EXTREME WEATHER EVENTS ANALYSIS OF EASTERN UTTAR PRADESH

Thesis

Submitted to the

A.N.D. University of Agriculture & Technology
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By

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Id. NO. A-14695/23

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Science (Agriculture)

in

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CERTIFICATE - I

This is to certify that the thesis entitled "**Extreme weather events analysis of Eastern Uttar Pradesh**" submitted in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)** with the major in **Agricultural Meteorology** of the **College of Agriculture,** Post Graduate Studies. Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya is a record of *bonafide* research carried out by **Mr. Akash Singh, Id. No. A-14695/23** 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 acknowledged.

23/7/25

Place: Kumarganj, Ayodhya
Date: 23 July, 2025

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CERTIFICATE – II

This is to certify that the thesis entitled **"Extreme weather events analysis of Eastern Uttar Pradesh"** submitted by **Mr. Akash Singh,** I'd No. **A-14695/23** to the Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya in partial fulfilment of the requirements for the degree of **'Master of Science' (Agriculture)** in the subject of **Agricultural Meteorology** has been approved by the Student's Advisory Committee after an oral examination on the same in collaboration with an External Examiner.

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CERTIFICATE-III

DECLARATION FOR ANTI-PLAGIARISM

I Akash Singh Id. No. A-14695/23 certify that the thesis entitled "**Extreme weather events analysis of Eastern Uttar Pradesh**" submitted in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture) in Agricultural Meteorology** to the College of Agriculture, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) is 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 willfully lifted up some others work, paragraph, 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

आकाश सिंह

Date: 23 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.

23/7/25

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Dean PGS

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ABBREVIATIONS USED

ABBREVIATION USED	FULL FORM
EPZ	Eastern Plain zone
NEPZ	North Eastern Plain zone
VZ	Vindhyan zone
T MAX	Maximum Temperature
T MIN	Minimum Temperature
Fig	Figure
%	Percent
/	Per
Mm	millimeter
Kg	Kilogram
°C	Degree Celsius
i.e	That is
No	Number
@	At the rate

Viz	Numely
BHU	Banaras Hindu University
ANDUA&T	Acharya Narendra Deva University of Agriculture and Technology
&	And
IMD	India Meteorology Department

CHAPTER-I

INTRODUCTION

India, being primarily an agricultural country, has an economy that is heavily dependent on weather patterns and their variability. The farming community is well aware of the influence of weather and its fluctuations on agricultural productivity. The possible impacts of climate change on the frequency and intensity of extreme weather events are a growing concern. These weather extremes can significantly affect agriculture and food security. However, their specific effects often remain unclear. This ambiguity may arise due to the complex interactions between extreme weather and other agronomic, environmental, and socio-economic factors that influence crop yields, as well as the lack of universally accepted definitions of what constitutes a weather extreme in agricultural contexts.

Climate change directly affects crop production, food security, and livelihoods. The average global temperature is projected to rise by 1.8°C to 4°C, leading to unpredictable changes in weather patterns, particularly in the intensity and distribution of rainfall and temperature. These extreme weather events contribute significantly to food insecurity, creating a precarious situation for global agriculture With limited arable land, producing enough food to meet the demands of a growing population under increasingly erratic weather conditions is a major challenge. The impacts of climate change on agriculture vary by region and latitude. For example, crop yields in lower-latitude countries are expected to decline, making them more vulnerable, while some higher-latitude regions may experience temporary yield benefits. Future temperature increases are forecasted to severely affect food production and pose a threat to sustainable development. By the end of the 21st century, global cereal production is expected to decline due to climate stress with the notable exception of millet, which is more resilient to extreme weather. Additionally, climate change is likely to intensify the frequency of erratic rainfall, strong winds, and pest outbreaks. These factors will further reduce crop yields and contribute to food shortages. It is estimated that if current trends continue, the risk of hunger could increase for approximately 170 million people by 2080. Without timely and effective climate management strategies, the situation may worsen further, threatening food systems, rural livelihoods, and global food security.

Extreme weather refers to conditions that go beyond the typical range of a region's climate, making such events rare or unusual by nature. These can be intense, abnormal, or out-of-season shifts in weather patterns that may last from just a few hours to several months. While not all extreme weather results in disasters, it often carries the potential for significant damage. What qualifies as extreme can vary between regions, depending on the local climate and preparedness. Events like hurricanes, tornadoes, or ice storms generally require specific conditions to form, and many extreme events are intensified by the interaction of multiple weather systems or additional environmental factors.

India frequently experiences several types of extreme weather events or climate irregularities due to sudden shifts in weather conditions. These include (i) cold waves, (ii) heat waves, (iii) floods, heavy rainfall, and landslides, (iv) cyclones and tidal waves, (v) droughts, and (vi) hailstorms or thunderstorms. Among these, floods and droughts are the most common, largely due to unfavorable changes in temperature and rainfall patterns. Both excessive and insufficient rainfall, as well as temperature extremes, significantly impact agricultural productivity. Rainfed farming systems are especially vulnerable because of year-to-year fluctuations in rainfall during the growing season, which can adversely affect both the quantity and quality of crop yields. When rainfall fails or natural disasters like floods and droughts occur, the results can be devastating leading to crop failures, food shortages, famine, loss of life and property, mass displacement, and a slowdown in national economic growth. Alarmingly, natural disasters cost India about 2% of its GDP and nearly 12% of central government revenue each year. According to the Intergovernmental Panel on Climate Change (IPCC), there is strong confidence that extreme weather will negatively affect food production **(Field and Barros, 2012).** Recent IPCC assessments and other research estimate a potential 10–40% decline in crop yields across India and South Asia by 2080–2100 due to rising temperatures and decreasing water availability for irrigation. For example, wheat production in India could drop by 4–5 million tons with every 1°C increase in temperature during the growing season, even after accounting for carbon fertilization, and the decline could be even greater if irrigation resources diminish further.

Climate change in India is expected to bring increased and more unpredictable rainfall, which will adversely affect the productivity of key crops like rice and wheat. However, even more crucial than long-term climate change trends is the urgent need to understand and manage the effects of climate variability and extreme weather events, which pose immediate and severe risks to agricultural output. Extreme weather events place considerable stress on plant growth and development. When such conditions surpass a plant's tolerance threshold, they can lead to serious reductions in performance and, in some cases, even result in plant death. Short-term but intense climatic disturbances like heat waves and cold waves are particularly harmful, often disrupting plant function and threatening survival. Repeated occurrences of these extremes have caused significant agricultural losses over the years, making them a notable consequence of climate change. Both very high and very low temperatures negatively impact plant productivity **(Ramakrishna *et al.,* 2013).** While extreme weather typically harms ecosystems and society causing floods, droughts, strong winds, or temperature extremes in certain regions or systems, these events may also offer benefits. For instance, the unusually warm and dry winter in the northern United States during the 1997–98 El Niño event led to major savings in energy costs ($5.6 billion), record gains in retail and housing sectors ($5 billion), and around 800 fewer winter-related deaths. On the flip side, the same event caused over $4 billion in damages and 200 fatalities in the southern and western U.S. due to storms. Similarly, some parts of Australia's northwest coast depend on infrequent tropical cyclones for most of their annual rainfall, and without these, essential systems like water storage could be at risk. This highlights the need for a broad and deep understanding not only of the past and potential future changes in extreme weather and climate, but also of their varied impacts across different human and natural systems **(Meehl *et al.,* 2000).**

Studying weather extremes in rainfed agriculture is essential for enhancing crop production and productivity, which are crucial for ensuring livelihood security. As global population pressure continues to rise, increasing employment and productivity in agriculture becomes increasingly important. Rainfed agriculture accounts for nearly 80% of global farming and is central to achieving food security. However, these rain-dependent areas often face challenges such as poverty, malnutrition, water shortages, severe land degradation, and inadequate infrastructure. To address these issues effectively, both fundamental and applied research must focus on developing sustainable rainfed farming systems tailored to the specific needs of each agro- climatic zone **(Thakur *et al*., 2014).** In many tropical regions, the frequency of droughts has increased, severely affecting agriculture particularly for small and marginal farmers. Similarly, floods have significantly disrupted food production in numerous countries. Rising global temperatures also pose a major threat to biodiversity: an estimated 20 to 30% of plant and animal species currently assessed may face a higher risk of extinction if the average global temperature increases by more than 1.5 to 2.5°C. When combined with elevated atmospheric CO_2 levels, such warming could lead to profound changes in ecosystem structure and function. This would negatively impact biodiversity, ecosystem services, and especially food supply. In lower latitudes, particularly in dry and tropical areas, even modest increases in local temperatures (1 to 2°C) are expected to reduce crop productivity.

Drought is often referred to as a "disaster in slow motion" because it develops gradually when rainfall is significantly below normal over an extended period typically a season or longer. Although it may persist for long durations, drought is generally considered a short-term climatic condition. Its severity can be intensified by factors like elevated temperatures, strong winds, and low humidity. Droughts are commonly defined either conceptually or operationally, and a global review of literature reveals nearly 150 different definitions **(Wilhite and Glantz, 1985).** According to **Bryant *et al.,* (2005),** who ranked natural hazards based on their characteristics and impacts, drought ranks highest among all hazards such as tropical cyclones, floods, and earthquakes due to its extensive duration, wide geographic coverage, and severe consequences. In the context of rainfed agriculture, rainfall is the most critical climatic factor influencing crop yields, especially in regions with minimal irrigation infrastructure. Inadequate rainfall often results in moisture stress, which significantly reduces crop productivity. This is particularly relevant for Uttar Pradesh, where rainfall patterns such as the timing of monsoon onset, periods of interruption during crop growth, and early withdrawal at the end of the season play a crucial role in determining the yields of rice and other kharif crops.

Many studies on global or regional climate change have focused on long term averages, such as annual or seasonal temperatures. Observational records show that the global mean temperature has increased by approximately 0.6 °C over the last century **(Houghton *et al.*, 2001),** with warming in daily minimum temperatures being more significant than that in maximum temperatures. Given these clear trends, it is expected that there will also be changes in extreme temperature events, such as a higher frequency of days with extremely low or extremely high temperatures. Elevated temperatures can reduce the yields of desirable crops due to increased development rates and higher respiration, which also encourages the growth of weed and pest populations. However, a shorter crop growth cycle may sometimes be beneficial, allowing crops to escape drought or frost. The use of late-maturing cultivars can also offset the effects of accelerated development in some cases. In regions where low temperatures currently limit production, global warming may extend the growing season and bring temperatures closer to optimal levels for crop assimilation. Moreover, global warming is associated with rising atmospheric CO_2 concentrations, which may enhance crop yields especially in water-limited environments. In India, year-to-year fluctuations in temperature and precipitation cause significant annual losses for farmers. Unseasonal rainfall, changes in relative humidity, and heavy dew events can alter the microclimate around crops, often leading to unexpected outbreaks of pests and diseases **(Sharma *et al*., 2013).**

Climate and its various attributes such as temperature, rainfall, humidity, and solar radiation are critical determinants of agricultural growth, development, and productivity. Changes in these climatic variables can significantly affect crop performance across different agro-ecological zones. While climate change is projected to have both positive and negative effects on crop yields, research suggests that the adverse impacts are likely to outweigh any potential benefits, particularly in vulnerable regions (IPCC, 2001).

Recent studies indicate that climate change could pose a serious threat to agricultural productivity in South Asian countries like India, where agriculture accounts for approximately 14.2% of the national GDP and is predominantly climate dependent. In India, nearly 80% of the annual rainfall occurs during the southwest monsoon season (June to September) (Government of India, 2001). Any disruption in the timing, intensity, or distribution of monsoonal rainfall can result in significant yield losses, and in some cases, total crop failure.

