y = 22.50 + 0.01$ t	$y = 23.39 + 0.01$ t	$y = 22.82 + 0.01$ t	$y = 23.76 + 0.003$ t	$y = 19.86 + 0.01$ t
	Mean rainfall (mm)	$y = 3.93 - 0.05$ t	$y = 5.25 + 0.22$ t	$y = 3.47 + 0.11$ t	$y = 3.90 + 0.04$ t	$y = 5.06 - 0.01$ t	$y = 3.44 + 0.04$ t	$y = 4.18 + 0.06$ t
Slope	Mean maximum temperature (°C)	0.01	0.01	−0.004	0.01	0.01	−0.004	0.01
	Mean minimum temperature (°C)	0.02	0.03	0.01	0.01	0.01	0.003	0.01
	Mean rainfall (mm)	−0.05	0.22	0.11	0.04	−0.01	0.04	0.06

Data Source India Meteorological Department, Government of India (2021)

Table 3.4 Estimation of climatic variables (2030–2040) in agro-climatic regions of West Bengal on the basis of time-series analysis

Weather components	Year	Hill zone	Terai zone	Old alluvial zone	New alluvial zone	Laterite zone	Saline coastal zone	All West Bengal
Mean maximum temperature (°C)	2030	15.83	30.05	33.11	33.46	33.14	32.87	29.93
	2040	16.03	30.25	33.03	33.66	33.34	32.79	30.13
Mean minimum temperature (°C)	2030	9.59	19.17	22.91	23.8	23.23	23.88	20.27
	2040	9.99	19.77	23.11	24	23.43	23.94	20.47
Mean rainfall (mm)	2030	1.88	14.27	7.98	5.54	4.65	5.08	6.64
	2040	0.88	18.67	10.18	6.34	4.45	5.88	7.84

Source Calculations based on Table 3.3

shows a slight future dip, while in case of rainfall, the situation is critical for the hill zone where the mean rainfall shows a drastic dip while the rate of change is mildly positive for the rest.

But in spite of this changing climate, in case of India there has been a steep rise in honey production; from 72.20 thousand metric tonnes in 2012–2013, it has jumped to 105.30 thousand metric tonnes in 2017–2018 (National Bee Board, 2019). The trend has been similar for West Bengal too; from 6340 tonnes in 2010–2011, it dipped to 5070 tonnes in 2012–2013 and reached 16,500 tonnes in 2017–2018 (Directorate of Economics and Statistics, Government of India, 2020). In this case, the production increase looks more staggering not purely based on actual increase in production but there is a computational perspective too; during the period 2011–2013, involvement of middlemen in commercial honey gathering was very high and the honey was siphoned off out of the state of West Bengal without getting accounted for but with governmental intervention and proactiveness of the cooperatives now the state's production is counted for itself only.

Many secondary sources have been shown that the climatic changes impacted on agricultural and horticultural product. But this study reveals a different scenario, there is sustainability in honey production in the state of West Bengal, even under these changing climatic conditions. Poor production of one zone or with one associated crop is made up through good productions in other zones or other associated crops as beekeepers migrate in different zones throughout the year and the bees' collect varieties of nectars. It is also revealed (Table 3.5) there is no correlation between honey production with mean maximum and minimum temperature, and mean annual rainfall in West Bengal. These climatic conditions do not significantly impact the production of honey as all sig values are more than 0.05.

Table 3.5 Correlation between honey production in West Bengal with maximum and minimum mean temperature and mean annual rainfall

		Max temp	Min temp	Rain fall	Honey
Honey	Pearson correlation	0.030	0.392	0.455	1
	Sig. (two-tailed)	0.935	0.262	0.186	
	N	10	10	10	10
	Spearman's rho				
Honey	Correlation coefficient	0.042	0.406	0.624	1.000
	Sig. (two-tailed)	0.907	0.244	0.054	
	N	10	10	10	10

Data Source India Meteorological Department, Government of India (2021) and Directorate of Economics and Statistics, Government of India (2020)

3.6.2 Production Scenario of Crops Related to Apiculture

Honey bees play very significant role for cross pollinating various agricultural and horticultural crops/plants which helps to increase the total production of crops as well as their quality. Beekeeping needs massive number of varieties of flowering plants and in modern beekeeping no region is self-sufficient for collecting honey. During migration beekeepers shifting their bee boxes in different areas with varying weather conditions which are suitable for different types of flowering plants. Still, many forests and even agriculture, horticulture farms remain unvisited by any pollinator due to lack of exposure. Since, from various sources, it has been oft repeated that changing climate affects both agriculture and apiculture industry, from the database available for West Bengal an attempt is being made to understand the production variability.

Some major crops, on which the beekeepers predominantly depend while migrating with their bee colonies are taken for analysis as those do have a direct bearing on production of honey. Changes of productions of those crops may change the production of honey. Table 3.6 reflects the production of honey along with the productions those major crops of West Bengal during 2010–2011 to 2017–2018. Here, sunflower, gram, lentil (masur), other pulses, rapeseed and mustard, litchi, mango, linseed, sesamum, coriander, cumin, fennel, and fenugreek are taken as major crops. In this study, it is revealed that litchi (−1.70%), coriander (−0.35%), cumin (−0.56%), fennel (−0.10%), and fenugreek (−0.18%) had shown negative growth rate and climate change may be the one of the main reasons behind these decrements. But in this situation, it is also revealed that, the CAGR of honey production is higher (14.64%) than all other major crops except lentil.

It is found (Table 3.7) that all crops including honey had shown at least one negative growth during these seven years of study period. It is also noticed that except sesamum and honey, all had shown more than one negative growth during 2011–2012 to 2017–2018. Seven year mean year-on-year growth of honey production is 26.85 which is the highest among the all-major crops. In the year 2011–2012,

Table 3.6 Comparing the production scenario of honey and other closely associated crops (unit in '000 tonnes) involved in bee foraging in West Bengal (2010–2018)

Closely associated crops assisting honey production	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	CAGR (%)
Sunflower	7.40	13.80	15.00	20.00	22.00	17.00	20.00	10.00	4.40
Gram	20.00	20.00	30.00	40.00	30.00	40.00	28.50	36.80	9.10
Lentil (masur)	50.00	90.00	60.00	60.00	60.00	94.00	80.00	150.00	16.99
Other pulses	180.00	130.00	190.00	250.00	240.00	330.00	260.00	440.00	13.62
Rapeseed and mustard	419.60	380.00	470.00	490.00	480.00	500.00	490.00	720.00	8.02
Litchi	85.12	85.27	90.00	93.90	76.75	75.28	77.65	75.48	−1.70
Mango	620.17	661.53	735.00	430.71	799.65	693.39	736.90	918.35	5.77
Linseed	1.40	1.50	1.30	2.00	1.90	2.40	2.45	2.40	8.00
Sesamum	168.70	167.20	185.20	205.00	213.60	214.00	217.14	228.50	4.43
Coriander	14.86	14.69	14.69	14.70	14.71	14.52	14.56	14.50	−0.35
Cumin	1.51	1.51	1.51	1.50	1.50	1.45	1.46	1.45	−0.56
Fennel	1.03	1.04	1.03	1.03	1.03	1.03	1.02	1.02	−0.10
Fenugreek	2.65	2.65	2.65	2.65	2.65	2.64	2.60	2.62	−0.18
Honey	6.34	4.65	5.07	15.00	15.50	15.60	15.80	16.50	14.64

Source Directorate of Economics and Statistics, Government of India (2020), Agricultural and Processed Food Products Export Development Authority (APEDA) (2020); National Horticulture Board, Government of India (2020) honey production had shown negative year-on-year growth (−26.66%) where pulses (−27.78%), rapeseed and mustard (−9.44%), sesamum (−0.89%), and coriander (−1.14%) had also shown negative growth. Actually, these four crops along with litchi are the most visited fields by the beekeepers of West Bengal as those are major honey-flow fields for them. Though sunflower had shown very positive growth (86.49%) in that year but it was not preferable fields of the beekeepers of West Bengal as its area of production was very small. In the year 2013–2014, the growth of honey was extraordinary (195.86%), the reason as already pointed out before was related to both actual production and proper documentation (which was bit lacking before). In that year, except mango and cumin all had positive growth. Flowering seasons of mango and litchi are almost similar and maximum beekeepers generally migrate to litchi fields as they are more productive. Hence, negative growth of mango did not hamper the honey production. Similarly, flowering season of sesamum, cumin, fennel, fenugreek, and coriander is almost same, so negative growth of cumin was substituted by the positive growth of remaining four. So, it is found that apiculture is more stable sector than other agriculture and horticulture sectors during the years 2010–2018.

Honey bees necessitate pollen and nectar for their nutrition and family reproduction. During collection of honey, most bees gain pollen passively from flowers. Hence, for their existence, honey bees not only fly for honey but also visit flowers to collection of pollen. Honey bees do not visit every flowering plant haphazardly, they continue their work until it is finished. So, if they do not find the production satisfactory for their closely related floral variety, they opt for the crops present in the nearby fields within their flight range for their foraging (Table 3.8). Since, in West Bengal rice, wheat, and maize are the major crops covering lot of agricultural fields the tamed bees often take resort to them too as alternatives to the primary ones. However, it is interesting to note that CAGR of honey production is higher than that of rice (1.98%) and wheat (−13.63%) production.

Few other common plants like groundnut, brinjal, okra, peas, potato, sweet potato, tomato, banana, guava, papaya, sapota, etc., are not again directly related with the positioning of the beehives but act as supporting varieties, if the primary crop production is unsatisfactory for bee foraging. It is revealed that except tur (14.99%), CAGR of honey production is higher (14.64%) than all those crops during the periods from 2010–2011 to 2017–2018. So, it can be said that, apiculture industry is steadier than other agricultural and horticulture sectors during the year 2010–2018.

It is found (Table 3.9) that seven years' mean year-on-year (2011–2012 to 2017–2018) growth of honey was higher than maize (19.59%), rice (2.12%), and wheat (−9.13%). It is also found that in the year 2016–2017 only year-on-year growth of production of honey was positive (1.28) beating the negative growth of remaining three major bee feeding crops. Similarly, the year-on-year average growth of production of honey is 26.85% which is higher than all the other minor crops except tur (53.12%). Climatic variability has impacted growth of production of these crops, and most of them have shown erratic variations while honey has managed to keep a positive and steady growth rate irrespective of all odds.

Table 3.7 Year-on-year growth of production of honey and other closely associated crops (unit in %) involved in bee foraging in West Bengal (2010–2018)

Closely associated crops assisting honey production	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	Mean	SD	Cov
Sunflower	86.49	8.70	33.33	10.00	−22.73	17.65	−50.00	11.92	43.01	360.86
Gram	0.00	50.00	33.33	−25.00	33.33	−28.75	29.12	13.15	31.12	236.70
Lentil (masur)	80.00	−33.33	0.00	0.00	56.67	−14.89	87.50	25.13	48.61	193.41
Pulses	−27.78	46.15	31.58	−4.00	37.50	−21.21	69.23	18.78	36.73	195.56
Rapeseed and mustard	−9.44	23.68	4.26	−2.04	4.17	−2.00	46.94	9.37	19.51	208.24
Litchi	0.18	5.55	4.33	−18.26	−1.92	3.15	−2.79	−1.40	8.07	−578.37
Mango	6.67	11.11	−41.40	85.66	−13.29	6.27	24.62	11.38	39.02	342.95
Linseed	7.14	−13.33	53.85	−5.00	26.32	2.08	−2.04	9.86	23.00	233.28
Sesamum	−0.89	10.77	10.69	4.20	0.19	1.47	5.23	4.52	4.74	104.93
Coriander	−1.14	0.00	0.07	0.07	−1.29	0.28	−0.40	−0.35	0.63	−181.82
Cumin	0.00	0.00	−0.66	0.00	−3.33	0.69	−0.59	−0.56	1.30	−234.50
Fennel	0.97	−0.96	0.00	0.00	0.00	−0.97	0.28	−0.10	0.69	−704.49
Fenugreek	0.00	0.00	0.00	0.00	−0.38	−1.52	0.66	−0.18	0.67	−377.64
Honey	−26.66	9.03	195.86	3.33	0.65	1.28	4.43	26.85	75.43	280.98

Sources Calculations based on Table 3.6

Table 3.8 Comparing the production scenario of honey and other remotely associated crops (unit in '000 tonnes) involved in bee foraging in West Bengal (2010–2018)

Remotely associated crops assisting honey production	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	CAGR (%)
Rice	13,050.00	14,610.00	15,020.00	15,310.00	14,680.00	15,750.00	15,300.00	14,970.00	1.98
Wheat	870.00	870.00	900.00	950.00	940.00	960.00	862.71	312.00	−13.63
Maize	350.00	360.00	420.00	520.00	660.00	720.00	710.00	1130.00	18.23
Groundnut	103.20	105.60	170.50	200.50	179.90	189.90	180.00	170.00	7.39
Brinjal	2870.60	2945.73	2965.60	2977.00	2985.44	3003.58	3025.81	3027.75	0.76
Okra	862.12	863.50	869.10	877.00	882.39	897.30	913.37	914.86	0.85
Peas	129.36	131.00	132.11	133.50	134.92	135.44	136.02	144.25	1.57
Potato	13,391.24	9693.33	11,591.30	9030.00	12,027.00	8427.00	11,052.60	12,782.50	−0.66
Sweet potato	235.74	236.96	236.10	236.00	242.38	239.81	240.62	220.44	−0.95
Tomato	1063.65	1104.50	1125.60	1141.50	1149.59	1204.43	1233.03	1265.25	2.51
Banana	1010.15	1053.99	1077.80	1097.50	1124.00	1172.34	1172.34	1200.00	2.49
Guava	178.85	179.78	184.00	186.00	190.60	198.79	202.95	215.20	2.68
Papaya	324.23	327.83	331.00	335.00	345.50	350.77	357.65	365.95	1.74
Sapota	43.58	43.61	44.80	45.40	46.10	46.73	46.97	48.20	1.45
Mandarin (orange varieties)	37.01	38.05	38.29	38.60	39.10	39.21	39.55	40.18	1.18
Nigerseed	2.50	2.40	2.80	2.80	2.80	3.10	3.01	3.15	3.36
Soyabean	0.30	0.60	0.50	0.40	0.40	0.40	0.44	0.60	10.41
Tur	2.20	0.50	2.10	2.10	2.90	4.20	3.70	5.85	14.99
Castor	0.05	0.10	0.1	0.1	0.1	0.1	0.06	0.04	−3.14

(continued)

Table 3.8 (continued)

Remotely associated crops assisting honey production	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	CAGR (%)
Honey	6.34	4.65	5.07	15.00	15.50	15.60	15.80	16.50	14.64

Source Directorate of Economics and Statistics, Government of India (2020), Agricultural and Processed Food Products Export Development Authority (APEDA) (2020), National Horticulture Board, Government of India (2020)

Table 3.9 Year-on-year growth of production of honey and other remotely associated crops (unit in %) involved in bee foraging in West Bengal (2010–2018)

Remotely associated crops assisting honey production	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	Mean	SD	Cov
Rice	11.95	2.81	1.93	−4.11	7.29	−2.86	−2.16	2.12	5.86	276.10
Wheat	0.00	3.45	5.56	−1.05	2.13	−10.13	−63.83	−9.13	24.64	−269.96
Maize	2.86	16.67	23.81	26.92	9.09	−1.39	59.15	19.59	20.31	103.71
Groundnut	2.33	61.46	17.60	−10.27	5.56	−5.21	−5.56	9.41	24.72	262.60
Brinjal	2.62	0.67	0.38	0.28	0.61	0.74	0.06	0.77	0.85	110.73
Okra	0.16	0.65	0.91	0.61	1.69	1.79	0.16	0.85	0.66	77.66
Peas	1.27	0.85	1.05	1.06	0.39	0.43	6.05	1.59	2.00	125.97
Potato	−27.61	19.58	−22.10	33.19	−29.93	31.16	15.65	2.85	28.26	992.25
Sweet potato	0.52	−0.36	−0.04	2.70	−1.06	0.34	−8.39	−0.90	3.50	−389.62
Tomato	3.84	1.91	1.41	0.71	4.77	2.37	2.61	2.52	1.40	55.48
Banana	4.34	2.26	1.83	2.41	4.30	0.00	2.36	2.50	1.50	59.81
Guava	0.52	2.35	1.09	2.47	4.30	2.09	6.04	2.69	1.90	70.41
Papaya	1.11	0.97	1.21	3.13	1.53	1.96	2.32	1.75	0.78	44.67
Sapota	0.07	2.73	1.34	1.54	1.37	0.51	2.62	1.45	0.98	67.70
Mandarin (orange varieties)	2.81	0.63	0.81	1.30	0.28	0.87	1.59	1.18	0.84	70.55
Nigerseed	−4.00	16.67	0.00	0.00	10.71	−2.90	4.65	3.59	7.62	212.28
Soyabean	100.00	−16.67	−20.00	0.00	0.00	10.00	36.36	15.67	41.60	265.43
Tur	−77.27	320.00	0.00	38.10	44.83	−11.90	58.11	53.12	126.23	237.61
Castor	100.00	0.00	0.00	0.00	0.00	−40.00	−33.33	3.81	45.84	1203.38
Honey	−26.66	9.03	195.86	3.33	0.65	1.28	4.43	26.85	75.43	280.98

Sources Calculations based on Table 3.8

3.6.3 Qualitative Analysis of Beekeepers' Perceptions

3.6.3.1 Beekeepers' Perceptions About Climate Change

Climate change is perceived as a most compelling issue affecting the survival of human life over the last century. United States National Climate Assessment (2014) stated that rising temperatures resulting the sea level rise, increase in number of extreme weather events, variability in rainfall and temperature are hindering the sustainability of natural resources and are affecting different sectors of economy adversely. But in most of the cases, common people are unaware about the harmful impact of this phenomenon and apiculture is not an exception. Generally, traditional ecological knowledge coupled with text book education leads to the perception of people about the surrounding environment. Hence, this study aims to assess the awareness about climate change among the beekeepers and its impact on the honey production through a perception study.

To assess the awareness level of beekeepers about climate change, a primary survey was carried out involving 339 respondents (out of which 4 refused to reply) active in the main honey-flow districts on the basis of random sampling, on the basis of a semi-structured questionnaire primarily involving ordinal approach (5-Point Likert Scale) suiting the ease the respondents.

The study indicates about 29% of beekeepers have strongly agreed and 12% of them only agreed about the effect of climate change, i.e. sea level rise and reduction in fresh water availability, indicating that many are quite conscious about this phenomenon. The beekeepers who ventured in the coastal areas were more aware about the sea level rise and reduction of area under mangrove forests (Partap, 2011). As high as 60% of people are aware of increasing number of cyclones. Almost 38% of the respondents strongly agreed about the phenomenon of increased drought and flood. Most of the respondents conceded about the manifestations of climate change through the rise of temperature and rainfall variability. They admitted to have experienced and suffered due to the rise of temperature and rainfall variability over the past years. More than 50% of respondents are strongly agreed and agreed about the change in the pattern of cold wave, heavy fog, and precipitation. However, a majority, i.e. 35% of beekeepers, disagreed about the reduction in agricultural production. Weighted mean calculated for each category represented the level of awareness of the beekeepers about climate change (Table 3.10).

In apiculture, monsoon period is the lean season as the flight of honey bees are restricted and the honey also gets diluted; so, they are fed by artificial food (mainly sugar) in this phase. Thus, irregular rainfall affects both quantity and quality of production. Reduction of mangrove forest due to climate change affects honey collection as the mangrove areas provide access to variety of wild floral resources for apiculture. Most of the respondents did not admit any perceptible reduction in agricultural produce due to climate change. The main reason behind it may be because the honey collectors were not much interested about production of crops other than the ones involved in honey production during the flowering seasons.

Table 3.10 Awareness of the beekeepers about climate change in the study area

5-Point Likert Scale	Sea level rise and reduction in fresh water availability		Increase in yearly cyclonic frequency		Reduced agricultural production		Increased incidence of drought and flood		Reduction in biodiversity		Increased variability in rainfall		Reduction of area under mangrove forest		Change in the pattern of cold wave, heavy fog	
x	f	Fx	f	fx	f	fx	f	fx	f	fx	f	fx	f	fx	f	fx
1	2	2	2	2	61	61	24	24	24	24	10	10	12	12	3	3
2	2	4	15	30	119	238	26	52	45	90	43	86	30	60	25	50
3	38	114	30	90	33	99	65	195	87	261	61	183	115	345	67	201
4	98	392	87	348	53	212	95	380	83	332	118	472	83	332	125	500
5	195	975	201	1005	69	345	125	625	96	480	103	515	95	475	115	625
Total	335	1487	335	1475	335	955	335	1276	335	1187	335	1266	335	1224	335	1379
Weighted mean		4.44		4.40		2.85		3.81		3.54		3.78		3.65		4.12

Data Source Field Survey, 2019–2020

3.6.3.2 Beekeepers' Insights About Impact of Climate Change on Honey Production

Apiculture industry either directly or indirectly is affected by climate change. Scientists established that nectar production increases after rainy days (Bonnier, 1879) and nectar initiation depends directly on humidity and temperature (Melin, 2002). Pre-monsoon season is suited for honey collection than the post-monsoon season as daylight span is more offering higher forage. During rainy season, honey bees are unable to fly outside for pasturage. So, rainy season is the off-season to beekeepers for migration. Stormy days are cause of obliteration of flowers and nectars which again indirectly affect honey bees as well as production of honey (Mandal, 2016). This is called dearth period and with irregularities in precipitation pattern this dearth period is going to extend hampering the production. 15–18 °C in winter and 28–32 °C in summer are suitable for honey bees (Mandal, 2016); extreme temperature both on the higher and lower sides affects honey bees to fly outside for collecting nectar hampering the production. High relative humidity is also very harmful for bee pasturage.

To get an idea about what the beekeepers ($n = 339$) felt about the climate change impacts on the honey production a set of questions on the basis of 5-Point Likert Scale was taken resort to (Table 3.11). Maximum beekeepers preferred "sunny weather" and "gentle wind" with low humidity for honey collection. The weighted means of "cloudy weather", "heavy rainfall" and "increasing relative humidity" are 1.35, 1.13, and 1.49, respectively, and pointed out that with the passage of time such number of days are increasing gradually; indicating these conditions to be non-congenial for honey production. Similarly, they also reported that "foggy weather", "increasing temperature" (> 32 °C), and "decreasing temperature" (< 15 °C) are unfavourable for honey collection as well as honey production. According to the statements of beekeepers', climate change affects production of flowering plants and crops on which honey bees depend but often the overall production of honey is not hampered due to the migratory nature of apiculture, the beekeepers move to places suiting the needs whenever they sense climatic disruptions and the honey bees are also accommodating enough to shift to crops of their second choice for forage.

3.6.3.3 Beekeepers' Insights About the Apiculture Industry

On the basis of this personal interactions and focused group discussions, a strengths, weaknesses, opportunities, and threats (SWOT) analysis can be done to find out how the climate change has influenced the primary stakeholders in this trade and affected the production and also the general standing of the sector (Table 3.12).

The beekeepers (both full-time and part-time ones associated with agriculture) were sceptical about the future of beekeeping as a profession. They pointed out issues like labour-intensive practices unsuitable in modern times, involvement of high maintenance cost caused by supplemental feeding and intensive transhumance, absence of adequate public funding, lack of regular trainings to keep them abreast

Table 3.11 Perception of the beekeepers about the local indicators of climate change

5-Point Likert Scale	Sunny weather		Cloudy weather		Heavy rainfall		Increasing relative humidity		Gentle wind		Foggy weather		Increasing temperature		Decreasing temperature	
x	f	fx	f	fx	f	fx	f	fx	f	fx	f	fx	f	fx	f	fx
1	0	0	250	250	300	300	198	198	0	0	197	197	182	182	118	118
2	0	0	63	126	32	64	117	234	0	0	129	258	134	268	100	200
3	16	48	23	69	7	21	24	72	46	138	13	39	23	69	97	291
4	55	220	3	12	0	0	0	0	87	348	0	0	0	0	15	60
5	268	1340	0	0	0	0	0	0	206	1030	0	0	0	0	9	45
Total	339	1608	339	457	339	385	339	504	339	1516	339	494	339	489	339	714
Weighted mean		4.74		1.35		1.13		1.49		4.47		1.46		1.44		2.11

Data Source Field Survey, 2019–2020

Table 3.12 Strengths, weaknesses, opportunities, and threats (SWOT) matrix of the apiculture sector in the study area

Strengths	**Weaknesses**
• Availability of good quality honey from variety of honey-flow regions • Abundant sources of nectars • Extensive field experience of many beekeepers • Easy migration in different fields throughout the state • Interest in modern beekeeping	• Absence of infrastructural endowments • Shortage of funds • Dearth of scientific training and exposure • Lack of knowledge about effective marketing strategies • Excessive middlemen dependency
Opportunities	*Threats*
• Low investment and scope for expansion • Importance attached to honey bees as an environmental bio-indicator • Increasing demand in consumer market • Soaring retail prices • Effective collaboration among the beekeepers (in form of cooperatives)	• Fear of lower production due to climatic variations in future • Increased instances of infections and diseases • Unscientific pest management in agricultural fields leading to contaminated honey • Middlemen exploitation • Competition from foreign low-quality synthetic honey

with the latest techniques, reduced strength of the honey bee colonies and pollen supply due to climatic, anthropic (pesticides), and biotic stresses, unequal competition from synthetic honey supplements. Maximum honey is purchased by different company via middlemen. These middlemen create distance between beekeepers and cooperative societies or companies as they control the local market. However, all is not that bleak as the honey bees who are regarded as essential for pollination ecosystem service for the conservation of plant biodiversity and the provision of agricultural goods are adaptive enough to depend on different sources of pollens and nectars offer enough support to the honey collectors. The agriculturalists look beekeeping as a supplementary income source and this can be pursued by the womenfolk too from their place of residence on seasonal basis. As honey production has not been much affected due to climate change, many in spite of the odds have hold onto it. Besides, the demand for honey as an immunity provider has sky rocketed in the COVID times increasing its retail price.

3.7 Conclusion

The global climate change has agricultural and horticultural productivity worldwide, and India too has not been an exception. From the global perspective, the apiculture industry has issued notes of concern about honey production, which is having an increasing market demand, as it is directly dependent on the health and yield of associated agricultural and horticultural crops. But in case of India, as well as West

Bengal, the case in point, both traditional and especially the modern method of apiculture has managed to stay away from the decreasing production trend as the diverse agro-climatic zones and migratory nature of honey collection have made the entire process adaptive to climatic variations, nurturing the dream of the National Beekeeping and Honey Mission to usher a "sweet revolution" in the country. When one variety of crop failure at a specific place affected the honey production, it was compensated by a different kind of forage based on a separate crop at a different location. Beekeepers of West Bengal are mostly aware about the climate change and its impacts which have helped them to cope with the variations and maintain sustainable production. In the study, it was observed that honey production is having a steady growth rate in last 8 years in West Bengal which ranks second nationally in production. To maintain this sustainable livelihood opportunity and the degree of adaptability, the beekeepers need holistic assistance from the central and state governments in the form of modern scientific equipment to the entrepreneurs, regular trainings and workshops for skill enhancement, formation of effective cooperatives for higher collective bargaining strength, strict quality control measure, and aggressive promotional strategies regarding bee wax, bee pollen, propolis, royal jelly, comb honey, bee venom for both domestic and export market.

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Chapter 4
The Impacts of Drought Disasters on Mexican Agriculture: An Interpretation from the Perspective of the Political Economy of Disasters

Juan Luis Hernández-Pérez and Deysi Ofelmina Jerez-Ramírez

Abstract Since 2020 and 2021, Mexico suffers in 88% of its national territory drought conditions, the second most serious drought event of the twenty-first century in the national territory. One of the economic sectors most vulnerable to these disasters is agriculture, on which the production, access, and availability of all people to food depend. Under this tenor, the present work's general objective is to analyze the preliminary productive, economic, social, and environmental effects caused by the current drought in the Mexican territory. The work is divided into three particular objectives: the first is to reflect on the idea that the effects of droughts are not only due to natural causes but also due to social, economic, and political factors associated with an uneven agricultural development process; the second objective is to show the impacts caused by droughts in Mexican agriculture, and the third is to analyze the institutional context of disaster risk management in the country. The methodology describes the main characteristics of loss, damage, and differentiated impact of hazards on exposed and vulnerable social elements addressed from the political economy perspective.

Keywords Drought · Agriculture · Disasters · Socioeconomic impacts · Mexico

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The original version of this chapter was revised: Author's given and family name has been corrected which was incorrect. The correction to this chapter is available at https://doi.org/10.1007/978-3-031-28251-5_19.

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4.1 Introduction

According to United Nations (U.N.), the year 2020, apart from being characterized as the COVID-19 pandemic, was the most significant climate-related disaster in history. According to the report of the United Nations Office for Disaster Risk Reduction (UNDRR, 2021) called: "2020, The non-COVID year in disasters. Global trends and perspectives", there were 389 recorded extreme events that resulted in 15,080 deaths, 98.4 million people affected, and economic losses of at least 171.3 billion dollars (CRED & UNDRR, 2021: 1–8).

In a broader perspective, the analysis presented in the "World Disaster Report 2020" prepared by the International Federation of Red Cross and Red Crescent Societies (IFRC), from the Basis Emergency Event Data (EM-DAT, for its acronym in English), indicates that in the last ten years (2010–2019) a frequency of 2850 disasters associated with natural hazards was recorded. Most of these (83%) were related to extreme climatic events caused by anthropogenic climatic variability (mainly floods, storms, and heatwaves). The disasters affected about 1.8 billion people, many of whom were injured, left homeless, or without subsistence, jeopardizing the progress made in sustainable development (IFRC, 2020).

Although extreme events such as storms and floods are the phenomena with the most remarkable recurrence in recent years, the phenomenon of drought is the one that has harmed localities the most, especially those with greater vulnerability. For example, according to EM-DAT, the total number of people affected by disasters in 2019 was 97.6 million. Of this total, droughts affected the most significant number of people with 48 million, while storms and floods affected 32 million and 14 million people, respectively. Under this tenor, drought appears as the most pressing natural threat globally (CRED & UNDRR, 2021).

It is known that the general consequences of droughts put at risk agricultural production, the access and availability of all people to food, biological use, and, therefore, food supply and security. Worse still, a drought can worsen in economic and social terms, channeling increases in the price of food, recession in the regional economic growth rate, loss of income for producers, conflicts between water sectors, deterioration of the quality of life, greater poverty, health problems, illegality, and finally, social instability, marginalization, and migration in vulnerable conditions, without forgetting the environmental services, cultural icons, and traditions that can be affected.

Unfortunately, according to estimates by the Intergovernmental Panel on Climate Change (IPCC), it is projected that the frequency and intensity of droughts will continue to increase due to global warming (IPCC, 2020).[1] This organization calculates that "the world population in arid zones vulnerable to water stress, intense droughts, and habitat degradation, is projected to reach 178 million people in 2050

[1] In 2019, global warming reached 1.1 °C above pre-industrial levels. Agriculture is feeling the effects. Rising greenhouse gas (GHG) concentrations are causing profound changes in the climate that ultimately affect agricultural production. These include an increase in the number of days with extreme temperatures, more severe and frequent droughts, floods, and storms (FAO, 2021: 136).

with a warming of 1.5 °C, increasing to 220 million people with a warming of 2 °C and 277 million people with a warming of 3 °C" (IFRC, 2020).

The IPCC also projects that the droughts that will intensify in the twenty-first century will do so in specific seasons and regions due to reduced rainfall and increased evapotranspiration. This will happen in Southern Europe and the Mediterranean region, Central Europe, Central North America and Mexico, Central America, Northeast Brazil, and Southern Africa (IPCC, 2020).

The case of Mexico is worrying since 2020, and during 2021, the national territory suffered the second most serious drought so far in the twenty-first century. The worst drought in the country so far this century is the one registered in 2011 and worsened in 2012. According to the United States Department of Agriculture, it is estimated that this period caused losses of more than 16 billion pesos. States, but the Agriculture Commission of the Chamber of Deputies of Mexico estimated a cost of 150 million pesos.

In light of this situation, although much more is known about the frequency and magnitude of events and where they are most likely to occur, most scientific studies or monitoring do not have a clear and complete understanding of the economic impact of disasters due to climate change, particularly in the agricultural sector. In this sense, the present work's general objective is to analyze the preliminary productive, economic, social, and environmental effects caused by the current drought in the Mexican territory.

The work is divided into three particular objectives: the first is to reflect on the idea that the effects of droughts are not only due to natural causes but also due to social, economic, and political factors associated with an uneven agricultural development process; the second objective is to show the impacts caused by droughts in Mexican agriculture; and the third is to analyze the institutional context of disaster risk management in the country.

The methodology used is based on a descriptive approach, since the main characteristics of the patterns of loss, damage, and differentiated impact of hazards on exposed and vulnerable social elements are addressed, also from the perspective of political economy, in the that people suffer more severe impacts regardless of the intensity of the threat and geographical location. The key research areas to be developed are the triggering event (s), the exposure of the social and environmental elements, the social and economic structure of the exposed communities, and the institutional and governance elements.

This research considers all the elements and dimensions that, from the social approach of disasters, intervene in the materialization of risk, emphasizing the conditions of social susceptibility from which the level of losses and impact is explained, especially in the agricultural sector, the characteristics of the threat (droughts) in highly complex environments such as climate change and the capacity for socio-institutional response. For this, we worked from questions that include the scale and intensity of the phenomenon in the last 20 years, the availability of adequate information (including predictions, warnings, and sources), and the structural characteristics of the national agricultural system and its structural characteristics and its exposure to external threats.

The work is structured in four sections and the conclusions. The first addresses the sociogenesis of risk associated with droughts, which is approached as a socio-environmental problem; the second and third sections indicate some current data on drought disasters in Mexico and the significant productive, economic, social, and environmental impacts of the 2020–2021 drought, respectively; the fourth section focuses on the description of the institutional context of disaster risk management on drought in the country; finally, some conclusions are presented by way of closing.

4.2 Droughts: Natural or Socio-Environmental Disaster?

Although it is a term in everyday use, drought is defined in several ways. One of the most accepted notions is the IPCC, a group that interprets these climatic irregularities as "an abnormally dry period long enough to cause a serious hydrological imbalance" (IPCC, 2012: 167).

The international scientific literature commonly distinguishes several types of this phenomenon: meteorological, agricultural, and hydrological (Esparza, 2014; Ortega-Gaucin & Velasco 2013). Meteorological drought refers to a deficit of precipitation; soil moisture drought, often called agricultural drought, refers to a moisture deficit in the root zone (layer of soil where the roots of crops are located); hydrological drought has been related to negative anomalies in the flow levels of streams, lakes, and groundwater (IPCC, 2012, 2014; National Drought Mitigation Center, 2002).

The fourth type of drought is caused by water scarcity, called socioeconomic drought, which can be caused totally or partially by human activities; that is, socioeconomic drought occurs when the demand for an economic good exceeds the supply as a consequence of the low availability of water (Esquivel, 2002). These definitions depend on the study region and are presumably based on knowledge of regional climatology.

In works derived from the social sciences, a determining factor for conceptualizing this problem is the cultural and socio-territorial aspects. These dimensions involve the perception of the affected population, social adaptation processes to the natural environment, knowledge-relationship, practice, and the type of community response to perceived risk (Antón & Díaz Delgado, 2000; Domínguez, 2016). Thus, what is recognized as a drought in the central and southern portion of Mexico, with more intense rainy seasons, will not necessarily be similar to what the population of the northern border perceives as such.

Although drought is a historical phenomenon in world climatology, like other extreme events, its current manifestation in terms of intensity, location, duration, and development, has been attributed by the scientific community to anthropogenic climate change.[2] The IPCC (2012) concluded that it is most likely that anthropic

[2] The Intergovernmental Panel on Climate Change (IPCC, 2012) defined climate change as a modification in the state of the climate that through the use of statistical tests can be identified by changes in the mean or variability of its properties and that persists during an extended period, typically

influence (in the context of the Anthropocene[3]) contributed directly to the increase in droughts observed in the second half of the twentieth century, taking into account the impact attributed to changes in precipitation and global temperature. Under this tenor, it is possible to rethink the notion of droughts as natural events, to be approached as socio-environmental processes that respond both to natural changes and alterations derived from economic, social, and political action (Hewitt, 1983; Leff, 1985; Lavell, 2000).

However, from an economic perspective, the comprehensive understanding of this problem is still seriously hampered by the idea of a "natural" disaster. This means research on the subject continues to be dominated by disciplinary approaches that focus too much on hazards and threatening physical phenomena, as well as the more immediate effects of loss and damage. One of the main reasons for the presence of this approach is because the traditional analysis of the causes of disasters such as droughts (present in different disciplines of the physical sciences such as hydrology, climatology, engineering, geography, among others) has a "physicalist" approach, which maintains that these phenomena are a natural result with an impact on a neutral or expectant economy and society.

From this logic, post-disaster response goals, above risk prevention and control objectives, are more likely. For governments, the post-disaster response usually has a more significant political payoff than risk reduction. Regarding the private sector, the search for profit generates a series of conditions and contradictions through which monetary compensation for damages is privileged, which discourages or blocks any prevention mechanism (Oliver-Smith et al., 2017).

This distortion also comes from the economist and neoliberal thesis that environmental deterioration is an inevitable product of economic development, so it is proposed to internalize environmental costs in the economic calculation through a market price system that punishes or regulates mismanagement of natural resources. However, the main criticism that has been made of this thesis is that environmental

decades or more. This change may be due to natural internal processes, external forces, or persistent anthropogenic changes in the composition of the atmosphere or in land use. For its part, the United Nations Framework Convention on Climate Change (UNFCCC), in its article 1, refers to this phenomenon as a climate change attributed directly or indirectly to human activity that alters the composition of the world atmosphere and that it adds to the natural climatic variability observed during comparable periods of time.

[3] It should be noted that the notion of Anthropocene precarious the notion that in global warming, we are all guilty, and therefore, we are all responsible; on the other hand, rather than talking about the Anthropocene, we live in the Capitalocene since the climate crisis of the twenty-first century was caused, to a large extent, by only 90 corporations, which have released into the atmosphere two thirds of the GHG generated since the beginning of the industrial era (Saxe-Fernández coord., 2018). This perspective takes up, in part, the pioneering postulates of classical Marxism, which indicates that it is essential to recognize that the relationships between nature and society must be approached dialectically, that is, society and nature mutually transform themselves in a historical process. Nature and history of human society are inextricably interwoven, and this mutually intersecting hinge is the axis of reflection and theorizing. Nature is, according to K. Marx, a moment of human praxis and at the same time the totality of what exists. In other words, there is no net separation between nature and society, since "nature, taken in abstract form, by itself, fixed in the separation of man, is nothing for man; on the contrary, nature is socially coined" (Schmidt, 1977).

deterioration is avoidable to the extent that there are alternatives for economic development that move away from the pressure for natural resources, particularly those of the Global South by the economies of the Global North (Fuchs Jordan & Sabatini, 1998). Thus, it is possible to understand what processes and results associated with the materialization of risk are intrinsic to a particular mode of development and growth.

One more reason is how the issue is handled on the public and institutional agenda. Disaster news and reports often place great emphasis on the occurrence of a significant and potentially dangerous physical event. Coverage quickly shifts to impacts, damage, loss of life, and the number of missing or trapped people. The absence or little attention to the root causes of the disaster is notable. In this way, the public's attention derives from concern for the response and recovery in the face of the emergency (Oliver-Smith et al., 2016), leaving aside the debate on political and social responsibilities.

From the social approach to disasters, these conservative treatments of risk have been questioned, and through the perspective of political economy, the nexus between economic development and disasters has been studied (Romero, 1986; Foladori & Delgado, 2020; Mansilla, 1996), emphasizing capitalist-type economic development processes, especially in developing countries. The environmental problems of the rich and peripheral nations, especially those of the latter, should not be abstracted from the context of the crisis of contemporary world capitalism.[4]

The emphasis on the socioeconomic causation of the emergency should not lose sight of the fact that the physical-environmental factor is still present; however, although droughts can be classified as natural hazards, they will only escalate to a disaster range to the extent that the prior vulnerability of the social context intervenes as a cause and potentiator of the adverse effects of the phenomenon.

Risk factors such as population growth, migration, land use and tenure patterns in rural and urban areas, infrastructure construction, environmental degradation, ecosystem depletion, use of technology, and poverty itself, among many others, should be taken into account for the diagnosis and response to socio-environmental problems such as droughts, taking as a broad framework of analysis the overall growth and development models. At the level of the neoliberal crisis, disasters, far from being anomalies that interrupt the systemic course, manifest themselves as logical paths of the accumulation of structural vulnerabilities.

The problem is not only unsafe conditions in the immediate context, but approach social dimension droughts also reduced abundance data on areas exposure, inventory losses and damages, spatial distribution impacts, and classification effects.

[4] Global warming is a class phenomenon. It is a class phenomenon within countries and between them. According to the Oxfam report entitled "Combating carbon emissions inequality", from September 2020, the richest 10% of the world's population (approximately 630 million people) generated 52% of accumulated carbon emissions, consuming almost a third (31%) of the global carbon budget in just those 25 years; meanwhile, the poorest 50% of the world's population (approximately 3.1 billion people) generated only 7% of accumulated emissions, consuming only 4% of the available carbon budget (Oxfam, 2020).

The Pressure and Release (PAR) model of Blaikie et al. (1996) has already dealt with distinguishing between the fragile physical environment, risk factors (also known as dynamic pressures), and the root causes that make up the economic-political macrosystem; the latter are more challenging to track than the first two categories. The immediate characteristics of the physical context generally monopolize the preliminary observation of disasters so that the most dynamic social processes and, mainly, the structuring forces remain hidden from public opinion.

Distinguishing between unavoidable and avoidable consequences in the cause-driver-unsafe condition equation is fundamental since although it is expected that disaster risk management (DRM) can solve civil protection and emergency response issues in the short and medium-term, it is challenging for it to autonomously solve and prevent the underlying structural dependencies and causal relationships. The latter require changes in the development paradigm and its ideological foundations beyond the reach, although they are part of the concern of DRM specialists and professional groups.

Following this logic, in the next section, some data on drought disasters in Mexico are detailed to later deal with identifying and analyzing the significant impacts on national agriculture.

4.3 Data on Disasters Associated with Droughts in Mexico

According to the changes observed worldwide, the areas with drought doubled in extension from the 1970s to the present (IPCC, 2012). Recent trends point to more severe drought conditions for the North American zone (Canada, Mexico, and the USA).

In Mexico, of the real emergencies reported during the last 20 years, 90% correspond to disasters related to hydrometeorological, meteorological, and climatic events (CRED, 2021). Episodes of heavy and heavy rainfall with significant runoff will be interspersed with more extended relatively dry periods with increased evapotranspiration. Furthermore, there is a consensus in most climate model projections on reducing precipitation during cold seasons in northwestern Mexico, with more frequent multi-year droughts (IPCC, 2012).

Since the 1980s and up to the present, six major drought events have been reported in the Country (CRED, 2021; Salgado Vega & González, 2009), with the year 2011 being the most severe in seventy years, a drought that caused damage in around 2.7 million hectares, in addition to economic losses close to 16 billion pesos and 2 million people affected (FAO, 2012). Unfortunately, in 2020, drought conditions were again identified due to low rainfall, which lasted until 2021 (Conagua, 2021d).

According to reports from the National Water Commission (Conagua) of Mexico, during April 2021, the most alarming figure was registered, since, in 88% of the national territory, drought conditions prevailed (see Fig. 4.1), that is, in 30 of the 32 entities of the country. This is because there was 25% less rain than usual in the last

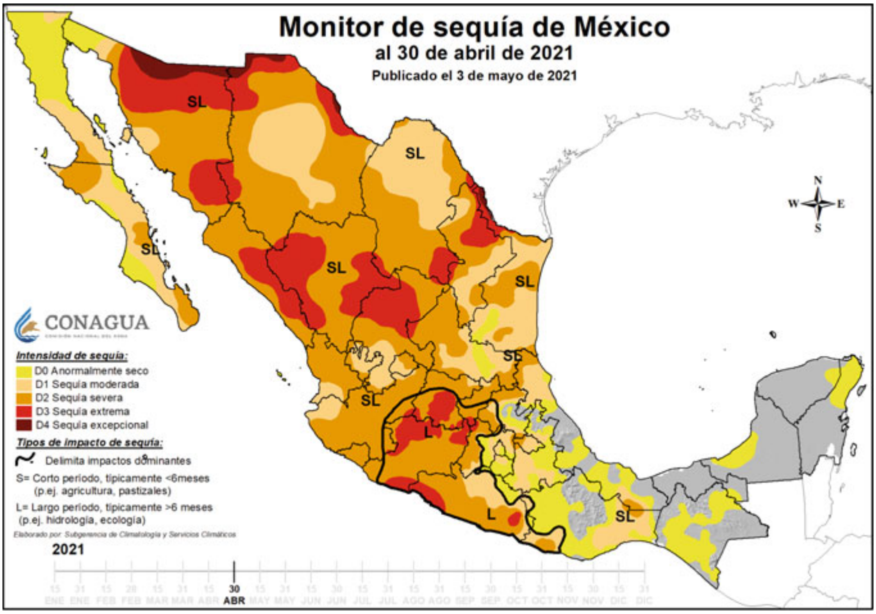


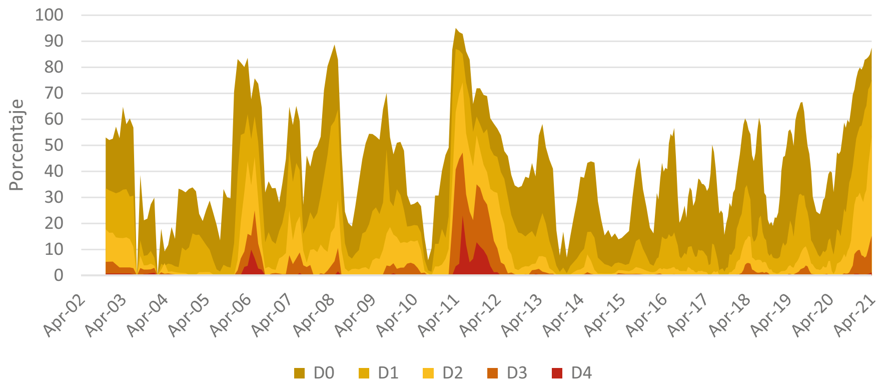
Fig. 4.1 Mexico drought monitor (2021). *Source* Taken from CONAGUA (2021a)

year and higher temperatures, thus becoming the second most serious drought in the country so far in the twenty-first century (Conagua, 2021a).

The drought mainly affected the northwestern states of the country, such as Sonora, Chihuahua, and Tamaulipas. In fact, during the same month, 56% of the country's municipalities (1381 localities) suffered from severe, extreme, and exceptional drought, which means that they suffered from generalized losses of crops, fires, total shortage of water in reservoirs, streams or wells, and an emergency is very likely due to the total absence of water.

The comparison of the intensity of this episode with other more recent ones is observed graphically below (see Graph 4.1). The graph shows the percentage of the national territory that is affected by drought (vertical axis). It is observed that the drought of 2011–2012 reached more than 90% of the national territory.[5]

[5] Types of droughts according to Conagua (2021a): Abnormally Dry (D0): It is a dry condition, it is not a drought category. It occurs at the beginning or end of a dry spell. At the beginning of a drought period: due to the short-term dryness, it can cause the delay in the sowing of annual crops, a limited growth of crops or pastures and there is the risk of fires. At the end of the dry period: water deficits may persist, pastures or crops may not fully recover. Moderate Drought (D1): There is some damage to crops and pastures; there is a high risk of fires, low levels in rivers, streams, reservoirs, troughs and wells, voluntary restriction on the use of water is suggested. Severe Drought (D2): Probable losses in crops or pastures, high risk of fires, water shortage are common, restrictions should be imposed on the use of water. Extreme Drought (D3): Major losses in crops and pastures, the risk of forest fires is extreme, restrictions on the use of water are generalized due to its scarcity. Exceptional Drought (D4): Exceptional and widespread losses of crops or pastures, exceptional risk



Graph 4.1 Percentage affected by drought in Mexico (2002–2021). *Source* Own elaboration based on data from Conagua (2021a)

The 2020–2021 drought is slightly less than 2011–2012 for two reasons. The first is the size of the coverage. While over 80% of the Mexican surface today has some degree of drought, the coverage was 90% ten years ago. Second, the drought of the past decade far exceeds the current one in intensity. The current peak is 15.24% of the country with extreme to exceptional drought, but in 2011, the area suffered from this emergency three times. The condition worsened due to deficit rainfall that country had been carrying since the previous year when rainfall was 3% lower than in 2019. In the same sense, it can be established that, although the intensity of the phenomenon was more significant in 2011, the "additional demand" as a consequence of the COVID-19 pandemic worsened the situation for this new period.

At this juncture, the authorities indicate as leading causes the ocean-atmospheric phenomena characteristic of the region and the geographical location conditions; as mentioned by the coordinator of the National Meteorological Service of Mexico: "Last year we had a very severe Niña and an Atlantic with relatively high temperatures. This favors precipitation in the southern region and does not favor it in the northern region" (BBC News World, 2021). This institutional stance reflects the tremendous weight given to natural factors, that is, to threats, an aspect that represents only one of the various dimensions of disaster processes. Similarly, analytical interest focuses on the unsafe conditions of the populations, leaving aside the structural issues that intervene as root causes in a context of significant vulnerability, as is the case of the agricultural sector.

of fires, total shortage of water in reservoirs, streams and wells, an emergency situation is likely due to the absence of water.

4.4 Impacts of Drought on Mexican Agriculture

As is known, drought is a phenomenon that affects the population, different economic sectors, and biodiversity, sometimes having irreversible effects. Unlike disasters associated with sudden hazards, drought evolves progressively over time and gradually destroys the affected region. In acute cases, drought can last for many years and cause devastating effects on agriculture, taking into account related risks such as forest fires, landscape damage, desertification, loss of crops, food shortages, and malnutrition; as well as the risk of an increase in outbreaks of epidemics, displacement of populations to other places and an increase in carbon emissions.

According to FAO (2021), 82% of damages and losses caused by drought were absorbed by agriculture in low- and lower-middle-income countries between 2008 and 2018. In this same period, drought was also the most destructive disaster to affect agriculture in Latin America and the Caribbean, causing USD 13 billion in crop and production losses.

In Mexico, agriculture is also one of the sectors most sensitive to this socio-environmental problem. This activity uses 74% of the water to irrigate the 22 million hectares planted annually to produce food and raw materials. In addition, the impact of the agricultural drought is uneven since, of the 22 million hectares planted in the country, 6.1 million have some irrigation capacity despite low rainfall, while the rest, 15.9 million hectares that are temporary, have no other alternative.

What is worrisome in this matter is the lack of rains 2020–2021 has caused that, of the 210 most important dams in the country that provide water to irrigated agriculture, there are 112 that present a deficit more significant than 50% in their storage. This is combined with the overexploitation of 115 aquifers of the 653 underground beds present in the national territory. This puts at risk the sowing of thousands of hectares of crops in the country during the next spring–summer productive cycle, and it is estimated that it could be around 30% (Conagua, 2021b).

According to the damage categories, the drought impacts can be classified as productive, economic, social, and environmental (see Table 4.1).

These factors are essential in the comprehensive analysis of diagnoses of disasters associated with droughts. So, taking account only of some items, general contextualization of effects 2020–2021 drought in Mexico and its eventual consequences on some strategic crops (either for the consumption of the population) is presented below or as raw material for the agri-food industry).

- *Productive effects*

Until now (August 2021), it is not possible to fully quantify the level of impact that the drought has caused on national agricultural production. However, it is possible to partially point out that, in the harvest season of the autumn–winter cycle corresponding to the agricultural year 2020, which began in December of that year and ends in September 2021, the damaged area (defined as damage total in the planted area) was 362,029 thousand hectares according to the preliminary figures prepared

Table 4.1 Impacts of the drought by category of damage

Productive	Economic	Social	Environmental
– Loss of agricultural, livestock, forestry, and fishing production – Loss of quality and safety—Recession in the national or regional economic growth rate	– Increase in energy demand – Decrease in activities of the dependent industry – Unemployment and non-payment of credits – Decrease in taxes and public income	– Loss of income for producers, merchants, and transporters – Shortage of quantity and quality of food – Health problems and increased morbidity in vulnerable sectors – Inequality in impact absorption – Conflicts between water users – Low quality of life – Increase in poverty and social instability – Marginalization and migration to urban areas or abroad	– Damage to ecosystems – Erosion and loss of soils – Degradation of water and air quality – Landscape degradation

Source Own elaboration based on data from Conagua (2021c)

by the Agrifood and Fisheries Information Service [Servicio de Información Agroalimentaria y Pesquera, SIAP] (2021) (SIAP). This figure is likely to increase because, as mentioned above, the referred harvest season has not ended (SIAP, 2021) (Table 4.2).

The damage at the regional level is more palpable than at the national level. Current drought conditions and water shortages are expected to hurt states essential for Mexico's export-oriented and domestic agricultural production, particularly those in the north. States such as Sonora, Sinaloa, Tamaulipas, Jalisco, Michoacán, Zacatecas, Guanajuato, and Chihuahua, which are the central producing states in various agricultural categories such as cattle, grains, legumes, fruits, and vegetables,

Table 4.2 Mexico. Advance of sowings and harvests

Year	Area (ha)		
	Sown	Harvest	Sinister
2018	15,862,102.01	6,478,178.62	46,341.97
2019	15,188,041.95	6,543,339.37	57,077.45
2020	15,743,419.43	6,549,913.01	110,907.94
2021	16,003,463.37	6,423,628.09	**362,029.00**

Source Own elaboration based on data from SIAP (2021)
Note The data correspond to the progress registered up to July of each year

are those that report the areas most affected by conditions of severe, extreme, and exceptional drought. These states represent between 60 and 70% of the total national agricultural and livestock production, so that the sector will be significantly affected in these areas.

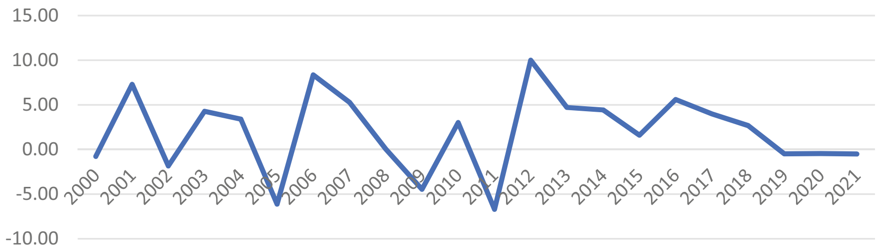
Livestock seems to be the agricultural activity that worries the most, as farmers announce reductions in animal inventories of 40% in Sonora and Chihuahua. Drought conditions have slightly affected livestock in the leading producing states such as Jalisco, Veracruz, and San Luis Potosí. However, the lack of rainfall and the dry climate has affected other essential states such as Sinaloa, Coahuila, and Tamaulipas, and the scarcity of water has modified the patterns/mechanics of livestock operations. Animal inventories are being drastically depleted, for example, in Sonora, where more than 300,000 heads have been slaughtered or sold to other states. Chihuahua ranchers face market prices approximately 20% below the average. This results from a lack of water and the fact that the animals do not reach optimum weight, for which the producers are forced to export as much livestock as possible to reduce expenses (FAS, 2021).

As for grains, water shortage conditions have also affected important north producer states as Sinaloa, Tamaulipas, and Sonora. In this case, The Foreign Agricultural Service, an agency with primary responsibility for the United States Department of Agriculture's (USDA) estimated that: "in Sinaloa, as white corn growers detected that the water levels in the dams fell to an average of 11% as of May 15th, 2021, production estimates were calculated lower, from 5.5 million tons initially at 4.8 million tons. Lack of rain and a dry environment has also affected Tamaulipas, so the current autumn–winter cycle is expected to reach 7.8 million tons, down from 8.3 million in the previous cycle. With sorghum, Tamaulipas, which represents 80% of sorghum in the autumn–winter cycle, has suffered a "perfect storm" this season: frost damage, delayed planting, lack of rain, and depletion of water reservoirs. This has resulted in an estimated production of 952,000 tons, almost half of the production reported in the previous cycle. Finally, the effect on wheat production in Sonora remains to be seen, but since farmers have reduced planting due to water supply uncertainty, the loss of wheat production is estimated to be between 150,000 and 160,000 tons" (FAS, 2021: 7).

- *Economic effects*

In global terms, the growth of the Mexican agricultural sector presents a volatile performance throughout the twenty-first century. In this period, the sector has suffered repeated crises, which have caused the sector to lose economic relevance concerning other branches of the national economy (Graph. 4.2).

In part, these decreases in the sector's growth were due to the effects caused by different droughts. In 2011, the affected area reached 90% of the national territory; practically, the entire country had some degree of this anomaly, registering a drop of −6.7% in the growth rate. The recent drought, registered in 2020 and lasted until 2021, which affected more than 80% of the territory, is another cause of the fall in the annual growth rate agricultural sector of −0.5%. Until now (August 2021), it is



Graph 4.2 Mexico. Agricultural GDP (2000–2021). Annual growth rate %. *Source* Own elaboration based on Instituto Nacional de Estadística y Geografía [INEGI]. System of National Accounts of Mexico (2021). *Note* Constant values at 2013 prices/Millions of pesos at 2013 prices

impossible to quantify the total impact on the growth rate, but it is estimated that this will reach a drop of 0.7%.

- *Social effects*

The main social consequence of this severe drought is the availability of food, global access, and, therefore, the supply and national food security are questioned. Worse still, the drought that afflicts the country can be aggravated in terms of increases in the price of food, loss of income for producers, conflicts between water sectors, decrease in living standards, increased poverty, health problems, illegality, and, finally, social instability, marginalization, and rural migration.

An example of the above is that the drought has triggered corn prices, thus affecting tortilla prices. The price of yellow corn, used mainly as animal feed, soared 78% in the last year, and that of white corn, used to make tortillas and other products for human consumption, increased 25%. The price of both types of grain reflects an essential impact on the cost of basic food for the Mexican population because due to its use, it has the potential to increase the price of daily consumption products such as meat, milk, eggs, and tortillas, among others. Only the price of corn in Mexico has risen 9.8% annually, whose average value accumulates nine consecutive months on the rise. According to official data obtained from the "Who is in Prices" platform of the Federal Consumer Prosecutor's Office (Profeco), in Mexico City, the average price of tortillas is 20 pesos; but in Monterrey, it reaches 22 pesos per kilo. The same food can be purchased for up to 27 pesos (GCMA, 2021).

Drought disproportionately affects poor and marginalized people, for whom the cost of this phenomenon is measured in terms of lives, livelihoods, and impoverishment. The population with a lack of access to nutritious and quality food in the country increased from 22.2% to 22.5% between 2018 and 2020, representing 1 million people (Coneval, 2021).

Finally, another effect is the lack of access to vital liquid. In Mexico, some populations do not have access to a supply of drinking water in adequate quantity and quality. In fact, according to INEGI (2021), some 44 million people do not have daily access to this vital liquid. On the contrary, seven private companies (national and foreign), including agri-food, control 70% of the water in the country. From this scenario of inequality and hoarding, the debate on the root causes of droughts in the national territory should be held.

- *Environmental effects*

In addition to the economy, the drought also affects the environment. Plants and animals depend on water. Drought can reduce the food supply and damage the habitat of these species. Sometimes this damage is only temporary, and other times it is irreversible; without forgetting that the environmental services of the affected biodiversity can be lost.

Drought conditions can also provide a substantial increase in wildfire risk. As plants and trees wither and die from lack of precipitation, they become potent fuels. Similarly, insect infestations increase the spread of disease to surrounding populations.

So far this year, our country faces the worst fires of the decade, according to the National Forestry Commission. This institution reported that in the first half of the year, 6 thousand forest fires were registered throughout the country, with a balance of 560 thousand hectares devastated by fire, of which 92% corresponded to herbs and shrubs and 2% to trees. The entities most affected in this period were Chihuahua, with 88,209 hectares damaged; Guerrero, 81 thousand 808; Durango, 72 thousand 564; Nayarit, 36 thousand 751 Chiapas, 34 thousand 474. The severe drought, which hit 85% of the national territory until the beginning of last month, caused that in the first three months of 2021, there were twice as many fires as in the same period from the previous year.

4.5 The Institutional Context of Disaster Risk Management in Mexico on Drought: Lessons, Progress, and Challenges

At present, most countries' primary institutional focus is related to disaster management and emergency response. Despite a variety of international institutional initiatives, including the International Decade for Natural Disaster Reduction (1990–99), the Yokohama Strategy and Plan of Action for a Safer World (1994), the Hyogo Framework for Action (MAH): Building the Resilience of Nations and Communities to Disasters (UNISDR, 2005), and more recently the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015), integrating the basics of risk reduction impact (DRR) in national policies and practices has been slow and far from comprehensive (Cutter et al., 2015). In fact, of the five HFA priorities, little progress was recently reported on Priority 4, explicitly addressing the underlying causes of disasters.

Within this logic, what is increasingly known as corrective risk reduction practices (which address existing risk) dominate prospective risk avoidance processes (UNISDR, 2015).

- *National Program Against Drought*

The generalized drought in Mexico in the 2010–2012 period led to a change in addressing this socio-environmental process. Legal elements were built, and the experience of coordination and attention to contingencies was documented to consider changing the attention to disasters associated with hydrometeorological phenomena, moving from the reaction to emergencies, toward a preventive model (Government of Mexico, 1992). As a corollary, in 2013, the National Program against Drought (PRONACOSE) was created (Conagua, 2014).

The program consists of the attention, monitoring, mitigation, and prevention of the recurrent phenomenon of drought in the national territory. The objective is to elaborate instruments that allow the integrated management of the Basin Councils about the management of water resources under the effects of this natural phenomenon, based on a new proactive and preventive approach (Arreguín-Cortés et al., 2016).

The federal government is administering the program through the National Water Commission. It is implemented by a group of institutions that includes public universities, research centers, government agencies, and national and international specialists in the matter.

The two elements of the program are.

(a) Prevention (monitoring-alerting; programs by basin, user, or use; research, evaluation, and updating of the programs).
(b) Mitigation or attention (which includes actions during and after the drought event). The mitigation actions seek to reduce federal participation and increase local participation; it is complemented by a line of action that corresponds to the acts of authority to guarantee water for human consumption.

The prevention element is composed of actions that are carried out before a drought, such as monitoring and early warning, the preparation, implementation, and evaluation of Drought Prevention and Mitigation Measures Programs (PMPMS), the strengthening of the legal framework, and the institutional coordination, training activities, dissemination of information and research on the subject.

All these actions aim to increase the resilience capacity of federal entities in the face of a drought so that the effects are minimal for the exposed population. An indispensable condition in the preparation of the PMPMS is the diagnosis of vulnerabilities (including the category of structural vulnerabilities) since it is from this information that the main actions of the program will be defined. Since the execution of these actions has to do with different sectors and the three levels of government, it is necessary to put into practice an organization between actors that ensures the optimization of resources and actions. It is proposed that some of the mechanisms in the basin councils serve this purpose, subject to the subsequent assumption of different coordination at the state, municipal, or sector level.

Mitigation or timely attention, this element is made up of all actions that are carried out during the event of a drought. In the first instance in 2013, this was addressed by following reactive institutional procedures already defined in different federal government agencies while the PMPMS were developed. For this purpose, the constitution of the Intersecretarial Commission for Attention to Droughts and Floods was the coordination framework at the federal level for the application of the resources of the National Disaster Fund (FONDEN) and the federal government agencies. The Working Group is also established to review the different federal programs and their operating rules for an effective and efficient application to mitigate the effects of the drought.

One of the main challenges of PRONACOSE has been to provide additional weight to the actions of the local authorities, with the federal government only providing subsidiary support in the areas with the most significant impact, mainly with humanitarian aid.

In this program's context, decisions for actions are generally taken based on previously studied scenarios, and the execution of the actions that are decided will have to follow protocols not only already outlined, but where possible, implemented through drills. This implies that, in advance, the coordination structure between the participating institutions (public or private) has been defined, avoiding duplication or omission.

Mitigation actions begin when the National Water Commission officially declares the phenomenon; however, it does not end precisely when the commission declares its conclusion but extends until the water conditions allow the expected continuation of productive activities. An essential part that corresponds to the commission in implementing exceptional measures contemplated in the general guidelines, for which the administrative, legal protocol is developed that allows the publication and execution of general agreements to guarantee the supply of water for human consumption. At the same time, the drought lasts to a severe or higher degree.

This effort by the public administration to address disasters associated with droughts is part of the strategies that the World Meteorological Organization, as well as other world-scale organizations, have undertaken to strengthen the generation of national policies to address the effects of this problem; however, the absence of a debate that incorporates the social, economic, political, and cultural implications of structural vulnerabilities continues to be observed, a situation that makes it difficult to achieve natural prevention and management objectives in the area of agriculture. For this reason, it is necessary and highly relevant that, regarding this contingency, Society and Governments promote a national agricultural plan that allows us to identify the productive potential of the country under new scenarios and climate, water and soil conditions, as well as the strengthening of markets, local and regional, promoting the production of healthy food (CMDRS, 2021).

4.6 Conclusions

Droughts have a severe, widespread, and underestimated effect on societies, ecosystems, and economies. They generate costs that disproportionately affect the most vulnerable people. The broad impacts of drought are often insufficiently studied, despite covering large areas, cascading through different systems and scales, lasting over time. They affect millions of people and many sectors and areas, such as agricultural production, public water supply, energy production, water transport, tourism, human health, and biodiversity, thus contributing to food insecurity, poverty, and inequality. The study of this socio-environmental problem has been restricted, long time, to the monitoring of natural phenomenon, ignoring the sociogenesis of disaster, therefore, the multi-causality of the risk.

Mexico has been a territory especially susceptible to droughts, presenting, between 2006 and 2021, four significant periods of water stress that have affected more than 80% of the national territory. The measurement of multidimensional effects presented in this work still coincides with the ongoing drought, whose outcome and implications for development are still uncertain. This research offers a first overview of the implications of the drought at the productive, economic, social, and environmental levels in the country, effects that the COVID-19 health emergency will most certainly deepen.

There is also a review of the set of strategies, reactive and prospective, that make up the National Program against Drought (PRONACOSE). These actions show the importance that the issue has had on the national political agenda. However, the particularities of the agricultural sector and its level of impact require institutional, legal, and administrative instruments that intervene from the critical analysis of current development patterns, which have promoted different contexts of vulnerability in the agricultural sector. While using water resources sustainably, achieving food security in the future will be a major challenge for us and future generations, with integral rural development as a primary objective. Agriculture is an essential user, and careful monitoring of water productivity is required in this sector and exploring opportunities to increase it.

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Part II
Extreme Climatic Events: Impacts and Adaptation Issues in Agrarian Environment

Chapter 5
Smallholder Livestock Farmers' Animal Health Management Practices in South Africa

M. Maziya, P. Tirivanhu, R. J. Kajombo, and N. A. Gumede

Abstract Primary animal health care is an important ingredient to sustainable and profitable livestock farming. The aim of the study was to investigate the animal health care management practices adopted by smallholder livestock farmers in South Africa. Combinations of multi-stage and stratified sampling techniques were used to select 591 farmers across five provinces in South Africa. The results revealed that farmers employed various primary animal health care practices to prevent diseases. The degree of uptake of the different primary animal health care practices differed across the five provinces. In general, dipping, vaccination and deworming were the most used disease preventative measures while disinfection, isolation and restricted access were the least used disease preventative measures. Although dipping was a common primary animal health care practice, the Free State lagged behind. Membership of livestock association and livestock expenditure were the major drivers of adoption of primary animal health care practices. The study also found that livestock farmers across the provinces were spending a significant amount of household income on primary animal health care. Household livestock management expenditure was influenced by household head education level, income, and herd size. In light of these findings, the study recommends that there should be targeted interventions on primary animal health care (i.e., provision of dipping infrastructure) driven through bottom-up approaches.

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5.1 Introduction and Background

Livestock systems play a significant role in the socio-economic well-being of the people in developing countries (Alam et al., 2021; Behnke & Muthami, 2011; Kosgey et al., 2008) and are a significant global asset with a value of at least US$1.4 trillion (Thornton, 2010). It is estimated that over 300 million people residing in sub-Saharan Africa depend on livestock as their main source of livelihood (Abdilatif et al., 2018). Livestock production is an important risk aversion strategy for vulnerable communities. They are important providers of nutrients and traction for crop production in smallholder farming systems. Livestock are also kept for prestige and wealth creation in some local communities. Livestock rearing also provides a source of income, and cattle specifically serve as a measure and store of wealth. For the majority of rural livestock farmers, livestock is used as a "bank" for emergency needs. As such, livestock can be a safety net in the current era of Covid-19 which has threatened the livelihoods of both urban and rural populations.

Despite the potential benefits of livestock farming, rural livestock farmers face a myriad of challenges that limit their capacity to generate adequate benefits from their livestock (Sikhweni & Hassan, 2013). A major constraint facing smallholder livestock farmers in South Africa is animal diseases. These diseases lead to high livestock mortality in rural livestock systems. Livestock diseases impact significantly on the livelihoods of rural people and are an impediment to the livelihoods of resource-poor farmers who depend on livestock. For instance, of the 16 animal diseases that have been indicated to be fatal in the world, eight of these mostly occur in sub-Saharan Africa (Wallace et al., 2014). The poignancy of this situation is that some of those eight diseases are zoonotic in nature; in other words, these diseases can spread from animals to humans (Rogan & Babiuk, 2005). Furthermore, in sub-Saharan Africa where veterinary services are considered not at par with current global standards, the ability of the countries in the region to handle such outbreaks may be insufficient. Lack of adequate control measures in this regard may result in morbidity and mortality in both people and animals (Rogan & Babiuk, 2005).

The South African government has put in place relevant legislation that sought to address/promote disease management. In particular, the *Animal Diseases Act*[1] provides for the control of animal diseases and parasites, to promote animal health and related matters. Both veterinary agents and livestock farmers are responsible for maintaining animal health and controlling the spread of disease through early reporting of diseases and implementing biosecurity measures. The implementation of primary animal health care measures reduces the spread of diseases. Besides, primary animal health care practices can minimize the direct and indirect negative economic effects of infections on humans. In addition, the implementation of primary animal

[1] In the *Animal Disease Act,* animals refer to any mammal, fish, bird, reptile or amphibian.

health care measures has been demonstrated to be the cheapest and most effective means of disease prevention with, significant financial gains.

It is also worth noting that resource-poor livestock farmers who are located in rural areas are highly dependent on state veterinary services due to their low household income, the high cost of veterinary medicines and private services, and their limited understanding of animal health care. Estimates from Stats SA (2018) suggest that only 1.3% of agriculturally active black households received agriculture-related training in 2017. In the same period, it is reported that only 6.3% of agriculturally active black households received livestock health services. The overall impression created by this is that access to agricultural support is extremely limited. A study (Jenjezwa & Seethal, 2014) in Hertzog in the Eastern Cape also found that veterinarians and Animal Health Technicians (AHTs) were severely constrained in terms of travel. Within government, there has also been an increasing recognition that extension services do not only lack the numbers of personnel to reach a large number of black farmers (DOA, 2008), more importantly, they lack the skills to support the diverse types of black farmers in the smallholder systems.

A review of existing literature reveals a scarcity of information on primary animal health care measures adopted by smallholder livestock farmers in South Africa. This study addresses this research gap and aims to provide a comparison of primary animal health care practices adopted by smallholder livestock farmers across five provinces in South Africa. To the best of the authors' knowledge, this is the first study in South Africa to have looked into smallholder livestock farmers' practices in primary animal health care.

5.2 Material and Methods

5.2.1 The Study Area

The study was conducted in five provinces in South Africa: Eastern Cape (EC), Free State (FS), North West (NW), KwaZulu-Natal (KZN), and Mpumalanga (MP).

5.2.2 Sampling

This study used a combination of multi-stage and stratified sampling techniques. The first stage involved the purposive selection of five provinces in South Africa: Eastern Cape, Free State, North West, KwaZulu-Natal, and Mpumalanga. The selected provinces had the highest number of farmers engaged in livestock farming (Stats SA, 2013). A simple random sampling without replacement method was used to select the districts, local municipalities, and the villages in each province. Two district municipalities were also purposively selected in each of the five provinces. Based on the 2011 census, there are 50,563 livestock owners in the selected local municipalities in the districts (Stats SA, 2010). The study employed a simplified formula for proportions suggested by Yamane (1967) to determine the sample size. Based on the formula, at 5% precision level where the confidence is 95% and where the degree of variability is 50%, the appropriate sample size is 397 households. However, to allow for non-responses and unavailability, a sample of 600 households was targeted across the provinces. A stratified proportional sampling procedure was used to determine the sample size per local municipality in each province. In the Eastern Cape, the size of the strata was 22,043 households, the required sample size was 150 and the actual sample size was 202. In the Free State, the size of the strata was 4871, the required sample size was 150 and the actual sample size was 119. In Mpumalanga, the total number of households was 12,222, the required sample size was 150, and the actual sample size was 147. In KwaZulu-Natal, the size of the strata was 60,043, the required sample size was 75, and the actual sample size was 51. Finally, in the North West, the size of the strata was 5383, the required sample size was 75, and the actual sample size was 74. In total, 593 households were interviewed across the five provinces but two questionnaires were discarded due to incomplete information and the remaining 591 questionnaires were used for analysis. The study focused on smallholder[2] livestock farmers owning less than 100 cattle or livestock owners owning a combination of cattle and small stock (goats and sheep).

A list of farmers obtained from AHTs of the respective districts within the different provinces. Community leaders and the AHTs facilitated the recruitment of participants and made sure that a diverse pool of livestock owners was available for interviews.

5.2.3 Data Collection

Using a pretested questionnaire, data was collected by a team of experts from Human Sciences Research Council (HSRC) between August and September 2016 (Habiyaremye et al., 2017). The team of experienced enumerators understood the local languages spoken by farmers in sampled districts. The questionnaire collected data on household characteristics, asset ownership, livestock holding, sources of income, access to information, agricultural extension services including training on animal handling and farmers' expenditure on primary animal health care products. The questionnaire also included information on farmers' knowledge, attitudes, practices, and perceptions toward vaccinations.

[2] Smallholder farmers are farmers who produce for household consumption, markets and earn revenue from farming business, which form a source of income for the household. This group of farmers has potential to graduate to commercial farming but need access to comprehensive technical and financial support (Carelsen et al., 2021).

5.2.4 Data Analysis

Data were analyzed using STATA version 15 and Microsoft Excel 2010. Descriptive statistics were used to analyze the survey results.

5.3 Results

5.3.1 Household Characteristics

The socio-economic characteristics of the livestock farmers are presented in Table 5.1. Male-headed households constituted 65.3% of those involved in livestock farming, almost double the proportion of female-headed households (34.7%). The Free State, North West, and KwaZulu-Natal provinces, at 80%, 74%, and 73%, respectively, had the highest proportion of male respondents. The average age varied from 58 to 60 years among the five provinces with Mpumalanga and North West at the highest (60 years) and KwaZulu-Natal at 50 years of age as the lowest average. Female household heads were on average, a few years older than their male counterparts in the North West, Mpumalanga, and KwaZulu-Natal while they were on average younger than their male counterparts in Eastern Cape and Free State provinces.

Mpumalanga had the highest proportion (41%) of livestock farmers who did not attain any form of formal education. The average household number varied from 3 to 7 people with the lowest (3) and the highest (7) reported in North West and KwaZulu-Natal provinces, respectively. The average household income was R2974, but there were sizable variations across the surveyed provinces. The highest average income by province was registered in the Free State (R3755), while farmers from Mpumalanga reported the lowest incomes with an average household income of only R2189.

The results show that KwaZulu-Natal farmers spent the least R997 on livestock welfare (i.e., supplementary feeding, vaccination, dipping, etc.) while North West farmers spent the highest (R3147) amount of money on their livestock.

Table 5.2 shows that 61.6% of the farmers had a livestock-based system while 38.4% practice mixed farming. The low proportion of farmers who also practiced crop farming maybe a result of poor rainfall because of the arid nature of the districts that were visited. Further, the results show that the majority of the farmers (74.8%) had more than 40 years of experience in farming with livestock. Table 5.2 also shows that more than half (59.2%) of the farmers keep their livestock in a communal land system and this has implications for grazing land and surveillance and management of diseases because livestock grazes together. About 17.9% of the farmers say that they have weekly contact with AHT, 17.4% said AHTs visit them once a month, 16.9% meet their AHT quarterly while 27.7% of the farmers reported that they meet with AHTs once a year.

