Agro–Climatic Characterization of Eastern Uttar Pradesh

Thesis

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By

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I.D. NO. A-14999/23

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

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CERTIFICATE-I

This is to certify that the thesis entitled **"Agro-Climatic Characterization of Eastern Uttar Pradesh"** submitted in partial fulfilment of the requirements for the degree of **M.Sc. (Ag.)** with the major in **Agricultural Meteorology** of the College of Agriculture, Post Graduate Studies, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya, (U.P.) is a record of bonafide research carried out by **Mr. Hayam Boboy Singh**, I.D. No. **A-14999/23** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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CERTIFICATE-II

This is to certify that the thesis entitled **"Agro-Climatic Characterization of Eastern Uttar Pradesh"** submitted by **Mr. Hayam Boboy Singh,** Id. no. **A-14999/23** to the Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya in partial fulfilment of the requirement of the degree of **Master of Science (Agriculture)** in subject of **Agricultural Meteorology** has been evaluated satisfactory and approved by the **Student's Advisory Committee** after an oral examination on same in collaboration with an external examiner.

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CERTIFICATE-III

DECLARATION FOR ANTI-PLAGIARISM

I, **Hayam Boboy Singh**, I.D. No. **A-14999/23** certify that the thesis entitled **"Agro-Climatic Characterization of Eastern Uttar Pradesh"** submitted in partial fulfilment of the requirements for the degree of M.Sc. (Agriculture) in **Agricultural Meteorology** to the College of Agriculture, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) is an original work and has similarities with published work not more than minor similarities as per the UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations, 2018, adopted by the university.

I declare that I have faithfully acknowledged, given credit to and referred to the research workers wherever their works have been cited in the text and body of the thesis. I further certify that I have not wilfully lifted up some others' work, para, text, data, results, etc. reported in the journals, books, magazines, reports, dissertations, thesis, etc., or available at websites and included them in this thesis and cited as my own work.

Place: Kumarganj, Ayodhya

Date: 22 **July, 2025** **(Signature of the candidate)**

CERTIFICATE FROM THE MAJOR ADVISOR

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Dean, PGS **Dean**

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Date: 22 July, 2025

(Hayam Boboy Singh)

CONTENTS

LISTS OF TABLES

LISTS OF FIGURES

ABBREVIATIONS USED

%	Percentage
/	Per
°C	Degree Celsius
&	And
@	At the rate
CV	Coefficient of variation
EUP	Eastern Uttar Pradesh
EPZ	Eastern Plain Zone
Fig	Figure
i.e.	That is
Kg	Kilogram
Mm	Millimetre
NEPZ	North Eastern Plain Zone
No.	Number
SD	Standard deviation
Tmax	Maximum temperature
Tmin	Minimum temperature
VZ	Vindhyan Zone
Viz.	Namely

INTRODUCTION

Climate change is associated to long-term shifts in global or regional climate patterns, primarily caused by anthropogenic activities that emit greenhouse gases into the atmosphere. It's a significant and persistent change in the statistical distribution of weather patterns over a long period, typically spanning decades or longer (Srinivasarao *et al*., 2024). Climate change includes warmer global land and ocean temperatures, a reduction in snow and ice cover, and altering patterns of atmospheric and oceanic circulation. Human activities are the primary cause of recent climate change such as burning fossil fuels like natural gas, coal, oil, and deforestation release large amounts of carbon dioxide (CO_2) and other heat-trapping gases into the atmosphere. These gases then retain heat from the sun and cause the planet to slowly warm, a phenomenon known as the greenhouse effect. 'Major greenhouse gases that cause global warming are believed to be CO_2, CH_4 and N_2O) and various fluorinated gases. CO_2 is the most important contributor, primarily caused due to burning of fossil fuels and deforestation. One of the most significant effects of climate change is global warming, which results to the rising average surface temperature of the Earth due to the increased greenhouse effect.

Weather is a key indicator for crop conditions. It may have its influence directly by influencing the growth structural characters of crop growth, plant population, number of tillers, leaf area etc. and indirectly by deciding the incidence of insect peculation and diseases also. The reaction of the weather parameters at various growth stages of crop may help to estimate its response in terms of final yield, as well as predict the crop yield in advance prior to its harvest. Crop yields are affected by both the frequency distribution and magnitude of the weather parameters. Therefore, the in-depth idea of the frequency distribution of weather parameter is also necessary while developing the pre-harvest model numerous studies on crop weather relationship have been investigated in past, in India and globally. This method is based on the assumption that meteorological data have been collected for several years and statistics on rice production are available for the same time period. IASRI, New Delhi has contributed a lot of things in this direction in various places of the country. Year-to-year variability of rainfall and extreme weather events, including floods and droughts and heatwaves are regarded to be the main reasons for yearly yield variations. Nevertheless, more subtle effect on weather conditions during crucial stages of crop growth, which can have a major influence on yield. 80% of the annual total rainfall of the Indian subcontinent arises from the Indian Summer Monsoon Rainfall (ISMR). ISMR remains dominant from June to September and the country's agriculture depends on it up to 60% (Diva & Geetika, 2019).

The Intergovernmental Panel on Climate Change (IPCC, 2021) has determined that human-generated discharging of greenhouse gases have already warmed the global climate by nearly 2°F (1.1°C) from the late 19th century till now. Within the upcoming few decades, the average global temperature is predicted to reach or surpass 1.5°C (about 3°F) above pre-industrial levels, leading to widespread damaging impacts across the planet. The extent and rate of climate change, along with the associated risks, heavily depend on the mitigation and adaptation actions taken in the near future.

Climate change and climate variability are posing major threats to community livelihoods and socio-economic development of the region of Eastern Uttar Pradesh in the past decades. Although Uttar Pradesh has well-developed agricultural research systems, use of modern science and technology in agricultural production is hindered by changing climate and weather variation. Inadequate research-extension–farmer linkages to facilitate demand-driven research and increased use of improved technologies continue to constrain efforts to increase agricultural productivity as farmers continue to use out dated and ineffective technologies. Uttar Pradesh is already seeing the effects: hotter summers and unpredictable rains are stressing crops. Rice and wheat – the backbone of this region's rice–wheat system – are especially sensitive to high temperatures (e.g. >35 °C can induce spikelet sterility in rice) (Devegowda *et al*., 2021). In short, global warming and altered monsoon patterns pose a growing challenge to Eastern U.P.'s agriculture and water resources.

Rainfall is vital for life it determines how much water is available for farming, gardening, raising animals, running industries, and even meeting daily household needs. But as the global climate continues to change, the way rain falls is changing too. We're seeing more unpredictable patterns, with some areas facing longer dry spells while others get hit with intense downpours.

This shift brings serious consequences: crops can fail, floods and droughts become more frequent, people are forced to leave their homes, and entire economies suffer. In fact, India loses nearly 2% of its GDP and about 12% of its central government revenue every year due to natural disasters. These are not just statistics they reflect real challenges that affect millions of lives.

Agroclimatic characterization – the systematic assessment of climate, soil and land use factors – is fundamental for sustainable agricultural development and climate-resilient planning (RK Singh & DN Singh, 1993). Characterization of the agro-climatic environments encompasses two kinds of inventories. The first includes the long-term historic records of climatic factors. This collection facilitates extrapolation to comparable areas. The second collection consists of the items that alter the trial duration, also known as real-time meteorological variables. This collection helps in interpreting results of particular trial and comparing real weather observed with long term historic records. This technical report will utilize only the first set of inventories. These drivers initiate the climatic extreme events; thus, prior prediction of these drivers would help to develop appropriate adoptive measures for the agriculture sector, and these would also be deployed as early warning tool for risk managements. Later, simulation analysis between rain-fed wheat yield and climate change was proven, which proves that climate change is impacting crop production and food security. Therefore, adaptive measures, such as advanced impact assessments by modelling, new generation agriculture production technologies, changes in sowing windows, precision and smart farming, modernisation of water supply and irrigation system, conservation tillage, input and management adjustments, better short- and long-term climate prediction, cluster agriculture transformation with interfaces with policy decision makers would be very good adaptation measures to ensure food security. Natural environments consist of elements from the system: climate (weather), soils and physiography (landform). These elements are source of water, energy nutrient and physical support of the farm-system may be provided in excess or shortage, and which also influence the occurrence of wed, insects, and diseases. Farmers try to control these elements by either modifying crops or animals or production systems suitably, or else altering those things which are under their control. Correspondingly, research is essentially concern with adapting germplasm and methods of production more precisely to specific environment. It is therefore essential to describe, synthesise, inventoried and classify the physical components of environments in order to guide the choice of research topics, to identify comparable environments in which technological innovations might prove useful, and to help in the interpretation and analysis of results from trial networks (Oldeman, 1988).

Agricultural production of crops is control by the combine effect of climatic variability, technology, soil tilth, genetics resources, and farm management decisions such as tillage, fertilizer application, manure application, and cultivars selection. The best current research on the causes and relationship between crop physiology and climate change highlight hoe detrimental climatic variability will be to maintaining sustainable world productivity (Aggarwal & Singh, 2010; Wani *et al*., 2010; Pathak *et al*., 2014; Chandrashekar, 2010; Aggarwal *et al*., 2009; Lobell and Gourdji, 2012;). When considering the influence of climatic different and change of crop production, as discussed above, it is clear that sugarcane farming would face challenges (Mall and Gupta, 2002; Bhaskaran and Nair, 2014; Singh *et al*., 2010; Srivastava and Rai, 2012; Mall and Singh, 2000; Samui *et al*., 2014).

Being India as a developing country, it is lately predicted that due to increase in average temperature crossing the threshold level, the agricultural productivity will be declining by 10-25% by 2080 (Mahato, 2014). According to IPCC (2013), in comparison to 1986 - 2005, the global mean surface temperatures are predicted to most likely to encounter an increase of 0.3 °C to 4.8 °C for 2081-2100. Harsh weather events like heat wave are projected presumably with higher frequencies and greater duration of cold waves occasionally in winters. Abnormality in water cycle were anticipated by IPCC (2013) forecasting the fact that retreating monsoon would be set back there by extending the monsoon season with more frequent and high intensity extreme events by the end of the century. There are several studies giving their point of view about the extreme climate changes (Piao *et al*., 2010; Chen *et al*., 2012; Laborte *et al*., 2012; Pathak, *et al*., 2014; Barlow *et al*., 2015 and Rezaei *et al*., 2015; Talukder *et al*., 2014) and the impact of the extreme events on the productivity of crops globally.

Climate variability had been predicted for 2050s for India that there will an increase in rainy days by 5-10 days in North-eastern India and foothills of Himalayas, in contrast there will be a decrease rainy days number in central and western India by 15 days, and average temperature increase by 2-4 °C. Frequnecy of flood is estimated with a variation of 10% by

2030s and an increase over 30% of magnitudes of that of 1970s (MoEF, 2010). Corresponding to a new study, the Indian ocean has accelerated in the past 20 years in a way similarly seen globally in the SPM. The global mean sea-level rise between 1901 and 2010 was 1.7mm yr^{-1}, and between 1993 and 2010, it was 3.2 mm yr^{-1}.

In the case of India, due to the extreme weather events, an unpredictable situation will be facing for crop productivity in various region putting in danger the socio-economic demand; consequently, to reduce the disaster risk in future we need to make better policy and planning (Mall *et al*., 2006; Geethalakshmi *et al*., 2011). In contrast to several crops cultivated in India, each of which have distinct abiotic and biotic optimum conditions, sugarcane yield is also affected by weather conditions. For instance, the ideal temperature range of for sugarcane production and recovery is between 25 - 35 °C with a total water demand of nearly 2000mm (IISR, 2011; Samui *et al*., 2014). Therefore, change in weather parameters like increase or decrease in temperature and precipitation conditions is responsible for the alteration of production of crop. As mentioned above that sugarcane is one of the major crops of Uttar Pradesh. The farmer's economic conditions are extremely dependent on the production of sugarcane. Even though, average production of sugarcane of the state has risen up with the fluctuating weather conditions from 39.5 t/ha (1950-51) to 59.2 t/ha (2009-10), whereas different regions of India which are major sugar producing area have an average yield of 70 t/ha. Climatic variability is a sensitive factor of crop production. There are several studies in the state and in the country too, analysis crop productivity and impacts of climatic variability, specifically for extreme events, yet studies on the state-by-state Agro-Climatic Zones are few. As a result, the following is an attempt to investigate the zone-specific impact of weather extremes on major crops such as rice and wheat with a focus on managing weather constraints and developing strategies for increasing/ sustaining production in the region through improve agronomic management.

The discriminant function has also been used by Agrawal (2002) to forecast pre-harvest statistics of rice yield by using weather variables. Environment plays a crucial role in production of crops. The E.U.P. has different environment and ecology as compared to other regions of the state and country.

Keeping above fact in view, the present research entitled “Agro-climatic characterization of the Eastern Uttar Pradesh” was proposed with the objectives given below:

1. Collection of weather data of the Eastern Uttar Pradesh.
2. Analysis of weather data of the Eastern Uttar Pradesh.
3. Studying the impacts of weather parameters on production of major crops in Eastern Uttar Pradesh.
4. Identifying the climatic constrains of the Eastern Uttar Pradesh.

Chapter - II

REVIEW OF LITERATURE

Biswas (1981) analysed on the classification on the basis of moisture availability index and its application to the dry farming tract of Gujarat. Day farming tract is classified into four zones; the zone D is the low potential area; rain-fed crops are possible to be raised in about 30-40 per-cent of the years. A short duration crops may be grown from area E at 40-45 per-cent of the years. Area F has the potential to raise a crop in 50-55 per cent of the years. Rain-fed crops may be raised more than 60 per cent of the years from area G.

Bhutiyani *et al.* (2007) studies carried over North-Western Himalayas showed that the change in winter rainfall is minimum, but there is a significant decrease in monsoon rainfall. Any changes in monsoon precipitation have a major impact on agriculture of this region.

Singh *et al.* (2008) studied on the rainfall during monsoon season and its variability that govern the cropping system in the Sabour region of Bihar. Long-term rainfall data was used to analysed the probability of occurrence of deficit/normal/excess rainfall for the better crop planning in the region.

Topoclimate are local climates that due to topographical differences in a given area. **Sastri *et al.* (2009)** mentioned that the topoclimates help in selecting crops and crop varieties based on local field hydrological differences, degree days and thereby phonological changes due to topographical variations. But in India intensive studies on ago-topographical features for agricultural planning were not done. In countries like New Zealand topoclimatic maps were prepared for understanding the degree days variation for pasture as well as crop growth (Richards, K 1999). Topoclimate and soil information can be used to introduce new crops.

Tao *et al.* (2009) investigated the impacts of weather and climate variability (change) on crop growth and production, especially at a large scale. Crop models that account for the key impact mechanisms of climate variability and are accurate over a large area must be developed. Here, we present a new process-based general Model to capture the Crop–Weather relationship over a Large Area (MCWLA). The MCWLA is optimized and tested for spring maize on the Northeast China Plain and summer maize on the North China Plain, respectively. We apply the Bayesian probability inversion and a Markov chain Monte Carlo (MCMC) technique to the MCWLA to analyse uncertainties in parameter estimation and model prediction and to optimize the model. Ensemble hind casts (by perturbing model parameters) and deterministic hind casts (using the optimal parameters set) were carried out and compared with the detruded long-term yields series both at the crop model grid (0.58 0.58) and province scale.

Kumar *et al.* (2010) analysed the trend in historical rainfall of Sagar district using parametric and non-parametric approaches. The analysis is carried out using 45 years data (1960-2004) of four rain gauge stations located in different tehsils namely Sagar, Khurai, Rehli and Banda. Mann-Kendall analysis, Sen's slope method and linear regression method are used for the trend analysis. The trend of summer season at Khurai station is showing a significant rising trend in rainfall while summer season at Rehli station is showing a significant falling trend. There is no significant rising or falling trend at any other station.