India has already experienced noticeable changes in climatic parameters such as temperature, relative humidity, sunshine hours, and rainfall. These shifts have raised concerns about irreversible damage to agricultural systems, particularly through reduced crop productivity, expanded pest and pathogen ranges, and reduced water availability for irrigation **(Pathak *et al.*, 2003).**

Research indicates that a 1.0°C increase in temperature could reduce paddy yields in Punjab by about 3%. Furthermore, when this warming is coupled with a 5% reduction in solar radiation, grain yield may decline by up to 9% **(Hundal and Kaur, 2007).**

The Eastern U.P which comprised of three zones such as Eastern Plain Zone (EPZ), North Eastern Plain Zone (NEPZ), and Vindhyan Zone (VZ) has great variability in extreme weather events. Extreme weather events like drought, flood, heat wave, cold wave, fog, thunder storm, dust storm, and hail storm causes considerable loss in crop productivity in the EPZ region. Use of improved climate and weather information and forecast along with efficient early warning systems contribute to the preparedness for extreme weather events to reduce loss of life and crop damage. For an instance, Providing forecasts and warnings of severe weather like extreme temperature, extreme cold, frost occurrence, and drought or flood in a timely manner contributes to preparedness. Better Agro-met. advisories helps in minimizing the impact of extreme weather events in the region. Very little work has been done on the climate extremes at regional level. Since the work on extreme weather events at micro level has not been done earlier. Hence present investigation entitled **"Extreme weather events analysis of Eastern Uttar Pradesh.** and its impacts on agriculture production" was proposed with the following **objectives;**

- To collect the historical weather data of Eastern Uttar Pradesh.
- To analysis the extreme weather event on Eastern Uttar Pradesh.
- To study about the impact of extreme weather events on major crop production.
- To identify the climatic constraints limiting the crop production.

CHAPTER-II

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the work done on the topic **"Extreme Weather Events Analysis of Eastern Uttar Pradesh"** Relevant works done on the different aspects have been collected & presented in the following text:

(1). To analysis the historical extreme weather events on Eastern Uttar Pradesh.

Chaudhary (1996) examined historical rainfall data and concluded that the districts of Raipur, Durg, Bilaspur, Balaghat, and Rajanandgaon had declining annual rainfall. This trend must be taken into consideration in future agricultural planning, and early maturing, high-yielding crop varieties must be developed and put into cultivation for successful agriculture, taking into account the weather package.

Arthur and Robert (2002) studied a long term, homogeneous set of daily maximum and minimum temperature data representing a subset of daily U.S. Historical Climatology Network Stations which used to analyze trends in extreme temperature occurrence across the contiguous United States. Time series of various lengths are analyzed with the longest spanning the period 1900-96. Trends in the annual occurrence of extreme maximum and minimum temperatures (eg values greater than the 90th, 95th, 99th percentile) are strongly influenced by high exceedences counts during drought periods in the 1930s 1950s. Peaks in exceedence trends across the country during years result in predominantly decreasing warm exceedence trends across the country during the 1930-96. This is uncharacteristic of recent years (1960-96) in which a large majority of stations show increase in warm extreme temperature exceedences.

Joshi and Rajeevan (2006) believed that an increase in the frequency and intensity of extreme precipitation events will be one of the most important effects of global warming brought on by an increase in greenhouse gases. According to their analysis, the majority of extreme rainfall indices have demonstrated notable upward trends near the west coast and in the northwest of the Peninsula. Nevertheless, two highland stations, Shimla and Mahabaleshwar, have demonstrated downward trends in certain extreme rainfall indices.

Bora *et al.* (2008) examined the daily rainfall in the Central Brahmaputra valley region of Assam for 36 years in order to look at how it changed on a weekly and monthly basis. Six years of the study period had a rainfall deficit, and six years had a surplus. The likelihood of drought occurring in July was determined to be nil. Similarly, the likelihood of drought in December was 0.053, but during the monsoon season it was 0.002 to 0.007. Additionally, the months of November, January, and February have higher odds of drought. There were roughly 40.56% dry months, 42.78% normal months, and 16.67% wet months throughout the Rabi season (October–February).Normal wet and drought weeks throughout the 36-year study were 40.71, 47.22, and 12.07%, respectively. For the maximum number of weeks, the 49th week was dry (34) and the 51st week (32). In a year, there was a 97% chance of experiencing 17 drought weeks, 15 normal weeks, and 3 wet weeks. Drought incidence was particularly common from week 1 to week 12 and week 42 to week 52. Likewise, a given year has a 3% chance of having 32 dry weeks, 26 normal weeks, and 12 rainy weeks.

Dilip Mahale *et al.* (2008) attempted to use rainfall data to assess the likelihood of monthly and annual droughts so that crops may be planned appropriately in the Dapoli region. For the Dapoli region, the typical surplus and drought months and years have been established for the years 1973–2005. Between 1973 and 2005, a total of 26 (15.76%) drought months were recorded in the Dapoli region during the rainy season. There was an 84% chance of six drought months in a year and a 6% chance of ten drought months. Despite this, the region shows a fairly low likelihood of drought, with at least three out of ten years likely to be drought years. The greatest ways to maximize crop output in the area are to conserve soil moisture and gather rainfall during the monsoon season. According to the findings of the rainwater surplus deficiency study, rainwater collection can take place between June and October, and stored water can be utilized to maximize agricultural yields.

Zhang *et al.* (2014) investigated extreme weather events, which include weather at the extremes of the historical distribution and weather that is exceptional, severe, or unseasonable. Due to global warming, they have increased in frequency and severity particularly in regions in the mid-latitudes. They result in significant financial and agricultural losses. Although it has rarely been an issue, defining the threshold of extreme weather events is crucial since it serves as the foundation for research on these phenomena.

The Detrended Fluctuation Analysis (DFA) method is presented to identify the threshold of extreme weather occurrences using extreme precipitation episodes in Anhuli, China as an example. It is used to examine the temporal and spatial distributions of extreme precipitation occurrences. in contrast to the conventional percentile approach. The long- term correlation of time series serves as the foundation for DFA.The DFA-calculated thresholds are significantly higher than the 99^{th} percentile, with lower values in the north and greater ones in the south. The annual precipitation spatial pattern and this spatial pattern are comparable. The frequency of days with extreme precipitation is clearly on the rise, particularly during the 1980s. The idea that more extreme events occur as a result of global warming is supported by this observation.

Bhan *et al.* (2015) investigated a catastrophic landslide caused by heavy rains that happened close to Leh in the Ladakh region of Jammu and Kashmir in the western Himalayas (34.09 "N/77.34 E) on August 6, 2010, between 0130 and 0200 hours IST. On the leeward side of the Zanskar Range, the area has little rainfall and is not known to see such severe weather. The rainiest months in Leh are July and August, according to an analysis of the city's daily and monthly precipitation. Additionally, the examination of yearly extreme rainfall occurrences reveals that the monsoon months of July, August, and September have been responsible for 40% of all annual extreme events. Contrary to popular perception, our investigation has shown that Ladakh is not reached by India's southwest monsoon. It has been discovered that the two recent heavy rainfall events on July 25, 2011, and August 5, 2010, were linked to westward moving cyclonic circulations in the middle troposphere (500 hpa) over the Tibet-Ladakh region during active monsoon conditions. This suggests that these systems are essential for producing heavy to very heavy rain over this region. Additionally, the impact of the region's orographic features which are typically thought of as impeding rainfall has been examined and it has been demonstrated that these features may actually be increasing rainfall due to westward- moving cyclonic circulations in the middle troposphere that are embedded in a large-scale favorable environment.

Singhal *et al.* (2022) using past extreme rainfall occurrences in eastern Uttar Pradesh from 2017 to 2020, the study identifies districts at risk based on socioeconomic factors and the frequency of extreme rainfall projections in order to create impact-based forecasts and warning matrices.

Schweer. (2022) the study examines flood risks in eastern Uttar Pradesh by evaluating flood inundation, stagnation, and susceptibility in the Rapti river basin using satellite data from 2008 to 2018. However, it makes no mention of past extreme weather occurrences other than flooding.

Bhatia *et al.* (2019) significant patterns in rainfall frequency and magnitude from 1901 to 2010 are revealed by the paper's analysis of extreme rainfall events over the Indo-Gangetic- plain, which includes eastern Uttar Pradesh. Heavy and very heavy rainfall events are on the decline, whereas moderate rainfall events are on the rise.

Le *et al. (*2024) the intense heat of 1743 in North China, not eastern Uttar Pradesh, is the main topic of the paper. It does not offer statistics on extreme weather events in eastern Uttar Pradesh because it examines historical papers pertaining to this particular incident.

Jenamani. (2012) instead of analyzing historical data on extreme weather events in eastern Uttar Pradesh, the research concentrates on extreme temperature changes over the east coast of India, namely over Orissa and Andhra Pradesh.

Kumar *et al. (*1989-2019) the study examines extreme weather conditions at the Narora site in eastern Uttar Pradesh between 1989 and 2019, with a particular emphasis on air temperature, humidity, wind gusts, and rainfall. This information is crucial for weather management plans and engineering design.

Gowtham and Das (2023) instead of east Uttar Pradesh, the paper focuses on extreme weather events in India's Raipur area. It highlights the necessity of climate adaption techniques by using RClimdex software to evaluate climatic indices and uncover notable trends in rainfall and temperature.

Kumar *et al.* (2021) while the eastern region of India typically experiences severe droughts once every 19 years or more, the study shows that eastern Uttar Pradesh endures severe droughts with a return time of 5 to 6 years, underscoring the region's vulnerability to catastrophic events.

(2). To study the impact of extreme weather events on major crop production.

Marmai *et al.* (2022) the production of key crops is greatly impacted by extreme weather events, which result in large yield losses. Under harsh conditions, the research shows a substantial likelihood of drastic yield reductions, especially for crops like sorghum and maize. The report emphasizes that high temperatures and extremely little precipitation are important variables, with South American and African regions showing the highest risks. This connection emphasizes how susceptible agricultural systems are to climatic shocks in developing nations, calling for focused policy interventions.

Nes *et al.* (2025) according to the paper's findings, major crop production is greatly impacted by extreme weather events. The bilateral export values of maize, rice, and soybeans are reduced by 48.2%, 53.4%, and 21.7%, respectively, due to 2-standard- deviation extreme weather events. Water balance deficits are the hallmark of these occurrences, which endanger agricultural production and have the potential to change the current trends in commodity exports. The long-term research shows that lower export values for all of these staple crops are correlated with more variable weather. Demonstrating how important it is to have flexible trade policy.

Schmitt *et al.* (2022) in Germany, severe weather events have a large impact on major crop output, especially through drought, which is the main cause of yield and monetary losses. One drought day, for example, can lower winter wheat yields by as much as 0.36%. Summer droughts caused winter wheat revenue losses of around 23 million euro annually on average between 1995 and 2019. While other occurrences like heat, water logging, and frost also have an impact on yields, their economic significance differs depending on the crop and the area.

Yin and Li (2024) the output of China's main crops is greatly impacted by extreme weather occurrences. Wheat yields are reduced by 2.1% during heat waves, 1.0% during frost events, 2.2% during droughts, and 1.7% during floods. These occurrences explain significant inter annual variation in yields: 18.9% for soybeans, 10.5% for maize, 21.4% for rice, and 23.6% for wheat. The study emphasizes how various crops are susceptible to particular harsh weather conditions, which has an impact on the region's overall food security.

Heino *et al.* (2023) globally, maize, rice, soybean, and wheat yields are consistently negatively impacted by co-occurring extreme hot and dry weather events; wheat is most susceptible, with yields increasing by up to six times. On the other hand, agricultural yields are also decreased by exceptionally cold and rainy weather, however the effects are less predictable and variable. The report emphasizes how likely it is that these harmful weather extremes will occur during the growing season, endangering the world's food supply and requiring farmers to develop adaptation plans.

Chhogyel *et al.* (2020) in Bhutan, main crop output is greatly impacted by extreme weather events such windstorms, droughts, and unexpected rains, which result in crop losses of 1–19%. The worst outcomes, according to farmers, were crop losses from weather-related occurrences (mean score of 4.10) and drying irrigation sources (mean score of 4.35). These occurrences cause problems by interfering with the supply of irrigation water in agriculture, requiring the use of climate-smart agricultural technologies for adaptability and better farmer-support systems.

Xiao and Qin (2024) the results of the study show that major crop production is greatly impacted by extreme weather occurrences. Yield losses are mostly caused by cold days (CD), warm degree days (WDD), and compound hot-windy-dry (HWD) conditions. The serious risks posed by these climate extremes are highlighted by the fact that a 10-day increase in CD results in a 3.2% drop in winter wheat yield, while 10 hours of HWD and 10°C day-1 WDD result in 7.5% and 2.7% declines in soybean and maize yields, respectively.

Markovic *et. al.* (2021) because they disrupt agronomic methods and provide uncertain yields, extreme weather events have a substantial impact on the production of important crops. According to the study, excessive irrigation decreased maize grain yield by 7.6% during an exceptionally rainy year. On the other hand, irrigation raised yields by up to 39.5% in exceptionally dry conditions. Furthermore, nitrate leaching and soil nitrogen levels were impacted by weather variability, highlighting the necessity of effective irrigation and nitrogen management to reduce adverse environmental effects and boost crop productivity in the face of climate change.