Table 5.1 Socio-economic characteristics of the farmers

Variable		EC	FS	KZN	MP	NW
Age	Male	59	61	49	58	56
	Female	57	57	51	61	65
	Average age	58	60	50	60	58
Gender (%)	Male	51	80	73	65	74
	Female	49	20	23	35	26
Family size	Average number	5	5	7	6	3
Farming experience	Average years	25	21	20	24	27
Education level (%)	No formal education	36	27	39	41	20
	Primary	36	38	37	21	33
	Secondary	25	31	24	33	42
	Tertiary	3	4	0	2	5
Livestock numbers	Average number of cattle	9	8	12	15	14
	Average number of sheep	13	2	0	0	5
	Average number of goats	8	0	17	5	12
Average income (R)	Monthly income	2928	3755	2500	2189	3728
Expenditure (R)	Expenditure on animal welfare per annum	1802	2614	997	1611	3147

5.3.2 Primary Animal Health Care Practices Adopted by Livestock Farmers

The degree of uptake of the different disease control measures differed across the five provinces. In general, smallholder farmers employed various primary animal health care measures to control diseases, as shown in Fig. 5.1. Deworming, dipping, and vaccination were the most commonly used methods of disease control, while disinfection, isolation, and restricted access were the least utilized methods. To reduce the occurrence of animal diseases, there should be an implementation of a sound vaccination program and parasite control through deworming. The results showed that there were fewer farmers who vaccinated and dewormed their livestock in Mpumalanga. In contrast, the province was doing very well in dipping which was attributed to the availability of state sponsored dipping infrastructure.

Mpumalanga was the least performing province regarding disease control across the five methods. The Free State was the best performing province in disease control. However, when it came to dipping, its performance was relatively low due to the lack of dipping infrastructure, which was readily available in the other four provinces. The Free State, however, showed success in other disease control methods.

Table 5.2 Farm characteristics of smallholder livestock farmers

Variable	Frequency	Percentage
Farming system		
Livestock based	364	61.6
Mixed	227	38.4
Farming experience		
< 10	48	8.1
10–20	50	8.5
21–30	31	5.2
31–40	20	3.4
> 40	442	74.8
Sources of land		
Own land	105	17.8
Communal	350	59.2
Leased	5	0.8
Municipal	139	23.5
Frequency of contact with AHT		
Weekly	106	17.9
Monthly	103	17.4
Quarterly	100	16.9
Once a year	164	27.7
Other	116	19.6

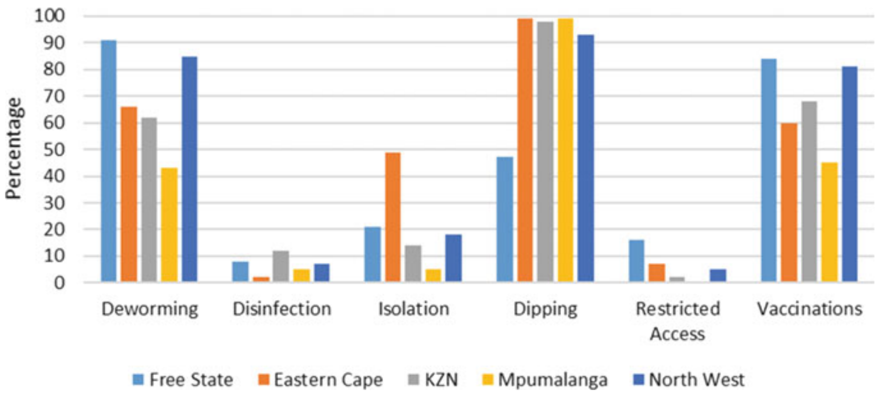

Fig. 5.1 Disease control measures adopted by livestock farmers

5.3.3 Drivers of Primary Animal Health Care Practices

Three categories of primary animal health care practices were identified: class 100, class 110, and class 111. Class 100 represents farmers who applied primary animal health care measures such as isolation of sick animals, dipping, disinfection, and deworming. Class 110 represents farmers who vaccinated their livestock while class 111 represents farmers who practiced both classes of primary animal health care.

The results of the discriminant analysis revealed that expenditure on livestock activities, access or no access to animal health information and membership or non-membership in a farmer association were significant factors that determined whether a farmer practiced primary animal health care practices (Fig. 5.2). The three classes of animal health care practices differ significantly, the main drivers being membership of an association and the level of expenditure on livestock activities. These two drivers contributed 91% toward the difference as indicated by centroid $F1$. With all other factors held constant, strengthening of these factors will significantly improve primary animal health care among smallholder farmers. Similarly, access to information and no access to information contributed only 9% toward the difference as indicated in centroid $F2$. Centroids $F1$ and $F2$ completely explained the difference between the three classes. Although access to information on new vaccines played a minimal role in influencing farmers' decision to apply primary animal health care practices, farmers with access to information were likely to apply all the three categories of primary animal health care. For those farmers who had access to information, animal health practitioners, and extension officers were their main sources. Most farmers reported that animal health practitioners visited their animals regularly for vaccination, especially against anthrax and black quarter.

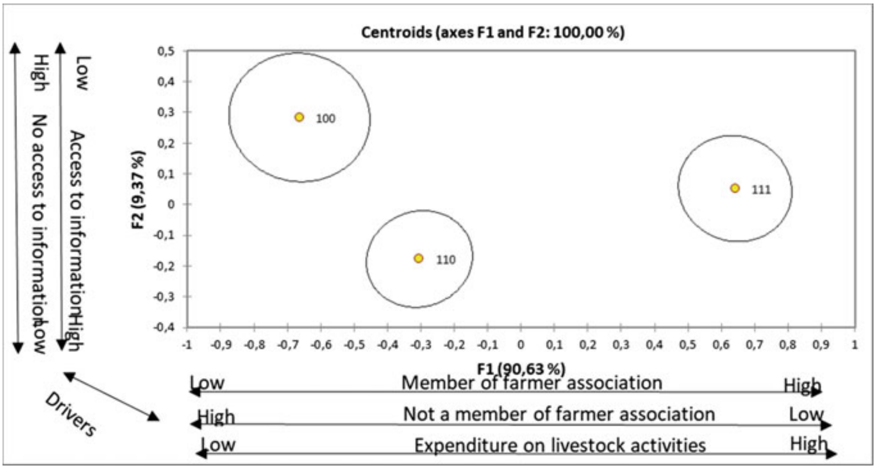

Fig. 5.2 Drivers of primary health care practices

5.3.4 Spending on Primary Animal Health Care

Figure 5.3 shows that about 70% of smallholder livestock farmers purchase antibodies to boost the immune system of their animals and that approximately 57% of the surveyed farmers purchase animal vaccines. However, when it comes to spending on animal feed and supplements, we found that less than half of the farmers purchased these products, 49% of the farmers do purchase animal feed while 43% reported having purchased supplements in the past 12 months.

Farmers spending on primary animal health care is to a significant extent not only influenced by level of education, but also total household income and number of cattle held by the farmer (Table 5.3).

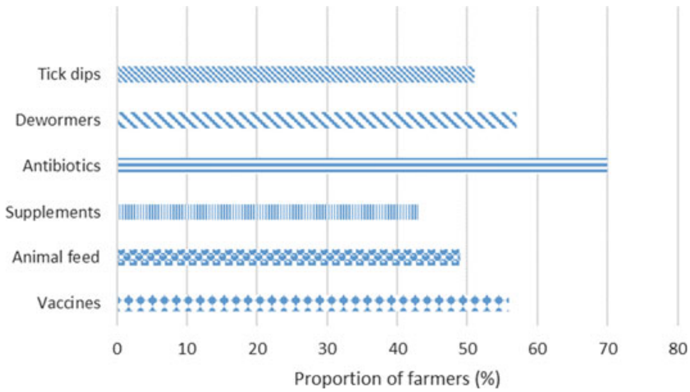

Fig. 5.3 Spending on primary animal health care

Table 5.3 Estimated spending on animal health care per annum

Variable	Coefficient	Standard deviation	$P > \|t\|$
Education level	412.25**	170.65	0.016
Total household income	0.20***	0.04	0.000
Number of cattle held	53.77***	8.01	0.000
Constant	223.27	374.11	0.552
Number of observations	523		
R-squared	0.226		
F	50.60		

Note ***and ** denote statistical significance at 1% and 5% levels, respectively

Table 5.4 Proportion of farmers who lost cattle due to disease

Province	Frequency	Percentage
Free State	56	28.7
Eastern Cape	62	31.8
KwaZulu-Natal	19	9.7
Mpumalanga	43	22
North West	15	7.7

5.3.5 Cattle Mortality

Table 5.4 shows that at 28.7% and 31.8%, the Free State and Eastern Cape, respectively, recorded the highest proportion of farmers who lost cattle due to disease. In contrast, KwaZulu-Natal and North West provinces reported the least mortality rates and farmers in these provinces reported to have received adequate state sponsored primary animal health care services.

5.4 Discussion

The majority (65.3%) of the livestock farmers engaged in livestock farming were males, and this is a clear indication that livestock farming (especially big stock, i.e., cattle) is a male dominated enterprise. This highlights the socio-economic and cultural importance of keeping livestock to low-resource farmers in rural areas (Ncobela & Chimonyo, 2015). These findings are similar to studies of Duguma et al. (2012) and Oladele et al. (2013) who reported that males dominated livestock farming. In the Mpumalanga province, a fair share (41%) of smallholder farmers did not attain any form of education. High literacy rates among smallholder livestock farmers can be a precursor for innovation and technology adoption (i.e., uptake and correct use of animal vaccines), resulting in higher productivity (Oladele et al., 2013). Level of education is directly related to the success of a farm and it influences farmers' decision making (Lubambo, 2011). The majority of farmers in the study areas had more than 40 years of experience in keeping livestock. These years of experience shows that farmers have been keeping livestock for a long time and it counts in good primary animal health care practices which evolve over many years of livestock keeping, in particular as it affects distinct identification of animal diseases. The finding that farmers age was above 50 across the provinces tallies with findings of Oladele and Moilwa (2010) that livestock, in general, is managed by older people. Farmers' age is important as it can be a proxy for farming experience, that is, older farmers tend to have more experience compared to young farmers.

Primary animal health care has the potential to prevent the occurrence of animal diseases thus reducing livestock mortality. Cattle mortality was high in the Free State (28.7%) where dipping infrastructure and extension support was lacking. These findings are consistent with those of Scholtz and Bester (2010) who also reported a mortality rate of 30.7% in communal areas. Disinfection, isolation, and restricted access were the least practiced primary animal health care measures, and this has wide implications because disease can spread easily in the community. Dipping was the most practiced primary animal health care practice across the provinces except for the Free State. This result conforms with the findings of the General Household Survey where it was reported that 6.3% of agriculturally active black households received livestock health services (Stats SA, 2018). Despite this minimal support, livestock farmers in the Free State were doing well in the execution of the other animal health care measures. This could be attributed to farmers spending more (R2614 per annum) on primary animal health care because of minimal government support. In an extension approach, companies selling animal health care and feed products in the Free State could be mobilized to become more involved in rural communities.

The significant role played by animal health practitioners is well documented (Catley et al., 2004; Leyland et al., 2014). While farmers from all provinces reported having access to an animal health practitioner, it is concerning that 17.9% reported weekly visits by an animal health practitioner while 17.4% are visited once a month. The remainder of the farmers is visited quarterly or once a year. This can be a fall out of inadequate veterinary services in rural areas either in number or by specialization. For instance, during our consultations with farmers in the Free State, AHTs indicated that they were severely constrained in terms of travel as each AHT is allotted a limited mileage per month and as a result cannot reach the majority of smallholder farmers.

Livestock farmers who are members of livestock associations were more likely to undertake primary animal health care measures. This result underscores the importance and value of livestock groups as a mechanism for information sharing and technology adoption in rural areas (Abebaw & Haile, 2013; DAFF, 2012). There is a correlation between expenditure on livestock activities and the implementation of primary animal health care practices. Level of education, as a proxy for human capital development, is significant ($P < 0.05$) and positively associated with expenditure on primary animal health care. This result underscores the role of education as a precursor for technology adoption. The results also show that total household income is significant ($P < 0.01$) and positively correlated with expenditure on animal health care signifying the role of other income sources (other than livestock sales) in the expenditure of animal health care products. Therefore, livestock farmers should be encouraged to also venture into other off-farm activities in order to diversify their income.

5.5 Conclusion

Primary animal health care is vital as it has the potential to prevent the occurrence of livestock diseases and mortality in smallholder livestock systems. Deworming, vaccinations, and dipping were the most practiced primary animal health care practices because of government support for these programs. However, although dipping is a common primary animal health care practice, the Free State lags behind. Cattle mortality was higher in the Free State where farmers reported a lack of government support and inadequate infrastructure. There is a need to revitalize dipping infrastructure in the Free State. Restricted access, disinfection and isolation were not sufficiently taken up by farmers across the five provinces. Developing and strengthening these disease management plans is key to avoid economic, environmental, and health impacts that may arise from disease outbreaks. From the results it is clear that farmers are not a homogenous group, there are differences in primary animal health care practices adopted by farmers across the five provinces. Therefore, this calls for targeted interventions that are driven through bottom-up approaches so that government delivers programs that are needed by farmers. Strengthening early warning systems and farmers' response capacity could play a pivotal role in the prevention of animal disease threats, through the sharing of information. Membership of livestock associations and level of expenditure on livestock activities were the main drivers of primary animal health care practices. Further, level of education, household income, and the number of cattle held are the main factors that affect spending on primary animal health care. Therefore, these factors should be considered when developing and implementing interventions that target smallholder livestock farmers.

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Conflict of Interest All the authors declare that they have no conflict of interest.

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Chapter 6
Identification of Spatio-Temporal Extent of Agricultural Drought Using Geospatial Techniques: A Case Study of Chhatna Block, Bankura District, West Bengal, India

Asraful Alam, Pradip Patra, Arijit Ghosh, and Lakshminarayan Satpati

Abstract One of the most extreme climatic occurrences, drought is distinct from other climatic phenomena in that it can happen at any time and in all climatic zones while also varying greatly from one area to another. Farmers in the region encounter considerable temporal and spatial variability in water supply during cropping seasons with frequent and longer dry spells. Agricultural drought is typical in dry land. Therefore, spatio-temporal variation in agricultural drought identification is important for policy maker as well planner. To examine the moisture surplus and deficit of the soil to crop, drought year has been estimated using Standardized Precipitation Index (SPI) 6 with the help of monthly precipitation of 116 years data. Seasonal "Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) have been estimated to derive three other indices: Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index". The multispectral band ratios have been performed to evaluate vegetation density and vegetation health to assess drought conditions over the study area (VHI). In order to determine the VHI of the study area for this paper, four years (1990, 2000, 2010, and 2017) were selected, out of which two experienced the severe drought (2000 and 2010).In the year of 1990 VHI value expressed that drought condition of this study area was ranges between moderate droughts to mild droughts but on the other hand in 2017 it fall in the category of severe drought (Below 20 VHI value). The four-year analysis period's findings indicated that the sample block is currently facing a moderate to severe drought situation.

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Keywords Agricultural drought · NDVI · Standardized precipitation index (SPI) 6 · TCI · Vegetation condition index (VCI)

6.1 Introduction

The physically occurring fact that exists when precipitation are considerably below the normal record levels, for that reason create serious hydrological imbalances which harmfully influences land resource production systems (UNISDR, 2009). Basically drought are of four types, Agricultural, Hydrological, Meteorological (climatic), and Socioeconomic. Some are try to define another one underground water drought (Mishra & Singh, 2010). Because soil moisture is frequently quickly depleted for plant growth, agriculture is one of the first industries to be impacted by drought. It is linked to many specific characteristics of meteorological dryness that have an impact on agriculture, with a focus on precipitation shortages, essentially the distinctions between actual and prospective evapotranspiration, and soil water deficits in a region. (Agnew & Chappell, 2000). In this research basic target is to identify spatio-temporal extent of agricultural drought in the selected study area. A drought in agriculture implies that there is insufficient rainfall to support typical crop production. On the other away we can explain that agricultural drought happens when rainfall and soil moisture are insufficient for the period of the mounting season to sustain healthy crop growth to ripeness. Satellite-borne remote sensing data are very important to know the droughts quality and prospects, for that our whole research basically based on the satellite-borne data. Various land cover types have been monitored using remote sensing, and biophysical parameters of land surfaces have also been estimated (Steininger, 1996). Land surface temperature (LST) and the Normalized Difference Vegetation Index (NDVI) have been constructed using multispectral and thermal data from Landsat. It gauges the thermal status of plants and vegetation condition (VCI) (TCI). One of the most widely used methods for tracking drought events has been using the Normalized Difference Vegetation Index (NDVI) as a probe for vegetation health. Various remotely sensed drought indices, including duration, intensity, severity, and spatial extent, have been developed and applied (Ji & Peters, 2003; Mishra et al., 2015). The combination of vegetation index and temperature has been appropriate for this research's structure and standard format. Strong correlations between NDVI and land surface temperature (LST) can be used to identify agricultural droughts and serve as early warning systems. The unique LST patterns are connected to the thermal properties of the different types of land cover (Lo et al., 1997). Using a variety of techniques, LST has been used to describe ecological drought, as outlined in the following (Aghakouchak et al., 2015). In many environmental systems, such as the hydrological and carbon cycles, as well as in the land surface energy budget, LST plays a crucial function as a control variable (Czajkowski et al., 2004). NDVI is a substitute indicator used for extracting and approximating vegetation covers in terms of percentage and density, which indirectly highlights the health of the vegetation (Tucker, 1979).

6.2 Study Area

The block of Chhatna situated in the western part of the Bankura district having latitudinal and longitudinal extension of 23°18′ 06″ N, 86° 58′ 58″ E. It is bounded on the West by the district of Purulia and entire east, north and southern parts are bounded by the blocks Bankura-I, Bankura-II, Gangajalghati, Saltora, and Indpur respectively. It covers an area of 441.00 km^2. The block of Chhatna belongs to Bankura upland. Much of its topographical uniqueness is indomitable by that of the Chotonagpur Plateau. This region is characterized by the undulating topographic features with hills and ridges. Susunia is the prominent peak of this block (Fig. 6.1). Out of 36 blocks under drought prone area program (DPAP-2002) of West Bengal, 7 blocks fall under Bankura districts, and Chhatna is the populous among them.

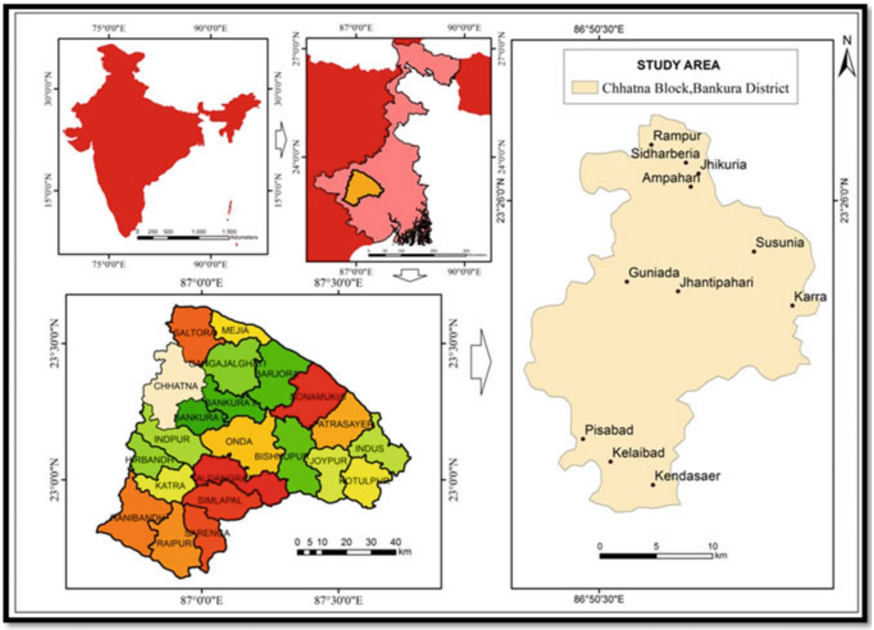

Fig. 6.1 Study area

6.3 Methodology

6.3.1 Standardized Precipitation Index

The Standardized Precipitation Metric (SPI) (McKee et al., 1993) is a very handy index for determining if a region has a moisture surplus or deficit. All Metrological Organizations (MO) worldwide are advised by the World Meteorological Organization (WMO) to use SPI in addition to their own indices to measure the severity of the drought. The main advantage of employing SPI is that it is multi-temporal in nature and can be used to demarcate several types of drought, such as meteorological drought, agricultural drought, and hydrological drought of an area. The research area's drought has been marked off in this instance using SPI with a time step of six months. To define the link between the probability and the precipitation, it is necessary to fit a probability distribution to the historical precipitation records for the timescale(s) of interest before computing the SPI. A standard normal distribution is then created using the inverse normal (Gaussian) function from the fitted probability distribution. The mean and variance SPI for the location and requested time period are 0 and 1, respectively, in a conventional normal distribution (Fig. 6.2).

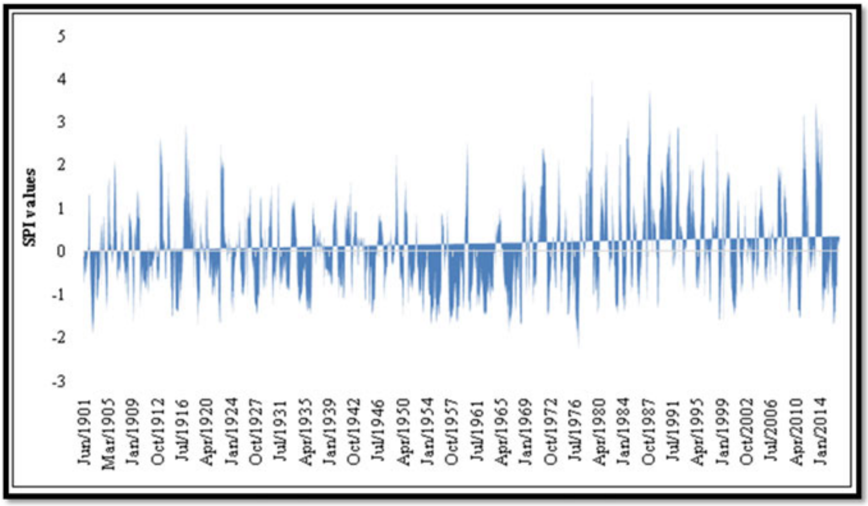

Fig. 6.2 SPI6 of Bankura district

6.3.2 Remote Sensing Drought

Geospatial technology has been utilized to define the extent of the drought after historical drought calculations (Fig. 6.2) and determination of the district's most significant drought year. For this purposes, both fine and coarse resolution satellite images can be used. Although, fine resolution satellite images have different lacuna like low temporal resolution, but remained effective to monitor spatial extend. Aman paddy is the main agricultural crop of Bankura. The Aman paddy have been cultivated between June July month and December month. The satellite images have cloud cover during June to September months. For that reason, Landsat thematic mapper (TM) and Landsat 8 satellite images of November month in the year of 1990, 2000, 2010, and 2017 have been used. Landsat satellite images were used to create indices like the "Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST)" using multispectral and thermal data (Rizqi et al., 2015). All satellite data was converted to sensor spectral-radiance using radiometric calibration in order to calculate the indices (Chander et al., 2009). Finally, the "Vegetation Condition Index (VCI) and Temperature Condition Index (TCI)" have been determined using the two sets of data. The final index, the Vegetation Health Index, was created using combined VCI and TCI data (VHI). In order to determine the level of agricultural drought at any time of the year, VHI takes into account the general condition of the vegetation and its rigor (Rizqi et al., 2015).The calculation of "VHI is given in the Fig. 6.3. The VCI has been calculated using NDVI to monitor vegetation condition" (Kogan, 1995). The equation of the VCI has been given below:

$$\mathrm{VCI} = \frac{(\mathrm{NDVI}\alpha - \mathrm{NDVImin})}{(\mathrm{NDVI\,max} - \mathrm{NDVImin})} \times 100$$

"Here, NDVIα represents NDVI value of current month, while NDVImin and NDVImax denote the minimum and maximum NDVI values, respectively, throughout the period of observation. The VCI has been recommended as drought tool; but only using of VCI have not enough to explain drought study perfectly, for that need to develop TCI to capture different responses of vegetation to in-situ temperature as supplementary information. To fulfillment of the whole processes needed to apply thermal channels for drought monitoring (Kogan, 1995) (Table 6.1). The TCI have been calculated with the help of following formula":

$$\mathrm{TCI} = \frac{(\mathrm{LSTmax} - \mathrm{LST}\alpha)}{(\mathrm{LSTmax} + \mathrm{LSTmin})} \times 100$$

"Here, LST α is the LST value of current or present month, LSTmin represent the minimum LST values and LSTmax denotes maximum LST values, considered from multiyear time series data. Lastly, the VHI has been calculated to evaluate the both category of vegetation stress and temperature to weigh up drought severity. The VHI can be articulated by following equation":

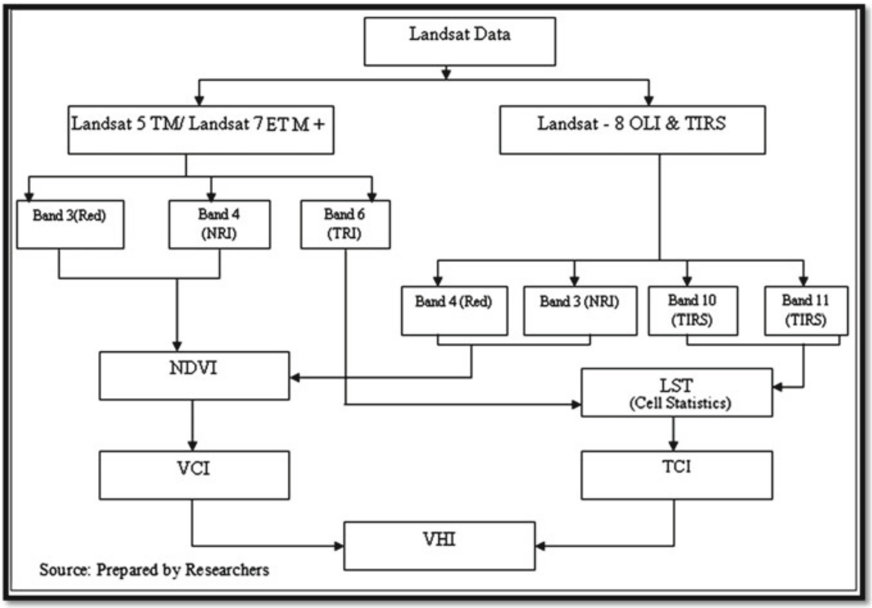

Fig. 6.3 Methodology

Table 6.1 Classification VHI value for drought mapping (Kogan, 1995; Rizqi et al., 2015)

Sl. no	Drought classes	VHI
1	Extreme drought	< 10
2	Severe drought	10–20
3	Moderate drought	20–30
4	Mild drought	30–40
5	No drought	> 40

$$\text{VHI} = \alpha\text{VCI} + (1 - \alpha)\text{TCI}$$

"Here, VHI is related to VCI and TCI by α and α equals to 0.5" and total five type of classification scheme for drought monitoring has been applied (Rizqi et al., 2015) for this research. These are given in Table 6.1. Time series data of NDVI and LST remains identical to explicate the several dry situations over the area (Wang et al., 2014). For this reason, time series comparison also conducted to know overall monitor drought condition in different years.

6.4 Results and Discussion

SPI6 (Fig. 6.2) demarcate the total time periods into segmented wet and deficit years, the highest deficit period has been observed during the 1940s to 1960s and thereafter, inter-annual variability persists. SPI6 very efficiently identified recent three drought years, i.e., 2000, 2010, and 2015–16 of Bankura district. Out of these, 2000 and 2010 remained moderate to severe drought years as the SPI6 value remains(−)1.5 to (−) 2.0. Geospatial technology has been used to find out spatial variability of dry condition within the region. Landsat data are used to evaluate drought trends as well as the severity of a given area's drought (the map's orange color) (both severity and duration). Thus, using Landsat data to monitor drought sensitivity in tiny and remote locations is a suitable strategy (Tran et al., 2017). Figures 6.5, 6.6, and 6.7 represent temporal and spatial distributions of NDVI, LST, and VHI. All maps represent increases of moisture and thermal stress in vegetation of the Chhatna block of Bankura district, where land is used for cultivation. Between 1990 and 2017, the combination of these factors accelerated a slow increase in drought severity, which raised the likelihood of agricultural losses. Figure 6.4 reveals temporal status of NDVI in the study area and lower the value indicate poor health condition of the vegetation and higher value indicate healthy vegetation. In 1990 the highest value of NDVI was 0.656 means it represents near about good condition for vegetation cover but in the year of 2017 it come near to moderately vegetation cover. Whereas in 1990, VHI value fall under moderate droughts to mild droughts (Fig. 6.4) class according to the Kogan FN classification of VHI but on the other hand it falls in the category of severe drought (Below 20 VHI values). Spatial variation also found in different years like in 1990 and 2017, southern part (Kendasaer, Kalaibad, Pisabad) of the study area was remained drought prone area and have poor vegetation condition. On the other hand, in 1990 the central part of the study area has remained moderately drought condition, but in 2017, it remained in severe drought condition.

6.5 Conclusion

In this study, we evaluated the capacity of remotely sensed LST, VCI, and derived VHI to represent drought condition over the study region, with the goal of applying those indices within the context of a near-real time drought monitoring system in the study area. The agricultural and social economies of India are heavily dependent on rainfall for agricultural production, yet even a small departure from the usual will have a significant influence on the country's agricultural productivity in the studied area. India's crop failure in recent years has also been blamed for a significant number of farmer suicides. It is crucial to first understand agricultural drought in order to increase agricultural production for monsoon-dependent nations like India. It is first imperative to investigate the agricultural drought both spatially and temporally to

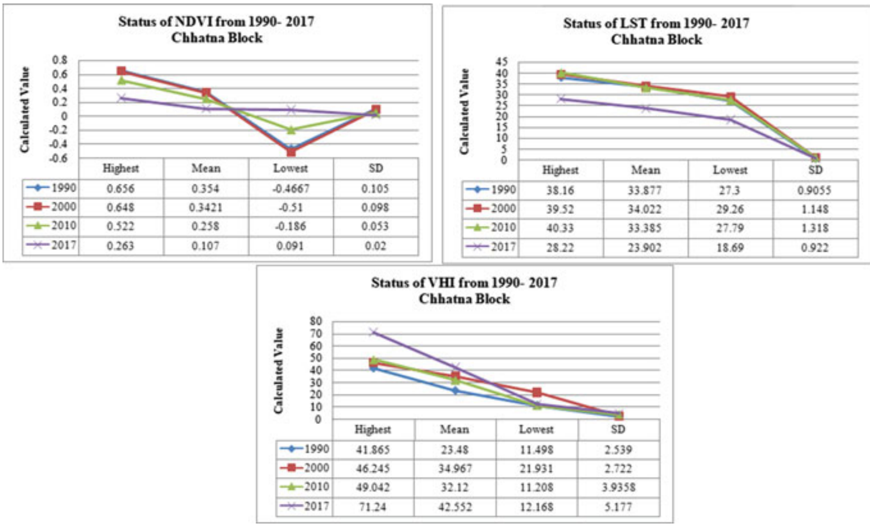

Fig. 6.4 Status of NDVI, LST, and VHI from the year of 1990 to 2017 in the study area

gain a sense of when and where the drought occurred in order to increase agricultural production for monsoon reliant countries like India (Vaani & Porchelvan, 2017). Using NDVI-based VCI, LST, and GIS, the current study creates drought intensity maps for the Chhatna block of Bankura district, West Bengal, India over a period spanning 1990 to 2017. The monsoon precipitation determines the region's crop productivity because the Chhatna block and the majority of the district practice rain fed agriculture. This study supports the fact that 2010 and 2000 both had the greatest droughts in terms of agricultural productivity. "According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), natural disaster frequency and intensity would both rise in the near future. Maximizing the irrigation facility to the field can be the top goal in order to reduce the effect of monsoon variability on the productivity of the crop. The aforementioned findings unequivocally demonstrate that the government must take the required actions to ascertain the causes of the study area's recurrent nature of drought and to implement preventative measures to avoid drought in the future. The state's agricultural productivity will grow as a result of the government taking measures to raise ground water levels, such as strengthening irrigation tank bunds and building percolation ponds and recharge structures.

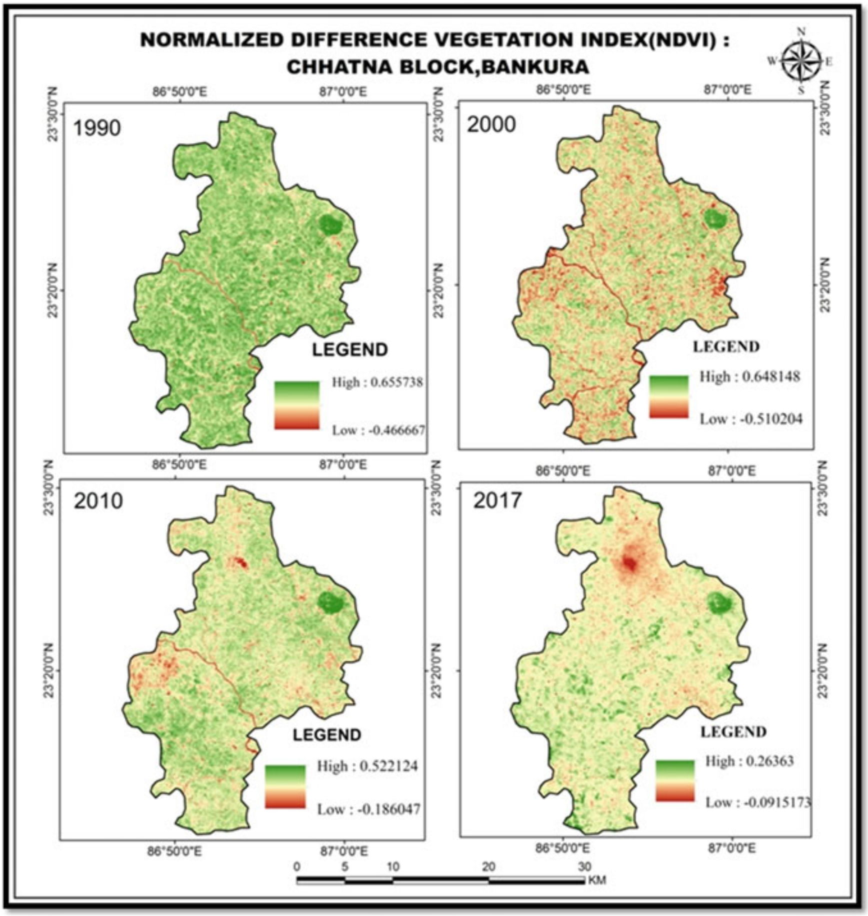

Fig. 6.5 Status of normalized difference vegetation index (NDVI) in the study area (1990, 2000, 2010 and 2017)

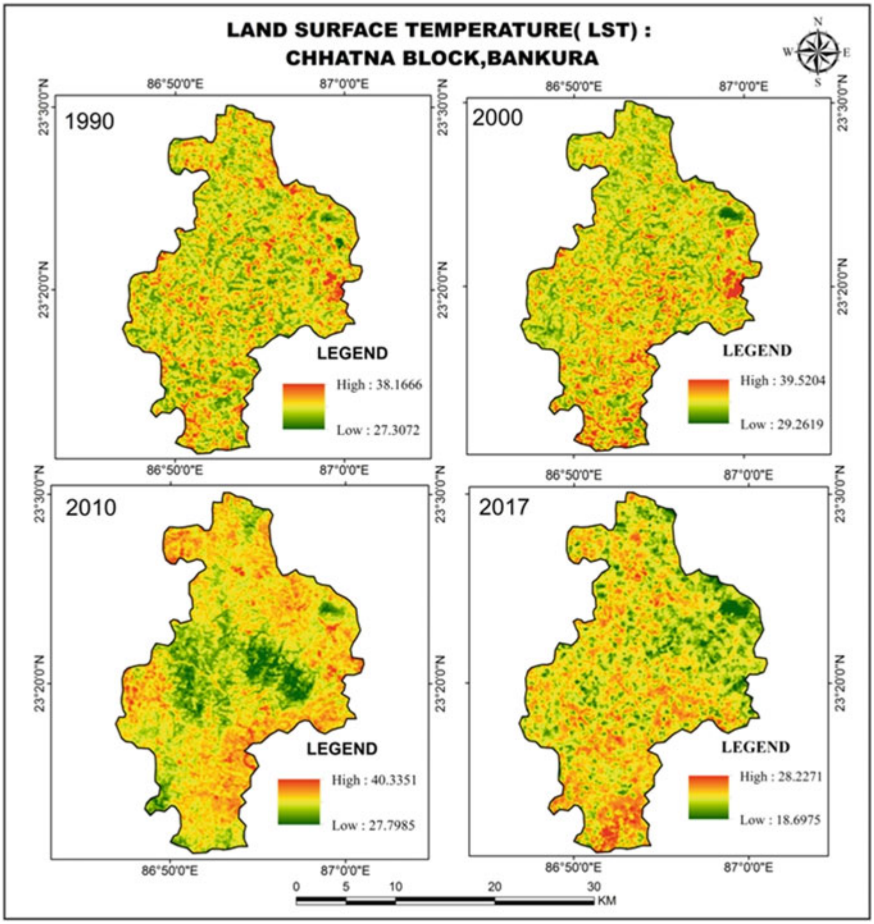

Fig. 6.6 Status of land surface temperature (LST) in the study area (1990, 2000, 2010 and 2017)

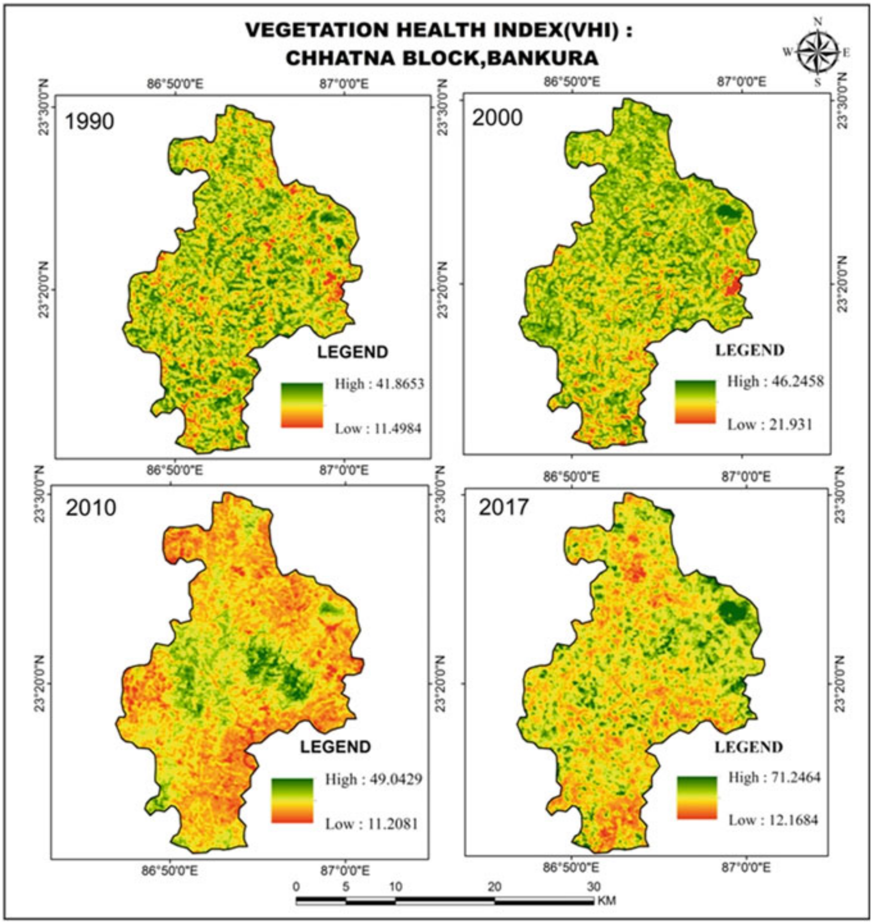

Fig. 6.7 Status of vegetation health index (VHI) in the study area (1990, 2000, 2010 and 2017)

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Chapter 7
Climate Change and Agriculture: Understanding Short-Term Impact of Climate Change in Selected Crop Production in West Bengal

Parama Bannerj and Radhika Bhanja

Abstract Human induced climate change in the past century has caused widespread losses and damages to both nature and people (IPCC in Climate change 2022: Impact, adaptation and vulnerability, 2022). According to a World Bank report (India: climate change impacts, 2013), climate change may directly interfere with the weather parameters affecting agriculture in terms of extreme heat wave, glacier melt, changing rainfall pattern, etc. The majority of its people relies on climate-sensitive livelihoods, like agriculture, which could negatively impact the economy growth that is tightly tied to the natural resource base. Agriculture in India, especially in West Bengal, is still susceptible to weather changes, and the future threat of climate change could make this susceptibility even worse. Estimating the effect of weather and climate on economic performance is the subject of a modest but expanding body of literature. However, the majority of these are cross-country studies or concentrate on developed nations largely for data reasons, so they might not be applicable. This research paper looks into the effects of weather change on agricultural productivity in the short term and, in turn, climate change effect in the long term with particular attention to the Indian state of West Bengal.

Keywords Climate change · Crop production · Vulnerability · Agroclimatic zone · *Climate variability*

7.1 Introduction

According to the literature, agricultural output is susceptible to climate variability brought on by climate change, which includes changes in temperature, CO_2 levels and rainfall patterns. Future food insecurity is predictable to be pointedly worsened by climate change, which will increase food prices and reduction food output. In some

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locations, these potential yield increases are expected to be constrained by extreme occurrences, particularly high heat and drought, even while gradual increases in temperature and carbon dioxide may result in more favourable conditions that could boost the yields of some crops (Mall et al., 2007).

Thus, crop production may respond to climate change in a selective manner, with some crops producing higher yields while others produce lower yields. The effects of crop output owing to climate change are a topic of discussion. IPCC (2001) predicted that the poorest nations would be hardest hit, with crop yields declining across the majority of tropical and subtropical regions as a result of scarcer water supplies and an increase in the incidence of new or altered insect pests. The influence of climate change on agriculture will be one of the key determining elements influencing the future food security of humanity on earth, according to some of the past experiences mentioned above. Not only is agriculture vulnerable to climate change, but it is also one of the main contributors to it.

The geographical variations in rainfall, temperature, crops and cropping systems, soils and management techniques make it difficult to determine how sensitive agriculture is to climate change. It has been noted that climate change affects on the wheat, rice and maize crops in South Asia have a wide range of production losses. Wheat, rice and maize yields in India were claimed to have decreased by 5%, 6–8% and 10–30%, respectively, as a result of global warming studies (Morey, 1981). However, there is a scope for further investigation. The article attempts to contextualise it a regional level for greater detail.

The goal of this study is to comprehend the effects of temperature or rainfall variation inside a specific regional frame over the course of a specific time period. West Bengal is an agrarian state in India. Despite making up just 2.7% of India's total land area, it houses close to 8% of the country's population. 7.1 million agricultural families, 96% of which are small and marginal farmers, may not be able to withstand the effects of climate change (Agriculture Department, Government of West Bengal, 2019).

The distinction between agricultural productivity and production is also crucial for this investigation. Production has frequently been explained in terms of productivity. Production is the overall amount of output, whereas productivity is the amount of output relative to the amount of resources used.

The study attempts to understand the trends in rainfall and temperature over a short-term period, in West Bengal and its impact on agricultural production, in West Bengal. The crop production and yield information were mapped across the agro-climatic zones of West Bengal. The rate of change of yield was calculated between 2010 and 2015, and the change was demonstrated. While some crops experienced negative impact in terms of production, some demonstrated positive.

7.2 Literature Review

NASA (2021) explained that climate change *is* "a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases to Earth's atmosphere. These phenomena include the increased temperature trends described by global warming, but also encompass changes such as sea-level rise; ice mass loss in Greenland, Antarctica, the Arctic and mountain glaciers worldwide; shifts in flower/plant blooming; and extreme weather events". The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as the change that can be directly or indirectly attributed to human activity and that modifies the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods. Global warming is only one aspect of climate change (Rukhsana et al., 2021).

According to Nelson et al. (2009), climate change is quite dangerous to agriculture. While fluctuations in precipitation can have an impact on crop yields, higher temperatures eventually produce optimal crop yields. Extreme weather occurrences and climatic variability are major global problems. According to Mall et al. (2007), growth and development of crop and its yield under normal conditions are controlled by weather conditions during the period of growth. However, if there are deviations from normal weather, the efficiency of agricultural inputs is low. According to IPCC Special Report on Climate Change and Land produced under the Sixth Assessment Cycle (2019), global warming may also threaten food security if there is a negative effect on agriculture. The report in its fifth chapter focuses on how climate change interacts food system. The report also pointed that climate change between the years 1981 and 2010 has led to decrease in global mean yields of maize, wheat and soybeans even when fertilisation and other agronomic adjustments were considered. The report also pointed that decreased agricultural production can lead depressed agricultural productivity and increased price rise.

Hari and Khare (2018), focusing on India, note that agriculture's significance is shown in its contribution to a significant portion of gross domestic product (GDP) (16%) and the ensuing employment (49%). The authors also highlight its susceptibility to weather fluctuations. For obvious reason, this vulnerability is accentuated by climate change threats. Guiteras (2009) in the paper *The Impact of Climate Change in Indian Agriculture* points out that over short to medium term, the impact of climate change on Indian agriculture is likely to be negative.

In a study of long-term climate change in India, Hari and Khare (2018) showed that while average monsoon rainfall dropped by 26 mm on average, yearly temperatures on average risen by 0.48° between 1970 and 2016. They highlighted the three main ways in which climate change will, over time, affect agricultural productivity: "a change in average temperature, a change in rainfall, and a change in the number of dry days".

West Bengal, an overwhelmingly agrarian state in India, with 7.1 million farm families, 96% of which are small and marginal farmers who may not be able to cope with the vagaries of climate change (Agriculture Department, Government of

West Bengal, 2019). The state is divided into agroclimatic areas according to the West Bengal State Action Plan (2010). All of the state's agroclimatic zones, with the exception of the hill area, show a decreasing trend in total precipitation, according to the West Bengal State Action Plan (2010).

In addition, the West Bengal State Action Plan (2010) noted that changes in precipitation during 2008 compared to 1990 occurred in the "Terai zone, New Alluvial zone, Old Alluvial zone, Red and Laterite zone and Saline Coastal zone", with changes ranging from −8.8% to 20.0% to 33.3% to 2.7% to 2.1%, respectively. In the new alluvial zone, the laterite zone and the saline coastal zone, the maximum temperature has decreased by less than 0.5% since the monitoring period began in the 1970s. The state as a whole is experiencing rising minimum temperatures. The Bay of Bengal experienced an increase in severe cyclonic storms (64–90 kts or 118–167 kmph) as well as tropical cyclonic storms (48–63 kts or 88–117 kmph) over the course of long-term monitoring from 1900 to 2008.

It has been attempted to comprehend how variations in climate within a chosen time period have affected crop productivity in the light of what has been seen in literature and specific studies. It also makes an effort to comprehend the causes of the shifts and offers policy recommendations.

7.3 Objectives of the Study

- Identify the observed climate change and associated extreme events or any changes in selected time period, in the identified agricultural zones in West Bengal
- To elucidate the factors affecting the changes in agricultural production of different crops amidst observed climate events within the similar time frame
- Correlating agricultural productivity changes with the observed climate data.

7.4 Methodology

The time period taken into account for any analysis in relation to climate change is vitally important for comprehending the results of various studies. Shorter-duration trend lines and longer-duration trend lines may be significantly different from one another. In order to address several important research problems, the study employs a district-level panel of agricultural productivity in West Bengal and a new dataset on rainfall and temperature, covering the years 2010–2015 and answering of following questions:

- "What have been the trends in rainfall and temperature over a short-term period, in West Bengal"?
- "What are the average effects of rainfall and temperature on agricultural productivity, in West Bengal"?

- "What is the short-run impact of climate change in West Bengal, examined through the impact of rainfall, temperature, and extreme events associated with them"?
- "How significantly will climate change affect agricultural productivity"?

The crop production and yield information were mapped across the agroclimatic zones of West Bengal. The rate of change of yield was calculated between 2010 and 2015, and the change was demonstrated.

7.4.1 Data Collection and Analysis

The current analysis is constructed on secondary sources of data gathered from the Bureau of Applied Economics and Statistics, Government of West Bengal, Kolkata and Evaluation Wings, Directorate of Agriculture, Government of West Bengal. The West Bengal State Action Plan on Climate Change report served as the source for delineating the agroclimatic zones (2016). The Bureau of Applied Economics and Statistics, Department of Statistics and Programme Implementation, Government of West Bengal, reports on government statistics were used to acquire data on agricultural output and yield.

Profile of the Study Area

West Bengal state contributes its boundaries with three separate countries, Bangladesh, Bhutan and Nepal, as well as four other Indian States, namely "Orissa, Jharkhand, Assam, and Sikkim, lies between 21° 25′ 24″ and 27°13′ 15″ north latitudes and 85°48′ 20″ and 89°53′ 04″ east longitudes". The state has a total population of 9.13 crore, making it the fourth most populous state in India and the ninth most populous state in the world, according to the 2011 census.

The state can be split into four physiographic regions: the Himalayan Region, the Eastern Fringe of the Chota Nagpur Plateau, the Deltaic Zone and the Remaining Areas of the Alluvial Plains. Except for the northern hilly region near the Himalayas, the state's climate is tropical and humid. On the mainland, the temperature typically ranges from 7 to 26 °C in the winter and from 24 to 40 °C in the summer. The state's various regions see differing annual rainfall amounts. Most rainfall, 200–400 cm, falls in North Bengal. About 200 cm of rain falls annually in coastal regions, 150–200 cm in the Ganga plain and the state's centre. The Bankura and Purulia districts frequently experience drought.

Agriculture of West Bengal is the main industry. Approximately, 70% of the rural population depends on agriculture for their livelihood, making up the majority of the 62.7% of the workforce in rural areas. Six agroclimatic zones that make up the state: the hill zone, terai zone, old and new alluvial zones, laterite zone, and saline coastal zone. Although West Bengal produces more rice than it needs, there are shortfalls in other areas, including the increase in the intensity of catastrophic events like cyclonic storms. Aila, a catastrophic cyclone, devastated the state on 25 May 2009, especially in its coastal districts. Saline water inundated significant portions of North and South 24 Parganas, severely damaging the region's agriculture of Sundarban.

7.5 Findings

The state has been delineated into agroclimatic zones, and observed climate date and crop productivity levels were mapped for a fixed time frame, for analysis.

7.5.1 Agroclimatic Zone

On the basis of climate, soil supply and the agricultural viability of the state, the agroclimatic zones of West Bengal can be divided into five zones, mainly hilly region, "old alluvial zone, new alluvial zone, red and laterite soil, and saline coastal zones". The hilly region occupies around 2% of the land area, with a steep and moderate slope with a cold and humid climate. The Gangetic plain comprising of new alluvial plain and old alluvial plain comprise of 55% of the area, and the climate varies from hot sub-humid to humid type with the temperature ranging from 10.5 to 31.1 °C. The area ranges from Udic soil moisture regime and thermic to hyperthermic soil temperature regime, and the length of growing period (LGP) varies from 270 to 300 days in a year. The average annual rainfall of new alluvial and old alluvial agroclimatic region is 2500 mm and 1400 mm, respectively. Here, near the Teesta basin, the texture of the soil is light, less basic in nature and rich in humus. In this zone, the colour varies from deep black to grey black longitudinally. In some regions, the soil is acidic and deficient in micro-nutrients required for plant growth. The older alluvium zone is a part of the Ganga basin, where the soil is deep, mostly neutral, fertile, with high water holding capacity. The texture varies from sandy loam to clay, and up to a certain horizon, formation of clay pans is visible. The soil is rich in humus and potash, however, exhibits phosphorous and nitrogen deficiency. In these agroclimatic zones, rice, wheat, potato, groundnut, pulses, oilseeds and spices are cultivated in largescale. The red and laterite zone is distributed in the districts of Birbhum, Bankura, Purulia and West Medinipur and is an extension of the Chotanagpur highland region merging into the Indogangetic plans of West Bengal. Occupying almost 22% of the geographical area, the region experiences hot sub-humid climate with average annual temperature ranging from 27.6 to 15 °C, and the yearly cumulative rainfall amounts to 1300 mm of rainfall, approximately. Falling in the hyperthermic soil temperature regime, the soil is light textured, porous, low in organic matter and high in phosphorous and mineral content. Rice, pulses and vegetables are cultivated in flat lands or terraces, and the yield is moderate. Below it lies the saline coastal regions of West Bengal, comprising mainly the districts of East Mednipur, Hooghly, Kolkata and South 24 Parganas. The region experiences warm humid summers and mild winters, with an annual average rainfall of 1900 mm. The soil is loamy and fine textured, containing high amounts of basic salts like sodium, calcium and magnesium. The soil is fertile with moderate NPK concentration. Due to the tidal flow of sea water through creeks and sub-tributaries, infiltration of salt water, the coastal zones have degraded the soil and water quality. Here, the paddy fields are found in low-lying lands, which are inundated by floods and due to poor drainage water stagnates throughout the monsoon period. Due to saltwater inundation, the underground water with shallow depth is saline in nature. Apart from rice, very few commercial crops are produced in this region (Fig. 7.1).

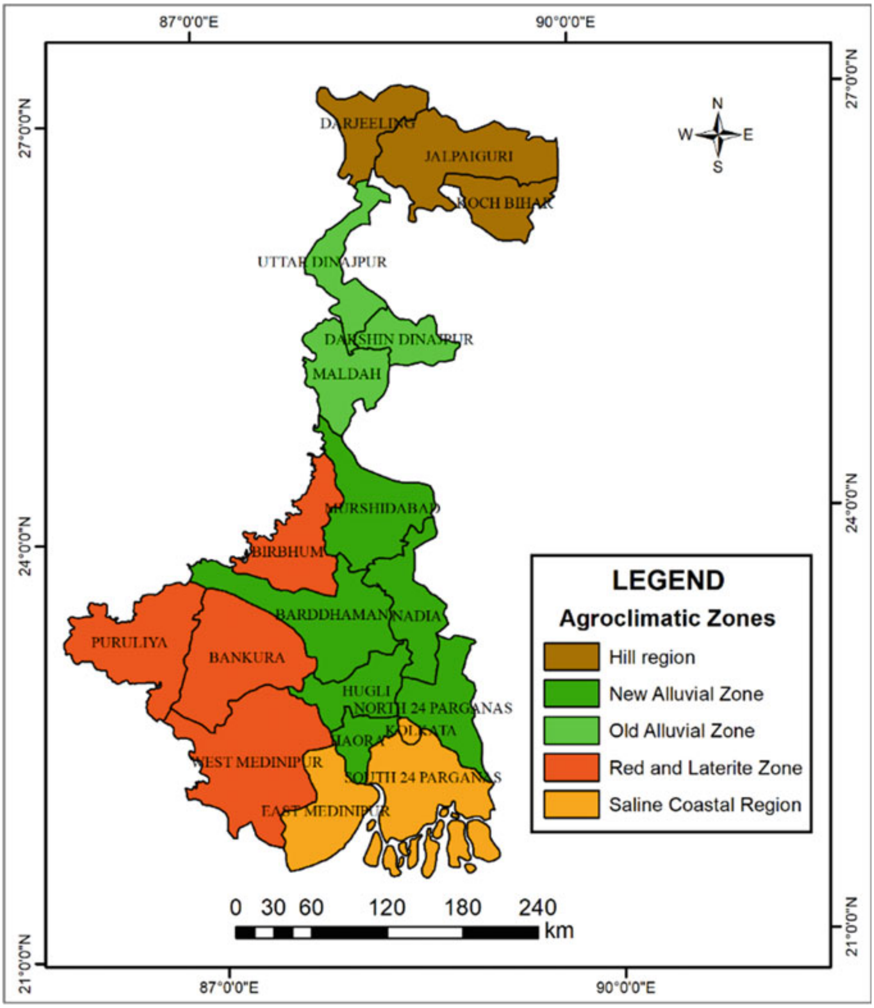

Fig. 7.1 Agroclimatic zones of West Bengal

Crop Production

Comparing the district-wise yield rates of major crops grown in West Bengal, it can be observed that amongst cereals, pulses, oilseeds and other crops, paddy is dominant. Paddy is grown in three different seasons—winter, summer and bhadui. In winter season, the paddy grown in Aman, followed by boro in summer and Aus in bhadui season. Amongst cereals, wheat and maize are grown extensively, and amongst fibres, jute is predominant. Mustard and til are also grown extensively in most of the districts. Comparing their production amongst based on the different agroclimatic zones, potato is highly produced in hilly region, the production of rice and potato is proportionally greater than other crops in terai and old alluvial region, apart from these crops, jute is also dominant in new alluvial zone. Amongst all the agroclimatic zones, proportional of wheat production is more in old alluvial zone than the other regions. In the coastal zone, because of the soil characteristics, cultivation of rice is more suitable than other regions.

From Fig. 7.2, it can be observed that Aman and boro are produced mostly in the old and new alluvial agroclimatic zone, and it is produced less in the red laterite zone when compared to the other zones. The yield of Aman varies from 1700 to 3200 kg/ha, and boro varies from 2000 to 4000 kg/ha. Within 2010–2015, maximum rate of change in the yield of Aman is found in new alluvial zone, while the maximum change for boro is visible in the hilly and terai zone. The yield reduced within this time only in Darjeeling district. The wheat productivity also increased lower alluvial zone and coastal saline region. The mustard yield is relatively low in all the districts, but a positive change is visible in the yield rate in Puruliya, Howrah, Uttar Dinajpur, Dakshin Dinajpur and Malda. In case of Jute, the yield has scaled down to 15–25 kg/ha in most of the districts and it is concentrated in southern districts of West Bengal. Overall, a rise in its yield in visible in the past decade in the hilly and old alluvial agroclimatic zones of West Bengal.

Changes in Temperature and Precipitation Level

The total annual precipitation, average annual minimum and maximum temperature of the districts in 2010 and 2015 were mapped and represented in Fig. 7.3. It can be observed that, except for the terai agroclimatic zone, other regions have experienced an increase in overall precipitation between 2010 and 2017. The change in the annual minimum and maximum temperature between that timeframe exhibits similar characteristics. The temperatures have decreased by 2° in both cases, especially in the red and laterite and saline coastal agroclimatic zones. In case of change in the average annual maximum temperature, a 2° rise in temperature can be seen in the new alluvial and red and laterite agroclimatic zones. A decrease in the average annual maximum temperature can be seen in hilly regions and saline coastal agroclimatic zones of Bengal.

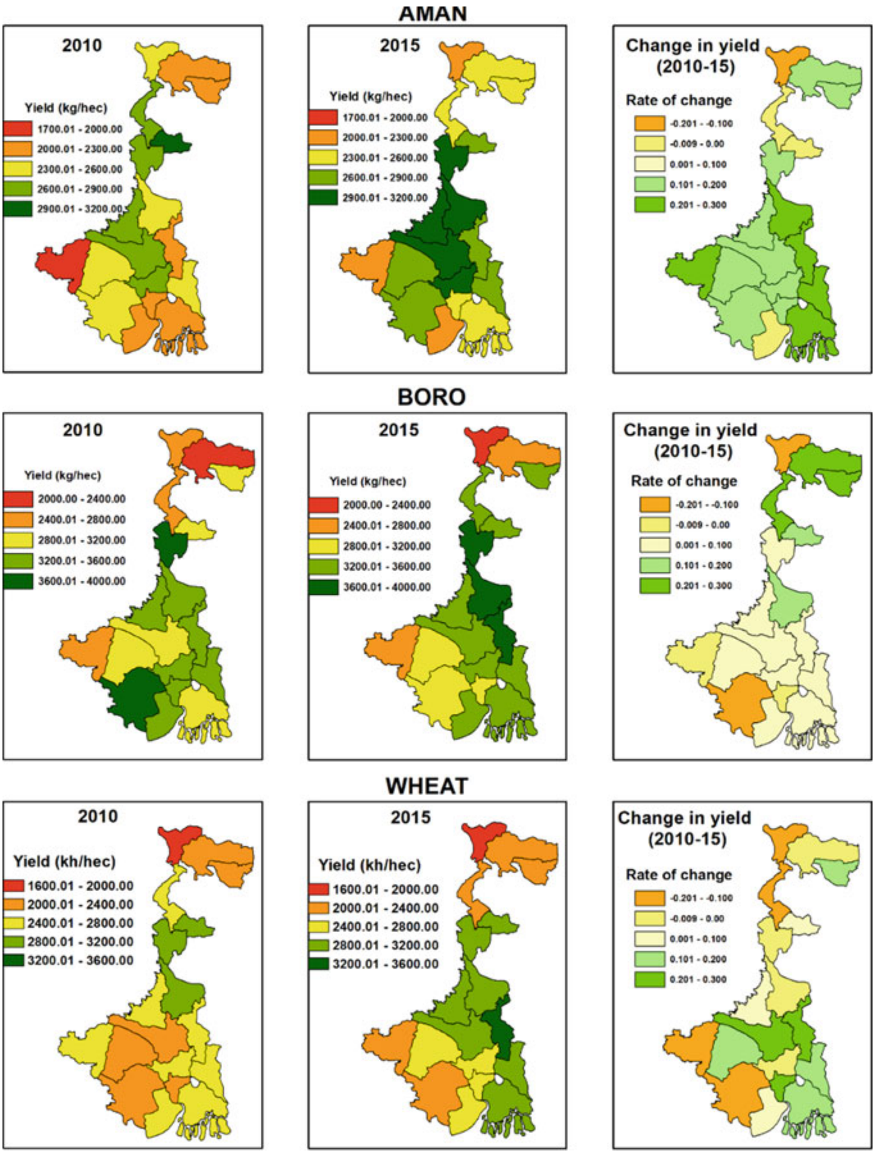

Fig. 7.2 Districtwide crop productivity level for the time 2010–2015

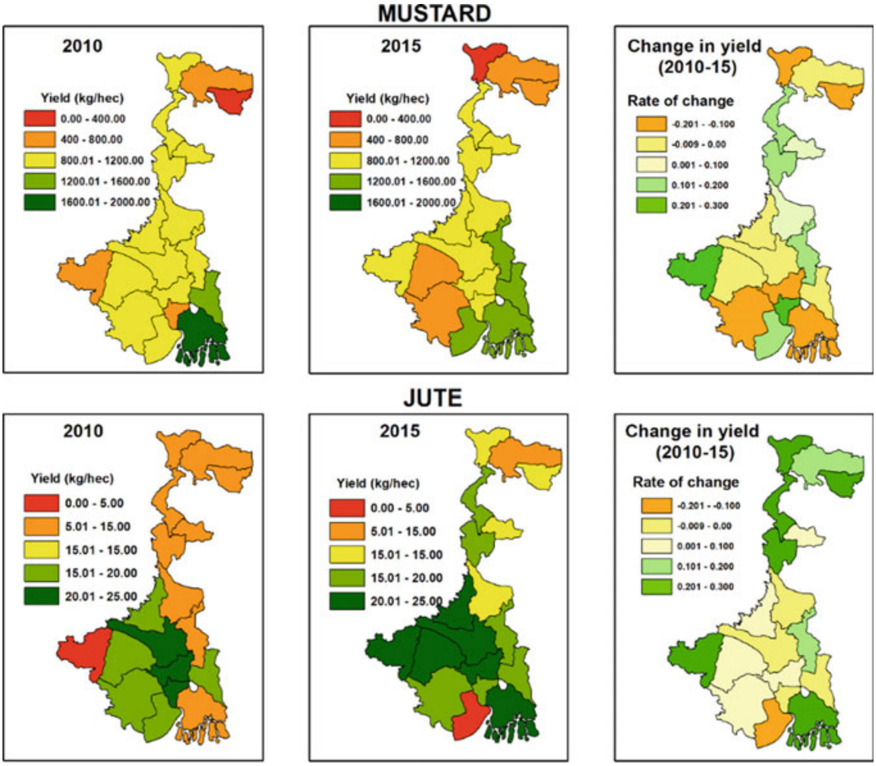

Fig. 7.2 (continued)

7.6 Analysis

7.6.1 Correlation Observed Climate Data with Crop Production

A positive significant correlation could be found when the rate of change of precipitation was compared to the rate of change in yield of Aman, Wheat and mustard crop between 2010 and 2017. However, no significant relationship could be derived between the rate of change of precipitation is compared to the rate of change in yield of boro and jute crop within the similar time frame. The precipitation rates have increased, and they foster better yields results in most of the staple crops produced by the farmers. Further the change in average annual minimum and maximum temperature of the districts between 2010 and 2015 shows significant negative correlation between the rate of change in yield of boro and mustard. The decrease in temperature may lead to poor yield and affect the market and livelihood of the farmers (Fig. 7.4).

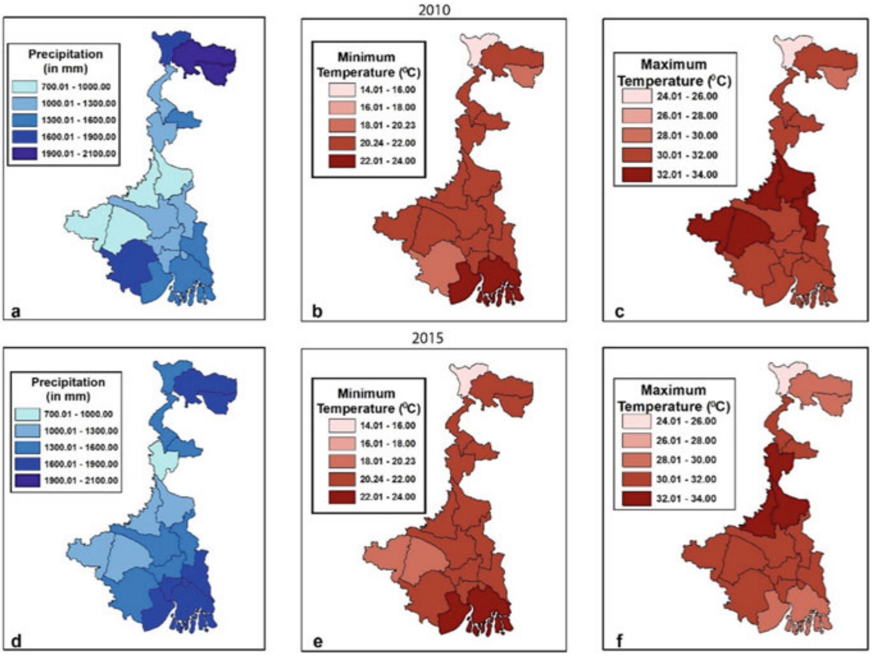

Fig. 7.3 Maps showing changes in precipitation level between 2010 and 2015 for districts in West Bengal

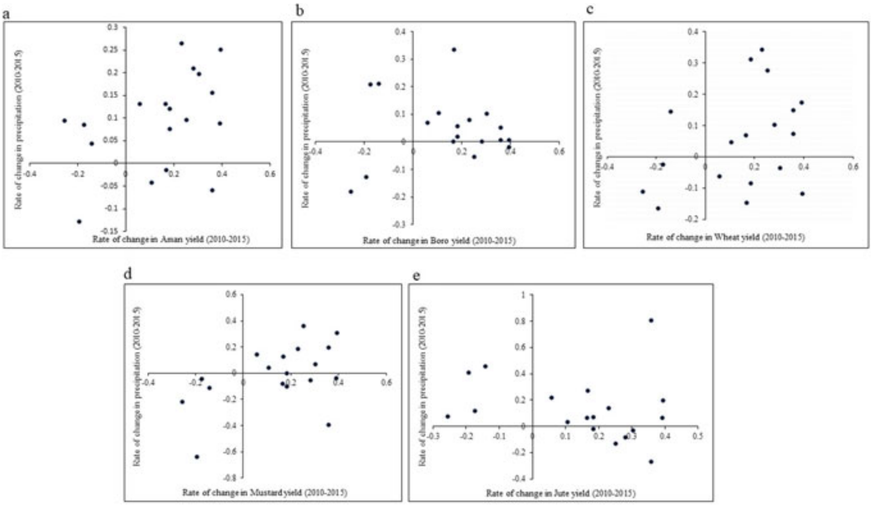

Fig. 7.4 Precipitation versus yield

The elevated temperature and CO_2 level by induced climate change are not only affecting the growth of the crop but also the cropping pattern of a region. Moreover, in recent past abnormalities in monsoon has been also observed. High temperature enhancing evaporation may give rise to higher rainfall which may be different from that expected.

7.6.2 Possible Impact

The climate change-induced agricultural vulnerability may lead to uncertain weather conditions. For farmers, it may lead to uneven water availability, lesser yield, low quality crops, lack of soil nutrients supply. Being a part of the developing economy, it may lead to lower level of scientific guidance during agricultural production, inadequate information regarding selection of crop seed, inadequate information of plant root moisture holding capacity or lower level of awareness of the market and growing technology.

7.7 Conclusion

The problem of climate change is a component of the more significant problem of sustainable development. As a result, when systematically incorporated into larger plans intended to increase the sustainability of national and regional development paths, climate policies can be more effective. Therefore, in order to reduce negative effects, we need to focus more on adaptation and mitigation research, capacity building, policy change, national/regional collaboration, support for national/global adaptation funding and other resources. Reducing vulnerability to long-term climate change is based on adaptation to climate variability and extreme events. When the rate of change in precipitation was compared to the rate of change in yield of the Aman, wheat and mustard crop between 2010 and 2017, a substantial positive association was discovered. However, there was no discernible correlation between the rate of change in precipitation and the rate of change in yield of the boro and jute crops over the same time period. The majority of the farmers' staple crops now provide superior yields thanks to rising precipitation rates. Additionally, there is a clear negative association between the rate of change in the yield of boro and mustard between 2010 and 2015 when looking at the average annual minimum and maximum temperatures of the districts. The market and farmers' means of subsistence may be impacted by the temperature drop and its potential impact on yield.

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Part III
Agriculture Under Changing Climate

Chapter 8
Resilience of Farmers in Response to Salinity Intrusion Problem in Agricultural Fields of Coastal Region of Bangladesh

Prabal Barua, Abhijit Mitra, Anisa Mitra, and Saeid Eslamian

Abstract Bangladesh is an agriculture depended nations where most of the population depend their livelihood on agriculture related activities. Climate Change is one of the biggest threat for Bangladesh because of frequent natural hazards outbreak in the nation and destroying the huge mass and properties over the year. Agriculture sector is one of major sector for Bangladesh that significantly damaged through reducing crop production, loss of agriculture land and shifting the profession of coastal people. This book chapter tries to explore the saline water intrusion and soil quality and fertility status of agriculture fields and also adaptation practices by the farmers communities in the study areas of south-eastern coast of Bangladesh. The present study reveals that surface water salinity were found high in everywhere and soil quality were alarming here. Soil pH was strongly acidic and soil color was black and blackish, brown and reddish but soil temperature was optimum for particular vegetable growth. Salinity level in agriculture field was also very strong and soil fertility status was moderate because sand and clay dominating soil structure, sandy loam, and silt loam leading soil texture and soil bulk density (g/cm^3) were moderate. Besides, the authors also discover some indigenous knowledge-based adaptation and coping practices of the farmers for reducing the impact of climate change in the study areas. Salinity intrusion problem in the agriculture field responsible for low production and economic loss for the farmers of the study areas. Farmers are trying to cope some crop innovation techniques for adopting with changing climatic circumstances.

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This book chapter will help to demonstrate adaptation practices by the farmers for reducing the salinity level of agriculture field which will be effective in the climate change vulnerable area of other parts of the country and worldwide while the area was affected by salinization problem.

Keywords Climate change · Salinity intrusion · Indigenous knowledge · Soil salinity · Coping practices

8.1 Introduction

The coastal region of Bangladesh is vulnerable to severe natural catastrophes including cyclones, storm surges, and floods along with other natural and man-made dangers such erosion, highly contaminated groundwater, saline water intrusion, water logging, and salinity in both water and soil. These catastrophes have put the entire coastal and marine environment in danger and rendered coastal residents exceedingly vulnerable (Islam, 2004). About 0.84 million hectares of the country's agriculture, or over 2.5 million hectares, are affected by salinity of varied intensities, which results in very poor land use. Coastal areas make up about 25% of the country's total cropland (Barua & Rahman, 2017; Barua et al., 2017).

Bangladesh positioned 165 as well as the 30th vulnerable countries to climate change among climate vulnerable 181 countries, (IDMC, 2021). The geographical and landscape position of Bangladesh creates it particularly susceptible to tremendous weather such as cyclone, flood, coastal erosion, and storm surges. Its susceptibility is generated not only through its biophysical locations, but also with its poor socio-economic conditions (Barua & Rahman, 2020; Barua et al., 2017). Bangladesh is an agricultural country, but agriculture is highly susceptible to climate change. This is expected that climate change has a worse impact on agricultural production in the new millennium through the problem of high temperatures, irregular rainfall, and severe climate change-induced events such as floods, cyclones, droughts, and rising sea levels (Hazbavi et al., 2018; Shameem & Momtaz, 2015).

In Bangladesh's agricultural sector, one of the main issues with land degradation that has a negative impact on agricultural land production is soil salinity. The Chittagong district in Bangladesh's southeast is subject to cyclones, tidal surges, flash floods, tidal & flash floods, earthquakes, and other natural disasters. From 1960 to 2016, 30 significant cyclones struck the entire district. Chittagong was struck by the deadliest cyclone of the twentieth century in 1991, and the most recent storm to cause coastal damage was Ruano in July 2016 when it struck Cox's Bazar Sadar, Anwara upazila (Sub-district), in the Chittagong district. Saline water and salinization are the main contributing factors to disasters such storms, tidal surges, flash floods, and tidal variation because they cause large amounts of saline water to arrive, overwhelm, and inundate coastal areas (Barua & Rahman, 2018, 2019).

The most important and in-demand agricultural crop for providing food and other necessities for the world's expanding population is rice (Shimono et al., 2010). Nearly

60% of the world's population is entirely dependent on rice cultivation (Maclean et al., 2002; Alam et al., 2021). Among all other crops produced in poor nations like Bangladesh, rice serves as a fastener. The production of rice takes up over 75% of all fertile land. As a result, any decrease in rice output due to climate change will seriously jeopardize the country's food security (Islam et al., 2020). Therefore, measuring the influence of climate change on rice cultivation and evaluating agriculture farmers' coping capability to adapt to climate change are the theme of pressing research.

The intrusion of salinity pretenses significant risks to fresh groundwater bodies as well as natural fresh water aquatic wetlands (Talukder et al., 2015). World Bank (2020) reported that a climate change will cause extensive submersion in low-lying areas and an increase in the rate of saline intrusion. The main cause of the rising sea level is climate change-induced global warming (IPCC, 2013). Besides, salinity intrusion through the aquatic river system has been greatly influenced by the dry flow of the Ganges–Brahmaputra-Meghna rivers. These two natural incident responsible for the additional outbreak of high-salinity interference in the coastal areas of Bangladesh. Because of rising salinity 20% of the more land compared to 1990 would be saline impacted and intensity of the salinity would be augmented by 15% (Barua & Rahman, 2021; Barua et al., 2020, 2021). Alam et al. (2020) suggests that increasing rate of salinity level in the sediment is about 0.90% per year. There are different sources of salinity intrusion in the coastal areas which are the part of the south-eastern coastal zone of Bangladesh. The paddy land becomes salinized due to its contact with the sea and continued flooding during high tides and ingress of sea water through Sangu river and creeks. As a result, the soil fertility status is reduced, changing traditional or old agricultural practices, and discouraging farmers from cultivating.

The prime objectives of this case study in a book chapter were to assess the soil and water salinity and current soil fertility status on paddy land and delivered some coping strategies to reduce salinization processes and improved fertility status in the study area.