The eco physiological models are widely used to forecast potential impacts of climate change on future agricultural productivity and to examine options for adaptation by local stakeholders and policy makers. However, protocols followed in such assessments vary to such an extent that they constrain cross-study syntheses and increase the potential for bias in projected impacts. **White *et al.* (2011)** reviewed 221 peer-reviewed papers that used crop simulation models to examine diverse aspects of how climate change might affect agricultural systems. Six subject areas were examined: target crops and regions; the crop model(s) used and their characteristics; sources and application of data on [CO2] and climate; impact parameters evaluated; assessment of variability or risk; and adaptation strategies. Wheat, maize, soybean and rice were considered in approximately 170 papers. The USA (55 papers) and Europe (64 papers) were the dominant regions studied. The most frequent approach used to simulate response to CO2 involved adjusting daily radiation use efficiency (RUE) and transpiration, precluding consideration of the interacting effects of CO2, stomatal conductance and canopy temperature, which are expected to exacerbate effects of global warming. The assumed baseline [CO2] typically corresponded to conditions 10–30 years earlier than the date the paper was accepted, exaggerating the relative impacts of increased [CO2]. Due in part to the diverse scenarios for increases in greenhouse gas emissions, assumed future [CO2] also varied greatly, further complicating comparisons among studies. Papers considering adaptation predominantly examined changes in planting dates and cultivars; only 20 papers tested different tillage practices or crop rotations. Risk was quantified in over half the papers, mainly in relation to variability in yield or effects of water deficits, but the limited consideration of other factors affecting risk beside climate change per se suggests that impacts of climate change were overestimated relative to background variability. A coordinated crop, climate and soil data resource would allow researchers to focus on underlying science. More extensive model inter-comparison, facilitated by modular software, should strengthen the biological realism of predictions and clarify the limits of our ability to forecast agricultural impacts of climate change on crop production and associated food security as well as to evaluate potential for adaptation.

Lobell and Gourdji (2012) studied on global scale grain productivity, notwithstanding the many other scales and outcome of interest to food security. Over the next few decades, CO2 trends are likely to increase global yields by roughly 1,8% per decade, At the same time, warming trend are likely to reduce global yield by roughly 1.5% per decade without effective adaptation, with a plausible range from roughly 0% to 4%. The upper end of this range is half of the expected 8% rate of gain from technological and management improvements over the next few decades. Overall, the net effect of climate change and CO2 on global average supply of calories is likely to be fairly closed to zero over the next few decades, but it could be as large as 20 % to 30% of overall yield trend. To reduce uncertainties in global impacts, better estimate of rates of global warming and responsiveness of crop yields to warming and CO2 would be particularly useful.

Hiremath *et al.* (2013) analysed on vulnerability indices in various part of Gujarat reveals that the variables pertaining to agricultural vulnerability were the major contributors in the overall vulnerability to climate change during the periods 1991 to 2008. Since the agricultural sector was found to have the greatest bearing there is needed to shift focus towards investment in adaptation research capacity: particularly, in the development of climate proof crops that can cope with wide range of climatic conditions. An improvement in the agronomic practices of different crops such as revising planting dates, plant densities and crop sequences can help cope with the delayed rainy seasons, longer dry spells and earlier plant maturity.

Crop simulation models can be used to estimate impact of current and future climates on crop yields and food security but require long-term historical daily weather data to obtain robust simulations. In many regions where crops are grown, daily weather data are not available. Alternatively, gridded weather databases (GWD) with complete terrestrial coverage are available, typically derived from: (i) global circulation computer models; (ii) interpolated weather station data; or (iii) remotely sensed surface data from satellites. **Wart *et al.* (2013)** study's objective is to evaluate capacity of GWDs to simulate crop yield potential (Yp) or water-limited yield potential (Yw), which can serve as benchmarks to assess impact of climate change scenarios on crop productivity and land use change. Three GWDs (CRU, NCEP/DOE, and NASA POWER data) were evaluated for their ability to simulate Yp and Yw of rice in China, USA maize, and wheat in Germany. Simulations of Yp and Yw based on recorded daily data from well-maintained weather stations were taken as the control weather data (CWD). Agreement between simulations of Yp or Yw based on CWD and those based on GWD was poor with the latter having strong bias and large root mean square errors (RMSEs) that were 26–72% of absolute mean yield across locations and years. In contrast, simulated Yp or Yw using observed daily weather data from stations in the NOAA database combined with solar radiation from the NASAPOWER database were in much better agreement with Yp and Yw simulated with CWD (i.e. little bias and an RMSE of 12–19% of the absolute mean). We conclude that results from studies that rely on GWD to simulate agricultural productivity in current and future climates are highly uncertain. An alternative approach would impose a climate scenario on location-specific observed daily weather databases combined with an appropriate upscaling method.

Oza and Kishtawal (2014) studied to understand the variability in rainfall, a spatio-temporal analysis of Indian summer monsoon rainfall was taken up. It analysed to identify trends in amount of Indian summer monsoon at various spatial scales. Daily gridded rainfall data for the period 1951-2010 corresponding to monsoon season and monthly rainfall data at meteorological sub-division level for 1901- 2010 were analysed. From the gridded data, a series of rainfall at agro-climatic regions was constructed. The analysis was based on linear trend analysis. Both parametric and non-parametric methods were used. From statistical analysis of data, it was concluded that there is a decreasing trend in all-India Indian summer monsoon rainfall. Northeast India is one big cluster having highly decreasing trend. Also, there is a strong agreement between gridded and meteorological subdivision-based rainfall.

Anthropogenic climate changes are a result of both global emissions of long-lived greenhouse gases (LLGHGs) and other short-lived climate pollutants (SLCPs). **Burney and Ramanathan (2014)** studied on roles of temperature and precipitation. Two potent SLCPs, tropospheric ozone and black carbon, have direct effects on crop yields beyond their indirect effects through climate; emissions of black carbon and ozone precursors have risen dramatically in India over the past three decades. Here, to our knowledge for the first time, we present results of the combined effects of climate change and the direct effects of SLCPs on wheat and rice yields in India from 1980 to 2010. Our statistical model suggests that, averaged over India, yields in 2010 were up to 36% lower for wheat that they otherwise would have been, absent climate and pollutant emissions trends, with some densely populated states experiencing 50% relative yield losses.

Sushant *et al.* (2015) studied the rainfall data for the period from 1901 to 2002 of the Cauvery River basins. Long term rainfall fluctuations have been identified by significant decreasing winter rainfall trend and increasing trend in post monsoon season with insignificant levels have been concluded based on the Linear trend and

Rice is the major crop of Uttar Pradesh, which covers about 36.5 per cent area of total gross-cropped area in Uttar Pradesh. **Pandey *et al.* (2015)** study mainly deals with the effect on weather variables. The study has been undertaken for rice crop in the district of Faizabad, Uttar Pradesh, India. The present study is formulated to determine the individual and joint effect of weather variables on rice yield. On the basis of R2, we found that individually sun shine (hr) is more important with 67.57 followed by wind velocity and rainfall with 48.63 and 46.74, respectively. The joint effect of weather variables is also playing an important role in case of rice crop. According to R2 more important combination is rainfall & wind velocity with 82% followed by rainfall & sunshine hr and wind velocity & sun shine hr 63% and 53.8, respectively.

Sugarcane is a cash crop in Uttar Pradesh; economic condition of the farmers is highly dependent on sugarcane production. However, average yield of the state has gone up from 39.5 t/ha (1950-51) to 59.2 t/ha (2009-10), was observed associated with fluctuating weather conditions, whereas other major sugar producing area in India have average yield of 70 t/ha. **Mall *et al.* (2015)** showed that there was an average rising trend in the annual minimum temperature (0.03° Cyr-1) over all the agro-climatic zones of the state. Out of nine agro-climatic zones, four zones namely South Western Zone, Central Plain Zone, Western Plain Zone and Eastern Plain zone, which were marked by decreasing annual rainfall trend. However, Vindhyan Zone, Mid-Western Zone and Bhabhar and Tarai Zone show rising trend. To explain better relation between cane yield and weather parameters this study also show that maximum, minimum temperature and moisture plays the most important role during germination, tillering, grand growth and ripening phases of the sugarcane. Considering extreme weather, we found that temperature below 25 °C, above 35 °C and 40 °C are slowing down the growth and finally reducing the final yield. It is also noticed that temperature and rainfall extremes had high possibility of governing sugarcane yields but there were also quite a number of instances wherein the extremes couldn't be reasoned directly for the yield fluctuations. Therefore, to sustain the productivity, this study recommends the improvements of the adoptive responses of varieties, management of the risk associated with extreme weather events by providing weather linked value-added advisory services to the farmers and crop insurance agencies.

Amin *et al.* (2015) studies the changing climate could have both beneficial and harmful effects on crops. Keeping the above view in mind, this study is undertaken to investigate the impacts of climate change (viz. changes in maximum temperature, minimum temperature, rainfall, humidity and sunshine) on the yield and cropping area of four major food crops (viz. Aus rice, Aman rice, Boro rice and wheat) in Bangladesh. Heteroscedasticity and autocorrelation consistent standard error (HAC) and feasible generalized least square (FGLS) methods were used to determine the climate-crop interrelations using national level time series data for the period of 1972–2010. Findings revealed that the effects of all the climate variables have had significant contributions to the yield and cropping area of major food crops with distinct variation among them. Maximum temperature statistically significantly affected all the food crops' yield except Aus rice. Maximum temperature also insignificantly affected cropping area of all the crops. Minimum temperature insignificantly affected Aman rice but benefited other three crops' yield and cropping area. Rainfall significantly benefitted cropping area of Aus rice, but significantly affected both yield and cropping area of Aman rice. Humidity statistically positively contributed to the yield of Aus and Aman rice but, statistically, negatively influenced the cropping area of Aus rice. Sunshine statistically significantly benefitted only Boro rice yield. Overall, maximum temperature adversely affected yield and cropping area of all the major food crops and rainfall severely affected Aman rice only. Concerning the issue of climate change and ensuring food security, the respective authorities thus should give considerable attention to the generation, development and extension of drought (all major food crops) and flood (particularly Aman rice) tolerant varieties.

Singh (2016) studied on the eighteen years (1991-2008) of weather data and yield data of rice and wheat for 9 districts of Eastern Uttar Pradesh was used to develop yield prediction equations. Models were validated with 2 years (2009 and 2010) data. Results indicated that models explained 51 to 79 percent variations for rice yield and 65 to 92 percent variations for wheat yield in different districts. The percent Mean Bias Error (MBE) was between -1.05 (Mau) to 6.17 (Mirzapur) for rice and from -6.56 (Mau) to 0.01 (Varanasi) for wheat crop. The percent Root Mean Square Error (RMSE) was between 6.87 (Jaunpur) to 11.60 (Sant Ravidas Nagar) for rice and from 5.52 (Mirzapur) to 11.11 (Mau) for wheat crop. This revealed that the models can be used to some extent for predicting the yield in different districts of Eastern Uttar Pradesh.

Basha *et al.* (2017) studied on the Surface Temperature changes over India by using 109 simulations from global coupled climate model with different external forcing during the 20^{th} and future projections under different RCP emission scenarios in the 21^{st} century. Based on the CMIP5 Multi mode simulations, the relative contribution of the external forcing such as natural (solar radiation, volcanic emissions) and human activities (GHGs, anthropogenic aerosols, land use) to the observed surface temperature during the last 100 years were computed. In addition, they have also considered the individual and combine effects of direct and indirect anthropogenic aerosols forcing. The evaluation of CMIP5 historic data with observational long-term trends were estimated by using robust regression analysis

Asfaw *et al.* (2018) examined the spatiotemporal dynamics of meteorological varieties in the context of changing climate. Particularly in countries where rain fed agriculture id predominant, is vital to assess climate induce changes and suggest feasible adaptation strategies. To that end, trend analysis has been employed to inspect the change of rainfall and temperature in north central Ethiopia using gridded monthly precipitation data obtained from Global Precipitation and Climate Centre (GPCC V7) and temperature data from Climate Research Unit (CRU TS 3.23) with 0.5-degree by 0.5-degree resolution from 1901 to 2014. Data have been analysed using coefficient of variation, anomaly index, precipitation concentration index and Palmer drought severity index. Furthermore, Mann-Kendall test was used to detect the time series trend. The result revealed intra and inter-annual variability of rainfall while Palmer drought severity index value proved the increasing trend of the number of drought years.

The historical daily data of rainfall and temperature were collected for the period of last 30 years (1985- 2015) for the various extreme weather events viz, Dry spell, Wet spell, Heat waves, Cold waves, and frost as to identify the impact of various extreme weather events. Based on the historical data results of **Arpita *et al.* (2019)** reveals that. In EPZ of U.P, the dry spell showed an increasing trend in recent years. The wet spell of 10mm for 7 days, 25mm for 3 days showed decreasing trend in recent years. S-W monsoon rainfall of EPZ of UP declined over the normal in recent years. Maximum days of heat waves were recorded in May (1.6 days) followed by June (1.5days). During the month of September there was no any heat waves, while during the month of March followed by August recorded lowest frequency of heat waves. Maximum days of cold waves (1.6 days) were recorded during the month of January followed by February and December month. The month of October and March have no cold wave in EPZ of U.P. The trend of extreme minimum temperature and extreme maximum temperature show decreasing trend against the normal value of 30℃ and 44℃

respectively. The total increasing trend of frost occurrence over the decades in the area will force to make strategy on contingent plan for major crops and adoptive measures from frost protection as to harvest highest genetic potential yield. Probability % of maximum frost occurrence during the month of January showed the decreasing trend of variation from 69% (1986-1995), 85% (1996-2005) and 63% (2005-2015) over the normal value of 72 %. Frost occurrence in the month of Dec- Jan will coincides with active tuber bulking phase in potato its effect is to bring about yield losses, and frost, foggy weather in winter months and occasional rains favours the late blight disease of potato in this region. So the decreasing tendency of frost days in January month in recent decades has beneficial impact on the growth of Rabi crops in the region.

Bhatla *et al.* (2020) conducted the estimates of fluctuation in climatic condition have a large impact on the production of selected crops such as rice (Oryza sativa), wheat (Triticum aestivum), maize (Zea mays), pulse, and sugarcane (Saccharum officinarum) which are the most prominent crops over Indo-Gangetic Plains (IGP). The influence of El Nino/La Nina on monsoon rainfall directly or indirectly affects the Indian crop over the Agro-Climatic Zones of Indo-Gangetic Plain (IGP). The detailed analysis has been carried out to show the impact of El Nino/La Nina and its association with crop production over sub-regions of IGP (lower, middle, upper, and trans IGP) during 1966–2009. During El Nino years, the production and yield of Rice and sugarcane have been affected in the middle and upper regions of IGP. The production of wheat decreased during La Nina events in the middle regions of IGP. The rice production has been severely affected by El Nino events over middle and upper IGP regions whereas wheat production increased. The decrease in maize production is observed in the upper and trans regions of IGP during El Nino. Pulse production decreased mainly in the middle, upper, and trans IGP during both events. The sugarcane production was highly affected during La Nina events overall sub-regions of IGP. The correlations among crop production, monsoon rainfall, and sea surface temperature (SST) anomaly of Nino 3.4 region during monsoon season are very insignificant during El Nino events. On other hand, La Nina event shows significant correlation over IGP. It has been noticed that on many occasions, deficit rainfall over IGP during summer monsoon season was responsible for decrease in crop production. Hence, alteration in Indian summer monsoon rainfall (ISMR) and sea surface temperature modulation of Nino 3.4 might have caused increase/decrease in the production of the crop.

Devegowda *et al.* (2021) carried out study on the rainfall trends and variation in Eastern Plain Zone of Uttar Pradesh for a time spanning of 37 years (1981-2017). Data for the period 1981-2017 were collected on yearly and monthly basis to calculate annual and seasonal rainfall trend and variation. Mann-Kendall (MK) test was used together with the Sen's Slope Estimator for the determination of trend and slope magnitude. South West (SW) monsoon has the highest share in the annual rainfall. Annual rainfall followed the same trend of SW monsoon, which is increasing over the period. North East (NE) monsoon and winter rainfall indicated decreasing trend over the years, whereas summer rainfall exhibited a significant increase. NE monsoon, winter rainfall and summer rainfall revealed more variation compared to SW monsoon and annual rainfall. The annual rainfall variability of Eastern Plain Zone, Ayodhya district indicated the highest variation in the annual rainfall with 23.89% whereas Chandauli with the least variation of 17.97%. EPZ agriculture depends on southwest monsoon occurs in June to September. SW monsoon followed the same trend of annual rainfall. Ayodhya district with the highest variation 26.83% and Chandauli with the least variation of 20.93%. Northeast monsoons received in October to December influence rabi crop production. Sant Ravidas Nagar exhibits the highest variation 96.46% and Mau revealed the least variation 76.42%. Winter rainfall occurred from January to February. Ghazipur and Mau indicated the lowest variation 79.86% and Ayodhya highest variation 90.02%.