Cogato *et. al.* (2019) especially for the most researched crops- rice, maize, and wheat, extreme weather events (EWE) have a large impact on agricultural production. Both rainfall and drought stress are strongly related to these crops, with floods mostly hurting rice and heat waves providing serious risks to wheat. But little is known about how EWE affects high-value crops like tomatoes and grapevines, which highlights important knowledge gaps on how EWE affects agricultural productivity and food security over the long run.

Du and Xiong (2024) extreme climatic conditions like heat waves, droughts, and floods pose a serious threat to major crop output, especially maize in Africa. Farmers' livelihoods suffer as a result of these occurrences, which also result in widespread production losses and a reduction in acceptable cultivation areas. The systematic review emphasizes how African agriculture's inadequate capacity for adaptation and data shortages amplify the effects of these weather extremes, highlighting the critical need for focused research and practical adaptation measures to improve resilience and food security.

Bras *et al.* (2021) in Europe, major crop production is greatly impacted by extreme weather disasters (EWDs); heatwaves and droughts reduce average cereal yields by 7.3% and 9%, respectively. During these periods, non-cereal yields also fell by 3.8% and 3.1%. Over the past 50 years, the intensity of the effects has increased, with losses in cereal production due to drought increasing by more than 3% a year. While cold waves caused decreases in both cereal and non-cereal yields, floods had only minor effects.

Mehrabi and Ramankutty (2017) significant losses result from extreme weather events, particularly heat waves and droughts, which have a big impact on major crop production. An estimated 237 billion was lost in production worldwide between 1961 and 2014, with grains suffering the most, at 190 billion. Cereal production losses were largest in countries like the USA, Angola, and Botswana, demonstrating how susceptible agricultural systems are to these calamities. The report emphasizes how agriculture needs better disaster risk reduction techniques.

Lesk. *et al.* (2015) the production of main crops is greatly impacted by extreme weather events, especially droughts and excessive heat, which lower national cereal production by 9–10%. Extreme heat mostly impacts yields, although droughts reduce both harvested area and yields. Production losses from recent droughts (1985–2007) were higher (averaging 13.7%) than those from previous droughts (6.7% between 1964–1984). Floods and extremely low temperatures, on the other hand, had no discernible effects on agriculture, underscoring the disparate ways in which various extreme weather events affect crop yields.

Habib-ur-Rahman et al. (2022) extreme weather events, such as droughts and erratic rainfall, significantly reduce yields of major crops like rice and wheat, with predictions indicating yield reductions of 15.2% for rice and 14.1% for wheat under climate change scenarios in Asia.

Sinha and Swaminathan (1991) an increase of 2°C in the mean air temperature might reduce rice output by around 0.75 t/ha in high-yield locations and by approximately 0.06 t/ha in low-yield coastal regions. Furthermore, wheat crop duration would be shortened by seven days and yield would be decreased by 0.45 t/ha with a 0.5°C increase in winter temperatures. Thus, a 10% decrease in wheat production would result from a 0.5°C increase in winter temperatures in the high-yield states of Punjab, Haryana, and Uttar Pradesh.

Hundal and Kaur (1996) investigated the effects of climatic change on Punjab's groundnut, rice, wheat, and maize crop productivity. A temperature increase of 1, 2, and 3°C over current conditions would decrease the grain yield of wheat by 8.1, 18.7, and 25.7%, rice by 5.4, 7.4, and 25.1%, maize by 10.4, 14.6, and 21.4%, and groundnut seed yield by 8.7, 23.2, and 36.2%, respectively, assuming all other climate variables remained constant.

Chatterjee (1998) found that under current conditions, maize and sorghum yields continually declined as temperatures rose. Sorghum potential yields fell by 7–12% on average when the temperature was raised by 1–2°C

Gupta *et al.* (2000) the average rice productivity in Jabalpur, Madhya Pradesh, ranged from 13 to 1000 kg/ha, with an average of 58g kg/ha. There was a substantial correlation between rice yield and the amount of rainfall, duration of the rainy season, and number of rainy days. Rainfed rice's overall productivity was unstable because of the regular variations in rainfall, the number of rainy days, and the length of the rainy season.

Sumathi *et al.* (2009) any changes in temperature, whether projected or observed, are essentially influenced by changes in other variables, like rainfall, that occur simultaneously. Both wealthy and poor farmers' yields decrease with a 3 degree Celsius increase in temperature. Every farmer's yield is nearly the same for a 5 °C temperature increase. It is crucial to take into account various farmer types when assessing the practical effects of climate change.

Samra *et al.* (2012) Punjab's wheat produced good yields during the flowering and seed formation stages of the cold wave conditions that prevailed between Rabi 2010– 11 and 2011–12.

Barlow *et al.* (2013) frost damage to wheat is more severe during the ear emergence and anthesis stages, which significantly lowers grain number and yield potential in Australia.

Duncan *et al.* (2014) the yield of wheat crops was more adversely affected by rising average minimum temperatures in the northwestern Indo-Gangetic plains of India during the thermosensitive times (anthesis and grain filling) than by rising maximum temperatures.

Rajath *et al.* (2023) extreme weather events significantly harm crop productivity, with projected reductions of 50.9% in wheat (USA), 46% in maize (China), 30% in sugarcane (India), and 17% in cotton (India), highlighting the urgent need for adaptive agricultural strategies.

(3) To identify the climatic constraints limiting the crop production.

Walia *et al.* (2024) inadequate rainfall, high air temperatures, low relative humidity, hot, dry winds, and high atmospheric water demand are some of the climate factors that restrict crop output. These factors all have a negative impact on agricultural productivity in arid farming areas.

Mitchell (2004) crop production in the red soils region of southern China is restricted by a number of climatic factors, such as high summer evaporation, late summer dryness, unpredictable summer monsoon onset and intensity, winter frost, and topographically-induced local microclimatic variability.

Dhir (2018) increased temperatures, changed precipitation patterns, and abiotic stresses like heat, drought, salinity, and nutrient shortages are some of the climate factors restricting agricultural productivity. Plant development and agricultural productivity are eventually impacted by these factors, which interfere with vital phenological, physiological, and biochemical processes.

Khan *et al.* (2010) the frequency of natural disasters like floods, droughts, and cyclones has increased, and rising temperatures and shorter winter seasons have a negative impact on crop development and yield. These factors are among the climatic restrictions affecting crop production in Bangladesh.

Lawson and Sivakumar (1991) crop output is restricted by climate factors. Include high temperatures, too much wetness, insufficient rainfall, uneven rainfall, high evaporative demands, and soil erosion. These regional variations have a major effect on agricultural productivity in the various climatic zones of West Africa.

Janmohammadi and Sabaghnin (2023) rising temperatures, decreased precipitation, irregular rainfall patterns, extended dry spells, and worsened soil constraints like decreased moisture content, organic matter, biodiversity, and nutrient availability are some of the climatic factors limiting crop production. These factors ultimately result in lower crop yields.

Casali *et al.* (2018) high temperatures and heat stress during the late vegetative and reproductive stages, as well as the quantity of rainfall in February, are the main climatic factors restricting maize output, according to the study. Temperate maize hybrids in the subtropical Chaco region are especially affected.

Tuninetti and Davis (2022) the study identifies climatic constraints that impact production stability, causing significant climate sensitivity and production delays in a number of regions, especially in the Mediterranean basin, South Asia, the central United States, and eastern Brazil. These constraints include temperature and precipitation fluctuations.

Meddonni *et al*. (2012) climate factors that restrict maize productivity include frost, drought stress, heat stress, low soil water content, and low temperatures. They affect the emergence of seedlings, the availability of water, and the total amount of grain produced during Argentina's maize growth cycle.

Neenu *et al.* (2013) increased temperatures that cause soil moisture loss, changed precipitation patterns, elevated atmospheric CO2 levels that create yield uncertainty, and changes in solar radiation that impact photosynthesis and total crop yield are some of the climatic factors restricting agricultural productivity.

Goud *et al.* (2022) crop yield is limited by climate factors. comprise changes in precipitation and air temperature, which lead to drought, flooding, chilling injury, and heat stress. Climate conditions are the main determinants of crop productivity because of the substantial impact these elements have on yield.

Climate Risk Management Vis-a-Vis Crop Productivity under Climatic Variability (2022) growing temperatures have a detrimental impact on growth phases and grain development, and growing greenhouse gas concentrations are among the climatic factors restricting agricultural yield. These elements lead to lower yields, hence mitigation and adaptation measures are required. climate changes effects on agriculture.

Tariq and Rashid (2020) crop output is restricted by climatic factors such as variations in air temperature, precipitation patterns, and atmospheric CO2 concentration. In light of climate change, these factors' intricate interactions provide serious obstacles to food security and agricultural productivity.

Thakur and Sharma (2024) increasing temperatures, changed precipitation patterns, and elevated atmospheric CO2 levels are some of the climatic factors restricting crop productivity. These elements, which disproportionately affect developing countries, result in decreased crop output, increased insect activity, and higher food prices.

Alotaibi *et al*. (2023) crop yield is limited by climate factors. include heat waves, droughts, floods, elevated temperatures, and erratic precipitation patterns. In addition to having a negative impact on food security, productivity, and agricultural systems, these changes also have an impact on the survival and dissemination of weeds, pests, and diseases.

Gorst *et al*. (2017) according to the report, crop productivity is limited by climate restrictions such rising temperatures, the effects of drought, and precipitation thresholds. It draws attention to India and Pakistan's deteriorating drought resistance and the changing interplay between agro-climatic variables and agricultural technology.

Awaad (2022) changes in temperature, humidity, and day length are among the climatic factors restricting crop output. These factors have a negative impact on plant physiological and biochemical processes, which in turn affect growth, blooming, fruiting, and ripening in a variety of agricultural systems.

Cotrina Cabolio (2023) the two main climatic factors limiting agricultural output are heat and drought. Through physical harm, biological disturbance, and biochemical anomalies, these abiotic variables adversely affect crop growth and yields, making it more difficult to comprehend how they affect agricultural production.

Chand Ray (2015) wave incidents have significantly increased over the past ten years, according to an examination of extreme weather events in eastern Uttar Pradesh. The stations most affected are Allahabad, Gorakhpur, and Varanasi, and the frequency of moderate and severe heat waves is noticeably higher, especially in June. According to the study, heat waves are more common in the eastern Uttar Pradesh plains, with 2010 having the most heat wave days in the previous 30 years.

MATERIALS AND METHODS

This chapter provides an overview of the research area, materials gathered for the study, their sources, and the methodology used for the current investigation, which is named **"Extreme weather events analysis of Eastern Uttar Pradesh."**

The IMD and the Agro-meteorological observatory, ANDUAT, Kumarganj, Ayodhya, and the Agro-meteorological observatory BHU, Varanasi, provided the historical temperature and rainfall data for Eastern Uttar Pradesh for the last 31 years (1994–2024). The following text provides a description of the study area's climate profile and demographics, as well as the materials and techniques used during the investigation**:**

3.1 DEMOGRAPHY OF EASTERN Uttar Pradesh

3.1.1. General description

Eastern Uttar Pradesh is located in the Indo-Gangetic alluvium at latitude 26° 47' North, longitude 82° 12' East, at an elevation of roughly 113 meters above mean sea level. The location has a humid subtropical climate and is frequently hit by weather extremes, such as freezing winters, scorching summers, and unexpected rainstorms. While there is no trend toward a change in the frequency or range of extreme maximum temperatures, the area's extreme weather occurrences are increasing in the relevant years. The area has seen an increase in fog frequency in recent decades.

Westerly hot winds begin in April and last until mid-June. The hottest months of the year are May and June. The lowest and maximum temperatures tend to rise from February to June and fall from July to December before dropping sharply with the lowest value in January. (**Tripathi *et al.*,1998*).***

3.2 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)

3.3 Climatic profile of Eastern U.P.

3.3.1 Weather during summer

March through May is considered the summer season. The temperature during the day stays quite high, typically rising above 45°C and occasionally reaching 47°C. The nights are comparatively colder. Typical of an extreme environment, the chilly air causes the temperature to drop as low as 28 °C.