8.2 Profile of the Study Area

Cox's Bazar district located south-eastern coast of Bangladesh and largest sea beach in the world situated in this coastal region. Cox's Bazar Sadar Sub-district consists of 10 unions, 140 villages and 40 Mahallas. Rapid urbanization has spread rapidly in this upazila over the years. Rasel and Parvez (2021) applied the satellite image for land use pattern analysis, for 2005, 2010, 2015, and 2020 through Geographic Information System (GIS) software. They found that urban and rural areas increased by 36.79 and 23.39 km^2 between 2005 and 2020, but salt & shrimp farming, a barren, hilly forest area, decreased significantly by 11.12, 41.43, and 6.96 km^2. Besides, 66% of the people in the seaside resort, and 80% of the people on the main beach, think that moving to the cities has disrupted the coastal area. An increasing number of hotels, resorts, and buildings near the coastal region are affecting the coastal ecosystem. This kind of rapid population growth in this study area associated with urbanization; expanding tourism and contributing industries a significant increase in demand for clean water–the result is excessive pumping of the coast groundwater. Pumping too much ground water nearby reduction of environmental recycling due to building cover, paved area, etc. has led to the infiltration of salt water into the area (Rafiq et al., 2017). There are significant differences in farming strategies between coastal and inland areas of the study areas. The largest grain yield is rice, and large vegetables aubergine (eggplant), cucumber, vegetable, beans, red amaranth, Indian spinach, tomatoes, peppers, sweet cucumber, bottle cider, spicy cucumber, and ridge.

According to the information of Department of Agriculture Extension, the main planting patterns of Cox's Bazar Sadar upazila are "Boro-Fallow *T. Aman*, Vegetable-Boro-Fallow-*T. Aman,* Fallow-Fallow-*T. Aman,* and Vegetable-Fallow-*T. Aman.* Among those, Boro-Fallow-T". Aman has been leading the way. This also found that some areas remain unoccupied between the Boro and Amon periods due to lack of adequate irrigation provisions. These areas, if used less, will greatly increase farmers' income, such as ensuring food security during epidemic conditions.

Barua and Eslamian (2021) found that Cox's Bazar farmers often grow local varieties of rice, i.e., paijam, barotia paijam, horidhan, and other highly productive species, namely, "BINA-7, BRRI Dhan-40, BRRI Dhan-41, BRRI by 49, BRRI by 45, BBRRI by 76, BRRI by 57, and BRRI" by 52 (salt-tolerant). Farmers depend on agricultural activities, especially land preparation, planting, planting, harvesting, and other important cultural activities. Number of active agricultural workers declining day by day, and farmers face major problems during the high season due to high wages rate.

The author conducted the study in Jhilwanja union of this sub-district (District Statistics, 2011 and BBS, 2013) which lies between 21° 28′ and 21° 30′ N latitudes and between 91° 58′ and 92° 02′ E longitudes (Fig. 8.1). According to the last population census, there are 79,203 people are living in the union with density of 2579/km^2 (BBS, 2011). Total area of this union is 2913 and 1515.38 ha (49.38%) are covered under hilly forest area. Soil pH found in the union as ranges between 4.5 and 5.7, soil texture found generally silt, soil salinity observed between 0 and 12 dS/m, pattern of sediment found complex because of the local differences among the sand, clay, and silt inside of the underlying sedimentary rock, common soil fertility recorded moderate, organic matter value is low, moisture sharing ability is found poor and fairly apposite for agricultural crops production because of large available hilly forest land. There are approximately 40% inhabitants of this union are involved directly or indirectly to the agriculture activities and they produce paddy, potato, ginger, betel leaf, onion, garlic, sugarcane, betel nut, pulse, wheat, ground nut, tobacco, rubber, and different vegetables (Municipal Manuel, 2013; BBS, 2001).

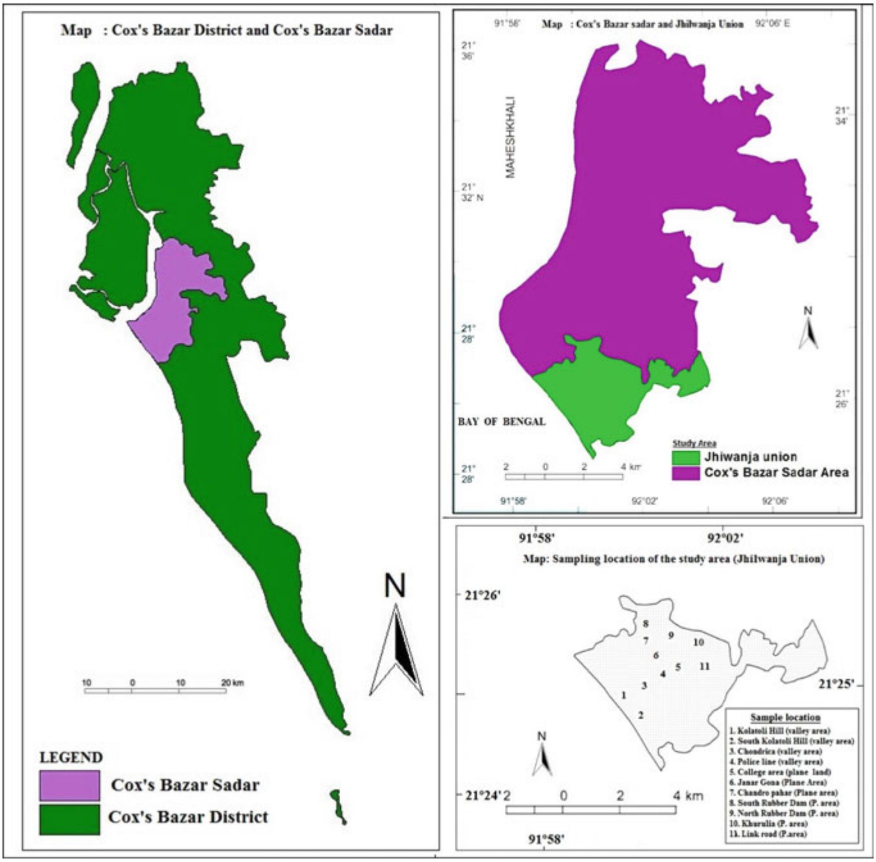

Fig. 8.1 Location of the study area (Cox's Bazar District, Cox's Bazar Sadar and Jhilwanja Union). *Source* Based map collected from Cox's Bazar Municipality, 2013 & LGED, 2003

8.3 Approach of the Study

The authors applied spot method and random sampling mechanisms for soil and water sample collection from the different agriculture rice fields. Soil and water samples were collected from the depth of 0 to 10 cm depth. There are 11 samples were obtained to assess the surface water salinity as well as soil fertility status. Samples were collected and analyzed from November 2019 to August 2020. Global Positioning System (GPS) was utilized to document the absolute locations of the collected samples (Table 8.1).

For soil samples, a transparent polythene bags were used to preserve the samples and each bag was labeled. These samples were dried in lab at room temperature (25 °C) for 20 days and then ground. To prepare the ground samples for chemical analysis, a 20-mesh sieve was used to sift the materials (Petersen, 2002). The Bangladesh

Table 8.1 Sampling location of the study area

S. no	Sampling station	GPS value
Site 1	Kolatoli Hill (valley area)	21° 24′ 50.9″–91° 59′ 13.2″
Site 2	South Kolatoli Hill (valley area)	21° 24′ 22.2″–91° 59′ 30.7″
Site 3	Chondrica (valley area)	21° 24′ 50.8″–91° 59′ 18.5″
Site 4	Police line (valley area)	21° 25′ 09.3″–91° 59′ 31.3″
Site 5	College area (Plain land)	21° 25′ 23.4″–92° 01′ 2.5″
Site 6	Janar Gona (P. Area)	21° 25′ 40.4″–92° 01′ 71″
Site7	Chandro pahar (P. area)	21° 25′ 42.5″–92° 01′ 9.9″
Site 8	South Rubber Dam (P. area)	21° 26′ 2.6″–92° 01′ 10.7″
Site 9	North Rubber Dam (P. area)	21° 26′ 7.7″–92° 01′ 12.8″
Site 10	Khurulia (P. area)	21° 25′ 52.3″–92° 01′ 44.6″
Site 11	Link road (P. area)	21° 25′ 6.6″–92° 01′ 38.8″

Council for Scientific and Industrial Research's environmental lab in Chittagong, Bangladesh, examined the labeled samples.

To tackle the research questions, mixed method approach has been used. The objective was to document the actual instances of loss and damage brought on by saline intrusion's negative impacts in the research area. A combination of qualitative methods (Focus Group Discussions, Key Informant Interviews, community consultation) and more quantitative methods was sought to accomplish this goal (questionnaire survey). Two unions' worth of study villages were selected after consulting disadvantaged groups and local government agencies during a pre-survey field trip.

Samples of soil were collected on the pre-weighted & Petridis to determine the moisture content of soils at various depths. The samples were held in an oven set at 105 °C for 24 h, after which they were cooled in desiccators, weighed once again, and the soil texture was determined using the hydrometer method. Temperature (0 °C) was measured with a thermometer, and bulk density was calculated using data from Saxton et al. (1986) and Pedosphere's adaptation of the Canadian soil texture triangle. ca. The electrical conductivity (EC-dS/m) of soil and surface water was measured using a conductivity meter (Rhoades, 1982), and soil pH was evaluated using a glass electrode pH meter in accordance with Jackson's 1962 description using a soil water ratio of 1:2.5. The wet-oxidation method developed by Walker and Black in 1934 and improved by Allison in 1965 was used to calculate organic carbon.

Table 8.2 Mechanical support and use of instrument for cultivation of land

Using mechanical support	%	Type of instrument	%
Yes	80	Tractor	30
		Power tiller	28
		Pleader	14
No	20	Plough	28
Total	100	Total	100

The amount of organic carbon was multiplied by the Van Bemmelen factor of 1.73 to obtain the organic matter; (Page et al., 1982). $CuSO_4$–Na, SO_4 catalyst mixture was utilized to measure total nitrogen using the micro-Kjeldahl digestion method. In order to measure the ammonia (NH_3) from the digestion, it was distilled with 40% Na0H into 5% Boric acid and titrated with 0.001N H_2SO_4 (Jackson, 1973). After being digested with nitric acid–perchloric acid, the total P of the soil samples was measured (Olsen & Sommers, 1982). The phospho-vanadomolybdate technique was used to colorimetrically assess P in the extract (Hanson, 1950). Olsen and Sommers (1982) used nitric acid and perchloric acid to digest soil samples to assess the K, Ca, and Mg content. The extract's K, Ca, and Mg content was then analyzed using an atomic absorption spectrophotometer. The final map was created using Arc GIS 9.3 software after all obtained data was evaluated using SPSS 18.0 and Microsoft Office Excel.

8.4 General Information About Agricultural Practices

Mechanical support and use of the instrument for the cultivation of land were changes with time. Mechanical support and instrument for cultivation directly involved economic status of framer, status of agriculture; subsistence or commercial, productivity of crops, and so on. The plough is a machine that used in farming for initial production of sediments. Plugs are traditionally drawn by animals like as horses or cattle, but in modern times may be drawn by the tractor machine. In the study area, a maximum of the farmers were used mechanical support (80.00%) during cultivation of crops and they were used different instruments such as tractor, power tiller, plough system, and pleader uses (Table 8.2). It was significant that, 20% farmers did not use any kind of mechanical support they were used traditional plough system during the cultivation period.

8.5 Sources of Water for Agricultural Purposes

In Bangladesh, two types of water sources used water for agricultural purposes such natural and artificial or man-made sources. Natural sources are rain water, river,

Table 8.3 Sources of water for agricultural purposes

Sources of water			
Natural	Percentage		Percentage
	51.25	Rivers/canals	25.12
		Rain	26.17
Artificial	48.71	Irrigated from surface inland water bodies	42.40
		Irrigated from ground water	6.28
		Total	100

lakes, canal, pond, and artificial sources are irrigation process. Irrigated water are two categories first is water irrigated from inland fresh water bodies and ground water sources pumped by submerged tube well, power engine, and digging (Table 8.3).

Current investigation reveals that farmers were equally depend on water from natural and artificial sources for agricultural. Rain and river water is the prime natural sources of water for agricultural practices and irrigated from surface inland water bodies and ground water were the major source of artificial or man-made source of water for agricultural practices in the study area. According to Table 8.3, 42.40% surface water in the study areas used for irrigation for agriculture purposes and 6.28% ground water sources used for irrigation in the crop field through deep tube wells and other medium. In Bangladesh, basically 60% water sources from surface water used for agriculture activities in the coastal areas while 40% ground water utilized for crop production (Barua & Eslamian, 2021).

8.6 Using Pattern of Pesticides and Fertilizers in Agricultural Field

Pesticide encompasses a large number of chemical compounds over 900 (EPA, The federal environmental pesticides control act, 1972). Pesticides control or prevent damage to crops by insect infestation and they are known poisons that include insecticides, fungicides, herbicides, bactericides, nematicides, growth regulators, fumigants, and fertilizers (Merttill, 2010). According to BBS (2009), total consumption of pesticide in Bangladesh was 25,466.43 metric ton in 2005 of which 16,895.6 metric ton was insecticide in the form of granules (14,061), liquid (2511.05), and powder (5771.74). In the study area, farmers were used three type of pesticides in agricultural fields such as insecticides (63.63%), herbicides (27.27%), and fungicides (9.09%) (Table 8.4). However, chlordane, basodin, and endrin type of insecticides, sobicron, and diafrom type of herbicides and copper sulfate represent on fungicide were frequently used in cultivated land.

Fertilizers are used to add nutrients such as nitrogen, phosphorus, and potassium to soil to enhance the quantity and quality of crop production and fertilizers also contain

Table 8.4 Types of pesticides use in agricultural land

Using pesticides	Categories of pesticides	% of pesticides	Chemical group	% of users
Thiodin	Insecticides	63.63	Endosulfan	4
Furadin	Insecticides		Chlorinated hydrocarbons/organochlorine	5.33
Aldrin	Insecticides		Chlorinated hydrocarbons/organochlorine	3.33
chlordane	Insecticides		Chlordance	14.66
Ripkord	Insecticides		Cypermelhrin	0.66
Basodin	Insecticides		Organophosphates	12.66
Endrin	Insecticides		Chlorinated Hydrocarbons/organochlorine	12.66
Diuron	Herbicides	27.27	Phenylureas	5.33
Sobicron	Herbicides			19.33
Diafrom	Herbicides		Chlorotrizine	8.00
Copper sulfate	Fungicides	9.09	Others	4.00
No response				10.00
Total				100.00

micronutrients such as iron, zinc, and other metals which are known to enhance plant growth (Merttill, 2010). Fertilizers are broadly divided into organic fertilizers or inorganic or commercial fertilizers. In Jhilwanja union, farmers were habitually used inorganic or commercial fertilizers in third agricultural fields (Table 8.5). Farmers commonly used urea (27.17%), triple super phosphate (23.54%), murate of potash (20.42%), and partially used single super phosphate, hyper phosphate, zinc, and others types of fertilizers in agricultural fields.

Organic fertilizers have been known to improve biodiversity and long-term productivity of soil, and may prove a large depository for excess CO_2 (Rees, 2009). In present investigation reveals that, major portion (57.34%) of the farmers were used organic manure while wastage of leaves, ash, and cow dung, respectively (Table 8.6). Significant portion of the farmers did not used organic fertilizers in their agricultural fields.

8.7 Soil and Water Quality Parameters Analysis

Soil and water quality decayed with soil fertility status is decreases due to continuous uses of fertilizers and pesticides in the agricultural field. Generally fertilizers are easily dissolved with water and soil but pesticides do not dissolve easily because they are persisting 80–120 years on the environment. As a results day by day top

Table 8.5 Major chemical fertilizers used in paddy land with their chemical bond, nutrients status, % of nutrients, physical structure and impurities

Name of chemical fertilizers	Chemical bond	Nutrients for crops	% of nutrients	Physical structure	% of field users	Impurities
Urea	$CO(NH_2)_2$	Nitrogen	N-46	Granular	27.17	–
Single super phosphate (SSP)	$Ca(H_2PO_4)_2$ + $CaSO_4.2H_2O$	Phosphorus sulphur	P-8 S-12 Ca-20	Granular	6.74	Cadmium, fluoride compounds and other heavy metals (chromium, manganese, nickel and zine)
Triple super phosphate (TSP)	$Ca(H_2PO_4)_2$	Phosphorus	P-20 S-1.3 Ca-14	Granular	23.54	
Hyper phosphate (HP)	–	Phosphorus	–	–	7.70	
Murate of potash (MP)	KCl	Potassium	K-50	Granular and powder	20.42	–
Zinc sulfate	$ZnSO_4.H_2O$	Zinc	Zn-36 S-18	Granular and powder	7.93	Chromium lead and arsenic
Gypsum	$CaSO_4.H_2O$	Sulphur	S-18 Ca-18	Powder	6.50	Cadmium
Total					100	

Table 8.6 Types of organic fertilizer use in agricultural land

Response	Percentage	Name of organic substances	Percentage
Yes	57.34	Cow dung	29.12
		Wastage of leaves	35.17
		Ash	35.71
No	42.64		
Total	100		100

soil quality are polluted, polluted surface water quality and land will be barren and also farmer take decision this land probable used for shrimp cultivation and other non-agricultural purposes. Following table summarize the soil and water quality of the selected parameters with their minimum, maximum, mean, and std. deviation. Table 8.7 summarizes the selected parameters of the surface water salinity and soil quality and fertility status on paddy fields.

Summarization of field data (Table 8.7) represent that minimum and maximum level of soil electric conductivity were low and little differences between mean and std. deviation content of soil electric conductivity in the study area. However, agriculture, irrigation, and land management practices can cause salt levels to rise. The

Table 8.7 Summarize of surface water salinity and soil quality & fertility status

Water quality					
Parameters	No. of sample	Minimum	Maximum	Mean	Std. deviation
Salinity (% 0)	11	0.42	45.10	24.8291	14.65116
Soil quality					
pH	11	1.80	3.60	2.8955	0.54150
Color	11	Reddish	Blackish		
Temperature (°C)	11	26.00	35.00	31.8182	2.60070
Salinity (% 0)	11	1.00	30.50	19.1727	12.01491
Soil fertility status					
Structure & textural class	11	Sandy	Sandy loam		
Bulk density (g/cm^3)	11	1.51	1.66	1.5809	0.04949
OC (%)	11	0.13	0.77	0.4473	0.18347
OM (%)	11	0.22	1.32	0.7718	0.31654

quantities of nitrates, potassium, sodium, chloride, sulfate, and ammonia have been associated with EC, despite the fact that it does not directly detect particular ions or salt compounds.

Salinity level of soil considered as major constraint to food grain production in coastal areas of the country (Haque, 2006). Present study found that, minimum, maximum, mean, and std. deviation was strongly significant here. Minimum salinity were found 0.42 ds/m in site 4 (police line area) and maximum salinity were 45.10 ds/m contained in site 5 (college area), mean salinity 24.83 ds/m, and std. deviation were 14.65 ds/m (Table 8.7).

The rate of physiological activity, such as enzyme activity, as well as physio-chemical features, such as nutrient transport and solubility, mineral weathering, and evaporation rates, among others, are all directly influenced by temperature. The temperature ranges from 260 °C at site 2 to 350 °C at site 6, with a mean of 31.810°C, and a standard deviation of 2.60 0 °C (Table 8.7). Hilly wind active and low content of salinity were reason for small content of temperature in South Kattoli villages but it was gradually increase toward plane agricultural fields because high-salinity content areas temperature absorbing capacity were high.

The water suitability for irrigation purpose varies on the amount and the type of salt the irrigation water contains. The higher the salt concentration of the irrigation water it is the greater the risk of salinization. The following table gives an idea of the risk of salinization according to the guideline of FAO (1985) (Table 8.8).

The type of salt in the irrigation water will influence the risk of developing sodicity: the higher the concentration of sodium present in the irrigation water (particularly compared to other soils), the higher the risk. It was highly remarkable that surface water salinity in nine samples were high or very strong because every paddy lands and adjoining water bodies were inundated by saline water (Table 8.9).

Table 8.8 Standard ranges of Salinity level in irrigation water (g/l)

Salt concentration of the irrigation water in g/l	Soil salinization risk	Restriction on use
Less than 0.5 g/l	No risk	No restriction on its use
0.5–2 g/l	Slight to moderate risk	Should be used with appropriate water management practices
More than 2 g/l	High risk	Not generally advised for use unless consulted with specialists

Table 8.9 Content of water salinity in the paddy field of Cox's Bazar (Jhilongja Union)

Range of limit	Number of samples	Percentage (%)
Less than 0.5 g/l	1	9.09
0.5–2 g/l	3	27.27
More than 2 g/l	7	63.63
Total	11	100.0

Large tidal creeks and the Sangu River are far too active, their salinity varying constantly. However, only two sites (sites 3 and 4) were determined to have low salinity or very mild salinity since these sites were located in the study region and were covered by high land (Fig. 8.2).

Soil color development and distribution of color within a soil profile are part of weathering. Three types of color were found in soil color on the paddy field including black or blackish, brown and red or reddish. About 54.54% samples were black or blackish, 36.36% were brown and 9.09% were found red or reddish in the study area (Table 8.10). It significant that hill covert area soils were red or reddish, generally we known that hill soil low fertile than others soil in our country and others fields soil were brown and black or blackish; these soil were perfect applicable or fertile for agricultural practices in the study area.

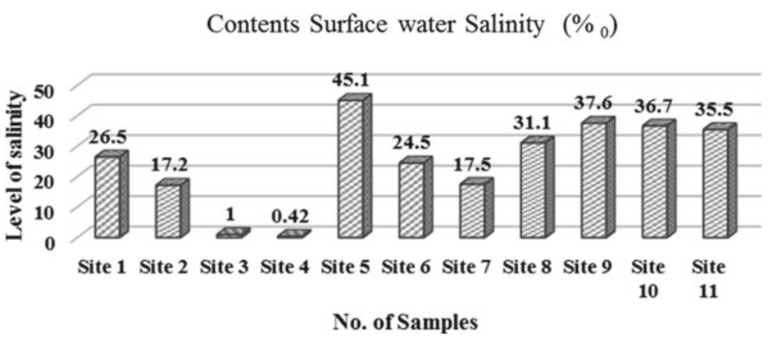

Fig. 8.2 Content of surface water salinity in paddy fields

Table 8.10 Content of soil color in the paddy field of Cox's Bazar (Jhilongja Union)

Range of limit	Number of samples	Percentage (%)
Black or blackish	6	54.54
Brown	4	36.36
Red or reddish	1	9.09
Total	11	100.0

Land inundate by saline water is causes the seepage of saline water into the adjacent paddy fields, causing problems in rice production (Hoque et al., 2013). A specific soil's relative percentage of soil separates is referred as its soil texture. Because the fraction of silt loam particles was higher on the plane soil than the amount of sandy loam and sand particles was higher on the hill soil, the plane land soil was found to be more fertile (Table 8.11) than the hill soil. It is significant that some plane land had medium-good fertility and sandy loam as the soil type. It remarkable that silty soils contain sufficient quantities of nutrients, both organic and inorganic and very fertile & rich in great water holding capacity and also these soils are good for agriculture.

Dry weight of unit volume of soil inclusive of pore spaces is called bulk density. It is expressed in terms of gm per cc 1bs per cubic foot. Bulk density of soil changes within total pore space present in the soil and it gives a good estimate of the porosity of soil. Average density of soil in bulk is 1.5 gm/cc. Organic soils have low bulk density as compared to mineral soils (Shukla & Chandel, 2000). Soil bulk density were moderate for paddy cultivation in the study areas (Table 8.12). On the above table shows soil bulk density was poor valley areas soil and soil bulk density was good in plane land soils. It notable that sites 5 and 6 (college area and Janar Gona area) both were plane areas but their bulk density were poor.

Table 8.11 Finding of Soil structure and texture in the study areas

S.n	Soil structure or separation				Soil texture	
	%Sand	%Silt	%Clay	Fertility status*	Textural class	Fertility status*
Site 1	92.9	2.5	4.6	Poor	Sandy	Poor
Site 2	62.9	30	7.1	Poor	Sandy loam	Medium good
Site 3	37.9	52.5	9.6	Good	Silt loam	Good
Site 4	57.9	35	7.1	Medium good	Sandy loam	Medium good
Site 5	60.4	35	4.6	Poor	Sandy loam	Medium good
Site 6	75.4	17.5	7.1	Poor	Sandy loam	Medium good
Site 7	75.4	17.5	7.1	Poor	Sandy loam	Medium good
Site 8	50.4	40	9.6	Good	Loam	Very good
Site 9	32.9	60	7.1	Very good	Silt loam	Very good
Site 10	35.4	57.5	7.1	Very good	Silt loam	Very good
Site 11	45.4	45	9.6	Very good	Loam	Very good

Table 8.12 Finding of soil bulk density in the study areas

Sample location	Bulk density (g/cm^3)	Fertility status
Site 1	1.66	Poor
Site 2	1.60	Poor
Site 3	1.51	Good
Site 4	1.59	Poor
Site 5	1.61	Poor
Site 6	1.63	Poor
Site 7	1.63	Poor
Site 8	1.53	Good
Site 9	1.55	Good
Site 10	1.55	Good
Site 11	1.53	Good

Soil pH is the most important factor in the nutrient available of soils. Soil pH provides various clues about soil properties and is easily determined. The most accurate method of determining soil pH is by a pH meter. Soil pH in the paddy field was strongly acidic (Table 8.13) here. Maximum pH content was found 3.60 and minimum 1.80, and mean of the pH were found 2.8955 and std. deviation 0.54150. It was noticeable that hill covert area soil pH were so acidic but it was gradually increase (Alkaline) toward plane agricultural fields.

Salinity causes unfavorable environment and hydrological situation that restrict normal crop production throughout the maximum salinity content were counted 30.50 ds/m in college area and minimum contents were found 1.0 ds/m in the site 2, 3, and 4 (South Kattaoli Sundarpur and Kultoli) respectively, mean of the salinity were 19.1727 ds/m and std. deviation were 12.01491 ds/m. It was notified that, sites 2, 3, and 4 were situated in the alongside of hill or high land and saline water did not easily enter here out of big natural disturbances like cyclone and storm surge. On the other sites, soil salinity were very strong because these area were active with tidal fluctuation, inundation of paddy land by saline water and site 5 along with tidal creeks these creeks directly active with bay of bangle and Sangu river (Table 8.13).

The physical, chemical, and biological characteristics of a soil are significantly influenced by soil organic matter. According to Lal, the rate of organic carbon sequestration in soil with the adoption of suggested technologies relies on the type of soil, the structure of the soil, rainfall, temperature, agricultural practices, and management practices. Organic matter should make up more than 3.5% of a healthy soil. However, in Bangladesh, the majority of soils have less than 1.7% and some even have less than 1% organic matter. A good agricultural soil has an OM concentration of at least 2.5%, according to soil resource development Bangladesh (SRDI, 2010). The soil's organic component is made up of both live and dead organic components. In peaty soil, it may be as high as 90%. When plants and animals die, their dead remnants are susceptible to decomposition, which is present in relatively small quantities in

Table 8.13 Finding of soil parameters of the Sample sites of the study areas

Sample no	pH	Salinity	EC mS/cm	% O.C	% O.M	Total % N	Total % P	Total % K	Total % Ca	Total %Mg
1	3.0	22.3	0.08	0.13	00.22	0.06	0.3075	0.20	0.0037	0.110
2	3.5	1	0.05	0.31	00.53	1.00	0.28	0.54	0.0009	0.434
3	1.8	1	0.01	0.62	10.07	1.02	1.135	1.04	0.0000	0.532
4	2.3	1	0.05	0.49	00.85	0.98	0.69	0.56	0.0002	0.160
5	2.8	30.5	0.10	0.53	00.91	1.04	1.0225	0.51	0.0003	0.115
6	3.0	25.5	0.09	0.27	00.47	0.73	1.03	0.33	0.0001	0.061
7	3.0	23.2	0.08	0.47	00.82	0.78	0.7875	0.26	0.0006	0.078
8	2.8	29.4	0.15	0.58	00.01	1.00	1.51	0.64	0.0001	0.313
9	2.6	22	0.12	0.77	00.32	1.23	0.3425	1.05	0.0003	0.584
10	3.5	29.4	0.05	0.46	00.79	0.88	0.7975	0.78	0.0003	0.614
11	3.6	25.6	0.01	0.29	00.50	0.31	0.8325	0.70	0.0001	0.029

sandy soil of arid zones (one or less than one percent). Poor organic matter content was found in the studied locations (Table 8.13).

The amount of salts in the soil is determined by soil electrical conductivity (EC) (salinity of soil). The activity of soil microorganisms, which influences essential soil processes like the emission of greenhouse gases like nitrogen oxides, methane, and carbon dioxide, is a significant indication of soil health and has an impact on crop yields, crop suitability, plant nutrient availability, and crop yields. Optimum limit of soil electrical conductivity (EC) is four categories such as low (2.0–4.0 dS/m), medium (4.1–8.0 dS/m), high (8.1–16.0 dS/m), and very high (> 16 dS/m) (SRDI, 2010). Range of soil electric conductivity was found low on the respect of referring level (2.0–4.0 dS/m) (Table 8.13).

Soil fertility status is very much essential for farmers and their family because maximum farmers are marginal and their livelihood directly involve with agriculture. So, high yielding of crops farmers are used different types of fertilizers and pesticides used for controlled pest in the agricultural fields. As a result used of fertilizers and pesticides is directly impacts on soil in the agricultural fields. Present study tried to explore the soil fertility status in the study area. Land inundate by saline water is causes the seepage of saline water into the adjacent paddy fields, causing problems in rice production (Ali, 2006). Salinity decreases the intake of N and P, as demonstrated by numerous studies (Sharpley et al., 1992). Salinity reduces the ability of plants to absorb potassium, and research has shown that adding more potassium to heavily salinized soils does not increase their ability to absorb the mineral (Marschner, 1995). However, there haven't been any reports on how applying N and P to saline soils may affect things. Although acceptable nutrient levels are present in the soil, saline soils cannot support the growth of plants, especially rice, since salinity inhibits the uptake of nutrients in suitable amounts due to a higher osmotic pressure in the plant soil system (Bhumbla, 1977). According to Chowdhury et al., (2011a), naturally saline water contains various dissolved solids composed mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, silica, Ca, Mg, sodium, and K.

The minerals constitutions of the soil are derived from the parental rocks or regolith. The minerals represent about 90% of the total weight of the soil. In the sediment, Nitrogen (N) comes from atmosphere in the form of nitrogen salts. Every year, 25–50 kg of nitrogen are fixed in each hectare of ordinary soil, whereas 35–60 kg and 100–400 kg of nitrogen are fixed in cultivated soil and soil with legume plants, respectively. According to De and Fritsch, certain blue-green algae may fix 201bs of atmospheric nitrogen per acre in fertile soil. The increase the yield of rice from 15 to 25%. Optimum limit of percentage of total nitrogen (N) is four categories such as low (< 0.180%), medium (0.180–0.360%), high (0.361–0.450), and very high (> 0.45) (Chowdhury et al., 2011a; SRDI, 2003). Nitrogen status demarked that considering agricultural field's areas were fertile and farmers were used different types of organic and inorganic fertilizers especially urea on paddy land.

Potassium (K) is another important nutrient, it not only important for the increase of fertility status but also directly involve on plants growth. Because large amounts of K are absorbed from the root zone in the production of most agronomic crops, it is classified as a macronutrient. Optimum limit of percentage of total potassium (K) is four categories such as low (< 0.15), medium (0.150–0.30), high (0.30–0.375), and very high (> 0.375) (Chowdhury et al., 2011a; SRDI, 2010). Minimum percentage of total potassium (K) were found 0.20, maximum were found 1.05 and mean were found 0.6009 shows % of total potassium status were good and very good for crops cultivation. Potassium level represent the considering agricultural fields were fertile and farmers were used different types of organic and inorganic fertilizers especially murate of potash fertilizers. Although, potassium are important for stimulates early growth, increases protein production, improves the efficiency of water use, is vital for stand persistence, longevity, and winter hardiness of alfalfa, and improves resistance to diseases and insects (Table 8.13).

Phosphorus (P) is essential for plant growth and it stimulates growth of young plants, giving them a good and vigorous start. Phosphorus exists in soils in organic and inorganic forms. Organic forms of P are found in humus and other organic material and inorganic materials is released by a mineralization process involving soil organisms. The activity of these microbes is highly influenced by soil moisture and temperature. Soil phosphorus is most available for plant use at pH values of 6–7. Optimum limit of percentage of total phosphorus (P) is four categories such as low (< 12), medium (12.1–24.00), high (24.0–30.00), and very high (> 30.0) (Chowdhury et al., 2011a; SRDI, 2003). Contents of % of total phosphorus were very low and low (Fig. 8.10) because portion of soil phosphorus were < 12 only one sample site 8 (south rubber dam area) soil phosphorus were medium (15.1) in the study areas (Table 8.13).

"Calcium (Ca) is the predominant positively charged ion (Ca++) held on soil clay and organic matter particles because it is held more strongly than magnesium (Mg++), potassium (K+), and other exchangeable cations. Soils normally have large amounts of exchangeable calcium (300–5000 ppm). Ideal limit of the percentage of total calcium (CA) is four categories such as low (< 3.0), medium (3.1–6.0), high (6.1–7.5), and very high (> 7.5)" (Chowdhury et al., 2011b; SRDI, 2010). Contents of soil calcium were too low on the paddy fields in the study area (Table 8.13).

Magnesium is located both in clay minerals and associated with cation exchange sites on clay surfaces. The primary and secondary minerals are important sources of Mg for plant nutrition, especially in unfertilized soil. Perfect limit of percentage of total calcium (Ca) is four categories such as low (< 0.75), medium (0.751–1.5), high (1.51–1.87), and very high (> 1.875) (Chowdhury et al., 2011b; SRDI, 2010). Lab analysis found that percentage of total magnesium were low contents on everywhere in the study area.

Correlations and Regression Between Soil Salinity and Physico-chemical Properties of Soil

The result of correlations among the soil salinity level and studied physico-chemical properties of agriculture, field soils of e study area have been given in Table 8.14.

According to the finding of the Table 8.14 indicates that soil salinity level is significantly positively linked with the soil pH, soil temperature, total Phosphorus

Table 8.14 Correlations between soil salinity (EC) and physico-chemical properties of soil

Physico-chemical properties	1	2	3	4	5	6	7	8	9	10
1 Soil pH	–									
2 Soil temperature (°C)	0.783**	–								
3 EC (dS/m)	0.917**	0.808**	–							
4 Bulk density (g/cm^3)	−0.427	−0.158	−0.326	–						
5 O. M (%)	−0.775**	−0.896*	−0.712*	0.251	–					
6 Total N (%)	−0.875**	−0.809**	−0.830**	0.500	0.853**	–				
7 Total P (%)	0.848**	0.624*	0.762**	−0.298	−0.480	−0.601	–			
8 Exchangeable K (%)	0.808**	0.828**	0.653*	−0.291	−0.738**	−0.738**	0.833**	–		
9 Exchangeable Ca (%)	0.115	0.289	−0.101	0.041	−0.579	−0.244	−0.159	0.250	–	
10 Exchangeable Mg (%)	0.884**	0.800**	0.785**	−0.510	−0.879**	−0.870**	0.597	0.714*	0.435	–

Note $*p = 0.05$, $**p = 0.01$

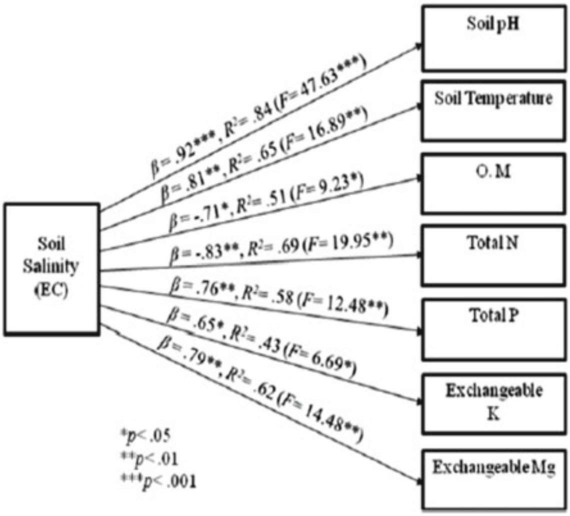

Fig. 8.3 Impacts of soil salinity on the different soil parameter

content, exchangeable Potassium (K) and Mg. Moreover, soil salinity is negatively linked with soil orgnic matter and Total Nitorgen (N) (Fig. 8.3).

The authors conducted simple regression study to assess the input of soil salinity on different soil parameters such as soil pH, soil temperature, organic matter, total nitrogen, total phosphorus (P), exchangeable potassium (K), and exchangeable magnesium (Mg). The finding of the regression study explained in Fig. 8.3 which found that soil salinity had a noteworthy input to soil pH ($\beta = 0.92$, $t = 6.90$, p 0.001), and value of R^2 explores that soil salinity could describe around 84% changeability in soil pH. The figure also assess that soil salinity was a momentous forecaster variable of soil temperature ($\beta = 0.81$, $t = 4.12$, $p < 0.01$) and organic matters ($\beta = -0.71$, $t = -3.04$, $p < 0.05$), which reveals that 1 unit raise in soil salinity augments–81 unit level in soil temperature and 71 unit reduce in organic matter value. Besides, total P, exchangeable K, total N, and exchangeable Mg also rely on soil salinity due to the soil salinity level strongly contribute to these nutrients parameters.

8.8 Community Perception of Salinity Levels in Rice Fields

Islam (2004) states that many coastal districts, including Chittagong, are facing increased levels of salinity in agricultural fields. A recent report shows that more than 1 million hectares of arable land in Bangladesh are affected by salinity intrusion caused by slow- and rapid-onset events (SRDI, 2010). It also points out that 71% of cultivated areas in Cox's Bazar Sadar Upazila are affected by high-level

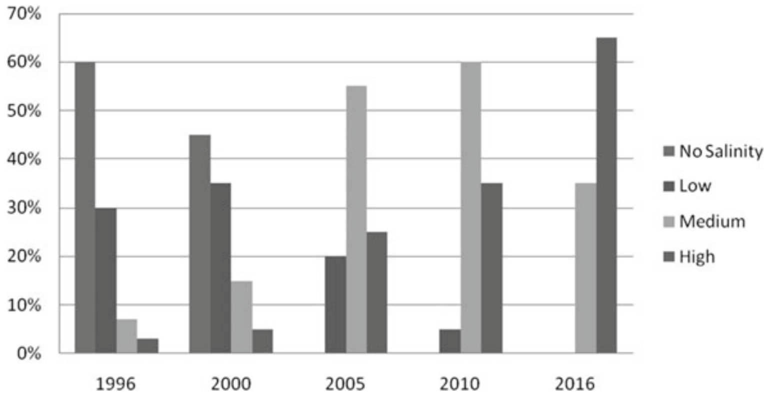

Fig. 8.4 Respondents' perceptions of trend of salinity during last 20 years in the study area

salinity (above 12 dS/m). According to the BBS, the net cultivated area in Chittagong decreased by about 7% from 1996 to 2015 (BBS, 2016). It was found that immediately after cyclone Mahasen which hit in the South-Eastern coast on June 13, 2013, total rice production in Chittagong decreased from 0.70 million tons in 2013 to 0.40 million tons in 2015 (BBS, 2013, 2015). The report also indicates that production of the principal rice crop (Aman rice) in Chittagong decreased substantially, from about 0.8 million tons in 2013 to 0.4 million tons in 2015.

Focus group participants and questionnaire respondents claim that salinity intrusion has increased sharply over the last decade and particularly over the past five years (Fig. 3). Current high salinity in rice fields is caused to a large extent by cyclone Mahasen, which hit the area in 2013. In 2016, when the fieldwork took place, about 65% of farming households experienced high salinity in rice fields (Fig. 8.4). It was found that all saline-free and low-salinity farmland has turned into medium- or high-salinity farmland, which has a severe impact on crop production.

Farmers in the study areas, mainly cultivate among rice varieties, which grow between April and August. In the past 20 years, the pattern of T. aman production at Jhilanja Union has been quite irregular. The data show that total T. aman production was more than 10,000 tons between 2000 and 2005, but was less than 7500 tons from 2006 to 2011. In 2012, the production of T. aman was about 6800 tons. Since then, it has decreased substantially by 25% and 15% in 2013 and 2014, respectively, in the study union (UAO, 2015). According to UAO data, a similar pattern was observed in the other study unions. Farmers mentioned that all four study villages in both the above mentioned unions had "zero production" of rice in 2013, immediately after cyclone *Mahasen* hit. After the cyclone, saline water entered into the agricultural field in the study areas due to damaged embankment and high level of storm surges. As a result, crop production in the Cox's Bazar Sadar upazila hamoered significantly. During the discussion with local farmers that production of *T.* aman crop has shifted from an average of 3.5 tons per hectare in 2012 to 0 tons per hectare in 2013 all the study areas. In the year after *Mahasen* (2013), some farmers in the study villages tried aman cultivation again, despite high-salinity levels, but their yields were less than 1 ton per hectare. In 2015, farmers in all four villages were able to slightly increase their aman yields to an average of 1.5 ton/ha. However, the yield was less than 50% of that of 2012 (the year before cyclone *Mahasen*).

There were different responses regarding the changes in rice production over the last 20 years. About 76% of farmers in the study villages believed rice production has decreased over the years. More than half of the respondents (51%) mentioned that rice production had "decreased a lot" over the last 20 years in the study areas (Fig. 8.5).

According to Fig. 8.6, it is found that most respondents (98%) identified salinity intrusion as the main cause of declining rice production, followed by lack of rainfall (65%). Other factors mentioned included excessive rainfall in short periods of time (called "sky floods' locally), pest attack, not having fertilizer at the right time, water logging, high cost of cultivation, and lack of irrigation water. All the farmers strongly believed that salinity intrusion in soil and water is the main challenge to rice farming in the study areas.

The study also indicated that loss and damage associated with salinity intrusion in rice production affects income groups (extreme poor, poor and non-poor) differently. The income of extremely poor households from rice cultivation was affected most. In 2013, the loss incurred by the extreme poor was about 70% of their last annual household income, whereas other households lost 40–45% of their last annual income. In addition, from 2013 to 2018, all the sampled households were gradually adapting in some way to reduce loss in rice production. But the poor and extreme poor households were recovering their situation at a slower rate than non-poor households.

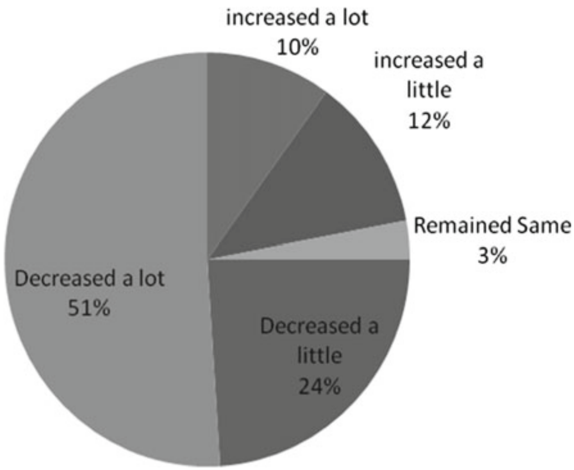

Fig. 8.5 Change in rice production in the study areas over the last 20 years

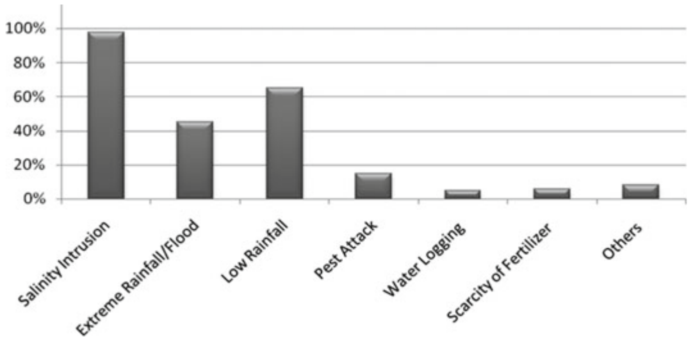

Fig. 8.6 Percentage of respondents on causes of reduction in rice production

8.9 Adaptation Practices by the Farmers for Reduce Salinization Problem

Farmers in the research areas have found that climate change and diversity directly affect the agricultural sector, especially the production of crops, fish, and livestock. That situation has led many people to adopt risk reduction strategies. Based on their experience, knowledge, and resources, they look for adaptation strategies to deal with climate change. Changes in rainfall patterns and rising temperatures have caused changes in growth, germination, and plant pests.

Below a certain level of salt, agricultural systems can block salt without changing their properties and feedbacks (Darnhofer, 2014). The implementation of flexible farming technologies such as salt-tolerant rice varieties, preparation of cropping the calendar, or controlling irrigation and water infiltration work effectively to prevent salt damage to rice and rice-shrimp systems (Nhan et al., 2012; Renaud et al., 2015). More solutions can be the development of early warning systems as well awareness of salt infiltration into water to reduce exposure systems at high-salt events. Structural adaptation measures such as the construction of a protective infrastructure and development of irrigation networks, as well as application of ecosystem-based adaptation measures such as mangroves reforestation and rehabilitation of wetlands, can also reduce magnitude of salt infiltration (Renaud et al., 2015; Smajgl et al., 2015). One of the dangers of structural steps is modification of exposure to risks and focus on one part of strength that may lower the quality of some of the strength components and all over time due to depletion of biodiversity, duplication of activity, and spatial variability (Adger et al., 2015; Biggs et al., 2012).

Farmers in the study area reported that the concept of pre-emptive adaptation is external. They plan ahead–they will wait until it happens, and then they will get used to it. They will look at the southern regions and think about how they farm. In contrast, participants in the southern part were interested in more plantations (fast-growing timber) as an option. The reason for the interest is that they hope the trees will change the climate and create more rainfall. If they are able to stop the increase in salt, it can allow the growth (in small amounts) of the pumpkin and watermelon. They also said they were unable to plant sesame seeds in early February due to high soil moisture, mainly due to the drainage system.

Farmers in all farming systems have seen a huge amount of this recovery from salt damage. During the interview, rice farmers say they will replant rice in salt washing and increasing fertilizer use compensation for damages. Rice-vegetable and vegetable systems can easily recover from salt damage because farmers can change vegetable crops. Fish pond, soft-shell turtle, and large fish pond systems, farmers often refer to the use of lime and fertilizer to reduce salt in the water beforehand return to farming activities. Ability to switch to other agricultural systems regardless of the farming system, most farmers negotiations indicated that they would continue their farming programs even if they lose two crops in a row. During the interviews, when asked to test their ability to perform change, fish pond, large fish pond, and double the rice farmers noted low conversion power, while rice-vegetables, greens, and soft-shell turtle growers have estimated the maximum volume of switching systems. Fish pond and large fish pond systems it is often difficult to reverse two rice or other systems due to mining and high financing the need to fill the pool. For rice-vegetable and vegetable systems, farmers can easily afford it turning their plans into fruits, bonsai, rice, and flowers. In between interviews, soft-shell turtle growers have also seen the rise switching power to other systems such as fish, integrated garden pond-animal shed systems, and vegetables (Nguyen et al., 2019).

They need new sesame plants that can withstand sudden stagnant water. Sesame provides the best yield when shown in the central highlands and the lowest yield in the low central medium. Women are more knowledgeable and pass on their knowledge to their children (future generations) to adapt to changing circumstances. Both men and women are concerned about local control over the flow of seawater. Trenches were blocked by large farmers to keep fish (reducing drainage systems). Pods can fall at any time. Farmers in Cox's Bazar Sadar, which includes the Southeast coast of Bangladesh, have suggested alternative adaptations to reduce salt intake in their agricultural areas found in Table 8.15.

Besides, to cope with climate change-induced natural disasters in the study areas, farmers applied alternative land-use practices like shrimp farming instead of crop production, embankment cropping, plantation of mangrove trees, and cultivation of saline-tolerant grass, using flood- and saline-tolerant rice, etc. Farmers of the study areas apply some climate-resilient agro-based practices, which are indicated in Table 14.5.

With the support of district agriculture office of Cox's Bazar, Bangladesh local farmers of the Cox's Bazar Sadar sub-districts of Chittagong district stated that they are using salinity-tolerant rice varieties such as T. Aman: BR-22 and BR-23; Bina shail flash flood; BRRI dhan 33, 56, 57, and 62; Bina dhan 7 and 16; BRRI dhan 47, 61, 67; Bina dhan-8 and 10; T. Aman: BRRI dhan 40, 41, 53, 54; and Aus: BRRI dhan 65; T. Aman: BR-22 and BR-23; cage fishing, mele (reed) cultivation, floating dhap cultivation, shifting planting time, short-duration rice varieties, integrated farming, crab patenting, semi-scavenger housing for goat, duck, and hen rearing, net fishing, dyke farming, salt-tolerant wheat like Bijoy, BARI Gom-25, BAU-1059 line; salt-tolerant

Table 8.15 Adaptation practices in the study area through responses of men and women

Proposed adaptation option	Response of women	Response of men
Replacing long duration T. Aman rice variety (BR-23, 150 day) with short duration variety (125–130 day) for further intensification or reducing risk	(i) Good for early harvest that may enable the risk of heavy rainfall for stormy weather during maturity of BR-23 and may reduce the risk of damaging sesame for water logging with rain water (ii) Needs optimum rainfall to transplant short duration Aman rice by August 20	Men responded as women but they emphasized on community approach for rat damage, proper drainage of rain or tidal water and easy harvest
Relay cropping of cowpea and grass pea with T. Aman rice under single T. Aman cropping area	May be possible in medium highland	The idea is good for medium highland but needs to be a community-based operation for protecting open grazing
Cultivation of direct dry seeded/dibbled or transplanted rice in Aus season	No response	(i) Can be tried in the medium highland after sesame or mungbean but needs short duration cultivars (ii) Aus rice depends on early Kharif 1 showers
Deepening of inner side existing canal of rice-fish culture under gher for storing more surface water for irrigation	No response	(i) May be 30–60 cm deeper is possible in existing canal of 120–150 cm width and about 60 cm deep (ii) If more, then need to increase the width of the canal but they expressed concern about taking up too much land
Specially built ponds for irrigating the dry season crop	No response	(i) Ponds with an area of 80–100 m^2 at 180–210 cm depth may be possible to store fresh surface water for irrigating rabi crops (ii) Cost and area expansion is a concern to them
Special Fertilizer application for reduce salinization problem	No response	Some farmers put gypsum and sugar solution (or solid form of sugar) to reduce salinity in the rice seedbed
Preparation of paddy fields	Men are working hard for reduced salinity intrusion problem	Frequent tillage of the rice fields for reduction of salinity during cultivation

potato: BARI Alo-22 CIP Clone 88.163; salt-tolerant sweet potato: BARI Mishti Alo-8,9, salt- and heat-tolerant pulses: BARI Mug-2,3,4,5,6, BM-01, BM-08 BARI Falon-1, BARI Sola-9; short-duration and salt-tolerant oilseeds: BARI Sharisha-14,15; BARI Chinabadam-9, BINA China badam-1, BINA China badam-2, BARI Soyabean-6 BARI Til-2,3,4; salt-resistant jute varieties by Bangladesh Jute Research Institute (BJRI): (i) HC-2, (ii) HC 95, (iii) CVL 1; salt-tolerant sugarcane varieties by Bangladesh Sugarcane Research Institute (BSRI): (i) ISWARDI-40 (Table 8.15).

Figure 8.7 explored that almost 39.2% of farmers applied salt-tolerance T. Aman varieties BR-22, BR-23, BR-22, and Bina shail; 18.1% of farmers use salt-tolerant BRRI dhan varieties BRRI 33, BRRI 56, BRRI 57, BRRI 62, BRRI 40, BRRI 41, BRRI 53, and BRRI 54; 17.9% of farmers use salt-tolerant BINA dhan varieties BINA 7, BINA 16, BINA 8, and BINA 10; and only 9.8% of farmers use the salt-tolerant Aus variety BRRI 65. Besides, 54.3% of farmers used alternate cropping, including mele (reed) cultivation, and salt-tolerant grass farming in the study area.

Salt-tolerant grass (fodder) farming is increasing day by day, as found during the community consultation. Resilient livestock farming, including semi-scavenger housing for livestock (hen, duck, sheep, and goat), is practiced by 75.6% of households to protect the livestock from climate-induced salinity and flood-oriented diseases. Fish culture is a common practice in coastal Bangladesh, but due to sea-level rise, tidal inundation, storm surges, and flood, this practice has been restricted in recent times.

This is found that due to high salinity, water logging problem and flood, farmers do not cultivate vegetables on all the agricultural land in the study areas. But in the last 20 years, through the initiative of government and non-government organizations, some climate-resilient practices like homestead farming, dyke farming, *gher/dhap* farming, or integrated farming have been introduced in the study area, and 65.7% of farmers are practicing such farming for their household needs (Fig. 8.7).

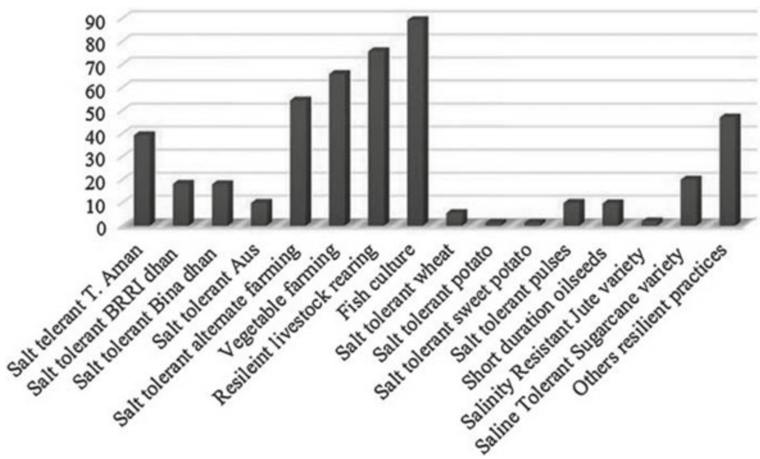

Fig. 8.7 Climate-resilient agro-based practices in the study areas

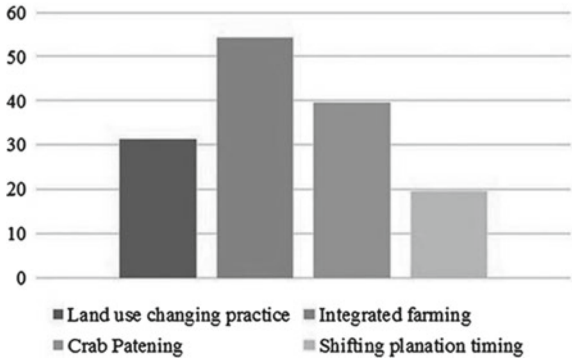

Fig. 8.8 Alternate climate-resilient practices in the study areas by the farmers

Commercial vegetable farming is not possible in the study area, as found from the community survey. Salt-tolerant wheat, jute, sugarcane, oilseed, pulse, etc., cultivation is practiced at a small scale. Land use changing practices, integrated farming, crab patenting, and shifting plantation timing are introduced as climate-resilient practices in the study area. 31.3% of crop producers are farming shrimp instead of the crop in their paddy fields, and some farmers changed crop calendar following seasonal crop suitability in the study area (Fig. 8.8).

8.10 Conclusion and Recommendation

It is now normal due to climate change impact, salinization process, and soil fertility status is an important factor for crop production in coastal area of Bangladesh. In general, coastal area of Bangladesh are law lying topography, enormous tidal creeks, and quite low in soil fertility. Soil salinity is a worldwide problem while Bangladesh is no exception to it. In Bangladesh, salinization is one of the major natural hazards that disrupting crop production mainly rabi season crops (wheat, barley, maize, boro, mustard, and vegetables) are affected due to different degrees of salinity. Salinization process not only changing the paddy crops rotation but also it discourage of farmers for cultivated crops in the study South-Eastern coast of Bangladesh. For this reason day by this fields did not cultivated as a result it be permanently considered as fallow or barren land and finally reduce it fertility and productivity. Presently rapid population growth, increased national food demand, climate change, increase salinization process, and loss of soil fertility are the main causes that place tremendous pressure on nation. So, time to come applying integrated coastal zone management (ICZM) than may reduce saline water intrusion and salinization process including increase soil fertility status can be ensure the food security for nation and next generation.

The current adaptation practices by the farmers not enough to adapt to increased levels of salinity particularly caused by extreme events. Along with these climate-related threats, the level of poverty, low resilience, and lack of alternative livelihoods result in significant losses for not just the study communities but also the population along the entire coast. People are leaving the shore in greater numbers, mostly due to the loss of employment prospects. If Bangladesh's population is to live and thrive in the long run, it urgently needs assistance in creating a climate-resilient agricultural. Numerous factors in the country are being impacted by climate change. For instance, the quality and quantity of the products supplied are declining as a result of some agricultural land in coastal areas being more salinized due to rising sea levels. The impacts of global warming on farming are evident, and they will undoubtedly get worse if climate-resilient farming practices are not embraced. Large tracts of agricultural land in southern regions are drying out because they are only millimeters above the brackish estuarine water. Because of increased salinity brought on by rising sea levels in the Bay of Bengal, crop yields are declining. There is also the worry of sea level rise, which would push the water line farther inland and harm the shoreline in terms of agricultural production, drinking water infrastructure, as well as putting other means of subsistence and other social security at jeopardy. Salinity increases in soils have had a significant negative influence on rice productivity, food security, and income during the past few decades. Low-lying agricultural land must be effectively safeguarded, while at the same time innovative and context-specific strategies, such as climate-resilient rice farming (seeds and techniques), must be investigated and put into practice. Despite all of these climate stressors, people are attempting to deal with the difficult situation by using both their traditional expertise of agrarian adaptation and newly developed technologies in the agricultural sector. The kind and amount of climatic influences, geographic location, and other factors all affect these adaptation possibilities. The methods are being used by the people of Bangladesh since they are well-known adaptation strategies for those disasters and extreme events that are caused by climate change. They are making every effort to increase their capacity for coping with the effects of climate change on the agriculture sector. Based on better technology already in use, these activities need to be developed and structured more. The government ought to take into account include local and indigenous agrarian adaptation practices in its pertinent policies and ought to develop fresh approaches for better putting those adaptation methods into effect.

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Chapter 9
The Ecological Significance to Maintain Rice Cropping Areas in the Rice Bowls of Kerala for Sustaining Food Security Under the Purview of Climate Change

P. Dhanya and K. Jayarajan

Abstract Rice fields in Kerala have reduced 76% over 42 years from 875,000 ha in 1970 to 208,000 ha in 2012. Secondary data show that rice cultivating areas in Kerala's rice bowl-Palakkad have 56% reduction over the past 50 years from 2010–2011 to 1960–61. Even then, there are discussions and arguments happening over Kerala to shift rice paddy fields to other commercial crops like rubber. Moreover, the demand–supply gap of rice in Kerala is widening at a faster rate, and it remains a food deficit state, constantly depending upon neighbouring states for food grains. This study was an endeavour to understand the significance of sustaining rice cultivation in the rice bowl, Palakkad not only for food and livelihood security, but also for preserving ecosystem services. The state has about 300,000 rice growers. This study also explores the outcomes from the Crop Simulation Model DSSAT on the projected rice yield for Palakkad region under changing climatic scenarios. It also tries to find out the best suitable rice variety for the rice belts of under changed climatic conditions. The yield of Uma and Jyothi—two major ruling varieties may be reduced by − 14.4 and − 21.8%, respectively, by 2100 for Palakkad Region. Compared to current rice productivity in the rice belts of Kerala, future rice yield due to climate change with medium emission scenario of IPCC is projected to reduce during mid-century (2021–2050) and end century (2071–2100) period. Unless there is efficient planning to provide smarter adaptive actions, it would affect local food security and livelihood security of the farmers. There is a need to have a lab to land transfer of temperature drought and flood-tolerant seed varieties in the rice belts of Kerala to tackle climate change impacts and widening demand–supply gaps. However, the ecosystem services that these rice paddy wetlands provide in maintaining ecosystems and biodiversity, flood water control, surface and groundwater conservations and aesthetic value to Kerala-Gods own country are invaluable. It is essential to sensitize the farmers and land owners on this ground.

Keywords Climate change · Crop simulation model · DSSAT · CERES · Rice · Adaptation · Ecosystem services

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9.1 Introduction

Global crop production needs to double by 2050 to meet the projected demands from rising population (Ray et al., 2013). Climate change poses serious threats to the global food production systems as the predicted global warming century under all the representative concentration pathways (RCPs) are projected to rise in the ranges of 0.3–1.7 °C (RCP 2.6), 1.1–2.6 °C (RCP 4.5), 1.4–3.1 °C (RCP 6.0) and 2.6–4.8 °C (RCP 8.5) for the years 2081–2100, relative to 1986–2005 (IPCC, 2013). Amongst all climatic variable, temperature rise is one of the most critical factor impacting agriculture production systems (Wheeler & von Braun, 2013). Climate change is probably one of the burning issues as an example of a modern environmental problem which stand as a threats to biodiversity and food security (Beck, 2005). The association between global warming, climate change and its indirect impacts on ecosystems is well documented by many researchers and IPCC (2018), Hare et al. (2010), Panda et al. (2014).

As far as cereal crops are concerned, rice is one of the chief crop cultivated in Asian countries, including India. Most of the annual rice production comes from tropical climate areas (Nguyen, 2004). Rice (*Oryza sativa* L.), the staple crop of Kerala, accounts for 7.33% of the total cropped area. The optimal requirements of climatic variables for a crop, like sunshine hour, temperature, rainfall, relative humidity and soil conditions, vary differently from each crops, etc. The present study area, Kerala, has a rich diversity of traditional rice varieties which have been evolved to suit various ecological conditions (Gopi & Manjula, 2018).

Paddy is grown in a heterogeneous environment with respect to topography, climatic conditions and cropping pattern in Kerala. Paddy crop lands can be seen at around 3 m below mean sea level (Kuttanad) to 1400 m above mean sea level (Munnar and Wayanad) in Kerala. Paddy cultivation in the rain-fed uplands area known as Modan and in the as single crops in fallow lands during summer Palliyals, double cropped uplands (both transplanted and semi-dry conditions), flooded lands of Kuttanad, in the wetlands of Kole and Pokkali (saline soils) sandy and deep ill drained regions of Onattukara Poonthalpadam (marshy conditions), laterite midlands and high altitude regions. In Kerala, different rice crop varieties are grown for 80–200 days over the course of all four seasons, under a variety of agroclimatic conditions. The majority of the wetlands used for rice cultivation are a result of the laterite midland environment. The two districts known as Kerala's "rice bowls", Kuttanad and Palakkad, account for 7 and 11% of the state's total rice land, respectively, whereas the distinctive Pokkali rice system only makes up less than 1% (Saseendran et al., 2000). Kerala's paddy-growing area has decreased from 347,455 ha in the agricultural year 2001–02 to 194,235 ha in the current year. This study aimed to comprehend the significance of maintaining rice agriculture in Palakkad, not only for the preservation of ecosystem services but also for the security of food and livelihood. The state has about 300,000 growers who depends solely on rice cultivation.

9.2 Study Area

Palakkad is Kerala's largest district with a population density of 659/km^2. It sits virtually in the middle of the state, extending across the midland plains and mountain highlands with no coastline. Through the Palakkad gap, the district connects the state to the rest of the country. This 32 to 42-km-wide natural break in the 960-km-long Western Ghats may be the most influential factor in the district's distinctive qualities, such as climate and culture. The longest river in Kerala, the Bharathapuzha, rises in the Anaimalai highlands and flows through the entire district. It serves as a gateway to Kerala because it is located at the base of the Western Ghats. The Palakkad district is located between latitudes 10°20′N and 11°14′N and longitudes 76°20′E and 76°54′E. The district borders the Tamil Nadu districts of Coimbatore in the east, Thrissur in the south and south-west and Malappuram in the north and northwest. Due to its extensive rice fields, Kerala's Palakkad district is known as the state's granary.

This study emphasizes the Palakkad district, considering its vast paddy-producing area in the state (Fig. 9.1). Palakkad district leads the way with 75,276 ha (39.81%) of the state's total wetland paddy area, followed by Alappuzha with 36,325 ha [19.21% of total wetland paddy area in the state (16%)]. A total of 83,000 acres, or 40% of the state's total paddy land, are under cultivation in Palakkad. The district is the primary rice-producing area of the state, along with the Kuttanad region in Alappuzha and the coastal portions of Thrissur district.

The soil conditions in the southern and north-eastern parts are clay and gravelly loamy. In the central part of the district, it is mostly gravelly loam. In the western and north-western parts, the soil is gravelly clay (Fig. 9.2). Soil detail is one of the most important factors in crop models after climate data. Palakkad receives a majority of its rain during south-west monsoon season, especially in the months of June and July (Fig. 9.3). Rivers such as Kunthipuzha, Bharathapuzha (Nila), Kalpathipuzha and Gayathripuzha are the lifelines of the district. Palakkad has 12 dams constructed exclusively for irrigating paddy fields. At present, Palakkad has 1575 total forest areas left. It is essential to conserve the natural resources of the district to maintain its biodiversity. The district shields 13.5% of the total forest area in the state and has 37% of the total ecological fragile land (EFL) in the state. The total forest area in Palakkad district is 1527.35 km^2; out of these 51.77 km^2 belongs to the EFL zone, 276 km^2 is dense forest, and 693 km^2 is under moderate forest cover.

9.3 Materials and Methods

9.3.1 Secondary Data

Secondary data on crop area have been collected from the Department of Economics and Statistics Government of Kerala. The daily weather data on maximum temperature, minimum temperature and sunshine hours for the growing seasons were

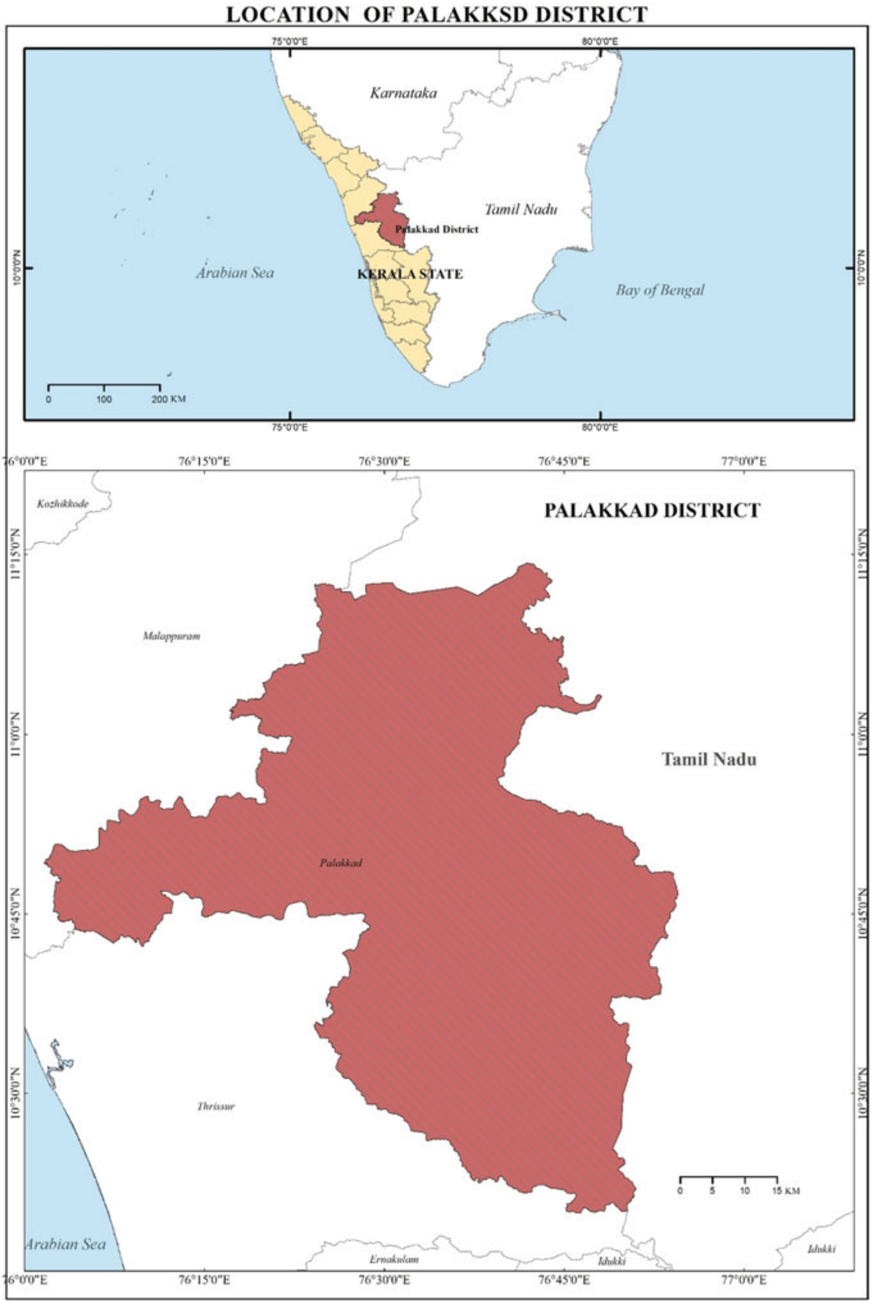


Fig. 9.1 Base map of the study area, Palakkad

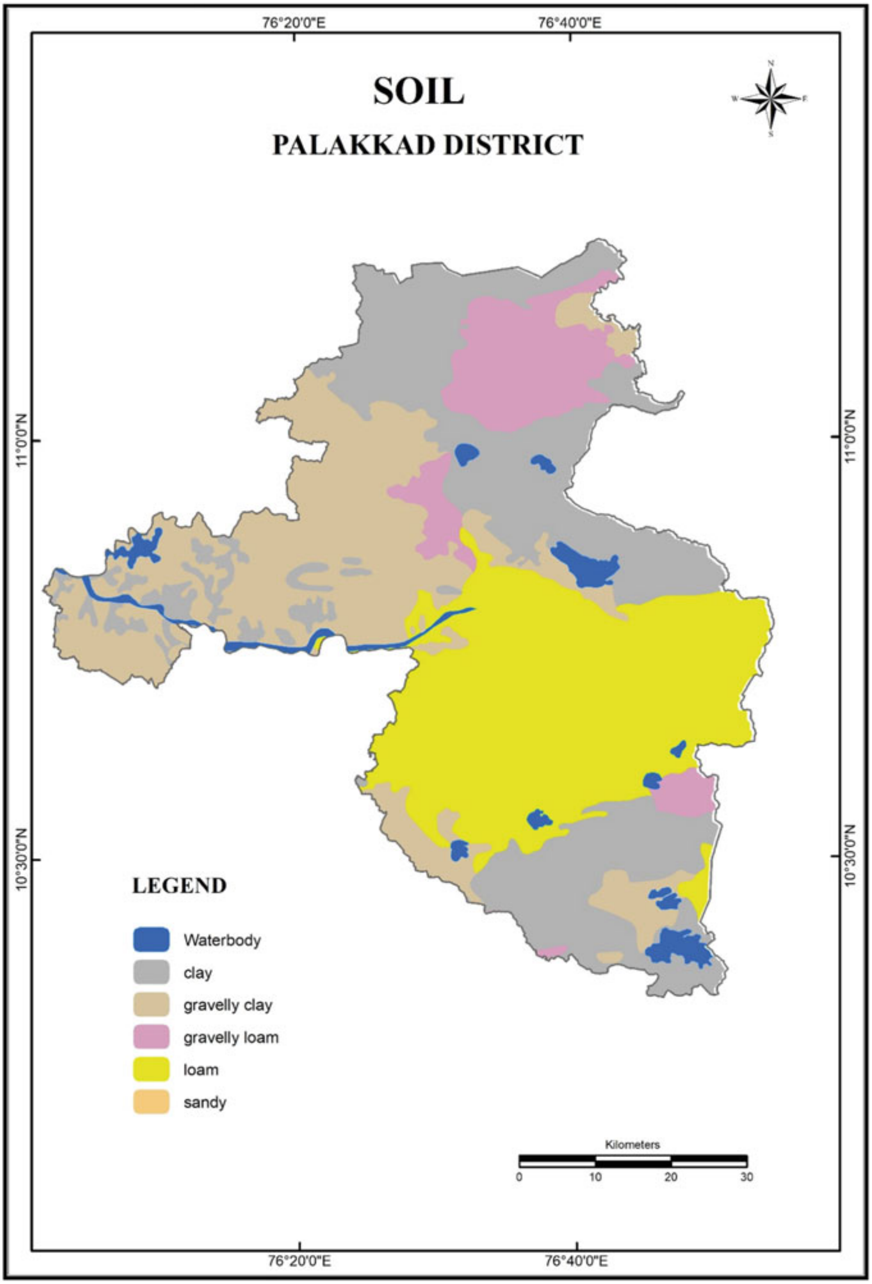


Fig. 9.2 Soil map of the study area

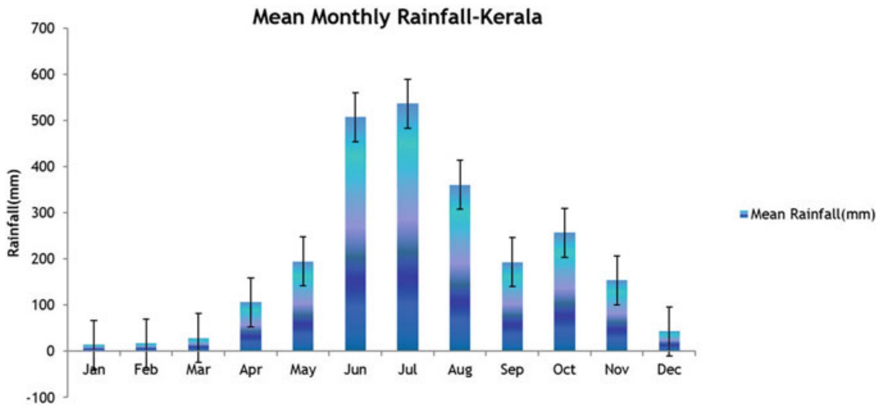


Fig. 9.3 Mean monthly rainfall of Kerala for the period 1970–2015

collected from Indian Meteorological Department. The daily gridded precipitation, maximum and minimum temperatures and sunshine hours were obtained from India Meteorological Department (IMD) at 0.25° spatial resolution for the period 1971–2017 for simulation purpose. Jyothi and Uma, the two widely cultivated rice varieties, were used for modelling.

9.3.2 Representative Concentration Pathway Trajectory 4.5 (RCP 4.5)

RCP4.5 is a stabilization scenario introduced in the IPCCs AR5, where it is assumed that total radiative forcing will be stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions (Fig. 9.4). It is developed by the MiniCAM modelling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute. Under this scenario, it is expected that radiative forcing will reach more than 650-ppm carbon dioxide equivalents by 2100 (Moss et al., 2010 and Van Vuuren & Carter, 2013).

9.3.3 Crop Simulation Model

The generic grain cereal simulation model CERES-Rice Version 4.5 was used to estimate the effect of aerosols on crop yield and has been integrated in the Decision Support System for Agrotechnology Transfer (DSSAT) (Fig. 9.5). Crop Estimation through Resource and Environment Synthesis (CERES) Rice within Decision Support System for Agrotechnology Transfer (DSSAT) package. For this study, the

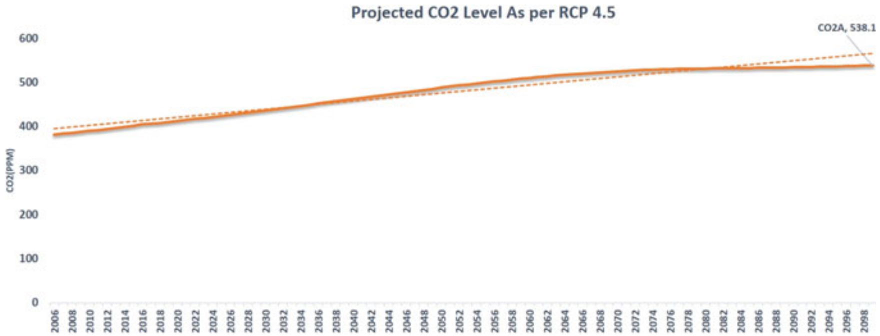


Fig. 9.4 Projected CO_2 levels in the atmosphere as per RCP 4.5 of IPCC AR5

model was employed to estimate the radiative influence of atmospheric aerosols on crop growth and yield. Temperature and CO_2 are vital for photosynthesis, hence for plant growth. The sensitivity of the CERES-Rice model to changing temperature, rainfall and CO_2 levels was analysed by arbitrarily creating anomalies in the base line climate data. Climate impact assessments have conducted to confirm the need to adapt to a changing climate. Two varieties used for the simulation are Jyothi and Uma. Genetic coefficients of the both the varieties are given as an input in Gencal component of DSSAT is provided in the Annexure.