Oldeman (1988) reported the agroclimatic characterization of Madagascar, the great variability of the climatic conditions and the abrupt changes over short distances from very wet regions to dry regions have been emphasized. Each unit of land and practically each single valley appears to have its own agroclimatic conditions. The agroclimatic map should be considered as an attempt to organize, characterize and delineate zones of a certain homogeneity of climatic regime. Climatic zones usually reflect vegetation zones, but not necessarily agricultural zones. This is well illustrated in Madagascar. The bulk of rice land is located outside the most suitable humid tropical Al zone. The majority of the rice lands are located in the Central highlands (39% of the total area), where climatic conditions are not highly favourable for rice cultivation, and where also soil conditions are not optimal.

The features of temperature extremes of varying intensities and length have changed is crucial considering climate change and its effects on industries like agriculture and health. **Dash and Mamgain (2011)** investigates how the frequency of extreme temperatures over India and its seven homogenous areas changed between 1969 and 2005 using a gridded temperature dataset from the India Meteorological Department. The frequency of cold nights throughout the winter months in India and its uniform northern parts, with the exception of the western Himalaya, has significantly decreased, according to the results. The frequency of chilly evenings has drastically decreased in southern regions compared to 1969–75. Only on the central peninsula is there a discernible upward trend in the number of warm summer days. Only in the last ten years, from 1996 to 2005, have the warmest summer days been observed throughout the nation and on the east and west coasts. Furthermore, the past ten years have seen the greatest number of hot, humid summer days and nights across the entire nation. In the northeast and north-central regions, there is a noticeable rise in the number of chilly days throughout the winter months. Variations in the frequency of warm and cold exceedances show that the west coast has warmed the most in comparison to all other regions. All things considered, these temporal and spatial variations in the properties of every type of temperature extreme point to general warming tendencies across a sizable portion of India.

Barlow *et al.* (2015) discussed about the simulating impacts of extreme heats and frost events on wheat crop production. Future climate scenarios are expected to increase the frequency of extreme weather events, such as heat shock and frost, which are already a major problem for grain growers. This study examines what is now known about how frost and high heat (heat shock) affect crop yields and how these effects are taken into account in modern process-based crop models. Wheat experiences a variety of physiological effects from heat shock and frost. They deduce from the literature that sterility and the abortion of produced grains near anthesis have the most effects on frost output. Reduced grain number (sterility and abortion of grains) during anthesis to early grain filling, as well as shorter grain filling time, are the two main effects of heat shock on yield. Because of these important physiological effects, crop models typically did not account for the non-linear response in grain production after a heat shock or frost event. They offer a conceptual model that explains how both a frost and a heat shock event alter grain number and, consequently, yield. They go over how crop response could be calculated in the models using heat/frost loads, canopy temperature, and daily maximum/minimum temperatures. Additionally, it is noted that more research is required to fully comprehend the impacts of temperature extremes' length on yield, the cumulative effects of several heat/frost episodes, and the interactions with other abiotic stresses like drought.

Global warming increased atmospheric CO_2 concentrations, and unpredictable rainfall patterns are the main causes of climate change, a phenomenon that has a significant effect on agricultural output. Given the uncertainty surrounding the feasibility of replacing fossil fuels entirely in the near future, the effects are only expected to worsen over the next few decades. Due of its reliance on the climate, **Bhaskaran and Nair (2014)** stated that agriculture will have to deal with both its advantages and disadvantages. Future projections and long-term observations demonstrate that climate change is indeed occurring and that both immediate and long-term solutions are urgently needed to lessen its detrimental effects on crop productivity. There are both positive and negative effects of high atmospheric CO concentration, temperature, unpredictable rainfall, etc. on crop growth and productivity, according to a wealth of data produced by study and real-time observations by many organizations and the IPCC. Since sugarcane is a long-lived C4 plant, research into how climate change affects it is necessary to maintain the production of sugar and energy. This paper reviews the findings from computer models and little in vitro research on how climate change affects sugarcane. The stomatal control of transpiration and the consequent rise in water usage efficiency occurred despite the prediction that the already CO, saturated photosynthesis of this C4 plant might not react favourably to increased ambient CO2 concentration.

Bhatla *et al.* (2016) studies about the El Nino La Nina impacts on crop production over different agro-climatic zones of Indo-Gangetic plain of India. The output of some crops, including the most important crops in the Indo-Gangetic Plains (IGP), rice (Oryza sativa), wheat (Triticum aestivum), maize (Zea mays), pulses, and sugarcane (Saccharum officinarum), is significantly impacted by estimates of climatic condition variability. El Nino/La Nina's impact on monsoon rainfall has a direct or indirect impact on Indian crops grown in the Indo-Gangetic Plain's (IGP) agroclimatic zones. The impact of El Nino/La Nina and its relationship to crop output across the lower, middle, upper, and trans IGP sub-regions between 1966 and 2009 have been thoroughly examined. In the middle and upper parts of IGP, rice and sugarcane yield and production have been impacted by El Nino years. In the IGP's center sections, wheat production fell during La Nina episodes. El Nino episodes across the middle and upper IGP regions have had a significant impact on rice production, whereas wheat production has increased. During El Nino, the upper and trans parts of IGP show a decline in maize output. During both instances, the middle, upper, and trans IGP saw the largest decreases in pulse generation. During La Nina events, sugarcane production was significantly impacted in all IGP sub-regions. During El Nino episodes, the relationships between crop productivity, monsoon rainfall, and the sea surface temperature (SST) anomaly in the Nino 3.4 region during the monsoon season are negligible. Conversely, there is a notable association between the La Nina event and IGP. Deficit rainfall over IGP during the summer monsoon season has frequently been seen to be the cause of a decline in agricultural yield. Therefore, changes in sea surface temperature modulation of Nino 3.4 and Indian summer monsoon rainfall (ISMR) may have led to an increase or reduction in agricultural output.

The study examines the effects of climate variability on rice yields throughout several agroclimatic zones in Uttar Pradesh, India, against the backdrop of the well-established relationship between climate and agricultural products. Long-term (annual and seasonal) weather and yield data sets were examined using the time-series non-parametric Mann-Kendall trend test by **Bhatt *et al.* (2019)**. The lowest temperature across all zones was shown to be rising between 0.06 and 0.44 °C per ten years. Maximum temperatures during the "kharif" season were seen to be rising in the majority of zones. With the exception of Bhabhar and the Tarai Zone, which had a very high decadal trend pointing to the occurrence of strong rainfall events, the data regarding annual and seasonal rainfall patterns were largely non-significant. Because of the high frequency of extreme rainfall events in three categories (>50 to <100 mm/day; >100 to <150 mm/day; and >150 mm/day), the North Eastern Plain Zone deserves special attention. Given the region's monthly and yearly variations in temperature and precipitation, the warming trend combined with the unpredictable rainfall patterns throughout time is probably going to have a big effect on the rice harvest. Therefore, it is imperative to establish methods that can address the effects of the current climatic variability on rice yields in this Indian state by creating appropriate adaptation choices for sustainable production.

Crop yields, water availability, and overall food security are all impacted by climate change, which presents serious issues for Indian agriculture. It is essential to use both adaptation and mitigation techniques to solve these issues. **Srinivasarao *et al.* (2024)** elaborates about adaptation approaches include shifting planting schedules, introducing water-saving methods, and encouraging robust crop types as ways to adapt agricultural operations to the changing climate. In order to improve farmers' and agricultural systems' resilience to the effects of climate change and support global climate objectives, adaptation and mitigation measures must be integrated in India. Indian agriculture can manage the challenges of climate change by fusing traditional wisdom with cutting-edge scientific methods, guaranteeing millions of farmers nationwide sustained food production and livelihood stability.

India produces a wide range of food crops, such as oilseeds, pulses, and cereals. The Central Government prioritizes diversified agriculture, and farmers are receiving financial and technical assistance to promote diversification, particularly in the fields of horticulture, floriculture, medicinal and aromatic plants, apiculture (pee-keeping), and sericulture. The government places a strong focus on infrastructure and food processing in its ongoing efforts to support the growth of the agriculture industry. To achieve world-class standards, technology and agri-infrastructure still have room for improvement and growth. The application of contemporary technologies, infrastructure development, and quality improvement are the primary focal points. **Chandrasekhar (2010).**

The scientific community has placed a greater emphasis on food security and its regional effects in the last ten years due to the rising awareness of the likelihood of climate change and the unmistakable evidence of changes in the climate over the 20th century. Crop simulation models have been widely utilized recently to investigate how climate change affects food security and agricultural output. The simulation models' output may be utilized to give farmers and others more choices for their agricultural system and to help them make wise crop management decisions. **R.K. Mall *et al.* (2006)** anticipated that as computers become more widely used in the ensuing decades, more professionals, farmers, and policy and decision makers would employ simulation models. Over the past ten years, a lot of study has been done in India to comprehend the type and extent of changes in agricultural yields brought on by anticipated climate change. An overview of the current understanding of the potential impact of climatic variability and change on India's food grain production is provided in this publication.

Crop prediction equations were developed using 18 years (1991–2008) of meteorological and rice and wheat crop data for 9 districts in Eastern Uttar Pradesh. **Singh *et al.* (2014)** used data for two years (2009 and 2010) to validate the models. The findings showed that models could account for 65 to 92 percent of the variances in wheat yield and 51 to 79 percent of the variability in rice output across various districts. For rice, the percent Mean Bias Error (MBE) ranged from -1.05 (Mau) to 6.17 (Mirzapur), whereas for wheat, it ranged from -6.56 (Mau) to 0.01 (Varanasi). Regarding rice, the percentage Root Mean Square Error (RMSE) ranged from 6.87 (Jaunpur) to 11.60 (Sant Ravidas Nagar), while for wheat, it ranged from 5.52 (Mirzapur) to 11.11 (Mau). This shown that the models may be somewhat utilized to forecast the yield in various Eastern Uttar Pradesh districts.

Global climate change is a change in the long-term weather patterns that characterize the regions of the world. **Mahato (2014)** elaborate that climate change may have long-term effects on agriculture in a number of ways, including crop yield and quality, growth rates, photosynthesis and transpiration rates, moisture availability, etc. Global food production is probably going to be directly impacted by climate change. A rise in the average seasonal temperature can shorten many crops' growing seasons and, as a result, lower their yield.

The effects of climate change on human lives and natural resources are profound. The information at hand points to negative effects on important economic sectors. In order to determine the effects in the 2030s, a 4x4 evaluation has been developed and cited by **MoEF (2010).**

Aggrawal *et al.* (2009) covered the main information requirements to lessen the adverse effects of climate change and weather variability on food security and land degradation, along with the opportunities and obstacles that exist between the information and services that are required. It implies that the limited scope of typical one-dimensional vulnerability studies may be addressed by vulnerability assessments based on a livelihood concept that incorporates climatic data and other socioeconomic elements. If the right institutional and regulatory support is provided, together with technology interventions to address the complexities of the various risks that agriculture faces, then both present and future climate hazards may be handled more effectively. Effective collaborations across organizations addressing issues related to food security, agricultural research, land degradation, and meteorological and hydrological services would be necessary for this.

Sugarcane is a crop that is sensitive to climate, its global spread is limited based on the appropriateness of certain climatic conditions. Though it started off as a relatively gradual phenomena, climate change is rapidly accelerating owing to both natural and massive human activity that is altering the atmosphere's makeup. Numerous climate models predict that temperatures, precipitation, and sea levels would likely rise in the upcoming decades, which is concerning. Future productivity and sugar yield are anticipated by **Srivastava & Rai (2012)** to be significantly impacted by the sugarcane's extreme sensitivity to temperature, precipitation, sunlight, and other factors. It is also commonly recognized that sugarcane is one of the world's most valuable commodities, and that demand for its byproducts—ethanol and sugar—is constantly rising on a worldwide scale. As a result, research on how to produce sugarcane effectively in the face of climate change has emerged as a key topic of focus and a major worry for scientists worldwide. The development of suitable cane varieties that are susceptible to changing climate conditions, land preparation, plantation timing and pattern, weed, disease, and pest management, nutrient management, appropriate timing, and sufficient water management are examples of advanced agronomic measures that appear to be effective in achieving high crop production with high-quality juice in the future.

Extreme high temperature occurrences are predicted to become more frequent in many parts of the world due to increased climatic variability and rising mean temperatures. Short bursts of high temperatures around blooming can have significant detrimental effects on cereal grain yields, according to empirical data; this phenomenon is increasingly being referred to as heat stress. Though it has only recently been realized that heat stress effects must be taken into account, crop models are now the greatest instruments available to study how crops will develop under future climatic circumstances. Then, general methods for simulating the effects of high temperatures in crop development models were compared with this state of the art in crop response to heat stress. **Rezaei *et al.* (2015)** discovered that a number of mechanisms, not all of which will be impacted by a "high temperature" environment, combine to produce the reported effects of heat stress on crop output. This intricacy demonstrates how crucial crop models are for organizing how high temperatures affect several processes across a variety of settings and crop phenological realizations.

Impacts of climate change pose a serious threat to food security and need to be much better understood. In the recent past, changes in timing and amount of precipitation, extremes in temperature and widespread drought are becoming quite common in most parts of the world. The last decade, that ended with 2010, was the warmest in the past. Climate models are the main tools available for developing projections of climate change in the future. However, the presence of large uncertainties in climate models and future emission scenarios predicting long-term changes in certain climate variables, in particular in regional scales, is a challenging task that climate modellers face today4,5. Future temperature projections using global circulation models (GCM) indicate an increase of 2.5–4°C from the current levels over the Indian subcontinent. Rice is one of the most important staple food crops which is predominantly grown in the Cauvery River basin, which is also known as the rice bowl of Tamil Nadu. **Geethalashkmi *et al.* (2011)** indicate that the productivity of rice crop declines by 41% for 4°C increase in temperature. Well calibrated and validated crop weather models could be used as an effective tool for assessing the impacts of future changes in climate. It is important to develop suitable adaptation strategies for sustaining the rice productivity to meet the demand of a growing population. In this article, two regional climate model outputs have been used to understand the climate change trends in the Cauvery River basin of Tamil Nadu for assessing the impact on rice productivity and designing suitable adaptation strategies to reduce the impacts of climate change.

A rigorous analysis was conducted by comparing the crop's weather experiences with the ideal climatic conditions at various growth stages. To determine the ideal ranges of meteorological factors at various growth phases, correlation and multiple regression approaches were employed. **Samui *et al.* (2003)** found that the most crucial factors during the germination stage were the highest temperature, morning humidity, and sunlight hours. At the germination stage, a maximum temperature of around 26.8°C was shown to be optimal. A higher maximum temperature was shown to be harmful, resulting in a lower yield. The crop preferred greater minimum temperatures (about 26.2°C), high relative humidity, and heavy rainfall during the flowering period. Light winds and lower maximum and higher minimum temperatures were shown to be beneficial for sugarcane development during the active and elongation periods.

For the years 2000–2020, **Singh *et al.* (2024)** calculated the Eastern Plain Zone of Uttar Pradesh's maximum and lowest temperatures and rainfall to show seasonal and yearly fluctuation. According to the research, the Eastern Plain Zone of Uttar Pradesh has an average temperature of 31.6°C. The year 2009 saw the highest average temperature of 32.5°C, while the year 2014 saw the lowest, 30.4°C. The temperature increased sharply and significantly between 2000 and 2020, rising from about 31.6°C to 32.5°C. An average temperature rise of about 0.9°C was seen even in 2009. Knowing the rainfall trend is one of the most important factors for many different businesses. In addition, the average annual rainfall decreased by 0.53 mm between 2000 and 2020.

Crop yield per unit area may be positively or negatively impacted by climatic variability, depending on local circumstances and crop types. In China, it is thought that warming is good for irrigated agriculture but bad for rainfed crops. For example, from 1951–2002, rice yields in the northeast seem to have grown by 4.5–14.6% per °C in response to nighttime warming. Conversely, higher daytime temperatures are probably going to result in a lower wheat production (6–20% per °C). **Piao *et al.* (2010)** demonstrates the need of crop-specific and regional research as well as the necessity of using a probabilistic approach to uncertainty. The country's wheat yields decreased by 4.5% between 1979 and 2000 as a result of rising temperatures. Recent warming may have also had an impact on maize yields; data from eight Chinese provinces from 1979 to 2002 indicates that maize yields decreased as temperatures rose.

Chapter - III

MATERIALS AND METHODS

This chapter outlines the materials and methods used in the research entitled **"Agro-climatic characterization of the Eastern Uttar Pradesh".** Historical temperature and rainfall data spanning the past 26 years (1998–2023) were obtained from the India Meteorological Department (IMD) and Banaras Hindu University, Varanasi. The climatic profile of the study area, along with the materials and methodologies employed during the investigation, are detailed in the following sections.