3.3.2 Weather during winter

The entire Eastern U.P. experiences much colder winters, with moderate daytime temperatures of about 24°C and chilly evenings that can drop as low as 2 to 4°C. Eastern regions were once relatively warmer, but as a result of shifting weather patterns, even these regions are currently experiencing severe cold waves. Temperatures in cities like Varanasi are consistently dropping below freezing. Winter begins in mid-November and lasts until the end of February. The Eastern U.P. Region has a lot of dew

3.3.3 Rainfall

The average annual rainfall in the Eastern U.P. is 1063 mm. According to (**Tripathi *et al*., 1998).** over 89% of the total rainfall occurred during the south-west monsoon (June to September), with the remaining 5-7 percent occurring during the winter. Even though there is a post-monsoon, it barely affects Eastern Uttar Pradesh, and during the winter months, there are only sporadic, light showers. Some of these showers are caused by western disturbances rather than the monsoon. The majority of rainfall occurs during the monsoon season; too much rain can cause floods, while too little rain can cause droughts. Therefore, in the Eastern U.P., floods and droughts are frequent occurrences. **(Anonymous, 2015)**

The Eastern Plain Zone of Uttar Pradesh is divided into eleven districts. Ayodhya and Varanasi is the representative district that has been chosen for the study.

Criteria used for analysis of extreme weather events

Dry Spell analysis:-

Using long-term (1994–2024) daily rainfall data from the representative district of the EPZ of UP, a trend analysis of monsoon (June–September) rainfall for various rainy spells was conducted. The trend of various rainfall periods was assessed using specialized tools for analyzing extreme weather occurrences. ≤2.5mm over a 10-days period to analyze the dry spell.

Wet Spell analysis:-

Using daily rainfall data from (1994-2024) for a representative district in the EPZ of Uttar Pradesh, a trend analysis of monsoon (June to September) rainfall for various rainy spells was conducted. To assess the tendency of several rainfall spells, specialized software for analyzing extreme weather events was employed. ≥10 mm for 7-days, ≥25 mm for 3-days, 50 mm for 2-days, and 100 mm of heavy rain for 1-day, in order to analyze the wet period in the chosen district

Heat wave analysis:-

Using the historical daily data of the maximum temperature of a representative district of the EPZ of UP gathered over the last 31 years (1994–2024), a heat wave analysis was conducted for the month of (March to September). Actual maximum temperatures for heat waves above 45°C and severe heat waves exceeding 47°C were utilized as criteria for the analysis. 4.5°C to 6.5°C is the departure from normal temperature for heat waves, while more than 6.5°C is the departure from normal for severe heat waves.

Cold wave analysis:-

Using historical daily data of the minimum temperature of a representative district of the EPZ of UP gathered over the last 31 years (1994-2024), cold wave analysis was conducted for the months of (October–March). For cold wave minimum temperatures of 4°C or lower, the criteria for analysis were based on the actual minimum temperature. A severe cold wave requires a minimum temperature of at least 2°C. When the station's minimum temperature falls below 10°C, the cold wave temperature deviates from normal by 4.5°C to 6.4°C, and the severe cold wave temperature deviates from normal by less than or equal to 6.5°C.

RESULTS AND DISCUSSION

The results of present investigation entitled **"Extreme weather events analysis of Eastern Uttar Pradesh"** have been presented in this chapter with the help of appropriate tables and suitable figures wherever necessary. The entire results analyzed over historical data of last 31 years obtained during the present investigation have been categorized in the following heads and furnished accordingly:

1. To collect the historical weather data of the Eastern Uttar Pradesh.
2. To Analysis the extreme weather events on Eastern Uttar Pradesh.
3. To study the impacts of extreme weather events on major crops production.
4. To identify the climatic constrains of the Eastern Uttar Pradesh.

4.1 To collect the historical weather data of the Eastern Uttar Pradesh.

To collect historical weather data for Eastern Uttar Pradesh, one can rely on several authoritative sources. The India Meteorological Department (IMD) is the primary agency that maintains and provides access to comprehensive weather records, including temperature, rainfall, humidity, and extreme weather events. Data can be accessed through IMD's official website or by submitting a formal data request for specific stations in Eastern Uttar Pradesh. Additionally, global climate data repositories such as NASA's POWER Data Access Viewer, NOAA's Climate Data Online (CDO), and the European Centre for Medium-Range Weather Forecasts (ECMWF) offer historical datasets with regional coverage. Local universities, agricultural research centers, and state meteorological observatories may also maintain relevant records. When collecting data, it is important to ensure temporal and spatial consistency, specifying the time range, parameters, and station locations. This data is crucial for climate research, agricultural planning, and risk assessment in the region. U.P. Collected and analyzed the daily weather data of maximum temperature. Minimum temperature and rainfall of selected district under study of Eastern Plain Zone for a long period (1994-2024) for the various extreme weather events Dry spell, Wet spell, Heat waves Cold waves etc. of Eastem Plain Zone of UP as to identify the impact of various extreme weather events.

4.2 To Analysis the extreme weather events on Eastern Uttar Pradesh.

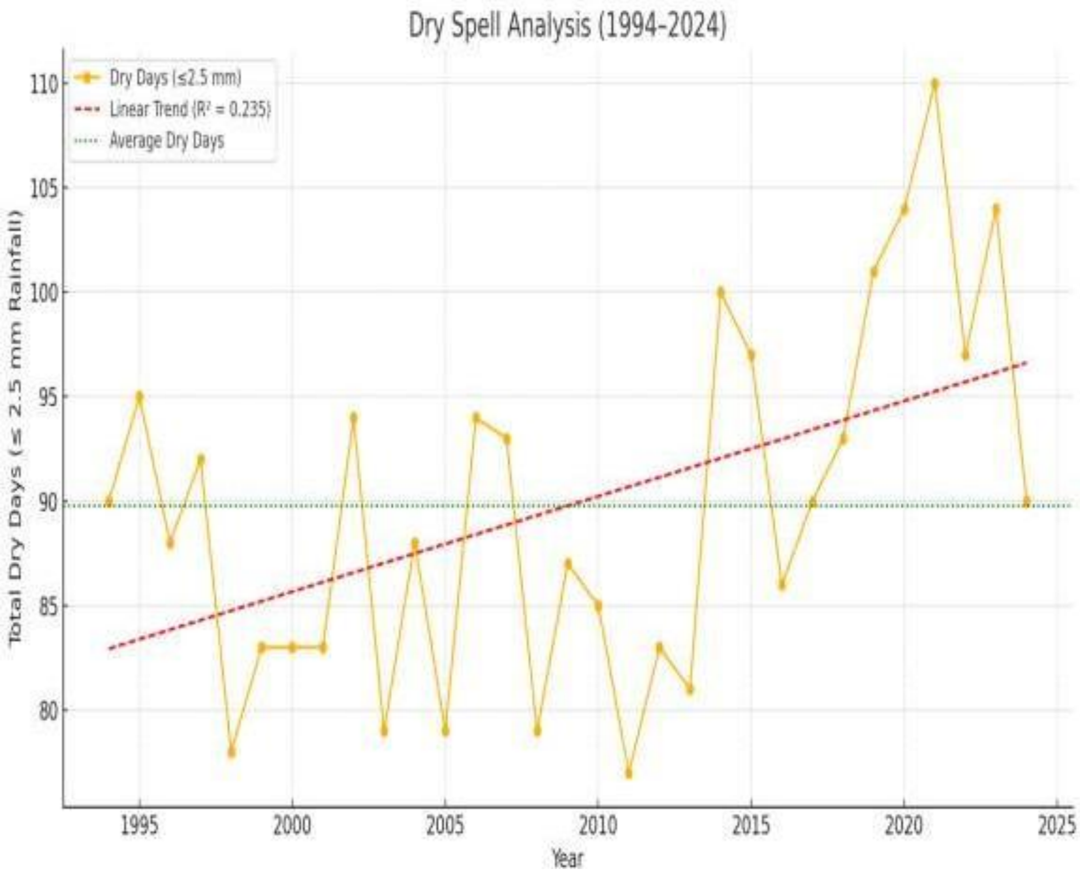
4.2.1 Dry spells Analysis of Ayodhya District (1994–2024)

The dry spell data from 1994 to 2024 reflects the total number of days each year with rainfall less than or equal to 2.5 mm which are considered "dry days." Over this 31 years period, the number of dry days in a year ranged from a minimum of 77 days in 2011 to a maximum of 110 days in 2021. On average, most years experienced between 85 to 90 dry days. From 1994 to around 2009, the number of dry days remained relatively stable, generally fluctuating between 78 and 95 days. However, beginning around 2014, there has been a noticeable increase in the frequency and duration of dry spells. In the past decade (2014–2024), several years recorded more than 100 dry days, including 2014, 2015, 2019, 2020, 2021, and 2023. This shift suggests that dry spells have become longer and more frequent in recent years, indicating a potential change in rainfall distribution patterns.

The analysis of dry days from 1994 to 2024 shows a gradual increase in dry spell duration over time, particularly after 2014. This trend may point to climate variability or shifts in seasonal rainfall, such as delayed or weakened monsoons. The growing number of dry days could have significant implications for agriculture, water availability, and overall ecosystem balance. Therefore, it is essential to consider adaptive water management practices, climate-resilient farming, and early warning systems to minimize the impact of these extended dry periods in the future.(Table no.4.1)

Table 4.1 Rainfall ≤2.5 mm for 10 days during 1994-2024 in Ayodhya

Years	**Total days (≤Critical value)**		**Total days (≤Critical Value)**
1994	90	2010	85
1995	95	2011	77
1996	88	2012	83
1997	92	2013	81
1998	78	2014	100
1999	83	2015	97
2000	83	2016	86
2001	83	2017	90
2002	94	2018	93
2003	79	2019	101
2004	88	2020	104
2005	79	2021	110
2006	94	2022	97
2007	93	2023	104
2008	79	2024	90
2009	87		



Graph 4.1 Rainfall ≤2.5 mm for 10 days during 1994-2024 in Ayodhya

Here's the graph (4.1) showing the total dry days (≤ 2.5 mm rainfall) from 1994 to 2024, along with a linear trend line. The R^2 (R-squared) value is displayed in the legend and indicates how well the linear model fits the data. **R^2 Value**: This measures the proportion of the variance in dry days that is predictable from the year. A higher R^2 indicates a better fit.

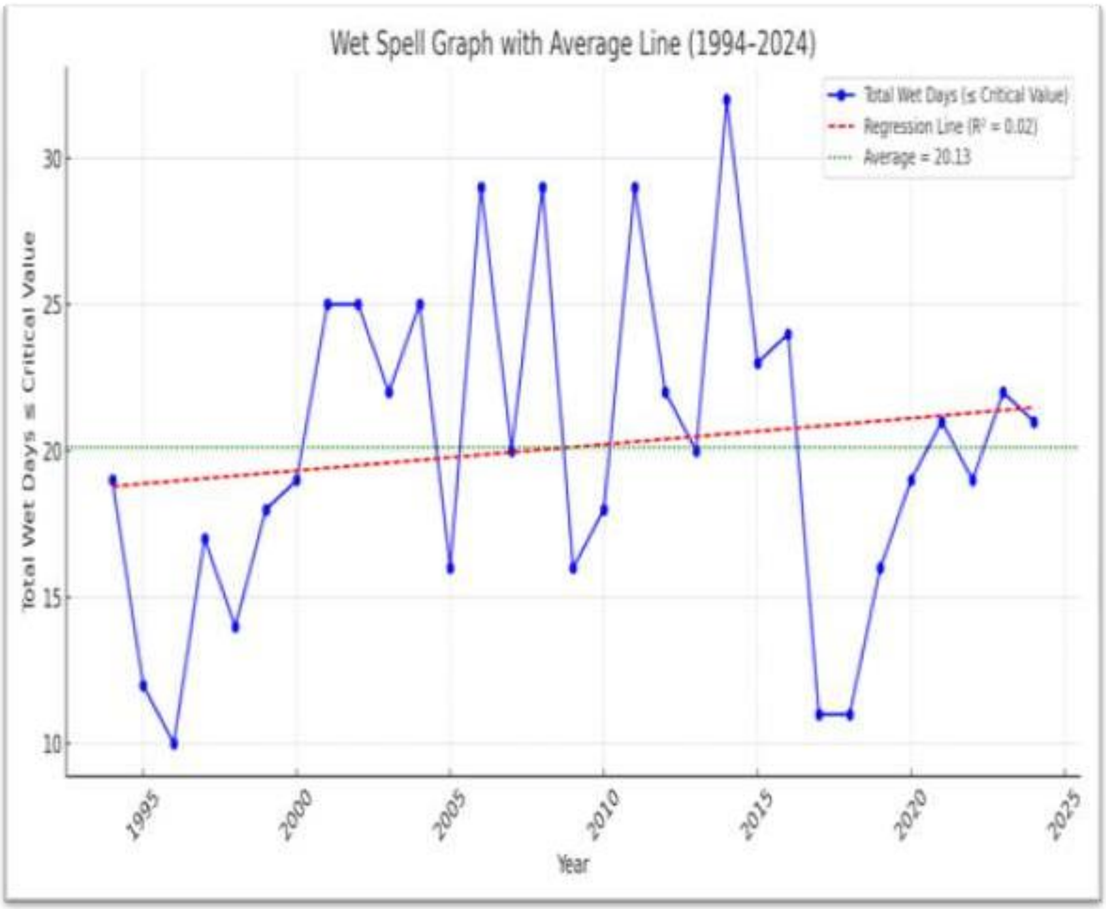
4.2.2 Wet spells Analysis Rainfall of Ayodhya District (1994–2024)

The wet spell analysis, based on the number of days exceeding the critical rainfall value over the years 1994 to 2024, reveals significant internal variability in rainfall patterns. Wet spell days range from a minimum of 10 days in 1996 to a maximum of 32 days in 2014. Notably, the late 1990s and early 2000s experienced relatively stable wet spell occurrences, typically ranging between 14 and 25 days per year. However, after 2010, fluctuations became more pronounced, with certain years like 2011, 2014, and 2016 showing elevated wet spell activity (above 23 days), while others such as 2017 and 2018 recorded notably fewer wet spell days (only 11 days). This inconsistent pattern may suggest an increasing unpredictability in rainfall distribution, potentially linked to changing climatic conditions.