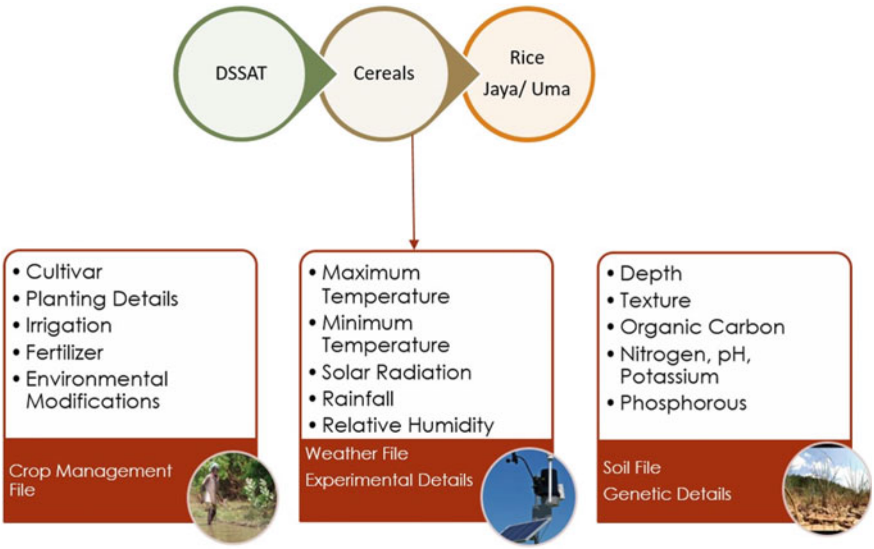


Fig. 9.5 Process of climate change impact assessment on rice varieties using DSSAT model

Table 9.1 Genetic coefficients used for the simulation purpose

Variety	Genetic coefficient							
	P1	P2R	P5	P20	G1	G2	G3	G4
Jyothi	581.7	022.5	488.4	10.5	56.1	0.0250	1.10	1.10
Uma	553.4	022.3	444.2	10.0	51.0	0.0250	1.10	1.10

Table 9.2 Decadal changes in the rice cultivation of Kerala from the reference period, 1960–61

District	1970–71	1980–81	1990–91	2000–01	2010–11	Overall change from 1960–61
Palakkad	10.00	− 13.10	− 20.66	− 18.52	− 18.96	− 49.93

Table 9.3 Projected change in climate, Palakkad. Under RCP 4.5

Variables	Near century	Mid century	End century
T Max (°C)	1.12	2.06	2.64
T Min (°C)	1.04	1.96	2.53
Rainfall (%)	− 8	− 2	3

9.4 Results and Discussion

9.4.1 Decadal Changes in the Rice Cultivation of Kerala

The maximum reduction in the paddy area − 20.66% was noticed during the period 1990–91. The recent decade during the period 2001–2010, the reduction in the area was − 18.96 (Table 9.1). The average yield in the district is 4–5 tonnes per ha, higher than the state average of 2.7 tones. But, rice in Palakkad faces stiff competition from crops like banana, ginger, rubber, coconut and mango. As per the latest available statistics (2014–15 year), the cropping intensity of Kerala is 128.5. The cropping intensity of Kerala has been reducing year by year. There are many traditional varieties cultivated in the state; however, the major ruling varieties are Jyothi and Uma. Hence, they are used for projecting future yield in the district. Lobell (2007) has reported that changes in diurnal temperature range and cereal yields to a great extent (Tables 9.2 and 9.3).

9.4.2 Predicted Rice Productivity for Palakkad, Kerala

Crop yield reduction was noticed under the future warming scenario for Palakkad. It also tries to find out the best suitable rice variety for the rice belts of under changed climatic conditions. The yield of Uma and Jyothi—two major ruling varieties may be reduced by − 14.4, − 21.8%, respectively, by 2100 for Palakkad Region. The yield was found to be reduced by − 8% in the mid-century period for Uma Variety and − 19.2% for Jyothi variety if temperature increases by 2 °C. Under elevated CO_2 conditions, the yield reduction was minimized (Figs. 9.6 and 9.7). Variety Uma performed comparatively better than Jyothi for Palakkad under warming scenario. However, variety Jyothi performed better under elevated CO_2 scenario for Palakkad with higher yield increments. The reason for rice yield decreases may be due to the intensification of temperature and reduction in rainfall, thereby reducing the crops maturity time of crops in the future. Palakkad rice belts area may experience significant heat stress in future due to warming, affecting farming operations. It is essential to adapt smartly to have sustainable crop yield and livelihood security and conserve the existing natural resources.

According to reports, without CO_2 fertilization, successful adaptation and genetic improvement, each degree Celsius rise in the world's average temperature will result

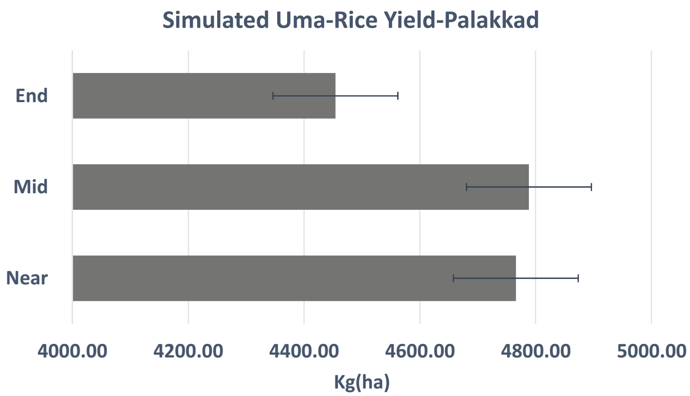


Fig. 9.6 Projected Uma rice yield, Palakkad, Kerala

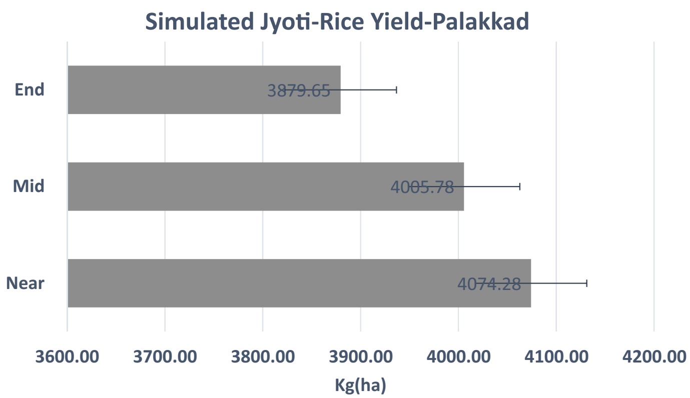


Fig. 9.7 Projected rice yield—Jyothi, Palakkad, Kerala

in an average reduction in worldwide yields of wheat, rice and maize of 6.0%, 3.2% and 7.4%, respectively (Chuang et al., 2017). The demand for water in the atmosphere will rise as the temperature rises, which could result in extra water stress due to greater water pressure deficits, which would affect soil moisture and yield (Gobin, 2010; Lesk et al., 2016) The CERES-Rice model's simulation findings demonstrated that the crop yields under the higher temperature circumstances are expected to be substantially impacted since rice is particularly sensitive to changes in ambient temperature (Challinor et al., 2010; Dhanya & Ramachandran, 2015; Ramachandran et al., 2017; Hoogenboom et al., 2012; Jones et al., 2003; Rosenzweig et al., 2014). However, for the execution of such measures for sustainable rice production, policy assistance to rice research and development to develop and transmit appropriate and efficient technologies will be essential (Ferrero & Nguyen, 2004; Venkateswarlu & Shankar, 2009).

9.4.3 Ecological Benefits of Rice Paddy Fields

The multitudes of the benefit of rice paddy fields, as ecosystem service provider, can be seen in the diagram (Fig. 9.8). Rain water is stored in the paddy fields or retained in the surface waters of lakes, marshes, etc. Paddy fields support groundwater replenishment, part of the rain water filters into the ground and recharges underground aquifers (groundwater reservoirs). It also helps in top soil retention—by slowing down the force of water, encouraging the deposition of sediments carried in the water and supports retention of nutrients and other substances in the soil. Ecosystem services provided by paddy fields include; groundwater recharge, production of non-rice foods, flood control, soil erosion and landslide prevention, climate change mitigation, water purification, helps in more evapotranspiration and formation of rain clouds, culture and landscape and support of ecosystems and biodiversity (Yosihiro, 2013). It assists in preserving agricultural biodiversity and the traditional aesthetics of the rice bowl's natural surroundings. The cultural landscape of Kerala includes paddy fields. Losing it would be equivalent to millions of Malayalis losing their minds and hearts because it is a big part of their nostalgia. In and around rice fields, wetlands species are used to efficiently remove fertilizers. The related insects, butterflies and bird fauna have plenty of room to grow and thrive here. It has been noted as a concern to the state's food security that the area, production and productivity of rice are dropping. However, due to population expansion, infrastructure development, etc., the study region is losing arable land every year. There is a need to promote good planning of cultivation at the village level because the main causes of altering agricultural land are determined to be rising cultivation costs, a labour scarcity, high input prices, etc. (Sekhara, 2019).

It is in the recent history that two major flood events happened in Kerala. In the year 2018, Kerala has experienced the largest disaster of flood and land slide after 1924. Kerala received heavy monsoon rainfall, which was about 256% more than the usual rain fall in Kerala, on the mid-evening of August 8, 2018, resulting in dams

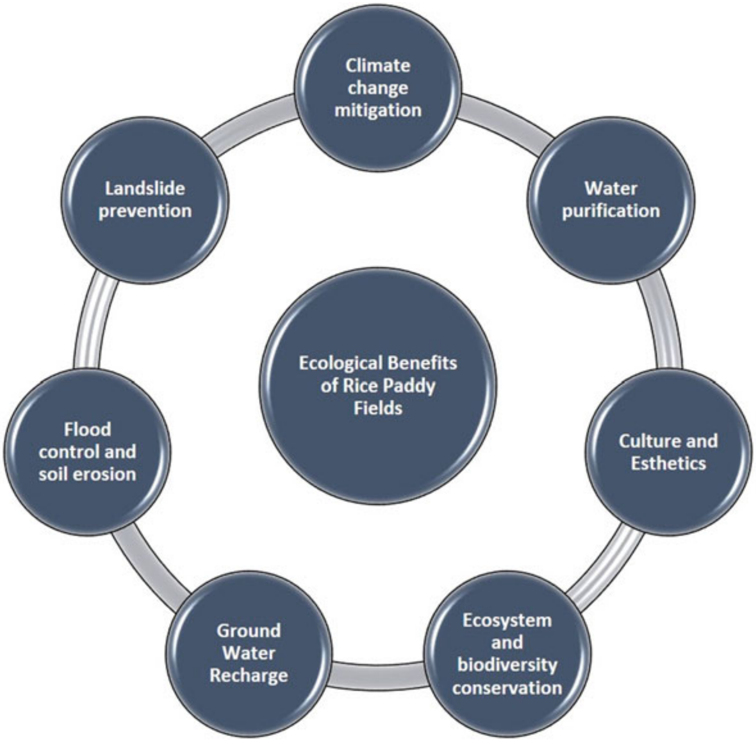


Fig. 9.8 Ecological benefits of rice paddy fields

filling to capacity; in the first 24 h of rainfall, the state received 310 mm (12 in.) of rain. Almost all dams in the district had been opened since the water level had risen above the maximum limit due to heavy rainfall, causing flooding in the low-lying areas. Due to water logging, major crops in the district have been negatively impacted. Harvest-ready rice standing crops was one of the worst hit.

Paddy wetlands act as a natural absorbent of flood water in the low-lying area. In recent times, most of the remaining paddy areas left as current fallow have been grabbed by real estate business and construction companies. Hence, there won't be any space for the infiltration and percolation water to go. Even then, there are discussions and arguments happening over Kerala to shift rice paddy fields to other commercial crop cultivation like tea, rubber, cardamom and black pepper plantations. Moreover, the demand–supply gap of rice in Kerala is widening at a faster rate, and it remains as a food deficit state, constantly depending upon neighbouring states for food grains. It should be noted that the neighbouring states are already water-scarce than Kerala, most of it are under the semi-arid category. Depending on these, semi-arid states for rice are not advisable as it will put pressure on their natural resources, especially groundwater for cultivation. Hence, sustainable rice cultivation must be followed for maintaining state's food security as Kerala receives a good amount of rainfall during both south-west monsoon season and north-east monsoon season.

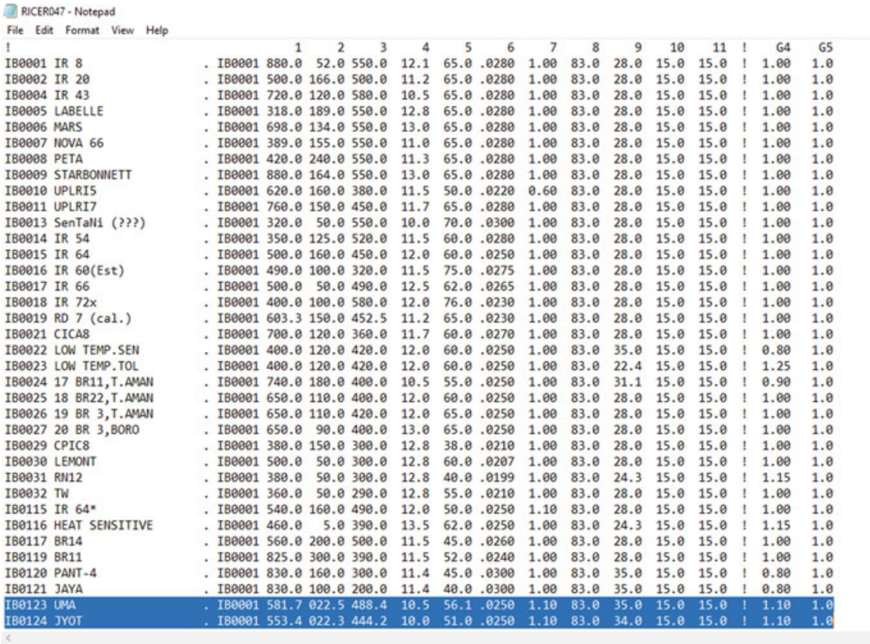
9.5 Conclusion

It can be concluded that the yield of the two major ruling rice varieties, Uma and Jyothi, may be reduced by − 14.4 and − 21.8%, respectively, by 2100 for Palakkad region. The productivity was found to be reduced by − 8% in the mid-century period for Uma variety and − 19.2% for the Jyothi variety if temperature increases by 2 °C. Under elevated CO_2 conditions, the yield reduction was minimized, but other physiological damages on quality may be assessed further. The variety, Uma performed comparatively better than Jyothy for Palakkad under a warming scenario. Lab to land transfer of temperature, drought and flood-tolerant seed varieties in the rice belts of Kerala is required to tackle climate change impacts and widening demand–supply gaps. However, the ecosystem services that the these rice paddy wetland provides in maintaining ecosystems and biodiversity, flood water control, surface and groundwater conservations and aesthetic value to Kerala are invaluable and cannot be measured only in terms of crop yield. It is essential to sensitize the farmers on this ground. Even though the water requirement in paddy cultivation is very high, the crop lands can increase water holding capacity of the catchment so that aquifers are recharged continually and flood flow is moderated. If government introduces strict policies and measures to regulate human activities, particularly non-agricultural activities in the vulnerable areas and spill areas/flood prone areas, so that human artefacts are not unduly exposed to flood vagaries, and excess river discharges are adequately accommodated and drained out. In recent years, there is stress on implementing nature-based flood protection measures or a hybrid of nature based and structural measures for flood management across the state; conserving paddy lands has multitudes of advantages. It may require planned nature-based and community-based efforts to improve the capacity of rice production systems to adapt to climate change as well as to mitigate the effects of rice production on global warming.

Acknowledgement The authors would like to thank Kerala State Higher Education Council, Government of Kerala for the research fellowship.

Annexure

See Fig. 9.9.



!			1	2	3	4	5	6	7	8	9	10	11	!	G4	G5
IB0001 IR 8	.	IB0001	880.0	52.0	550.0	12.1	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0002 IR 20	.	IB0001	500.0	166.0	500.0	11.2	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0004 IR 43	.	IB0001	720.0	120.0	580.0	10.5	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0005 LABELLE	.	IB0001	318.0	189.0	550.0	12.8	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0006 MARS	.	IB0001	698.0	134.0	550.0	13.0	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0007 NOVA 66	.	IB0001	389.0	155.0	550.0	11.0	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0008 PETA	.	IB0001	420.0	240.0	550.0	11.3	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0009 STARBONNETT	.	IB0001	880.0	164.0	550.0	13.0	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0010 UPLRI5	.	IB0001	620.0	160.0	380.0	11.5	50.0	.0220	0.60	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0011 UPLRI7	.	IB0001	760.0	150.0	450.0	11.7	65.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0013 SenTaNi (???)	.	IB0001	320.0	50.0	550.0	10.0	70.0	.0300	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0014 IR 54	.	IB0001	350.0	125.0	520.0	11.5	60.0	.0280	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0015 IR 64	.	IB0001	500.0	160.0	450.0	12.0	60.0	.0250	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0016 IR 60(Est)	.	IB0001	490.0	100.0	320.0	11.5	75.0	.0275	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0017 IR 66	.	IB0001	500.0	50.0	490.0	12.5	62.0	.0265	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0018 IR 72x	.	IB0001	400.0	100.0	580.0	12.0	76.0	.0230	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0019 RD 7 (cal.)	.	IB0001	603.3	150.0	452.5	11.2	65.0	.0230	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0021 CICA8	.	IB0001	700.0	120.0	360.0	11.7	60.0	.0270	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0022 LOW TEMP.SEN	.	IB0001	400.0	120.0	420.0	12.0	60.0	.0250	1.00	83.0	35.0	15.0	15.0	!	0.80	1.0
IB0023 LOW TEMP.TOL	.	IB0001	400.0	120.0	420.0	12.0	60.0	.0250	1.00	83.0	22.4	15.0	15.0	!	1.25	1.0
IB0024 17 BR11,T.AMAN	.	IB0001	740.0	180.0	400.0	10.5	55.0	.0250	1.00	83.0	31.1	15.0	15.0	!	0.90	1.0
IB0025 18 BR22,T.AMAN	.	IB0001	650.0	110.0	400.0	12.0	60.0	.0250	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0026 19 BR 3,T.AMAN	.	IB0001	650.0	110.0	420.0	12.0	65.0	.0250	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0027 20 BR 3,BORO	.	IB0001	650.0	90.0	400.0	13.0	65.0	.0250	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0029 CPIC8	.	IB0001	380.0	150.0	300.0	12.8	38.0	.0210	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0030 LEMONT	.	IB0001	500.0	50.0	300.0	12.8	60.0	.0207	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0031 RN12	.	IB0001	380.0	50.0	300.0	12.8	40.0	.0199	1.00	83.0	24.3	15.0	15.0	!	1.15	1.0
IB0032 TW	.	IB0001	360.0	50.0	290.0	12.8	55.0	.0210	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0115 IR 64*	.	IB0001	540.0	160.0	490.0	12.0	50.0	.0250	1.10	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0116 HEAT SENSITIVE	.	IB0001	460.0	5.0	390.0	13.5	62.0	.0250	1.00	83.0	24.3	15.0	15.0	!	1.15	1.0
IB0117 BR14	.	IB0001	560.0	200.0	500.0	11.5	45.0	.0260	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0119 BR11	.	IB0001	825.0	300.0	390.0	11.5	52.0	.0240	1.00	83.0	28.0	15.0	15.0	!	1.00	1.0
IB0120 PANT-4	.	IB0001	830.0	160.0	300.0	11.4	45.0	.0300	1.00	83.0	35.0	15.0	15.0	!	0.80	1.0
IB0121 JAYA	.	IB0001	830.0	100.0	200.0	11.4	40.0	.0300	1.00	83.0	35.0	15.0	15.0	!	0.80	1.0
IB0123 UMA	.	IB0001	581.7	022.5	488.4	10.5	56.1	.0250	1.10	83.0	35.0	15.0	15.0	!	1.10	1.0
IB0124 JYOT	.	IB0001	553.4	022.3	444.2	10.0	51.0	.0250	1.10	83.0	34.0	15.0	15.0	!	1.10	1.0

Fig. 9.9 Genetic coefficient details used for simulation

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Chapter 10
Crop Diversification: An Adaptive Option for Climate Change Resilience in West Bengal

Rukhsana

Abstract Climate change can have negative consequences for agricultural production resulting in increased vulnerability to agricultural systems. Crop diversification can improve resilience in agriculture through a variety of ways to suppress pest outbreaks and reduce pathogen transmission, by buffering crop production from the effects of future climate scenarios, as well as greater climate variability and extreme events. Such gains point to the clear value of adopting crop diversification to improve resilience, yet adoption of crop diversification has been seen slow. This paper examines the diversity of crop (HI) in context of climate change and vulnerability (IPCC) in a coastal state West Bengal of India. The study utilizes 16 selected variables obtained from secondary sources and estimates the climate vulnerability indices amongst all districts using exposure, sensitivity and adaptive capacity of IPCC (Climate Change 2014: Synthesis Report. IPCC, Geneva, Switzerland, 2007) method. The region of crop diversification (HI) was developed to detect diverse agricultural impacts. The districts have been ranked on the basis of IPCC vulnerability index where low rank number shows the most vulnerable district and high rank number indicates lowest vulnerability district. The vulnerability is varying from 0.0148 highest vulnerability in South 24 Parganas district with rank 1, 0.0022 lowest vulnerability in Howrah district with rank 18. District Howrah recorded for highest crop diversification (0.001) and lowest vulnerability (0.0022). It has been found that most vulnerable districts have medium crop diversification while low vulnerable districts reported for high cop diversification which indicates that crop diversification can be increased to reduce the vulnerability. Some districts in West Bengal have been cited as effective traditional systems of farming, lack of technology, average holding size and low diversification of per capita income. The expansion of crop diversification depends on improvement in production risk through technical assistance, quality input supply, insurance cover and the existence of modern storage-processing centres in the region. It is found that agricultural sector is gradually moving towards higher value crops in agro-climatic zone of West Bengal and its districts.

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Keywords Agro-climatic zone · Districts · Crop diversification · Climate change · IPCC vulnerability

10.1 Introduction

Climate change's increase in average global temperature has a negative impact on food security and agricultural production in addition to harming human health. Because the agricultural sector's output stability in the agricultural landscape depends on the availability of sufficient water for the development and strengthening of the process, it becomes the most unbalanced sector (Farina, 1998; Rukhsana et al., 2021a, 2021b). The growing threats posed by the climate to food, livelihood and agricultural security highlight the need for a transformational approach to sustainable development. Evidence showing how the agriculture sector is significantly impacted by changing weather circumstances, which is likely to rise in austerity, supports this (Campbell et al., 2016; IPCC 2013, 2014; Khanal & Mishra, 2017; Lobel et al. 2011; Rukhsana et al., 2021a, 2021b). Irregularities of weather and the sudden arrival of extreme weather like drought, flood, etc., outbreaks of pests and diseases affect crop productivity (Gornall et al., 2010; Rukhsana et al., 2021a, 2021b), soil productivity (Tang et al., 2008), water quality, moisture content and resources (Malek et al., 2018; Misra, 2014). Rapid urbanization, reckless land use and deforestation are factors in the urban revolution phase that cause climate change brought on by humans (Abu Hatab et al., 2019).

Resilience is explained as the tendency of a system to maintain its organizational structure and productivity after a disturbance (Holling, 1973). Thus, a resilient agricultural system will continue to give an important service such as food production when challenged by severe drought or major deficits in rainfall (Heal, 2000). Agricultural systems require that practice in conjunction with adaptation and mitigation to reduce climate risk (Campbell et al., 2016). Adaptation is increasingly considered as a key component of the response to climate change and was shown to reduce vulnerability or increase resilience in response to observed or expected changes in climate and associated extreme weather impacts (Brooks & Adgar, 2005). Smithers and Smit (1997) defined adaptation as "a change in a system in response to some force or disturbance in our case related to climate".

Around 800 million people are still suffering from chronic hunger worldwide despite significant improvements and advances in efforts to promote food security. This problem is particularly severe in developing countries (FAO, 2015). Crop diversification offers several advantages, particularly for small farmers who can enhance their income, reduce poverty, create jobs, make wise use of land and water resources, adopt sustainable farming methods and improve the environment. Crop diversification is frequently necessary to replenish the natural resource base that has been exhausted or to improve the natural resources. It is a frequent belief that cropping systems have changed, or new ones have been implemented in order to preserve or raise the value of natural resources. Additionally, it has been noted that the pattern of diversification stabilizes agricultural income at higher levels, allowing for the inclusion of new and more lucrative crops (Saleth & Maria, 1995). The number of crops that can be grown is directly determined by the spatial variation of the crops, which is related to one another by the essential scientific method known as crop diversification. It focuses on a shift from low-value to high-value agriculture and is a significant method of raising agricultural output. Where there is a higher level of agricultural technology and a lower degree of diversification, the physical and socioeconomic factors of the region play a crucial role in regulating crop diversification (Dutta, 2012; Raju, 2012; Rukhsana et al., 2021a). Farmers and the environment can benefit from a variety of agricultural systems that improve agricultural losses due to pests and other risks, have favourable effects on ecosystem performance and provide considerable services for agriculture (Bommarco et al., 2013; Chaplin-Kramer et al., 2011; Gardiner et al., 2009), Agricultural diversification found to be increased for climate change (Altieri, 1999; McCord et al., 2015; Rukhsana, 2021) and reduced risk of farmers related with climatic factors (Bradshaw et al., 2004; Lin, 2011). Diversified agriculture increased to soil stability and household income (Abson et al., 2013; Barrett et al., 2001; Bigsten & Tengstam, 1970; Demissie & Legesse, 2013; Makate et al., 2016; Mhango et al., 2013; Njeru, 2016). This paper examines the diversity of crop or specialization at the district level and agro-based zone of West Bengal and to know the association between crop diversification and climate change in selected zone of west Bengal.

The study will focus on the eastern Indian state of West Bengal, which shares international borders with Bangladesh and Nepal and is located between 27°13′15″ and 21°25′24″ north latitude and 85°48′20″ and 89°53′04″ east longitude. West Bengal is divided into 341 development blocks and 66 sub-divisions in 19 districts (Fig. 10.1). Since the pre-independence period in West Bengal, the variation in crop pattern is a very recent phenomenon apart from the tea case of the crop harvest. Rice is a dominating crop in West which achieved at a very high productivity in paddy cultivation during the eighties and nineties. Crop diversification considered as a way to increase the contribution to the production ratio of non-rice crops in order to found the higher agricultural growth rates in future. Apart from boosting development, it is felt that diversification can also contribute to higher nutrition levels, poverty alleviation, employment generation and sustainable natural resource management.

Data base and Methodology: The Bureau of Applied Economics and Statistics, Government of West Bengal, publishes the Statistical Abstract and Economic Review of West Bengal, on which the current study is based. The literature contains a variety of techniques for determining the degree of diversification. The degree of crop diversification was measured statistically using a variety of techniques, such as maximum ratios, the Simpson index, the entropy index, the modified entropy index, the composite entropy index, the give index and the Herfindalh-Hirschman index, among others. These indexes have been employed in the work of Kumar et al. (2012), Benin et al. (2004), Chand (1996) and Pandey and Sharma (1996). Each of these tools has unique benefits and restrictions regarding the amount of data needed

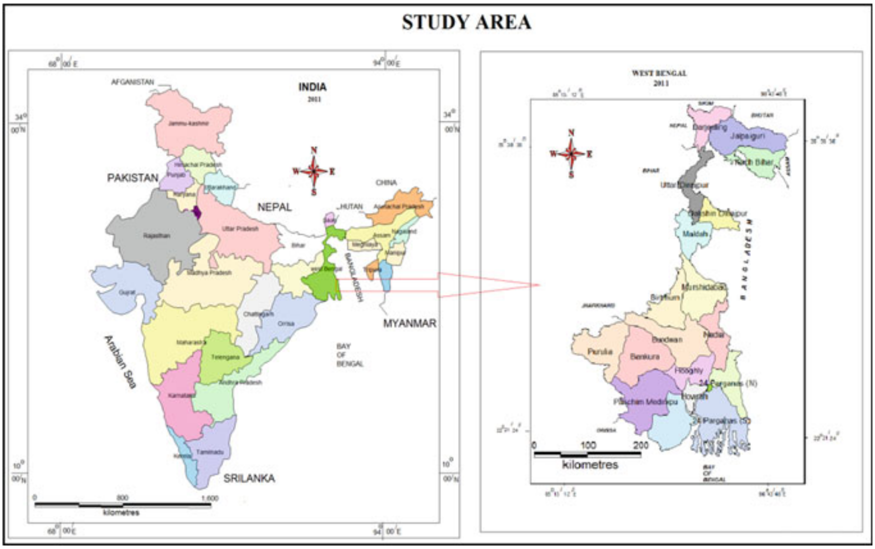

Fig. 10.1 Location map of West Bengal

and the simplicity of calculation and interpretation. Additionally, results obtained through these methods are more or less the same.

For the purpose of figuring out crop diversification for particular crops of interest, the crop diversification (CDI) index has been calculated. The Herfindalh index (HI) is subtracted from one to obtain the CDI. A CDI value of zero indicates specialization whereas a value greater than zero indicates agricultural diversity. The CDI is a measure of concentration and has a direct relationship to diversification. As a result, it is simpler to spot farmers who use crop diversification techniques. The research region's crop diversification area has been enhanced using the heritage index algorithm. The Herfindalh index, which is provided below, is calculated by adding the squares representing the acreage proportion of each crop in the total area planted. Mathematically, the index is given as below.

$$\text{“Herfindalh Index (HI)} = \sum_{i-1}^{N} P_i^{2}\text{”}$$

where N represents the total number of crops and P_i is area proportion of the i-th crop in total cropped area. With the increase in diversification, the Herfindalh index would decrease. This index takes a value one when there is complete concentration and approaches zero when diversification is perfect. Thus the Herfindalh index is bounded by zero and one.

Vulnerability LVI-IPCC: The present study measures the vulnerability amongst all districts of West Bengal and used the 16 selected variables taken from secondary sources and computed the vulnerability indices amongst all districts using exposure, sensitivity and adaptive capacity of IPCC (2007).

Normalization of indicators: Due to the varied scales of all the sub-components, data have first been normalized. The formula has been used to convert variables based on the Human Development Index, which was used to calculate the life expectancy index, which is the ratio of the difference between the actual life expectancy and a minimum that has been chosen in advance, as well as the range between the maximum and minimum life expectancy that has been decided upon in advance (UNDP, 2007).

Without normalization, several parameters cannot be combined to create a standard value for composite indicators. In order to normalize indicator values of exposure, sensitivity and adaptive ability that fall between the 0 and 1 scale of standard values, UNDP (2016) technique for the computation of the Human Development Index is followed. Utilizing normalized indices, functional correlations between parameters and susceptibility were discovered, showing that vulnerability rises (falls) with indicator value. For this purpose, the normalization is done using Eqs. 10.1 and 10.2 (UNDP 2006).

Few indicators indicate positive association with vulnerability and rest negative relationship with vulnerability.

$$\text{index}_{X_{ij}} = \frac{X_{ij} - \text{Min}\{Xij\}}{\text{Max}\{Xij\} - \text{Min}\{Xij\}} \tag{10.1}$$

The functional relationship is expected to be positive relationship with vulnerability has been used Eq. 10.1, and for negative relationship that vulnerability will decrease with increase in the values of indicators used Eq. 10.2.

$$\text{index}_{X_{ij}} = \frac{\text{Min}\{Xij\} - X_{ij}}{\text{Max}\{Xij\} - \text{Min}\{Xij\}} \tag{10.2}$$

where X_{ij} is the original sub-component for district, and Xij_{min} and Xij_{max} are the minimum and maximum values, respectively, for each sub-component determined using data from all districts.

Intergovernmental Panel on Climate Change (IPCC) was developed the Livelihood Vulnerability Index method in the context of climate change on the basis of adaptive capacity, exposure and sensitivity (IPCC, 2007).

Assigning weights to indicators: After calculating the normalized data, the index is created by giving weight. Components have been weighted using (Gebreegziabher et al., 2018) unequal method of Iyengar and Sudarshan (1982) which is statistically sound and well suitable to construct the composite index of vulnerability to climate change as developed by Feyissa et al. (2018). The choice of weights in this way will also ensure that large changes in one indicator do not overwhelm the contributions of other indicators and distort inter-regional comparisons (Iyengar & Sudarshan, 1982). From Iyengar and Sudarshan's method, the weights are summed to vary contrariwise as the variance over the regions in the respective vulnerability indicators, i.e., the weight W_j determined using Eq. 10.3.

$$W_j = K/\sqrt{\mathrm{Var}_{i(Xij)}} \tag{10.3}$$

where K is a normalizing constant and computed using Eq. 10.4.

$$K = \left[\frac{1}{\sum_{j=1}^{j=m} \frac{1}{\sqrt{\mathrm{Var}_{i(Xij)}}}} \right] \tag{10.4}$$

The calculated weights were used to construct component index.

After normalized and weights assigning, the sub-components were averaged using Eq. (10.5) to calculate the value of each major component:

$$M_d = \frac{\sum_{i=1}^{n} \mathrm{index}_{sdi}}{n} \tag{10.5}$$

where M_d = one of the major components for district d and index_{sdi}, i represents the sub-components, indexed by i, that make up each major component and n is the number of sub-components in each major component.

Once values for each of the all-major components for a district were calculated, they were averaged using Eq. (10.6) to obtain the district-level LVI:

$$\mathrm{VI}_d = \frac{\sum_{i=1}^{n} w_{Mi} \; M_{di}}{\sum_{i=1}^{n} w_{Mi}} \tag{10.6}$$

$$\mathrm{VI} = \frac{\text{Exposure} + \text{Sensitivity} + \text{Adaptive Capacity}}{3}$$

$$\mathrm{LVI} = \mathrm{IPCC}_d = (\text{Exposure} - \text{Adaptive capacity}) * \text{Sensitivity} \tag{10.7}$$

where VI_d the “Vulnerability Index for district d, equals the weighted average of the major components. The weights of each major component, w_{Mi}, are determined by the number of sub-components that make up each major component and are included to ensure that all sub-components contribute equally to the overall LVI (Sullivan et al., 2002). In this study, the LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable)”. Finally, vulnerability index for each district has been calculated as an unweighted average of three components. Based on the index scores, districts were ranked in descending order where districts with higher scores indicate greater food security (Table 10.1).

Table 10.1 Selected components and functional relationship with vulnerability

Components of vulnerability	District-wise sub-indicators			Source
Exposure	E1	Average max temperature	(+)	Meteorological Department, Government of India (2011)
	E2	Average min temperature	(+)	Meteorological Department, Government of India (2011)
	E3	Average rainfall (mm)	(+)	Agricultural Meteorologist, Directorate of Agriculture, Government of W.B. (2011)
Sensitivity	S1	Population density (persons per sq. km)	(+)	Census of India, 2011
	S2	Food grains production in thousand tonnes	(−)	Director of Agriculture and Government of West Bengal, Statistical Abstract, 2015
	S3	Cropping intensity	(−)	Director of Agriculture and Government of West Bengal, Statistical Abstract, 2015
	S4	Main cultivators (%)	(−)	Census of India, 2011
	S5	Net sown area in thousand hectares	(−)	Director of Agriculture and Government of West Bengal, Statistical Abstract, 2015
	S6	No. of small farmers (in person)	(+)	Agricultural Census, Directorate of Agriculture, Government of W.B. (2011)
	S7	Main agricultural population (in person)	(+)	Office of the Director of Census Operation, West Bengal
Adaptive capacity	A1	Literacy rate (% of total population)	(−)	Census of India, 2011
	A2	Total no. of livestock (per sq. km.)	(+)	Dy. Director of Animal Resources and Development Parishad Office (2011); 18th All India Live-stock Census, 2007
	A3	% of average farm size	(−)	Agricultural Census, W.B., District Statistical Handbook, 2013

(continued)

Table 10.1 (continued)

Components of vulnerability	District-wise sub-indicators			Source
	A4	% of PCI (at constant price 2001–02)	(−)	Bureau of Applied Economics and Statistics, Government of West Bengal
	A5	Length of roads (in km)	(−)	Public Works (Roads) Department, Government of West Bengal (2010)
	A6	AAY (ration card holder person) in reference to show people live below poverty line (% of total population)	(+)	Department of Food and Supplies, Government of West Bengal

10.2 Result and Discussions

West Bengal's economy is mostly dependent on agriculture, which employs roughly 39% of the total labour force and accounts for 12% (2004–05) of the Gross State Domestic Product at constant prices (Census of India, 2011; Statistical Abstract, 2015). Small and marginal farmers (95.4%) account for the majority of the landowners in West Bengal's agriculture sector and only hold 0.07 ha of land per person (State of Environment Report, West Bengal, 2016).

Based on climatic characteristics, soil structure, texture, type, topography in relation to ground water availability, etc., West Bengal is categorized into 6 agro-climatic zones, including hill zone, terai zone, old alluvial zone, new alluvial zone, red lateritic zone and coastal saline zone. Amongst these, stressed areas include the highland region, the terai region, the red lateritic region and the coastal saline region (State Environment Report, West Bengal, 2016). West Bengal is the world's top producer of rice, potatoes, vegetables, fish and meat. It also plays a significant role in the production of pineapple, litchi, mango, mandarin oranges and flowers. It meets around 33% of India's need for potatoes and 66% of its demand for jute (Economic Review 17–18). Different food products are grown in various agro-meteorological zones and are impacted to diverse degrees by variations in weather conditions. Given the state's significant land availability constraints, West Bengal has India's highest cultivation intensity (185%). The soil and water resources are severely stressed by the high agricultural intensity. However, other advantages including abundant surface and groundwater resources, fertile alluvial belts, regular and healthy rainfall and strong irrigation infrastructure have made it possible for the state to play a crucial role in ensuring the nation's food security.

Variability of Crops Diversification and Climate Change in Agro-climatic Zones of West Bengal: Six agro-climatic zones exist in Bengal, including the hill zone, terai zone, old and new alluvial zones, red and laterite zones and coastal and salinity zones. Details about these zones, their locations, physiography and climate are provided in Table 10.2. The red and laterite zone of West Bengal experiences temperatures ranging from a minimum of 1100 mm to a maximum of 3500 mm, with the hilly region seeing temperatures as low as 8.4 °C and the red and laterite zone as high as 37 °C.

According to an analysis of the Indian Meteorological Department (IMD) data (during 1951–2010), the annual mean maximum temperature (+ 0.01 °C per year) taken from 19 surface meteorological stations in West Bengal shows an increasing trend. However, there is no annual trend in annual mean and annual mean minimum temperature, whereas seasonal trends were observed (Rathore et al., 2013). The West Bengal SAPCC State Action Plan on Climate Change (2012) proposed adaptation strategies for agriculture. The Government of India directed all States and Union Territories to prepare State Action Plans on Climate Change (SAPCC) in 2009, which would be relevant with the strategy outlined in the National Action Plan on Climate Change (NAPCC). West Bengal agriculture is highly susceptible to climate change due to its geographical exposure like coastline, Himalayan areas and its drier districts as well as its socioeconomy sympathy. Zone-wise descriptions of the potential climatic changes impact on the sector given in Table 10.3, based on its analysis, the SAPCC 2012 provided an elaborate list of adaptation strategies. Many of these strategies have been implemented by the agriculture department and the Economic Review 2016–17 advised that following measures were accentuated: Diversified Cropping programme (52, 53 Economic Review 2016–17 and 2017–18) Farm Mechanaization (Economic Review 2016–17 and 2017–18), Conservation of Soil Moisture (56 Economic Review 2016–17), Enhanced Water Harvesting (57 Economic Review 2016–17) and Extensive training and Capacity Building to control climate change and betterment for agriculture sector. Table 10.3 shows the description of potential climate change impact and crop diversification in Agro-climatic Zone of West Bengal; it shows the significantly move of crop diversification (Table 10.3). The sample mean of the Herfindahl index was counted as the highest in hill zone (0.04), terai zone (0.04) and coastal zone (0.04), due to highly climatic challenge, small farmers slowly moving towards diversity of crop to uplift their income.

District-wise crop diversification and climate vulnerability in West Bengal: Using the Herfindahl index method of crop diversity, West Bengal has been categorized into five groups (very high, high, medium, low, and very low crop diversified regions). The spatial structure of crop diversification at the district level in West Bengal is depicted in Fig. 10.2 and Table 10.4, which reveals that only three districts experienced significantly higher levels of diversity in terms of agricultural practises during the 2012–2013 period. The highest Herfindahl index was 0.057, which was the sample mean of the Herfindahl index. Contrarily, West Bengal's northern parts are where crop diversification is most prevalent. Howrah (0.001) is the district with the highest level of diversity, followed by Dakshin Dinajpur (0.01), Birbhum (0.01) and Cooch Behar (0.01). (0.01).

Table 10.2 Distribution and description of agro-climatic zones of West Bengal

Agro-climatic zones	Hill region (2.4–8 lakh ha)	Terai zone (2.15 ha)	Old alluvial zone (17.54 ha)	New alluvial zone (15.30 ha)	Red laterite zone alluvial zone (24.84)	Saline coastal region (14.57 ha)
Districts name	Hilly areas of Darjeeling	Remaining area of Darjeeling district, Cooch Bihar and Jalpaiguri, Kalimpong and Alipurduar	North Dinajpur, South, Dinajpur and Malda	Murshidabad, Nadia, 24 N. Parganas, Haora, Hooghly and Burdwan	Birbhum, Bankura, Puruliya, West Medinipur	East Medinipur, Hooghly, 24 South, Parganas, Kolkata
Description and GSM weather station	Terraced, brown forest, shallow, highly acidic (pH 4–6), moderately fertile soil Temperature range: 8.9–14.9 °C Annual rainfall: 3550 mm	Sandy to Sandy loam soil Temperature range: 12.8–32.3 °C Annual rainfall: 2000–3500 mm	Old alluvial zone Mostly flat, Loam, deep, mostly neutral soil Temperature range: 15.1 to 35.3 °C Annual rainfall: 1600–1800 mm	Flat to rolling, Light to heavy, acidic to neutral (pH 5.7) soil Temperature range: 15.6–35 °C Annual rainfall: 1200–1700 mm	Undulating, coarse textured, susceptible to erosion, acidic soil Temperature range: 14.8–37 °C Annual rainfall: 1100–1300 mm	Alluvial, fine textured, saline soil Temperature range: 16–34 °C Annual rainfall: 1500–1700 mm

Source Prepared by author detail obtained from http://www.environmentwb.gov.in/pdf/WBSAPCC_2017_20.pdf

Table 10.3 Agro-climatic zone-wise potential climate change impact and crop diversification in West Bengal

Agro-climatic zone	Main crops	Potential climate change impact description	Crop diversification index 2012–2013
Hill zone	Maize, rice, potato, vegetables, soybean cardamom, ginger, orange, medicinal plants, tea, etc.	Due to rise of temperature and increase in runoff from rainfall leads to erosion and landslides Increase in extended drought periods leads to decrease the productivity of Darjeeling tea High winter temperature Effects on potato and wheat farming and degrade the quality of seed	0.04
Terai zone	Rice, jute, tea, potato, pulses, oilseeds pineapple etc.	long winter period favourable to wheat farming in this area, but increase Winter temperatures reduced wheat yields and destroyed seed quality in the region	0.04
Old alluvial zone	Rice, wheat, maize, jute, groundnut, linseed, mustard, lentil, sesame, vegetables, pigeon pea, black gram, green gram, etc.	In this zone, extensive use of water for irrigation reduced to surface run off and dries to natural water bodies Productivity of rice crop would be at risk due to water strain in future and wheat productivity declined due to short winters, Excess temperature 45–46 °C in summers effects on the productivity of oilseeds, pulses and also livestock	0.06

(continued)

In West Bengal, locations particularly vulnerable to cyclones include the districts of East South 24 Parganas, North 24 Parganas, Midnapore, Howrah, and Hooghly. On the other hand, places that are designated as being drought prone include districts like Bankura, Purulia, Birbhum and portions of Paschim Midnapore. This is mostly because of inadequate rainfall and a poor soil structure. Malda, Murshidabad, North

Table 10.3 (continued)

Agro-climatic zone	Main crops	Potential climate change impact description	Crop diversification index 2012–2013
New alluvial zone	Rice, wheat, maize, jute, groundnut, linseed, mustard, lentil, sesame, vegetables, pigeon pea, black gram, green gram, rapeseed, Niger, etc.	This area experienced of low water availability water which decreased the boro rice production and Jut production which requires humid climate with temperature fluctuating between 24–38 °C. Increase in temperature impact the productivity of jute New grey alluvial soils receiving good depth siltation from annual floods are best suited for the growth of jute, any increase in rainfall intensity in this region can remove alluvial silt deposits which affect jute productivity Yield of potato reduced due to augmenting of winter temperature	0.07
Red lateritic zone	Rice, maize, millets, pulses vegetables, safflower, mustard, Niger, toria, potato, vetiver, sesame, sabai, etc.	The rainfall in this region is naturally less because compared to other agro-climatic regions West Bengal is further declining, maximum and minimum temperatures are also increasing 27% of the agricultural land area is irrigated, agriculture is mainly dependent on rainfall. The quality of the soil and its nutrients is reduced	0.08

(continued)

and South Dinajpur, South 24 Parganas, Howrah and Hooghly are some of the flood-prone areas as well as the Darjeeling and portion of the Jalpaiguri districts that are most susceptible to landslides. The variables of vulnerability along with their functional relationship has been explained in Table 10.1. The district-wise vulnerability indices of West Bengal along with the crop diversification districts are shown in Table

Table 10.3 (continued)

Agro-climatic zone	Main crops	Potential climate change impact description	Crop diversification index 2012–2013
Coastal saline zone	Rice, chilli, vegetables, sunflower, sesame, *Lathyrus* watermelon, etc.	Infiltration of saline water in agricultural land resulting in reduced the yield and more risk to the farmer. After Aila, salinity increased in soil tested up to 40 km from Kolkata • Increasing the natural salinity of the soil due to frequent infiltration of seawater; resulting in loss of agricultural land and people are migrating to others place • Prolonged summer has increased the attack of insects and pests on crops and delayed winter has weakened the cultivation of winter crops	0.04

Sources
1. Principles of Agronomy, Yellamanda Reddy & Sankara Reddi (2010). Kalyani publishers, Ludhiana
2. NARP status reports for different Agro-climatic Zones (1991). Bidhan Chandra Krishi Viswavidyalaya
3. Sahaj & Nayban (2008). Ananda Agency, Kolkata
4. State of Environment Report, West Bengal (2016), West Bengal Pollution Control Board
5. CD compiled by Author, Calculation is based on data from Statistical Handbook West Bengal (2012–13) published by Bureau of Applied Economics and Statistics Department, Kolkata, West Bengal Office of the Directorate of Agriculture, Government of West Bengal Average from Table

10.4. The districts have been ranked on the basis of IPCC vulnerability index where rank 1 shows most vulnerable district and rank 18 indicates lowest vulnerability district. It has been found that the vulnerability is varying from 0.0148 highest vulnerability in South 24 Parganas district, 0.0022 lowest vulnerability in Howrah district. South 24 Parganas is the most vulnerable district, ranks first followed by the district Murshidabad, North 24 Parganas, Malda, Uttar Dinajpur and so on while crop diversification found medium in these districts (Table 10.4). Low vulnerability districts have highest agriculture diversification like Howrah, Purba Medinipur, Birbhum and Darjeeling. It indicates that crop diversification can be augmented to reduce the vulnerability in lowest districts of crop diversification. As a result, it was noted that over the aforementioned era in the State of West Bengal, areas like Birbhum and Uttar Dinajpur had significantly improved in terms of crop diversity. In the districts

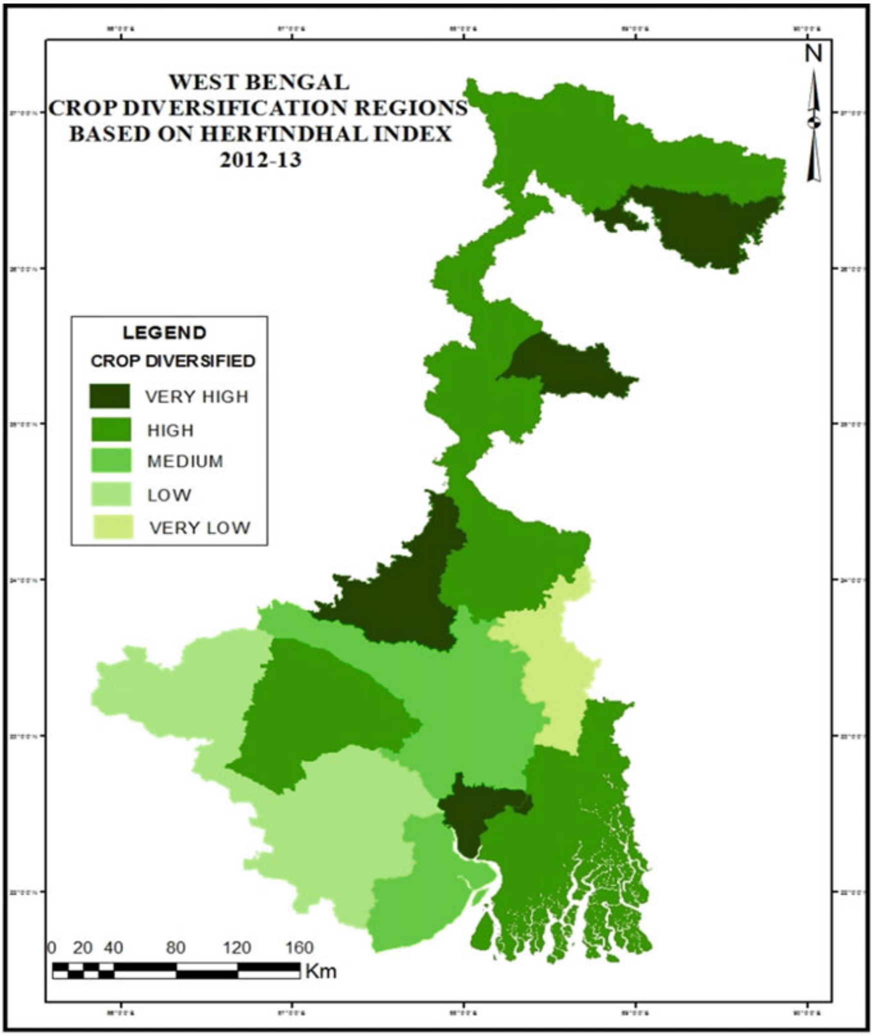

Fig. 10.2 Crop diversification in West Bengal

of Hoogly (0.08), Burdwan (0.08) and Purba Mednipur (0.08), there has been a slight diversification (Fig. 10.2; Table 10.4). Due to improvements in irrigation infrastructure, adjustments to institutional holding sizes and increased market accessibility, these districts made substantial advancements in the agriculture sector overall and in the diversification of crops in particular during the 2012–2013 period. In red laterite zone, where there is naturally less rainfall than in other agro-climatic regions, zone-wise was shown to have the lowest diversification (0.08). West Bengal is further declining; maximum and minimum temperatures are also increasing. 27% of the

Table 10.4 Crops diversity in West Bengal at district level

S.No.	Name of the district	Crop diversification, 2012–13	IPCC-VI, vulnerability, 2011–12	Rank of IPCC-VI, vulnerability
1	Burdwan	0.06	0.0101	6
2	Cooch Behar	0.01	0.0094	7
3	South 24 Parganas	0.03	0.0148	1
4	North 24 Parganas	0.02	0.0124	3
5	Bankura	0.02	0.0089	9
6	Dakshin Dinajpur	0.01	0.0085	12
7	Darjeeling	0.04	0.0082	15
8	Howrah	0.001	0.0022	18
9	Malda	0.03	0.0109	4
10	Hoogly	0.08	0.0091	8
11	Jalpaiguri	0.03	0.0084	13
12	Murshidabad	0.03	0.0131	2
13	Nadia	0.25	0.0086	10
14	Paschim Medinipur	0.17	0.0086	11
15	Purba Medinipur	0.08	0.0060	17
16	Uttar Dinajpur	0.02	0.0101	5
17	Purulia	0.13	0.0083	14
18	Birbhum	0.01	0.0074	16
Total average		0.057	0.0092	

Source Compiled by Author, Calculation is based on data from Statistical Handbook West Bengal (2012) published by Bureau of Applied Economics and Statistics Department, Kolkata, W.B Office of the Directorate of Agriculture, source for IPCC-vulnerability (Table 10.3)

agricultural land area is irrigated; agriculture is mainly dependent on rainfall. The quality of the soil and its nutrients is reduced.

10.3 Conclusion

West Bengal agriculture is highly susceptible to climate change due to its geographical exposure like coastline, Himalayan areas and its drier districts as well as its socioeconomy sympathy. A diversified crop management policy can be promoted if farmers have a better idea of adopting diverse techniques to maximize production and profits under the climate change. This study shows that the northern parts of West Bengal such as Darjeeling, Jalpaiguri, Cooch Behar, Dakhin Dinajpur, Uttar Dinajpur, Burdwan and Malda have made tremendous progress in the period of crop diversity in the state of West Bengal during the study period. Cooch Behar district, which is counted for much diversification in terms of agriculture due to the population of the district, is dominated only by agribusiness. The highest temperature is favourable and strongly relates to the vulnerability. Additionally, it is noted that the major cultivators and cropping intensity are both positive and significant, demonstrating how these factors positively influence vulnerability. It has been reported from the above analysis that South 24 Parganas is the most vulnerable district, ranks first followed by the district Murshidabad, North 24 Parganas, Malda, Uttar Dinajpur and so on while crop diversification found medium in these districts. On the other hand, low vulnerability districts have highest agriculture diversification like Howrah, Purba Medinipur, Birbhum and Darjeeling which shows that crop diversification can be increased to minimize the vulnerability in low crop diversification regions. Interesting result found that district Howrah recorded for highest crop diversification (0.001) and lowest vulnerability (0.0022). Therefore, it has been safely declared that, most of the districts of West Bengal are trying to move towards diversification of crops, and some of them have made significant progress in this area. At the same time, there are also districts in the state of West Bengal that are trying to advance along with crop specialization. However, there is spatial variation in crop concentration which is the result of various physiological, hydrological, pedological and socioeconomic factors.

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Part IV
Farmers Perceptions of Climate Change and Adaptation Strategy

Chapter 11
Unraveling the Interplay Between Indian Agricultural Sector, Food Security, and Farms Bill: Key to Sustainable Development Goals

Rashmi Rai and K. Lakshmypriya

Abstract Agriculture, along with its allied sectors, plays a significant role in the economic progress and expansion of any country; despite tremendous economic progress, India's agriculture sector is in jeopardy for various reasons. Agriculture in rural areas has been the primary source of income for the poor. With the growing susceptibility, policymakers' main problems are to design ways to promote sustainable agriculture to achieve the Sustainable Development Goals (SDGs). The Sustainable Development Goals emphasize the relevance of agriculture and the need to revitalize agribusiness worldwide by aiding farmers, increasing investments in research, technology, and market infrastructure, and increasing knowledge sharing. It may lead to spur innovation and give farmers more power. One of the essential advantages of urban agriculture is its potential to boost social capital and civic participation in low-income neighborhoods. As a result, the most critical goal in agricultural development for food security should be to raise productivity and diversify food production. Diversification of crops should be encouraged among farmers. This would aid in the fight against starvation, but it would also assist in preventing biodiversity loss and strengthen farmer resilience. Hence, our Chapter attempts to analyze the poor food security and what strategies will contribute to the SDG goals to reduce hunger in India as well worldwide. It elucidates a variety of obstacles and opportunities for successful, sustainable, and resilient agriculture. It also covers topics such as the recent agricultural bill and its long-term implications for our growth and a few important takeaways that could help us get closer to our objectives, mainly through the application of technology.

Keywords Agriculture · Legislation · Food security · Inclusion · Sustainability

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11.1 Introduction

Indian farmers are the backbone of our country's economy since the Indian economy has been dependent on primary agriculture, and Indian farmers have made substantial contributions to the economy. Still, somehow they have been neglected for years. With increased susceptibility, policymakers' main problems are to design policies to promote sustainable agriculture to achieve the SDGs. In this context, it is critical to guarantee that current efforts are redirected toward increasing the efficiency and efficacy of various projects to produce a blueprint for establishing a sustainable model that the developing countries can emulate. By 2050, global population growth and rising income may have increased food demand by 50%. Our planetary borders, on the other hand, are already reaching their limitations. Land and freshwater resources, which are the foundation of our food production, are under severe strain. At the same time, seas, forests, and other ecosystems are being degraded at a rate never seen before. Conflicts for resources and the destructive impact of climate change threaten to plunge millions of more people into abject poverty and starvation. And, as is customary, the world's poorest suffer the most.

More than 20 million people in countries like Yemen, Northern Nigeria, South Sudan, and Somalia desperately need food assistance (The Importance of Agriculture for Meeting the SDGs—Kofi Annan, 2017). The implementation of the Sustainable Development Goals (SDGs) by the United Nations in 2015 led to broad recognition of agriculture's indispensable role in ensuring socioeconomic progress. It is one sector that provides and sustains the livelihood of 40% of the world's population. Agriculture corresponds to goal two of (SDG), which intends to eradicate hunger. However, to varying degrees, the agriculture sector has a vital role in goals 12, 13, 14, and 15 that deals with responsible consumption and production, climate action, and conserving aquatic and terrestrial life. Goal 5, which strives to increase women's land rights to ownership, also prioritizes agriculture. As a result, this sector is vital to achieving the SDGs under the 2030 Agenda for Sustainable Development. This Chapter is structured in four parts which mainly discusses the current scenario of agriculture in India; the second part elaborates on the challenges of food security to attain sustainable goals; the third part ponders over the recent farm's bill that was introduced and its implications on the future agricultural sector, and fourth part conclude on the key takeaways that can implement to mitigate the challenges.

11.1.1 Agricultural Scenarios in India

Agriculture is an essential source of living for humans because almost 50% of India's population is dependent on it. Rs 19.48 lakh crore is the estimated Gross Value Added (GVA) assigned by the agriculture, trawling, and forest-ranging department in the Financial Year 2020. The advancement of GVA in cultivation and allied sectors settled at 4% in FY20.

The Food Corporation of India is ready to consider gigantic development, expanding the commitment they made to the global exchange of food every year because of the massive capability for expansion, especially inside the food preparation industry. Indian Cuisine and the staple merchandise are ranked as the 6th most significant one, with trade imparting 70% of the pacts. The Indian food production constitutes 32 percent of its cuisine market, probably India's most prominent business. It holds 5th place due to the establishment, exertion, commerce, and anticipated growth.

Market Size

- Our country is focusing on enhancement in the production of grain by creating 298 million tons by 2020–21. Nevertheless, currently, our nation could only reach a target of 295.67 million tons.
- According to second propel gauges, growing crops in India were evaluated at a track record of 320.48 million metric tons by 2020 (India and Reports, 2020). India has the most significant domesticated animal community of almost 535.78 million, contributing to thirty-one percent. During the current fiscal year, the output of manufactured dairy products is expected to increase by 10% to INR 283,000 crore (USD 37.58 billion) (April 2020–March 2021).
- Maltose creation in the country has arrived at 26.46 metric tons between September 2019 and June 2020 as per India's sugar plant collaboration.
- The Indian natural cuisine section is relied upon for developing the Compound Annual Growth Rate of ten percent during 2014–2024 and mainly assessed by Klerkx et al. (2019), arriving at a total estimate of 74,000 crores by 2024, ranging from 2699 crore in 2015, which is close to 386.31 million dollars.
- Most seasoned huge scope manure producers crossed 10 lakh creations and deals marked by March 2020.
- Eight thousand four hundred crore contemplations, approximated to 1.18 billion U.S. dollars, are reported for involvement in alcohol creation.
- As the manufacturing hub, Gujarat will contribute to around Rs 650 crore in developing its 9th plant by settle India.
- The Agricultural Research Council and The Veterinary Research Institute drew two indicative units concerning the Japanese Encephalitis LGM ELISA dispatched in October 2019 (Fig. 11.1).

Although monetary value added to the GDP has increased from 74 billion USD in 1991 to 459 billion USD in 2019, the agriculture industry's GDP percentage has dropped by 11% from 1991 to 2019 and only contributes 16% presently. With the integration and transforming force of Industry 4.0, Indian agriculture can move toward sustainable agricultural processes that ensure minimal land degradation and optimum utilization of factors of production. In the following sections, the current scenario and trends in Indian agriculture are discussed. The technological innovations brought by Industry 4.0 for the agricultural process are also explained.

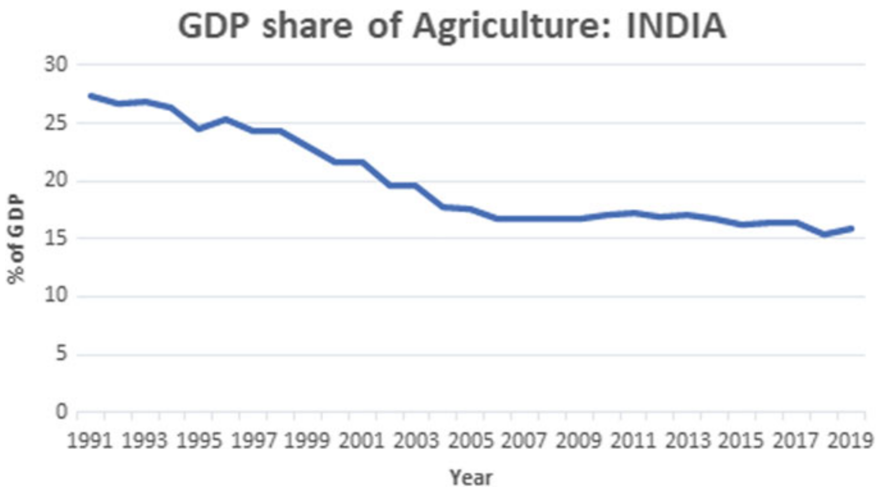

Fig. 11.1 GDP share of agriculture sector

11.1.2 Trends in Agricultural Sector

The occupational choices of the rural workers, especially the rural workers in the agricultural sector, have shifted from farming to non-agricultural occupations in the past three and half decades. This is a critical point to note while addressing contemporary agrarian trends. As per the 38th round of the National Sample Survey (NSS) in 1983, 77% of the families in rural areas depend on agriculture for their livelihoods. But, the rural households' reliance on agriculture fell to 50% according to the latest round of a Periodic Labour Force Survey (PLFS) for 2018–19. Moreover, the contribution of this sector to the national GDP has also fallen from 34% in 1983–84 to 16% in 2018–19. Likewise, its contribution to Gross State Domestic Product (GSDP) has also exhibited a similar pattern throughout the same period (Figs. 11.2 and 11.3).

Although monetary value added to the GDP has increased from 74 billion USD in 1991 to 459 billion USD in 2019, the agriculture industry's GDP percentage has dropped by 11% from 1991 to 2019 and only contributes 16% presently.

The significant 20% drop in employment share from 1991 signals the diversification of non-agricultural industrial employment; even as the workers' pay has increased by 1.35 times over 30 years, it is lower than 2000 USD per year.

The percentage of agricultural land and arable land has not seen significant change over the past three decades. Due to a lack of innovation and technology utilization, there is much need for the industrial revolution to increase productivity and lower land utilization to tackle climate change.

The GVA statistics are essential for understanding how the actual economy's main sectors are performing. The output, or domestic product, is essentially a calculation of GVA plus net taxes. Here, in Fig. 11.4, the various sectoral representations are

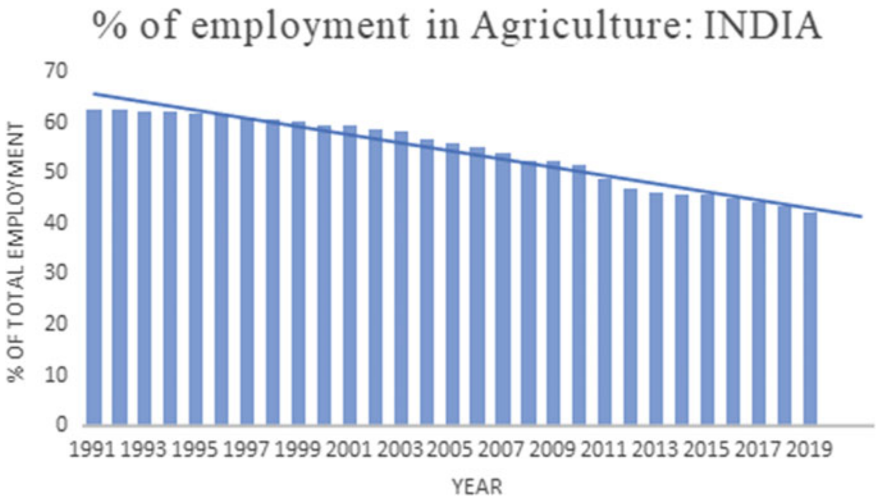

Fig. 11.2 Employment in agricultural sector (percentage of total employment)

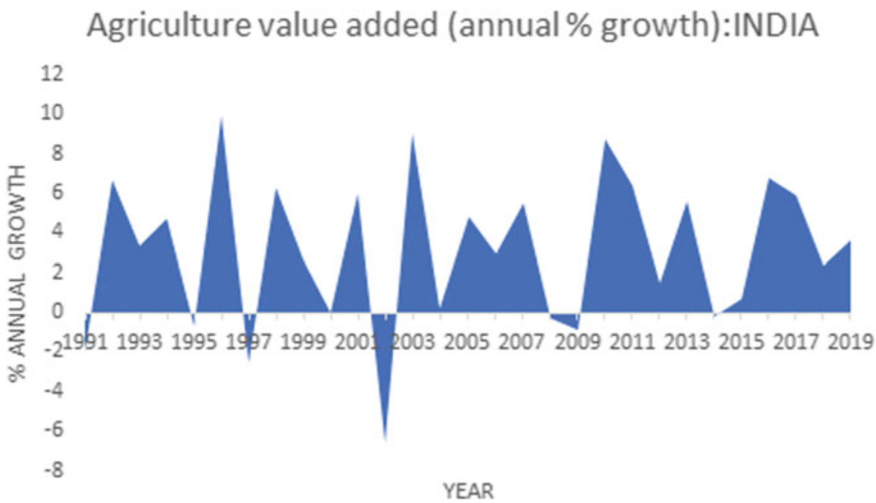

Fig. 11.3 Agriculture, forestry, and fishing, value added (annual % growth)

done to estimate the gross value added by the agricultural sector to the Country's Economic Performance.

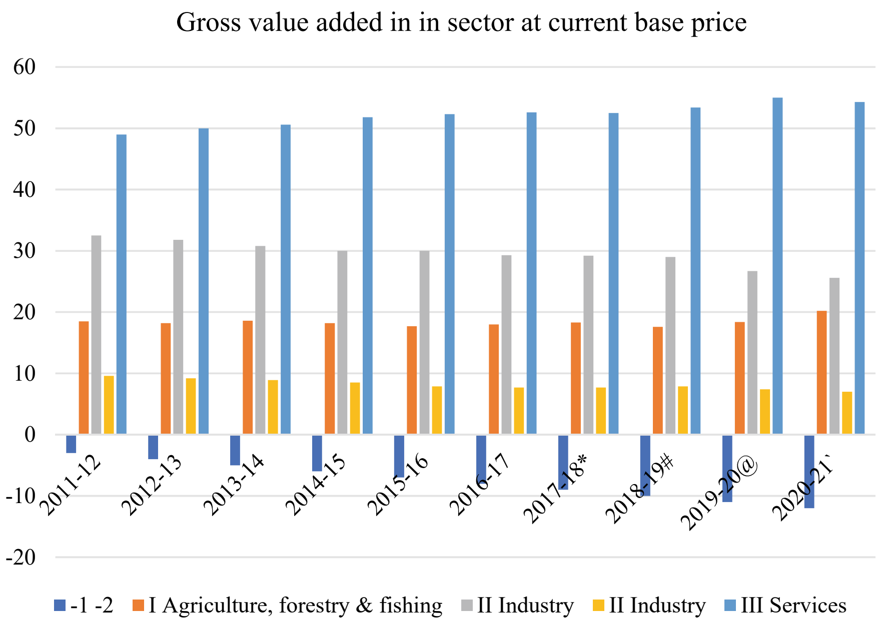

Fig. 11.4 Gross Value added in agricultural sector at current base price. *Source* National Statistical Office

11.1.3 Sustainable Agriculture and Government Initiatives in India

Food grain self-sufficiency has always been a priority for the Indian government, which hasn't always made agriculture sustainable. Agricultural productivity and production, which had increased dramatically in the 1970s and 1980s, began to drop in the 1990s. These slowdowns have increased since 2000, with negative growth rates in overall agricultural and food grain production from 2000–01 to 2002–03 (Economic survey of India 2001–2002, 2002). The decline in farm output and productivity growth rates is a severe concern for food security, livelihood, and the environment.

Some significant government activities have been listed below:

- Indian Prime Minister has introduced a plan for the Animal Disease Program to eradicate foot and mouth and domesticated Malta fever in animals. (Da Silva et al., 2020). This all happened in September 2019, and by May 2020, Rs. 13,345 crore was allotted to this plan.
- National Bank for Rural and Agricultural Development declared speculation for about Rs. Six hundred crores were helping in the value proposition of horticulture surrounded by new companies.

- Foreign Direct Investment has been flowing 100% by India's Govt. showcasing various Indian Cuisine items among the various programmed courses.
- The budget of 2019–20 has announced a Yojana where a fixed amount of money of Rs. 4000 at the age of 60 years.
- The Transportation and Marketing Department, in collaboration with the Government of India, helps to hold up the agrarian shares and helps in framing the farming costs.
- The latest Agricultural Policy was framed in 2018 by the Govt. of India. This is meant to increase the horticultural trend in the coming years by 59 billion U.S. Dollars by 2023 (Da Silva et al., 2020) and 110 billion U.S. Dollars with the medium of providing an exchange master plan system.
- Society is specifically meant to provide agricultural credit to give twenty thousand one hundred crores for covenant mutual profit through advanced innovation.
- Many irrigation facilities are provided to enhance water facilities in the farming areas to avoid deserted land, leading to an investment of Rs. 49,000 crore in the name of Pradhan Mantri Sinchai Yojana, (Department of Agriculture, Cooperation & Farmers Welfare (DAC&FW) Minister of Agriculture and Farmers Welfare Government of India, 2019).
- Agribusiness helps in remarkable food division and involves 10% of the production. Additionally, the dedication of Rs. 5900 crore as speculation has the way for superfoods in our nation. The marine processing scheme has been implemented for ensuring packaged products.

11.1.4 Food Security and Sustainable Agriculture: Pillars of Sustainable Development Goals

The outbreak of the pandemic only made things worse. Global food supply networks were hampered negatively due to travel restrictions in many countries and lockdown measures to stop the virus from spreading. This resulted in harmed livelihood and raised the prices of essential food products. According to a recent analysis published by the United Nations Food and Agriculture Organization in 2020, even without considering the pandemic's impact, 840 million people will be underfed by 2030, according to a "The State of Food Security and Nutrition in the World 2020" (2021). The pandemic has the potential to treble the number of individuals who are food insecure (UNSDG|Policy Brief: The Impact of COVID-19 on Food Security and Nutrition, 2021).

Agriculture-led growth has the potential to be a valuable development approach. However, this is not universally applicable because it is context-specific primarily, and a specific set of requirements must be met, such as agriculture accounting for a substantial proportion of employed people. As a result, there is no one-size-fits-all approach for agriculture's contribution to economic growth. But, there is little doubt that because agriculture employs a substantial proportion of the poor, it has enormous potential to decrease poverty through broad-scale pro-poor growth. Numerous regulations were introduced in the Parliament in September 2020. The regulations are envisioned to allow agricultural producers to be sold outside of mandis, eliminate impediments to inter-state crop trade, and enable automated farm produce trading (India Today, 2020).

The prevalence of hunger and malnutrition among the most vulnerable parts of the Indian population indicates that food insecurity at the household and individual levels can coexist with adequate food grain production due to inefficient management and distribution systems. The issue here that needs to be addressed is that, can India cater to its starving and malnourished citizens? Food security is dependent on adequate domestic and foreign sources, as proven by the COVID-19 issue. In practice, a future without hunger, as articulated in the concept above, demands food policy innovation as a whole. Food security as a development goal necessitates macro-level cross-sectoral innovation in any regent, ranging from regulating innovation in food production techniques (farming and seed cultivation) to innovation. It protects the product from contamination for various reasons, including ecological imbalance or human intervention. At the same time, intelligent government policy can ensure adequate supply and assistance (Tripathy, 2019). A well-balanced diet and the prevention of micronutrient deficiencies and non-communicable diseases like cancer and cardiovascular disease need regular consumption of various fruits and vegetables. Despite this known fact, the global per capita fruit and vegetable consumption is expected to be 20–50% below the recommended minimum. Low consumption of fruits and vegetables has been credited to be one of the world's top ten risk factors for mortality. This situation is primarily due to bad nourishments or poor eating habits in rich countries and poverty and food insecurity in underdeveloped countries. (Sustainable agriculture is fundamental to food security, need to bring seed diversity back: India at U.N., 2021).

Sustainable agriculture methods increase resource efficiency by producing more agricultural output with less land, water, and energy while retaining profitability. These essentially include, among other things, strategies for safeguarding and strengthening crops and soil, boosting water absorption, and applying effective seed treatments. While Indian farmers have long followed these principles, new technology has increased their effectiveness.

11.1.5 Challenges to Food Security

Is there a legitimate need for additional food in the world? Given the vastly unequal food distribution globally, one might believe that distributing food more evenly will alleviate the food crisis. The increased use of water, fertilizer, and pesticides has substantially impacted ecosystems, freshwater supplies, and greenhouse gas emissions, impacting the agricultural sector. Food insecurity rose to 6.8% from 2018–2020, and today India is home to the most significant number of hungry people in the world, with over 200 million people. The pandemic further took the number to around 9.7 crores facing food insecurity in the country. India ranks at the bottom with 94th position in The Global Hunger Index (GHI) 2020 out of 107 countries with a GHI of 27.2; this points out India's unresolved challenge in ensuring food security. There are multiple issues that the country faces in this effort. During the pandemic, the food insecurity rose above 1.97 crores; ironically, this occurred when the government had an unprecedented 100 million tons of food grains in its godowns (Hunger amid abundance report, 2021)—more than any other country's food reserves. The country with the world's largest grain stockpile—120 million tons as of 1 July 2021—is home to a fourth of the world's hungry people (Bansal, 2021).

- Inadequate food distribution through public distribution systems (PDSs) contributes to the country's rising food insecurity. This is mainly due to the public distribution systems (PDSs) inability to account for a mobile migrant population, its continued use of an outdated population estimate for grain allocation, and its ignorance of ground realities when it comes to the issuing of ration cards and Aadhaar cards, among other issues. Further, the criterion for issuing ration cards under the PDS system is based on identifying the households as BPL identifying a family as below poverty line (BPL) and above poverty line (APL). This system is not standardized, and each state has its yardstick to measure the same. This excludes households eligible for subsidized or free supply of food grains and essential commodities through the PDS system (Upadhyay, 2021).
- Income levels of the farmers: The affordability of food is determined by the income levels of farming families. Food distribution is a significant issue. The public distribution system (PDS) is not functioning correctly. Families that are extremely impoverished but have a sufficient income cannot avoid a food crisis. Food security may or may not be aided by globalization. However, some argue that globalization will undoubtedly improve food security through commerce, but this is a point of contention. We must strive for food security in developing nations by increasing and stabilizing food production using technology and practices that are both economically and environmentally sustainable. Agriculture requires a great deal of diversification. We can't afford any more hunger, malnutrition, or famine. Because horticultural and livestock products supply more nutrients, middle-class households have been spending more on them in recent years as their income has increased and their eating patterns have changed. On the other side, impoverished farmers whose income has remained relatively stable see this as a way to increase their earnings. To maintain their families, marginal farmers shift to higher income-generating occupations (Singh Jaswal, 2014).
- Water Mismanagement: Agriculture is heavily dependent on water resources and, at the same time, polluter of water resources too. The increasing risks as a result of water mismanagement, according to OECD report (2017) highlights its impact on crops, markets, trade, and food security. Climatic change and increased urban population density and water demands from the energy and industry sectors further add to farmers' distress in cultivation. Furthermore, due to the expansion of polluting industries, salinization induced by increasing sea levels, and the water mentioned above supply changes, water quality is anticipated to decrease in many places. This has posed a severe concern to food security. The misery is

exacerbated by unfairness in irrigation water allocation across crops, with more than 60% diverted for the two water-intensive crops (sugar cane and rice). These two crops are grown extensively in some of the country's most water-stressed areas. These should be relocated to sites with a higher water table. Instead, less water-consuming crops like millets and pulses should be grown. According to the NITI Aayog report (2017), Rajasthan, Andhra Pradesh, Gujarat, and Madhya Pradesh have improved water management practices. In contrast, 60% still have not been serious about water conservation.