DEMOGRAPHY OF EASTERN UTTAR PRADESH

3.1 General Description:

Eastern Uttar Pradesh is geographically located between approximately 25°N to 27.5°N latitude and 81°E to 84.5°E longitude, with an average elevation of about 113 meters above mean sea level. The region forms a significant part of the Indo-Gangetic plains and is characterized by fertile alluvial soil, enriched by rivers such as the Ganges, Ghaghara, and others. The climate is typically subtropical, featuring hot summers, a distinct monsoon season, and cool winters.

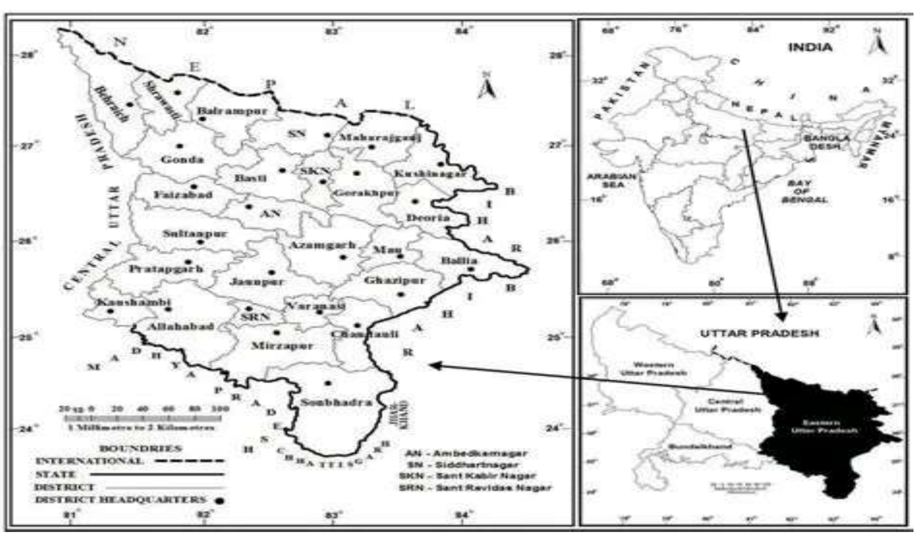

Fig. 3.1 Map of Eastern Uttar Pradesh (Source: Shakeel, A. 2013)

3.2 Climate profile of Eastern Uttar Pradesh:

Uttar Pradesh experiences a predominantly humid subtropical climate with dry winters, although some areas in the eastern region exhibit semi-arid conditions. Agriculture in Eastern Uttar Pradesh is largely dependent on rainfall and is primarily practiced by small and marginal farmers. The region frequently faces challenges such as floods, droughts, and soil salinity, which impact agricultural productivity. The dominant cropping pattern consists mainly of rice and wheat cultivation.

3.3 Seasons:

1. Winter Season / Cold Weather Season (December, January and February)
2. Summer season/ Hot weather season (March, April and May)
3. South-west Monsoon (June, July, August and September)
4. Post-monsoon (October and November)

3.4 Mean Temperature:

Mean temperature refers to the average temperature over a specific period of time, such as a day, month, season, or year. It gives a general idea of how hot or cold the weather has been during that period.

$$\textbf{Mean Temperature} = \frac{\boldsymbol{Sum\ of\ all\ temperature\ reading}}{\boldsymbol{Number\ of\ reading}}$$

Eastern Uttar Pradesh experiences a diverse range of temperatures throughout the year due to its humid subtropical climate. Summers, extending from March to June, are typically hot and dry, with maximum temperatures often soaring between 40°C to 45°C, and occasionally reaching up to 47°C. This period is marked by intense heat and low humidity. The monsoon season begins in late June and lasts until September, bringing moderate to heavy rainfall along with a slight drop in temperature. During this time, average temperatures range from 28°C to 32°C, offering some relief from the scorching summer heat. The post-monsoon period (October to November) sees further decline in temperatures, averaging around 25°C to

30°C. Winters, from December to February, are generally cool and pleasant, with average daytime temperatures ranging between 10°C and 20°C. However, night temperatures can drop significantly, sometimes falling as low as 3°C or even below 0°C in certain areas. This seasonal variation in temperature plays a crucial role in determining the agricultural patterns and crop cycles of the region.

3.5 Rainfall:

Eastern Uttar Pradesh receives an average annual rainfall ranging from 1000 to 1200 mm, with approximately 90 percent of this occurring during the southwest monsoon season, which lasts from June to September. During the winter season, around 5 to 7 percent of the total annual rainfall is recorded. According to a study by **Tripathi *et al.* (1998),** the post-monsoon season has minimal impact on the region, with only occasional mild showers, often caused by western disturbances rather than the monsoon itself. In Eastern Uttar Pradesh, excessive rainfall during the monsoon season can lead to flooding, whereas inadequate rainfall may result in drought conditions, both of which significantly affect agriculture. The region is comprises of 3 agro-climatic zones viz. North Eastern Plain Zone, Eastern Plain Zone and Vindhyan Zone.

3.6 Total rainfall:

Rainfall is measured on a daily basis; therefore, its weekly, seasonal and annual totals are considered for analysis. Among the seasonal totals, rainfall during monsoon season is further categorized as crop-growing season rainfall.

3.7 Mean total rainfall:

The mean weekly, seasonal and annual rainfall is worked out to study the rainfall climatology of that area. The formula is given below:

$$P = \frac{1}{n}\sum_{i=1}^{n} Pi$$

Where:

- Pi = rainfall at single station.
- i and n = no. of station.
- P = mean total rainfall (mm).

3.8 Yield Data:

The yield data of Rice and Wheat crop for Eastern Uttar Pradesh were taken from DACNET (Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare) for 26 years (1998-2023).

3.9 Standard deviation (SD):

Standard deviation is a statistical measure that quantifies the amount of variation or dispersion in a set of data values. It tells you how much the individual data points deviate, on average, from the mean (average) of the data set.

$$\sigma = \sqrt{\frac{n}{1}} \sum_{i=1}^{n} (xi - \mu 2)$$

Where:

- σ\sigma = Standard deviation of the population.
- N = Number of data points in the population.
- xi= Each individual data point.
- μ\mu = Mean (average) of the population.

3.10 Coefficient of variation (CV):

The coefficient of variation (CV) is used to assess the variation in rainfall on annual and seasonal basis. According to the research of **Ahamed *et al.* (2021),** CV is a statistical measure expressed in percentage that indicates the degree of variability of data points in a data set relative to mean. A larger CV value indicates that the rainfall time-series data is more variable and the climate is less predictable.

$$\boldsymbol{Coefficient\ of\ variation} = \frac{\sigma}{\mu}\boldsymbol{X100}$$

Where:

- CV = coefficient of variation
- σ\sigma = standard deviation
- μ\mu = mean.

3.11 Methodology:

To conduct this study, historical weather data, specifically rainfall, for districts in Eastern Uttar Pradesh will be collected from reliable sources such as the India Meteorological Department (IMD) and the Directorate of Agriculture. Weather analysis will be carried out on the collected data using appropriate meteorological tools. The study aims to identify climatic production constraints in the region. Data from the period of 1998 to 2023 will be utilized, depending on availability. The historical data will be analyzed to assess climatic variability and to make future predictions.

3.12 Linear regression analysis:

A statistical method for figuring out the relationship between two variables usually a dependent variable and an independent variable is linear regression analysis. It is frequently used to find patterns within a dataset. The procedure entails determining the strength of the link between the observed data points and a linear equation. For this study, it is used to analysed the correlation between the weather parameters viz. rainfall, Tmax and Tmin and the production (major crop of Uttar Pradesh). To determine whether there is a relationship between the variables of interest, the data is analysed using methods like scatter plots prior to applying linear regression. Linear regression could not be a suitable model if no significant connection is discovered. The correlation coefficient, which goes from -1 to +1, may be used to measure how strong the association is.

Chapter - IV

RESULTS AND DISCUSSION

This chapter presents the findings from the study entitled **"Agro-climatic characterization of the Eastern Uttar Pradesh".** The results, based on an analysis of historical data spanning the past 26 years, have been systematically organized under specific categories and are discussed in detail below:

1. Collection of weather data of the Eastern Uttar Pradesh.
2. Analysis of weather data of the Eastern Uttar Pradesh.
3. Studying the impacts of weather parameters on production of major crops in Eastern Uttar Pradesh.
4. Identifying the climatic constrains of the Eastern Uttar Pradesh.

Rainfall data were gathered on daily basis and analyzed for the different districts of the different agro-climatic zones located in Eastern Uttar Pradesh, covering the long-term period from 1998 to 2023. The analysis focused on calculating standard deviation and conducting trend and correlation analyses to assess the impact of various meteorological parameters on the region.

4.1 Collection of weather data of the Eastern Uttar Pradesh.

Historical weather data, with a particular focus on rainfall in Eastern Uttar Pradesh, was collected for the period spanning 1998 to 2023. The data was sourced from the Indian Meteorological Department, Lucknow, and the Department of Agronomy at Banaras Hindu University. Long-term records of rainfall, along with maximum and minimum temperature data, were analyzed using MS Excel and Mann-Kendall test analysis. The daily weather data was seasonally categorized into Winter/Cold Season, Summer Season, and Southwest Monsoon/Post-Monsoon, and was analyzed based on standard meteorological weeks. For rice cultivation, the critical period ranges from the 27th to the 42nd meteorological week, whereas for wheat, it extends from the 45th to the 15th week of the following year. The primary objective of this study is to develop a reliable and high-quality historical weather dataset by effectively addressing missing data. A variety of imputation methods were applied; each tailored to different types of missing values. The results of the experiment indicates that two of the intended methods are particularly effective and hold strong potential for broader application.

4.2 Analysis of weather data of the Eastern Uttar Pradesh (EUP).

4.2.1 Analysis of the maximum temperature, minimum temperature & rainfall of Eastern Plain Zone.

The presented table 4.1 offers a comprehensive seasonal analysis of climatic variables, focusing on maximum temperature and minimum temperature (Tmax and Tmin) and rainfall, including their statistical measures: mean, standard deviation (SD), and coefficient of variation (CV%). The data clearly demonstrates notable seasonal variations in temperature and precipitation. Amidst the Summer season (March to May), the region experiences the highest average maximum temperature, reaching 39.44°C, accompanied by a relatively high Tmin of 34.31°C. Nevertheless, in this time rainfall remains low, averaging only 56.80 mm, reflecting typically hot and dry conditions. The standard deviation and CV values are low for temperature, indicating stable heat levels with minimal fluctuations. In stark contrast, the Southwest Monsoon (June to September) brings a substantial shift in weather patterns. Tmax and Tmin drop to 34.87°C and 26.97°C respectively, providing relief from the summer heat, while rainfall surges to 780.46 mm, making it the wettest season. Interestingly, the rainfall CV for this period is extremely low (0.28%), suggesting a highly consistent monsoonal pattern year after year. Moving into the Post Monsoon period (October to November), temperatures continue to decline with a Tmax of 29.57°C and a Tmin of 17.37°C. Rainfall drastically reduces to 44.48 mm, but this period exhibits high variability in rainfall, as indicated by the highest CV value of 6.51%, signifying unpredictable rain events likely due to residual monsoonal activity or local atmospheric disturbances. Finally, the winter season (December to February) marks the coldest part of the year, with the average minimum temperature dipping to 10.08°C and the maximum temperature settling at 25.43°C. Rainfall is minimal at 28.45 mm, and while temperature remains quite stable (CV for Tmin is 4.42%), there is slightly more consistency in rainfall compared to the Post Monsoon period. Overall, the seasonal data captures a clear climatic cycle hot and dry summers, cool and wet monsoons, transitional post-monsoons, and cold, dry winters. The low temperature CV suggests reliable seasonal temperature patterns, while rainfall exhibits greater inconsistency, particularly outside the core monsoon months.

Table 4.1 Seasonal and annual mean value, standard deviation, coefficient of variation of temperature and rainfall of EPZ (1998 to 2023).

Period	Temperature (°C)						Rainfall (mm)		
Season	Tmax			Tmin			Mean	SD	CV (%)
	Mean	SD	CV (%)	Mean	SD	CV (%)			
Summer (March to May)	39.44	0.71	1.81	34.31	0.71	2.08	56.80	1.47	2.58
SW Monsoon (June to Sep.)	34.87	0.92	2.64	26.97	0.53	1.96	780.46	2.20	0.28
Post Monsoon (Oct. to Nov.)	29.57	0.43	1.46	17.37	0.68	3.94	44.48	2.89	6.51
Winter Monsoon (Dec. to Feb.)	25.43	0.53	2.09	10.08	0.44	4.42	28.45	0.95	3.34
Annual									
1998	32.57	6.75	20.72	20.28	6.75	33.26	1155.79	8.75	0.76
1999	32.60	6.40	19.63	20.11	7.39	36.73	769.1	5.10	0.66
2000	33.00	5.80	17.58	19.71	7.57	38.42	934.37	6.99	0.75
2001	32.86	5.99	18.23	20.10	7.72	38.39	910.19	6.47	0.71
2002	32.65	6.53	20.00	20.43	7.32	35.82	706.4	5.65	0.80
2003	32.88	6.67	20.29	20.14	7.82	38.81	623.1	3.60	0.58
2004	32.71	6.22	19.02	20.43	7.08	34.64	626.5	5.03	0.80
2005	32.74	6.66	20.34	20.51	7.26	35.42	839.68	6.16	0.73
2006	32.91	5.30	16.10	20.54	6.94	33.80	769.95	5.42	0.70

2007	32.51	6.35	19.53	20.05	7.69	38.34	973.78	6.29	0.65
2008	32.58	6.26	19.21	19.85	7.17	36.14	1351.66	8.89	0.66
2009	32.84	6.27	19.09	20.34	7.35	36.12	692.91	4.72	0.68
2010	32.78	7.15	21.81	20.91	7.88	37.68	823.61	5.90	0.72
2011	33.07	6.32	19.11	19.87	7.52	37.84	1003.51	6.78	0.68
2012	32.86	7.25	22.06	19.50	8.21	42.10	891.29	6.86	0.77
2013	32.79	6.32	19.27	19.52	7.54	38.62	1058.5	8.68	0.82
2014	33.39	7.08	21.20	19.86	8.05	40.55	934.45	7.06	0.76
2015	33.08	6.31	19.07	20.72	7.30	35.25	713.63	5.94	0.83
2016	33.17	6.78	20.44	20.71	7.78	37.55	1006.81	6.32	0.63
2017	32.91	6.50	19.75	20.70	7.65	36.95	867.65	7.05	0.81
2018	33.11	6.39	19.30	20.40	7.84	38.45	841.05	6.17	0.73
2019	33.27	7.90	23.75	20.56	8.00	38.91	1098.19	9.84	0.90
2020	33.05	6.10	18.46	19.42	7.48	38.50	1099.37	7.23	0.66
2021	33.39	5.98	17.91	19.92	7.01	35.19	1269.2	8.46	0.67
2022	33.22	7.68	23.12	20.01	8.09	40.40	886.4	6.91	0.78
2023	33.31	5.93	17.80	20.12	5.75	32.26	802.06	5.29	0.66

4.2.2 Analysis of the maximum temperature, minimum temperature & rainfall of North Eastern Plain Zone.

The seasonal climatic data provided highlights significant variations in rainfall and temperature patterns across different times of the year. During the Summer season (March to May), the region experiences its highest maximum temperature, averaging 38.26°C, indicating intense heat. The average Tmin during this period is 22.22°C, suggesting warm nights as well. Rainfall in summer is relatively low at 90.76 mm, which aligns with the typically dry and hot pre-monsoon conditions. Inspite the heat, the low coefficients of variation (CV%) for both temperature and rainfall indicate a stable and consistent climate during this season. Transitioning into the Southwest Monsoon (June to September), a noticeable drop in temperature occurs, with Tmax averaging 34.82°C and Tmin at 26.54°C, offering some relief from the summer heat. However, the most defining feature of this season is the dramatic increase in rainfall, averaging 965.44 mm, making it the wettest season by far. The extremely low CV% for rainfall (0.39%) further confirms that this period is highly reliable for consistent monsoonal rains, which are important for agriculture and water resources.