While wet spell days have shown no consistent increasing or decreasing trend over the 31-year period, the data highlights the dynamic nature of rainfall events and the importance of monitoring wet spells closely for water resource management, agriculture planning, and climate impact assessments. Years like 2014 and 2006 stand out for their higher frequency of wet spells, which may indicate short periods of intense rainfall, whereas years like 1996 and 2017 represent drier conditions despite being categorized under wet spell events. (Table no. 4.2)

Table 4.2 Rainfall ≥10 mm for 7 days during 1994-2024 in Ayodhya

Years	Total days (≤Critical value)	Years	Total days (≤Critical Value)
1994	19	2010	18
1995	12	2011	29
1996	10	2012	22
1997	17	2013	20
1998	14	2014	32
1999	18	2015	23
2000	19	2016	24
2001	25	2017	11
2002	25	2018	11
2003	22	2019	16
2004	25	2020	19
2005	16	2021	21
2006	29	2022	19
2007	20	2023	22
2008	29	2024	21
2009	16		



Graph 4.2 Rainfall ≥10 mm for 7 days during 1994-2024 in Ayodhya

The Wet Spell Graph (4.2) (1994–2024) displays the annual variation in the number of days classified as wet spells, defined as days with rainfall less than or equal to a specified critical value. The blue line in the graph represents the actual recorded data for each year, showing fluctuations in wet spell occurrences over the 31-year period. A red dashed line has been added to indicate the linear regression trend, helping to visualize whether the number of wet spell days is generally increasing or decreasing over time. The R^2 value provided alongside the trend line shows the strength of this linear relationship, with values closer to 1 indicating a stronger fit. Additionally, a green dotted line represents the average number of wet spell days across the entire period, serving as a benchmark to compare individual years. Years above this line experienced more wet days than the long-term average, while those below it had fewer. Overall, this graph helps to identify patterns, trends, and anomalies in wet spell frequency, which can be useful for understanding long-term climate behavior and informing agricultural or environmental planning

4.3 Rainfall ≥25mm for 3 days during 1994-2024 in Ayodhya

Data pertaining to the wet spell ie rainfall >25mm for 3 days of Eastern UP have been presented in Table-4.3 and depicted in Fig-3. It is obvious from the data that the trend of wet spell was above its normal value up to the year 1999, while year 1999 onwards, the wet spell was recorded below its normal value (10.5 days).

Table-4.3 Rainfall ≥25mm for 3 days during 1994-2024 in Ayodhya

Years	Total days (≤Critical value)	Years	Total days (≤Critical value)
1994	11	2010	9
1995	7	2011	16
1996	6	2012	8
1997	14	2013	13
1998	11	2014	5
1999	16	2015	7
2000	7	2016	9
2001	14	2017	11
2002	7	2018	8
2003	17	2019	11
2004	8	2020	15
2005	9	2021	10
2006	8	2022	9
2007	4	2023	12
2008	18	2024	8
2009	11		

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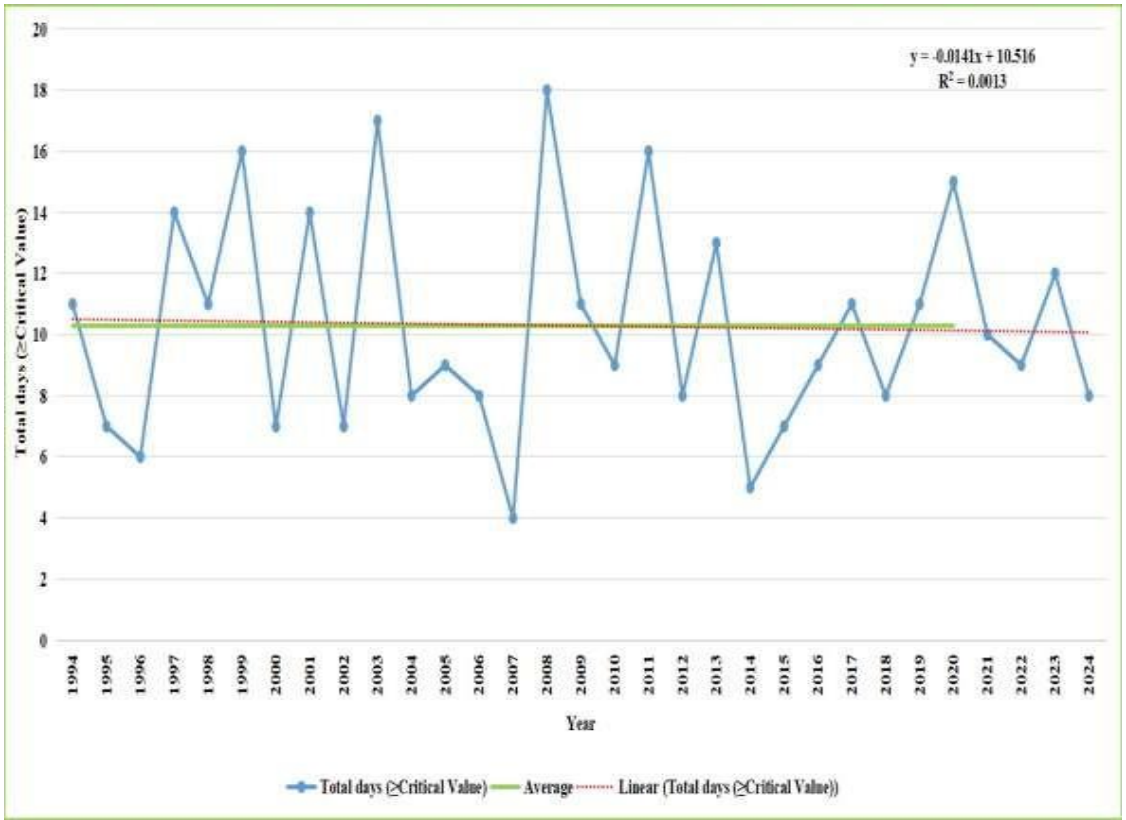


Fig-4.3 Rainfall ≥25mm for 3 days during 1994-2024 in Ayodhya

4.4 Rainfall ≥50mm for 2 days during 1994-2024 in Ayodhya

Data pertaining to the wet spell i.e. rainfall >50mm for 2 days of Eastern UP have been presented in Table-4.4 and depicted in Fig-4. It is obvious from the data that the trend of wet spell was equal to the normal up to the year 2000. while year 2000 onwards wet spell was recorded slight below its normal value (3.8 days).

Table-4.4 Rainfall ≥50mm for 2 days during 1994-2024 in Ayodhya

Years	Total days (≤Critical value)	Years	Total days (≤Critical value)
1994	4	2010	1
1995	3	2011	6
1996	2	2012	5
1997	9	2013	8
1998	4	2014	3
1999	6	2015	2
2000	4	2016	3
2001	3	2017	6
2002	1	2018	5
2003	6	2019	3
2004	3	2020	4
2005	3	2021	5
2006	5	2022	4
2007	1	2023	6
2008	6	2024	3
2009	3		

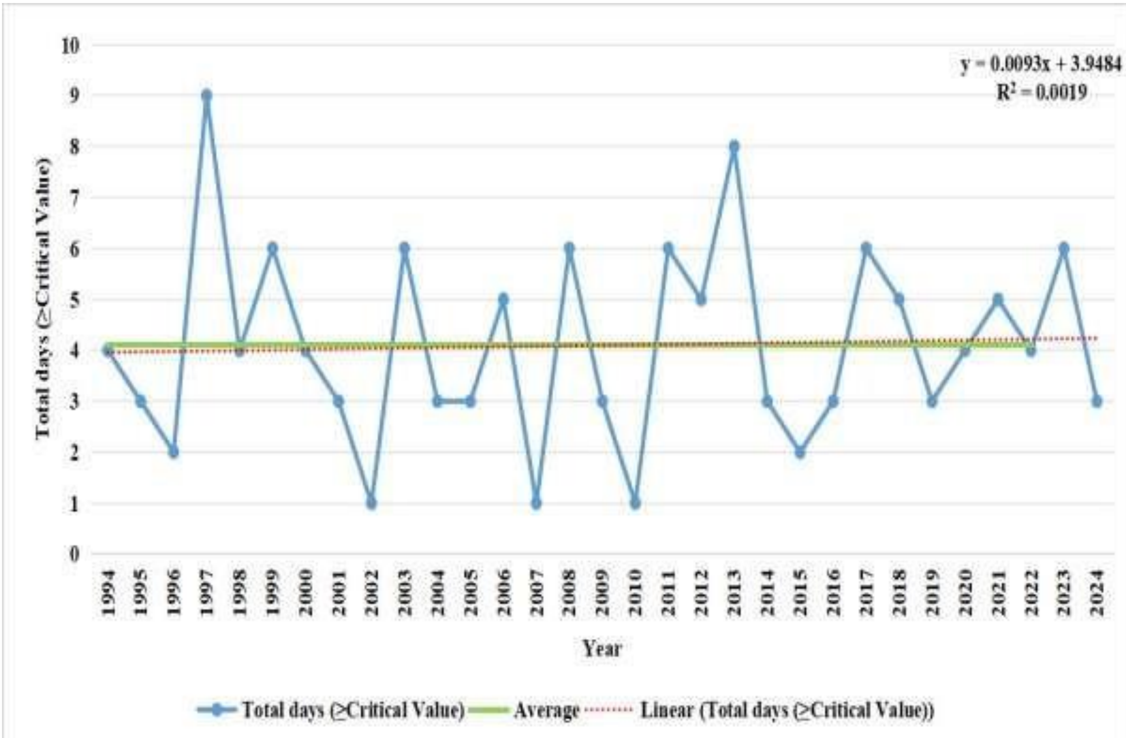


Fig-4.4 Rainfall ≥50mm for 2 days during 1994-2024 in Ayodhya

4.5 Rainfall ≥100mm for 1 days during 1994-2024 in Ayodhya

Data pertaining to the wet spell i.e. rainfall ≥100mm for 1 day of Eastern Up have been presented in Table- 4.5 and depicted in Fig- 4.5 It is obvious from the data that the trend of wet spell was above the normal up to the year 2001, while year 2001 onwards wet spell was recorded was below its normal value (0.68 days).