- Subsidies on Agricultural Inputs: A subsidy (agricultural subsidy) is essentially a government infusion of cash paid to farmers and agribusinesses to supplement their income, enable them to utilize cost-efficient practices, manage the supply of agricultural products, and create a wedge between the selling price and production costs. Subsidies of farming inputs are disproportionately distributed. Large landowners are benefitted than marginalized farmers, who are the primary beneficiaries according to government norms. While the Indian population is now food secure, these issues may jeopardize food security in the long run as India will emerge as the largest populous country, surpassing China.
- Food Sufficiency: India has continuously strived to achieve food sufficiency since independence and has made remarkable progress since 2000. The government announced a series of initiatives in 2016 to double farmers' incomes by 2022. The PDS ensures that Indians are provided with essential food grains and supplies for basic living, but it lacks the dietary requirements for a healthy lifestyle. Over the last two decades, the government has taken significant steps to address malnutrition of its marginal population through mid-day meals in schools, dietary rations to pregnant and lactating mothers, and free food grain distribution through a public distribution system for those living below the poverty line.
- Changing climatic conditions, poor farming methods, and irrigation mismanagement are anticipated to pose difficulties to food security, despite efforts to enhance the PDS. The current context calls for the introduction of technology-aided farming leveraged by comprehensive policies to build a nation on the sustainable development goal of zero hunger.

11.2 Methodology

A narrative review (Cronin et al., 2008) was used to conduct a review and synthesis of the literature to address the contentious and complex research question of how food security could help reach the world the sustainable development and to propose a direction for future research and development in the field. There are several methods for performing a literature review of research studies and reports (Snyder, 2019); nevertheless, a narrative approach was chosen as the best tool for interpreting and critiquing existential studies on quality of life.

The objectives of this research were as follows:

(i) To understand the role of agriculture in food security
(ii) To assess the various farm legislation and its impact food security
(iii) To suggest strategies to enable the Indian Agricultural Industry reach the Sustainable Development Goals to achieve food security.

11.2.1 Agritech, Farm Legislations, and Food Security

The pandemic has raised multiple concerns on the livelihood of the rural population in India, who are heavily dependent on agriculture. The strict lockdown measures disrupted the supply chain and forced 130 million farmers to look for alternate means to sell their products and resist the monetary crunch. The Indian farming ecosystem has undergone rapid changes with increased rural internet penetration and affordable digital technologies. Government agencies and investors have shown increased interest in developing agriculture through investments in the agricultural sector, especially high-end technology. The technological interventions are aimed not only to leverage crop productivity but also to develop an efficient supply chain in the trade of agricultural produce, ensure quality standards are adhered to in trade practices, and optimize production costs for price competitiveness. Agricultural exports in India grew significantly from 2020–2021 (Export products agriculture, 2020). Agriculture and related product exports increased by 17% to $41.25 billion in 2020–2021 (Ministry of Commerce and Industry Report, 2021). This may sound very optimistic, but according to the U.N. reports, in 2017, India will surpass China and become the most populous country by 2030. This implies that the country will face a massive spike in demand for agricultural and allied produce, which needs technological and policy-level interventions to meet the future demand and enable India to ensure food security to its projected 1.5 billion population by 2030. Agricultural reforms have immensely contributed to gaining this stability and changed the way agricultural products were sold by allowing private investment in establishing markets, contract farming, futures trading, etc. The digital revolution has opened new possibilities of tackling farming woes of receding water tables, reducing arable land, climatic changes, pest control issues, and access to markets.

Industry partners and agri-startups have bought various technology and artificial intelligence-aided tools to improve farmers' quantity, quality, operational efficiency, and farm produce. Nanotech applications, soil and water sensors, and GPS technologies increase crop health and diagnose infections early. The adoption of these tech-enabled farming requires skill development, government support, and policy interventions. The farm bills passed by the Indian Parliament, The Farmers Produce Trade and Commerce (Promotion and Facilitation) Act, the Farmers (Empowerment and Protection) Agreement of Price Assurance and Farm Services Act, and the Essential Commodities (Amendment) Act are focused on empowering the farmers by eliminating intermediaries. The three enactments serve to bring the farmer close to the market and engage in free trade beyond the physical boundaries regulated by APMC. Farmers will have a more extensive territory to sell their produce and alternative channels to sell in competitive markets that will benefit them. They will have access to a broader market through digital technologies, which will enable the farmers to fetch better prices.

Further, contract farming agreements will cap the price fluctuations. This would enable the farmers to adopt the latest cultivation techniques, increasing yield and crop quality. These legislations have a futuristic approach in taking India toward food security by empowering farmers at multiple levels. In the long run, India could emerge as the food bowl of the world.

11.2.2 Key Takeaways: Removing the Barriers to Achieving Sustainable Goals

Herger (2020) in his research mentioned that the agricultural sector has myriad effects on the sustainable development of India, mainly in social, economic, and environmental spheres. This sector is a means for people to earn an essential livelihood; it feeds the population and provides raw materials for other vital industries. It is like a big market with great capacity, creating a vast platform for foreign exchange earnings. Agriculture also firmly regulates poverty rates and equality among the population, so the agricultural sector plays a crucial role in sustainable development. A prospective track is a need of the hour for India to be on the right pathway of accomplishing the future crop production requests and meeting SDG 2 (Zero Hunger) (Workie et al., 2020; Rampal, 2021). Following strategies could help curb the fallouts resulting from the COVID-19 pandemic and help achieve food security.

- An effective coping mechanism could be meticulously expanding food and social safety programs, particularly in rural areas, and supplying essentials and other food items for households below the poverty line.
- An alternative scheme could be to assist the unguarded and vulnerable segments of the society like migrant workers, landless laborers, pro-poor, and pregnant ladies with some fixed remittance to meet their basic needs of lives.
- Due to the pandemic, many emerging economies like India have faced the obstacle of supply disruption. Therefore, there is a need for suitable interference like nourishing the storage potential for improving the buffer stock and distribution would help to counter-attack these unpleasant circumstances.
- Strengthening the technology and maximizing the use, reach, and benefits of Information and Communication Technologies could be a very efficient coping strategy to overcome the issues faced due to COVID-19.
- Disseminating information about the ethnic food system and its promotion would help make India self-sufficient and safeguard the local food system, targeting SDG 2.

- Genuine public awareness campaigns to keep the public well informed, encouraging them not to hoard the essential item and support basic hygiene, will ultimately lead to market stability.

The primary aim should be to expand the cultivated lands and increase crop yields in India. Some farmers and laborers do not have access to technologies and other financial resorts for future stakes, so relocation to more commercial aligned farming approaches or establishing small farmers collective into producer companies is a solution. India should also be considered a particular case for future agriculture intensification scenarios as it would play an inevitable and pivotal role in improving food security and influencing SDG2 (Paroda & Joshi, 2019). Transformation of small subsistence units into larger farms and technology intensification would substantially change the farm structures. Furthermore, environmental policies should target implementing sustainable intensification for maximum output, minimum biodiversity losses, and fostering soil carbon segregation to improve soil fertility and decrease global warming. Collaborative efforts and united worldwide response are unavoidable for effective and efficient response, control, and achieving SDG2 (Hinz et al., 2020). Further studies on pandemics and various other strategies and cures are imperative to fill the knowledge gaps. The proposed suggestion could help recharge the agricultural sector and revitalize the Indian economy, hence, making it self-reliant.

11.3 Conclusion

Agriculture serves as a growth engine for a country's economy, which is critical for most developing countries. And one thing is sure: Agriculture will not remain the same but will continue to evolve quickly. There are many problems ahead, but there are also many chances. The primary goals of sustainable and inclusive development in the SDGs will not be easy to accomplish. It has become evident that sustainable development entails far more than simply addressing material deficits. The localization of SDGs is critical to any plan to fulfill the 2030 Agenda's goals. This entails relevant institutions and stakeholders adopting, planning, implementing, and monitoring the SDGs at all levels, from national to local. Promoting sustainable agriculture while assisting small-scale farmers and ensuring fair access to land, technology, and markets are all critical steps in the fight against hunger and poverty. It also needs international collaboration to provide infrastructure and technological investments to boost agricultural production. This also highlights the importance of all countries cooperating to guarantee enough investment in associated infrastructure by incorporating and embracing innovative technology to increase agricultural output *(Sustainable Development Goals|NITI Aayog; UN report,* 2017*).*

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Chapter 12
Correlation Between Volumetric Loading Rate and Removal Efficiency of Bio-chemical Oxygen Demand and Chemical Oxygen Demand for Waste Water Treatment by Improved Bio-tower Technology in Ganga River Basin (India)

Ankit Singh, Anju Singh, Sateesh Karwariya, Govind Pandey, Shruti Kanga, and Suraj Kumar Singh

Abstract The most often utilised parameters for the characterisation of wastewaters are biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Both parameters have advantages and disadvantages, and the choice is usually based on several factors, such as the amount of time it takes to determine each. To aid in the design and operation of wastewater treatment facilities, it is necessary to obtain a connection between BOD and COD for various wastewater treatment plants. The volumetric loading rate and removal effectiveness of BOD and COD of two wastewater treatment plants were compared in this article. The WWTPs chosen encompassed

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various areas of Prayagraj, located on the Ganga River. The association between BOD and COD discovered will aid in evaluating treatment processes.

Keywords Improved bio-tower technology · Total suspended solid · Chemical oxygen demand · Removal efficiency · Volumetric loading rate

12.1 Introduction

Solid and liquid wastes are generated in every society. The liquid element of wastewater is essentially the community's water supply after it has been contaminated by various sources. Wastewater can be characterised as a mixture of liquid or water-carried wastes evacuated from dwellings, institutions, commercial and industrial establishments, as well as any groundwater, surface water or stormwater present. If untreated wastewater is allowed to build up, the decomposition of the organic components it contains can release enormous amounts of foul-smelling gases. Furthermore, untreated wastewater often includes a variety of harmful or disease-causing microbes that live in the human intestine or may be present in particular industrial waste (Singh et al., 2016). Toxic chemicals can also be found in wastewater. For these reasons, in an industrialised society, the immediate and painless evacuation of sewage from its generation sources, followed by treatment and disposal, is not only desired but also vital. Domestic, municipal and industrial wastewater can be treated in various ways (Ministry of urban development, New Delhi). Specific parameters in raw sewage on the high side must be lowered according to pollution control board guidelines by undergoing particular treatment. One is to provide oxygen for BOD elimination, known as biochemical oxygen demand (Nagesh, 2004). This is accomplished through many aeration techniques, such as surface aeration or diffused aeration, which all require external power to operate. Natural air draught is a way utilised in Bio-Towers to achieve aeration without the usage of external electricity. The trickling filter with plastic media, commonly known as the 'Bio-Tower', is becoming increasingly popular as it is incredibly efficient while occupying less plot area and requiring much less power (Rao, 2013).

Natural air draught is used in Bio-Towers to achieve aeration without external electricity. Bio-tower works on a straightforward and reasonable principle. The Bio-Tower is a sort of treatment for attached growth. When waste is fed from the top of the Bio-Tower, the microorganisms in the wastewater form a colony on the surface of the plastic media, which provides stability and a larger surface area (Spellman, 2014). The temperature inside the Bio-Tower rises above the ambient temperature throughout this process, and the hot air inside the Bio-Tower is discharged from the top (because it is light). Fresh air rushes from the bottom of the Bio-Tower to substantiate air loss, forming a cycle of air movement that meets the Bio-air Tower's requirements to a large part. As previously stated, there are different methods for reducing BOD in various units of the specific technology used to treat wastewater (Metcalf and Eddy Inc., 2003). However, the detailed study/survey of Bio-Tower with forced aeration for removal of BOD in attached growth technology Bio-Tower/s with the natural draft or with forced aeration from the bottom may be available. Still, a Bio-Tower with powerless forced aerators installed on top of the tower is a new concept we have developed (Wastewater Treatment Plants, Office of Water Programs, Washington D.C.). By incorporating forced aeration into Bio-Tower Technology, constraints caused by natural air draught will be eliminated, and the plant will function better without spending any energy on aeration within the Bio-Tower (Tarak & Fsar, 2004). A forced aeration technique in Bio-Tower Technology is introduced by providing a non-conventional and environmentally beneficial wind-operated air exhaust mechanism at the top of the Bio-Tower, according this innovation (Dong et al., 2019; Mian et al., 2018). The wind-operated air exhaust system rotates and eliminates air inside the Bio-Tower due to the average wind speed, allowing fresh air to enter from the bottom of the Bio-Tower. Forced aeration is performed by providing a wind-operated air exhaust mechanism at the top, and oxygen from the fresh air is used to eliminate the BOD (Abdel Fatah & Al Bazedi, 2019; Tik & Vanrolleghem, 2016).

The procedure above is carried out by providing cover and forced aeration via a wind-operated air exhaust mechanism on top of a standard Bio-Tower, which is operated by wind speed, enhancing air circulation and improving effluent quality to a higher level than the conventional Bio-Tower. The air movement is accomplished by a wind-operated air exhaust system at the top. Thus, no additional power is necessary (Municipal Sewage Treatment by HNB Engineers Pvt. Ltd.). The Bio-Tower Technology is a variation of the trickling filter technology used to handle industrial, domestic and municipal waste. It enhances performance without significantly increasing costs and eliminates all system flaws.

The main advantages of Bio-Tower technology are as follows:

1. Maintenance of temperature.
2. Guaranteeing aeration in any climatic conditions.
3. Controlling foul smell/odour.
4. Controlling sludge volume.
5. Working well in every season as it will be covered from the top.
6. No power is required to run the air exhaust.

12.2 Study Area

The research area includes a sewage treatment plant (STP) based on improved Bio-Tower Technology, located on the right bank of the Ganga in Prayagraj's north-west direction. Figure 12.1 shows a satellite image identifying the plant's location. Figure 12.2 depicts the flow diagram of a sewage treatment plant with upgraded Bio-Tower Technology erected in Kodra and Ponghat. Ponghat and Kodra's STPs have 10 MLD and 25 MLD, respectively. HNB Engineers Pvt. Ltd. built the plant for the U.P. Jal Board as part of the Ganga pollution control unit, and it was completed in time for the Kumbh Mela in 2013.

Fig. 12.1 Satellite view of STP based on bio-tower technology in Kodra and Ponghat Plant

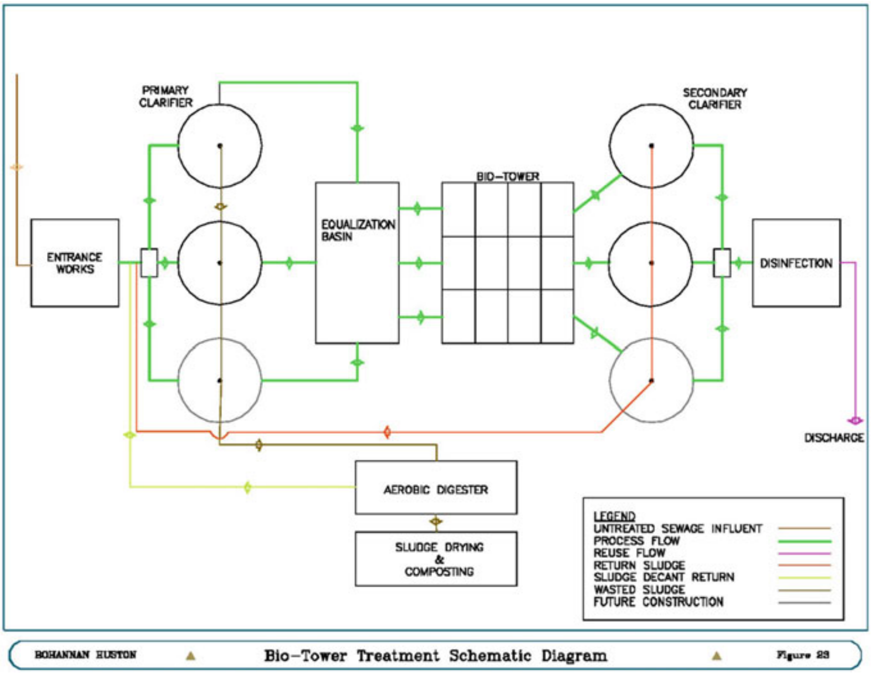

Fig. 12.2 Flow diagram of sewage treatment plant based on bio-tower technology in Allahabad City (India)

The performance of the STP based on Improved Bio-Tower Technology was evaluated in terms of wastewater characterisation in order to produce a comparative account of the pollution load before and after the treatment procedures, as well as to determine their efficiency.

12.3 Results

VLR and removal efficiency of BOD and COD are directly related in a wastewater treatment system. As the VLR increases, the removal efficiency of BOD and COD tends to decrease. This is because the treatment system relies on microorganisms to break down the organic matter in the wastewater. When the VLR is high, the microorganisms may not have enough time to fully degrade the organic matter, leading to lower removal efficiency. On the other hand, when the VLR is low, the microorganisms have more time to break down the organic matter, resulting in higher removal efficiency. However, it is important to note that the relationship between VLR and removal efficiency is not always linear, and other factors such as the type and concentration of organic matter in the wastewater, the type of microorganisms present in the treatment system and the operating conditions of the system can also affect the removal efficiency.

The study carries out the volumetric loading rate and removal efficiency of both BOD and COD from June to December 2016 of both the plants Ponghat Plant and Kodra Plant, followed by the overall average ratio of COD/BOD shown in the figures given below. Figure 12.3 shows the correlation of removal efficiency and volumetric organic loading rate of BOD for July 2016 in Ponghat Plant and Kodra Plant. Low efficiency results reflect the anaerobic reactor's inability to handle the wide range of volumetric loading rates as well as the high average influent COD concentration. The regression study here revealed a strong association between BOD, with $R^2 = 0.398$ for the Ponghat Plant and 0.076 for the Kodra Plant. For Ponghat Plant and Kodra Plant, respectively, the treatment process in this plant must be functioned to the regression equations of BOD $y = -\ 310.63x + 96.884$ and $y = -\ 67.929x + 93.464$. As per Fig. 12.4, $R^2 = 0.6$ for the Ponghat Plant and $R^2 = 0.03$ for the Kodra Plant are the regression analysis results for COD and COD regression equations, $y = -\ 68.686 + 94.98$ for the Ponghat Plant and $y = -\ 2.265x + 97.494$ for the Kodra Plant.

Another regression analysis was conducted for removal efficiency versus volumetric organic loading rate of BOD and COD for August 2016 in Ponghat Plant and Kodra Plant. In this analysis, we discovered a strong correlation between removal efficiency and volumetric organic loading rate of BOD, with $R^2 = 0.387$ for August 2016 in Ponghat Plant and $R^2 = 0.387$ 0.794 in Kodra Plant. The regression equations for BOD for August 2016 in Ponghat Plant and Kodra Plant shown in Fig. 12.5. Figure 12.6 shows the correlation of removal efficiency and volumetric organic loading rate of COD $R^2 = 0.687$ for August 2016 in Ponghat Plant and $R^2 = 0.476$

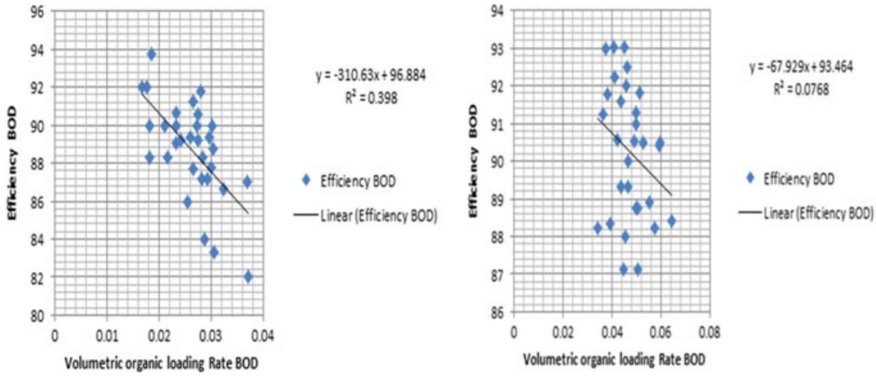

Fig. 12.3 Correlation of removal efficiency versus volumetric organic loading rate of BOD for July 2016 in Ponghat Plant and Kodra Plant

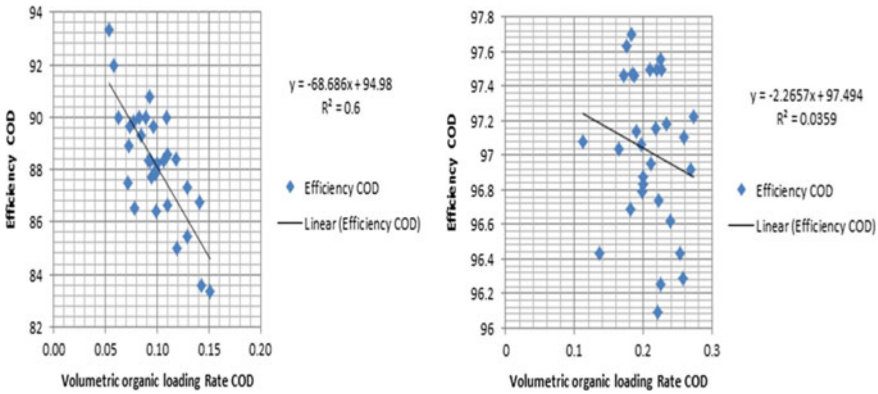

Fig. 12.4 Correlation of removal efficiency versus volumetric organic loading rate of COD for July 2016 in Ponghat Plant and Kodra plant

in Kodra Plant. Regression equations of COD for August 2016 in Ponghat Plant and Kodra Plant are $y = -66.298x + 93.959$ and $y = -38.452x + 95.452$.

Figure 12.7 shows the correlation of removal efficiency versus volumetric organic loading rate of BOD for September 2016 in Ponghat Plant and Kodra Plant as well as the correlation of removal efficiency versus volumetric organic loading rate of COD for September 2016 have shown in Fig. 12.8. As per the analysis, the correlation of removal efficiency and volumetric organic loading rate of BOD is $R^2 = 0.528$ in Ponghat Plant, $R^2 = 0.070$ in Kodra Plant and loading rate of COD is for $R^2 = 0.069$ in Ponghat Plant and $R^2 = 0.120$ in Kodra Plant. Regression equations of BOD and COD for September 2016 in Ponghat Plant and Kodra Plant are $y = -187.16x + 94.927$, $y = -108.33x + 97.308$, $y = -77.07x + 95.292$ and $y = -22.288x + 91.139$, respectively.

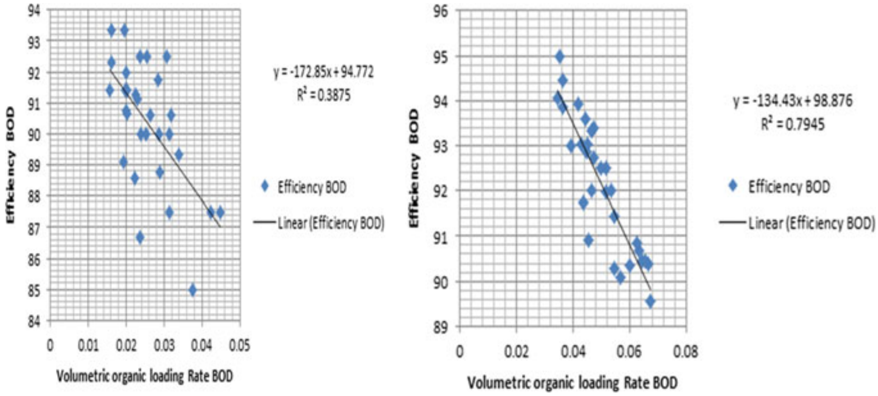

Fig. 12.5 Correlation of removal efficiency versus volumetric organic loading rate of BOD for August 2016 in Ponghat Plant and Kodra Plant

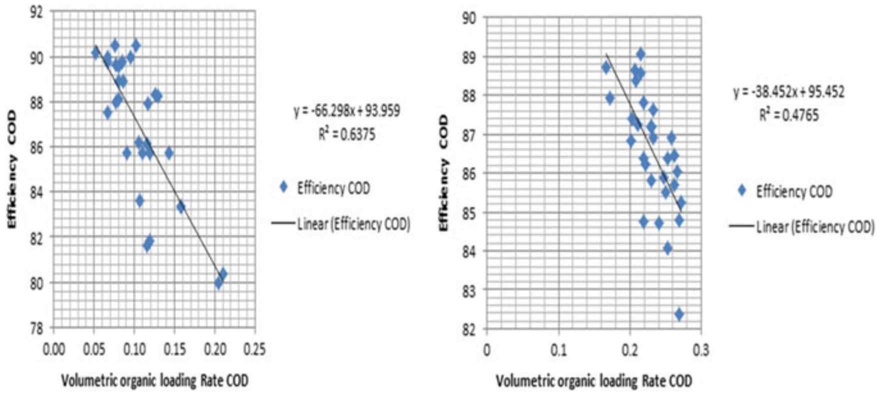

Fig. 12.6 Correlation of removal efficiency versus volumetric organic loading rate of COD for August 2016 in Ponghat Plant and Kodra Plant

The correlation of removal efficiency versus volumetric organic loading rate of BOD for October 2016 in Ponghat Plant and Kodra Plant is shown in Fig. 12.9, and the correlation of removal efficiency versus volumetric organic loading rate of COD shown in Fig. 12.10. Removal efficiency and volumetric organic loading rate of BOD is $R^2 = 0.444$ and COD is $R^2 = 0.525$ in Ponghat Plant as well as regression equations of BOD and COD for October 2016 in Ponghat Plant is $y = -228.58x + 95.092$ and $y = -87.758x + 95.648$, respectively. In Kodra Plant, the loading rate of COD is for $R^2 = 0.069$ in Ponghat Plant and $R^2 = 0.120$ in Kodra Plant. Regression equations of BOD and COD for September 2016 in Ponghat Plant and Kodra Plant removal efficiency and volumetric organic loading rate of BOD are $R^2 = 0.369$ and COD is $R^2 = 0.377$. Regression equations of BOD and COD for October 2016 in Kodra Plant are $y = -128.73x + 97.562$ and $y = -39.703x + 95.232$.

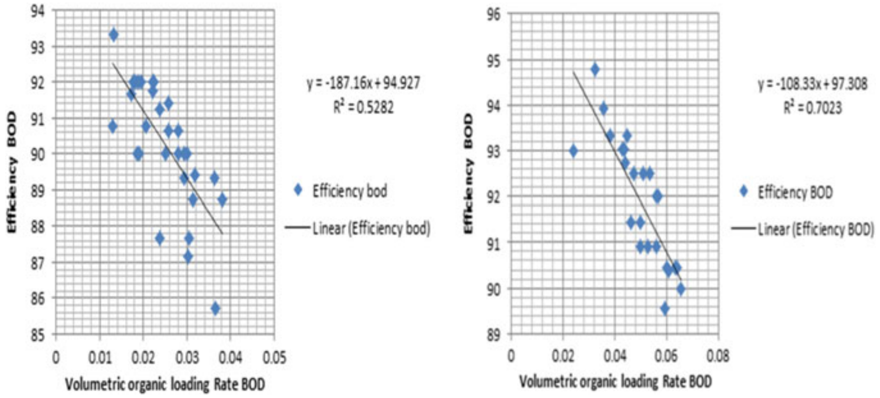

Fig. 12.7 Correlation of removal efficiency versus volumetric organic loading rate of BOD for September 2016 in Ponghat Plant and Kodra Plant

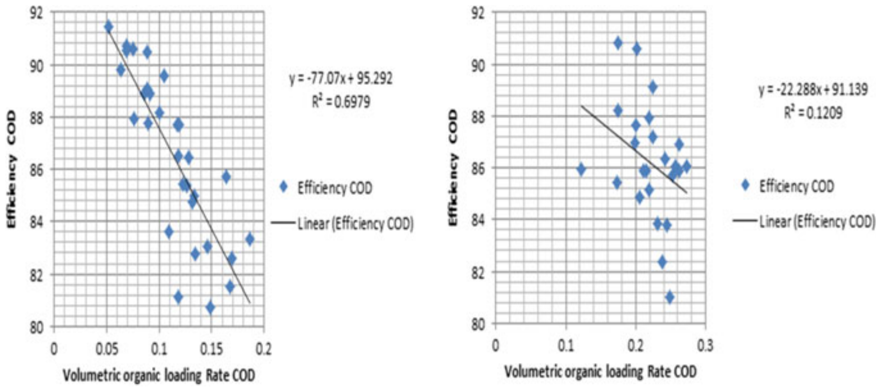

Fig. 12.8 Correlation of removal efficiency versus volumetric organic loading rate of COD for September 2016 in Ponghat Plant and Kodra Plant

Figure 12.11 shows the correlation of removal efficiency versus volumetric organic loading rate of BOD for November 2016 in Ponghat Plant and Kodra Plant. Removal efficiency and volumetric organic loading rate of BOD is $R^2 = 0.1886$ in Ponghat Plant, $R^2 = 0.245$ in Kodra Plant, and regression equations of BOD November 2016 in Ponghat Plant and Kodra Plant are $y = -143.87x + 93.73$ and $y = -70.479x + 94.463$, respectively. As per Fig. 12.12, removal efficiency and volumetric organic loading rate of COD is $R^2 = 0.670$ in Ponghat Plant, $R^2 = 0.099$ in Kodra Plant, and regression equations of COD for November 2016 in Ponghat Plant and Kodra Plant are $y = -81.14x + 95.838$ and $y = -16.141\text{x} + 89.997$, respectively.

Figure 12.13 depicts the correlation of removal efficiency versus volumetric organic loading rate of BOD for December 2016 in Ponghat Plant and Kodra Plant

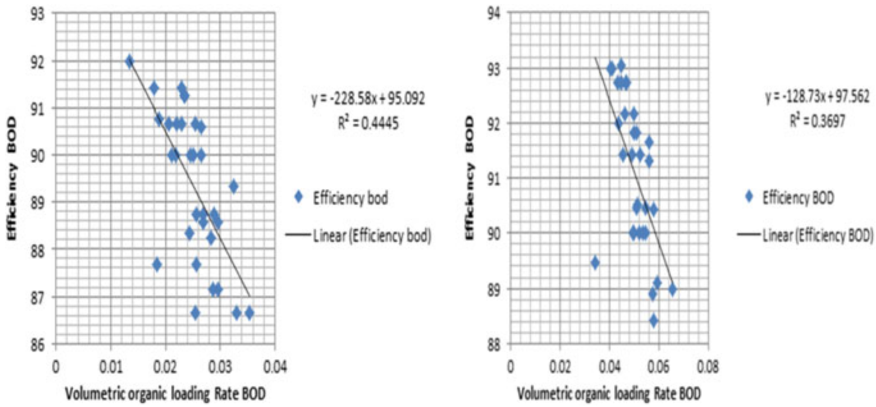

Fig. 12.9 Correlation of removal efficiency versus volumetric organic loading rate of BOD for October 2016 in Ponghat Plant and Kodra Plant

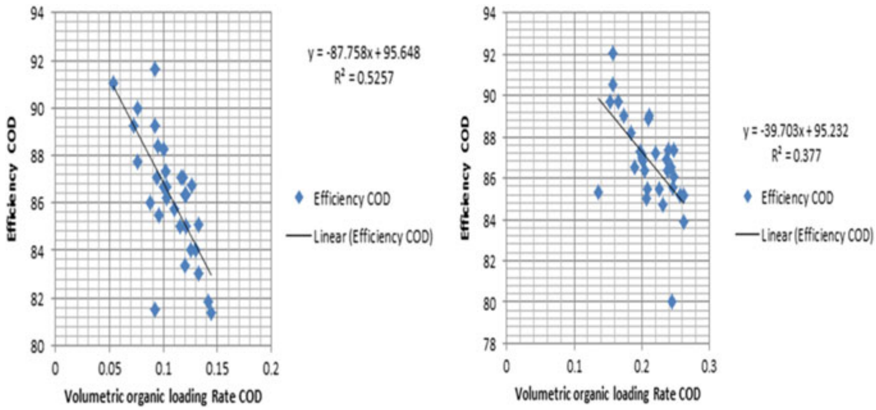

Fig. 12.10 Correlation of removal efficiency versus volumetric organic loading rate of COD for October 2016 in Ponghat Plant and Kodra Plant

as well as Fig. 12.14 shows the correlation of removal efficiency versus volumetric organic loading rate of COD for December 2016. As per the analysis, the correlation of removal efficiency and volumetric organic loading rate of BOD is $R^2 = 0.484$ in Ponghat Plant, $R^2 = 0.420$ in Kodra Plant, and loading rate of COD is for $R^2 = 0.403$ in Ponghat Plant and $R^2 = 0.476$ in Kodra Plant. Regression equations of BOD and COD for December 2016 in Ponghat Plant and Kodra Plant are $y = -253.71x + 96.187$, $y = -125.9x + 97$, $y = -55.198x + 9.997$ and $y = -37.592x + 95.281$, respectively.

The COD/BOD ratio is a measure of the proportion of biodegradable organic matter in a sample of water compared to the total amount of degradable organic matter. The ratio is typically greater than 1, but it can be equal to 1 if the sample

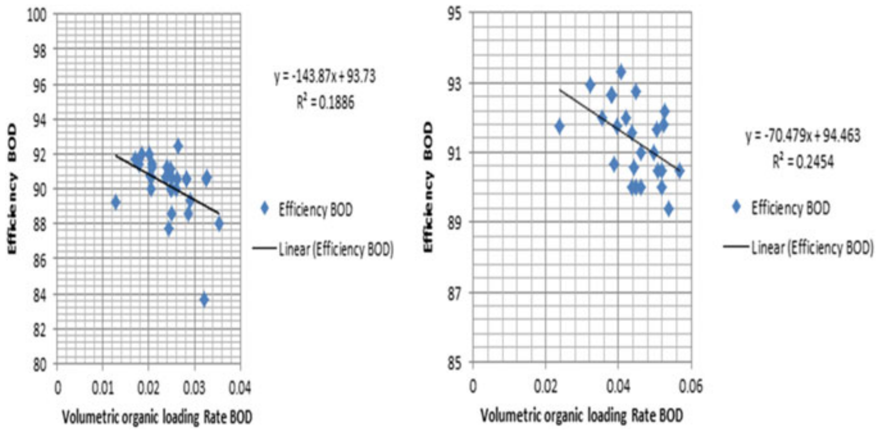

Fig. 12.11 Correlation of removal efficiency versus volumetric organic loading rate of BOD for November 2016 in Ponghat Plant and Kodra Plant

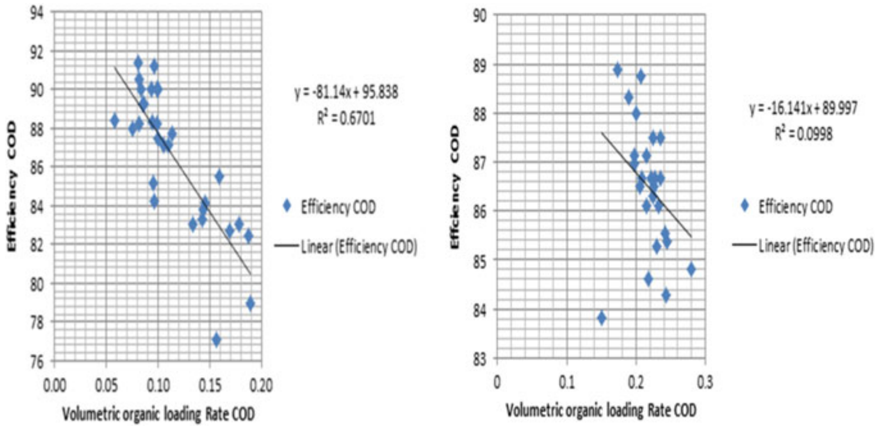

Fig. 12.12 Correlation of removal efficiency versus volumetric organic loading rate of COD for November 2016 in Ponghat Plant and Kodra Plant

contains only biodegradable organic matter. In fresh water, both the COD and BOD are usually low, so the COD/BOD ratio may be close to 1. Figures 12.15 and 12.16 show graphical representation of overall average ratio of COD/BOD in Ponghat and Kodra Plant from July 2016 to December 2016.

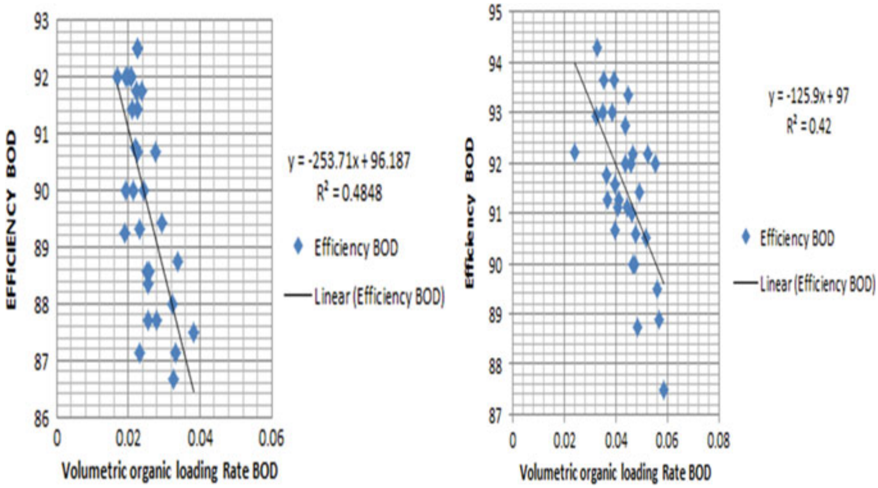

Fig. 12.13 Correlation of removal efficiency versus volumetric organic loading rate of BOD for December 2016 in Ponghat Plant and Kodra Plant

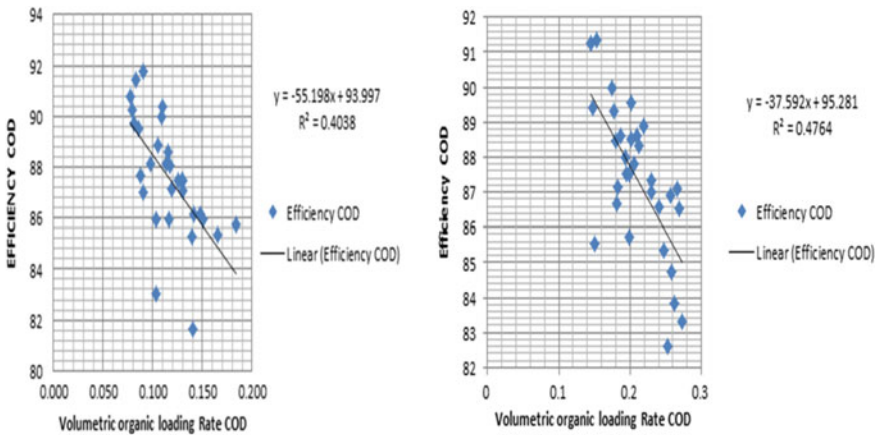

Fig. 12.14 Correlation of removal efficiency versus volumetric organic loading rate of COD for December 2016 in Ponghat Plant and Kodra Plant

12.4 Conclusions

The performance of two STPs in running conditions was evaluated in Prayagraj, namely the 10 MLD-based STP at Ponghat Plant and the 25 MLD-based STP at Kodra Plant. The following findings of the research are as follows:

- The Figs. 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 12.10, 12.11, 12.12, 12.13 and 12.14 depict the relationship between the removal efficiency of BOD (Biochemical

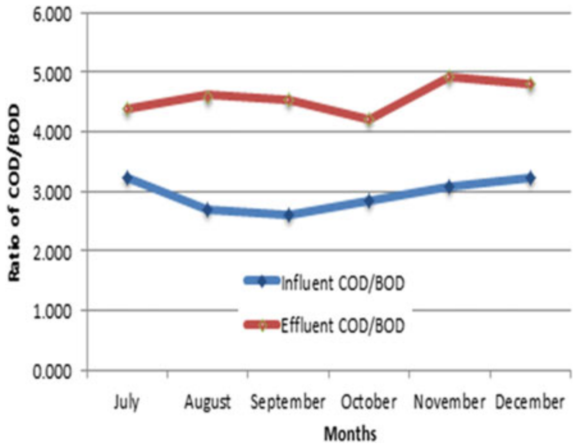

Fig. 12.15 Overall average ratio of COD/BOD in Ponghat Plant

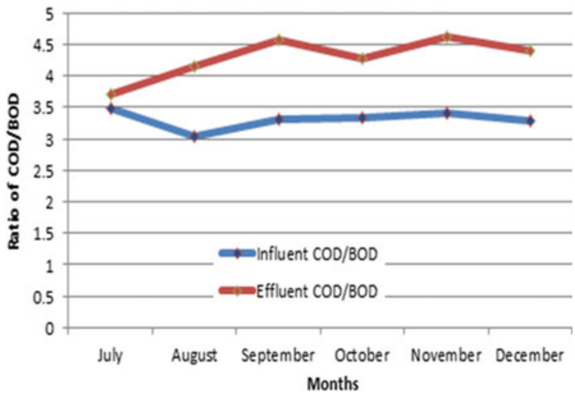

Fig. 12.16 Overall average ratio of COD/BOD in Kodra Plant

Oxygen Demand) and COD (Chemical Oxygen Demand) and the volumetric organic loading rate in sewage treatment plants.

- The volumetric organic loading rate refers to the amount of organic matter (in terms of BOD or COD) that is added to the treatment system per unit volume of the reactor. When the organic loading rate is high, it can lead to incomplete degradation of organic matter and reduced removal efficiency of BOD and COD. The figures demonstrate that as the volumetric organic loading rate increases, the removal efficiency of BOD and COD decreases. This relationship is often represented by a curve that shows that removal efficiency is inversely proportional to the organic loading rate. Therefore, to maintain the high removal efficiency of BOD and COD in sewage treatment plants, it is crucial to carefully monitor and control the volumetric organic loading rate. By doing so, the treatment process can be optimized to ensure that the organic matter is fully degraded, and the effluent meets the required standards for discharge into the environment.

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Chapter 13
Site Suitability in Water Harvesting Management Using Remote Sensing Data and GIS Techniques: A Case Study of Sulaymaniyah Province, Iraq

Shaho Noori, Redvan Ghasemlounia, and Abbas Mohammed Noori

Abstract The human-induced water use changes and the climate change effects have impartially led to long-term drought, water shortages and some casual flood incidents. These have greatly impacted the northern region of Iraq over the past few decades. Water resource management has become a key to resolve this dilemma, particularly for the arid and semi-arid areas. Harvested water could be exploited for consumption, domestic and animal use. Moreover, it is considered to be a valuable resource for irrigating agricultural lands. This study aims to identify appropriate sites for rainwater harvesting in the Sulaymaniyah province, Iraqi Kurdistan region. These processes have been done by using remote sensing, Geographic Information System (GIS) techniques and multi-criteria decision-making (MCDM). Analytical hierarchy process (AHP) model has been used to find out suitable locations for water harvesting. The criteria considered were runoff, slope, soil type, land cover and drainage density. Each factor is assigned to its weight depending on its effect. Based on the findings, the average region that is outstanding and very well suited for water collection is 32% of the whole area. The model that has been applied in the current study is extremely significant and supportive for water resource management.

Keywords GIS · Remote sensing · MCDM · AHP · Rain water harvesting

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13.1 Introduction

In the near future, water availability will be very important for various purposes, especially for domestic and irrigation use. Thus, it becomes important to tap as much water as possible into the river basin as possible. Harvesting water is one of the essential methods used to tap water by constructing irrigation facilities such as test dams, storage ponds and stop dams. Water preservation acts as a way of avoiding precipitation variability as an insurance strategy (Payen et al., 2012).

Decades of war and maladministration and the growing demand due to population growth have considered water a scarce resource in Iraq, by Iraq's developing neighbours, Iran, Syria and Turkey, by worse droughts recently recalled. Difficult water shortages in some areas have in recent years prompted thousands of people to leave their places, and this phenomenon is likely to increase with continuing droughts condition in Iraq. Alternative proposals for reducing Iraq's water shortages therefore urgently need to be enforced (Al-Abadi et al., 2017).

Owing to climate change and high population growth, water demand is on the rise (Schewe et al., 2014). However, Iraq is an agriculture-based country and water demand increases in order to guarantee food security, for further agricultural production (Noori et al., 2019).

Aridity and climate variability in the arid and semi-arid areas are the main threats to farmers. These areas have low average yearly precipitation levels and wildly varying distribution of spatiotemporal precipitation. The dryland residents have produced and constructed many rainwater harvesting (RWH) methods to increase water supplies for the cultivation and development of livestock (Adham et al., 2016).

Rainfall may be the most critical concept in the water balance equation, so it is one of the challenges for engineer's designer and hydrologists to interpret historic data of rainfall and hydrology in terms of potential occurrence probabilities. Annual maximum analysis over the catchment at different daily or better predictive is a fundamental method of safe and economic planning, water management and hydraulic system design (Gavit et al., 2018).

RWH is used to induce, capture, save and use local surface water for agriculture and domestic in the arid and semi-arid countries (Gupta et al., 1997). The main goals for hydrological engineers include an understanding of the performance of the RWH, the catchment water output and flood flows to plan structures for the harvest of rainwater. Structures for the RWH are designed to capture, within a specific recurrence interval, as much of the anticipated river as possible while meeting crop/tree water requirements (Adham et al., 2016).

The collection and management of surface water and flooded water are the most effective irrigation options in dry areas, particularly for domestic use and agricultural. The main aim of water harvesting is to capture, store and make available the rivers or groundwater for a region with adequate water where water deficits arise (Botha et al., 2011).

Rainfall data can be checked on the likelihood and frequency of receiving expected precipitation amounts for different likelihood (Bhakar et al., 2008). Use equivalent computational techniques to predict the average daily precipitation of predicted events from available evidence (Kumar & Kumar, 1989). Rate rainfall analysis is a way of addressing multiple water supply concerns (Kumar et al., 2007). Therefore, in the preparation and development of water sources for small dams, lakes, storm drains, drainage systems and rainwater storage facilities (Dabral et al., 2009), the likelihood and duration of the occurrence of potential rainfall events should be used to minimize the risk of floods and drought cycles.

New technologies have been developed in recent times to address the shortcomings in traditional water scraping methods such as GIS, remote sensing and multi-criteria decision-making that can be applied to accurately assess catchment rush production, incorporate spatial and time differences of catchment properties in resource estimation and make informed decision-making (Saxena et al., n.d.).

The soil and drainage trends must be captured in GIS remotely for the efficient localisation of the required systems, and the watersheds have distinct physiographical characteristics, such as geomorphology, structures, and land use-land cover (LULC).

In recent years, geographical information systems offered a complex and effective forum to combine data from remote sensing and runoff models to optimally position WH structures, normally using spatial analysis instruments (Nykanen, 2011). Description of suitable WH-built fields is also achieved by the integration of numerous overlays and index-based multi-criteria decision analysis (MCDA) variables using GIS that can provide GIS with a range of effective essential decision-making techniques and procedures (Gbanie et al., 2013).

Analytical hierarchy process (AHP) between MCDM approaches is commonly used in different fields of decision-making (Lai, 1995). It provides the product of complex decision-making that is versatile, low-cost and understandable. Hajkowicz and Collins (2007) revealed that AHP is perhaps the technique of most common use in all other methods that are available when considering the application of the MCDM technique for controlling water supplies. Indeed, the global academic community has widely recognized the GIS-based AHP strategy as a strong method to analyse spatial decisions (Rahmati et al., 2015).

Accordingly, MCDM and GIS are implemented in order to enhance site suitability analysis capabilities (Abdulkareem et al., 2018). A Spatial Decision Framework is used for in-depth research with the use of GIS (Abdullahi et al., 2014). Some crucial elements of MCDM include a small range of alternatives and a clear collection of solutions, involving knowledge about the decision-maker's decisions and relying on outcomes (Chakhar & Martel, 2003). When a person addresses an MCDM, the value and weight of the non-substantial characteristics and evaluations of the alternatives must be understood. Simple additive mass, the perfect point form, analytical hierarchy (AHP) and fugitive emblem are the most widely known MCDM models (Noori et al., 2019).

Many site suitability studies were recorded using multi-criteria assessment and analytical hierarchy process in each (Ahmad & Verma, 2016, 2018; Ahmad et al., 2015; Bamne et al., 2014; Banai-Kashani, 1989; Bodin & Gass, 2004; Gavade et al., 2011; Haas & Meixner, 2005; Harker & Vargas, 1987; Salih & Al-Tarif, 2012; Teknomo, 2006; Triantaphyllou & Mann, 1995). As the decision-making method, Analytic Hierarchy Process calculates the percentage value of different criteria in the determination of suitable locations.

The government use regulates the runoff as a means of collecting and storing the rainwater and accumulated rain for a number of purposes (Mzirai & Tumbo, 2010), including irrigation, animal uses, household use, agriculture, drainage and industrial uses.

There are various studies in the world concerning water harvesting and the conservation of water. Some of the past water harvest studies have been discussed in this section. A technique for water harvesting in drought ecosystems from West Asia and North Africa has been developed by Oweis and Hachum (2006). Most rainwater is wasted by dry environmental evaporation, and thus, rainwater production is extremely poor. By using a GIS-based model of suitability, which included integration by Multi-Criteria Assessment (MCE) of different factors the dry spell problem will appear (Ketsela, 2009).

Micro catchments were used to identify ideal water storage areas, using commercially accessible remote sensing instruments and GIS to identify rainwater harvesting areas in the mainland of Zanzibar (Tanzania) and Unguja Island (Munyao, 2010). Micro- and macro-catchments have been used to map and identify various potential impoundment sites using the multi-criteria assessment process through the integration of remote sensing data, GIS and hydrological modulation (MCE). Multi-criteria appraisal approach (MCE). The effect has been evaluated on agricultural development in the Pangani basin catchment area of Chome-Makanya in Tanzania (Mzirai and Tumbo, 2010). Researchers confirmed that, during the dry season, rivers were used as additional irrigation, and the production of crops with rainfall-fed rain was increased by more than 120%.

The management of the water resources includes management of demand and water supply, including conservation of rainwater capturing, groundwater collecting and reservoirs. Depending on the worldwide studies, the world will face water scarcity and Iraq will be one of these countries.

The precipitation in Iraq is very seasonal and takes place in winter between October and May, except the north and northeast parts of the country where precipitation takes place between November and April. The estimated average annual rainfall is from 1200 mm to less than 100 mm in the northeast (Bazza et al., 2018).

The Iraqi ministry of water resources through its management responsibility decided to build 9 large dams and 18 small dams, for the hydrological and related modelling studies, as well as central and field office for water quantity and quality control. The restoration of sealants, including drought and seasonal water shortages, also plays a major role in response to hydraulic disasters. Create a water management plan aimed at rehabilitating drought areas and reducing the likelihood of potential hydrological disasters (UNDP, 2013).

13.2 Data and Methodology

The outcome of this study is based on the various types of data gathered from many sources. The data acquired for the determination of successful rainwater harvesting areas include the ASTER Digital Elevation Model (DEM), Soil Maps, Satellite Imagery Landsat 8 OLI, Geographic Paths, Environment Data and Rainfall (Fig. 13.1).

13.2.1 Study Area

Sulaymaniyah Province is recognized as the densely populated areas of Iraq, and it is experiencing a state-accelerated progress expansion where it is the capital of culture in the Iraqi Kurdistan Region (Aziz & Qaradaghy, 2007). The statistical directorate of Sulaymaniyah (SSD) is responsible directorate for collecting and recording real data on the population and other issues affecting the whole community. However, since the general census was not conducted from (1987) in Kurdistan, SSD relies on data provided by the Directorate of Food Distribution Sulaymaniyah, known as the Food Coupon (SFDD). Often, these details are incorrect (Fulfillment et al., 2013). According to the statistics that we have at the rate of increase over linear and exponential equations, this number is in spite of the huge number of the refugee and IDPs that live in Sulaymaniyah in addition to the people that who get residence to live there and they are from other countries. As well as according to KRSO (2018), the population of the Sulaymaniyah has been estimated by 2014, as its over two million people, and this made me think about this study to calculate the availability and quantity of the water in the city and compared it with the population number (Fig. 13.2).

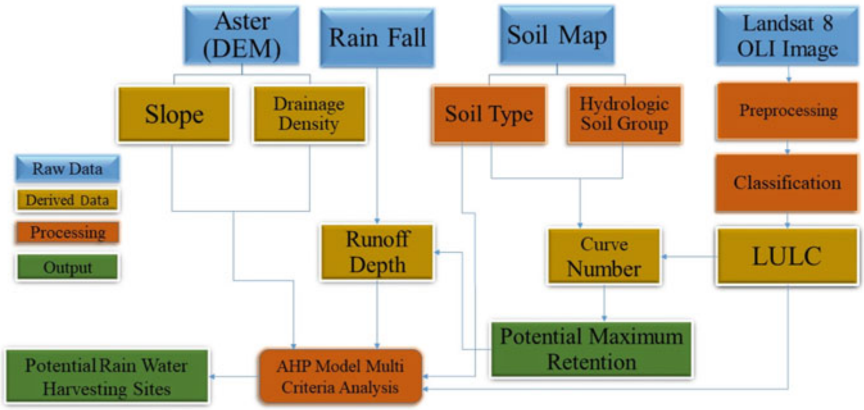

Fig. 13.1 Overall process for identifying suitable sites for rain water harvesting

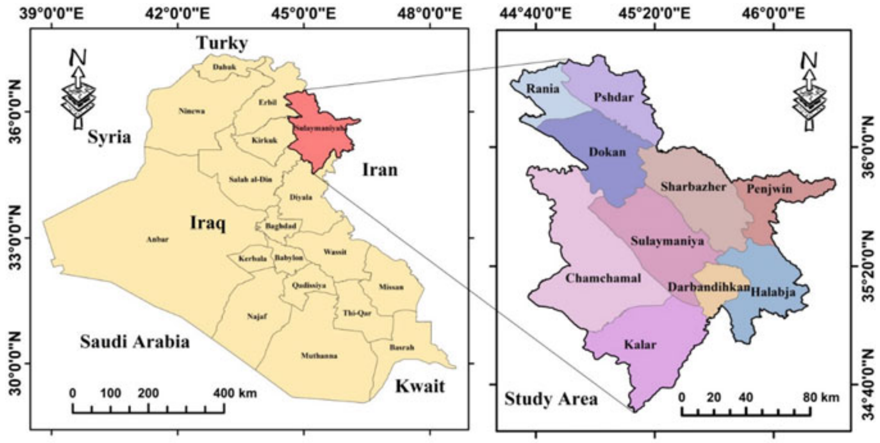

Fig. 13.2 Iraq map shows Sulaymaniyah province with its ten districts

13.2.2 Data

1. The digital elevation model (DEM) was extracted and downloaded from United States geological survey (USGS). The DEM resolution is 30 m, and the format of the raster data is the date of the WGS84 data.
2. Temperature data from 2008 to 2018 were obtained from Kurdistan Region Government of Iraq's ministry of agriculture and water resources.
3. Precipitation data from 2009 to 2019 were obtained from Kurdistan Region Government of Iraq's ministry of agriculture and water resources.
4. North Iraq geology map was obtained from the ministry of industry and minerals (Iraq geology survey). It was revised in 2014 and the chart scale 1:250,000.
5. Soil map of Iraqi was taken from the ministry of industry and minerals (Iraq geology survey). The soil map describes the texture, density and colour of the area. The size of the map is 1:1,000,000.
6. The Earth Science Data Interface 3 images are downloaded from satellite imagery (Landsat 8 OLI). The shot was taken on 26 May 2020 by the satellite. Raster layers resolution of 30 m for six bands, including the 1 to 5 bands, and the seven bands. These details identify the land cover of the field study. The satellite image georeferenced is WGS84 Datum 38N.

13.2.2.1 Software Data

Four programme forms are used in this study including:

(a) ArcMap has been used to digitization and interpolation the data, and to obtain and find out the final maps for the figures and charts.
(b) ENVI 5.1 was used for utilized for pre-processing and treatment (classification).

(c) Microsoft Excel (Plus 2016 version 16.0.4266.1001) was used for the data preparation and analysis.
(d) Microsoft word plus 2016 version 16.0.4266.1001 has used for preparing and writing the thesis.

13.2.3 Preparing Data and Modelling

Five criteria have been selected for the detection of possible water harvesting sites, including runoff, soil type, slope, drainage density and LULC. These parameters were selected on the basis of previous studies by another researcher.

13.2.3.1 Digital Elevation Model (DEM)

Hydrological criteria were obtained using the GIS (ArcGIS 10.4) package. The 30 m resolution digital elevation model can be derived from the accumulation of hydrologic models of stream and slope. Each drain was eliminated in order to ensure continuity of flow to the downstream end prior to the use of DEM for the evaluation of the parameters.

Altitude

The altitude of the sample area was derived from DEM. The height ranged from 166 m above sea level to 3412 m. The digital elevation map after plugs is shown in Fig. 13.3.

Stream Network

The following steps have been made to reduce the accumulation of flow and drain trends:

1. The flow direction defines the flow rate of water to each cell. In order to classify the flow of the central cell directly to its neighbouring cells, it determines its direction using the deterministic 8 patterns (Moghadas-Bidabadi, 2009).
2. The approximate flux increase by measurement of the flux path grid reveals how many cells flow to each cell (gives water). The role of accumulation is important for drainage perception.
3. The cell determination of a threshold for drainage flow accumulation is used to assess streams in the study region with values greater than the threshold. In the flux estimate, the threshold given is compared to each cell's value.

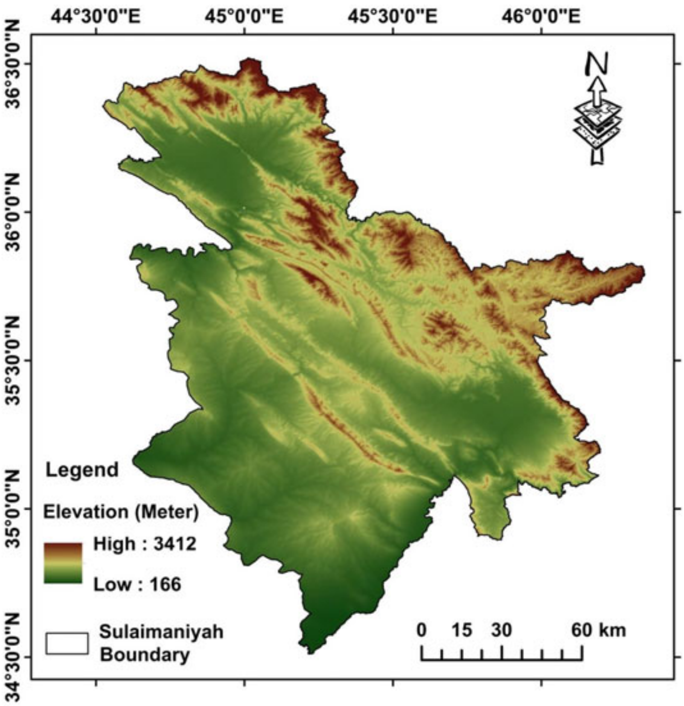

Fig. 13.3 Elevation model of Sulaymaniyah Province

Strahler classification for linking the drainage network is used to assign a numerical order. It can be converted to a vector layer after classification of network drainage. Figure 13.4 demonstrates the distribution of channels in the study area. It is necessary for the drainage system to select the storage area and also to calculate the storage area with a flow accumulation.

In the northern part of the study area, the drainage system is deeper and denser more than the south part, because the northern part is more undulating and more mountainous, giving rivers diversified.

13.2.3.2 Rainfall Analysis Distribution from the Network of Rain Gauges

Precipitation stations in Sulaymaniyah governorate are spread throughout the region of analysis and are arranged accurately for measuring the localized precipitation. Measurements of rainfall points reflect monthly values from 2009 to 2019. In areas with no rainfall point measurements, interpolation was used to estimate rainfall. To interpolate the precipitation for the region, 11 rainfall stations are used. Figure 13.5 illustrates the rainfall.

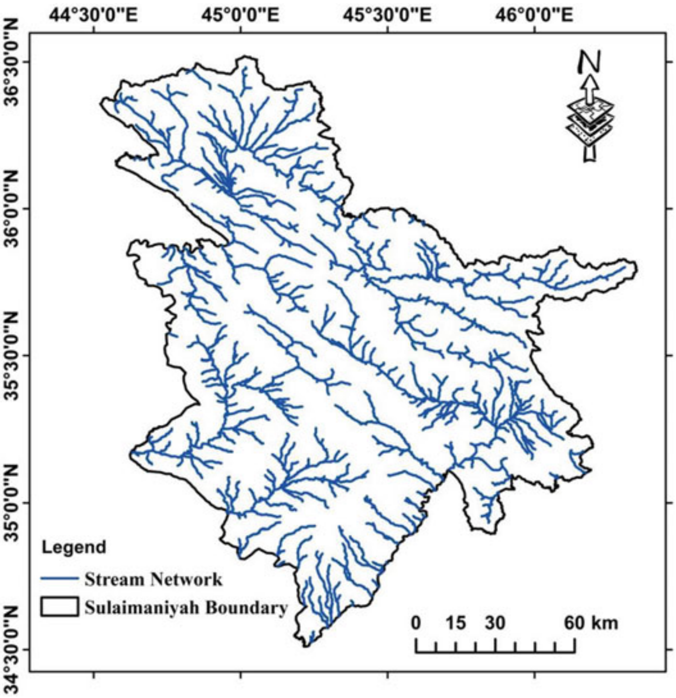

Fig. 13.4 Stream network of Sulaymaniyah result from flow accumulation

13.2.3.3 Drainage Density

The drainage density seems to be the total length of the rivers and streams determined by the scale of the overall drainage basin. It is a measure of how efficiently a waterfall drains or how badly it drains through a channel stream. The channel is the reciprocal of the channel management constant, and the reciprocal of the overland flow is two times long (Choudhari et al., 2018).

$$DD = \frac{\sum_{1}^{n} L}{A} \tag{13.1}$$

where

DD Drainage Density
L Stream Length
A Basin Area.

According to Abd Manap et al., it is influenced by the existence and composition of geological formations, the potential for soil absorption by precipitation, the vegetation type, the rate of infiltration and the angle of slope. It has to do with the permeability of geological material in the reverse direction. The higher drainage

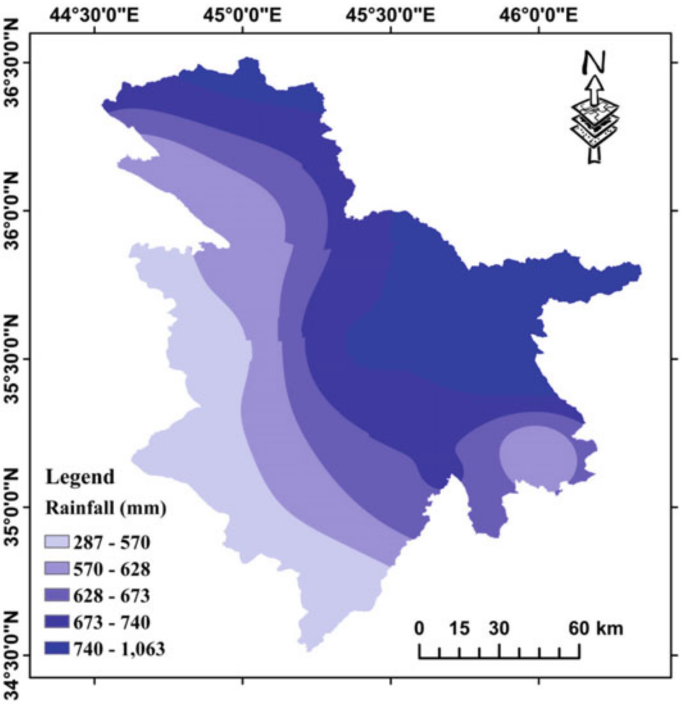

Fig. 13.5 Average annual rainfall spatial distribution in Sulaymaniyah Province

density, the larger the surface is, the less possible it is to recharge the soil. Mandal et al. (2016) demonstrated that the area with low drainage density is more suitable for the possibility of a good groundwater regeneration and higher weight should be assigned to it. Drainage density was calculated in the sample area using Kriging density estimation techniques. It was divided into five groups and weighted on the basis of its importance in the selection of suitable groundwater storage sites (Fig. 13.6).

13.2.3.4 Slope

The slope is created by a topographical proportion, which would be the connection of height differences of the two points divided by a horizontal straight line of two points (de Winnaar et al., 2007a), and the course is taken from FAO. Description of the digital elevation model (DEM) is listed as five percentage categories (de Winnaar et al., 2007b). Table 13.1 indicates the identification of the pistes in 5 positions.

Steep slopes are a very critical consideration for the distribution and implementation of precipitation. High-rain mountainous regions are known as suitable high-runoff regions (de Winnaar et al., 2007a). The slope of the study area according to

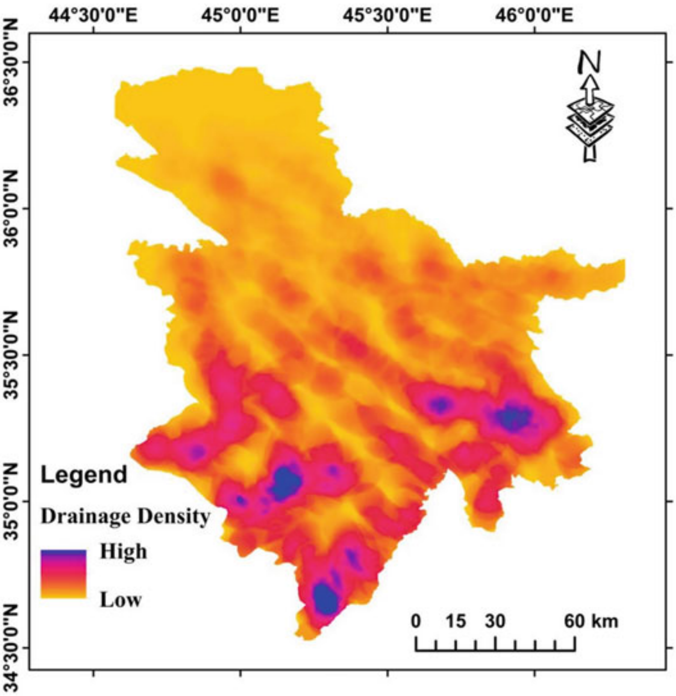

Fig. 13.6 Drainage density of Sulaymaniyah province

Table 13.1 Slope classification

No.	Slope class	Slope (%)
1	Flat	< 2
2	Undulating	2–8
3	Rolling	8–15
4	Hilly	15–30
5	Mountainous	> 30

de Winnaar et al. (2007a)

FAO is shown in Fig. 13.7. The research zone has moderate paths in the southwest, with steep hills and deep valleys in the north and northwest.

13.2.3.5 Land Use-Land Cover

Land cover was obtained from 30 m space resolution from satellite imaging (Landsat 8) recorded in May 2020. The land cover was derived using ENVI software. A supervised grouping added a separate land cover-land use type. Three classes of people were used for training site identification (Senf et al., 2015) in integrating fake

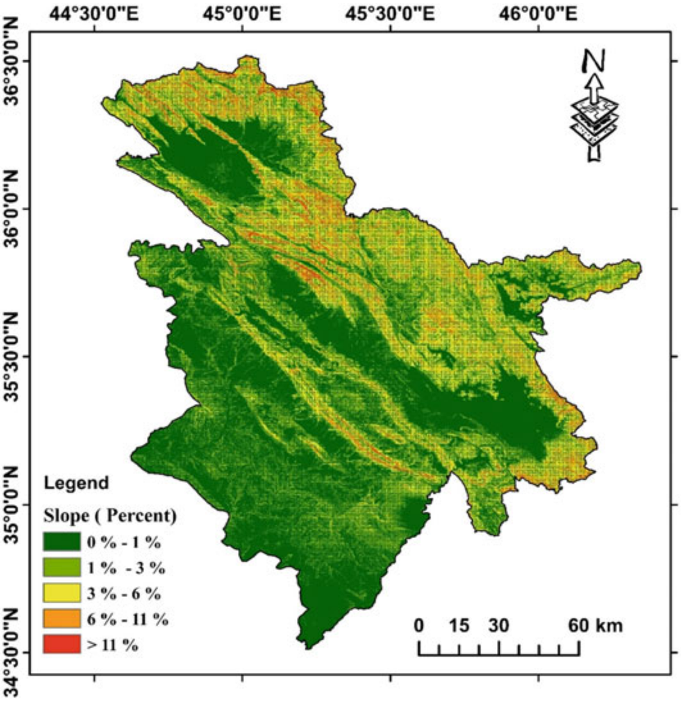

Fig. 13.7 Slope classification of Sulaymaniyah governorate

colour composite pictures with a reference map and the Google map. An example of an educational class such as urban, agricultural, greenery, water and bare soil is a training site according to the scheme of Anderson level 1. Expectations for each knowledge class were generated through the training site characterization. For classifying ground cover, the highest likelihood algorithm was used.

The study area was utilized by four classes of land cover: bare land, urban, water and vegetation (Fig. 13.8). When choosing suitable areas to pick water harvesting sites, ground cover is a significant parameter.

13.2.3.6 Soil Map

Raster soil has been preserved (JPG) in appreciation soil of the three northern provinces in the Kurdistan Region's soil chart. In the geo-reference soil map, ArcGIS 10.4 was used and then translated to vector data. However, in the region under analysis, 9 groups were found as shown in Fig. 13.5 (Buringh, 1960).

In the plain and mountain areas, the shape and colour of the soil are distinct. Strong clay sand, loam silt and silt mud, and maximum depth 140 cm are the composition of the soils in the plain areas. The soil colour ranges from light yellow to dark brown.

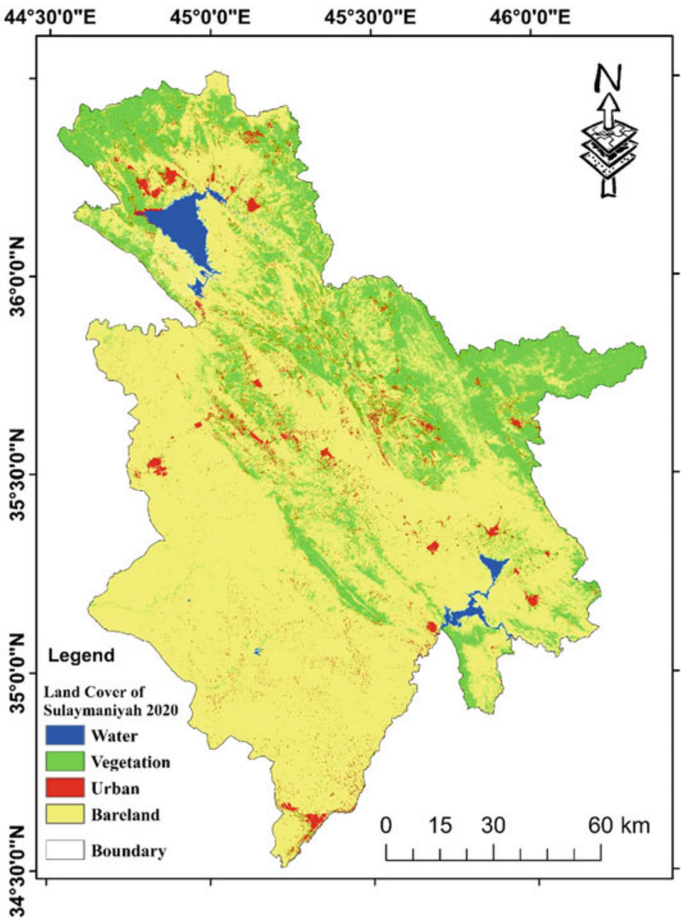

Fig. 13.8 Sulaymaniyah land use-land cover

The soil textures are sandy mud, loam silt or loam clay sand in the mountainous areas with an average depth 130 cm. Both light and dark light have a floor colour. The Iraq soil chart based on northern Iraq is shown in Fig. 13.9.

13.2.3.7 Soil Conservation Service—Curve Number Model

Estimated runoff depth is a significant factor in the assessment of suitable site for rainwater harvesting. After a flood (Melesse & Shih, 2003), the runoff depth is used to test the available water source. The soil conservation service and curve number (SCS) modelling were used to approximate the runoff depth in the sample area. The ground cover chart was obtained from remote sensing. ArcGIS 10.4 was used to compute

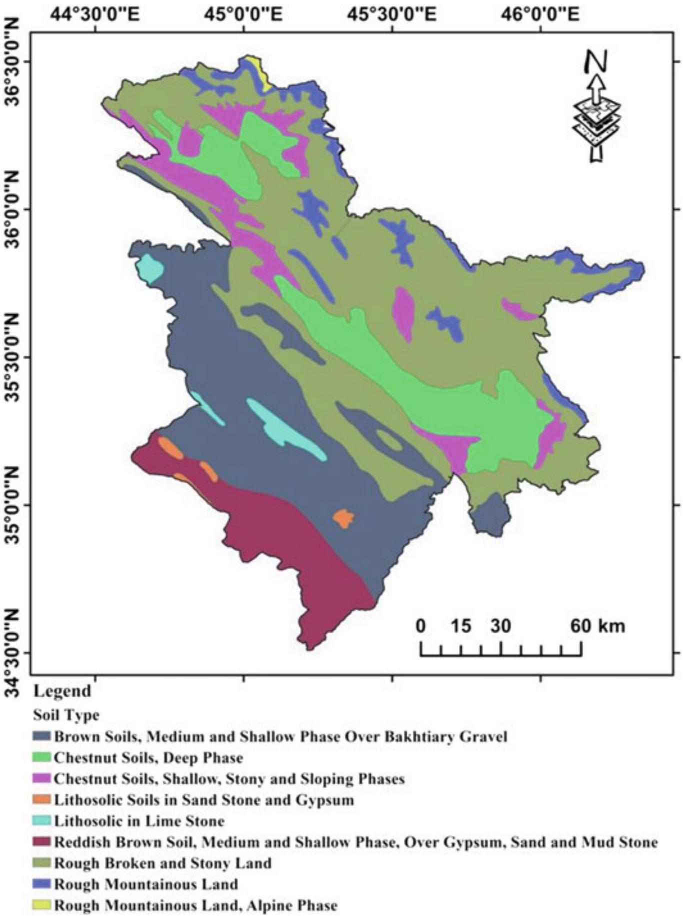

Fig. 13.9 Soil map of the study area

precipitation data and digitize the soil chart of the study area. The efficiency of soil communication system was used to determine the runoff depth from the precipitation for the preparation of water harvest (Gupta et al., 1997). The equation of the soil conservation service model can be expressed as below (McKinney et al., 1993).

$$Q = \frac{(P - \mathrm{Ia})2}{(P - \mathrm{Ia}) + S} \tag{13.2}$$

where

Q runoff depth (mm)
P rainfall (mm)
S potential maximum retention after runoff starts (mm)

Ia initial abstraction (mm) its standard taken from TR55.

Primary abstraction requires all lose before runoff, evaporation and vegetative interception water. By analysis of rainfall estimation, Ia = 0.2*S* (Melesse & Shih, 2003) as assigned to several small field basins. Therefore, it is possible to express soil conservation service equation in the following terms:

$$Q = \frac{(P - 02S)2}{(P + 0.8S)} \tag{13.3}$$

By using the curve number (CN) in Eq. (13.4), the potential maximum retention after runoff starts can be calculated (*S*) (Melesse & Shih, 2003):

$$S = \frac{254{,}000}{(\mathrm{CN})} - 254 \tag{13.4}$$

The strategy of the soil conservation service (SCS) focussed on runoff curve number (CN). The effect of soil and land cover on precipitation processes is calculated at the curve number. The number of curves (CNs) ranges from 1 (100% absorption by rain) to 100. Lower curve numbers indicate lower runoff, while the higher curve numbers indicate higher ripples and runoff values (Melesse & Shih, 2003).

13.2.3.8 Estimating Curve Number

Curve number used to identify drainage resources for a particular land cover-land use. The curve number value is used as an input parameter in the soil preservation service runoff equation. For the study area, a pixel-by-pixel estimated number is calculated via the map on the land and the land map that was reclassified in soil hydrology and hydrology as shown in Table 13.3. Infiltration relies on the soil feature that influences precipitation and runoff. In compliance with a United States Geology Study (UNGS), land use and property classification method (A, B, C and D) (McKinney et al., 1993). Soil management project model separates all properties into four hydrological soil classes. The classification of soil hydrology depends on penetration and various soil composition (Melesse & Shih, 2003). The hydrologic soil groups on the basis of the USGS classification system are defined in Table 13.3. In the study area alone, classes B, C and D have been found (Table 13.2).