Following the monsoon, the Post Monsoon season (October to November) witnesses further cooling, with Tmax and Tmin dropping to 29.69°C and 17.52°C, respectively. Rainfall significantly decreases to 51.89 mm, but this season is marked by high variability in precipitation, as reflected by a CV% of 7.01%, indicating that post-monsoonal rains are erratic and less predictable. Finally, the Winter Monsoon (December to February) brings the lowest temperatures of the year, with Tmax averaging 24.87°C and Tmin dropping to 10.23°C, creating cool and pleasant conditions. Rainfall is minimal, averaging 46.84 mm, but its CV% (3.44%) suggests moderate variability, indicating occasional winter showers or localized weather events. Across all seasons, temperature patterns show low variability, reinforcing the predictability of thermal conditions year-round. However, rainfall, especially during the post-monsoon and winter periods, shows notable fluctuation, underlining the importance of adaptive planning for water management. This seasonal breakdown offers valuable insight into the climate dynamics of the region, which can guide agricultural practices, infrastructure development, and disaster preparedness. (Table 4.2)

Table 4.2 Seasonal and annual mean value, standard deviation and coefficient of variation of temperature and rainfall of NEPZ (1998 to 2023).

Period	Temperature (°C)						Rainfall (mm)		
Season	Tmax			Tmin			Mean	SD	CV (%)
	Mean	SD	CV (%)	Mean	SD	CV (%)			
Summer (March to May)	38.26	0.75	1.98	22.22	0.72	3.24	90.76	1.99	2.20
SW Monsoon (June to Sep.)	34.82	0.98	2.82	26.54	0.47	1.80	965.44	3.79	0.39
Post Monsoon (Oct. to Nov.)	29.69	0.37	1.25	17.52	0.59	3.40	51.89	3.64	7.01
Winter Monsoon (Dec. to Feb.)	24.87	0.44	1.78	10.23	0.41	4.01	46.84	1.61	3.44
Annual									
1998	31	6.46	20.84	20.09	7.50	37.35	845.78	5.57	0.66
1999	31.8	6.41	20.16	20.45	7.30	35.67	570.67	3.92	0.69
2000	32	5.74	17.94	19.82	7.12	35.91	996.39	12.19	1.22
2001	31.5	5.75	18.25	20.18	7.43	36.82	742.64	5.06	0.68
2002	32.3	6.73	20.84	20.73	7.34	35.41	624.97	5.36	0.86
2003	32.1	6.59	20.53	19.90	7.62	38.29	787.97	5.39	0.68
2004	32.1	6.29	19.60	19.85	6.77	34.12	946.91	7.18	0.76
2005	32.6	6.44	19.75	20.04	6.89	34.41	1030.02	6.48	0.63
2006	32.6	5.14	15.77	20.12	6.57	32.63	1029.65	9.12	0.89
2007	32.3	6.18	19.13	19.55	7.40	37.85	1183.35	7.36	0.62
2008	31.8	5.85	18.40	19.68	6.79	34.52	1627.21	10.62	0.65
2009	33.3	6.62	19.88	20.02	7.34	36.67	1026.97	8.20	0.80
2010	32.8	7.13	21.74	20.35	7.67	37.69	1012	7.40	0.73

2011	31.7	6.21	19.59	19.68	7.34	37.29	1319.48	10.85	0.82
2012	32.4	7.50	23.15	19.35	8.01	41.37	1147.67	9.44	0.82
2013	31.2	6.34	20.32	19.34	7.27	37.61	1356.42	8.72	0.64
2014	31.3	7.02	22.43	19.60	7.81	39.83	963.59	6.29	0.65
2015	32.6	6.02	18.47	19.94	6.90	34.59	1113.27	6.94	0.62
2016	32.7	5.70	17.43	20.52	6.82	33.26	1371.07	9.34	0.68
2017	32.5	5.94	18.28	20.39	7.04	34.53	1365.72	8.84	0.65
2018	33.2	5.88	17.71	19.92	7.14	35.83	1565.04	11.64	0.74
2019	31.8	7.17	22.55	19.86	7.47	37.62	1508.35	11.78	0.78
2020	30.5	5.73	18.79	19.22	7.10	36.96	1371.43	8.97	0.65
2021	32.6	5.71	17.52	19.64	6.66	33.90	2020.49	12.19	0.60
2022	31.2	7.62	24.42	19.67	7.60	38.66	1290.7	9.84	0.76
2023	32.8	5.79	17.65	20.06	6.65	33.13	1211.82	7.73	0.64

4.2.3 Analysis of the maximum temperature, minimum temperature & rainfall of Vindhyan Zone.

The seasonal and annual climatic data from the region shows fascinating trends in rainfall and temperature distribution across different periods. During the Summer season (March to May), the maximum temperature (Tmax) reaches an average of 34.55°C, indicating moderately high heat, while the minimum temperature (Tmin) averages 19.17°C, reflecting relatively cooler nights compared to the daytime. The summer rainfall is 64.21 mm, with a coefficient of variation (CV) of 2.26%, suggesting some fluctuations but generally stable rainfall during this season. Moving into the SW Monsoon (June to September), temperatures drop notably, with Tmax averaging 29.46°C and Tmin at 23.15°C, providing a much cooler and more humid environment. Rainfall during the monsoon is extremely high, with an average of 814.48 mm, making this period the primary source of annual precipitation. The low CV of 0.32% for monsoon rainfall points to high consistency and reliability of the monsoonal rains year after year, crucial for agriculture, water resources, and overall ecosystem stability.

In the Post Monsoon season (October to November), the temperatures slightly decline further, with Tmax and Tmin averaging 28.01°C and 15.66°C, respectively. Rainfall reduces significantly to 41.33 mm, and a moderate CV of 5.35% suggests relatively steady but slightly variable rainfall events, often seen as sporadic showers after the retreating monsoon. The Winter Monsoon season (December to February) is characterized by the lowest temperatures annually, with Tmax averaging 23.89°C and Tmin dropping to 9.01°C, presenting cool and crisp conditions. Rainfall during winter is modest, averaging 27.32 mm, with a CV of 3.26%, indicating occasional winter rains, often associated with western disturbances.

Looking at the annual climatic trends from 1998 to 2023, there is a slight variation in both temperature and rainfall over the years. Tmax has fluctuated between around 29.19°C (2022) to 32.86°C (2016), while Tmin ranged from approximately 17.12°C to 20.10°C. The standard deviations (SD) and coefficients of variation suggest moderate variability in temperature, highlighting subtle impacts of climate variability and perhaps early signs of regional climate shifts. Rainfall across the years shows a wide spread: from 542.35 mm (2006) to 1207.6 mm (2000), with CVs hovering around 10–12% for most years, indicating moderate interannual variability in total precipitation. Some years, like 2000 and 2018, experienced notably higher rainfall, possibly linked to intense monsoon activity, while years like 2006 and 2023 witnessed drier conditions. Additionally, years like 2022 and 2023 show elevated CVs for temperatures and reduced rainfall, which could hint at growing climate anomalies such as delayed or weakened monsoons.

Overall, this extensive dataset paints a clear picture: the region experiences hot summers, heavy and consistent monsoonal rains, mild post-monsoon conditions, and cool winters. Over the last two decades, while the core seasonal patterns have remained intact, increasing variability in annual rainfall and occasional temperature extremes hint at gradual climatic changes that need closer monitoring for future planning in agriculture, water management, and disaster risk reduction. (Table 4.3)

Table 4.3 Seasonal and annual mean value standard deviation coefficient of variation of temperature and rainfall of VZ (1998 to 2023).

Period	Temperature (°C)						Rainfall (mm)		
Season	Tmax			Tmin			Mean	SD	CV (%)
	Mean	SD	CV (%)	Mean	SD	CV (%)			
Summer (March to May)	34.55	1.00	2.72	19.17	0.88	4.07	64.21	1.45	2.26
SW Monsoon (June to Sep.)	29.46	3.03	10.28	23.15	0.99	4.29	814.48	2.57	0.32
Post Monsoon (Oct. to Nov.)	28.01	0.91	3.25	15.66	1.66	10.61	41.33	2.21	5.35
Winter Monsoon (Dec. to Feb.)	23.89	1.31	5.47	9.01	1.84	20.48	27.32	0.89	3.26
Annual									
1998	30.71	4.69	15.27	18.9	6.84	36.19	866.5	6.43	0.73
1999	30.6	6.19	20.23	18.8	6.73	35.80	1005.9	7.21	0.72
2000	31.52	4.74	15.04	17.61	7.54	42.82	1207.6	4.65	0.39
2001	30.6	6.19	20.23	18.23	7.52	41.25	768.01	6.75	0.88
2002	31.51	4.75	15.07	18.82	6.84	36.34	1030.7	6.45	0.63
2003	30.64	6.18	20.17	18.91	6.74	35.64	869.4	5.13	0.59
2004	30.53	6.17	20.21	17.3	7.35	42.49	1148.4	4.7	0.41
2005	31.52	4.74	15.04	18.49	6.72	36.34	687.3	5.94	0.86
2006	31.61	4.71	14.90	18.21	6.62	36.35	542.35	3.95	0.73
2007	30.25	6.09	20.13	18.8	6.73	35.80	739.4	4.96	0.67

2008	31.34	4.82	15.38	18.75	6.86	36.59	883	7.45	0.84
2009	30.43	4.81	15.81	19.24	6.15	31.96	836	4	0.48
2010	31.91	4.07	12.75	18.92	6.81	35.99	1011.2	3.62	0.36
2011	31.82	4.08	12.82	19.53	6.62	33.90	1050.2	7.62	0.73
2012	30.63	6.18	20.18	19.7	6.24	31.68	1026.6	7.84	0.76
2013	31.15	4.83	15.51	18.66	6.16	33.01	1000.31	8.06	0.81
2014	32.34	5.12	15.83	20.04	5.49	27.40	983	6.36	0.65
2015	32.67	5.79	17.72	20.1	5.55	27.61	960	5.81	0.61
2016	32.86	5.89	17.92	19.09	6.84	35.83	890	8.3	0.93
2017	32.43	5.69	17.55	20.02	5.51	27.52	930.9	5.78	0.62
2018	30.91	6.11	19.77	19.5	6.63	34.00	1001.1	5.65	0.56
2019	31.88	4.66	14.62	18.09	6.15	34.00	998.1	7.82	0.78
2020	30.32	6.19	20.42	18.18	6.12	33.66	990.2	7.26	0.73
2021	31.13	4.55	14.62	19.21	6.88	35.81	977.1	7.98	0.82
2022	29.19	7.12	24.39	18.21	6.09	33.44	888.9	6.35	0.71
2023	30.33	6.15	20.28	17.12	7.25	42.35	786.8	5.36	0.68

4.2.4 Trend analysis of Eastern Plain Zone during 1998-2023

Maximum Temperature

The graph illustrates the trend of maximum temperature (Tmax) from 1998 to 2023. The blue line shows the annual variation in Tmax, the orange line indicates the normal line while the black line represents the linear trend over the period. Overall, the maximum temperature shows a slightly increasing trend, as indicated by the positive slope (0.0256) of the trend line. The R^2 value of 0.5712 suggests a moderate correlation, meaning that while there is a general upward trend, the year-to-year variations are quite significant. The temperature fluctuated between approximately 32.79°C and 33.39°C, with noticeable rise in certain years like 2013 and 2014, where the maximum temperature rise sharply. Despite occasional spikes, the long-term trend implies a heating up pattern over the study period. (Fig. 4.1)

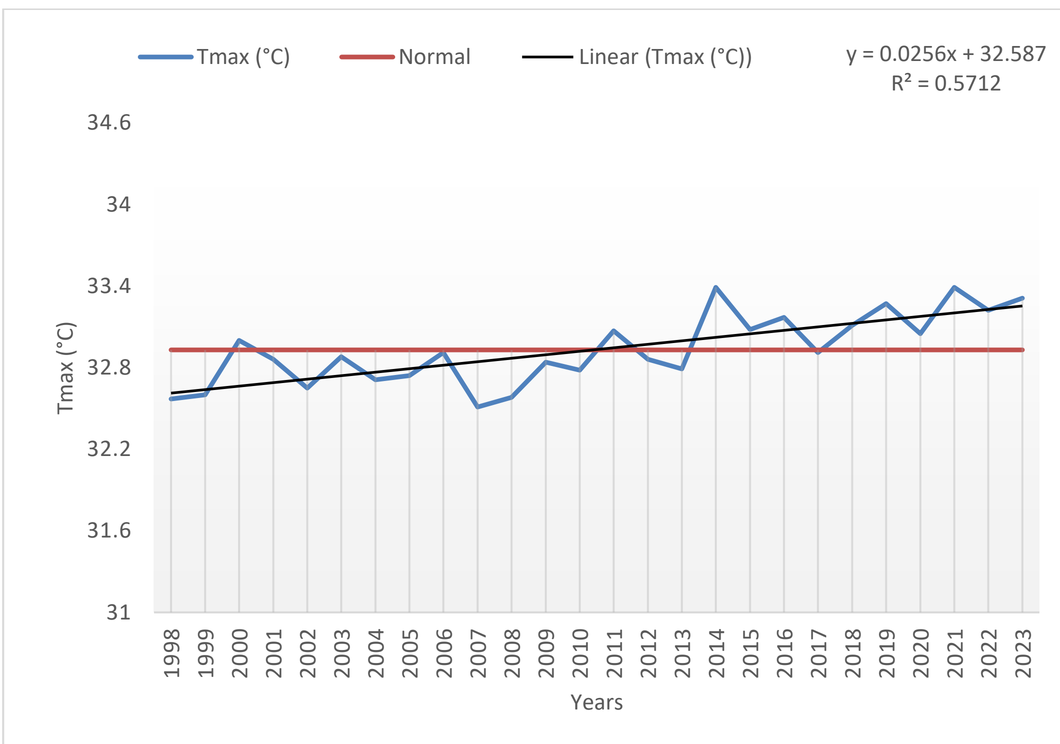

Fig. 4.1 Annual trend of maximum temperature at Eastern Plain Zone during 1998-2023

Minimum Temperature

Fig.4.2 shows the trend of minimum temperature (Tmin) from 1998 to 2023. The blue line represents the annual fluctuations in Tmin, the orange line indicates the normal line while the black line indicates the linear trend. Over the observed period, the minimum temperature shows a very slight decreasing trend, as reflected by the positive but very small slope (-0.0063) of the trend line. However, the R^2 value is extremely low (0.0126), suggesting almost no meaningful relationship or consistent trend over time. The Tmin values mostly fluctuated between 19.5°C and 20.56°C, with some noticeable dips around 2012 and 2019. Despite short-term variations, the overall minimum temperature has remained relatively stable over the years.