Table-4.5 Rainfall ≥100mm for 1 days during 1994-2024 in Ayodhya

Years	Total days (≤Critical value)	Years	Total days (≤Critical value)
1994	1	2010	0
1995	1	2011	1
1996	0	2012	0
1997	0	2013	2
1998	0	2014	0
1999	1	2015	1
2000	0	2016	0
2001	1	2017	1
2002	0	2018	0
2003	0	2019	1
2004	1	2020	2
2005	0	2021	0
2006	0	2022	1
2007	1	2023	0
2008	2	2024	1
2009	1		

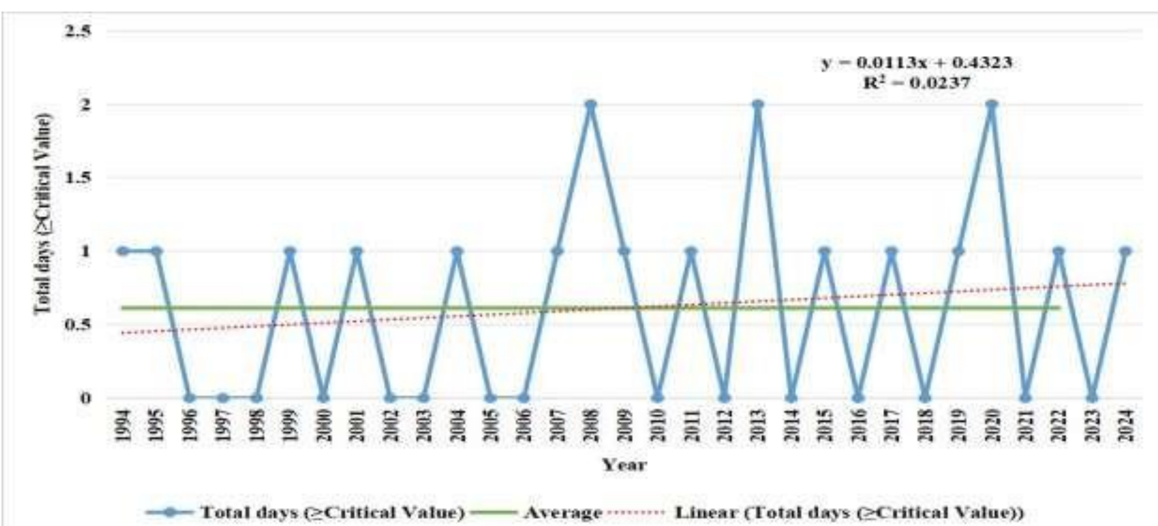


Fig-4.5 Rainfall ≥100mm for 1 days during 1994-2024 in Ayodhya

4.2.6 Dry spells Analysis of Varanasi District (1994–2024)

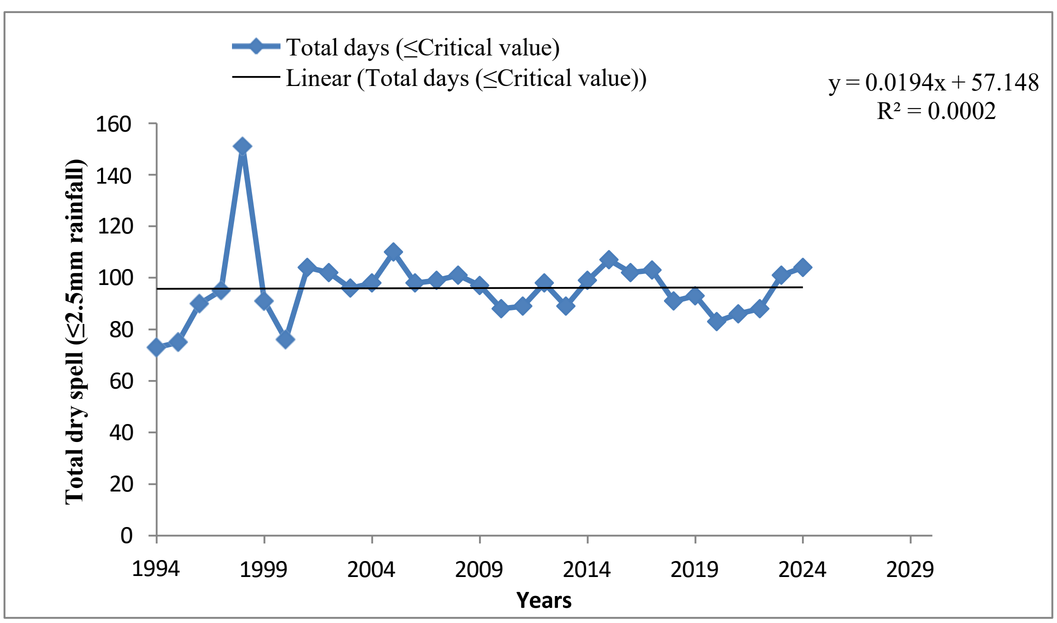
The dry spell analysis for Varanasi from 1994 to 2024, based on the number of days with rainfall less than or equal to a critical threshold, reveals notable variability in annual dry conditions. The number of dry days ranged from a low of 73 days in 1994 to a peak of 151 days in 1998, indicating a year of extreme dryness. Over the years, fluctuations in dry spell duration can be observed, with several years such as 2001, 2005, 2023, and 2024 showing over 100 dry days, suggesting prolonged periods of insufficient rainfall. In the most recent decade, the data reflects a consistent trend of moderate to high dry spell durations, typically ranging from 83 to 107 days annually. This pattern indicates that dry conditions have become more persistent over time.

The data suggests that while dry spell lengths have varied over the years, recent trends point toward an increasing frequency of extended dry periods in Varanasi, which may have

significant implications for agriculture, water supply, and climate resilience planning. (Table no.4.6)

Table 4.6 Rainfall ≤2.5 mm for 10 days during 1994-2024 in Varanasi

Years	Total days (≤Critical value)	Years	Total days (≤Critical Value)
1994	73	2010	88
1995	75	2011	89
1996	90	2012	98
1997	95	2013	89
1998	151	2014	99
1999	91	2015	107
2000	76	2016	102
2001	104	2017	103
2002	102	2018	91
2003	96	2019	93
2004	98	2020	83
2005	110	2021	86
2006	98	2022	88
2007	99	2023	101
2008	101	2024	104
2009	97		



Graph 4.6 Rainfall ≤2.5 mm for 10 days during 1994-2024 in Varanasi

Here's the graph (4.6) showing the total dry days (≤ 2.5 mm rainfall) from 1994 to 2024, along with a linear trend line. The R^2 (R-squared) value is displayed in the legend and indicates how well the linear model fits the data. **R^2 Value**: This measures the proportion of the variance in dry days that is predictable from the year. A higher R^2 indicates a better fit.

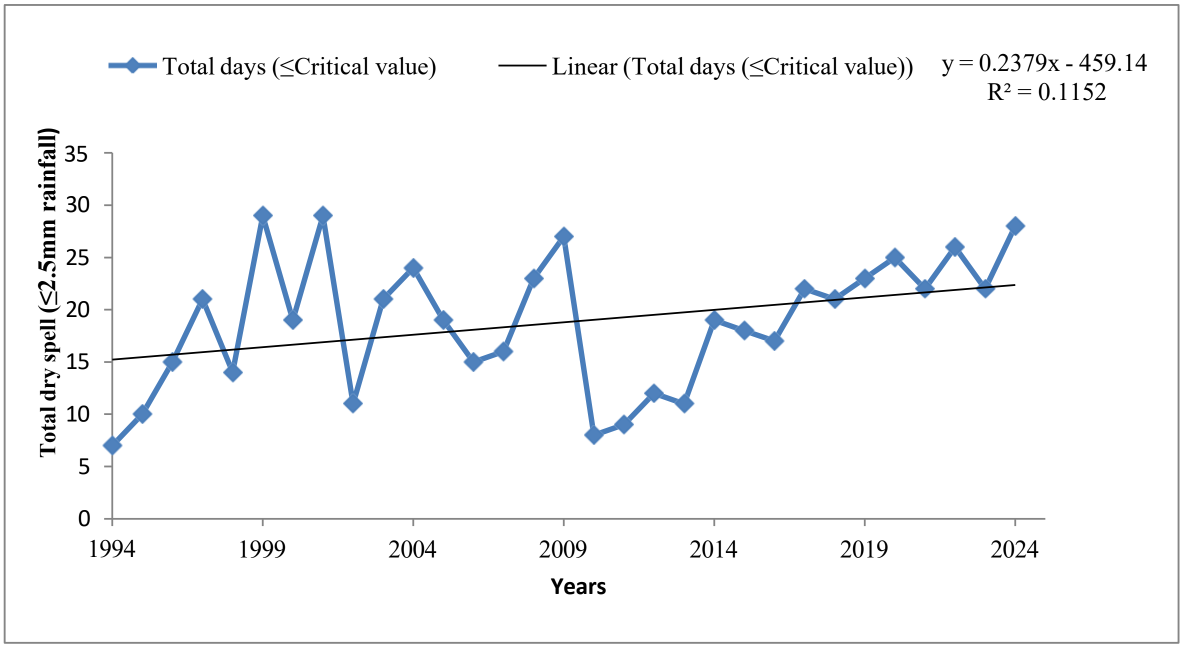
4.2.7 Wet spells Analysis Rainfall of Varanasi District (1994–2024)

The table (4.7) presents yearly data on the total number of days during which rainfall was less than or equal to a critical value, likely indicating days with rainfall of at least 10 mm over a consecutive 7-day period or a related threshold. From 1994 to 2024, the number of such days varies significantly each year, ranging from as few as 7 days in 1994 to as many as 29 days in 1999 and 2001. This variation reflects changes in rainfall frequency and intensity over the years, with some years experiencing more frequent moderate rainfall events and others having fewer. The overall pattern suggests fluctuations in climatic or weather conditions influencing rainfall distribution across these three decades.

The data shows a general increasing trend in the number of days with rainfall meeting or staying below the critical value, indicating a possible rise in the frequency of moderate rainfall events over the years. This trend may point to changing climate patterns or shifts in regional weather behavior, emphasizing the need for further investigation to understand the causes and potential impacts on water resources, agriculture, and planning.

Table 4.7 Rainfall ≥10 mm for 7 days during 1994-2024 in Varanasi

Years	Total days (≤Critical value)	Years	Total days (≤Critical Value)
1994	7	2010	8
1995	10	2011	9
1996	15	2012	12
1997	21	2013	11
1998	14	2014	19
1999	29	2015	18
2000	19	2016	17
2001	29	2017	22
2002	11	2018	21
2003	21	2019	23
2004	24	2020	25
2005	19	2021	22
2006	15	2022	26
2007	16	2023	22
2008	23	2024	28
2009	27		



Graph 4.7 Rainfall ≥10 mm for 7 days during 1994-2024 in Varanasi

The graph 4.7 illustrates the annual variation in the total number of days with rainfall less than or equal to 10 mm defined as dry spell days over the period from 1994 to 2024. The data reveals considerable fluctuations in dry spell days across the years, with some years such as 1999, 2001, and 2024 experiencing as many as 28–29 dry days, while others like 1994 and 2010 recorded significantly fewer, around 7–8 days. A linear trend line has been fitted to the data, indicating a gradual increase in the frequency of dry spell days over the three-decade period. The positive slope of the trend line confirms this upward trend, although the R^2 value of 0.1152 suggests that the correlation is weak, and much of the year-to-year variation is not explained by this linear trend alone. Overall, while the data does not show a dramatic shift, it points toward a subtle but consistent rise in dry spell frequency, potentially reflecting emerging changes in regional rainfall patterns or climatic conditions.

4.8 Rainfall ≥25mm for 3 days during 1994-2024 in Varanasi

Data pertaining to the wet spell ie rainfall >25mm for 3 days of Eastern UP have been presented in Table-4.8 and depicted in Fig-8. It is obvious from the data that the trend of wet spell was above its normal value up to the year 2016, while year 2016 onwards, the wet spell was recorded below its normal value (11.67 days).