Hydrological soil groups of the study area can be found in Table 13.2 (see Sect. 2.3.7). However, the hydrological soil groups in the study area are illustrated in Fig. 13.8.

High runoff ability is found in the northern part of the area because this zone is stony and low infiltration with mountain terrain. The colour of the soil is clay or clay silt. There is a mild runoff opportunity in the south of the sample region, as the soil types in the area range from undulating to plain. The colour of the surface is loam silt (Fig. 13.10).

Table 13.2 Soil groups and corresponding soil texture

Soil group	Runoff description	Soil texture
A	Poor runoff capacity due to high infiltration rates	Sand, loamy sand and sandy loam
B	Moderate infiltration rates contributing to reasonable runoff capacity	Silty loam and loam
C	High/moderate drainage capacity due to slow penetration speeds	Sandy clay loam
D	High runoff capacity at very low infiltration rates	Clay loam, silty clay loam, sandy clay, silty clay and clay

McKinney et al. (1993)

Table 13.3 Runoff curve number for combinations of different land cover and hydrological soil groups

Land cover	A	B	C	D
Bare soil	77	86	91	94
Other agriculture	49	69	79	84
Urban	77	85	90	92
Water	97	97	97	97

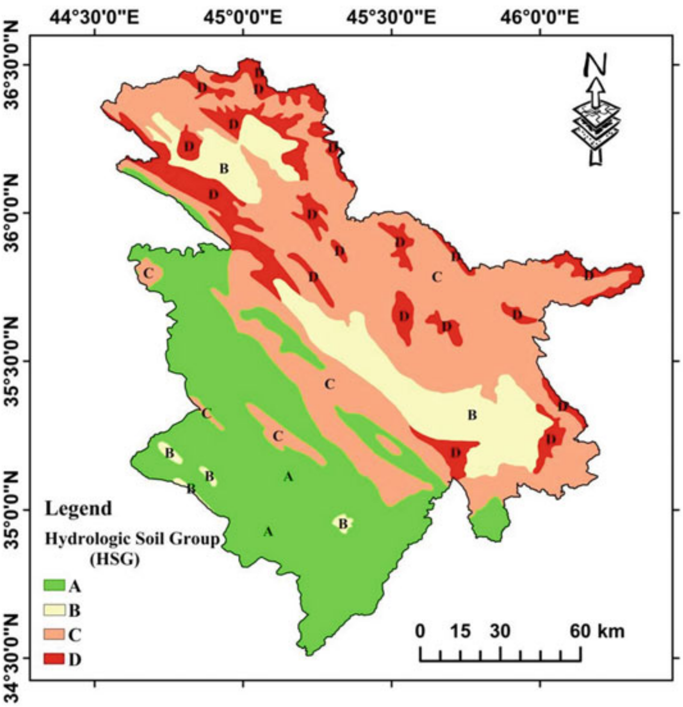

Fig. 13.10 Classification soil map into hydrologic soul group (A, B, C and D) in the study area

Table 13.4 The intensity of relative importance

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

Drobne and Lisec (2009)

There are many factors that affect the hydrological conditions and have a close relationship with them such as land surface cover, drainage and reflection and the surface conditions in the basin (Munyao, 2010). In accordance with the map of the hydrological soil group in ArcGIS, the land cover given in Fig. 13.6 can be used to align the hydrological soil group with land cover (see Appendix 1). Values of curve numbers from Appendix 2 are depending on USGS method (A, B, C and D).

This led to the production of curve numbers using the U.S. Land Deck (USGS) and hydrologic soil group system (McKinney et al., 1993). Table 13.4 (Ebrahimian, 2012) presents the curve value of the number of each hydrological group of soils and the corresponding land cover class. A high curve number value (for example, 94) refers to an area with high-runoff potential and low infiltration. A low curve number value (such as 49) suggests a region with a low runoff and high infiltration potential.

13.2.3.9 Evaluation Runoff Depth

After developing maps of curves showing initial rainfall abstrusion through vegetation and soil, the next step was to measure the maximum theoretically retaining value. Equation 13.4 determined the value of S for each pixel. Then, in Eq. 13.3 we used S to find the depth of runoff.

13.2.3.10 Evaluation of Rainwater Harvesting Sites

For determining potential rainwater harvesting areas, not all factors have the same importance. Consequently, for the various factors, various weights were listed. The suitability of the site for rainwater depends upon a range of potential sites determining the best site by evaluating all of the sites' characteristics. The weights of the parameters known as the analytical hierarchical method (AHP) are calculated by the paired comparison. This methodology is focussed on the application of various parameters

(Drobne & Lisec, 2009). Analytical hierarchy process identifies the potential site for rainwater using the multi-criteria assessment module (Al-Subhi Al-Harbi, 2001). In choosing and specifying suitable locations, ArcGIS ecosystem has effective planning and decision-making instruments.

13.2.4 Multi-criteria Decision-Making (MCDM)

GIS is not only a decision-making process, but is a method for decision-making. For that purpose, GIS analytical capabilities in site adaptation must be incorporated in weighting or decision-making technologies such as Multi-Criteria Decision Methods (MCDM). GIS is used for detailed research in the sense of a space decision, on the other hand, while the MCDM compares the set of specified choices (Joerin et al., 2001). Via the Boolean protocol or weighting procedure, MCDM may help achieve results as a fitting map for the particular objective (Fung & Wong, 2007). MCDM is a vital option since the effects are heavily influenced (Al-Shalabi et al., 2006). In accordance with the MCDM's characteristics and functionality, the specificity of the judgement issue can be identified (Abdullahi et al., 2014; Salminen et al., 1998).

13.2.4.1 Selection Criteria

The criteria are focussed on the availability of data in the field of study. The runoff depth requirements for each pixel are highly significant in deciding which region has more rainwater than in other areas (Tsiko & Haile, 2011). Various slope types influence the infiltration and runoff volume, thus rainwater harvesting is strongly dependent on the type of slope (Munyao, 2010). The rainwater harvest should not exceed 1% in a macro-catchment (Tumbo et al., 2006). High drainage density in an area with adequate rainfall leads to higher runoff. The density of drainage is also a function of the method for collecting water. The study has used runoff, slope, drainage network and land cover type of soil to determine the water conservation potential of certain areas. It has used a model using soil conservation service (SCS) model to measure the runoff depth at each pixel. The amount of rainwater collected in each pixel was determined by measuring the amount of water in the infiltration rate of each pixel and the soil texture (Tumbo et al., 2006). It was also determined by the size and distance of soil particles that regulate water movement.

13.2.4.2 Analytic Hierarchy Process (AHP)

AHP is one of the most widely used methods for multi-criteria evaluation (MCE). AHP has been used in a wide range of practical applications in various areas, including site selection (Abdullahi et al., 2014; Drobne & Lisec, 2009). All considerations do

Table 13.5 The pairwise comparison matrix

	Runoff depth	Slope	Soil texture	Drainage density	Land use
Runoff depth	1	2	3	4	5
Slope	0.4	1	2	3	4
Soil texture	0.36	0.4	1	2	3
Drainage	0.3	0.3	0.4	1	2
Land use	0.2	0.3	0.33	0.4	1
Summation	2.28	4.4	6.8	10.5	15

not have the same significance for the assessment of future dam site location. As a result, different level of value was established for the various variables.

Multi-attribute Decision Analysis

There are various approaches for combining decision-making into a multi-criteria decision analysis. The weighted linear combination (WLC) is used in this thesis to calculate the sum of the weighted parameters. An empirical hierarchical technique, known as a pairwise comparison, is used to apply the WLC process. The weighted linear combination is performed in two steps within the GIS environment: first, the weights associated with the mapping layer parameters are determined and, second, the preference for all hierarchical tiers, including the alternate category, is combined (Drobne & Lisec, 2009).

Selecting Criteria Weights

Therefore, it is useful for decision-makers to consider the relative importance of the parameters. Decision-making with several parameters involves different considerations. The decision-making mechanisms are focussed on the weight of each factor and are the key step in assessing the weight (Drobne & Lisec, 2009). To gather the weights of the parameters, the multi-criteria evaluation (MCE) module is used. In the study, the review process is a contrast in pairs (AHP). This approach was by Saaty (1977), and each vector can be measured in pairs using the research method. The weight of the parameters in Saatys technology is determined by adding a square matrix of reciprocal equalization of the two variables (Drobne & Lisec, 2009). The comparison by pair compares two parameters to decide which condition for a given function is more relevant than another. Table 13.5 indicates the two-criteria rating (Drobne & Lisec, 2009; Saaty, 1977).

The following measures should be taken into consideration to determine the weights of the criteria:

Table 13.6 Normalized matric calculation

	Runoff depth	Slope	Soil texture	Drainage	Land use	Weight (%)
Runoff depth	0.44	0.45	0.44	0.38	0.33	*0.41*
Slope	0.22	0.23	0.29	0.29	0.27	*0.26*
Soil texture	0.15	0.11	0.15	0.19	0.20	*0.16*
Drainage	0.11	0.08	0.07	0.10	0.13	*0.10*
Land use	0.09	0.06	0.05	0.05	0.07	*0.06*

1. Build a corresponding matrix of the parameters. The definition of the pairwise comparison matrix is seen in Table 13.5, which applies to the intersection of the same parameters in the raw column as seen in the diagonal of the matrix (grey colour). The C1.3 cell applies to the value of criteria 1 rather than criteria 3. Determine the number of the values in each column of pairwise matrix in this step. In this study, five criteria were considered and priority was given to the criteria set out in the previous studies and to the opinions of the expert by means of a questionnaire to be explained later in this chapter. As well as, the sub-criterion of each of the major variables is often assumed the same as the main criteria.
2. A questionnaire has been done to collect and record information on a particular issue. It consists of a list of questions with providing clear instructions and room for answers and administrative information. We did the questionnaires for a specific purpose that related to the goals of research, and we use the findings clearly from the start.

Quantitative and qualitative research, i.e. numerical research (how many? how often? how satisfied?), normally relates to structured questionnaires. Frameworks can be used in a number of survey situations, in this context.

In this analysis, the questionnaire is structured to provide an opinion on the weight ages of environmental evaluation parameters and the importance of some experts who have know-how in various fields of study. This questionnaire consists of a matrix for comparison in parallel in this analysis and the experts who assign preference to the element (see Appendix 3).

3. The normalized matrix is computed in this step. To fill the values of normalized matrix, divide each cell in the pairwise matrix by its total column (see Table 13.6). The sum of each row is then determined from the resultant in Table 13.6. These ratios are the proportional weights of the parameters.

Estimating Consistency of Pairwise Comparison

The specificity of the relationship is determined by the compatibility ratio (CR) measurement (see Eq. 13.5). For measuring the relative weighting of each parameter, the precision ratio is used. The precision ratio is the relationship between the Consistency Index (CI) and the Random Index (RI). The comparison of the variables

Table 13.7 Average random consistency index (RI)

Number of criteria (n)	1	2	3	4	5
Random Index (RI)	0	0	0.58	0.9	1.12

Drobne and Lisec (2009)

is appropriate if the precision ratio is less than 10%. The accuracy ratio otherwise causes comparisons to be re-evaluated.

$$CR = \frac{CI}{RI} \tag{13.5}$$

The Random Index (RI) can be retrieved from a particular table prepared by Saaty (1977), based on the order of the matrix. Table 13.6 displays the values of the random variable by the number of parameters.

To obtain the consistency index (CI), we follow this way (Table 13.7).

Multiply the weight of the first criterion (runoff depth = 0.41) in Table 13.6 by the total of the first column of the original pairwise comparison matrix which is equal to 2.28 in Table 13.5. Then, multiply the weight of the second criterion (slope) by the total of the second column of the original pairwise comparison matrix. Repeat this procedure for all weight criteria. Finally, the summation of these values gives the consistency vector ($\lambda = 5.11$), which is used to compute the consistency index according to Eq. 13.5.

The consistency index (CI) has been calculated by using Eq. 13.6:

$$CI = \frac{\lambda \max - n}{n - 1} \tag{13.6}$$

where

λ max (Weight1 * $S1$ + Weight2 * $S2$ + Weight3 * $S3$ + …)
n number of criteria.

The value of the consistency index from the above process is 0.027. We applied consistency ratio equation (CR) of this study and the result is 2%, which is less than 10%, so the comparison between the factors is acceptable, while if the CR rate is more than 10% the comparison between the factors will be not acceptable and we should recheck the work.

13.3 Results

In this study, an Adequacy Map was created in the ArcGIS setting using the AHP tool and graded into five suitability classes: bad, medium, decent and very high satisfaction. The resulting map reveals that the central and southern regions are ideal

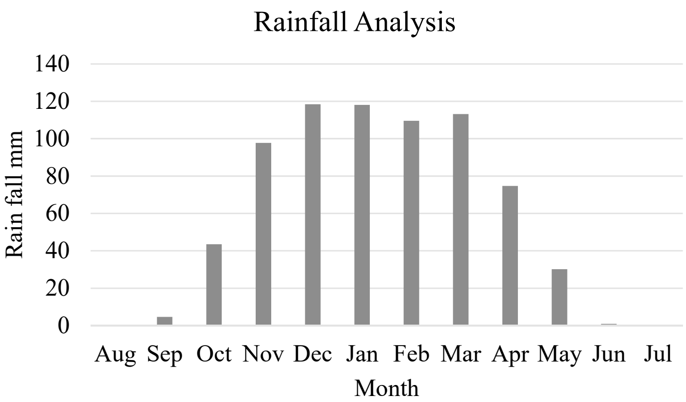

Fig. 13.11 Average of monthly rainfall in the study area 2009–2019

for rainwater harvesting potential areas. The proposed rainwater collection sites are made from highly desirable locations. However, some regions of the North part, some areas of the North East and some parts of the Northwest in the study area are listed as less acceptable and suitable.

13.3.1 Rainfall Analysis

The weather in the study site between the Mediterranean and the warm steppe climate is changing. Moist and dry conditions for this climate are typical (Kahraman, 2004). The typical 10-year data shows the season of precipitation indicated from October to May. Between June and September, the dry season takes place. Figure 13.11 shows the average rainfalls per month for 2009–2019. The global average annual runoff from December to April in the high rainy season to the rate of 75%. The short rainy season between May and June and September and December adds up to 25% to the usual runoff year, while the rainy period in July and August is almost zero.

13.3.2 Potential Runoff

The runoff potential in the study area for regular rainfall years was divided into 5 layers which were not appropriate (> 813 mm), less appropriate (662–813 mm), appropriate (529–662 mm), quite appropriate (404–529 mm) and suitable (< 404 mm). Fuzzified runoff depth layer map reveals that a large part of the sample region is very suitable for extremely suitable applications. A substantial portion of the research area is also ideal for the storage of rainwater in terms of runoff depth.

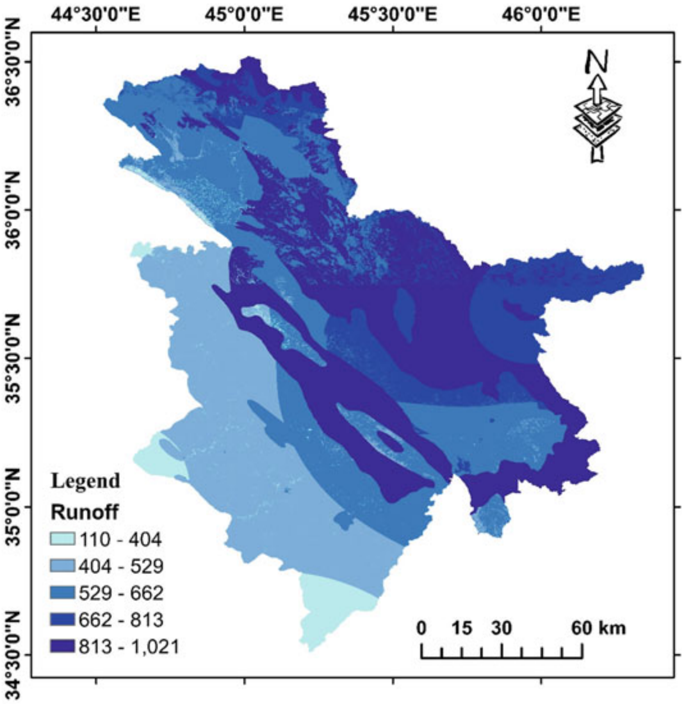

Fig. 13.12 Potential runoff map

However, some of the eastern, northern and north-eastern regions of the study region are less suitable for rainwater harvesting (Fig. 13.12).

Curve numbers (CN), based on the use of equations, are obtained to classify the potential runoff. The curve number is based on two multivariate constructs, namely the land use group and the hydrological soil group (HSG).

The HSG map is drawn up from the manual TR 55 soil series. Depending on the penetration and drainage capacity, the soil is classified into four classes A, B, C and D known as HSG. The key features of HSG (Weerasinghe et al., 2011) are set out in Table 13.3. The scale of the HSG area is seen in Fig. 13.10.

13.3.3 Soil

Soil map of study area shows 9 main groups as seen in Fig. 13.9, and the major portion of the area was covered by rugged fractured and stony ground, spread over 7158 km^2 in the central and southern sections of the study country. The next main soil groups are grey, medium and low over 4353 km^2, followed by chestnut, which covers 2226 km^2 in the 3rd section. Bakhtiary gravel 4353 km^2 four reddish-brewed soils, medium and shallow level, in a patch covering an area of 1418 km^2 of gypsum, sand and dung stone are extracted. The chestnut soils, shallow, stony and sloping phases occupy 1196 km^2. The rough mountainous and lithosol soil in the limestone occupied 744 km^2 and 234 km^2, respectively. The last section covering the lithosoil bit region is sandstone and gypsum soil and rugged mountainous terrain, alpine process 94 km^2 and 28 km^2. The fuzzified existing soil outcome has also shown that some areas of the area of study are from an exceptionally suitable class for RWH, except in the central mountainous zones, the northern, north-eastern and some western parts of the study.

13.3.4 Slope

The findings for fuzzification showed that the most southern and central portion of the sample region is < 1, which is very fine for RWH. However, significant part of the research area in eastern and north regions are more than 11 fluctuation values, which is considered not suitable for water harvesting. The area's pathways were classified into five-pitch grades, including approximately 0–1%, mild 1–3%, fairly smooth 3–6%, fairly steep 6–11% and very steep > 11%, respectively. In eastern and southerly regions, as well as the central section of the areas, the higher altitudes are covered, such as the Mount, which creates steep slopes in the northern part. Certain central parts of the study area to the southwest are appropriate for RWH (Fig. 13.7).

13.3.5 Drainage Density

Drainage density ranged between 1.5 < and > 2/km^2 within the sample area. The findings of the fluctuation in the drainage density show that the south and western areas of the research region are highly well matched. In the southeast and the north of the study area, though, unique regions are less fit. The area with broad irrigation surface densities is less favourable for collecting rainwater on the ground surface and is thus superior to low surface drainage area according to the point of view of rainwater harvesting as shown in Fig. 13.6.

13.3.6 LULC

The LULC map of the area is classified into four categories, such as bare land, water, urban and vegetation. The largest part of the study area of 125,552 km^2 is covered by bare soil, followed by vegetation of 3703 km^2 and urban area of 854 km^2 and the remainder by water of 313 km^2. Fuzzified LULC map reveals that the central and southern sections of the study show vegetation and bare land ideal for rainwater harvesting, while the area under the settlement is fuzzified as not appropriate with membership value 0 as shown in Fig. 13.8.

13.3.7 Rainwater Harvesting Potential Map

Runoff depth, slope, land use-land cover, soil texture and drainage density combined in multiple capacities provided appropriate units for assessment of rainwater development sites. ArcGIS used a multi-criteria appraisal (weight linear combination) in a model constructor in the criterion layers. Map shows the possible sites for rainwater harvesting in the Sulaymaniyah Governorate (Fig. 13.13).

The multi-criteria evaluation study contributed to assessing general rainwater harvesting suitability zones. Five comparable units suggested alternative locations for water collection: excellent, very good, good, moderate and poor. The constraint area (built-up layer) was not the required area. Figures 13.13 and 13.14 show possible rainwater collecting sites and the proportion of the area that is protected by numerous water harvesting suitability areas.

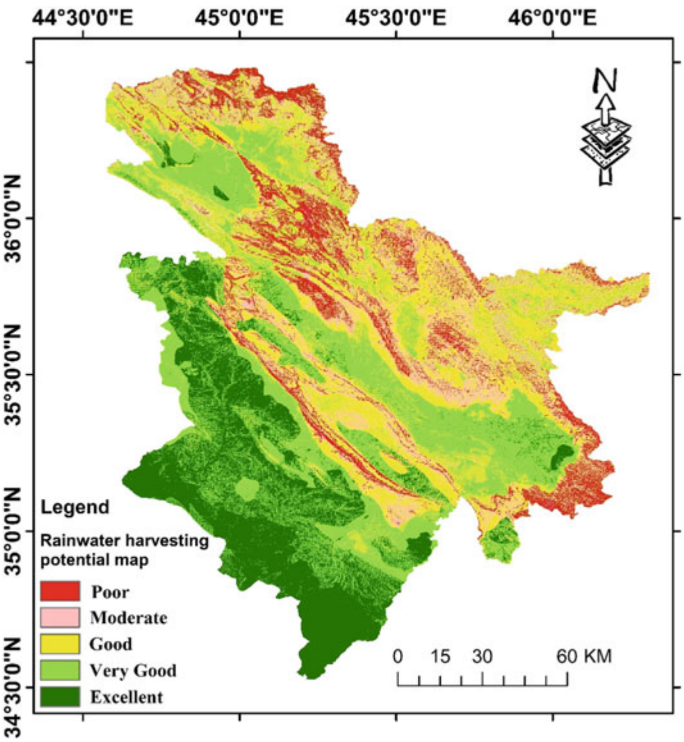

Fig. 13.13 Rainwater harvesting potential map for the study area

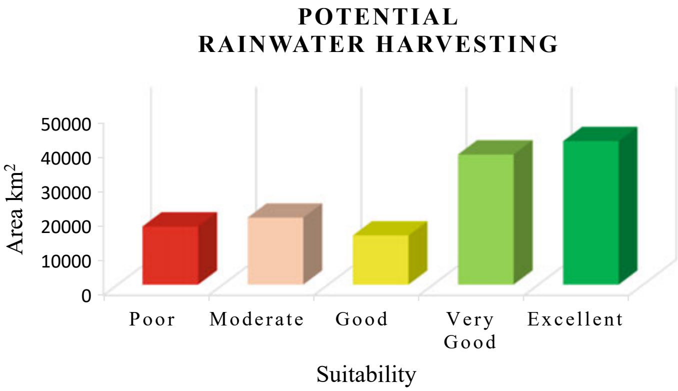

Fig. 13.14 Percentage of areas suitability for rainwater harvesting

Most northern areas of the study region were determined to be not ideal for the collection of water. The northern area is clearly concentrated in the steep slopes and thick hydrological system. High above 529 m and steeper than 11% on slopes are the key areas decided as acceptable areas for water development. In the southern part of the research, region are the main areas that are known as a medium- and medium-aptitude regions. These areas are less than 529 m long and less than 6% on the slopes. Areas with low to very low water harvest suitability are more influenced by runoff depth and slope than by other criteria. Future water harvest sites map indicates that nearly 79,557.42 km^2 of desirable and highly acceptable areas are protected. There are nearly 36,518.16 km^2 of low and low-fit areas, while the moderate area of fitness is just 14,346.42 km^2.

The areas are not recommended for RWH and its poor area 13%. Also, 15% is rated as moderate. As well as 11% of the total area is considered as good. The very good area that is extracted for water harvesting is 29%. The rest 32% are exceptionally excellent for collecting rainwater.

13.4 Discussion

The acknowledgement is a multi-objective and multi-criteria issue of a suitable site for water collection in the study area. This research varies from other experiments in the amount of determining factors used such as rainfall, slope, soil texture, DD and LULC. The five factors are used to assess suitable water locations. In this study, the amount and weight of each factor depend on the number and percentage of the use of each factor in the literature papers.

Multiple dependent variables, such as land cover, soil texture, slope, drainage density and runoff, were considered for multi-criteria assessment, land cover was taken from a 30-m LANDSAT satellite image. The Iraq Kurdistan Governorate soil map has been digitized. Pitch 2 of the slope was drawn by the digital elevation model. A digital elevation model was derived from the drainage density map. Furthermore, the soil control model was used to assess the depth of runoff in the study area. The parameter values have been reclassified from zero to one to hit a single 30 m standard on each sheet as numerical values.

The current study produces the future selection model for rainwater sites by identifying more influential and appropriate variables to select possible sites using the AHP modelling method. The correlation coefficient between factors listed was near zero for most of the variables, which implies, excluding rainfall-runoff correlation, that there is no structural codifying between the variable. The surface rinse is an important hydrological measure in surfactants and associated experiments.

The research proposes an optimized approach to modelling the spatiotemporal pattern of runoff areas with remote sensing feedback and GIS-supporting data using the SCS-CN-model (Kumar & Jhariya, 2017). In this form of hydrological analysis, integration of RS and GIS is a successfully applied solution (Haile & Suryabhagavan, 2019; Shamsi, 2005).

The selecting acceptable sites by reducing the water's flow rate, encouraging the sediment to settle and minimizing erosion can be made. This ensures that land and water are covered (Potter & Zhang, 2009). Underneath the rinse field, percolation tank sites with an earth gradient of 3–6% that allows water to percolate across layers were identified. Percolation tank is valuable to the environment when the water flows continuously and steadily into an aquifer (Wang et al., 2011).

The zone of excellent to very good groups was mostly populated with land slopes between 0 and 6 °C. The current geological and geomorphological characteristics make a high level of water penetration and groundwater regeneration.

The method used in this study was RS and GIS techniques and is of great significance and benefits to the management of water resources in the Sulaymaniyah governorate and elsewhere in Iraq. The SSGWR maps are useful for the management and protection of water supplies and identify suitable locations for different methods of water harvesting.

13.5 Conclusion

Choosing an appropriate water harvesting location in most of the world's cities is an important task. The most popular tools for these purposes are remote sensing and GIS. Remote sensing offers data and knowledge on the research region while GIS involves spatial processing and simulation in order to generate appropriate locations. In addition to the devices, a process or technique for determining the conditioning factors leads to water harvest suitability at the field. Decisions based on AHP are among the common techniques used in literature. AHP and the decision-making mechanisms have been incorporated into this study. The weights subsequently came from decision-making models, and the appropriateness maps were developed in GIS. The model was analysed and compared with a new methodology.

In Sulaymaniyah area, the model for the conservation of the soil was applied to estimate the river depth using average annual rainfall from 2009 to 2019. The precipitation study reveals that a considerable annual depth of rainfall can be harvested. The outcome shows that the runoff depth volume is greater than the reservoir water storage capacity. These excess water volumes guarantee that the rainy season tanks are filled. The findings also reveal that the volume of rush in the north and the south portion of the sample region is very different. The mean depth of runoff in the south section is about 110 mm, while the estimated depth of runoff in the northern section is more than 1000 mm.

In conclusion overall, the highly suitable regions are 32% of the area and 29% of the area are suitable. As well as 11% of the area are fine. While the remaining 28% is less and not desirable. In this case, we can benefit from this huge amount of the potential area for water harvesting and using the stored water for domestic, industrial and animal use, as well as facing the problem of desertification and using it for agriculture. Rainwater development should be extended by a field analysis because the geographical reach of the survey does not guarantee that all locations in a zone defined as low-level areas are still low-level areas. Any location in the region identified as suitable does not mean that it is appropriate, as some of these locations may be socially influenced by enclosed areas, small villages or other hydraulic factory systems.

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Chapter 14
Futuristic Climate Change Impacts on Rice and Groundnut Production Over Tamil Nadu State, South India

D. Rajalakshmi, Dhanya Praveen, R. Jagannathan, and V. Geethalakshmi

Abstract Climate change that we are experiencing nowadays is an unprecedented change that is challenging not only human survival but also all living organisms including plants. Now, we are at a tipping point that there should be some adaptation and mitigation interventions to be coined and followed for the sustainable development. Agriculture is an important sector that definitely needs the standard operating procedures for feeding the existing and growing population amidst futuristic climate change. As the crop production is mainly dependent on the weather and climate, the impact of climate change knowledge would be an advantage to take informed decisions. In the current chapter, we discuss the research findings and reviews regarding the futuristic climate change on two major crops, rice and groundnut of Tamil Nadu state in India. The future impact assessments and adaptations for the crops, rice and groundnut projections for future decades, are explicitly discussed using the crop simulation models output by various researchers. The crop yield predictions based on the outputs from the crop simulation models indicated that the yield of these crops decreases due to the increase in temperature, but when we consider the carbon dioxide fertilisation effect, the declining yield for both the crops showed a minimising trend. Sowing date adjustments are one of agronomic adaptations to offset negative impacts. The increasing trend for some decades despite the increase in temperature was due to the nature of the C3 crops that has high carbon dioxide compensation point. After assessing the impact, this review also focuses on the existing and suggested adaptation strategies proposed for climate resilience. This information can assist the decision-makers in selecting an appropriate and climate smart strategies to ensure food security, minimising climate risks and sustainable agriculture development in the futuristic climate.

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Keywords Climate change · Impacts · Rice and groundnut · Tamil Nadu · Adaptation

14.1 Introduction

Climate is a single factor that determines the distribution of living organisms on earth like the atmosphere that determined our mother earth as the only habitable planet till date. Climate change in a simple term is the change in average weather that happens due to natural or human-induced activities. There are several definitions available for climate change. According to UNFCCC, "Climate change" means 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 periods. When we speak about climate change, it is no more a content in the text books, but we are experiencing them that are evident from the extreme events that are occurring in short return period around the globe. The present generation is at the tipping point that needs to take proper decision for sustainable development. Agriculture sector is one of the sectors that will have adverse impact due to the climate change, currently and also in the future. Every civilization has flourished well when the people had enough food. So, any impact on food production system will have detrimental effect for the mere cause of survival. With the advent of growing population and to feed them, sustainable development is must in agriculture sector. So, the people and country both can prosper. To know about the future change in climate, there are several scenarios that are determined by the Intergovernmental Panel on Climate Change (IPCC) to assess the impact of climate change (Pörtner et al., 2022). The IPCC is started in 1988, as a scientific body that oversees the scientific evidence and research throughout the world related to climate change and brings out several assessment reports that help for informed decisions and proper policy-making. There are currently five assessment reports available, and they help the researchers, scientists, and government organisation to know how the climate will behave when particular scenario is followed in the future. By knowing the behaviour of future climate, proper adaptation and mitigation strategies can be effectively coined and climate resilient agriculture is possible for sustainable food production.

14.2 Future Climate Change

The future climate change is well explained in IPCCs' assessment reports. The future climate is ascertained mainly using climate models. They developed several scenarios over the decades like Special Report on Emission Scenarios (SRES), Representative Concentration Pathways (RCPs), and Shared Socioeconomic Pathways (SSPs) for climate models to understand the realm of future climate. The climate models are well upgraded and the confidentiality is increased over the years. The climate data for a particular location are extracted from the climate model outputs using different techniques like statistical and dynamical downscaling. The negative and positive aspects of various downscaling methods have been reviewed by Fowler et al. (2007) and have recommended the dynamical downscaling over other techniques. All the results from climate models showed contently that we will experience increase in temperature, frequent extreme events, and the precipitation which varies in different places and sea-level rise, that questions the very basic need of survival with prosperity. These weather-related extremes' increase is evident and also will frequent in the future that will have direct impact on agriculture. The sole sector decides the food security of a nation.

14.3 Impact of Climate Change on Crops

Climate change affects the agriculture sector both directly and indirectly by affecting the yield directly and affecting indirectly by irrigation source, pest, and so on. Figure 14.1 illustrates the climate change impact on agriculture.

In agriculture, the impact of climate change varies depending upon the type of crops like C3 crops, C4 crops or CAM. In general, C3 species represent approximately 85% of all higher plant species, C4 represents 5%, and CAM species represents the remaining 10% (Kumar et al., 2017). Most of the agriculture crops falls under C3 and C4 categories. The C3 and C4 plants respond differently under changing climate.

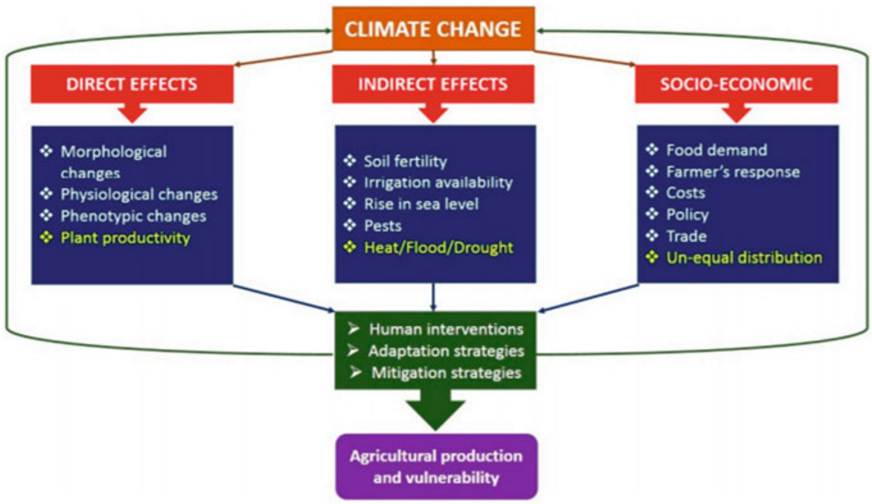

Fig. 14.1 Direct, indirect, and socio-economic effects of climate change on agricultural production. Adapted from Raza et al. (2019) review

One of the main factors for this is the Carbon dioxide Compensation Point (CCP). The CCP is the points where the rate of photosynthesis is equal to rate of respiration with respect to carbon dioxide. Generally, the CCP is high in C3 plants and low in C4 plants. The reason is being photorespiration in C3 and PEP carboxylase in C4 plants (high affinity towards carbon dioxide).

The increase in temperature in turn affects the crop health and yield by impacting on the photosynthesis and respiration of plants. There are ample studies that show that the yield of the crops and quality of the produce are going to be affected due to the increase in temperature, and this yield reduction is checked to certain extent of temperature increase due to carbon dioxide fertilisation effect.

Most of the staple food crops like rice, wheat and oil seed crops like groundnut, soybean fall under C3 category. So, our further discussion is focussed on C3 crops under changing climate. The C3 crops respond positively for enhanced carbon dioxide concentration. They produce more biomass when influenced by carbon dioxide fertilisation. These C3 crops cannot tolerate high temperature and produce less yield. When these both criteria of enhanced carbon dioxide and temperature are considered, the C3 crops showed increase in yield up to certain temperature increment (due to carbon dioxide fertilisation effect) and then decrease due to increase in temperature.

14.4 Rice and Ground Nut Cultivation in Tamil Nadu

The main seasons in the study area are the Sambha, which is dependent on the northeast monsoon (i.e. the post-monsoon rainfall), and the Kuruvai cultivation, which relies on the southwest monsoon showers. The rice crop calendar starts with Kuruvai (June–September), Sambha (August–November), and is followed by Navarai (December–January) and Sornavari (April–July), which are purely dependent on the tube well and the tank irrigation. The major rice varieties grown in each of these seasons are ADT 37, 47, Mdu-5, and ADT1-45 (Raza et al., 2019). These main varieties take 105–110 days for maturity. In contrast, during Sambha, medium- and long-duration varieties are grown, including IWP, ADT44, ADT-43, CR1009, ADT38, TRY1, 2. These mature within 135–150 days.

With respect to the groundnut crop production, the major cultivating season is found to be the winter, locally known as Margazhi Pattam (December–January). The main varieties grown during this time are TMV 7, VRI-2, ALR3, and CO(gn). During Masi Pattam (February–March), the TMV7, CO-2, and VRI-2 varieties are cultivated; and during summer or Chithirai Pattam (April–May), CO-2, CO-3 and VRI-2, TMV7 varieties are cultivated (Ramachandran et al., 2017).

14.5 Rice and Groundnut Production Under Changing Climate

Rice is the staple food of Tamil Nadu state of India and one of the major producers of groundnut crop among all the states of the major five groundnut growers in India (Premnath, 2020). The discussion further will focus on the rice and groundnut production in Tamil Nadu state of India. The crops are cultivated in both rainfed and irrigated conditions. Several studies were carried out on rice and groundnut productions of the state under changing climate, and both the crops showed an increase in yield under changing climate till mid-century; then, yield decreases mainly attributed to increase in temperature without water limitation. The rice yield response to changing climate by Geethalakshmi et al. (2011), is given in Fig. 14.2, where the R^2 0.790. The PRECIS and RegCM3 control and CO_2 enriched are the output of PRECIS and RegCM3 regional climate model for climate data. Control represents no carbon dioxide enrichment and CO_2 enriched means carbon dioxide enrichment considered, and the experiment was done for Cauvery Delta Zone of Tamil Nadu, the basin considered as rice bowl of Tamil Nadu using DSSAT crop simulation model. The experiment results clearly show that when the climate change without carbon dioxide fertilisation occurs, there is complete decline in yield of rice crop, whereas when we consider carbon dioxide enrichment effect, the yield drops only after mid-century that is attributed to high temperature under A1B scenario.

The study on groundnut showed that the yield was projected to decrease for both control and CO_2-enriched conditions. However, under enriched CO_2 conditions, the yield was observed to be decreasing lesser when compared to that of control for groundnut that was attributed due to the C3 nature of the crop as they increase the production due to the higher CO_2 saturation nature of the crop though it was affected by the temperature increase at the end of the twenty-first century. Figures 14.3 and 14.4 illustrate the groundnut yield variation under changing climate over entire Tamil Nadu state.

14.6 Adaptation Strategies for Sustainable Development

Optimum planting dates, which provided the highest yield under different weather conditions, were determined from simulations of the baseline and the climate change scenarios. Changing sowing dates was found to be an agronomic adaptation method to minimise the vagaries of climate variability and unexpected weather changes. The experimental sowing dates (Fig. 14.5) used in the simulations were 1st September, 15th September, 1st October, 15th October, and 1st November. Simulation outcomes showed that rice crop sowed on 1st November showed a yield increase of 2.2%. This type of agronomic management would be the most fitting adaptation strategy to minimise the negative impacts.

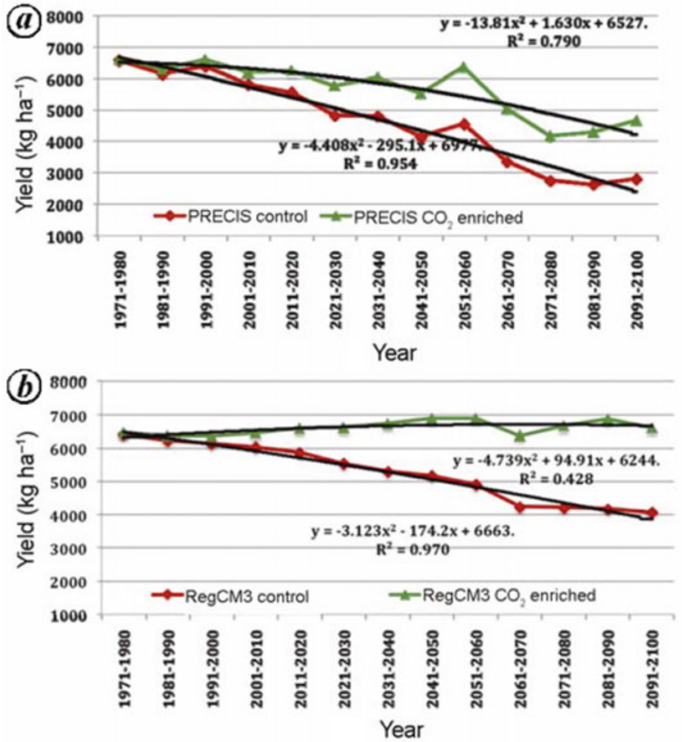

Fig. 14.2 Rice yield over Cauvery Delta Zone of Tamil Nadu state under changing climate. (PRECIS and RegCM3 are regional climate model, control represents without carbon dioxide enrichment, and CO_2 represents carbon dioxide enrichment)

Detecting the changes in climate and its impacts includes a thorough analysis of both observed climates and predicts how the future climate would unfold (Krishna Kumar et al., 2011). Concentrations of current emission levels indicate that we are now committed to decades of temperature rise and sea-level rise for more than 100 years. Based on IMD analysis, the annual mean temperature over India also reported a rise of 0.56 °C. Kothawale and Rupa Kumar (2005) have mentioned that the warming was more during winter and post-monsoon season in India. If this continues, sustaining food production is a cause of concern Gupta et al. (2016) and FAO (2010).

Amidst the uncertainty in climate change, the rice and groundnut production showed declining trend from mid-century irrespective of CO_2 fertilisation effect on both the C3 crops. Naresh Kumar et al. (2012) has carried out impact assessment on major crops in ecologically sensitive areas, viz. the Western Ghats (WG), coastal districts, and northeastern (NE) states of India, using InfoCrop simulation model. Irrigated rice and potato in the NE region, rice in the eastern coastal region, and coconut in the WG are likely to gain. Irrigated maize, wheat, and mustard in the NE

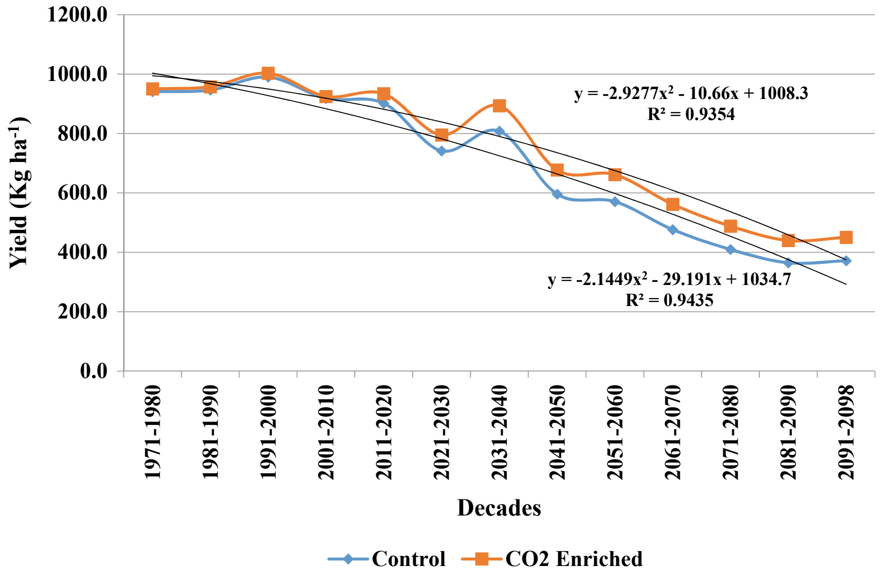

Fig. 14.3 Impact of PRECIS HQ0 climate over groundnut (TMV 7) yield

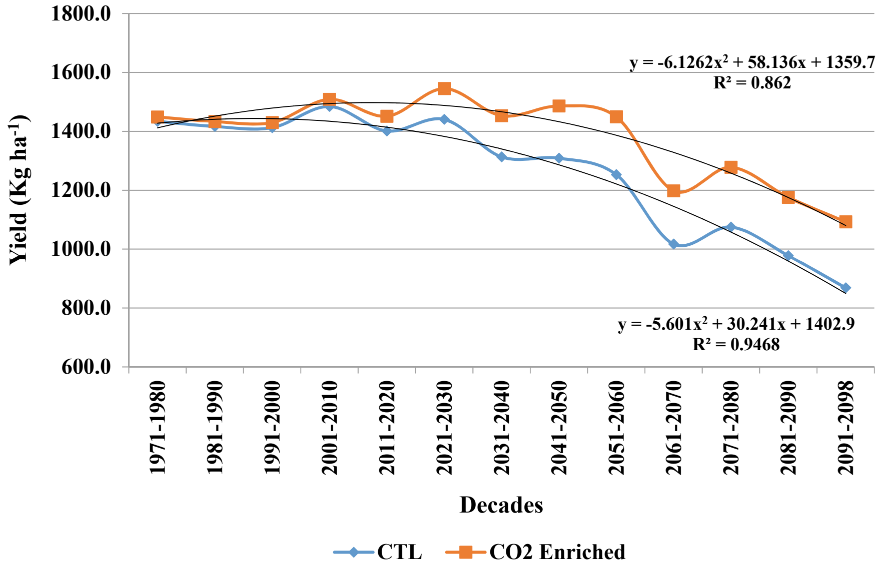

Fig. 14.4 Impact of RegCM4 climate over groundnut (TMV 7) yield

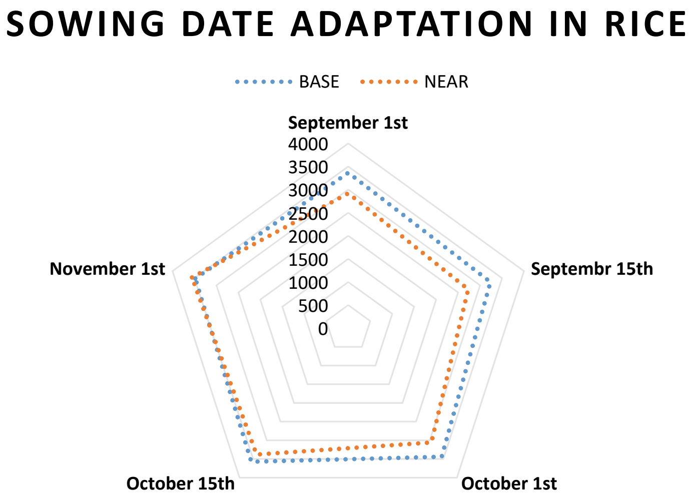

Fig. 14.5 Impact of different sowing date adaptations on rice yield

and coastal regions and rice, sorghum, and maize in the WG may lose. Adaptation strategies such as change in variety and altered agronomy can, however, offset the impacts of climate change. Srivani (2007) has used InfoCrop crop simulation model to assess the probable impacts of climate change on rice crop yield for different places of Tamil Nadu. The days to anthesis and crop duration were getting reduced due to climate change. An yield reduction of 15.3% was predicted in the end of twenty-first century for Thiruvallur areas.

To have sustainable crop production under future climate, proper adaptation and mitigation strategies are to be followed to maintain the food security (Arora, 2019). A combination of planned and autonomous adaptation such as following weather forecasts, selecting crops based on forecasted rainfall, and existing water availability, change of sowing dates to better use of optimum weather for the crop growth, etc., Dhanya and Ramachandran (2015). In mitigation, breeding of varieties that grow well under changing climate needs to be identified or gene pooling for adapting under high CO_2-enriched condition along with temperature increment should be bred (Rajalakshmi et al., 2012). The adaptation strategies give us a way to ameliorate the effect, and mitigation gives us a concrete variety that best suits the future climate conditions.

14.7 Conclusion

Under the changing climate, our future will have increase in temperature of 2 °C or more with poor distribution of rainfall and increased CO_2 in the atmosphere. The future climate will have adverse impact on the rice and groundnut crop over Tamil

Nadu region. This change can be ameliorated by adapting proper strategies and mitigation measures. Developing and distributing cultivars which are well adapted to the future warming are the need of the hour. Planned, socio-economic, and institutional interventions are required to mainstream climate change adaptations at the farmer's filed as part of securing food and nutritional security and livelihood.

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Part V
Sustainable Adaptive Options to Combat Global Warming and Climate Change

Chapter 15
Assessment of Soil Suitability for Sunflower Cultivation in Sagar Island, India

Sabir Hossain Molla and Rukhsana

Abstract Scientific management of soil resources and introduction of suitable agricultural practices are necessary to reduce the human impact on natural resources, especially on soil system. The present study assessed the suitability of soil for sunflower (*Helianthus annuus*, L) cultivation in the coastal saline agro-ecological environment of Sagar Island, based on the essential soil quality requirements such as soil texture, soil pH, electrical conductivity (E.C), organic content, soil depth, nitrogen (N), phosphorus (P), and potassium (K). To generate suitability map layers using weighted sum overlay techniques in the Arc GIS 10.5 platform, an analytical hierarchical procedure (AHP) has been used to rank the various suitability factors. The entire island has been classified into four suitable classes, namely 'highly suitable (S1)', 'moderately suitable (S2)', 'marginally suitable (S3)', and 'not suitable (N)' areas. Accordingly, more than 80% of the study area were found to be highly (54.48%) and moderately (30.03%) suitable for sunflower crop production. Overall, the findings revealed that the soil fertility of the study area has a huge potentiality for the sunflower crop. Therefore, the present research provided information at the local level that could be used by farmers to select cropping patterns and suitability.

Keywords Soil suitability · Sunflower (Helianthus annuus · L) · Analytic hierarchy process (AHP) · Geographical information system (GIS) · Soil quality

15.1 Introduction

One of the most crucial natural resources for agricultural production, human socioeconomic development, and life sustenance is soil (Bandyopadhyay et al., 2003, p. 62; Gandhi & Savalia, 2014). Natural resources are under tremendous pressure due to the world's expanding population (Hanh et al., 2017; Santana-Cordero et al., 2016), which results in a multitude of environmental issues for land and water systems (Tengberg et al., 2016). A large population like India results in a strong demand for

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food. Traditional agriculture also reaches its limits at this period. Consequently, a crisis results from an unfit demand–supply nexus (Alam et al., 2021). Consequently, appropriate land-use and management policies are required to reduce the severity of human impacts (Brevik, 2013; Lal, 2009). As a result, the technique of land suitability analysis is required to accomplish this (Kihoro et al., 2013; Molla et al., 2020). This technique assesses the degree of appropriateness of land for a particular purpose and determines the primary characteristics that limit crop output (Halder, 2013; Molla et al., 2020; Rukhsana & Molla, 2021a, b). The potential of a tract of land for increased crop production in a sustainable manner is a function of crop requirements and measures how well a land unit's characteristics match the needs of a specific land use (FAO, 1976; Mustafa et al., 2011; Rukhsana & Molla, 2021a, b). More recently, advanced Geographic Information System (GIS) components with a variety of geostatistical methods have added additional dimensions to challenges relating to site appropriateness evaluations (Bal et al., 2018; Bhagat et al., 2009; Choudhury et al., 2013; Kumar et al., 2010; Motuma et al., 2016).

In soil-site suitability analysis for sunflower cultivation, due to the high controllability over cropping systems, some fundamental edaphic properties (e.g., soil texture, pH, electrical conductivity, organic carbon content, soil depth, and nutrient availability) are considered. Sunflower (*Helianthus annuus*, L.) is an important oilseed crop worldwide and is one of the major winter crops of the Sagar Islands, the setting of the vast lower delta complex on the continental shelf of the Bay of Bengal. Sunflower's economic significance cannot be overestimated. Depending on the variety, the seed, which can be consumed raw or roasted, contains 36–45% oil and is used to make margarine, lubricant, paint thinners, and soap. (Ogunremi, 1988). The crop is quite drought resistant due to the deep root system of sunflowers, which can grow up to 3 m deep and disseminate surface lateral roots (Meinke et al., 1993; Rachidi et al., 1995). Currently, it is grown on 500 ha of agricultural land on the island, with a productivity of 0.89 mt/ha, greater than the national average of 0.69 mt/ha but lower than the average for the entire world (1.32 mt/ha; Krishna et al., 2014). Farmers have been forced to pursue crop intensification haphazardly without knowledge of soil-site suitability guidelines for the adoption of location-specific crops due to poor socioeconomic conditions with high vulnerability to ecological disaster combined with booming population growth and shrinking agricultural landholdings from severe coastal erosion (Mandal et al., 2020). Therefore, the objective of this study was to delineate the soil suitability area for sunflower cultivation by adopting some pertinent FAO principles (FAO, 1978, 1994, 1996) in addition to using geospatial techniques and the Analytical Hierarchy Process (AHP) based on chosen soil production parameters in accordance with FAO guidelines. The recent study will be extremely helpful, especially in motivating farmers to plant sunflower crops in the proper fields.

15.2 Materials and Methodology

15.2.1 Geographical Overview of the Study Area

Sagar Island is located between 21° 37′ 20″ North to 21° 52′ 28″ North latitude and Longitude 88° 2′ 17″ East to 88° 10′ 25″ E, at the continental shelf of the Bay of Bengal, the largest delta complex of the Indian Sundarbans and bounded by the Muriganga River on the east, the Hooghly River on the north and west, south is the Bay of Bengal (Fig. 15.1). The elevation of this island is in range of 2.5–3.5 m above means sea level. But, the size of this island is declining due to geomorphic submergence and sea-level rise over the decades (Chand et al., 2012; Lakshmi & Patterson, 2010). Many natural calamities like cyclones, depressions (Chand et al., 2012), the intrusion of saline water (Majumdar & Das, 2011), and heavy coastal erosion (Bandyopadhyay, 1997; Gopinath, 2010) are occurred frequently in this region. The island ecosystem consists of 42 villages with eight Gram Panchayats, and currently, total geographical area (GA) of the island is approximately 23,321 ha including 61% under agricultural production of which highest 46.5% is under rainfed lowland rice cultivation. The length of the coastal periphery of this island is approximately 67.8 km. During winter season, the mostly grown crops are Boro rice (irrigated rice), potato, sunflower, chili, khesari (pea), mustard, and lentil (Mandal & Choudhury, 2014).

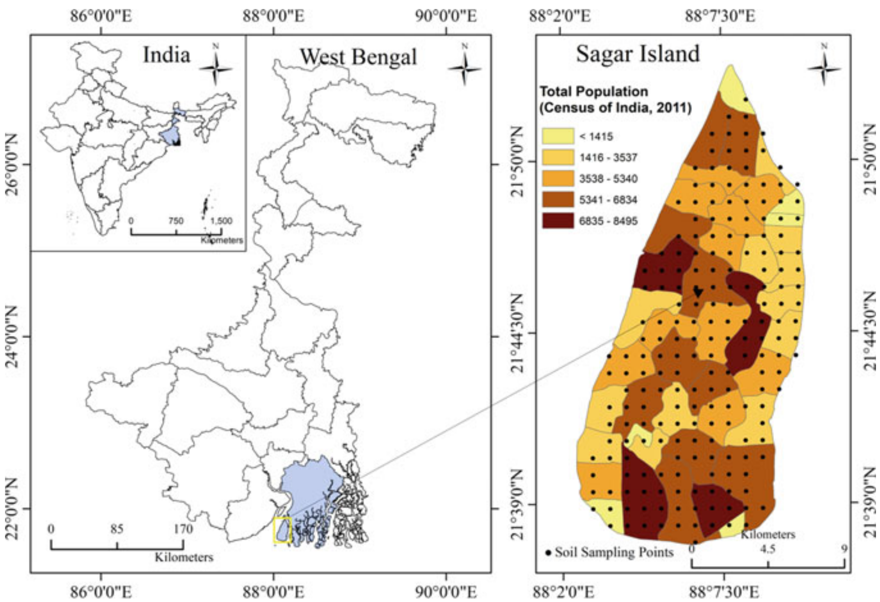

Fig. 15.1 Location of the study area

Table 15.1 Materials and data sources used for sunflower suitability assessment

Materials	Sources
Toposheets map	79C/1, 79C/2; RF 1:50,000; SOI
Landsat 8 OLI	earthexplorer.usgs.gov
Soil texture	Soil testing lab, RAKVK, Nimpith (ICAR)
Soil depth	indiawaterportal.org
Soil pH	
Electrical conductivity	
Organic content	National Bureau of Soil Survey and Land Use Planning (NBSS & LUP)
Nitrogen (N)	
Phosphorus (P)	
Potassium (K)	
Experts' opinions	Literature survey and local agronomist knowledge

15.2.2 Data Sources

The most important conditions for soil to meet in order for sunflowers to be grown were identified through interviews with local agronomists, a variety of literature reviews, and the opinions of sunflower crop specialists. Soil texture, soil pH, electrical conductivity (E.C), organic carbon content, soil depth, nitrogen (N), phosphorus (P), and potassium were the first variables that were taken into account in this study to determine the best zones for growing sunflowers (Table 15.1). The LULC map of the research area was created using the satellite-derived LULC data from Landsat 8 OLI for the year 2019. The geo-referencing process employed a topographical map from the Survey of India. Due to the Island's modest spatial extensions, the climatic characteristics have been regarded as spatially uniform and hence eliminated from the analysis. Similar to the slope of the soil, which ranged from 0 to 3%, and the amount of stoniness, which was zero, both of which were not taken into account.

15.2.3 Generation of Different Thematic Layers for Soil Suitability Assessment of Sunflower Cultivation

The parameters included soil texture, soil pH, soil electric conductivity, organic carbon content, soil depth, nitrogen (N), phosphorus (P), and potassium (K) (Fig. 15.4a–d and 15.5a–d, respectively) have been considered to identify soil suitability for sunflower crop requirements according to the FAO guidelines (1976) (Table 15.2). Criteria maps for soil texture (Fig. 15.4a) and soil depth (Fig. 15.5a) were geo-referenced and area of interest (AOI) was extracted; subsequently, vector layers were produced through on-screen digitization, and these vector layers were rasterized through conversion tool in Arc GIS 10.1 software. Thematic layers of soil

Table 15.2 Suitability levels and data ranges of eight parameters for sunflower cultivation

Parameters/suitability levels	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Soil texture	L, SIL, CL	SICL, SCL, SL	LS, C	Sandy
Soil pH	6.5–8.0	5.5–6.5	4.5–5.5; 8.0–8.5	< 4.5 and > 8.5
Soil E.C (dS/m)	< 0.50	0.50–1.00	1.00–1.50	> 1.50
Organic carbon (%)	> 0.75	0.50–0.75	0.25–0.50	< 0.25
Soil depth (cm)	> 50	35–50	20–35	< 20
Nitrogen (N)	> 300	200–300	100–200	< 100
Phosphorus (P)	> 20	10–20	5–10	< 5
Potassium (K)	> 750	500–700	350–500	< 350

Source FAO (1976), Sys et al. (1991a, b), Mandal et al. (2020)
Note C clayey, *CL* clayey loam, *SIC* silty clay, *SICL* silty clay loamy, *SIL* silty loam, *L* loamy, *SL* sandy loam, *LS* loamy sand

pH, electrical conductivity, organic carbon content, nitrogen (N), phosphorus (P), and potassium (K) (Figs. 15.4b–d and 15.5b–d) are generated using point data that were in the Excel sheet which later transformed into shapefiles and applied inverse distance weightage (IDW) in the GIS environment to calculate the spatial distribution across the study area. The overall flowchart of methodology that followed in this research is illustrated in Fig. 15.2.

15.2.4 *Standardization of Criteria Layers*

All of the selected criteria are in different units, so executing the weighted overlay method requires converting them to the same units and therefore a standardized value. All the parameters considered for sunflower suitability assessment were standardized based on FAO land suitability classification (FAO, 1976) and other guidelines (Mandal et al., 2020; Sys et al., 1991a, b) (Table 15.2). Further, the significance of a class within a single criterion has been categorized by assigning weight using the pairwise comparison matrix (PWCM) (Table 15.4). This process of determining the relative importance of each class of criteria is known as standardization (Prakash, 2003). For the weighted sum overlay, the vector layer of all criteria maps has been converted to a raster layer which is shown in Figs. 15.4 and 15.5. After that, all raster layers were reclassified and used for the input data to the weighted sum overlay method which finally creates the soil suitability map for sunflower cultivation (Fig. 15.6).

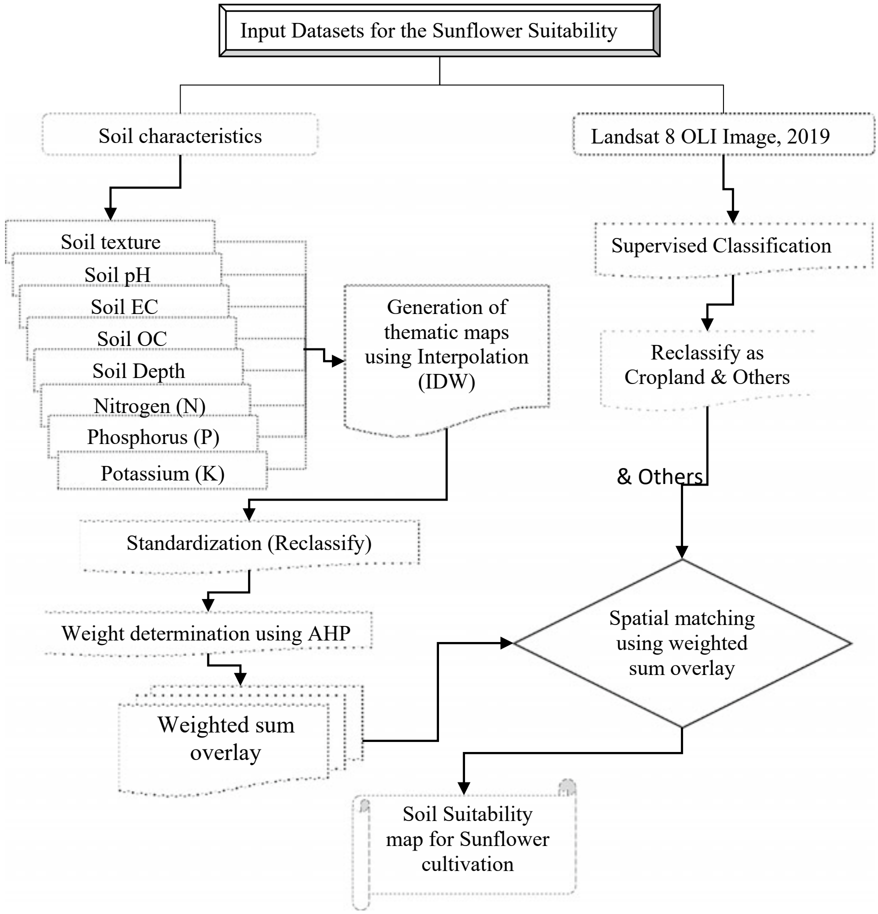

Fig. 15.2 Flowchart of the methodology for delineation of soil suitability zones for the sunflower cultivation

15.2.5 Weight Assignment for Multi-criteria Decision-Making

For the purpose of determining the weight, two factors are compared. The pairwise comparison matrix (PWCM), which was created using the analytical hierarchy procedure, was calculated using the Saaty (1980) scale with values ranging from 9 to 1/9. The row factor is more significant than the column factor, according to a grade of 9. The diagonal is given a value of 1 because one parameter is being compared with itself, whereas a rating of 1/9 means that the row factor is less significant than the column factor. The matrix is divided into two triangles (upper and lower), where the upper triangle equals the lower one exactly (for instance, if the rating of soil texture in relation to soil depth is 5, the rating of soil depth in relation to soil texture will be 1/5). Table 15.3 shows a pairwise comparison matrix for the research.

It should be noted that for preventing bias through criteria weighting, the consistency ratio (CR) was used.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}},$$

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1},$$

Where

lambda ($\lambda_{\max}$)	is the maximum Eigen value.
CI	consistency index.
CR	consistency ratio.
RI	random index.
n	the numbers of criteria or sub-criteria in each pairwise comparison matrix.

A consistency ratio (CR) of 0.10 or less indicates a reasonable level of consistency (Saaty, 1977). The CR result for soil suitability analysis of sunflower cultivation is 0.0378 (Table 15.3), indicating that the comparison of soil characteristics was completely consistent and the relative weight was chosen appropriately in this particular study.

To overlay the map layers, weighted sum overlay techniques have been applied. In this study, individual map layers, as well as each sub-layer within a criterion, were separately weighted according to their importance using the AHP process (Table 15.3). After assigning weights, all the raster layers and classes were overlaid in the GIS environment to obtain the soil suitability map for sunflower cultivation.

$$\mathrm{SI} = \sum_{i=1}^{n} W_i X_i,$$

where SI represents the suitability index for each map pixel, W_i is the weight value of parameter ith, X_i is the sub-criterion score of parameter ith, and n is the number of suitability layers (Elaalem et al., 2010; Rukhsana & Molla, 2021a, b). The above formula is applied to each thematic layer.

15.2.6 LULC Classification and Overlay with Soil Suitability Map

To improve the results, we performed land-use/cover (LULC) supervised classification in Erdas Imagine 14.0 and land was reclassified into two major divisions as

Table 15.3 Pairwise comparison matrix of criteria in AHP

Criteria	Soil texture	Soil pH	Soil E.C	Soil O.C	Soil depth	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Weight
Soil texture	1	2	2	3	5	6	7	9	0.3012
Soil pH	1/2	1	2	2	3	5	6	8	0.2120
Soil E.C	1/2	1/2	1	2	3	4	5	7	0.1674
Soil O.C	1/3	1/2	1/2	1	3	4	5	6	0.1336
Soil depth	1/5	1/3	1/3	1/3	1	3	5	6	0.0900
Nitrogen (N)	1/6	1/5	1/4	1/4	1/3	1	2	2	0.0425
Phosphorus (P)	1/7	1/6	1/5	1/5	1/5	1/2	1	2	0.0313
Potassium (K)	1/9	1/8	1/7	1/6	1/6	1/2	1/2	1	0.0224

Maximum Eigen value (λ_{max}) = 8.3729.
$n = 8$.
Consistency index (CI) = $(\lambda_{max} - n)/(n - 1) = 0.0533$.
Random index (RI) = 1.41.
Consistency ratio (CR) = CI/RI.
CR = 0.0533/1.41 = **0.0378**.

Table 15.4 Areal and percentile distribution of the selected criteria and sub-criteria in the study area

Soil-site characteristics	Unit	Weight	CR	Sub-criterion (with ranges)	*Weight*	*CR*	Area (ha)	Area (%)
Soil texture	%	0.3012	0.0378	Fine	0.3202	0.0158	20,327.49	87.18
				Fine loamy	0.5571		2054.97	8.81
				Coarse loamy	0.1250		1371.28	5.58
Soil pH	In H_2O	0.2120		< 5.50	0.1219	0.0439	7950.78	33.47
				5.50–6.50	0.2633		11,586.02	48.77
				6.50–8.00	0.5579		4072.95	17.14
				> 8.00	0.0569		147.41	0.62
Electrical conductivity	(ds/m)	0.1674		< 0.50	0.4824	0.0054	3714.39	15.64
				0.50–1.00	0.2718		6854.39	28.85
				1.00–1.50	0.1575		8442.95	35.54
				> 1.50	0.0883		4744.85	19.97
Organic content	%	0.1336		< 0.30	0.1285	0.0048	5324.42	22.41
				0.30–0.60	0.2766		11,744.06	49.43
				> 0.60	0.5949		6692.52	28.17
Soil depth	cm	0.0900		< 0.35	0.1199	0.0639	2858.68	12.03
				0.35–0.50	0.2721		475.85	2.00
				> 0.50	0.6080		2042.09	85.96
Nitrogen (N)	Kg ha^{-1}	0.0425		< 200	0.2611	0.0463	1349.15	5.68
				200–300	0.3278		17,200.02	72.40
				> 300	0.4111		5207.91	21.92
Phosphorus (P)	Kg ha^{-1}	0.0313		< 10	0.1976	0.0462	3487.22	14.68
				10–20	0.3119		13,012.30	54.76
				> 20	0.4905		7262.13	30.56
Potassium (K)	Kg ha^{-1}	0.0224		< 1500	0.1061	0.0332	10,281.64	43.27
				1500–2300	0.2605		11,729.47	49.37
				> 2300	0.6333		1748.81	7.36

cropland (12,632.38 km^2) and others (1175.43 km^2) (Fig. 15.3). Further, parameters based on the soil suitability map and the LULC map were overlaid using the weighted sum overlay technique in spatial analysis tools of ArcGIS 10.5 software to obtain more defined soil suitability areas for sunflower cultivation.

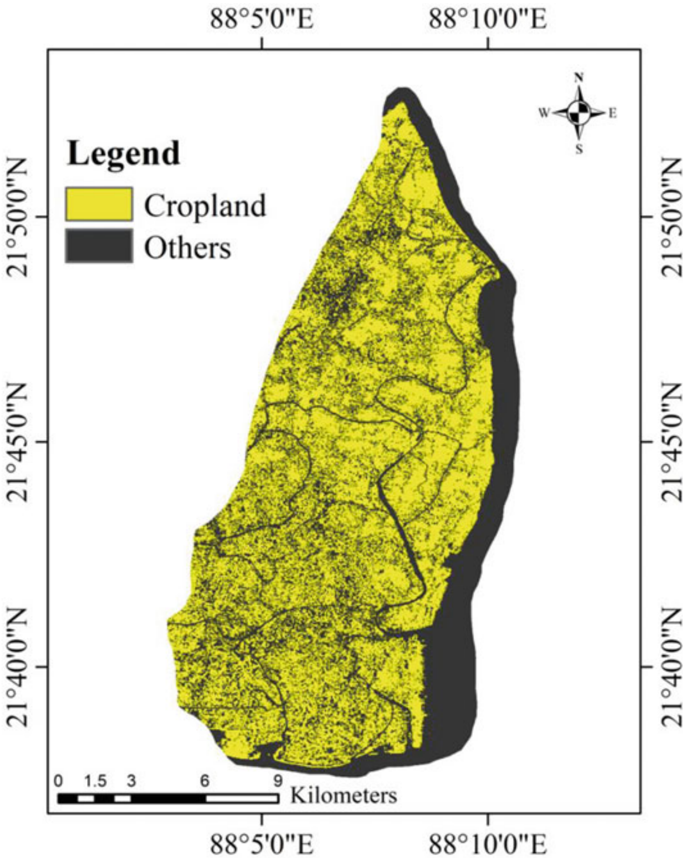

Fig. 15.3 Spatial extent of cropland and other categorized across the study area

15.3 Results and Discussion

15.3.1 Description of Factor Maps

In this study, eight soil quality indicators, namely soil texture, pH, electrical conductivity, organic carbon, soil depth, and NPK concentration were considered to map the soil suitability of sunflower cultivation in the Sagar Island of West Bengal. All indicators are explained below, and their measured concentrations, weight, consistency ratio are summarized in Table 15.4.

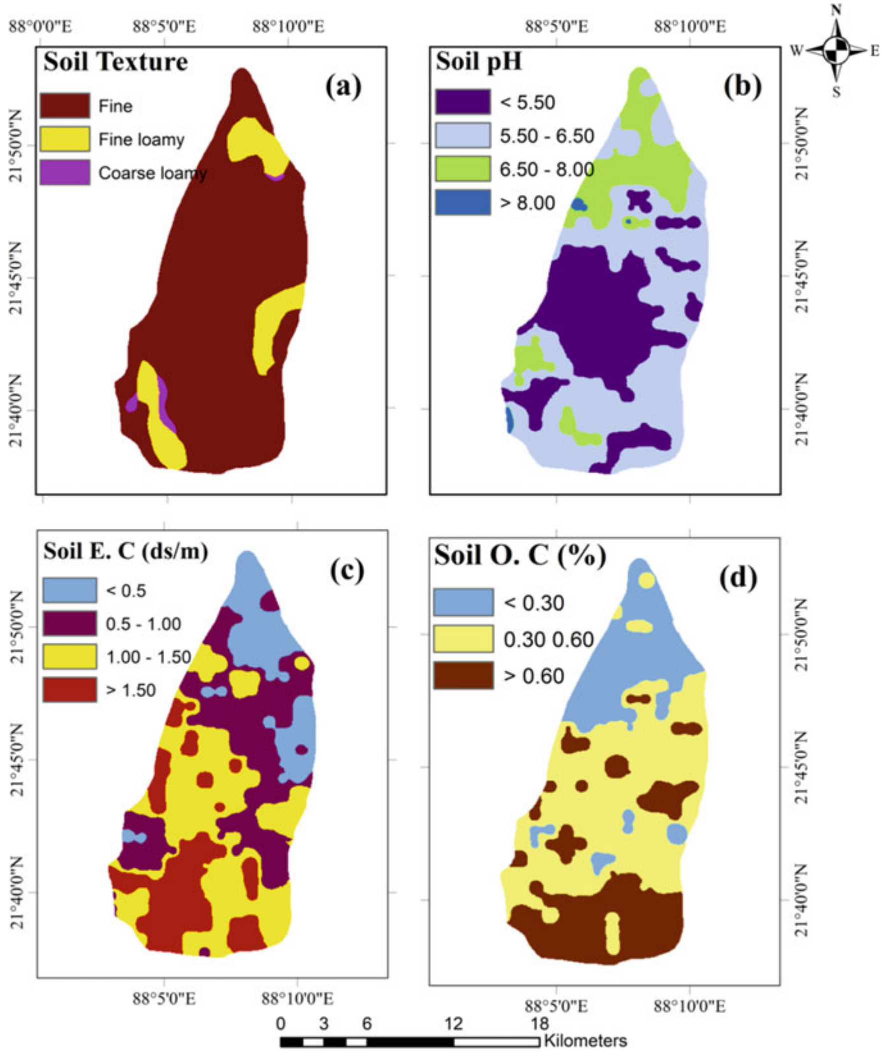

Fig. 15.4 Thematic data layer representing: **a** soil texture, **b** soil pH, **c** electrical conductivity, and **d** organic carbon

15.3.2 Soil Physical Properties

The majority of the arable land of this region is dominated by fine soil (87.18%), followed by fine loam (8.81%), distributed in the northeastern and southwestern part, and coarse loam (5.58%) with small pockets located in the southwestern part of the island (Fig. 15.4a) (Table 15.4). Fine loamy soil is given a high rating (0.5571) for sunflower suitability by the AHP method because of its maximum availability of

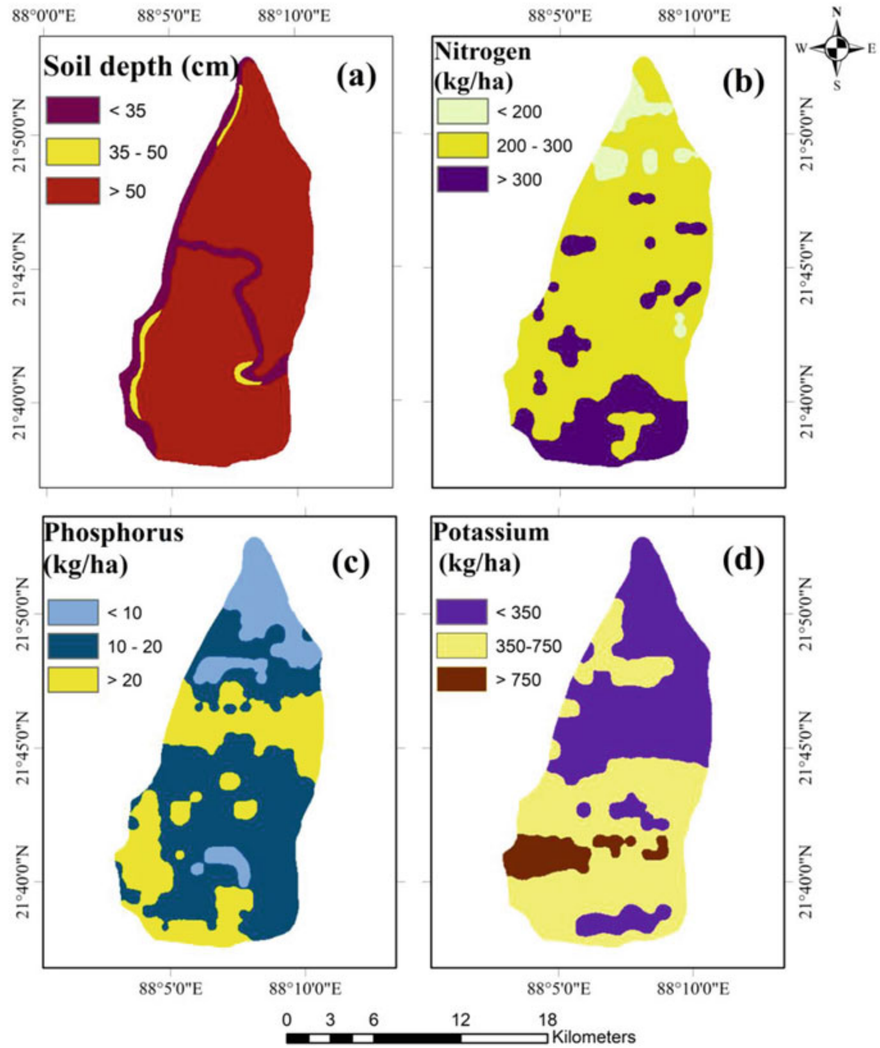

Fig. 15.5 Thematic data layer representing: **a** soil depth, **b** nitrogen, **c** phosphorus, and **d** potassium

microorganisms. Deep soil has more room for roots than shallow depth soil. Crop growth and yield at soil depth are highly reliable. In fact, in the island, most areas (85.96%) have soil depths > 50 cm (Fig. 15.5a), as they attained high weight (0.6080) (Table 15.4).