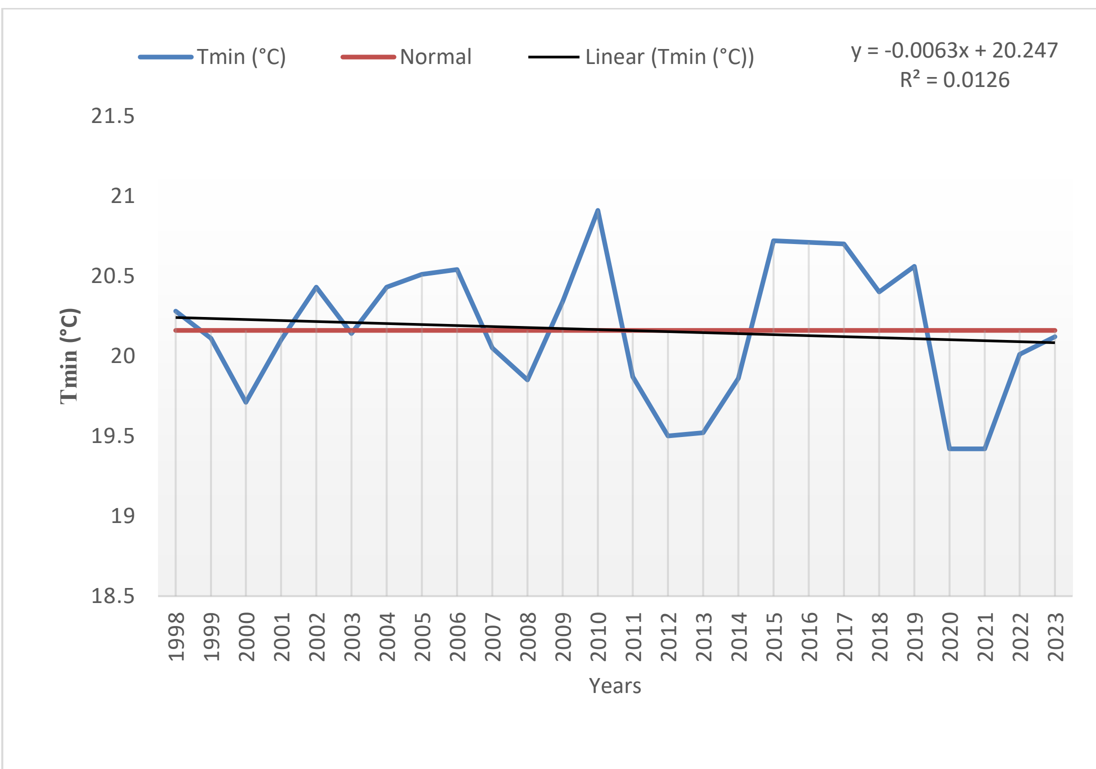

Fig. 4.2 Annual trend of minimum temperature at Eastern Plain Zone during 1998-2023

Rainfall

The graph presents the trend of annual rainfall sums from 1998 to 2023. The blue line shows the year-to-year variations in total rainfall; the orange line indicates the normal line while the black line indicates the linear trend over the period. The slope of the trend line (6.1233) suggests a slight increase in rainfall over time, although the R^2 value of 0.0636 indicates a very weak correlation. Rainfall amounts fluctuated significantly, ranging from around 600 mm to nearly 1400 mm, with notable peaks observed around 2008 and 2021. Despite considerable inter annual variability, the overall pattern points to a marginal increase in rainfall amounts during the study period. (Fig.4.3)

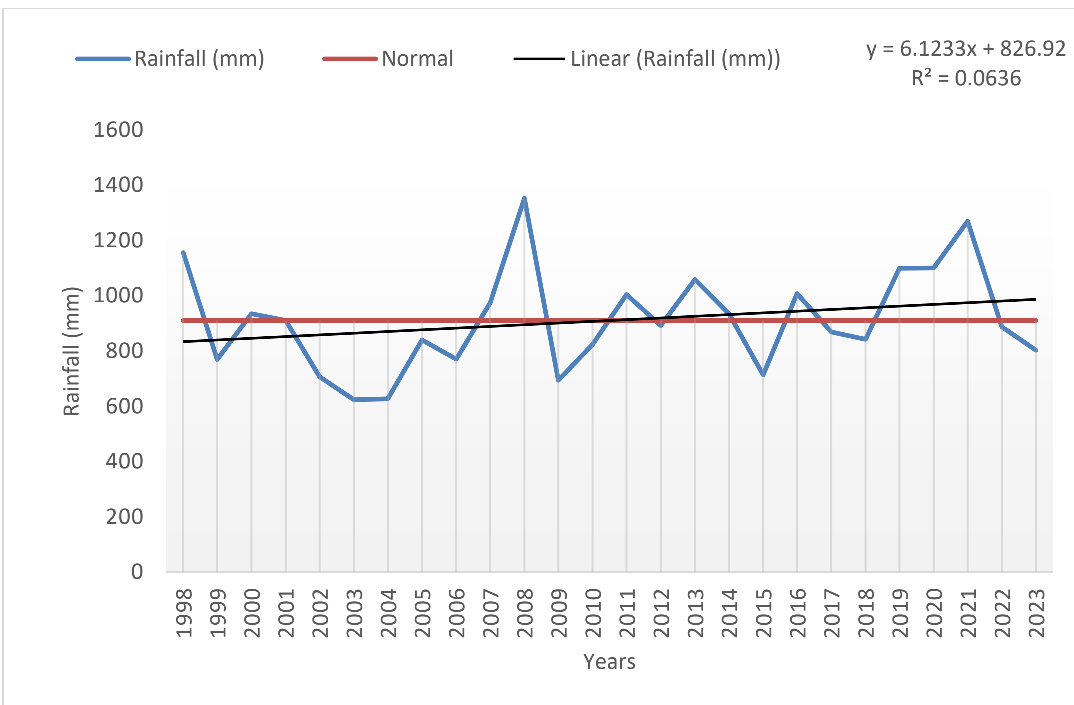

Fig. 4.3 Annual trend of rainfall at Eastern Plain Zone during 1998-2023

4.2.5 Trend analysis of North Eastern Plain Zone during 1998-2023

Maximum Temperature

Fig. 4.4 depicts the trend of maximum temperature (Tmax) from 1998 to 2023. The blue line shows the annual fluctuations in Tmax, the orange line indicates the normal line and the black line represents the linear trend. Over the study period, Tmax shows a clear increasing trend, as indicated by the positive slope (0.0086) of the trend line. The R^2 value of 0.009 suggests a very weak correlation, meaning that the upward trend is not consistent over time. Tmax values varied between approximately 30.5°C and 33.3°C, with higher temperatures recorded in the early years of the century and a gradual decline toward more recent years. This pattern indicates a notable rising up of maximum temperature until 2018 and a noticeable cooling trend up to 2023. Overall, it shows a slight increasing trend across the observed period.

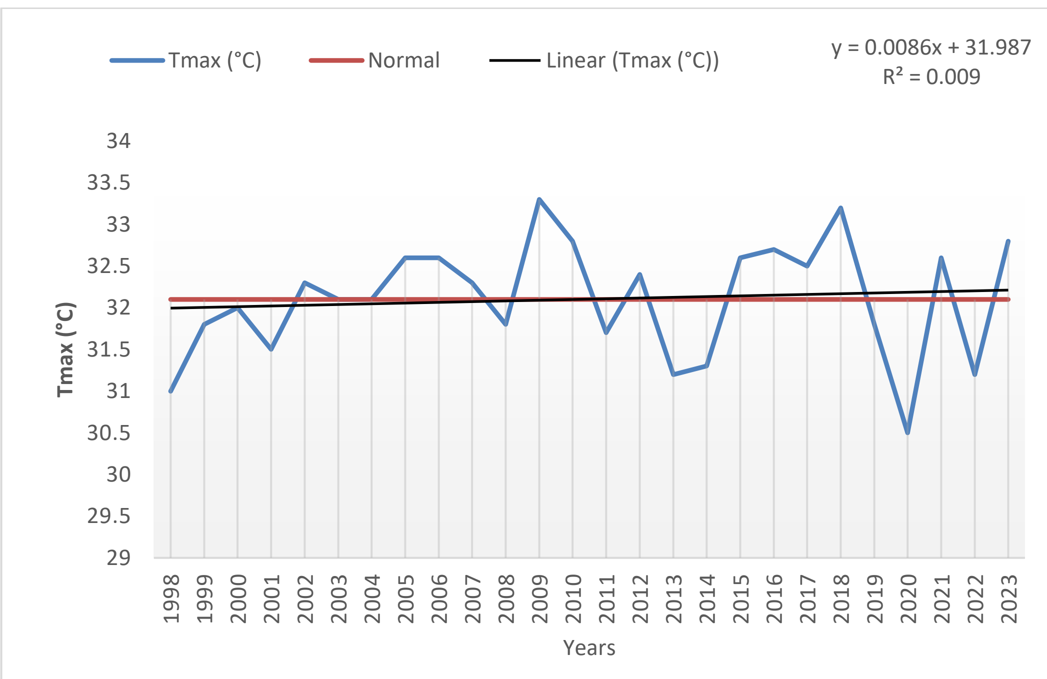

Fig. 4.4 Annual trend of maximum temperature at North Eastern Plain Zone during 1998-2023

Minimum Temperature

The graph illustrates the trend of minimum temperature (Tmin) from 1998 to 2023. The blue line represents the year-to-year variations, the orange line indicates the normal line while the black line shows the linear trend. Over the studied period, there is a slight decreasing trend in minimum temperatures, as indicated by the negative slope (-0.0166) of the trend line. The R^2 value of 0.1135 points to a weak correlation, suggesting that while the overall trend is downward, annual variations are quite noticeable. The Tmin values generally fluctuated between 19.22°C and 20.8°C. Although there are some peaks and dips, the general pattern indicates a mild cooling trend in minimum temperatures across the observed years. (Fig. 4.5)

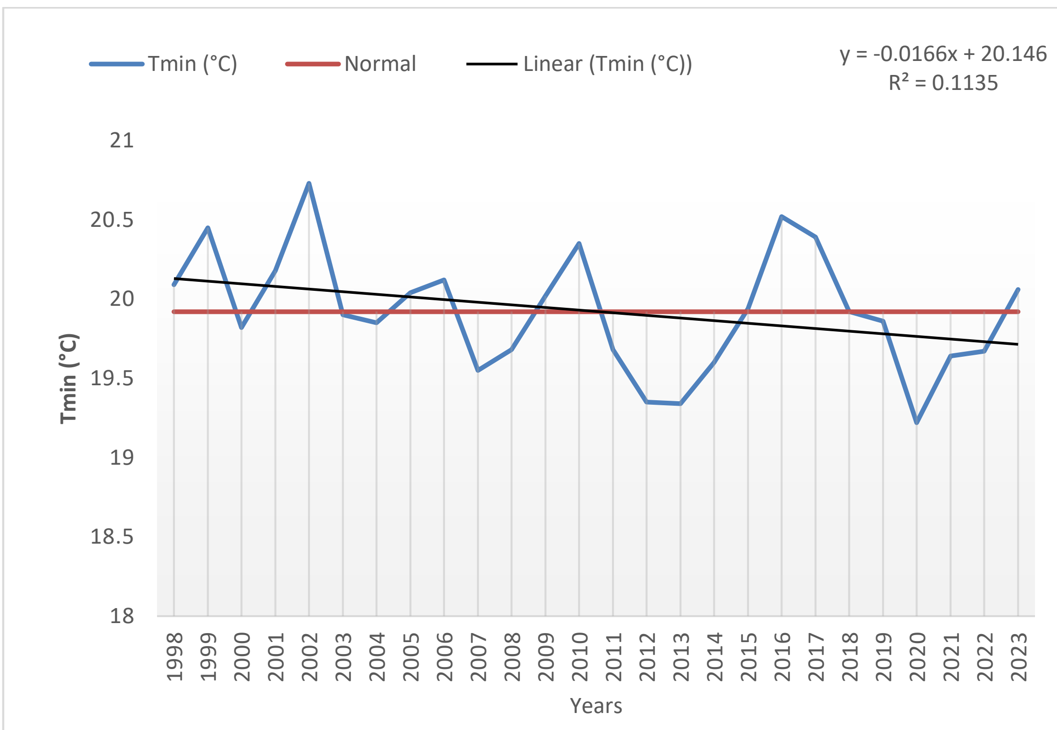

Fig. 4.5 Annual trend of minimum temperature at North Eastern Plain Zone during 1998-2023

Rainfall

The graph shows the annual rainfall sum from 1998 to 2023. The blue line represents the yearly variation; the orange line indicates the normal line while the black line illustrates the overall linear trend. Over the period, rainfall shows an **increasing trend**, with a positive slope of **31.988**, indicating that on average, rainfall has been rising each year. The R^2 value of **0.5561** suggests a moderate to strong correlation, meaning the trendline reasonably fits the data. Annual rainfall amounts have a large variation, ranging from 600 mm to over 2000 mm. Despite some fluctuations, the overall pattern highlights a noticeable increase in total rainfall over the study period. (Fig. 4.6)

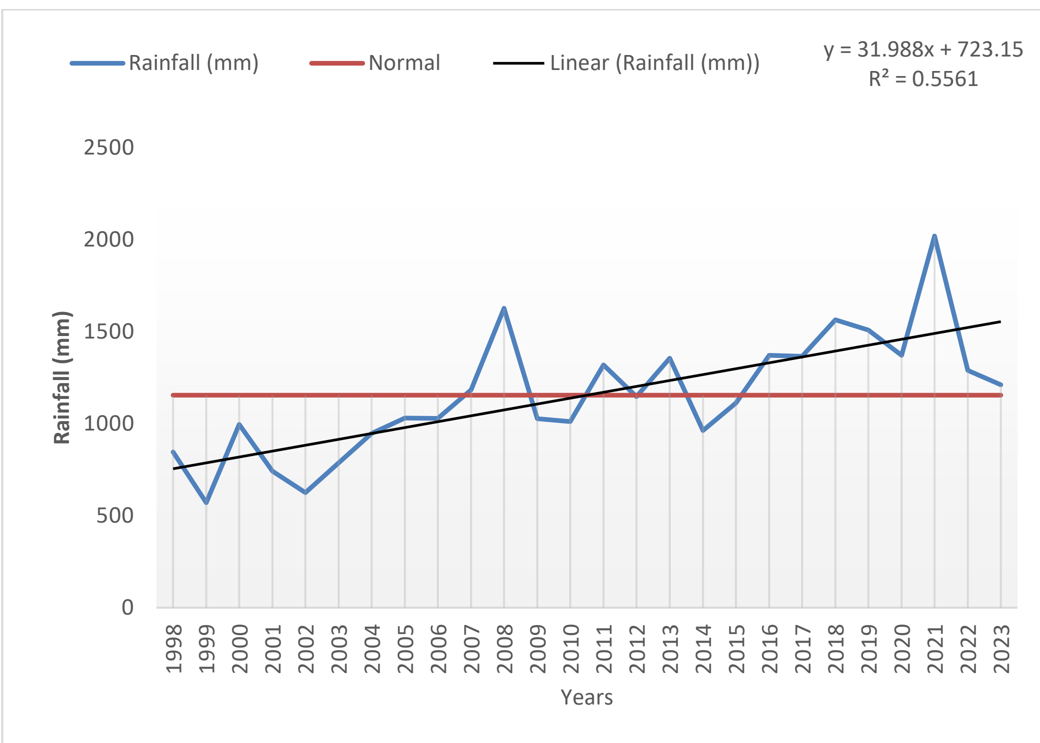

Fig. 4.6 Annual trend of rainfall at North Eastern Plain Zone during 1998-2023

4.2.6 Trend analysis of Vindhyan Zone during 1998-2023

Maximum Temperature

The graph illustrates the trend of maximum temperatures (Tmax) from 1998 to 2023. The blue line shows the year-to-year variation, the orange line indicates the normal line and the black line represents the linear trend. Overall, the trend line has a slightly positive slope of 0.0062, suggesting a very small increase in maximum temperature over the years. However, the R^2 value is 0.003, indicating that the linear trend explains almost none of the variation in the data — meaning the Tmax values are quite scattered with no strong long-term trend. Tmax fluctuated between about 29°C and 33°C across the study period, but there is a slight increasing pattern is evident. (Fig. 4.7)

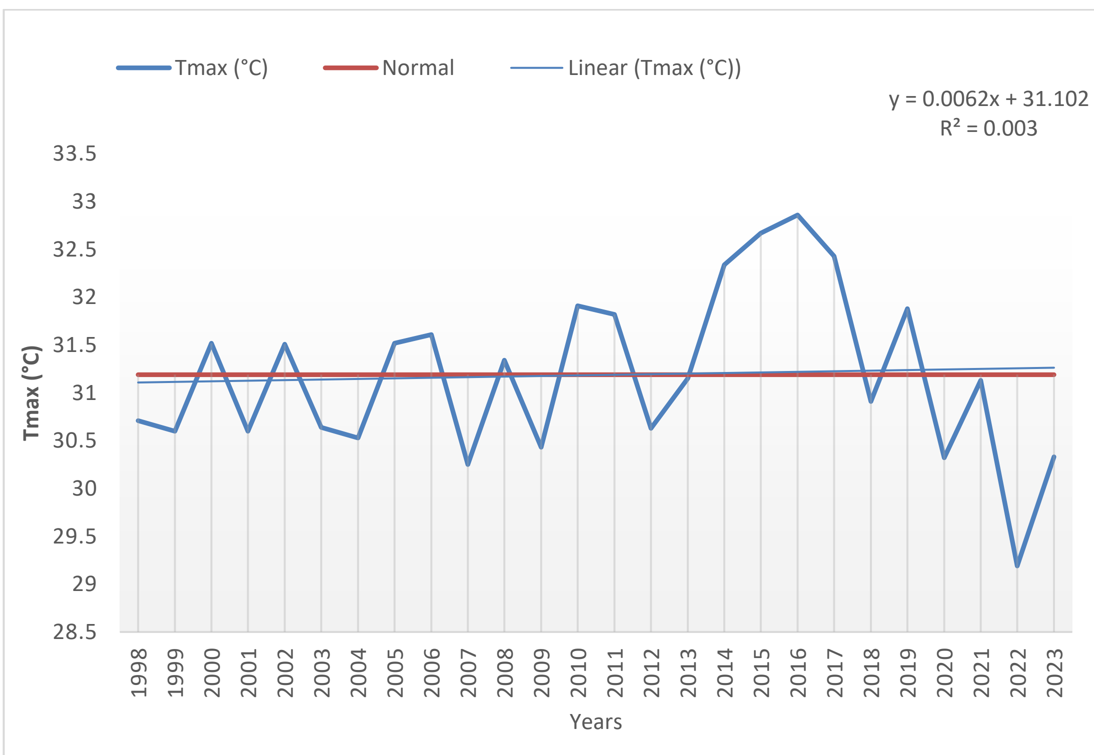

Fig. 4.7 Annual trend of maximum temperature at Vindhyan Zone during 1998-2023

Minimum Temperature

This graph shows the trend of minimum temperatures (Tmin) from 1998 to 2023. The blue line represents the annual variation; the orange line indicates the normal line while the black line shows the linear trend. The trend line has a slightly positive slope of 0.0137, indicating a very mild increase in minimum temperature over time. However, the R^2 value is only 0.0178, meaning the trend explains less than 2% of the variation — in other words, the year-to-year Tmin values are quite scattered without a strong trend. Minimum temperatures ranged mostly between 17°C and 20°C across the years. (Fig. 4.8)