Table-4.8 Rainfall ≥25mm for 3 days during 1994-2024 in Varanasi

Years	Total days (≤Critical value)	Years	Total days (≤Critical value)
1994	9	2010	8
1995	12	2011	11
1996	13	2012	7
1997	10	2013	15
1998	12	2014	11
1999	14	2015	11
2000	10	2016	17
2001	13	2017	11
2002	7	2018	12
2003	10	2019	17
2004	9	2020	13
2005	9	2021	24
2006	12	2022	12
2007	15	2023	12
2008	13	2024	7
2009	6		

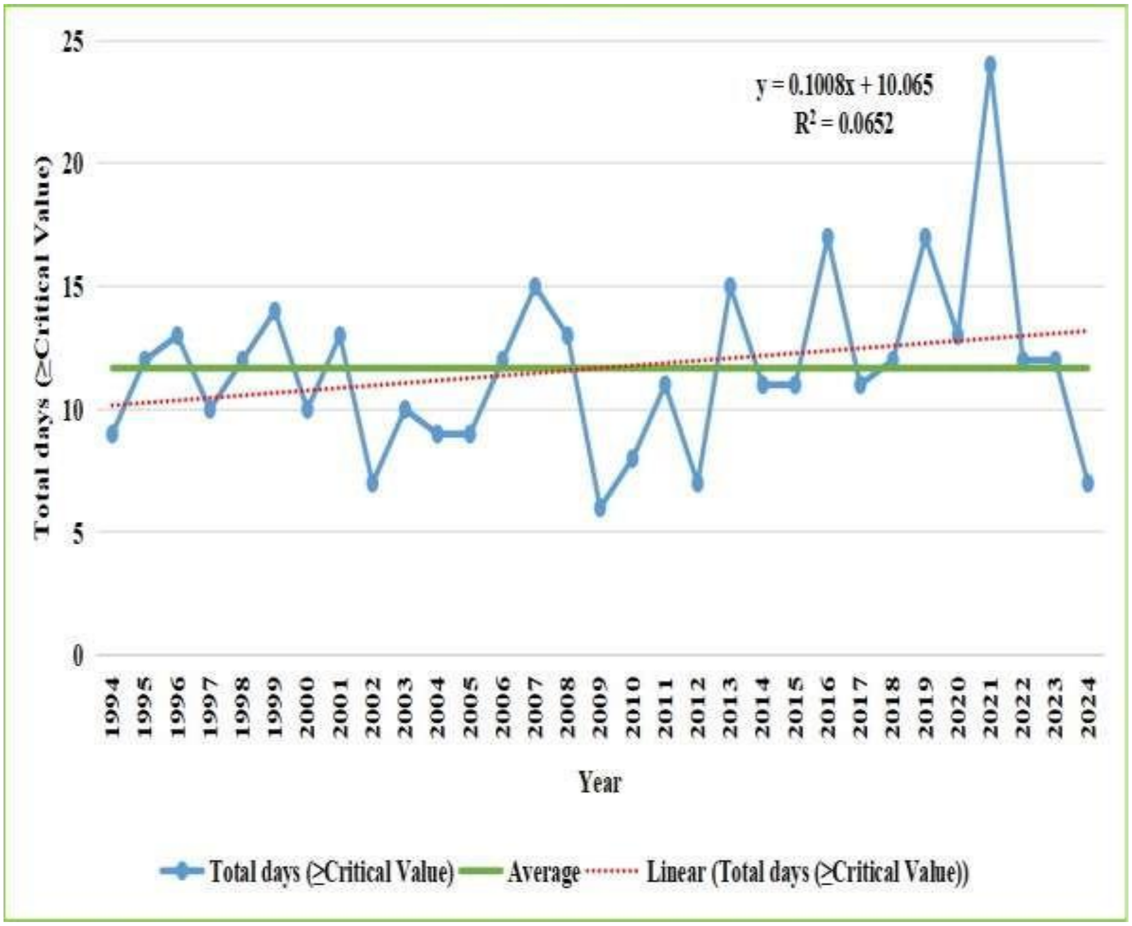


Fig-4.8 Rainfall ≥25mm for 3 days during 1994-2024 in Varanasi

4.9 Rainfall ≥50mm for 2 days during 1994-2024 in Varanasi

Data pertaining to the wet spell i.e. rainfall >50mm for 2 days of Eastern UP have been presented in Table-4.9 and depicted in Fig-9. It is obvious from the data that the trend of wet spell was equal to the normal up to the year 1997. while year 1997 onwards wet spell was recorded slight below its normal value (4.35 days).

Table-4.9 Rainfall ≥50mm for 2 days during 1994-2024 in Varanasi

Years	Total days (≤Critical value)	Years	Total days (≤Critical value)
1994	3	2010	2
1995	6	2011	6
1996	5	2012	1
1997	4	2013	3
1998	4	2014	4
1999	5	2015	6
2000	4	2016	7
2001	7	2017	4
2002	3	2018	6
2003	0	2019	7
2004	1	2020	9
2005	4	2021	15
2006	4	2022	6
2007	2	2023	1
2008	3	2024	1
2009	2		

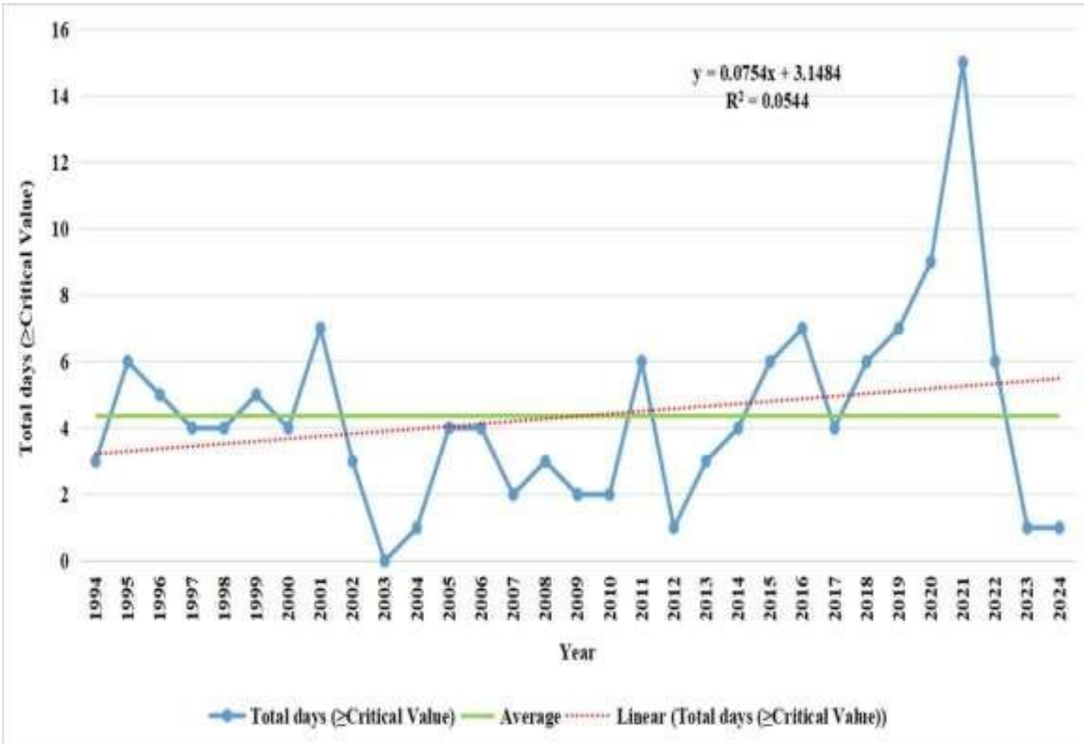


Fig-4.9 Rainfall ≥50mm for 2 days during 1994-2024 in Varanasi

4.10 Rainfall ≥100mm for 1 days during 1994-2024 in Varanasi

Data pertaining to the wet spell i.e. rainfall ≥100mm for 1 day of Eastern Up have been presented in Table- 4.10 and depicted in Fig- 4.10 It is obvious from the data that the trend of wet spell was above the normal up to the year 2002, while year 2003 onwards wet spell was recorded was below its normal value (0.77 days).

Table-4.10 Rainfall ≥100mm for 1 days during 1994-2024 in Varanasi

Years	Total days (≤Critical value)	Years	Total days (≤Critical value)
1994	1	2010	1
1995	0	2011	1
1996	0	2012	0
1997	1	2013	0
1998	1	2014	1
1999	1	2015	1
2000	1	2016	0
2001	1	2017	0
2002	1	2018	0
2003	0	2019	2
2004	0	2020	4
2005	0	2021	5
2006	0	2022	0
2007	1	2023	0
2008	1	2024	0
2009	0		

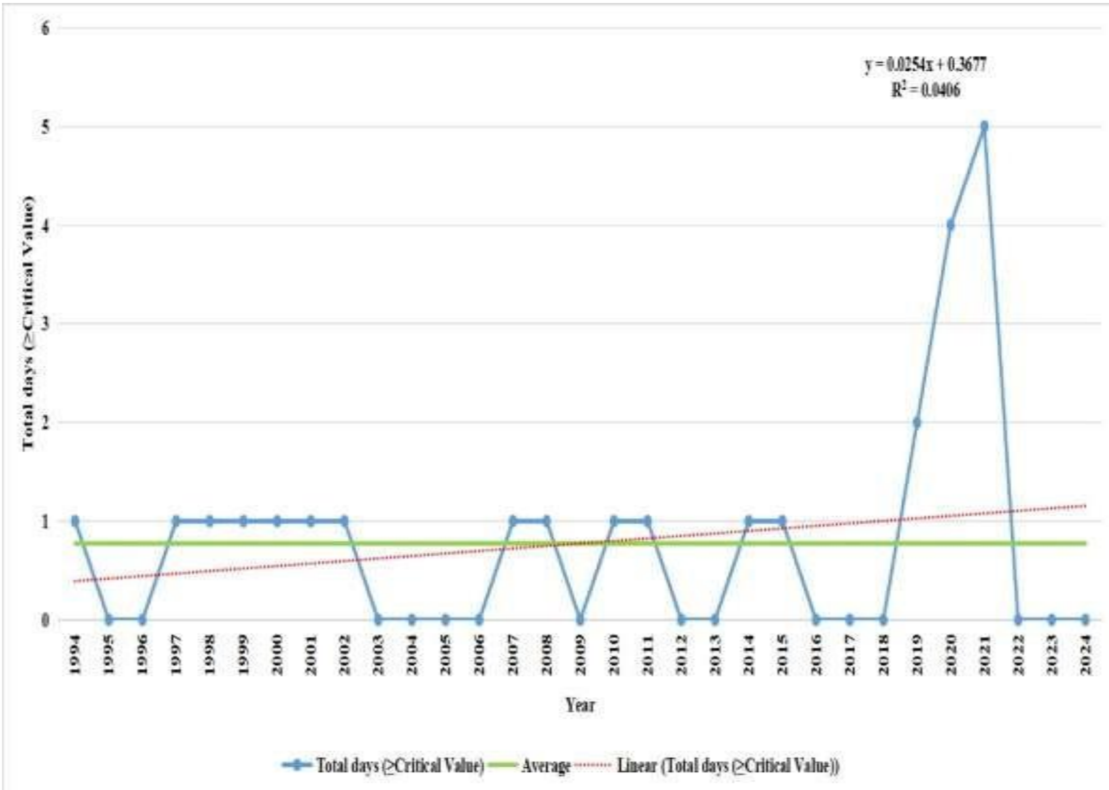


Fig-4.10 Rainfall ≥100mm for 1 days during 1994-2024 in Varanasi

4.2.11 Heat Wave Analysis of Ayodhya district of Eastern Uttar Pradesh.

A heat wave is a period of unusually high temperatures that lasts for two or more consecutive days and is significantly hotter than the average for a particular region and time of year. It typically occurs during the summer months and can cause serious health risks such as heat stroke, dehydration, and exhaustion. According to the India Meteorological Department (IMD), a heat wave is declared when temperatures reach 40°C or more in plains, 37°C or more in coastal areas, and 30°C or more in hilly regions, especially if the temperature is 4.5°C or more above the normal. Heat waves can also increase electricity demand, affect agriculture, and contribute to water shortages. To stay safe during a heat wave, people are advised to stay indoors during peak heat hours, drink plenty of water, wear light clothing, and avoid strenuous activities.

Table-4.11 Frequency of days of heat wave estimated using IMD criteria at Ayodhya

Frequency of days of heat waves	
Months	**Days of heat waves**
March	3
April	21
May	48
June	47
July	27
August	10
September	3
Annual	**159**

From the table (4.11) it is clear that the highest number of heat wave days occurred in May (48 days) and June (47 days), which are typically the hottest months in many parts of India. April (21 days) and July (27 days) also experienced a significant number of heat wave days, while March, August, and September had relatively fewer such days. In the observed year, a total of 159 days were affected by heat waves, indicating a severe heat-related climatic condition. This data reflects the growing impact of global warming and climate change, leading to an increase in both the frequency and duration of heat waves. The peak in May and June also suggests the need for timely heat preparedness plans, especially for agriculture, water management, and public health systems. Understanding these patterns is crucial for effective disaster risk reduction and long-term climate adaptation strategies.