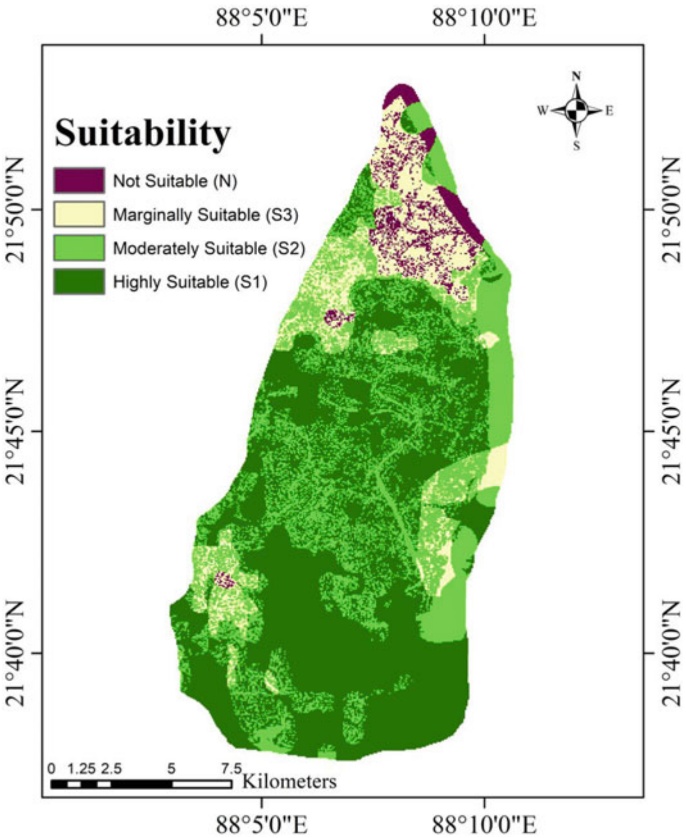

Fig. 15.6 Soil suitability map for sunflower cultivation

15.3.3 Soil Chemical Properties

A wide variation has been seen in the soil reaction of the selected study area, i.e., from extremely acidic (pH: 3.94) to moderately alkaline (pH: 8.45). Though the majority of the area (48.77%) falls under slightly acidic to near neutral in reaction (pH: 5.50–6.50), this zone is acquired a high rating (0.5579) due to its highly conductive nature of nutrients (Fig. 15.4b) (Table 15.4). The spatial variability of electrical conductivity is given in Fig. 15.4c which showed that 35.54% is marginally suitable for sunflower cultivation, 28.85% moderately suitable, 15.64% highly suitable, and 19.97% was not suitable in the study area (Table 15.4). The spatial distribution pattern of organic content in the selected study area showed that approximately 22.41% was recorded low (< 0.30%), 49.43% medium (0.30–0.60%), and 28.17% found high (> 0.60%) (Fig. 15.4d), and it is positively correlated with sunflower or any other crop yield due to its beneficial contribution to soil properties. The available nitrogen (N) in the surface soil varied from 131.98 to 445.3 kg/ha, with an average content of 266.17 kg/h across the study area. The spatially explicit nitrogen distribution map showed that the middle range (200–300 kg/ha) of available N is concentrated in parts of the entire central (Bishunpur, Purushottampur, and Kirtankali) islands (Fig. 15.5b). Island soils were high in available P content (Fig. 15.5c) with an average content of 18.34 kg/ha, although wide variations have been observed (3.6–78.20 kg/ha). The available K materials (350–700 kg/ha) (Table 15.4) have been reported a lot of soil (49.37%), which is concentrated in the southern and northeastern parts (Fig. 15.5d) of the island, and the reason might be due to very high clay contents.

15.3.4 Soil-Site Suitability of Sunflower Cultivation

Figure 15.6 displays the soil suitability map for the sunflower crop, which was determined using weighted sum overlay utilizing spatial analyst tools in ArcGIS 10.5. Each suitability category has a different number of hectares available: extremely suitable (S1) 12,706.43 ha, moderately suitable (S2) 7002.47 ha, marginally suitable (S3) 2742.72 ha, and not suitable (N) 869.50 ha, which correspond to 54.48%, 30.03%, 11.76%, and 3.73% of the total land area, respectively (Table 15.5). The moderately and highly suitable categories make up around 84.51% of the entire research field. As a result, the study area's average yield was very high, considering that minor portions (15.49%) fell into the categories of marginal and unsuitable areas, the other two classifications. As a result, it is possible to achieve economic levels of agricultural production by growing sunflowers in highly and moderately suitable locations, and it is also possible to diversify by growing other crops in marginally suitable areas, which will boost the income of marginal farmers (Rukhsana & Molla, 2021a, b).

Based on consideration of these results of physico-chemical properties of soil, it has been noted that the highly suitable areas (54.48%) are characterized by textural class—fine loamy (SCL, CL, SICL), soil pH level between 6.50 and 8.00, electrical conductivity level < 0.50, organic carbon more than 0.75%, soil depth > 0.50 cm, NPK concentration > 300 kg/h, > 20 kg/h, above 350 kg/ha, respectively, and this zone is distributed across the southern portion (Bishnupur, Kirtankhali, Purusottampur, Sibpur, Dhablat, Bishalakshmipur, Chemagari, Mahishmari, Beguakhali, and Sagar Mouza), central-west (Krishnanagar, Naraharipur, Harinbari, and Radhakrishnapur

Table 15.5 Distribution of individual suitability classes of sunflower cultivation

Suitability class	Area (sq. km)	Coverage (%)
Not suitable (N)	869.50	3.73
Marginally suitable (S3)	2742.72	11.76
Moderately suitable (S2)	7002.47	30.03
Highly suitable (S1)	12,706.43	54.48
Total	23,321.12	100

Mouza), and central portion (Mahendraganj, Nagendraganj, Debimathurapur, Kayalpara, Haradhanpur, Khan Saheber Abad, and Khas Ramkarerchhar Mouza) of the Island. On the other hand, a very little portion (3.73%) of this Island have been identified as not suitable areas for sunflower cultivation, and this zone is concentrated on the northern portion (Kastala, Sapkhali, Kachuberia, and Bamankhali Mouza) and northeastern portion (Muriganga, Companir Char, Sikarpur, and Ramkrishnapur Mouza) of the study area, which characterized by intensive salt stress with an upper threshold limit of 3.00 ds/m, pH levels less than 4.5 or more than 8.5, textural classes as course loamy, shallow soil depth, lack of NPK concentration on soil, and almost zero resources of groundwater for irrigation which undoubtedly reduce the fertility and ability of the soil to sustain crop growth and consequently minimize sunflower crop production.

15.4 Conclusion

The results obtained from this study specify that the use of GIS and application of Multi-Criteria Decision-Making using AHP could provide a better database and guide map for decision-makers allowing for crop substitution to accomplish better agricultural production. Additionally, local farmers can use this application to select their cropping patterns. But, since they are not educated enough to apply these techniques, so local Government should introduce them at the clusters' level to improve productivity. In conclusion, sunflower plantation currently is an essential oil crop with high demand in Indian markets. However, there are only a few areas in India where planting this crop. In the near future, research is required to study and collect data about sunflower potentiality by accenting factors affecting the quality of the sunflower oil crop.

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Chapter 16
Agricultural Bill 2020 in India: Agricultural Policy and Transition to Sustainable Agriculture and Self-reliance

Asraful Alam, Nilanjana Ghosal, Amir Khan, and Lakshminarayan Satpati

Abstract In the background of making India self-reliant (Atmanirbhar Bharat), the agricultural sector may play the most effective role than any other sector in India. The task of achieving self-sustainability and self-reliance in agricultural sector depends not only on infrastructural and governance reform, but also on decreasing agri-imports' bill and more focus on increasing farmer's income and their self-dependency. Since independence, the agricultural sector of India remained highly regulated by government agencies, but the new agricultural bills that have been passed recently in 2020 mainly aim to free the farmers of our country and to help to rise the income of the farmers making them self-reliant. All the three bills are collectively designed to reduce barriers that diverse agri-food supply chain actors face in connecting to farmers and creating a unified national market "*One Nation—One Market*." The present study has the following objectives: first, to understand and study the newly introduced agricultural bills by discussing their strength and weakness; second, after understating the new agricultural bills to find out the main reason behind the recent ongoing farmer's protest toward the new farm bills; third, to link the present agricultural policy with the sustainable agriculture and self-reliance. It is observed that the newly introduced agricultural policy has created much confusion among the farmers of our country. Thus, it is suggested that the Government of India should clarify all the fears and confusions of the farmers and guide them well about the new agricultural bills to achieve self-sustainability and self-reliance in the agricultural sector.

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16.1 Introduction

India's rapid economic growth among the G-20 nations since 2014 is partly attributable to an expansive reform program that has been put into effect since that year (Organization for Economic Cooperation and Development, 2018). The principal instrument of India's public policy is its five-year plans that have been adopted since independence to balanced development (The Economic Times, 2017). Agriculture is a key sector of our country's economy as it contributes to both employment and GDP (Organization for Economic Cooperation and Development, 2018). Over 70% of the rural households of India depend on agriculture. Agriculture also contributes about 17% to the total GDP and provides employment to over 60% of the population of our country (Arjun, 2013). It is also worthy to mention that the country has also adopted methods of sustainable agriculture by improving access to inputs such as fertilizers and seeds, as well as better irrigation and credit coverage for which agricultural production has been increasing on an average at about 3.6% annually since 2011 (Organization for Economic Cooperation and Development, 2018).

Agriculture in India has remained a highly regulated sector with governmental agencies and parastatal exercising a prevalent influence over it. The country has made an impressive progress on the agricultural front during the last three decades (Arora, 2013; Rukhsana et al., 2021). It is a cause for concern that since independence, there has been no comprehensive statement concerning Indian agricultural policy. In this context, the Ministry of Agriculture, Government of India, came up with a Draft Agricultural Policy Resolution in July 1990 along with a Standing Advisory Committee on Agriculture (SACA) with Sharad Joshi as the chairman, organized by the planning commission. The main objective is being the representation of the views of the agricultural/farming community of India. The Standing Advisory Committee on Agriculture considered agriculture to be the focal point of the economy and listed some of the major objectives such as meeting food and nutrition requirements for the increasing population, reduction of unemployment and more aiming to achieve the goal of self-sufficiency in production of food and eradicate its dependence on imported food grains (Nadkarni, 1993). The Indian government also made contributions to a number of agricultural advancements, including land reform, the creation of the Agricultural Price Commission, a new agricultural policy, investments in research and extension services, the availability of financing, and the upgrading of rural infrastructure (Tripathi & Prasad, 2010).

Though the corona virus lockdown across the entire country has brought economic activities to a near halt, the Government of India is expecting that the agricultural sector could be a silver lining for the Indian economy (Sambyal, 2020). To ensure this, September 14, 2020, appeared to be to a turning point for the Indian agricultural sector as the government passed three ordinances to unshackle farmers from the restrictive marketing reign that had, for decades, controlled the marketing of agricultural products. These ordinances ensure to alleviate the problems of marketing channels, post-harvest management, as well as farming technology and bring them directly to the hands of the farmers. The national vision of the farm sector is to double the income of farmers by 2022. This move is also believed to be revolutionary since income is intrinsically linked to how the markets of the harvested produce function (Shridhar, 2020).

The new agricultural bills that have been passed recently mainly aim to free the farmers of the country and get rid of the intermediaries and brokers which will lead to a rise in farmers' income and productivity. The latest amendments are also noted to be historic as this will give farmers opportunities to sell their products to whomever they want and wherever they want (Sharma, 2020a, 2020b). Moreover, the bills propose to create a system in which the farmers and traders can sell their purchase outside the Mandis. Further, the cost of transportation gets reduced as it encourages intrastate trade. The agricultural bill formulates a framework where the farmer can access modern technology and talk directly with agribusiness companies, retailers, exporters for selling their products. The small and marginal farmers with less than five hectares of land get better benefit from this agricultural bill. Therefore, the clear aim of these reforms is to ensure freedom of choice for farmers in the agribusiness marketplace and reorient agricultural policies to transform the lives of the farmers (Sambyal, 2020).

16.2 Methodology

In this study, methodology of systematic literature review along with inductive reasoning has been used. With the help of systematic literature, the researchers associated with this paper have tried to make an in-depth study regarding the newly passed agricultural bills, 2020, in order to bring a bigger and actual picture into consideration. Researchers have extensively read several documents, and approximately, about 70 papers contain relevant information about policies associated with the recent agricultural bill, 2020. Ample analytical studies have been done on how the three newly introduced bills will benefit the farmers of India as well as nourish the economy of our country. The present study also includes the way our farmers have reacted toward the bill and how the New Agricultural Policy, 2020, will help India to reach toward sustainable agricultural development and achieve the long-desired dream of becoming self-reliant. The gray literature reviewed ranged from formally published documents, journals, and various articles. To be precise, researchers have carried out a more qualitative analysis of the study to put forward a clear scenario of the newly passed Agricultural Policy, 2020.

16.3 Results and Discussion

Agriculture in India is means of livelihood for majority of the population, and agricultural policies play a key role in the process of agricultural economic growth (Shikur, 2020). It is to be remembered that the agricultural developments during the last 50 years have been shaped by three persistent forces of change, i.e., globalization, technology, and people (Keulen, 2007). The introduction of Green Revolution has been noted to bring favorable changes in the Indian Agricultural System (Pingali et al., 2019). However, the farmers of India face several restrictions in marketing their produce. In order to promote barrier-free sale and purchase of the agricultural produce for the farmers and create "One India, One Agriculture Market" that will lay the foundation for ensuring golden harvests for our hard-working farmers, the new agricultural policy, 2020, majorly has been introduced (Ministry of Agriculture and Farmers Welfare, 2020). For all overall understandings, the newly introduced farm bills and its presumed impacts on the farmers of our country have been discussed as follows.

16.4 Understanding the New Farm Bills, 2020

The farm bill is a legislative package that is enacted roughly every five years and has a big impact on how farming is done, how food is grown, and what kinds of food are produced. The farm bill establishes the foundation for our food and agricultural systems, encompassing initiatives like crop insurance for farmers, sustainable food availability for low-income people, the introduction of farmer training programs, and the promotion of sustainable farming methods (Sharma & Tanya, 2020). It is on September 27, 2020, that the honorable President of India Shri Ram Nath Kovind gave assent to the new farm bills passed by the parliament (Jagannath, 2020). The recently launched famous Farm Bill 2020 aims to introduce new reforms in the agricultural sector and attract private investments as well (Almeida, 2020).

The following is a discussion of the three Indian Parliament-passed legislations that intend to bring about new agricultural reforms in Farm Bill 2020:

New farm bills	Discussion
(i) Farmers' Produce Trade and Commerce (Promotion and Facilitation) Bill, 2020	This law allows farmers to sell their products anywhere within the country under the "*One Nation—One Market*" concept (Almeida, 2020). This bill also intends to create an environment where farmers and traders have the freedom to decide how to sell and buy their products, enabling profitable prices through vibrant alternative trading markets. The measure also provides a framework that facilitates electronic commerce and matters related to it as well as guarantees transparent and barrier-free intrastate and interstate trade (Shreya, 2020a)
(ii) The Farmers (Empowerment and Protection) Agreement of Price Assurance and Farm Services Bill, 2020	The bill allows individual farmers entering into contracts with buyers as per their choice, thereby; farming is done as per their agreement. Price certainty before planting crops is one of the biggest benefits that farmers get from this bill (Almeida, 2020). This act supports luring private sector investment for creating supply chains, exporting Indian farm products to domestic and international markets, and developing agricultural infrastructure (Shreya, 2020a)
(iii) The Essential Commodities (Amendment) Bill, 2020	Cereals, pulses, oilseeds, onions, and potatoes would no longer be considered essential commodities under this proposed law, and stock holding restrictions would no longer be imposed on them unless "extraordinary circumstances" such as war, famine, an unusual price increase, or a natural disaster occurred (Almeida, 2020)

The Indian government has consistently argued that these bills would improve the lot of Indian farmers and would provide them access to big dealers and exporters, which would promote agriculture (Sharma & Tanya, 2020). These legislation therefore intended to implement desperately needed changes to the agricultural marketing system, establish middleman-free trading zones, and bring the market to the farmers (Rishikesh, 2020).

16.5 Strengths and Weaknesses of the New Farm Bill

India saw a strong protest after the Parliament passed the three agriculture-related bills. The newly introduced agricultural bills replaced the ordinances issued in June 2020. The bills were passed majorly to bring change in some of the key aspects in agricultural economy such as price of agricultural commodities, trade of agricultural products, farm services that includes contracts, and stock limits for essential commodities (Maurya, 2020). Still, a great opposition has been observed regarding this new legislation, with farmers opposing the new agricultural bills. On the other hand, states like Maharashtra and Kanpur farmers seem to be in the favor of this new farm bill 2020. Thereby, there is a total confusion regarding the bill among both farmers as well as the common public. Hence, both sides of the new agricultural bill need to be analyzed (Chetia, 2020).

The strengths and weaknesses of the newly introduced agricultural bills that have been discussed individually are as follows:

New farm bills	Strengths	Weaknesses
(i) Farmers' Produce Trade and Commerce (Promotion and Facilitation) Bill, 2020	• The newly introduced bill aims to create an ecosystem where farmers and traders enjoy the freedom to sell and purchase farm produce outside registered "mandis" • It tends to promote both barrier-free inter as well as intrastate farmer's produces • This provision helps to reduce both marketing and transportation costs and helps farmers in getting better prices in return of their products • This bill bestows a facilitative structure for electronic trading (Times of India, 2020)	• The states will lose revenues. According to study, states would not be able to collect the "mandi fees" if farmers start selling their products outside the registered Agricultural Product Market Committee (APMC) markets • This new bill may in due course end the Minimum Support Price (MSP)-based acquisition system (Times of India, 2020)
(ii) The Farmers (Empowerment and Protection) Agreement of Price Assurance and Farm Services Bill, 2020	• This bill can act as assistance for the farmers, to enter into various contracts with agribusiness firms, processors, wholesalers, and exporters for sale of future farming products at a pre-agreed price • It facilitates to transfer the risk of market unpredictability from farmers to sponsors • This bill empowers farmers to get access to modern technology and in return get finer inputs • With this new bill, farmers can go in for direct marketing by getting rid of the intermediaries for full price realization (Times of India, 2020)	• Farmers that work under contract agricultural agreements are inferior negotiators when it comes to getting what they want • It is assumed that sponsors may not like to deal with many small as well as marginal farmers (Times of India, 2020)

(continued)

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New farm bills	Strengths	Weaknesses
(iii) The Essential Commodities (Amendment) Bill, 2020	• This agricultural bill facilitates to remove items like cereals, pulses, oilseeds, onions, and potatoes from the list of essential commodities • The new bill will likely attract private sectors toward farm sectors and will also do away with the fears of private investors taking part in excessive regulatory inferences in business operations • It will provide assistance in bringing investments for farm infrastructures like cold storage and modernizing food supply chain • This agricultural bill will assist farmers and consumers by bringing in price stability • This provision is expected to create a competitive market environment and slash the wastage of farm produce (Times of India, 2020)	• Price limits for "extraordinary circumstances" are expected to soar for which they are likely to be never triggered • Stocking commodities by big company will have greater freedom. Thereby, they may dictate terms to farmers which may lead to fewer prices for cultivators (Times of India, 2020) • This effectively validates stockpiling of commodities, which can be disastrous for the prices of essential items like vegetables and pulses (Shetty, 2020)

Agriculture is the backbone of Indian economy (Maurya, 2020; Rukhsana & Alam, 2022). The passing of the bills is a step providing a bigger platform to the farmers. It is assumed that with the introduction of the new agricultural reforms, farmers will get desired price for their agricultural products. The new farm bill is expected to bring comprehensive changes in the lives of the farmer. With the introduction of the new bills, it is anticipated that agricultural growth will be accelerated through various private sector investments which includes construction of agricultural infrastructure and supply chains for Indian farm produce in national global markets, generate employment opportunities as well as nourish the economy of our country (Rana & Gunjan, 2020). However, these changes are expected to result into farmers losing their commissions, and state governments stand to lose crucial tax revenues (Maurya, 2020). Therefore, before passing such measures, the government is required to consider the views of farmers as well as the states. Additionally, the administration must improve the government market places known as APMCs and close any gaps in them because our farmers are the heart and soul of this country, and ensuring their development and upliftment is the top priority (Rana & Gunjan, 2020).

16.6 Reaction of Farmers Toward the New Farm Bill, 2020

India's recently passed farm legislation has sparked broad and active protests all around the nation. In agrarian regions like Punjab, Haryana, West Bengal, Karnataka, Tamil Nadu, and Uttar Pradesh, thousands of farmers have violently protested by blocking highways and delaying trains (Sankar, 2020). Even, Shiromani Akali Dal, the ally of Bharatiya Janta Party (BJP) withdrew from the present ruling party in India, and the Union Minister of BJP, Shrimati Harsimrat Kaur Badal, submitted her resignation in protest against the new farm bill (Business Today, 2020). Many state governments and farmers' unions attached to political parties have already moved the matter to the Supreme Court, citing various violations (Sankar, 2020). While the Prime Minister, Mr. Narendra Modi termed the new agricultural reforms as a "watershed moment" for Indian agriculture, opposition parties have labeled them to be "anti-farmer" and compared them to a "death warrant" (BBC News, 2020). Farmers mostly belonging to states like Punjab and Haryana, which operate state-run Agricultural Produce Market Committees (APMC) on a large scale, are majorly making protests as they are worried that the new agricultural bills, which aim to deregulate the agricultural market mechanism very tightly, might reduce their price security in future. Farmers fear that the new bills will leave them powerless in dealing with major corporate if APMCs cease to exist due to inactivity platforms (Pandey, 2020). Another reason of concern among farmers and many economists that large corporate may take over contract farming in this regard (Kaul, 2020). Even, farmers, majorly hailing from Punjab and Haryana, are worried that Minimum Support Price (MSP), which used to act as their safety net since the introduction of Green Revolution since 1960s, might get snatched away under the ploy of giving the farmers more playing ground and greater platforms (Pandey, 2020). Besides the farmers, the commission agents are also opposing these ordinances as they are in a distress that the new laws will bypass their business and will leave them jobless (Sehgal, 2020). Farmers protesting the recently enacted farm bill by the Central Government marched to Delhi for all these reasons, primarily from Haryana, Punjab, and Uttar Pradesh. Farmers would not return until the contentious farm laws are deemed invalid, according to the Samyukt Kisan Morcha and All India Kisan Sangharsh Coordination Committee, which are primarily leading the protests. Indian Prime Minister Shri. Narendra Modi has made an effort to reassure farmers that neither the government acquisition system nor the MSP program will be terminated. However, the two disputing sides have not arrived at any fruitful conversations as a result of the presence of both fear and misinformation (Pandey, 2020). On November 27, even, the Union Agriculture Minister, Narendra Singh Tomar, encouraged farmers to put a halt to their demonstration and engage in a peaceful conversation with government officials to express their opposition to the new farm legislation (Times Now News, 2020). Simple measures like statutory backing to the minimum selling prices and procurement in the new bill can be used to eradicate the farmers' concern in order to put an end to their protests regarding the new farm bill. If all other factors, such as roads connecting villages to markets, electricity supply, climate-controlled storage facilities, and the ability to compete with food processing companies who want to buy their produce, are reliable and powering those facilities, farmers may choose to sell their products directly to consumers without the use of middlemen. Consequently, it is the government's job to fully explain all the details and subsequently better help our farmers in this regard (Nath, n.d.).

16.7 New Farm Bill 2020—A Road Toward Sustainable Agricultural Development in India

Agriculture is a fundamental human activity that depends intrinsically on natural processes and the concept of "sustainable agriculture" has emerged in the present world to make a major impact in the agricultural sector (Oberč & Arroyo Schnell, 2020). Sustainable development has been a guiding principle for all economic and political sectors since the UN Conference on Environment and Development which took place in Rio in 1992 (Siebrecht, 2020). The word "sustain," is derived from the Latin word *sustinere* (sus, from below and tenere, to hold), which means keeping in existence or maintaining, implying long-term support or permanence (Gold, 1999). The Brundtland Report defines sustainable development as growth that satisfies current demands without jeopardizing the capacity of future generations to satisfy their own needs (Kroll, 2020). In case of agriculture, sustainable describes farming systems which are "capable of maintaining their productivity and usefulness to society indefinitely". Such systems must include conservation of resources and should be socially supportive, commercially competitive, and environmentally sound as well (Gold, 1999). This provides another way of ecologically solving issues related to food production both fundamental and applied (Lichtfouse et al., 2009). There is a broad unison that sustainable agriculture is seen as essential for global sustainable development (Siebrecht, 2020). It must be noted that sustainable agriculture should take into account environmental, social, as well as economic sustainability as they are believed to be the three central pillars of sustainable development (Oberč & Arroyo Schnell, 2020). Though the recently passed agricultural bill in India has created a discontent and confusion among most of the farmers, the newly introduced bills intent to transform the agricultural infrastructures of our country for the better (Singh, 2020a, 2020b). According to the Prime Minister, Mr. Narendra Modi, the three newly passed bills is a watershed movement in the history of Indian agriculture and will ensure a complete transformation of the agriculture sector as well as empower crores of farmers (Roy, 2020). The newly introduced agricultural bills are expected to provide farmers with more opportunities to sell their produce. It is anticipated that the three bills will provide a significant impact on stimulating the growth of the farm sector. It is also expected that the newly introduced agricultural reforms will ease the flow of investments, create critically needed post-harvest infrastructures, and further help to open up market access for farmers to attain better profits (Sharma, 2020a, 2020b). Welcoming the new steps taken by the Prime Minister, Federation of All India Farmer Associations (FAIFA) claims that new farm bill will give farmers the freedom to trade around states and authorize them to turn into traders of their own produce. The new regulation is said to bring about an environment where there is a freedom of choice, enjoyed by both farmers and traders, for selling and purchasing of agricultural products. These crucial steps taken by the government will also additionally serve as keystone for visualizing a fair market for farmers that will support them to receive their fair price by letting them be in control of their incomes with freedom to trade (The Economic Times, 2020). Therefore, it can be said that these visionary bills not only ensure farmer's prosperity and doubling of their income but also guarantee a sustainable, profitable, and safe future for the farming community by developing new agricultural practices without degrading our environment (Lichtfouse et al., 2009).

16.8 New Agricultural Reforms: A Step Toward Self-reliant India

India may have a chance to become self-reliant even if the novel coronavirus has caused an unparalleled disaster. India has a fantastic opportunity to carefully organize its economy and apply innovative thinking (Naik, 2020). In the context of making India *Atmanirbhar* or self-reliant, the task of achieving it in agriculture is considered to be much easier and more cost-efficient compared to other sectors of the economy (Singh & Ranjith, 2020). In the year 1841, American lecturer Ralph Waldo Emerson first used the word "self-reliance." Emerson characterized self-reliance as having faith in one's current ideas, abilities, originality, conviction in one's own abilities, and living one's own life (Marinova & Hossain, 2006). The Government of India has tried to bring milestone drives toward the development of farmers becoming self-reliant in the country by implementing new reforms for the benefit of the farming community, popularly known as "AtmaNirbhar Krishi" in India. Recently, in order to restore the three ordinances that were enacted during the Covid-19 lockdown, the Union government passed three bills, in order to bring a wide change, majorly to create an impact in the agricultural sector. The three bills, namely Farmers' Produce Trade and Commerce (Promotion and Facilitation) Bill, 2020, The Farmers (Empowerment and Protection) Agreement of Price Assurance and Farm Services Bill, 2020, and The Essential Commodities (Amendment) Bill, 2020, are expected to bring remarkable changes in the agrarian sector (Sharma & Tanya, 2020). The three newly introduced bills are expected to help our farmers to become self-reliant by doubling their income and freedom to sell and purchase farm produce even outside the registered "mandis" (Jawandhiya & Ajay, 2020). Emphasizing the significance of agricultural sector, Prime Minister Narendra Modi stressed on farmers being self-reliant in India, and as per him, the country would progress only if the rural economy as well as farm sector strengthens. The newly introduced reforms are expected to bring positive changes in the agricultural sector, and with the help of the bills, farmers presently have the power to sell their crops to anyone and anywhere they get higher price of their produce (Varma, 2020). The Prime Minister believes that the farm sector plays a major role in efforts to build a self-reliant India and it has showed its prowess during the Covid-19 pandemic (The Week, 2020). What can also be assumed from the newly introduced agricultural policy is that participation of the private sector and foreign investment will lead to economic prosperity. Besides, new cold storage will be built where farmers will be able to keep agricultural products and able to sell them at a higher cost. With the advent of the newly introduced three bills, modern technology will replace traditional farming that will help farmers to empower themselves (Singh, 2020a, 2020b). Therefore, it can be said that foundations of a self-reliant India would be a major success only when the rural economy and farmers of our country are strengthened (Varma, 2020).

16.9 Linking Sustainable Agricultural Development with Self-reliance in India

Self-reliance and sustainable development both depend on natural life being able to meet its basic needs (Marinova & Hossain, 2006). The economy has been harmed by the rising number of Covid-19 cases in India and the ensuing lockdown, but the pandemic crisis has also taught important lessons about achieving self-reliance so that no one is interdependent on anybody else and instead achieves self-sufficiency (Shreya, 2020b). The Prime Minister, Mr. Narendra Modi called for Aatmanirbhar Bharat (self-reliant) initiative on May 12, 2020, and pitched for not just “Make in India” but also “Make for the World,” with focus on exports. According to him, it is the only path to rebuild India, popularly known as “New India” (Alam et al., 2021). The occurrence of Novel Coronavirus has opened opportunities for all the governments, especially developing countries like India to design their own economic revival packages (Jain, 2020). As per our Prime Minister, the foundation of self-reliant India majorly lies in the rural economy and in hands of our farmers. Hence, it is important to nourish them (Varma, 2020). It is believed that the task of achieving self-reliance and self-sustainability is required to begin with the agricultural sector of our country (The Economic Times, 2020). With an aim to transform the agriculture into a Sustainable Enterprise, the Ministry of Agriculture and Farmers’ Welfare on September 14, 2020, took a host of historical pro-agriculture landmark initiatives toward the development of “Aatmanirbhar Krishi” in the country by executing three landmark reforms significantly for benefit of the farming community. The three newly introduced bills are believed to provide farmers with greater freedom. The reforms are regarded as another giant leap toward liberalization and free market regime. The newly introduced agricultural policy is also expected to further motivate APMCs to be more effective and well organized in providing cost-effective services to farmers for a coherent marketing of their produce. To make agriculture sustainable and prepare farmers to be self-reliant in the coming days, National Agriculture Market (e-NAM), an innovative initiative has been introduced by the Government of India, to strengthen the farmers accessibility digitally to numerous markets and buyers and bring transparency in price discovery mechanism as well as price realization based on quality of produce (Sharma & Tanya, 2020). Developing skills in farming and reaching self-sufficiency in domestic food production are the most essential factor to attain sustainable recovery (Hinduja, 2020). Hence, the newly introduced agricultural bills seek to make the agrarian sector of the country progressive as well as reach sustainability and visions to make the farmers, who are considered as the souls of our nation, to be Atmanirbhar, commonly known as self-reliant in the coming future (Mitter, 2020).

16.10 Findings

Inspire of economic activities coming to a sudden halt due to imposition of nationwide lockdown for rapid spread of Covid-19, the newly passed farm bills, 2020, aims to introduce new reforms in the agricultural sector as well as attract private investments (Almedia, 2020). Agriculture is considered to be the backbone of Indian economy, and it is supposed that the passing of the three bills will bring comprehensive changes in the lives of our farmers (Maurya, 2020). The introduction of the new agricultural policy, 2020, aims to accelerate the economic growth of our country through various private sector investments and gives farmers and traders the freedom to sell and purchase their farm produce outside their registered "Mandis" (Times of India, 2020). The newly introduced agricultural bills tend to provide farmers with more opportunities to sell their produce and open up market access for farmers to attain better profits (Sharma, 2020a, 2020b). The implementation of new reforms is also expected to help farmers to become self-reliant popularly known as "AtmaNirbhar Krishi in India" (Sharma & Tanya, 2020). However, the new changes are anticipated into farmers losing their commission and government stand to lose crucial tax revenues (Maurya, 2020). This resulted into widespread protest by thousands of farmers across the country. Farmers majorly hailing from Punjab and Haryana which operate state-run Agricultural Produce Market Committees (APMC) on a huge scale are extensively making protest as they fear that the introduction of the three bills will deregulate agricultural market mechanism tightly. Even, the opposition parties of our India have labeled the new agricultural reforms as "anti-farmer" and compared it to a "death-warrant" (BBC News, 2020). To end the ongoing protests, the acting Government of India has urged farmers to sit with their representatives for a peaceful dialog as the three new bills aim to help farmers to empower themselves. From the advent of lockdown, India is making all efforts to achieve the goal of self-reliance and it is to be remembered that Atmanirbhar Bharat will achieve victory in actual only when rural India and farmers of our country become strengthened (Varma, 2020).

16.11 Conclusion

Agriculture is a very important sector of Indian economy, and lot of changes has been observed in this area since independence (Kapoor, 2015). The new agricultural policy 2020 has been mainly introduced with the expectation to bring silver lining in the Indian economy. The three new agricultural bills are expected to bring a revolutionary change in the country and will also help to raise the income of the farmers making them self-reliant (Sambyal, 2020). The new reforms are also considered to be advantageous for both small and marginal farmers, who own less than two acres of farmland each. The three new bills are also observed to bring remarkable benefits for agro-tech startups and organized players who connect farmers to various agribusinesses, food processors and exporters, agro-warehousing companies, and cold storage providers as well as supply chain and logistics operators to ensure transparency (Mitter, 2020). The farm bills are said to bring remarkable effect in positively impacting farm growth. The new agricultural reforms are anticipated to create an ecosystem where farmers and traders will enjoy privileges of barrier-free interstate as well as intrastate trade and commerce outside the physical premises of markets notified under State Agricultural Produce Marketing legislations (Sharma, 2020a, 2020b). However, certain farm organizations like Bharatiya Kisan Union (BKU), big agricultural bodies like the All India Kisan Sangharsh Coordination Committee (AIKSCC), and some sections of farmers are seen to oppose the bill as according to them, these bills will benefit none, except the big corporate, and are supposed to knock down the farmers' livelihood eventually after its application. The implementation of these laws could lead to the farmers losing rights to their own land and being swallowed by the companies. It has also been observed that many farmers are absolutely confused regarding the newly introduced bills. Thus, it is suggested that government should clarify all the fears of the farmers and guide them well regarding the new bills (Nath, n.d.). The newly introduced agricultural policy has created havoc among the farmers in the nation. Still, the latest amendments in the bill are historic as it has been introduced for the future benefits of the farmers (Sharma, 2020a, 2020b). Therefore, the newly introduced agricultural bills majorly focus on sustainable agricultural productions and aim farmers to become self-reliant as "*Atmanirbhar*" has become the latest "*Mantra*" of New India, and this has to begin with the farmers who are considered as the heart and soul of our nation (Sharma & Tanya, 2020).

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Chapter 17
Urban Heat Island (UHI) Resilience Plan in Varying Climatic Conditions Using Geospatial Approach: A Case Study of Rajkot City

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Abstract During the twenty-first century, urbanization and industrialization are rapidly growing in India, adversely destroying the climate. Urban Heat Island can be discerned in urban areas due to anthropogenic activities, industrialization, deforestation, etc. The main peculiarity of the UHI effect is a rise in temperature in core urban areas than their rural surroundings, leading to excessive energy usage and putting the urban population at significant risk of morbidity and mortality. Therefore, the study of UHI is crucial for adaptation to climate change and making the city resilient. In this study, the LST and air temperature (ambient) of Rajkot city were assessed. We derived isotherm for Rajkot city for three locations: Trikon Baugh, Madhapar Chowk, and

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Atika industrial area having diverse typologies. The inconsistency between LST and ambient air temperature has been found out. Carbon dioxide and carbon monoxide, which contribute to the UHI effect, were also analyzed for these locations. From the analysis, UHI's resilient strategies, effectiveness, and resilience were established to help provide recommendations for applying resilient strategies. The four central resilient systems are integrating reduction and response of UHI for existing policies and programs, strengthening and building green infrastructure, alleviating cool roofs, and creating cool road infrastructure. Detailed demonstration of resilient strategies was given through T.P. scheme-10 of Rajkot.

Keywords Ambient air temperature · Urban heat island · Climate change · Resilience plan · Rajkot city

17.1 Introduction

On the Saurashtra peninsula, which is prone to drought, is Rajkot. Wet and dry bulb thermometers, which are used to measure air temperature and humidity, are commonly housed in this common shelter for meteorological equipment. Extreme daytime temperatures in the summertime range from 39 to 43 °C. The winters are pleasant, with overnight lows in January of about 10 °C. Using the Stevenson screen, the Indian Meteorological Department (IDM) gauges the air's temperature every three hours. Large temperature variations at ground level must be prevented by keeping it 1.2 m above the ground. It has louvered sides to promote air flow and is painted white to reflect radiant heat because the air temperature in the shade, not the sunlight, is what is being measured. The Stevenson screen is used by IDM to gauge the temperature. A rain gauge is also used to measure precipitation. Rajkot's citywide average temperature is rising by 0.3 °C per year. According to data from the past 20 years, Rajkot's average temperature was 34.3 °C in 1995 and was 34.6 °C in 2017. Accordingly, Rajkot's typical temperature of 35 °C might be attained by 2030.

The winter season has been observed in the month from December to February. The maximum temperature has been observed in the range between 27 and 33 °C and the minimum temperature in the range between 12 and 17 °C. In January, there is the lowest temperature which means that there are no heat waves (Fig. 17.1).

Figure 17.2 shows the temperature prognosis for the summer season. March–May have been observed as summer months. In those months, there are high temperature and heatwaves. Also, Urban Heat Island phenomenon has been observed in the summer season. In the summer season, there have maximum temperature ranges between 33 and 43 °C. The maximum temperature rises up to 43 °C in May.

In the monsoon season, there is a sudden change in temperature due to precipitation. June–September have been considered as monsoon months. Starting in June, there is a temperature up to 40 °C that is drastically lowered at 31 °C in July and August due to heavy rainfall. In the month of September, there is a slight increase in temperature because the intensity of precipitation is reduced (Fig. 17.3).

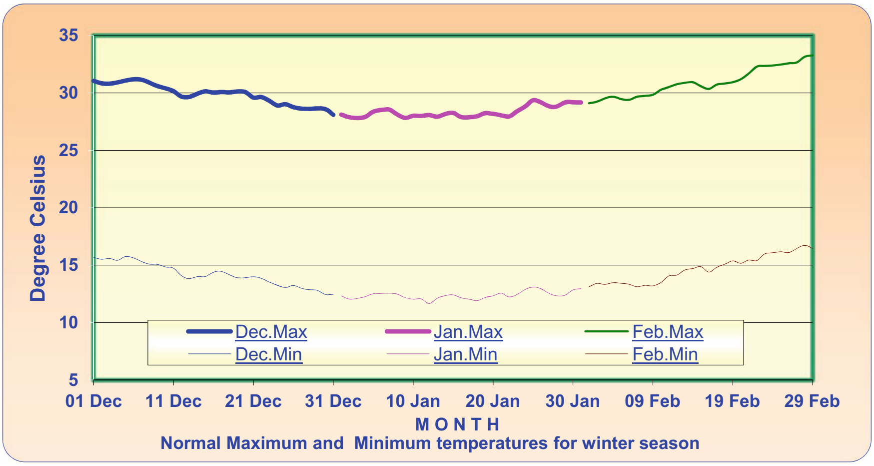

Fig. 17.1 Normal temperature of the winter season

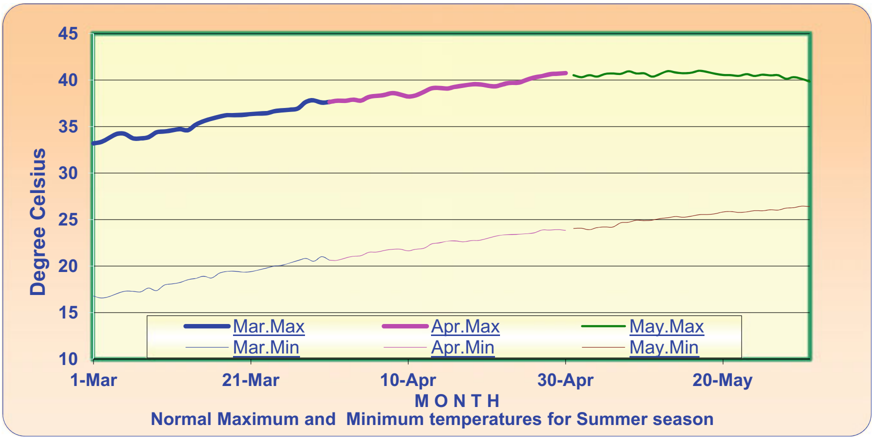

Fig. 17.2 Normal temperature of the summer season

October and November are observed as post-monsoon months. In these months, there is no drastic variation in temperature, but there is a normal temperature observed range between 31 and 35 °C, which is more comfortable for humans. In November, the winter season starts, so the temperature is reduced to 31 °C (Fig. 17.4).

Above Fig. 17.5 shows the extreme high and low temperatures from 1969 to 2017. The maximum highest temperature of 50 °C was observed in the year 1978. The minimum lowest temperature of 5 °C was observed in the years 1973 and 2008.

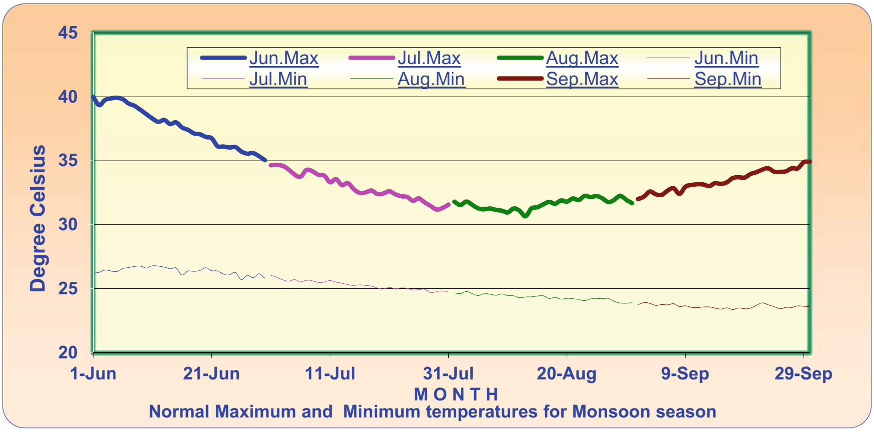

Fig. 17.3 Normal temperature of monsoon season

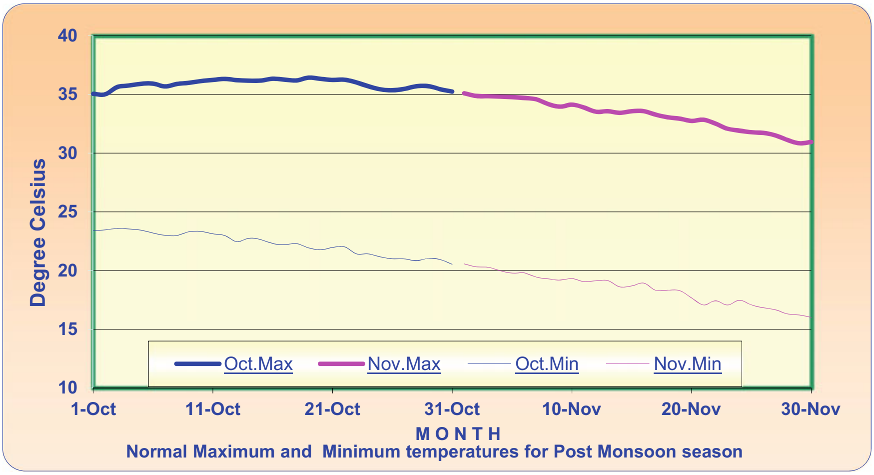

Fig. 17.4 Normal temperature of post-monsoon season

17.2 Study Area

Three typologies of urban areas have been studied: TOZ, mixed-use development, and the industrial regions such as Trikon Baugh, Madhapar Chowk, and Atika (Fig. 17.6).

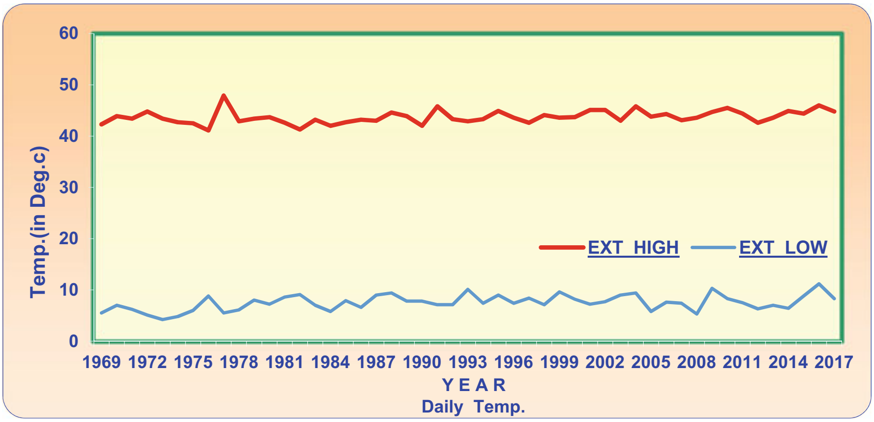

Fig. 17.5 Daily extreme temperatures

Fig. 17.6 Satellite image of Rajkot showing different locations selected for study

17.2.1 Transit-Oriented Zone Typology (P1): Selection Criteria

Madhapar Chowk is cross-road located on Jamnagar road that is state highway and 150 ft ring road, which is arterial road of Rajkot city. This cross-road is highly traffic

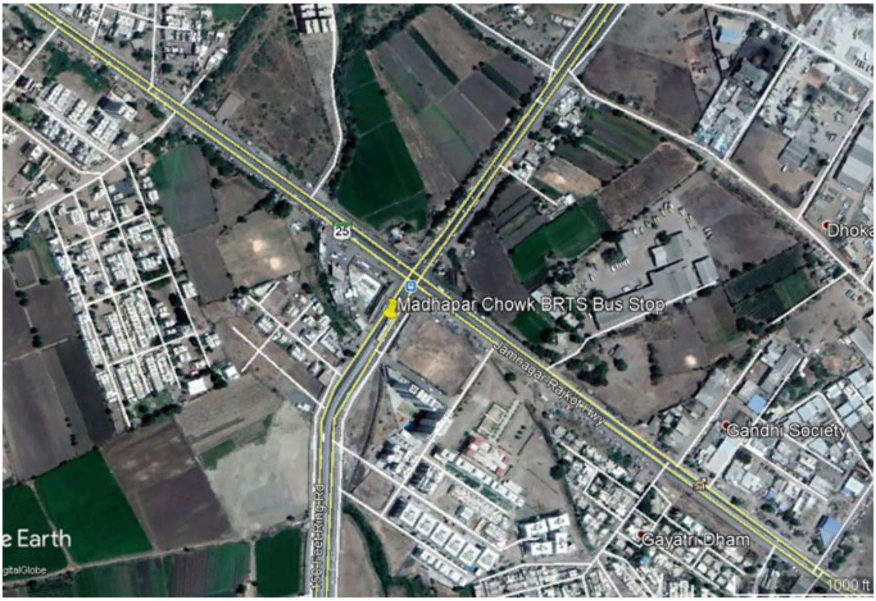

Fig. 17.7 Location of Madhapar Chowk

congested, and it is the entry point to Rajkot city from Jamnagar. It also connects the Jamnagar, Morvi, and Ahmedabad. Due to the connection with many cities, heavy vehicles are more at Madhapar Chowk. Surrounding area is vacant as shown in Fig. 17.7, but after 500 m, there is mix used development.

17.2.2 Central Business District Typology (P2): Selection Criteria

Trikon Baugh is located in the central area of Rajkot city. Main arterial roads pass through it and it is the central business district of Rajkot. Local main market and many corporate offices are located in the nearby area. It is the main location for Rajkot Mass Transit System (RMTS). Bus station is located behind Trikon Baugh. This is the busiest location of Rajkot city due to CBD. There is residential, commercial, and mix used typology (Fig. 17.8).

Fig. 17.8 Location of Trikon Baugh

17.2.3 Industrial Typology (P3): Selection Criteria

Atika industrial area is located in the southern part of Rajkot city and nearer to Gondal road. Medium- and small-scale industries are located here (Fig. 17.9). Due to the industrial area, there are fewer residential dwelling units, and most of the residents are workers or lower class people working in industries. Low motor vehicles, goods carrying vehicles are heavily concentrated in this area. Air quality index has been observed higher in this area owing to many hazardous and illegal industries.

Other environmental factors as carbon content and air quality index are also included which is also responsible for UHI.

Fig. 17.9 Location of Atika industrial area

17.3 Results and Discussion

17.3.1 Ambient Air Quality

17.3.1.1 Ambient Air Carbon Content

Carbon dioxide is mainly responsible for the greenhouse gas effect. GHG is directly prudent for UHI. As per Indian standard, there is the category of CO_2 level that is for human health. These are Table 17.1:

Indian standard says that the acceptable limit of CO_2 in the air is less than 600 ppm. If CO_2 concentration is more than 600 ppm, then it is noticeable because it will harm the living organisms. Figure 17.10 shows the CO_2 concentration over the entire city.

Table 17.1 Carbon dioxide levels in ambient air

	CO_2 (ppm)
Normal	350–450 ppm
Acceptable	< 600 ppm
Complaints of stiffness and odor	600–1000 ppm
General drowsiness	1000–2500 ppm

A maximum average concentration of 737 ppm has been observed at Atika industrial area. It is due to high CO_2 emissive manufacturing industries.

Figure 17.11 shows the CO_2 concentration at Madhapar Chowk from January to April. It is observed that many days in which concentration of CO_2 in air is more than the acceptable limit.

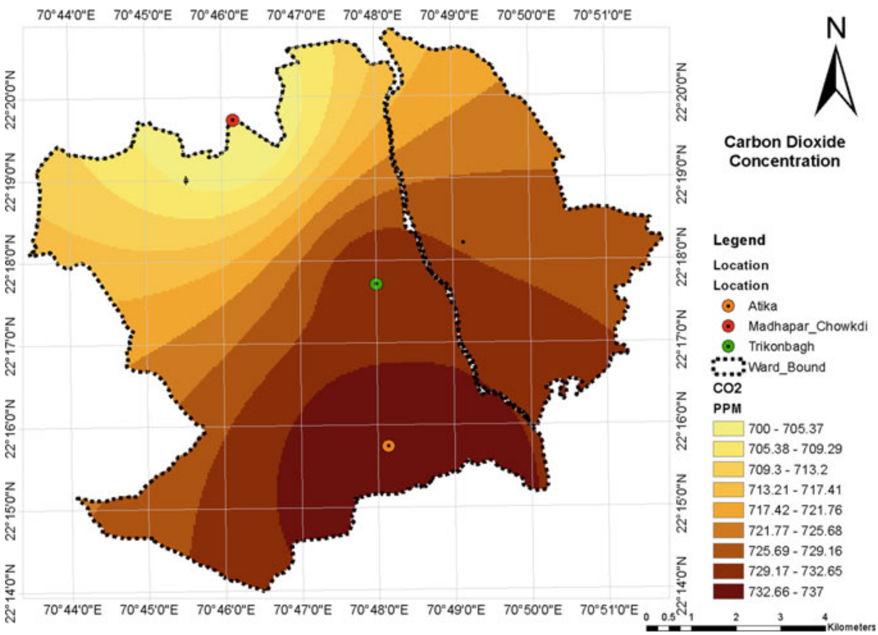

Fig. 17.10 CO_2 concentration in Rajkot

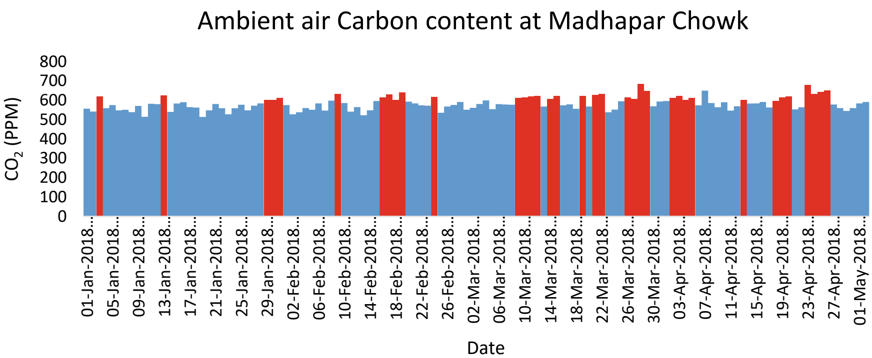

Fig. 17.11 CO_2 level at Madhapar Chowk

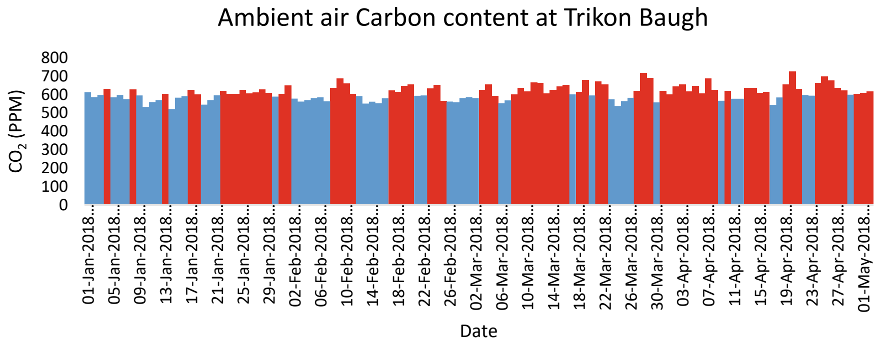

Fig. 17.12 CO_2 level at Trikon Baugh

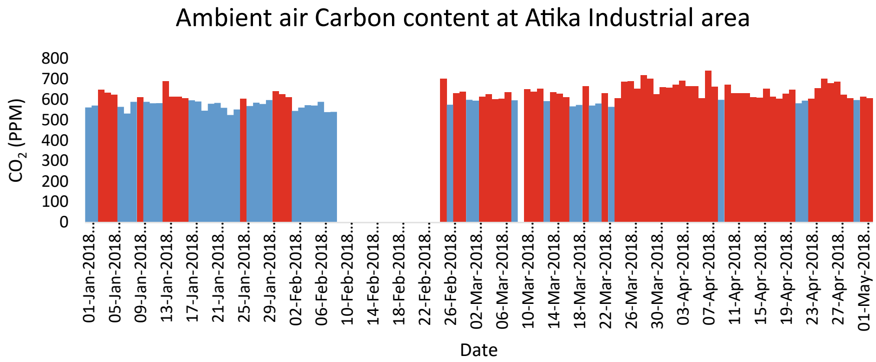

Fig. 17.13 CO_2 level at Atika industrial area

Figure 17.12 shows the CO_2 concentration at Trikon Baugh from January to April. It is observed that too many days in which concentration of CO_2 in air more than acceptable limit.

There are some data that are missing due to scientific error in the instrument. Figure 17.13 shows the CO_2 concentration at Atika industrial area from January to April. It is observed that much more days in which the concentration of CO_2 in the air is more than the acceptable limit. One reason for it is that Atika is an industrial area and is also congested, and there are no any trees or plants. Due to that, Fig. 17.13 for Atika shows more concentration of CO_2.

17.3.1.2 Ambient Air Carbon Monoxide Content

Carbon monoxide is the important pollutant, which is ubiquitous in urban environment. CO is produced mostly due to incomplete combustion. As per Indian standards, there is a category of CO level for human health (Table 17.2). These are:

Table 17.2 CO level in ambient air

	CO (ppm)
Good	< 1
Satisfactory	1–2
Moderately polluted	2–10
Poor	> 10

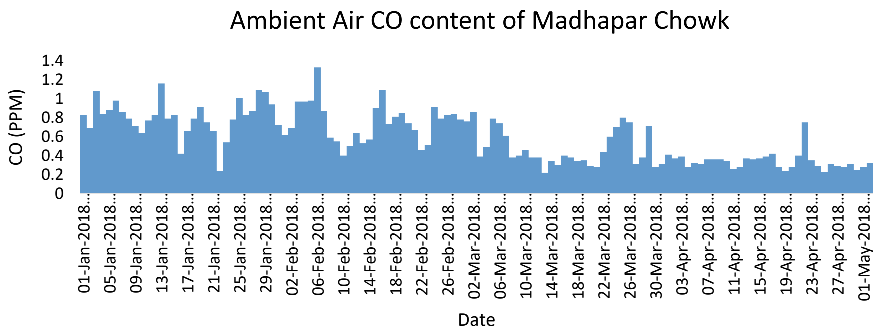

Fig. 17.14 CO level at Madhapar Chowk

Indian standard says that acceptable limit of CO in air is 1–2 ppm. If CO concentration is more than 2 ppm, then it is noticeable because it will harm the living organism.

Madhapar Chowk is located on the periphery of the Rajkot city boundary, and it is a part of the transit-oriented zone. Development is less in the surrounding area, so CO concentration at Madhapar Chowk has been observed at a satisfactory level (Fig. 17.14).

Trikon Baugh is the CBD of Rajkot and bus station is nearer, traffic congestion over here. Observation from Fig. 17.15 is that in many days, concentration of CO is beyond the satisfactory level, which will harm the environment and humans.

Atika is an industrial area. There are some data, which are missing due to scientific error in the instrument. Figure 17.16 shows that only one day that there was the concentration of CO was beyond its satisfactory level. It is noticeable that there is less concentration of CO in Atika even though the area is industrial.

17.3.1.3 Ambient Air Quality Index (AQI)

AQI is the mixture of eight pollutants such as CO, CO_2, SO_x, NO_x, PM2.5, PM10, O_3, NH_3 which is harmful to the environment and has a relation with UHI (Table 17.3).

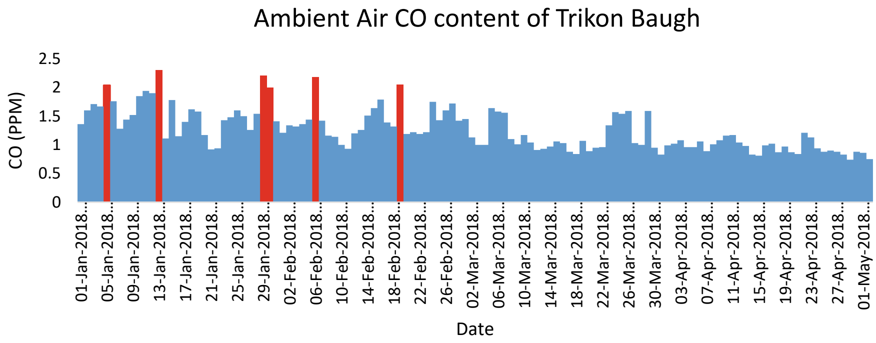

Fig. 17.15 CO level at Trikon Baugh

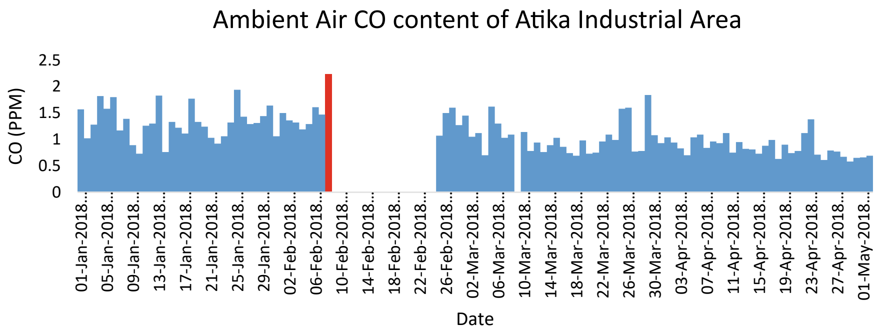

Fig. 17.16 CO level at Atika industrial area

Table 17.3 AQI category

Category	Value
Good	0–50
Satisfactory	51–100
Moderately polluted	101–200
Poor	201–300
Very poor	301–400
Severe	401–500

Observation from Fig. 17.17 is that only one day that there was moderately polluted AQI from four months has been observed. Otherwise, there is satisfactory AQI which has been observed.

Significant AQI is observed from Fig. 17.18. There is no trend of AQI; sometimes, there is good AQI and sometimes satisfactory.

Figure 17.19 shows that only one day there was moderately polluted AQI for four months. Otherwise, there is satisfactory AQI which has been observed. There are

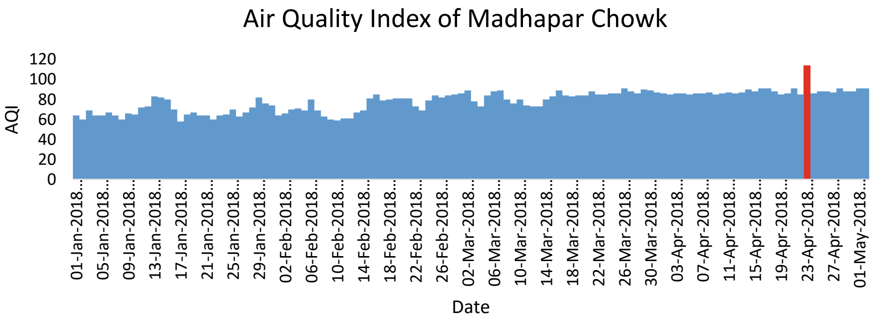

Fig. 17.17 AQI at Madhapar Chowk

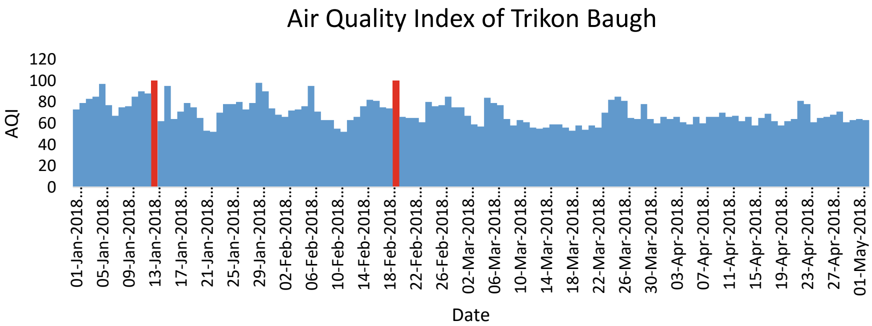

Fig. 17.18 AQI at Trikon Baugh

some data, which are missing due to scientific error in the instrument. There was a drastic variation in AQI in the winter season, and in summer, there was no intense variation in AQI.

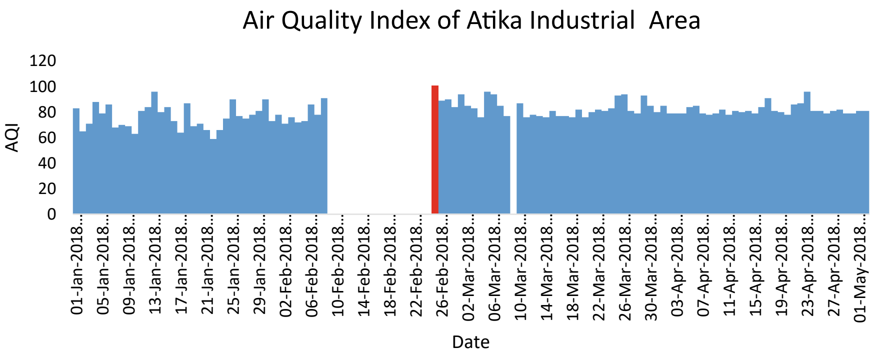

Fig. 17.19 AQI at Atika industrial area

17.3.2 Urban Heat Island Resilience Plan

The analysis revealed that the heat island effect ranks right behind global warming and requires careful consideration. The ecosystem, flora, and animals, as well as human health, may be impacted. In this chapter, the UHI resilience plan is proposed for the entire Rajkot city. This plan aims to reduce the significant threat of UHI within the city limit and reduce the pollutants, which contribute to increasing temperature.

Since the causes and effects of UHI are highly localized, this plan contains different resilient strategies for Rajkot. To know the significant threats of UHI, this study took different locations defined by its built form, use, and typology. From the analysis, it was found that two locations are highly critical for UHI as listed below:

1. **Trikon Baugh—Central Business District and mix use typology**
2. **Atika industrial area—industrial typology**

UHI resilience strategies mentioned below should be implemented on the entire city, but these UHI resilience strategies must be implemented at the above-mentioned two locations that are highly critical for the UHI effect. Strategies are implemented in different phases; the first pilot implementation project should start from two highly critical locations, Trikon Baugh and Atika industrial areas. The entire city should be covered in the other phases by implementing UHI resilience strategies (Fig. 17.20).

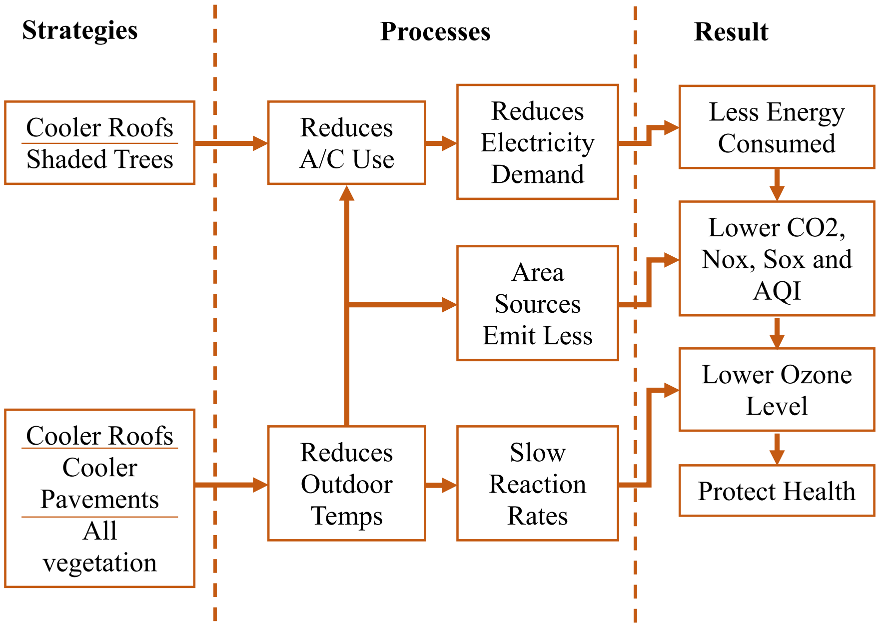

Fig. 17.20 Overall strategies proposed to make city Urban Heat Island resilient with considering air pollution. *Source* (Akbari, 2005)

- Strategy 1: Integrating reduction and responses of UHI for existing policies and program.
- Strategy 2: Strengthen and built green infrastructure.
- Strategy 3: Alleviate cool roofs.
- Strategy 4: Create cool road infrastructure.

17.3.2.1 Strategy 1: Integrating Reduction and Responses of UHI for Existing Policies and Program

As per the above analysis, Urban Heat Island effect has been observed within city limit and it varies through its typology and ambient air quality. Haphazard development, migration toward city, urban sprawl, high density, thermal property of fabrics and anthropogenic heat area some of the activities, which contributes to the UHI, effect in urban areas. Mitigation measures should be like increasing vegetation, using more reflective materials in buildings and roofs, using low albedo materials in pavement, promoting maximum use of public transportation, and maintaining H/W ratio for development of area to prevent access to direct sunlight in living space. These mitigation measures have been adopted in many cities like Delhi, Mumbai, Pune, Bhopal, and Ahmedabad recently, and considerable reduction has been observed in the UHI effect by using the above-mentioned measures. The existing policy review is shown in below Table 17.4. Based on that review, proposed policy and implementation suggestions are given in Table 17.5.

Rising environmental issues, particularly UHI, should be incorporated in the spatial planning framework through Table 17.5. The governmental framework of four ministries has addressed the UHI phenomenon. Some of them directly include the UHI, and some include indirectly. Implementation suggestions are based on the importance of casual factors in a particular policy. Grading is given from 1 to 5, where 1 stands for less need of implementation and 5 stands for implementation to a grate extend.

Under MoEF, NEP provides a comprehensive vision for the anticipation of environmental degradation and natural environmental issues like flora–fauna, deforestation, air pollution, and climate change effects. While NMGI promoting green cover, MNRE and MoP give nod to UHI through approving energy-efficient appliances and buildings and promoting green roofs. MoUD framework links the UHI with climate change, growing energy demand and ecological impact causes. NMSH covers energy demand and energy usage, and URDPFI and NUTP include the urban geometry, microclimate and surface characteristics, and area location.

Volunteer rating systems such as LEED, GRIHA, and ecological clearance encourage the use of material with high albedo value, vegetative cover, and impervious surfaces under shaded spaces. Open spaces, green cover, and shaded spaces are included in building bye-laws. Government institutions should incorporate the effect of UHI through this strategy.

Table 17.4 Existing policy of UHI

Policy Instruments	Acknowledgement of UHI effect	Land-use Planning	Building Morphology	Surface Characteristics	Urban Lifestyle	Implementation Suggestions
	EXISTING POLICY FOR URBAN HEAT ISLAND					
		Identification of Causal Factors / Suggested Mitigation Measures				
MoEF						
National Environmental Policy						
National Mission on Green India						
National Conservation Strategy &Policy Statement on Environment & Development						
Environment Clearance (EC/EIA)						
MoUD						
National Mission on Sustainable Habitat						
National Urban Transport Policy						
Urban and Regional Development Plan Formulation and Implementation						
JNNURM						
Model Building Bye Law						
MNRE-						
National Solar Mission						
MoP-						
Efficiency						
Bureau of Energy Efficiency						
Energy Conservation Building Code (ECBC)						
Rating Systems						
ICBC (LEED) Rating						
GRIHA						

UHI direct inclusion | UHI indirect inlcusion

Table 17.5 Proposed policy for UHI

Policy Instruments	Land-use Planning	Surface Characteristics	Ambient Air pollution	Area Location	Anthropogenic Heat	Population	Urban Geometry	Urban Lifestyle	Grading 1 to 5
	PROPOSED POLICY FOR URBAN HEAT ISLAND								
	Identification of Causal Factors / Suggested Mitigation Measures								Implementation Suggestions
MoEF									
National Environmental Policy									3
National Mission on Green India									4
National Conservation Strategy & Policy Statement on Environment & Development									4
Environment Clearance (EC/EIA)									4
MoUD									
National Mission on Sustainable Habitat									5
National Urban Transport Policy									5
Urban and Regional Development Plan Formulation and Implementation									4
JNNURM									2
Model Building Bye Law									5
MNRE-									
National Solar Mission									2
MoP-									
National Mission for Enhance Energy Efficiency									3
Bureau of Energy Efficiency									3
Energy Conservation Building Code (ECBC)									4
Rating Systems									
IGBC/LEED Rating									5
GRIHA									5

UHI Direct Inclusion | UHI Indirect Inclusion

17.3.2.2 Strategy 2: Strengthen and Built Green Infrastructure

Vegetation cover and trees help lower surface and air temperature and make urban climate cool through shading and evapotranspiration. The plantation of trees and vegetation can directly or indirectly reduce air pollutants, which are contributed to the UHI effect. Trees directly reduce CO_2 emission by the photosynthesis process and indirectly reduce demand for cooling, ultimately reducing energy consumption. The energy consumption in Rajkot city is 15.7-million gigajoule. Maximum energy is consumed by the transportation sector, followed by residential buildings. Figure 17.21 shows the energy consumption of Rajkot city.

The increase in energy consumption results in the higher the emission of CO_2. Sun rays enter into earth's atmosphere; some of them reflect back, but high emission of CO_2 cannot reflect back to the sun rays. It traps the heat within the earth's atmosphere which is responsible for UHI effect. Figure 17.22 shows the sector-wise CO_2 emission of Rajkot. Maximum CO_2 is emitted by residential sector followed by industry and transportation sector. The CO_2 emission in Rajkot city is 2.06 million tons.

From the above analysis of ambient air for three locations such as Trikon Baugh, Madhapar Chowk, and Atika industrial area, it is observed that the concentration of CO_2 is significantly high at Atika industrial area 737 ppm that is beyond its permissible level. At Trikon Baugh, there is soaring concentration up to 732 ppm observed. Both of these locations have CO_2 concentration beyond permissible levels. To maintain the concentration of CO_2 in atmosphere less, vegetation is the main source. It improves the air quality through oxygen production, carbon sequestration, and reducing smog that built up more temperature rise. Proper selection and location of tree can reduce temperature and CO_2 concentration and make building or area cool.

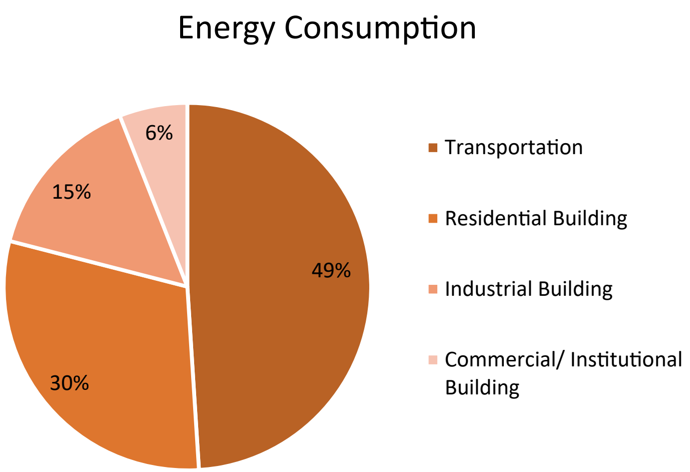

Fig. 17.21 Energy consumption by sector in Rajkot

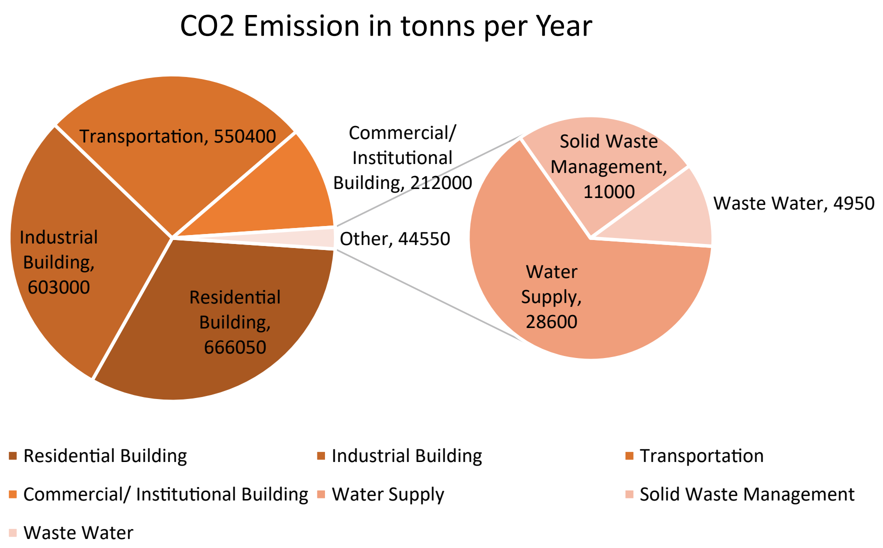

Fig. 17.22 CO_2 emission of Rajkot city

A mature tree can reduce carbon emission by 18 kg annually and sequester 4.5 kg–11 kg of carbon. A four-shaded tree with the crown area of 50 m^2 can reduce carbon combustion by 16,000 tons per year. One mature tree can reduce cooling energy by 1% and heating energy by 2%. One tree can reduce temperature by 0.3 °C. To reduce CO_2 emission, Table 17.6 shows the percentage CO_2 reduction and the required numbers of trees. The area required for the tree is also mentioned in Table 17.6; approximate area of one tree is taken as 0.8 m^2.

As per Table 17.6, to reduce 25% of CO_2, 28.6 million trees should plant within the city. The local government should initiate a program for tree plantation and give rewards to encourage people to plant and protect trees. The government should consider tree plantation in building bye-laws and investigate whether trees are planted after construction has been done. If trees are not planted, he/she should not use any basic amenities provided by the local government.

The storage and capture of carbon and is one of the green infrastructures that trap CO_2, transport it, and store it at a particular place. CCS can capture up to 90% CO_2 from industrial sites. There are three main techniques:

Table 17.6 Numbers of the tree to reduce CO_2 in Rajkot

Reduction in CO_2 emission (%)	Nos. of trees	Area required (km^2)
100	114.7 million	91.76
50	57.3 million	57.3
25	28.6 million	28.6

The post-combustion procedure entails chemically cleaning the industry's exhaust gas (Fig. 17.23).