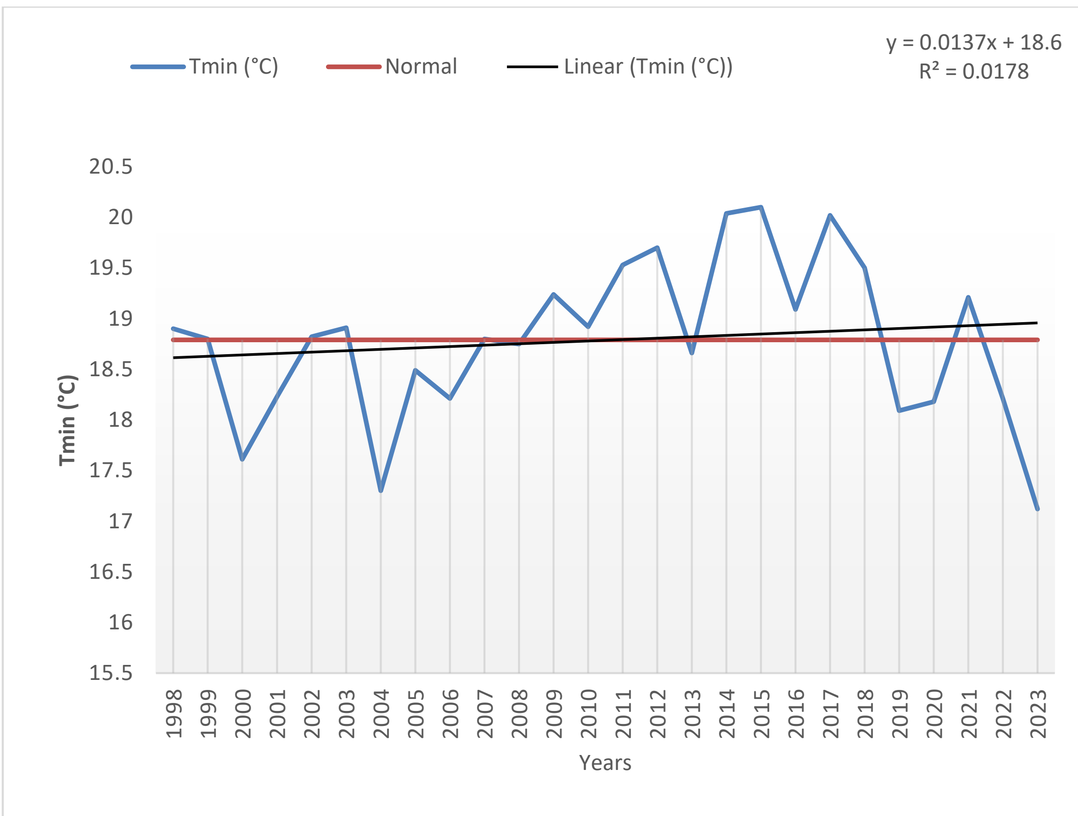

Fig. 4.8 Annual trend of minimum temperature at Vindhyan Zone during 1998-2023

Rainfall

The graph shows the annual rainfall sum from 1998 to 2023. The blue line represents the yearly variation; the orange line indicates the normal line while the black line illustrates the overall linear trend. Over the period, rainfall shows an **increasing trend**, with a positive slope of 0.5752, indicating that on average, rainfall has been rising each year. The R^2 value of 0.001 suggests a moderate to strong correlation, meaning the trend line reasonably fits the data. Annual rainfall amounts varied widely, ranging from about 800 mm to over 1400 mm. Despite some fluctuations, the overall pattern highlights a noticeable increase in total rainfall over the study period. (Fig. 4.6)

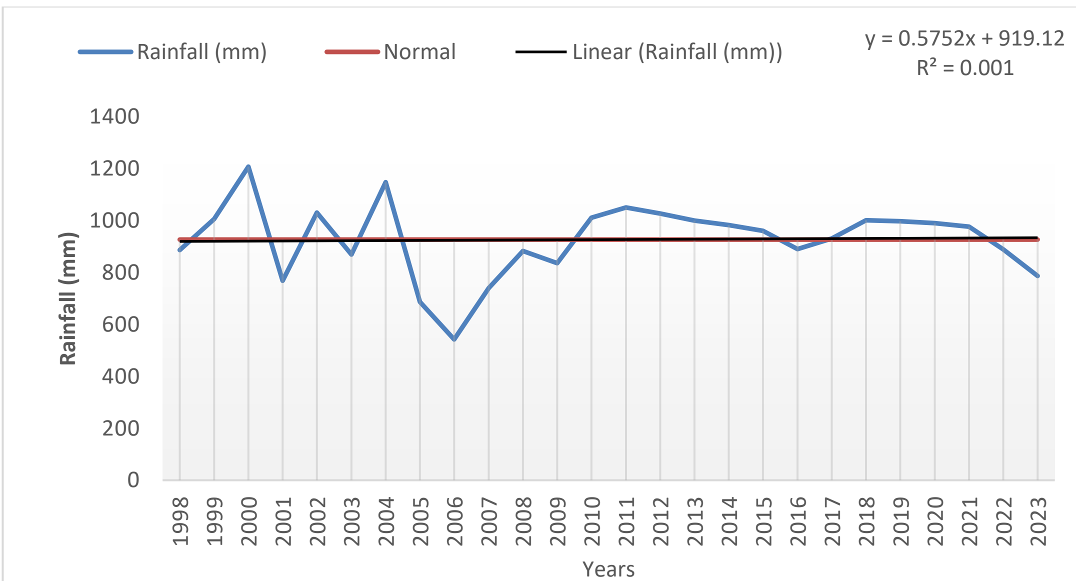

Fig. 4.9 Annual trend of Rainfall at Vindhyan Zone during 1998-2023

Bhutiyani *et al.* (2007) found increasing trend in maximum, minimum, mean and diurnal temperature range over the Northwestern Himalayan region during the 20th century. Frequency of occurrence of hot days and hot nights showed widespread increasing trend, whereas that of cold days and cold nights showed widespread decreasing trend during the period 1970–2005 over India as a whole and seven homogeneous regions. The frequency of occurrence of hot days was found to have significantly increased over the east coast, west coast and interior peninsula, whereas that of cold days showed significant decreasing trend over Western Himalaya and the west coast. The three regions, east coast, west coast and northwest, showed significant increasing trend in the frequency of hot nights.

4.3 To study the impacts of weather parameters on production of major crops in Eastern Uttar Pradesh

The correlation analysis between weather parameters and rice production in Eastern Plain Zone reveals important insights. Maximum temperature (Tmax) has a moderate positive correlation (+0.30) with rice yield, suggesting that a slight increase in daytime temperatures may benefit rice growth, possibly by accelerating physiological processes. However, minimum temperature (Tmin) shows a strong negative correlation (-0.81), indicating that higher night time temperatures have a severely detrimental effect on rice production, potentially due to increased respiration rates and stress on the plants. Rainfall presents a weak negative correlation (-0.11), suggesting that variations in rainfall alone have a relatively minor and slightly adverse effect on rice yields in the region. Overall, the results highlight that minimum temperature plays a critical role in determining rice productivity in Eastern Plain Zone. (Table 4.3.1)

Table 4.4: Inter relationship between Production of rice and maximum temperature, minimum temperature & rainfall of Eastern Plain Zone during 1998-2023.

Parameters	Production (tones)
Tmax	0.30*
Tmin	-0.81**
Rainfall	-0.10*

*** Significance of r<0.444 at 5%, **significance of r<0.561 at 1%.**

The correlation analysis between weather parameters and rice production in Eastern Plain Zone reveals significant relationships. Maximum temperature (Tmax) has a strong positive correlation (+0.697) with rice yield, indicating that higher daytime temperatures within an optimal range favorably influence rice growth and productivity. In contrast, minimum temperature (Tmin) exhibits a moderate negative correlation (-0.613), suggesting that higher nighttime temperatures negatively affect rice production, likely due to increased plant respiration and stress during the night. Similarly, rainfall shows a moderate negative correlation (-0.537) with rice yield, implying that excessive or poorly distributed rainfall may adversely impact crop development, possibly through waterlogging or increased disease pressure. These findings highlight the critical influence of temperature and rainfall patterns on the rice production system in Eastern Plain Zone. (Table 4.3.2)

Table 4.5 Inter relationship between Production of wheat and maximum temperature, minimum temperature & rainfall of Eastern Plain Zone during 1998-2023.

Parameters	Production (tonnes)
Tmax	0.697**
Tmin	-0.613**
Rainfall	-0.537*

*** Significance of r<0.444 at 5%, **significance of r<0.561 at 1%.**

The correlation analysis for rice crop production in the North Eastern Plain Zone region shows distinct relationships with key weather parameters. Maximum temperature (Tmax) exhibits a moderate positive correlation (+0.559) with rice production, suggesting that higher daytime temperatures within an optimal range may enhance rice growth and yield. Conversely, minimum temperature (Tmin) has a strong negative correlation (-0.783), indicating that lower night-time temperatures can significantly reduce rice production, possibly due to stress on the crop during critical growth stages. Rainfall shows a weak negative correlation (-0.129) with rice production, implying that excess or poorly distributed rainfall might slightly hinder crop yields. Overall, the data suggests that maintaining favorable maximum temperatures while avoiding very low minimum temperatures is crucial for maximizing rice production in North Eastern Plain Zone. (Table 4.3.3).

Table 4.6 Inter relationship between Production of rice and maximum temperature, minimum temperature & rainfall of North Eastern Plain Zone during 1998-2023.

Parameters	Production (tonnes)
Tmax.	0.559*
Tmin.	-0.783**
Rainfall	-0.129*

*** Significance of r<0.444 at 5%, **significance of r<0.561 at 1%.**

The correlation analysis of wheat crop production in the North Eastern Plain Zone region reveals clear patterns in how weather parameters impact yields. Maximum temperature (Tmax) shows a strong positive correlation (+0.770) with wheat production, indicating that higher daytime temperatures, when within an optimal range, can promote better crop development and maturation. In contrast, minimum temperature (Tmin) has a strong negative correlation (-0.727), suggesting that lower night-time temperatures may negatively affect wheat growth, possibly leading to delayed maturity or cold stress during critical growth stages. Rainfall displays a moderate negative correlation (-0.496), implying that excessive or poorly distributed rainfall could harm wheat yields, likely due to issues like waterlogging, increased disease pressure, or nutrient leaching. Overall, the results emphasize the importance of warm, stable daytime temperatures and careful water management for achieving high wheat production in North Eastern Plain Zone. (Table 4.3.4)

Table 4.7 Inter relationship between Production of wheat and maximum temperature, minimum temperature & rainfall of North Eastern Plain Zone during 1998-2023.

Parameters	Production (tonnes)
Tmax.	0.770**
Tmin.	-0.727**
Rainfall	-0.496*

*** Significance of r<0.444 at 5%, **significance of r<0.561 at 1%.**

The correlation analysis for rice crop production in the Vindhyan Zone region shows relatively weak relationships with the key weather parameters. Maximum temperature (Tmax) has a low positive correlation (+0.32) with rice production, suggesting a slight benefit from higher daytime temperatures, but the influence is not very strong. Minimum temperature (Tmin) shows a very weak negative correlation (-0.03), indicating almost no impact of night-time temperatures on rice yield. Similarly, rainfall exhibits a very weak positive correlation (+0.02), implying that variations in rainfall patterns have minimal direct effect on rice production in this region. Overall, the findings suggest that in Vindhyan Zone, rice production is less sensitive to changes in temperature and rainfall compared to other regions, possibly due to better adaptation practices, irrigation facilities, or the naturally stable local climate. (Table 4.3.5)

Table 4.8 Inter relationship between Production of rice and maximum temperature, minimum temperature & rainfall of Vindhyan Zone during 1998-2023.

Parameters	Production (tonnes)
Tmax.	0.311*
Tmin.	-0.028**
Rainfall	0.018*

*** Significance of r<0.444 at 5%, **significance of r<0.561 at 1%.**

The correlation analysis for wheat crop production in the Vindhyan Zone region highlights moderate relationships with weather factors. Maximum temperature (Tmax) shows a moderate positive correlation (+0.414) with wheat production, suggesting that higher daytime temperatures generally support better wheat growth and yield, as long as they remain within the crop's tolerance range. Minimum temperature (Tmin) also exhibits a weak positive correlation (+0.146), indicating that slightly warmer night-time temperatures have a minor beneficial effect on wheat yields. Rainfall shows a weak negative correlation (-0.174), suggesting that higher rainfall might slightly reduce wheat production, potentially due to issues like excess soil moisture, disease development, or delayed harvesting. Overall, in Vindhyan Zone, wheat production appears to favor moderate warmth and controlled rainfall conditions for optimal growth. (Table 4.3.6)

Table 4.9 Inter relationship between Production of wheat and maximum temperature, minimum temperature & rainfall of Vindhyan Zone during 1998-2023.

Parameters	Production (tonnes)
Tmax.	0.414**
Tmin.	0.146*
Rainfall	-0.174**

*** Significance of r<0.444 at 5%, **significance of r<0.561 at 1%.**

As indicated by **Bewket (2009),** although the correlation coefficients may not be statistically significantly, it should be noted that any form of correlation between rainfall and crop production is indicative of the fact that farmers are vulnerable. Farmers therefore have to adopt the best possible mechanisms to mitigate the effects of rainfall uncertainty/variability. However, as observed by **Bezabih *et al.* (2011),** some uncertainties will still arise if farmers decide to change crop production strategies in response to rainfall variability by adopting techniques such as using new crop varieties, new agronomic practices, changing their planting dates, and adapting their plots and cultivation methods to new crops.

4.4 To identify the climatic constrains of the Eastern Uttar Pradesh.

4.4.1 Temperature (maximum and minimum):

Subtropical climate prevails in eastern part of the state, because of seasonal variations; it encounters a number of climatic barriers that affect agriculture as well as the health and living standard of the local population. The summer season of the region (March to June) is very hot with average maximum temperature ranging from 38–42°C and maximum temperature going up to 45°C during peak summer months, i.e. May and June. Minimum temperatures in these days will be around 26°. The winter, on the other hand, is from December to February is chilly with maximum average temperature while the minimums hovers between 22°C–25°C and a minimum of 5°C though sometime it even can go down to 2°C during the cold waves. The average daily maximum is about 32°C with the average minimum being 18°C.

Minimum temperature showed a strong negative correlation for production of rice in eastern plain zone and North Eastern plain zone districts and a very weak negative correlation in Vindhyan zone district. Minimum temperature showed a strong negative correlation for production of wheat in eastern plain zone and North Eastern plain zone districts and a very weak negative correlation in Vindhyan zone district.

For rice production, eastern plain zone, North Eastern plain zone, Vindhyan zone districts showed a moderate positive correlation with maximum temperature (Tmax). In case of wheat production, eastern plain zone, North Eastern plain zone, Vindhyan zone districts showed a strong positive correlation with maximum temperature (Tmax).