Before the fuel is put into the furnace, pre-combustion CCS occurs by first turning coal into a clean gas and removing the CO_2 *generated during the process* (Fig. 17.24).

Oxy-fuel burns coal in an environment with a higher percentage of pure oxygen, producing exhaust that is virtually entirely made of carbon dioxide (Fig. 17.25).

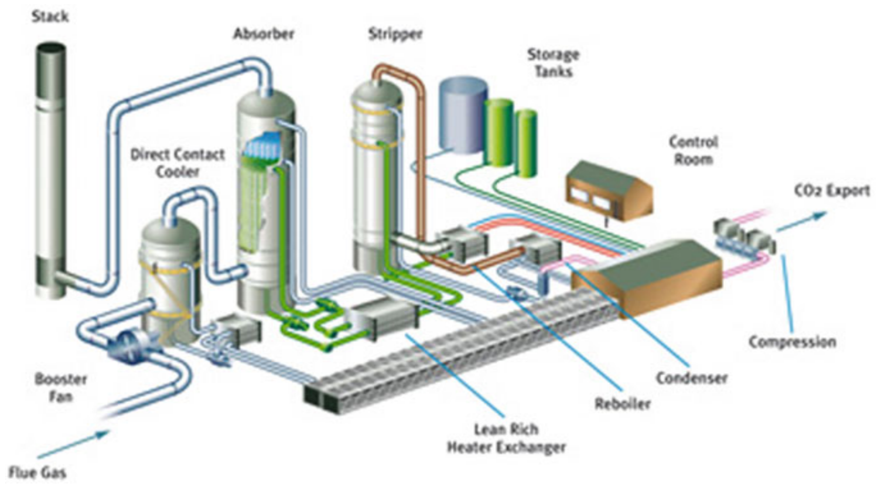

Fig. 17.23 Post-combustion process

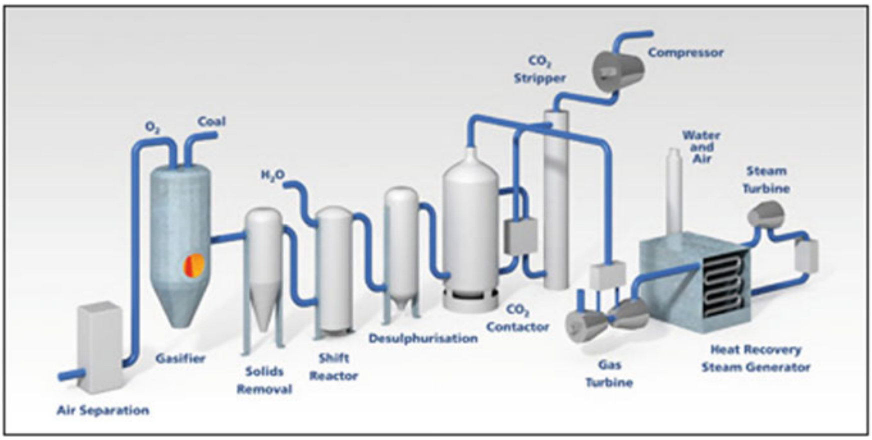

Fig. 17.24 Pre-combustion process

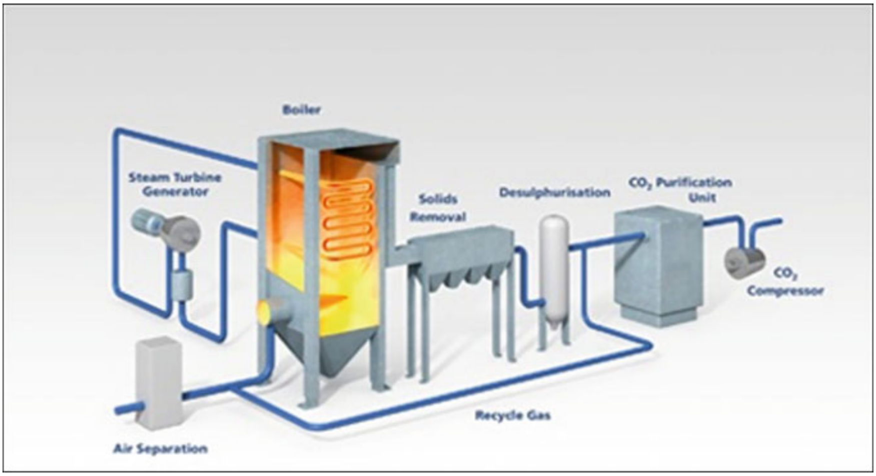

Fig. 17.25 Oxy-fuel system

After being caught, the CO_2 is liquefied, transported—sometimes over several hundred miles—and then buried in appropriate geological formations, deep saline aquifers, or abandoned oil fields.

Recommendations

- An awareness program should be initiated by local government.
- Tree plantation campaign and CCS awareness campaign should be initiated by government and NGOs.
- Tree plantation is already included in building bye-laws, but there is no monitoring system, so proper monitoring system should be implemented by government.
- There should be stick rules like one who is not planting trees as per law he/she should not utilize basic amenities provided by government.
- Due to valid reason one have to cut tree, he/she have to replace that tree to other place rather than cutting it.
- Every industry should have reserved area for plantation of trees.
- Every industry should install CCS technology.

17.3.2.3 Strategy 3: Alleviate Cool Roofs

In Rajkot city, roof constitutes almost 56% of the land surface area. Most of solar energy gets absorbed by roof and transfers the heat inside building. Absorbed solar energy increases temperature up to 80 °C and thus increases ambient air temperature of surrounding area. A dark-colored roof absorbs more solar energy than light-colored roof. Higher reflectivity and emissivity of roofing material can store less heat and radiate it back to atmosphere. Cool roofs are the roofs, which reflect more solar radiation and less absorb heat. It can help to address the UHI effect. Light surface of roof reflects greater solar radiation; hence, very less solar heat is absorbed. In addition, cool roofs transfer lesser heat into building through conduction.

Albedo (solar reflectance) value and emissivity of a roofing material play important role to reduce UHI effect. High albedo surfaces stay much cooler than low albedo surface. Figure 17.26 shows three different types of roofing material and its effect on surface temperature. Darker roof reflects less heat and white roof reflects higher heat and higher thermal emittance. High absorptive and less emissive surface contributes to a greater extend in keeping higher temperature and thus indirectly increasing energy demand. Increasing energy demand contributes into more CO_2 emission and more polluted environment owing to more smog formation in warm environment. It is estimated that retrofitting of 100 m^2 of roof generates 10 tons of CO_2 emission ("Urban Heat Island Effect And Its Mitigation", n.d.).

The conventional roof has lower reflectance but high thermal emittance; black asphalt roof can reach up to 75–85 °C in summer season. Metallic roof has higher reflectance and lower emittance and can warm to 66–77 °C. A cool roof with both high reflectance and high emittance peak temperature of only 43–46 °C in summers. Conventional roofs can be 31–47 °C hotter than the air, while cool roofs can be stand within 6–11 °C of the background temperature. This reduced surface temperature can reduce ambient air temperature (EPA, 2008a, 2008b, 2008c).

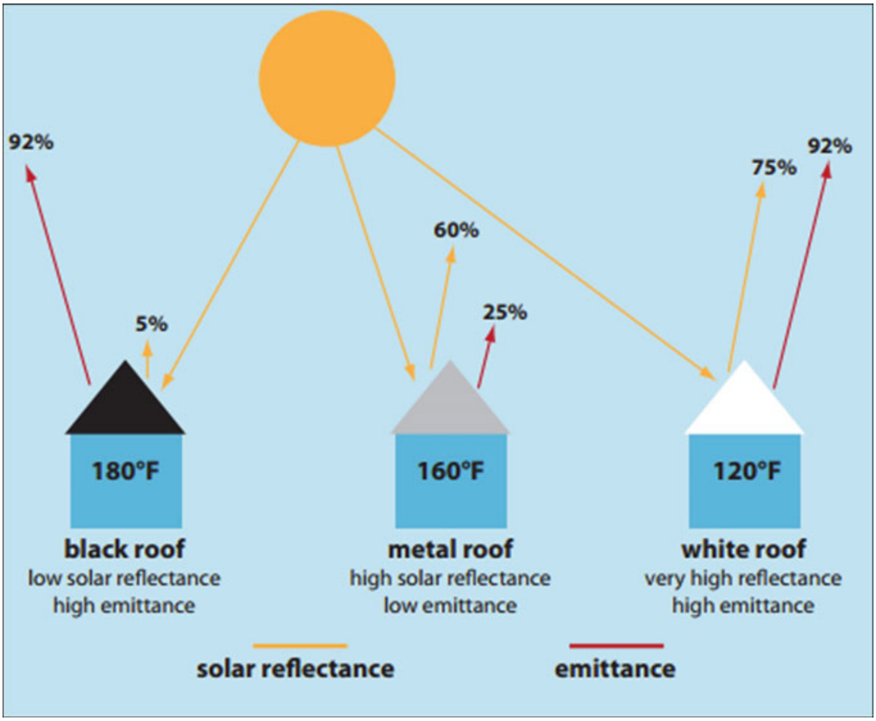

Fig. 17.26 Effect of reflectance and emittance on roof surface temperature

Cool roofing can be done by using roof coating such as white elastomeric coating, cool color polymer coating for tiles. Other materials such as Broken China Mosaic Terracing, Modified Bitumen, and RCC with elastomeric coating are simply finished with broken white glazed tiles and cool colors (Dikshit, n.d.). By using mentioned material on roof, it will decrease the energy demand by 12–46%. Reduced energy use reduces GHG emissions from a home or building by 6–7% while also reducing ozone precursor emissions. The cool roof has a lower propensity to warm the air around it and accelerate the development of ozone (Babazadeh & Kumar, 2015; Bocchiaro & Zamperini, 2016; Cambridge Systematics, 2005; Corburn, 2009, da Silva & Moench, 2014, EPA & EPA, 2016; Eraydin & Taşan-kok, 2013; Joshi et al., 2015; Kotecha, 2021; Rizwan et al., 2008; Rosenthal et al., 2008; Stone & Rodgers, 2001; TARU & CDKN, 2016; USA Environmental Protection Agency, 2013; York, 2015).

Depending upon type of roofing, material can cost 0–20% more per m^2. Compared to traditional roof so are easy to incorporate into current practice. Cool roofs can decrease energy cost and therefore help to alleviate climate change.

Recommendations

- Awareness program should be initiated by local government.
- Public education should provide to all residents to install cool roofs.
- Local government should install cool roof in public buildings to encourage use of cool roof.
- Local energy company should give incentive to install cool roofs in new and old constructions.
- Offer repayment program to building proprietors who install cool roofs, and refund is in the form of relaxation in installation bill or reimburse for some of the price of installation.
- Cool roofs should be mandatory in any type of construction.
- Cool roofs should be included in building bye-laws and NBC.

17.3.2.4 Strategy 4: Create Cool Road Infrastructure

In Rajkot city, road constitutes almost 13% of the land surface area. All the roads are paving with asphalt and bitumen that give smooth surface and all weather roads for the movement of vehicles. However, there is a problem that surface covering with black asphalt increases heating of city by sunlight. UHI effect in city is partially due to paved surface having low albedo and impervious material. Through cool paving technology, UHI effect should be mitigated. This pavement technology tends to store less heat and make surface cooler. This traditional paving has low albedo and less emissivity, which traps the heat, and rises the surface temperature and ultimately causes UHI effect. Traditional asphalt and bitumen pavement, surface temperature reaches up to 48 to 67 °C in summer and in turn rise surrounding air temperature. By using cool pavement, surface temperature would be reduced by 10–20 °C.

Cool pavement is mostly dependent on materials albedo value. Albedo is the proportion of solar energy mirrored by surface. Figure 17.27 shows the albedo value

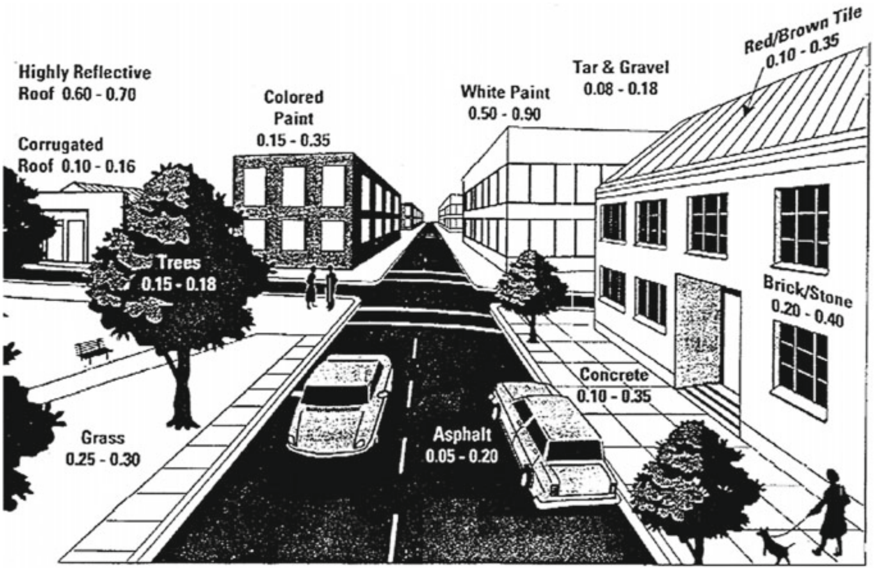

Fig. 17.27 Albedo value of different surfaces

of different materials. Conventional paving material has albedo value ranges from 0.05 to 0.40. It has been observed that every 10% increase in albedo could decrease surface temperature by 4 °C (USA Environmental Protection Agency, 2008). Cool pavement mitigates UHI by lowering air and surface temperature.

The main types of cool pavement include reflective pavement, permeable pavement, vegetated permeable pavement, and light color pavement.

According to EPA, if pavement reflection increases by 10–35% throughout city, air temperature reduced by 0.6 °C. Stormwater management can be done through the permeable pavement, and permeable paver could reduce runoff temperature by 2–4 °C (Table 17.7). Cooler air temperature can also decrease the formation rate of ozone at ground level and ultimately reduce evaporative emissions from vehicles. Cool pavements prevent the premature failure of pavement by reducing surface temperature. Cool pavement provides illumination at nighttime, enhances visibility, reduces lighting requirements, and ultimately lowers energy demand. Due to better water drainage, good visibility, and higher traction, cool pavement increases road users' safety.

The price of cool sidewalk is 10–20% more than that of standard pavement. High-traffic regions may suffer from the necessity of frequent repaving, recoating, and replacement of pavements to preserve their high albedo.

Table 17.7 Types of cool pavement

Name of cool pavement	Material	Area of application
Conventional asphalt pavement	Asphalt binder mixed with aggregate, modified with high albedo material or rise reflectance after installation	Wide range of function from parking lots to highways
Conventional concrete pavement	Portland cement, water, aggregate	Trails, roads and parking lots
Resin-based pavement	Tree resins in the place of bitumen to bind aggregate	Lower traffic area, trails, and parking lots
Colored asphalt and colored concreate	Pigment or seals to increase reflectance	Lower traffic area, trails, and parking lots
Non-vegetated permeable pavement	Shredded rubber in asphalt, pervious concreate, block pavers	Lower traffic area, trails, and parking lots
Vegetated permeable pavement	Aggregate bound in liquid asphalt	Resurfacing of low volume road and highways
White topping	Concrete layer greater than 10 cm thick with fibers	Resurfacing road segment, intersection, and parking lots
Microsurfacing	Thin sealing layer, light color for high solar reflectance	Low-to-medium volume road

Recommendations

- Local government should encourage cool pavement through mandates.
- Prohibition of coloring agents like carbon black, etc.
- Life cycle analysis should require for public paving decisions.
- Enforce the use of waste products like fly ash (light in color) with high albedo value.
- The local government should provide incentives or rewards to the developer, which construct roads and highways to encourage cool pavement.
- ULB should offer a limited or full reimbursement of stormwater management fees for fitting permeable pavement that reduces the runoff.

17.3.3 Demonstration of UHI Resilience Action Plan Through T.P. Scheme-10

Above spatiotemporal analysis and environmental factors showed that several locations were good candidates for detailed study. These areas constitute significant heat islands and have relatively high concentrations of CO_2. Among these areas, this study focuses on Atika industrial area that is constituted under T.P. scheme-10. Figure 17.28 shows T.P. scheme-10 with levels of LST.

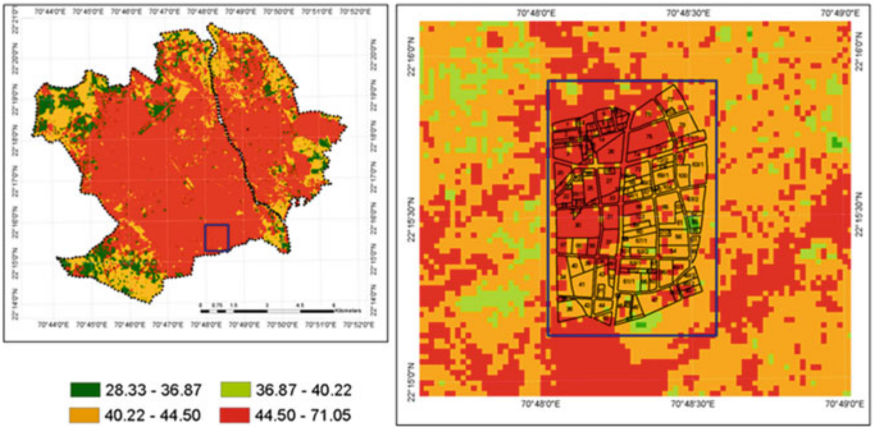

Fig. 17.28 UHI in Rajkot

17.3.3.1 About T.P. Scheme-10

Atika is an industrial area, but there is also a residential, commercial, and institutional area. Figure 17.29 shows LULC of T.P. scheme-10. T.P. scheme-10 has 30% industrial area, out of them 27% are manufacturing industries; processing units and other sectors are fall under remaining 3%, 12.3% commercial area, and 57.7% residential area. There are two plots of area 2311 and 2739 m^2 reserved for the garden, but some residential encroachment has been observed there.

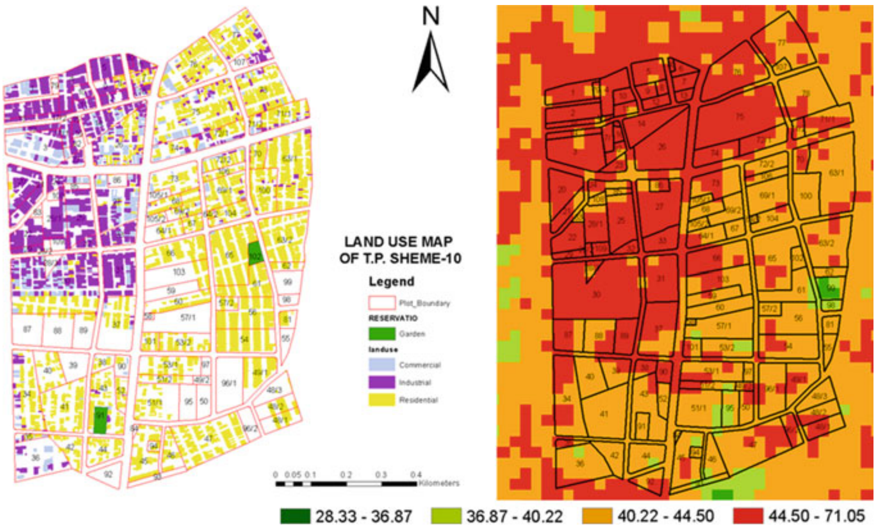

Fig. 17.29 Land use map and LST map of T.P.-10

The total population of T.P. scheme-10 is 22,500 people. There are a high proportion of migrated peoples who are working in nearby industries. About 80–90% population of this area is working in industries. There are mostly low-income group and medium-income group residents. According to the survey, 85% of houses are in good condition, 14.8% are livable, and 0.2% are dilapidated. As per survey, 92% of roofs are concrete roofs, 6.7% roofs are metal/G.I. roofs, 0.8% roofs are burnt brick roofs, and 0.5% are area tiles' roofs. Burnt bricks are used 96% in walls, unburned bricks are used 2.5% in walls, and concrete is used 1.5% in walls.

Implementation of Strategy 2: Strengthen and built green infrastructure

- *Applying vegetation cover*

  As per the survey and above-mentioned LU and LST map, there is high temperature up to 71 °C in core industrial area and 44 °C in residential area. According to RMC manufacturing and production, industries emitted 603,000 tons of CO_2 per year. As discussed earlier in strategy 2, one mature tree can reduce surface temperature by 0.3 °C. In T.P. scheme-10, there is maximum surface temperature of 70.05 °C. To reduce this temperature, 240 trees should be planted and area required to plantation of 240 trees is 600 m^2 (1 tree = 2.5 m^2). Few trees have more carbon sequestration capacity shown in Table 17.8. If below-mentioned trees should be planted, carbon emission would reduce rapidly and ultimately surface and air temperature can reduce. Few of mentioned tree species are critically endangered, so it can be conserved. By applying, this surface temperature would be lower down from red zone to orange or light green zone.

The last stage of CSS is the storage of carbon. Carbon is stored in porous geological formations located several kilometer under earth's surface, and it should have top layer of impermeable strata. Geological strata of Rajkot is clay loam to clay type. Impervious layer followed by porous layer (cap rock layer) is 5000 m deep where CO_2 should be stored (Mohapatra, 2013). This process is called geosequestration.

As per the survey, industrial sites emit 603,000 tons of CO_2 per year, which can be reduced by 60,300 tons of CO_2 per year if CCS technology should be installed in all industries. After many years, this stored carbon will be converted into oils and natural gas. This CCS system should reduce CO_2 and ultimately reduce temperature.

- *Implementation of Strategy 3: Alleviate cool roofs*

  Higher surface temperature is also due to materials used in roofs (Akbari, 2002). As per the survey, 92% property is having concrete roofs (mostly residential properties and some industries also), 6.7% property is having metal/G.I. roofs (mostly industrial sheds), 1.3% property is having burnt brick roofs and tiles roofs. Concrete and metal roofs are conventional roofs having lower solar reflectance and higher emittance.

Industrial sites have maximum temperature up to 71.05 °C due to carbon emission and conventional roofing material. If all industries located under T.P. scheme-10, install cool roofing materials like white elastomeric coating on metal/G.I. roofs;

Table 17.8 Carbon sequestration of trees

Name of tree	Image of tree	Local name	Carbon sequestration (kg/tree)
Kigelia pinnata		Cucumber tree	35.681
Millingtonia hortensis		Aksh limdo	52.58
Grevillea robustra		Silver oak	25.67
Peltophorum petrocarpum		Tamrafali	23.90
Agardirachta indica		Neem tree	8.70

then, surface temperature will reduce from 71 to 43 °C and reduce energy demand by 10–12%.

The residential area has concrete roofs with high emittance and lower solar reflectance, so the surface temperature of the residential area is high and consumes more energy for cooling (Aflaki et al., 2017). If all residential and commercial properties should install cool roofing materials like cool color polymer coating for tiles, Broken China Mosaic Terracing, Modified Bitumen, RCC with elastomeric coating or simply finished with broken white glazed tiles and cool colors can reduce surface temperature from 45 to 36 °C. China Mosaic and cool colors are cheap in cost and easy to apply in existing property. This type of cool roof is having 6 °C–11 °C higher temperature than the ambient air temperature.

- *Implementation of Strategy 4: Create cool road infrastructure*

  T.P. scheme-10 consists road area of 0.187 km^2. Main road is having 24 m of ROW and internal roads are having 7.5 and 9 m of ROW. Road network is shown in Fig. 17.30. Based on the perception study of T.P. scheme-10, all roads are paved and asphalt roads. Traditional asphalt roads absorb more solar radiation and emit more energy; thus, surface temperature reaches up to 48–67 °C in very high summer season. This higher temperature can impair water quality. Using cool pavement technology in study area will reduce surface temperature by 10–20 °C.

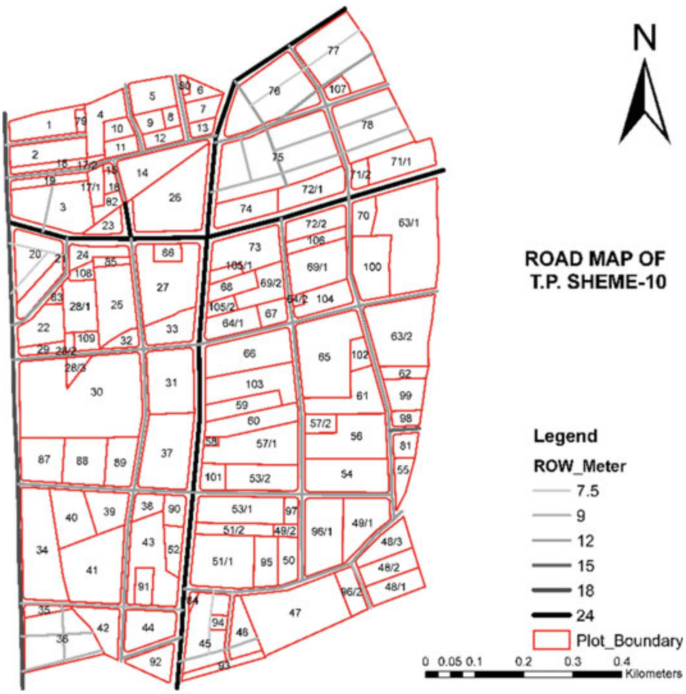

Fig. 17.30 Road network of T.P. scheme-10

As discussed earlier, cool pavement technology depends on albedo value of material used as pavement. Higher the albedo value, lower the surface temperature. Asphalt pavement is generally used in T.P. scheme-10, which has lower albedo value of 0.05–0.2. 24 m roads under T.P. scheme-10 are having wide range of function from parking lots to highways. This road should use cool pavement as asphalt road made by adding asphalt binder mixed with aggregate, modified with high albedo material will reduce surface temperature by 10–20 °C. In addition, plant above-mentioned trees on all medians. Resin-based pavement, colored asphalt and colored concrete, non-vegetated permeable pavement, vegetable permeable pavement, white topping, and microsurfacing should be used in other internal and sub-main roads to reduce surface temperature.

An internal road of 7.5 m ROW should be made by vegetated permeable pavement, which allows the surface to percolate water. During summer, season surface runoff should percolate into the ground through this type of pavement and it makes inner soil strata cool and increases water table (Ahmed, 2018). White topping is the cheapest cool pavement technology. The resurfacing concrete layer is greater than 10 cm thick, with fibers applied on the surface to increase albedo value. Due to medium-to-high traffic, microsurfacing should be adopted on these roads using a thin sealing layer and light color for high solar reflectance to increase albedo value. Finally, it will reduce the surface temperature of roads. By thoroughly applying four strategies, surface temperature and CO_2 emission should be reduced, making T.P. scheme-10 UHI resilient area. Ultimately, fight against climate change. This demonstration of the T.P. scheme should apply to the whole city, and it should make Rajkot Urban Heat Island resilient owing to climate change.

17.4 Conclusion

Urban growth is severely hampered by climate change which is the result of UHI. The more well-known effect of climate change producing energy and environmental issues in cities is urban heat island. Significant research has been done to develop UHI resilience action plans and mitigation strategies in order to lessen the impact of UHI. Through geospatial analysis and ambient temperature isotherms, the major goal of this research project is to make Rajkot's urban area more heat-resistant. For the purpose of finding UHI, spatiotemporal analysis was done. To track the temperature trend for the research area, forecasts of the ambient air temperature were made for the winter, summer, and monsoon seasons. The temperature of the surrounding air has increased by 0.3 °C. The surface temperature and the temperature of the surrounding air were compared. There is difference of 2.5–3 °C between surface and air temperatures. Air pollutants can also be considered in the analysis to see the effect of UHI and air quality. Surface and air temperatures differ by 2.5–3 °C. To determine how UHI and air quality interact, air contaminants can also be taken into account in the analysis.

Locations were then determined using various typologies, including Madhapar Chowk-TOZ, Trikon Baugh-CBD, and Atika industrial area. IMD's measurement of the ambient air temperature served as the basis for the temperature isotherm. Isotherms show that the air is hot to the touch; Trikon Baugh recorded an average temperature of 38.5 °C at its highest point. The CBD is in Trikon Baugh. Because the central bus terminal is closer to Trikon Baugh and Rajkot's most congested region, more CO_2 and CO emissions from moving vehicles are to blame for the area's high temperatures. Due to the industrial region, Trikon Baugh has the highest CO emission levels, whereas Atika has the highest CO_2 levels. The UHI effect is mostly caused by CO_2 and CO.

Based on above scrutiny, UHI resilience plan can be proposed. Various factors and their importance in mitigation plan has been discussed in previous chapter. Four mitigation strategies such as integrating reduction and responses of UHI for existing policies and program, strengthen and built green infrastructure, alleviate cool roofs, and create cool road infrastructure, are proposed in UHI resilient action plan. UHI resilience action plan should implement on entire city, but this UHI resilience strategies must implement at Trikon Baugh and Atika because there is high concentration of CO, CO_2 and have high surface and air temperatures. Strategies are implemented in different phases; the first pilot implementation project should start from two highly vulnerable locations such as Trikon Baugh and Atika industrial area.

Vegetation cover could reduce pollution and air temperature. In Rajkot city 15.7 million-giga joule energy consumption and 2.06 million tons of CO_2 emission. To reduce 100% CO_2 emission, 114.7 million tress should be planted. For a 50% reduction, 57.3 million trees should plant, and for 25% reduction, 28.6 million trees should plant. Cool roof has peak temperature of 43–46 °C in summer. Cool roof can be 6–11 °C hotter than the air. Cool pavement reduces the surface temperature of pavement. Traditional pavement surface temperature reaches up to 48–67 °C in summer and in turn rises surrounding air temperature. By using cool pavement, surface temperature would be reduced by 10–20 °C. Lower surface temperature decreases the UHI effect and reduces the CO_2, CO, NO_x, SO_x and ultimately reduces the rate of ozone formation at ground level. Stormwater management can be done through the permeable pavement and permeable paver could reduce runoff temperature by 2–4 °C. Public health can be improved by adopting these resilience strategies. Finally, one demonstration of all four strategies on T.P. scheme-10 shows the implementation of resilient strategy and how much land surface temperature will be reduced by adopting these resilient strategies. Eventually, it shows that above-mentioned resilient strategies should decrease UHI effect due to climate change.

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Chapter 18
Identifying Suitable Sites for Alternative Agriculture in Drought-Prone Akarsa Watershed, West Bengal

Ujjal Senapati, Shrinwantu Raha, Tapan Kumar Das, and Shasanka Kumar Gayen

Abstract Identification of potential agricultural sites in drought-prone environment is always a challenging aspect. Though several researchers have tried to identify drought in Akarsa watershed, but previously no attempt has been noticed to identify the potential alternative agricultural sites in this watershed. This research is designed to identify the alternative agricultural sites with the help of Analytic Hierarchy Process (AHP) and weighted overlay technique. To do this, 9 parameters are selected which are distance from settlements, proximity to ponds, slope, ground water, drainage density, land use-land cover (LULC), distance from roads, distance from vegetations and distance from drainage. Those parameters are overlaid, and ultimately suitable areas of alternative agricultural systems are determined. 27% area is identified under plantation agriculture, 25% area is identified under fruit culture, 17% area is identified under mixed culture, 7% area is identified under horticulture and rest portions (24% area) are observed with several other anthropogenic activities which include settlements and industrial activities. Total 10 suitable sites are identified under plantation agriculture and fruit culture each. 4 suitable sites are identified under the mixed culture, and 6 suitable sites are identified under horticulture. As the distance from settlement, proximity to pond, slope, ground water, distance from road, distance from vegetation and distance from drainage increases, the availability of mixed culture and horticulture decreases but fruit culture and plantation agriculture increase and vice versa. Further, the result is validated from the identification of primary survey and relevant existing literatures. The findings presented in this research are having tremendous implications in drought management of Akarsa watershed.

Keywords Alternative agriculture · Analytic hierarchy process (AHP) · Distance from settlements · Slope

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18.1 Introduction

Drought is a recurrent phenomenon which hits almost every climatic region with varying intensities (Bhunia et al., 2020; Gidey et al., 2018). Droughts generally have their worst hit in the traditional agricultural system and with respect to developing countries; it has severe negative impacts for life and livelihood for farmers (Altieri et al., 2015; Ashraf & Routray, 2013). It is among most dreaded phenomena which may have severe threat to country's socioeconomic balance (Raha et al., 2022). Among 4 types of drought (i.e. agricultural drought, meteorological drought, socioeconomic drought and hydrological drought), agricultural drought is one of the most complex phenomena which directly exploits the livelihoods of the rural people (Das et al., 2019; Potopová et al., 2015). Agricultural drought generally occurs due to deficiency in soil moisture (Dalezios et al., 2017; Park et al., 2017). According to the IPCC (2013), drought is going to heat more than 9 billion people worldwide in the upcoming decade (Thornton, 2012; Zhang et al., 2018). With about 9 million people, West Bengal is one of the most populated states in India (Anjana et al., 2017; Pal et al., 2017). Specifically, Western portions of the West Bengal face severe agricultural and meteorological drought several times in the recent decade (Raha & Gayen, 2019a; Senapati et al., 2021). Raha and Gayen (2019b, 2020) predicted meteorological drought of Purulia and Bankura Districts up to the year 2035 and asserts that drought phenomena in these regions will be *severe* in the upcoming decades. Spatiotemporal assessments of meteorological drought of Gangatic West Bengal (GWB) are done by Ghosh (2019), and he asserts that severe drought proneness typically exists in Western portions of West Bengal. Agricultural drought is another important aspect in these regions which originates simultaneously with meteorological drought. Agricultural drought directly degrades the groundwater storage (Senapati & Das, 2021; Senapati et al., 2021) in Purulia and Bankura, and as a result, agricultural production is severely affected. According to SAFE (2011), Purulia and Bankura was the worst hit with agricultural production falling to 27–30% and around 280,000 ha of agricultural land was lying vacant, facing drought. Over 70% families of Purulia and Bankura are dependent on agriculture, and severe agricultural and meteorological drought proneness has put an end on their source of livelihood (Palchaudhuri & Biswas, 2016, 2019). Therefore, formation of new strategies will help in drought relief measures, which in turn will provide the agricultural security to these regions.

So, by considering above perspectives, mitigation of drought, by incorporating the alternative agricultural system, is one of the most essential needs in the recent era (DeLong et al., 2015; Shiferaw et al., 2014). Researchers should work to enhance the farmers' decision-making process so that the farmers can adapt with the severe, extreme or moderate drought-prone situation (Khanal et al., 2018). Unfortunately, majority of the research works on drought are very far from the practical and realistic approach towards mitigating it in a practical essence. Most of the climatologists of the world just focus on the spatiotemporal simulation and prediction of the meteorological and agricultural drought, and most of which hardly have any realistic application towards the mitigation and adaptation in drought-prone environment

(Bandyopadhyay et al., 2020). In most of the cases, agricultural drought is assessed from the remote sensing-based satellite imagery (e.g. Dey et al., 2021; Carrão et al., 2016; Sishodia et al., 2020). This research considers 9 most important variables to identify suitable sites of alternative agriculture in drought-prone Akarsa watershed, West Bengal, by using Analytic Hierarchy Process (AHP). In this case, the system of alternative agriculture is identified with horticulture, fruit culture, floriculture, mixed culture and plantation agriculture. Horticulture is one of the important sectors of agriculture which consists of fruits, flowers, vegetables, spices, tuber crops, mushrooms, bamboo, plantation and aromatic plants (Gaur et al., 2018; Sonah et al., 2011). *Fruticulture* is defined as the advanced technique to culture fruit in field, for the immediate cash (Badejo et al., 2012; Thompson et al., 2020). *Floriculture* is one of the most important branches for the culture of the ornamental plants (Getu, 2009; Randhawa & Mukhopadhyay, 2001). The research selects floriculture in the alternative agricultural system because of its immediate cash-holding nature and its ability to endure extreme temperature (Jain, 2010; Jisha et al., 2013). According to Hegde et al. (2020), heat is required for the growth of flowers and the petal colours affect flower temperature. Mixed farming ensures the planting of more than one crop together which is more likely to serve better profit in the alternative agricultural system (Beets, 2019; Brooker et al., 2015). Plantation agriculture is considered in the agricultural system because substantial amount of profit can be earned by this agricultural system after engaging substantial amount of labour and capital. More importantly, the basic advantage of plantation agriculture is that this agricultural system is possible to those areas where only production of one crop is possible (Hartemink, 2005).

After originating from the highland of Purulia, Akarsa watershed becomes a dissected plateau by heavy erosion and surface weathering (Senapati & Das, 2020). Although above researchers have tried to explore the drought phenomena of West Bengal as well as western portions of West Bengal, they have failed to formulate the alternative agricultural system. In such scenario, potential site identification for alternative agricultural system in drought-prone Akarsa Watershed is a very noble attempt.

18.2 Methodology

18.2.1 Sources of Data

Overall, 3 spatial data sources are utilized in this research. LULC data is obtained from the LANDSAT-8 OLI dataset (2014) which is obtained from the USGS Earth Explorer (https://earthexplorer.usgs.gov/). Drainage map is prepared from the SRTM DEM (https://earthexplorer.usgs.gov/) which has spatial resolution of 30 m. Ground water data (2013–14) is obtained from the official website of Central Ground Water Board (CGWB) (http://cgwb.gov.in/Documents/Ground%20Water%20Year%20Book%202013-14.pdf). Information about road is obtained from the Open Street Map (https://www.openstreetmap.org/). In every case, spatial layers are prepared through the ARCGIS-10.2.2 software.

18.2.2 Study Area Description

The Akarsa Watershed is originally a part of the Dwarakeswar River basin. The highland of Purulia is the original source region of Akarsa. Geologically, it is the part of the Chota Nagpur Plateau (Senapati & Das, 2020). This basin is extremely dissected with rugged topography and undulating lands with major existence of granite and schist. Some parts of the basin are covered by the presence of amphibolites and hornblende schist formations (CGWB & GSI). The Akarsa River flows from Western to Eastern direction following the general slope of the region. It has an area of approximately 346 km^2, and this area is characterized by semiarid and dry tropical monsoon climatic condition in which most of the rainfall is concentrated during July to September (Sen et al., 2004). Overall, 3 stations are noticed at Akarsa Watershed and those three stations are Bankura, Purulia, and Fulberia (Table 18.1). In Bankura station, 1633.75 mm. average rainfalls are recorded. In Kashipur station, average rainfall in between 2010 and 2017 is noted as 1677.6 mm. At Fulberia station, average rainfall is noted as 1481.11 mm. Average temperatures fluctuate between 38 and 40 °C by considering three stations. The Akarsa watershed is located at the eastern part of Purulia covering the Hura, Puncha, Kashipur C.D. Block and the western part of Bankura covering Chhatna, Indpur, Bankura-I block (Fig. 18.1).

18.2.3 Utilization of Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is a multiple decision-making tool based on Eigen value approach (Ansah et al., 2015; Goepel, 2013). It is widely used in evaluation, cost–benefit analysis, allocations, and decision-making (Singh, 2016) process. According to Saaty (2001), AHP is an objective mathematical process where subjective preferences may be incorporated for accurate generalization. The wider applicability of AHP is due to its simplicity, ready to use, and great flexibility (Ho & Ma, 2018). In this present study, the Analytic Hierarchy Process (AHP) (Wind & Saaty, 1980) method is used to analyse the weight values of each thematic layer involved in the potential alternative agricultural spot identification. Overall, 3 step procedures are followed in this research.

18.2.3.1 Selection of Parameters

At the first step, 9 parameters are identified to determine potential alternative agricultural sites. Those 9 parameters are (i) distance from settlements, (ii) proximity to ponds, (iii) slope, (iv) ground water, (v) drainage density, (vi) land use-land cover (LULC), (vii) distance from roads, (viii) distance from vegetation cover and (ix) distance from drainage.

Table 18.1 Descriptive statistics of rainfall and temperature of our study region

Stations ID	Duration	Longitude	Latitude	Average rainfall (mm)	Max rainfall (mm)	Min rainfall (mm)	Average temperature (°C)	Max temperature (°C)	Max temperature (°C)
Bankura	2010–2017	87.0842	23.2054	1633.75	2859.6 (2017)	1035.5 (2010)	38	36	39
Kashipur	2010–2017	86.6759	23.4025	1167.92	1777.6 (2011)	752.7 (2010)	39	37	40
Fulberia	2010–2017	86.5545	23.3239	1481.113	2069.9 (2013)	867.6 (2010)	40	39	41

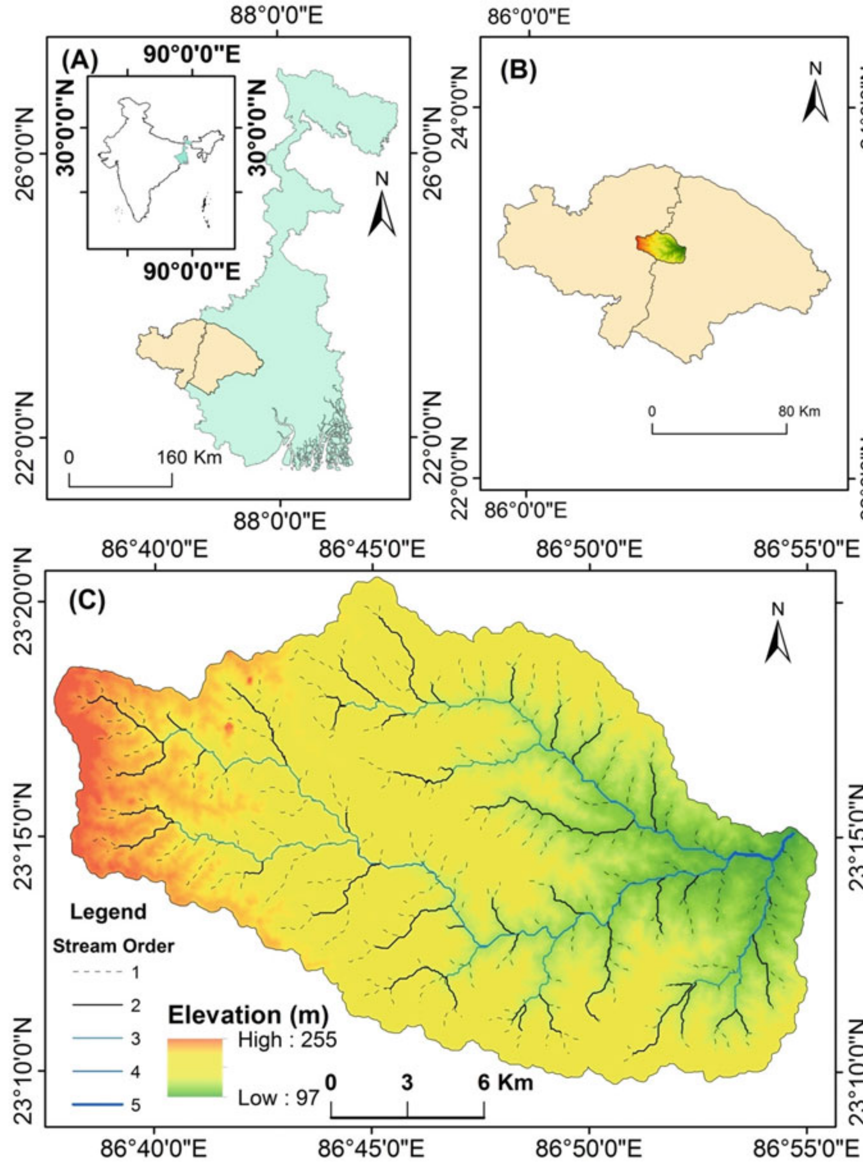

Fig. 18.1 Location map of the study area

18.2.3.2 Construction of Pair-Wise Comparison Matrix

In multi-criteria decision analysis (MCDA) method, Analytic Hierarchy Process (AHP) (Saaty, 1980) is often applied for the determination of weighted values of each factor. The AHP comparison matrix consists of an equal number of rows and columns, where scores are recorded on one side of the diagonal, while values of 1 are placed in the diagonal of the matrix (Kumar & Anbalagan, 2016). For the construction of a pair-wise comparison matrix, each criterion is rated against every other criterion by assigning a relative dominant scale between 1 and 9 (Table 18.2). The relative scale of all these parameters is given based on different criteria and preferences (1. equally important; 3. moderately important; 5. strongly important; 7. very strong importance; 9. extremely important; 2, 4, 6, and 8 are intermediate values). Thereafter, the weighted values of each criterion have been determined using AHP pair-wise comparison matrix (Table 18.3). Each row of pair-wise comparison matrix values describes the relative importance between two criteria. For instance, the first row represents the significance of *distance from settlement* in comparison with other seven criteria positioned in the column. In this matrix, the rows follow the inverse value of each criterion and its significance with other (e.g. the *distance from settlement* is little more important than the distance from drainage; hence, the value of *distance from settlement* is 1 and *distance from drainage* is 2; thus in the next row *distance from drainage* is having a value of ½ and so on). In Table 18.4, weights are normalized and a standardized pair-wise comparison matrix is formed and criteria weights are obtained. *Distance from settlement* obtains highest weightage (about 24%) as it has highest influence in the potential agricultural site selection. *Distance from drainage* achieves second place and it obtains 20% weightage. At the successive level, *Drainage density* (17% weightage), *proximity to ponds* (13% weightage), *ground water* (11% weightage), *distance from road* (5% weightage), *distance from vegetation* (2% weightage), *slope* (2% weightage) and LULC (1% weightage) are taken into consideration (Table 18.4). Every raster variable is divided into 5 subclasses, and individual weightage of those classes is also assigned through the direct allocation method (Arbel, 1989; Odu, 2019) (Table 18.6).

Consistency ratio (CR) was calculated in order to determine whether the pair-wise comparisons were consistent or not (Yilmaz, 2016). One of the strengths of the AHP method is that it allows for inconsistent relationships while providing a CR as an indicator of the degree of consistency or inconsistency (Chen et al., 2010; Feizizadeh et al., 2013). If the CR < 0.10, it indicates a good level of consistency to recognize the class weights.

$$\text{Consistency ratio} = \frac{\text{Consistency Index (C.I.)}}{\text{Random Consistency Index (RI)}}$$

where

$$\text{Consistency Index} = (\lambda_{\max} - n)/(n - 1)$$

Table 18.2 Description of scales for pair comparison with AHP

Scales	Degree of preferences	Descriptions
1	Equally important	The contributions of two factors are equally important
3	Moderate importance	Experiences and judgement slightly tend to certain factor
5	Strong importance	Experiences and judgement strongly tend to certain factor
7	Very strong importance	Experiences and judgement tend to certain factor with extreme strong
9	Extreme importance	There is sufficient evidence for absolutely tending to certain factor
2,4,6,8	Intermediate values	In between two judgements

Source Saaty (1990)

Table 18.3 Pair-wise comparison matrix

Distance from settlement	Distance from drainage	Drainage density	Proximity to ponds	Ground water	Distance from road	Distance from vegetation	Slope	LULC
1	2	2	3	3	4	5	6	7
0.5	1	2	3	3	4	5	6	7
0.5	0.5	1	3	3	4	5	6	7
0.33	0.33	0.33	1	3	4	5	6	7
0.33	0.33	0.33	0.33	1	4	5	6	7
0.25	0.25	0.25	0.25	0.25	1	2	3	4
0.2	0.2	0.2	0.2	0.2	0.5	1	2	3
0.16	0.16	0.16	0.16	0.16	0.33	0.5	1	2
0.14	0.14	0.14	0.14	0.14	0.25	0.33	0.5	1

where λ_{max} is the principal eigenvalue and n is the number of factors.

Random Consistency Index (Table 18.5) is derived from the randomly generated reciprocal matrices (Saaty, 1980). According to Saaty (1980), if consistency ratio is below 0.1 the matrix becomes consistent. In our study, consistency ratio is 0.0198 which is less than 0.1. So, here matrix (Tables 18.3 and 18.4) is consistent and the estimated criteria weights can be utilized for agricultural susceptibility zone identification.

18.2.3.3 Assign Weightage and Weighted Overlay

A simple spatial overlay procedure is followed to get the final map. Final output has been classified into 4 zones which are (i) fruit culture, (ii) horticulture, (iii) plantation

Table 18.4 Determination of weightage from pair-wise comparison matrix

Distance from settlement	Distance from drainage	Drainage density	Proximity to ponds	Ground water	Distance from road	Distance from vegetation	Slope	LULC	Weightages
0.291869	0.405993	0.311226	0.270444	0.218031	0.181132	0.17341	0.164384	0.155556	0.241338
0.145935	0.202997	0.311226	0.270444	0.218031	0.181132	0.17341	0.164384	0.155556	0.202568
0.145935	0.101498	0.155613	0.270444	0.218031	0.181132	0.17341	0.164384	0.155556	0.174
0.09729	0.067665	0.051871	0.090148	0.218031	0.181132	0.17341	0.164384	0.155556	0.133276
0.09729	0.067665	0.051871	0.030049	0.072677	0.181132	0.17341	0.164384	0.155556	0.110448
0.072967	0.050749	0.038903	0.022537	0.018169	0.045283	0.069364	0.082192	0.088889	0.054339
0.058374	0.040599	0.031123	0.01803	0.014535	0.022642	0.034682	0.054795	0.066667	0.037938
0.048645	0.033833	0.025936	0.015025	0.012113	0.015094	0.017341	0.027397	0.044444	0.026648
0.041696	0.028999	0.02223	0.012878	0.010382	0.011321	0.011561	0.013699	0.022222	0.019443

Table 18.5 Random Index (RI) value

n	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source Saaty (1990)

Table 18.6 Subjective weightages of different subclass

Factors	Sub-class	Weightages	Factors	Sub-class	Weightages
Distance from settlement (m)	300	100	Distance from road	100	100
	600	75		200	100
	1000	50		400	75
	1500	25		600	50
Distance from drainage	100	100	Distance from vegetation	1000	25
	300	75		100	25
	500	50		200	25
	700	25		300	50
	1000	25		500	75
Drainage density	0.00481–0.691	100	Slope	700	100
	0.692–1.06	100		0–1.324	100
	1.07–1.42	75		1.324–2.56	100
	1.43- 1.87	50		2.56–4.063	75
	1.88–3.25	25		4.06–8.66	50
Proximity to ponds	50	100	LULC	8.66–22.52	25
	100	100		Water bodies	0
	300	75		Settlement	0
	500	50		Fallow land	25
	700	25		Natural vegetation	0
Ground water	2.83–3.448	100		Agricultural land	50
	3.449–3.723	75			
	3.724–4.34	50			
	4.341–5.728	25			
	5.729–8.845	25			

agriculture and (iv) mixed culture. Figure 18.2 determines overall methodological framework of the research.

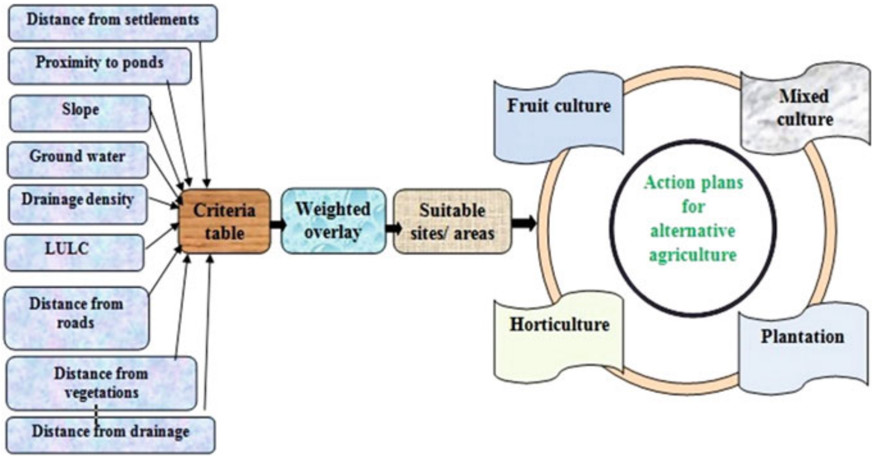

Fig. 18.2 Methodological framework

18.3 Results

Figures 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 18.10 and 18.11 determine the spatial assessments of considered variables in this research. Figure 18.3 represents *distance from settlements* which are classified into 4 buffer zones, i.e. 300 m, 600 m, 1000 m and 1500 m. 100%, 75%, 50% and 25% weightages are assigned to 300 m, 600 m, 100 m and 1500 m buffer zones, respectively. Figure 18.4 determines *distance from drainage* of the study area. Here, 5 buffer zones are selected and those are 100 m (100% weightage), 300 m (75% weightage), 500 m (50% weightage), 700 m (25% weightage) and 1000 m (25% weightage). Figure 18.5 determines *drainage density*, and in this map, 5 buffer zones are selected. Those 5 buffer zones are 0.004–0.691 km/km^2 (100% weightage), 0.692–1.06 km/km^2 (100% weightage), 1.07–1.42 km/km^2 (75% weightage), 1.43–1.87 km/km^2 (50% weightage) and 1.88–3.25 km/km^2 (25% weightage). *Proximity to ponds* is determined at Fig. 18.6. Here also, 18.5 buffer zones are determined. Those are 50 m (100% weightage), 100 m (100% weightages), 300 m (75% weightages), 500 m (50% weightage) and 700 m (25% weightages). *Average groundwater level* of the study area varies from 2.83 to 8.845 mb/gl (Fig. 18.7). 5 zones are selected here, and those 5 classes are 2.83–3.448 mb/gl (100% weightages), 3.449–3.723 mb/gl (75% weightage)., 3.724–4.34 mb/gl (50% weightage), 4.341–5.728 mb/gl (25% weightages) and 5.729–8.845 mb/gl (25% weightage). Total 18.5 buffer zones are identified at *distance from the road* raster (Fig. 18.8). Those 5 zones are denoted as 100 m (100% weightages), 200 m (100% weightages), 400 m (75% weightages), 600 m (50% weightages) and 1000 m (25% weightages). Similarly, *distance from vegetation* is also classified into 5 zones, i.e. 100 m (25% weightages), 200 m (25% weightages), 300 m (50% weightages), 500 m (75% weightages) and 700 m (100% weightages) (Fig. 18.9). Figures 18.10 and 18.11 determine the slope and LULC map of the study region, respectively. *Slope* of Akarsa Watershed fluctuates between 0° and 22.5°. Slope of Akarsa Watershed is classified into 5 individual classes, i.e. 0°–1.32° (100% weightages), 1.33°–2.56° (100% weightages), 2.57°–4.06° (75% weightages), 4.07°–8.66° (50% weightages) and 8.67°–22.5° (25% weightages). LULC are classified into 5 categories which are water bodies, settlement, fallow land (25% weightages), natural vegetation and agricultural land (50% weightages). Finally, all the raster layers are spatially overlaid and alternative agricultural sites are identified (Fig. 18.12). Final raster has been classified into 4 zones. *Horticulture* corresponds to the first zone; *mixed culture* corresponds to the second zone; *fruit culture* corresponds to the third zone, and *plantation agriculture* exists at the last sector of the map. 27% area in the study region is identified with plantation agriculture, 25% area is identified with fruit culture, 17% area is identified with mixed culture, 7% area is identified with horticulture, and another 24% area is identified with several other anthropogenic activities (Table 18.7) which include permanent settlement structure and industrial activities. Total 18.10 suitable sites are identified under plantation agriculture and fruit culture each. 4 suitable sites are identified under the mixed culture, and 6 suitable sites are identified under horticulture (Fig. 18.12). So, as the distance from settlement, proximity to pond, slope, ground water, distance from road, distance from vegetation and distance from drainage increases, the availability of fruit culture and horticulture decreases but mixed culture and plantation agriculture increases and vice versa (Table 18.6).

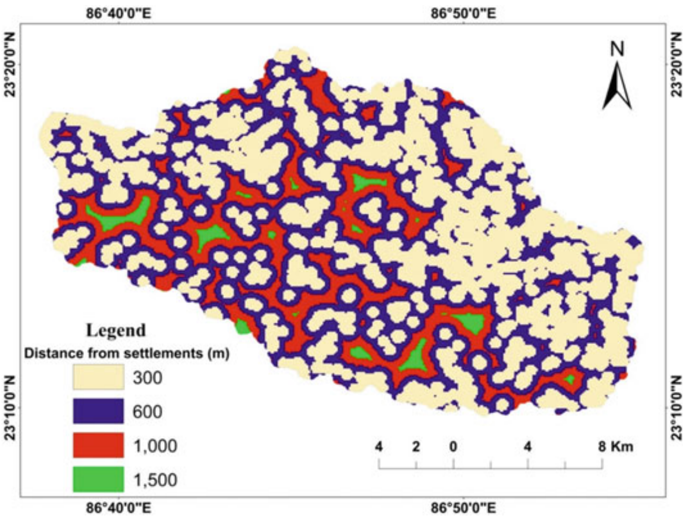

Fig. 18.3 Distance from settlements

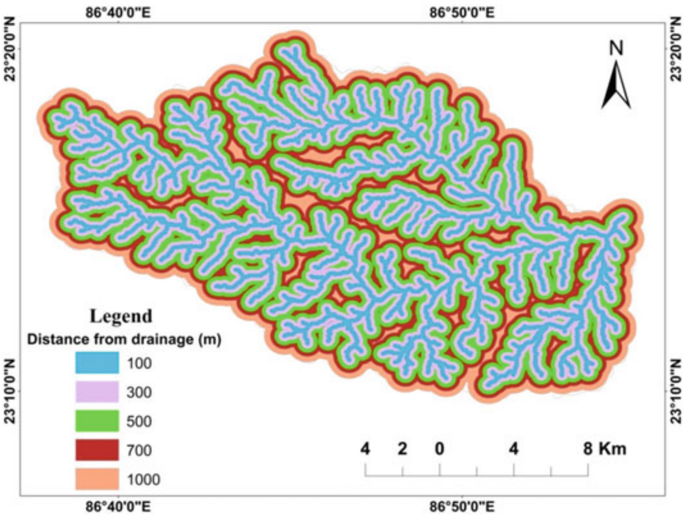

Fig. 18.4 Distance from drainage of the study area

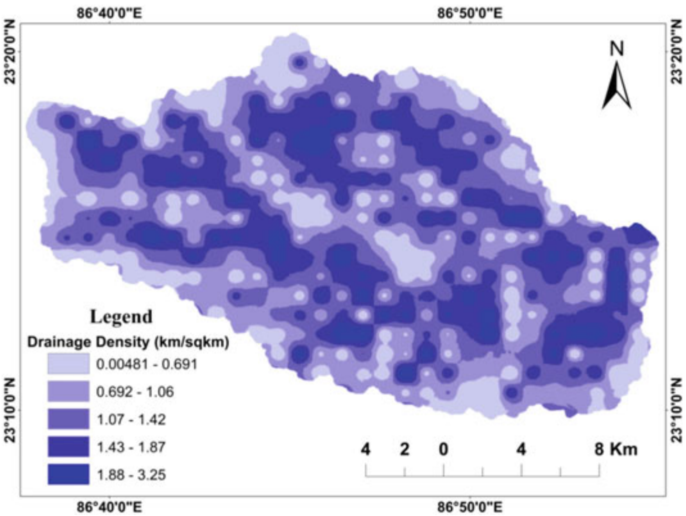

Fig. 18.5 Drainage density of the study region

18.4 Validation and Discussion

To validate the result, authors have conducted extensive field survey in between 2017 and 2019. Total 35 alternative agricultural sites are identified by the authors for the

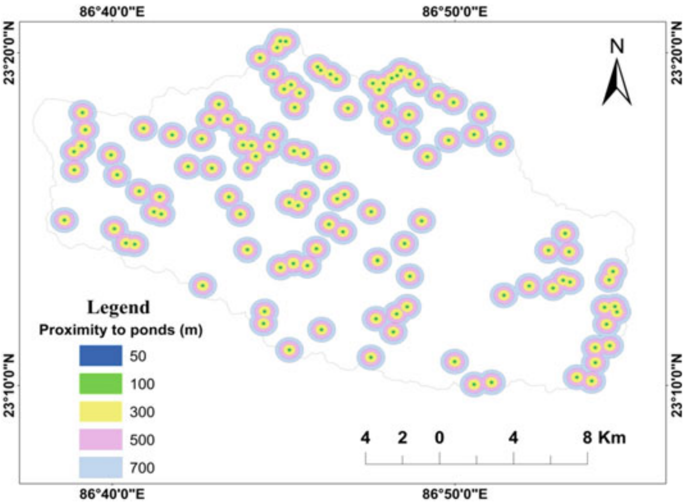

Fig. 18.6 Proximity to ponds of the study region

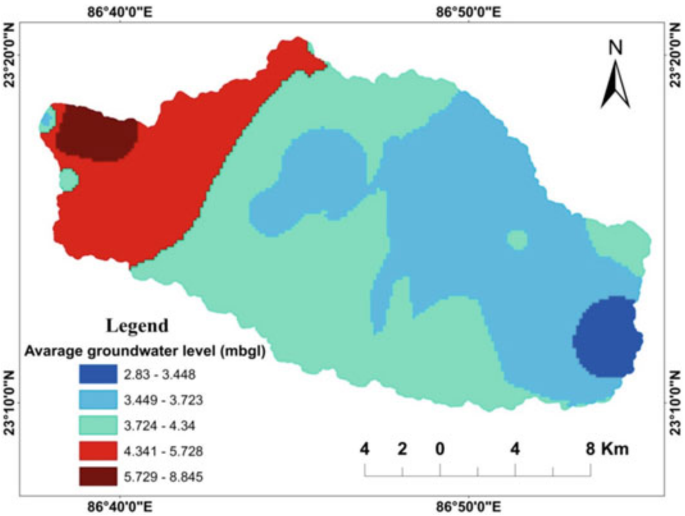

Fig. 18.7 Average ground water level of the study region

validation purpose. Pre-existing conditions of 4 sites are agreed by authors, and conditions of another 31 sites are not agreed. Thus, the overall accuracy of the model is obtained as 85% (Table 18.7). From different field photographs also, the accuracy of our results is clearly shown (Plate 1–Plate 4). So, the research has produced the fairly accurate results on which anybody can rely on. Further, by analysing various existing literatures on alternative agriculture, several plant species are identified which can be

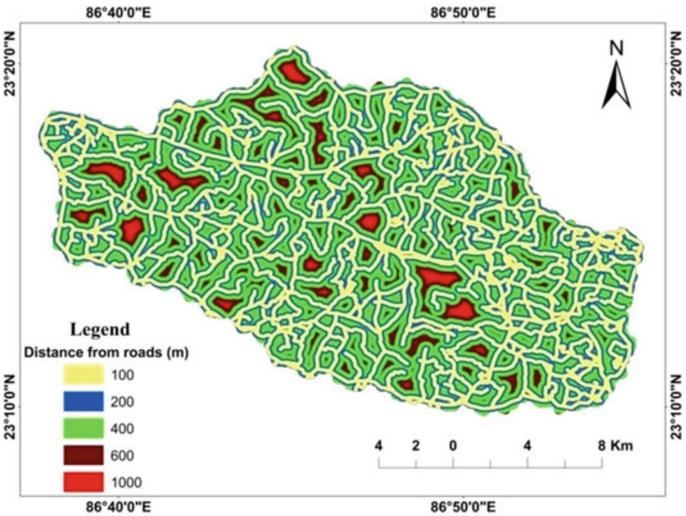

Fig. 18.8 Distance from road of the study region

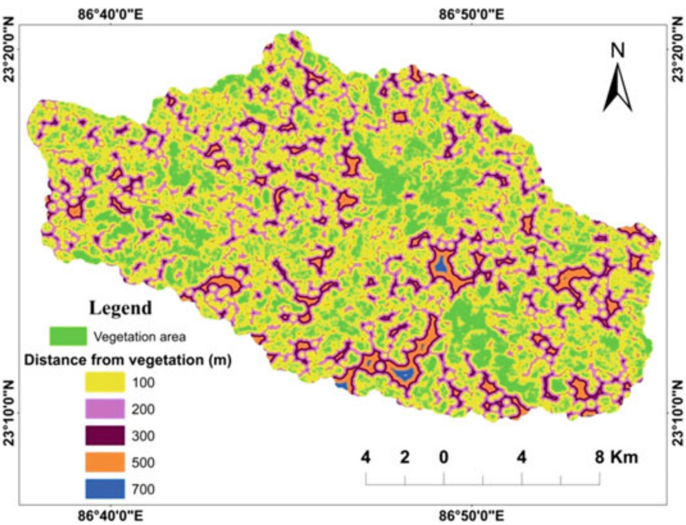

Fig. 18.9 Distance from vegetation of the study area

cultivated or cultured in several zones of the alternative agriculture of Akarsa watershed. In the zone of Horticulture, Lettuce, Cabbage, Cauliflower, Legumes, Potato, Beat, Bean, Peas, Melon, Carrot, Squash, Cucumber and Tomatoes can be cultivated (Arteca and Richard, 2015). Cultivation and management of shrubs or vines can also be encouraged (Dixon, 2019) in these portions of the study region. Mixed culture can be stirred in the second zone where various types of crops together with livestock

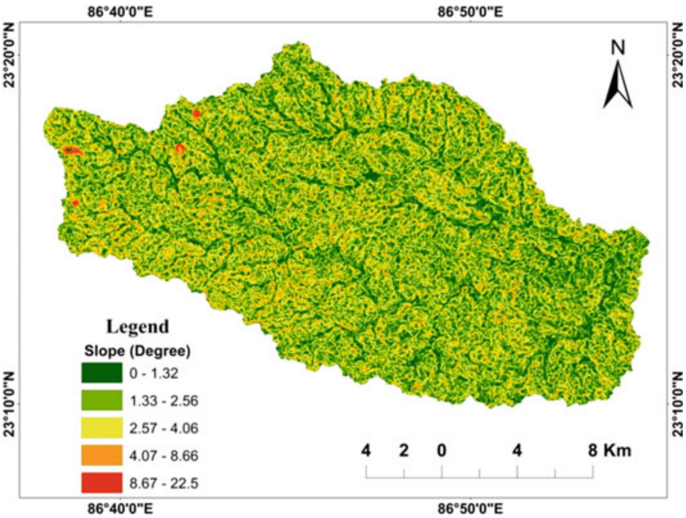

Fig. 18.10 Slope map of the study area

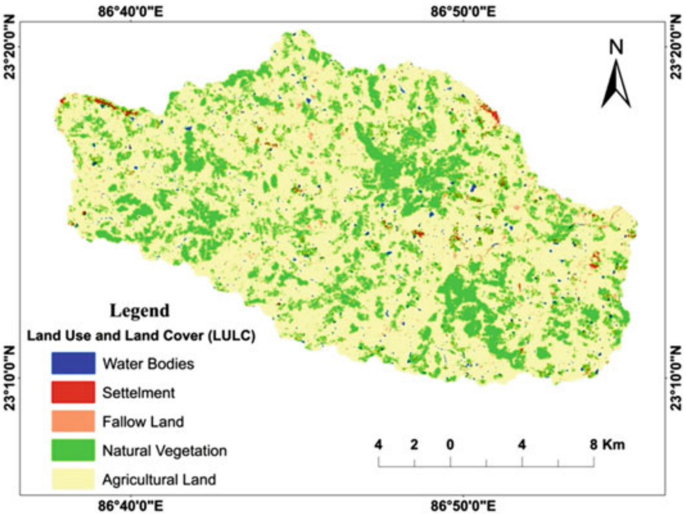

Fig. 18.11 LULC map of the study area

(Dimkpa et al., 2020; Kirkegaard et al., 2014) can be nurtured and cultured. Mixed culture, in drought-prone Akarsa watershed, may produce significant advantages. A mixed farm in this portion may be inspired to cultivate the cereal crops such as wheat or rye, simultaneously with rearing cattle, sheep, pigs or poultry (Peyraud et al., 2014; Smith et al., 2018). Dung of the cattle may serve as the potential fertilizer of cereal

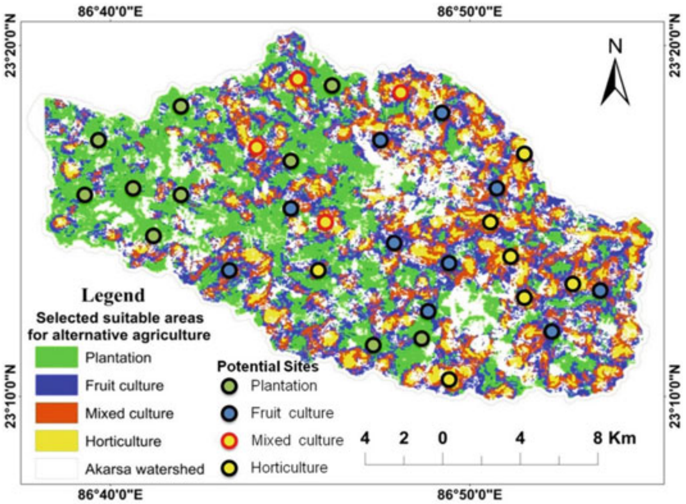

Fig. 18.12 Suitable areas and potential site identification for alternative agriculture

crops (Rahman et al., 2016; Slade et al., 2016). Mongongo (Ricinodendron Rautanenii), Yehib (Cordeauxia Edulis), African Plum (Harpephyllum Caffrum), Yellow Pitaya (Selenicereus Megalanthus), Red Pitaya (Hylocereus undatus), Cereus peruvianus (Cereus Peruvianus) and Desert apple bor (Ziziphus Mauritiana Lam), White Sapote (Casimiroa Edulis), black sapote (Diospyros Digyna), Sclerocarya Birrea, Argania Spinosa, Manilkara Zapota and Cereus Peruvianus may be cultivated in the zone of fruit culture (Mizrahi et al., 2002). Several Indian fruits such as Guava, Papaya, Pineapple, Jackfruit, Mango, Banana, Kaju, Palm or Persimmon can also be encouraged in this zone. Plantation agriculture is another important option in drought-prone Akarsa watershed, and it is spotted in the last zone of drought-prone Akarsa. The most important cause of the fact is that plantation agriculture requires a large amount of land (Gonzales, 2014; Nadaraja et al., 2021) which is generally not available in the just alongside of Akarsa. As this watershed is drought-prone, the bank of this watershed is densely populated, creating the Wet-Point settlement. Agro-forestry can also be prompted just beside the bank of Akarsa, where relatively high moisture content (Slawinska & Giannakis, 2017; Lin, 2007, 2010) is available. Otherwise, the local habitants of the relatively drier sections of this portion may be cheered to do the Social Forestry. With the continuous community-based efforts, the barren land Akarsa may be recovered (Shortall et al., 2015; Zhang & Huisingh, 2018). Social forestry in this section can also be done to strengthen the rural development which indirectly reflects on the region's sustainable development (Knickel et al., 2018; Shortall et al., 2015).

So, as the distance from settlement, proximity to pond, slope, ground water, distance from road, distance from vegetation and distance from drainage increases, the availability of mixed culture and horticulture decreases, so in these, increasing

Table 18.7 Potential agricultural site selection from the field

No	Lat	Long	Real farming conditions	Proposed farming	Matching between real and proposed farming
1	23.22532	86.90779	Mustard farming	Horticulture	Agree
2	23.23491	86.89946	Mixed farming	Mixed culture	Agree
3	23.21379	86.88771	Aman paddy	Plantation	Disagree
4	23.2154	86.88	Mixed farming	Mixed culture	Agree
5	23.20044	86.87926	Mustard farming	Mixed culture	Agree
6	23.19804	86.88314	Fallow land	Fruit culture	Agree
7	23.20381	86.87109	Aman paddy	Mixed culture	Agree
8	23.20946	86.86451	Papaya farming	Mixed culture	Agree
9	23.23062	86.84438	Aman paddy	Fruit culture	Disagree
10	23.23759	86.82538	Mixed farming	Mixed culture	Agree
11	23.2364	86.82491	Agro-forestry	Mixed culture	Disagree
12	23.23682	86.80877	Aman paddy	Horticulture	Agree
13	23.24312	86.8012	Aman paddy	Mixed culture	Agree
14	23.2699	86.80004	Fallow land	Plantation	Agree
15	23.24427	86.79477	Mixed farming	Mixed culture	Agree
16	23.24449	86.79073	Mustard farming	Mixed culture	Agree
17	23.24714	86.78181	Agro-forestry	Plantation	Agree
18	23.24817	86.78085	Agro-forestry	Plantation	Agree
19	23.28543	86.64721	Aman paddy	Horticulture	Agree
20	23.25329	86.67906	Papaya farming	Plantation	Agree
21	23.28196	86.70003	Mixed farming	Mixed culture	Agree
22	23.28007	86.68932	Fallow land	Plantation	Agree
23	23.28429	86.79088	Papaya farming	Mixed culture	Agree
24	23.2916	86.80959	Mixed farming	Horticulture	Agree
25	23.29178	86.80694	Banana farming	Fruit culture	Agree
26	23.2144	86.79834	Mustard farming	Fruit culture	Agree
27	23.21241	86.80181	Mustard farming	Mixed culture	Agree
28	23.2127	86.80116	Mixed farming	Fruit culture	Agree
29	23.19995	86.80101	Agro-forestry	Plantation	Agree
30	23.19923	86.79545	Mixed farming	Horticulture	Agree
31	23.25857	86.75214	Mixed farming	Fruit culture	Agree

(continued)

Table 18.7 (continued)

No	Lat	Long	Real farming conditions	Proposed farming	Matching between real and proposed farming
32	23.27151	86.74115	Mustard farming	Mixed culture	Agree
33	23.28574	86.73079	Forest	No culture	Agree
34	23.28626	86.7216	Fallow land	Plantation	Agree
35	23.2915	86.69879	Agro-forestry	Fruit culture	Disagree

class value gains higher importance. On the other hand, in case of fruit culture and plantation agriculture, reversed feature is noticed. The main reason behind it is that fruit and the cereal crops under plantation agriculture can endure severe temperature (Aldababseh et al., 2018; Chandio et al., 2020).

So, in these cases, as the class values increase, importance or weightages also increase and vice versa. As plantation agriculture and fruit cultivation are less dependent on water, relatively higher number of suitable sites (10 in each case) are available in both cases. Horticulture and mixed culture demand relatively higher amount of water and as the Akarsa watershed is drought prone; so relatively lesser numbers of sites are available under those categories (Fig. 18.13).

18.5 Conclusion

In summary, potential alternative agricultural sites at Akarsa watershed are identified in this research with the help of Analytic Hierarchy Process (AHP) and weighted overlay technique. Overall, 9 spatial layers are selected for the estimation of alternative agricultural sites. Those 9 spatial layers are distance from settlements, proximity to ponds, slope, ground water, drainage density, LULC, distance from roads, distance from vegetations and distance from drainage. Those nine parameters are overlaid and ultimately suitable areas of alternative agricultural systems are determined. 27% area is identified with plantation agriculture, 25% area is identified with fruit culture, 17% area is identified with mixed culture, and horticulture is identified in the 7% area of the study region. As the distance from settlement, proximity to pond, slope, ground water, distance from road, distance from vegetation and distance from drainage increases, the availability of fruit culture and horticulture decreases but mixed culture and plantation agriculture increases and vice versa. Total 10 suitable sites are identified under plantation agriculture and fruit culture each. 4 suitable sites are identified under the mixed culture, and 6 suitable sites are identified under horticulture. Further, the result of this research is validated using primary survey-based observations and related existing literatures which makes the research more productive and valuable.

Fig. 18.13 Validation of potential agricultural sites with field photographs, **Plate: 1** The field of Mustard (Lat: 23.22 N, Lon: 86.90 E), **Plate: 2** The field of Banana (Lat: 23.29 N, Lon: 86.80 E), **Plate: 3** The field of Cabbages (Lat: 23.29 N, Lon: 86.79 E)**, Plate: 4** The existence of fallow land (Lat: 23.28 N, Lon: 86.68 E)

In the drought-prone environment, demarcation of alternative agricultural sites is an important hallmark for the regional planning perspective. This study is an advanced step to mitigate agricultural drought of Akarsa watershed.

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Correction to: The Impacts of Drought Disasters on Mexican Agriculture: An Interpretation from the Perspective of the Political Economy of Disasters

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Correction to:
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The author's first name and given name were incorrect and these have been corrected as follows: The correct order should be "Juan Luis (given names) Hernández-Pérez (last name) & Deysi Ofelmina (given names) Jerez-Ramírez (last name)". The chapter has been corrected.

The chapter and the book has been updated with the changes.

The updated version of this chapter can be found at
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