4.4.2 Rainfall:

Rainfall in Eastern Uttar Pradesh is highly seasonal, with an average annual precipitation between 900 mm and 1,200 mm, most of which is received during the southwest monsoon from June to September. July and August are the wettest months, each contributing heavily to the total rainfall, while the post-monsoon and winter months remain largely dry. The region typically records about 49 to 55 rainy days per year. Humidity levels are high during the monsoon, often exceeding 70%, but during peak summer months, humidity drops below 25%, intensifying the dry heat. Furthermore, the area frequently experiences "Loo" winds — hot, dry, and dusty winds during late spring and early summer, exacerbating drought-like conditions. These climatic extremes, particularly erratic rainfall distribution, high temperatures, and intense dry spells, pose significant constraints on agriculture, water resources, and overall rural livelihoods in Eastern Uttar Pradesh.

Rainfall shows an increasing trend, especially during the monsoon season, though with significant year-to-year variability. Production of rice in eastern plain zone, North Eastern plain zone districts showed a weak negative correlation with rainfall and Vindhyan zone showed an insignificant positive correlation. For wheat production, eastern plain zone, North Eastern plain zone, Vindhyan zone districts showed a moderately negative correlation with rainfall.

Chapter - V

SUMMARY AND CONCLUSION

The results of present study entitled **“Agro-climatic characterization of the Eastern Uttar Pradesh”** presented in preceding chapter have been summarized in this text. The present investigation was done with the following objectives:

1. Collection of weather data of the Eastern Uttar Pradesh.
2. Analysis of weather data of the Eastern Uttar Pradesh.
3. Study the impacts of weather parameters on production of major crops in Eastern Uttar Pradesh.
4. Identify the climatic constrains of the Eastern Uttar Pradesh.

The summarized results are as follows;

This thesis investigates the long-term weather patterns in Eastern Uttar Pradesh, focusing primarily on rainfall and temperature variations from 1998 to 2023. The weather data, sourced from the Indian Meteorological Department and Banaras Hindu University, were analyzed to understand seasonal trends, variability, and potential impacts on agricultural practices, particularly rice and wheat cultivation.

Key findings include:

1. **Climatic Trends in Eastern Plain Zone:**
    - **Temperature**: Over the study time, the maximum temperature (Tmax) exhibited slight fluctuations with a slight upward trend. The minimum temperature (Tmin) remained fairly stable with minimal downward variation.
    - **Rainfall**: Seasonal rainfall varied significantly, with the Southwest Monsoon bringing the highest rainfall. A slight increase in annual rainfall over the years was noted, but with notable inter-annual variability.

- **Seasonal Variations**: Temperatures were highest during the summer season, with the Southwest Monsoon providing significant rainfall and temperature relief. Post-monsoon and winter seasons saw reduced rainfall and cooler temperatures.

2. **Climatic Trends in North Eastern Plain Zone:**
   - **Temperature**: The region showed a noticeable rising trend in Tmax, while Tmin displayed a slight decline over the years.
   - **Rainfall**: There was a clear upward trend in total rainfall, especially during the monsoon period, which is crucial for the region's agricultural activities.
3. **Climatic Trends in Vindhyan Zone District:**
   - **Temperature**: Maximum and minimum temperatures exhibited minimal long-term trends, with no significant warming or cooling detected.
   - **Rainfall**: Rainfall patterns showed moderate fluctuations, with an overall slight increase, particularly during the monsoon season.
4. **Data Imputation and Missing Values**: A significant portion of the investigation involved the development of methods for handling missing data, where several imputation techniques were tested. Two methods were identified as particularly effective and applicable for broader use in weather data analysis.
5. **Trend Analysis**: For each plain zone, trend analysis of temperature and rainfall indicated varying patterns. EPZ and NEPZ showed a rising trend in temperature, while Vindhyan Zone displayed more stability. Rainfall generally increased over the years, particularly in North Eastern Plain Zone, while other regions showed fluctuating rainfall patterns, underlining the variability in the region's climate.
6. This section of the thesis examines the impacts of weather parameters on the production of major crops in Eastern Uttar Pradesh, focusing on rice and wheat. The analysis reveals distinct correlations between weather factors and crop yields in different districts.
7. For rice production in Eastern Plain Zone, maximum temperature (Tmax) showed a moderate positive correlation (+0.30), suggesting slight benefits from higher daytime temperatures. However, minimum temperature (Tmin) had a strong negative

correlation (-0.81), indicating that higher nighttime temperatures are detrimental to rice growth. Rainfall had a weak negative correlation (-0.11), with minor adverse effects on yield. In contrast, wheat production in Eastern Plain Zone showed a strong positive correlation (+0.697) with Tmax and a moderate negative correlation (-0.613) with Tmin, highlighting the importance of warm daytime temperatures and cooler nights for optimal wheat growth. Rainfall also showed a moderate negative correlation (-0.537), indicating that poor rainfall distribution may hinder yields.

8. In North Eastern Plain Zone, rice production displayed a moderate positive correlation (+0.559) with Tmax, but a strong negative correlation (-0.783) with Tmin, emphasizing the detrimental effect of low nighttime temperatures. Rainfall had a weak negative correlation (-0.129). Wheat production in North Eastern Plain Zone showed a strong positive correlation (+0.770) with Tmax and a strong negative correlation (-0.727) with Tmin, suggesting that warm, stable daytime temperatures are essential for high wheat yields. Rainfall had a moderate negative correlation (-0.496), pointing to the adverse effects of excess rainfall.
9. In Vindhyan Zone, the correlations between weather parameters and rice production were weak. Tmax had a low positive correlation (+0.32), Tmin had an almost negligible negative correlation (-0.03), and rainfall showed an insignificant positive correlation (+0.02), suggesting that rice production in this region is less sensitive to weather fluctuations. For wheat, Tmax showed a moderate positive correlation (+0.414) and Tmin a weak positive correlation (+0.146), while rainfall had a weak negative correlation (-0.174), indicating that for wheat production moderate warmth and controlled rainfall conditions are suitable.
10. Overall, the analysis highlights that temperature, especially nighttime temperature, plays aa vital role in determining crop yields in the region, with rainfall patterns also significantly affecting productivity, particularly for wheat.

Conclusions:

On the basis of the above results, it may be concluded that,

The climatic trends across Eastern Plain Zone, North Eastern Plain Zone, and Vindhyan Zone reveal a general rising trend in maximum temperatures for Eastern Plain Zone and North Eastern Plain Zone, while Vindhyan Zone remains relatively stable. Rainfall shows an increasing trend, especially during the monsoon season, though with significant year-to-year variability.

Effective data imputation techniques were developed to address missing weather data, ensuring more accurate analysis. Trend analysis indicates that temperature and rainfall patterns vary across zones, influencing agricultural productivity. Crop-weather correlation analysis shows that minimum temperature critically impacts crop yields, particularly rice, across the region, with higher night time temperatures being detrimental. Maximum temperatures generally favor crop growth when within an optimal range, and excess or poorly distributed rainfall tends to negatively affect yields, especially for wheat. Overall, temperature management, especially of nighttime temperatures, and proper management of water are very important for enhancing rice and wheat production in Eastern Uttar Pradesh.

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APPENDICES

Annual average maximum temperature (°C) of Eastern Plain Zone.

Years	Temperature (°C)
1998	32.57
1999	32.60
2000	33.00
2001	32.86
2002	32.65
2003	32.88
2004	32.71
2005	32.74
2006	32.91
2007	32.51
2008	32.58
2009	32.84
2010	32.78
2011	33.07
2012	32.86
2013	32.79
2014	33.39
2015	33.08
2016	33.17
2017	32.91
2018	33.11
2019	33.27
2020	33.05
2021	33.39
2022	33.22
2023	33.31

Annual average minimum temperature (°C) of Eastern Plain Zone.

Years	Temperature (°C)
1998	20.28
1999	20.11
2000	19.71
2001	20.1
2002	20.43
2003	20.14
2004	20.43
2005	20.51
2006	20.54
2007	20.05
2008	19.85
2009	20.34
2010	20.91
2011	19.87
2012	19.5
2013	19.52
2014	19.86
2015	20.72
2016	20.71
2017	20.7
2018	20.4
2019	20.56
2020	19.42
2021	19.42
2022	20.01
2023	20.12

Annual average rainfall (mm) of Eastern Plain Zone.

Years	Rainfall (mm)
1998	1155.79
1999	769.1
2000	934.37
2001	910.19
2002	706.4
2003	623.1
2004	626.5
2005	839.68
2006	769.95
2007	973.78
2008	1351.66
2009	692.91
2010	823.61
2011	1003.51
2012	891.29
2013	1058.5
2014	934.45
2015	713.63
2016	1006.81
2017	867.65
2018	841.05
2019	1098.19
2020	1099.37
2021	1269.2
2022	886.4
2023	802.06

Annual average maximum temperature (°C) of North Eastern Plain Zone.

Years	Temperature (°C)
1998	31
1999	31.8
2000	32
2001	31.5
2002	32.3
2003	32.1
2004	32.1
2005	32.6
2006	32.6
2007	32.3
2008	31.8
2009	33.3
2010	32.8
2011	31.7
2012	32.4
2013	31.2
2014	31.3
2015	32.6
2016	32.7
2017	32.5
2018	33.2
2019	31.8
2020	30.5
2021	32.6
2022	31.2
2023	32.8

Annual average minimum temperature (°C) of North Eastern Plain Zone.

Year	Temperature (°C)
1998	20.09
1999	20.45
2000	19.82
2001	20.18
2002	20.73
2003	19.9
2004	19.85
2005	20.04
2006	20.12
2007	19.55
2008	19.68
2009	20.02
2010	20.35
2011	19.68
2012	19.35
2013	19.34
2014	19.6
2015	19.94
2016	20.52
2017	20.39
2018	19.92
2019	19.86
2020	19.22
2021	19.64
2022	19.67
2023	20.06

Annual average rainfall (mm) of North Eastern Plain Zone.

Year	Rainfall (mm)
1998	845.78
1999	570.67
2000	996.39
2001	742.64
2002	624.97
2003	787.97
2004	946.91
2005	1030.02
2006	1029.65
2007	1183.35
2008	1627.21
2009	1026.97
2010	1012
2011	1319.48
2012	1147.67
2013	1356.42
2014	963.59
2015	1113.37
2016	1371.07
2017	1365.72
2018	1565.04
2019	1508.35
2020	1371.43
2021	2020.49
2022	1290.7
2023	1211.82

Annual average maximum temperature (°C) of Vindhyan Zone.

Years	Temperature (°C)
1998	30.71
1999	30.6
2000	31.52
2001	30.6
2002	31.51
2003	30.64
2004	30.53
2005	31.52
2006	31.61
2007	30.25
2008	31.34
2009	30.43
2010	31.91
2011	31.82
2012	30.63
2013	31.15
2014	32.34
2015	32.67
2016	32.86
2017	32.43
2018	30.91
2019	31.88
2020	30.32
2021	31.13
2022	29.19
2023	30.33

Annual average minimum temperature (°C) of Vindhyan Zone.

Years	Temperature (°C)
1998	18.9
1999	18.8
2000	17.61
2001	18.23
2002	18.82
2003	18.91
2004	17.3
2005	18.49
2006	18.21
2007	18.8
2008	18.75
2009	19.24
2010	18.92
2011	19.53
2012	19.7
2013	18.66
2014	20.04
2015	20.1
2016	19.09
2017	20.02
2018	19.5
2019	18.09
2020	18.18
2021	19.21
2022	18.21
2023	17.12

Annual average rainfall (mm) of Vindhyan Zone.

Years	Rainfall (mm)
1998	886.5
1999	1005.9
2000	1207.6
2001	768.01
2002	1030.7
2003	869.4
2004	1148.4
2005	687.3
2006	542.35
2007	739.4
2008	883
2009	836
2010	1011.2
2011	1050.2
2012	1026.6
2013	1000.31
2014	983
2015	960
2016	890
2017	930.9
2018	1001.1
2019	998.1
2020	990.2
2021	977.1
2022	888.9
2023	786.8

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Abstract

This study investigates climatic trends and their impacts on the production of major crops—rice and wheat—in Eastern Uttar Pradesh, focusing on the Eastern Plain Zone (EPZ), North Eastern Plain Zone (NEPZ), and Vindhyan Zone (VZ). Analysis of temperature data revealed a slight upward trend in maximum temperatures in EPZ and NEPZ, while minimum temperatures remained stable or declined slightly. In VZ, both temperature extremes showed minimal long-term variation. Rainfall trends displayed moderate variability across all zones, with an increasing trend during the Southwest Monsoon, a vital period for agricultural activity. Missing climate data were addressed using multiple imputation techniques, from which two methods emerged as particularly effective for improving dataset accuracy. The study employed correlation analysis to understand how climatic variables influence crop yields. In EPZ, rice yield exhibited a moderate positive correlation with maximum temperature and a strong negative correlation with minimum temperature, while wheat yield was strongly positively associated with maximum temperature. In NEPZ, both crops were highly responsive to temperature fluctuations, and excess rainfall moderately reduced yields. In VZ, rice production was less sensitive to weather, whereas wheat showed moderate positive correlation with maximum temperature. Overall, the results indicate that minimum temperatures, particularly night-time lows, play a crucial role in determining crop yields. Additionally, rainfall variability, especially during critical growth phases, significantly affects wheat production. The findings underscore the need for climate-resilient agricultural practices focusing on temperature regulation and efficient water management to sustain crop productivity amid changing climatic conditions.

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सारांश

यह शोध पूर्वी उत्तर प्रदेश (पूर्वांचल) में मुख्य फसलों – धान और गेहूं – के उत्पादन पर जलवायु प्रवृत्तियों के प्रभाव का विश्लेषण करता है, जिसमें पूर्वांचल क्षेत्र (EPZ), पूर्वोत्तर मैदान क्षेत्र (NEPZ), और विन्ध्यन क्षेत्र (VZ) पर विशेष ध्यान दिया गया है। तापमान प्रवृत्तियों के विश्लेषण से पता चला कि EPZ और NEPZ में अधिकतम तापमान में धीमी वृद्धि की प्रवृत्ति रही, जबकि न्यूनतम तापमान अपेक्षाकृत स्थिर रहा या थोड़ी कमी आई। VZ में अधिकतम और न्यूनतम तापमान में दीर्घकालीन प्रवृत्ति न्यूनतम रही। वर्षा के पैटर्न ने मध्यम स्तर की परिवर्तनशीलता दिखाई, विशेषकर दक्षिण-पश्चिम मानसून के दौरान वर्षा में समग्र रूप से वृद्धि देखी गई, जो कृषि उत्पादन के लिए अत्यंत आवश्यक समय होता है। मौसम संबंधी अपूर्ण आँकड़ों को अनेक इम्प्यूटेशन तकनीकों के प्रयोग द्वारा हल किया गया, जिससे जलवायु डेटा की सटीकता बढ़ाने के लिए दो प्रभावी विधियाँ सामने आईं। प्रवृत्ति विश्लेषण से यह ज्ञात हुआ कि विशेषकर NEPZ में वर्षा समय के साथ धीरे-धीरे बढ़ती रही, जबकि तापमान की प्रवृत्तियाँ जिलों में एकसमान नहीं थीं। फसल उत्पादकता पर मौसमीय घटकों के प्रभाव का सहसंबंध विश्लेषण के माध्यम से मूल्यांकन किया गया। EPZ में धान की उपज का अधिकतम तापमान से मध्यम सकारात्मक और न्यूनतम तापमान से उच्च नकारात्मक सहसंबंध था, जबकि गेहूं की उपज अधिकतम तापमान से उच्च सकारात्मक सहसंबंध में थी। NEPZ में गेहूं और धान दोनों की उपज पर अधिकतम एवं न्यूनतम तापमान का गहरा प्रभाव था, जबकि अत्यधिक वर्षा का मध्यम नकारात्मक प्रभाव देखा गया। VZ में धान का उत्पादन मौसम के प्रति कम संवेदनशील था, जबकि गेहूं उत्पादन का अधिकतम तापमान से मध्यम सकारात्मक संबंध था। कुल निष्कर्ष यह बताते हैं कि पूर्वी उत्तर प्रदेश में न्यूनतम तापमान, विशेषकर रात्रिकालीन तापमान, फसलों की उपज को महत्वपूर्ण रूप से प्रभावित करता है। वर्षा की परिवर्तनशीलता भी, विशेष रूप से गेहूं के लिए, एक महत्वपूर्ण कारक है। यह शोध जलवायु-लचीली कृषि की आवश्यकता को उजागर करता है, जिसमें तापमान चरम सीमाओं का नियंत्रण और जल का कुशल उपयोग आवश्यक होगा ताकि परिवर्तनीय जलवायु परिस्थितियों में भी फसल उत्पादन बनाए रखा जा सके।

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