4.2.12 Heat Wave Analysis of Varanasi district of Eastern Uttar Pradesh.

Table-4.12 Frequency of days of heat wave estimated using IMD criteria at Varanasi

Frequency of days of heat waves	
Months	**Days of heat waves**
March	5
April	14
May	33
June	23
July	10
August	8
September	3
Annual	**96**

The frequency of heat wave days in Varanasi, estimated using the IMD criteria, varies throughout the year. In March, there are typically 5 days experiencing heat waves. This number increases significantly in April, reaching 14 days. The highest frequency occurs in May, with 33 days of heat waves recorded. June also sees a substantial number of heat wave days, totaling 23. As the monsoon progresses, the number of heat wave days decreases, with July having 10 days and August 8 days. By September, the heat wave days reduce further to just 3. Overall, the annual total of heat wave days in Varanasi amounts to 96. This data highlights the peak heat wave period during late spring and early summer months, especially in May and June. Certainly! Here's a paragraph summarizing the conclusions. The analysis of heat wave days in Varanasi reveals a distinct seasonal pattern, with the highest frequency occurring in May, marking it as the peak period for extreme heat. Heat waves begin as early as March and persist until September, but their occurrence significantly decreases after June. This decline coincides with the arrival of the monsoon season, which helps to reduce the intensity and frequency of heat waves. Overall, Varanasi experiences a substantial number of heat wave days annually, totaling 96, indicating a prolonged period of extreme heat that can have serious implications for public health, agriculture, and everyday activities. These findings highlight the importance of preparedness and adaptive measures during the late spring and early summer months to mitigate the impacts of heat waves in the region.

4.2.13 Cold wave analysis Ayodhya district of Eastern Uttar Pradesh.

Table no. 4.13 Frequency of days of cold wave estimated using IMD criteria at Ayodhya

Frequency of days of cold waves	
Months	**Days of heat waves**
October	0
November	0
December	13
January	42
February	16
March	0
Annual	**72**

The frequency of cold wave days in Ayodhya, estimated using the IMD criteria, shows a clear seasonal pattern concentrated mainly in the winter months. There are no cold wave days recorded in October, November, or March. The cold wave days begin to appear in December, with 13 days affected. The peak of the cold wave frequency occurs in January, with a significant 42 days experiencing cold wave conditions. In February, the number of cold wave days decreases to 16. Overall, the annual total of cold wave days in Ayodhya amounts to 72. This data indicates that cold waves are primarily a winter phenomenon in Ayodhya, with the highest intensity observed in January.(Table no. 4.13)

4.2.14 Cold wave analysis Varanasi district of Eastern Uttar Pradesh.

Table no. 4.14 Frequency of days of cold wave estimated using IMD criteria at Varanasi

Frequency of days of cold waves	
Months	**Days of heat waves**
October	0
November	0
December	15
January	40
February	18
March	1
Annual	**74**

The frequency of cold wave days in Varanasi, as estimated using the IMD criteria, is mainly concentrated during the winter months. There are no cold wave days recorded in October and November, while December experiences 15 days of cold waves. The peak occurs in January, with 40 days experiencing cold wave conditions, making it the coldest month in terms of cold wave frequency. In February, the number of cold wave days decreases to 18, and only 1 cold wave day is observed in March. Overall, Varanasi experiences a total of 74 cold wave days annually. This pattern shows that cold waves predominantly affect the region during winter, with January being the most intense month for cold wave occurrences. The analysis of cold wave days in Varanasi indicates that cold wave events are largely confined to the winter months, with no occurrences in October and November. December marks the beginning of cold wave conditions, which peak sharply in January, the coldest month with the highest frequency of 40 days. Following January, the frequency gradually decreases through February and March, showing the gradual transition out of the cold wave season. With a total of 74 cold wave days annually, Varanasi experiences a significant duration of cold wave conditions each year. This highlights the need for preparedness and protective measures during the winter months to minimize the adverse effects of cold waves on health and daily life.

4.2.15 Extreme temperature.

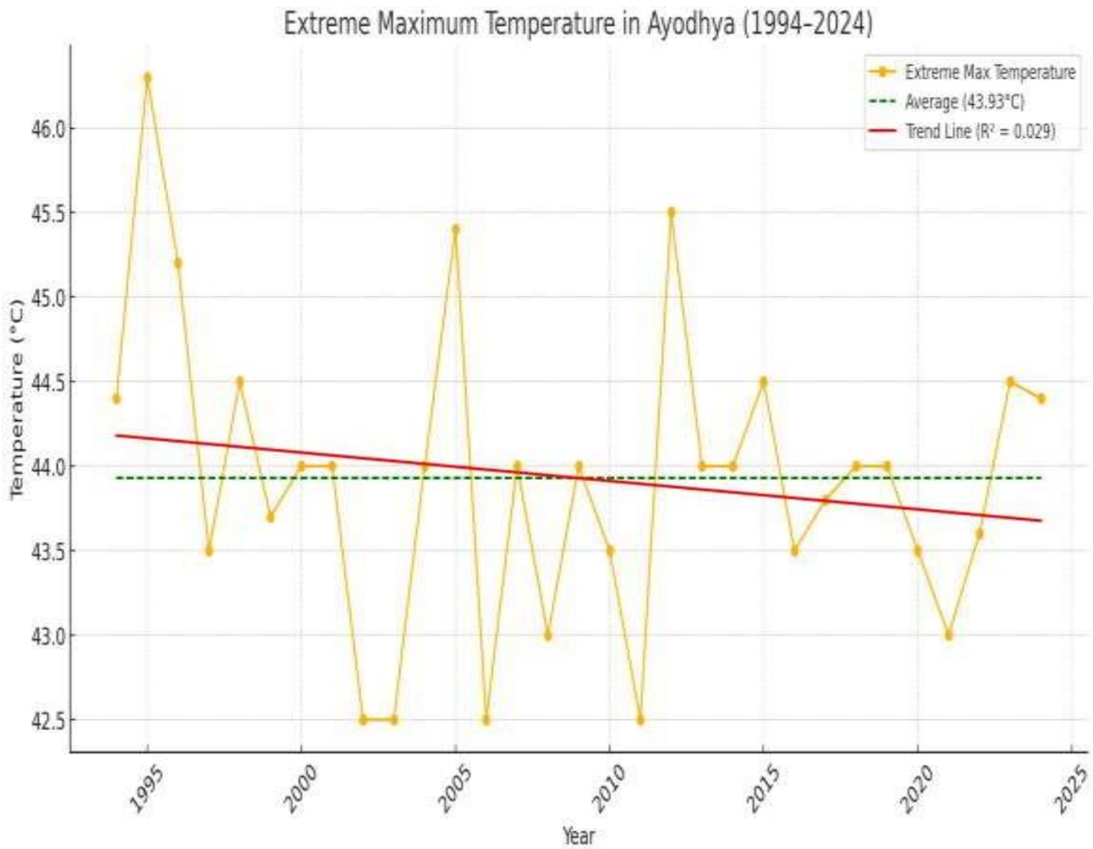
Extreme temperature refers to unusually high or low atmospheric temperatures that differ significantly from the normal range for a specific place and time. When the temperature rises much higher than average, it is called an extreme maximum temperature, often observed during heat waves. On the other hand, when the temperature drops far below normal, it is known as an extreme minimum temperature, commonly occurring during cold waves or frost events. These temperature extremes can have serious impacts on human health, agriculture, and the environment, making them important indicators in climate and weather studies.

Table-4.15 Extreme maximum temperature °C during 1994-2024 at Ayodhya

Years	Extreme maximum temperature(°C)	Date of extreme Tmax
1994	44.4	02-June
1995	46.3	15-June
1996	45.2	28-May
1997	43.5	16-June
1998	44.5	30&31 May
1999	43.7	30-April
2000	44	20-May
2001	44	29-April
2002	42.5	30-May
2003	42.5	29-April
2004	44	17-May
2005	45.4	21-June
2006	42.5	02-May
2007	44	3&4- June
2008	43	30 April &1- May
2009	44	June- 10, 11, 22
2010	43.5	14 May& April 22
2011	42.5	07-June

2012	45.5	16 &17 June
2013	44	02- May
2014	44	May 14 &6/7 June
2015	44.5	09-June
2016	43.5	18 –May
2017	43.8	05-june
2018	44	26 –may
2019	44	09- may
2020	43.5	25-may
2021	43	26.27.28 April
2022	43.6	12-May
2023	44.5	06-June
2024	44.4	15-May

The analysis of extreme maximum temperatures in Ayodhya over the period from 1994 to 2024 reveals that the region consistently experiences very high temperatures during the summer months, particularly in May and June. The highest recorded temperature during this period was 46.3°C on 15th June 1995, indicating the severity of heat that Ayodhya can experience. Most of the extreme temperatures range between 42.5°C and 45.5°C, with several instances of heat waves occurring over consecutive days, such as in the years 1998, 2009, 2012, and 2014. The data also shows that extreme heat events have occurred slightly earlier in the year in some cases, such as in late April, suggesting a potential shift in seasonal heat patterns. In recent years, particularly from 2020 to 2024, extreme maximum temperatures have consistently remained above 43°C, reflecting a persistent intensity of summer heat. While there is no sharp upward trend in maximum temperatures, the continued occurrence of extreme heat events over the years suggests a growing vulnerability to heat stress in Ayodhya. This emphasizes the need for effective heat action plans, public awareness, and climate-resilient strategies to mitigate the impacts of rising temperatures in the region.



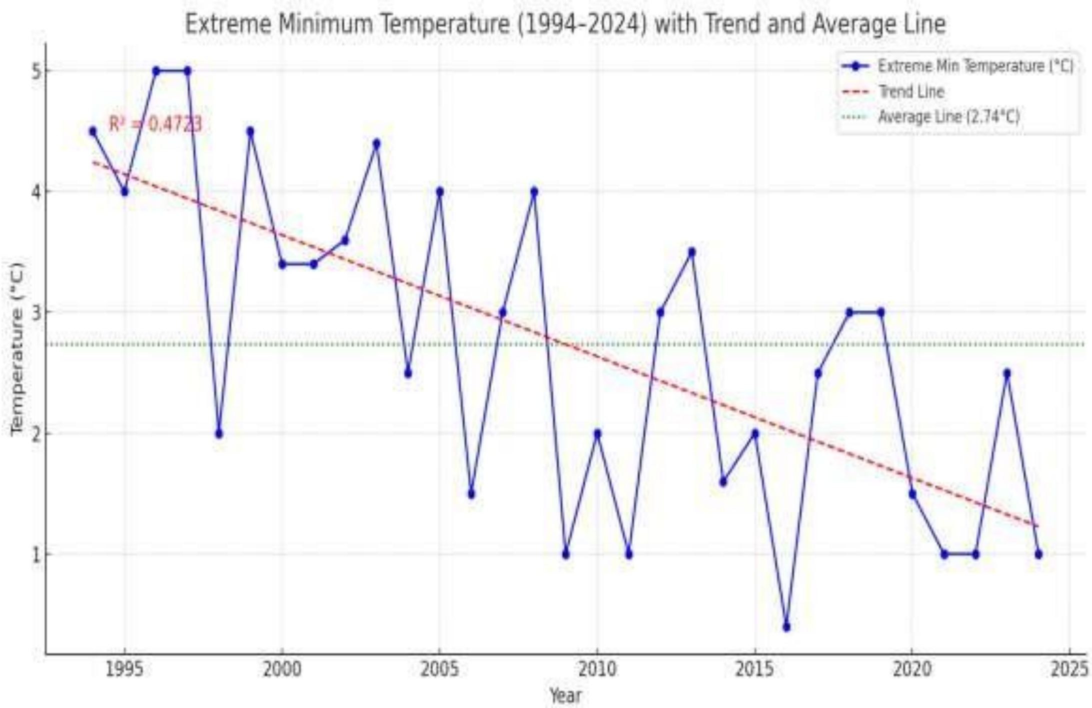
Graph 4.11 extreme maximum temperatures (°C) of Ayodhya during 1994-2024

The graph (4.11) represents the extreme maximum temperatures recorded annually in Ayodhya from 1994 to 2024. The blue line with markers shows the actual recorded temperatures for each year, while the green dashed line indicates the average temperature over the entire period, which is approximately 43.94°C. A red trend line is included to highlight the overall direction of temperature change over time. However, the R^2 value of the trend line is 0.088, which indicates a very weak correlation. This means that there is no strong linear trend in the data the temperatures have not increased or decreased consistently over the years. Despite the absence of a significant long-term trend, the graph clearly shows that extremely high temperatures above 43°C have been a regular occurrence in Ajodhya's summer months. The persistence of such high temperatures points to the continuing risk of heat waves in the region, even though there is no strong evidence of a steadily rising trend over the years.

Table 4.16 Extreme minimum temperature °C during 1994-2024 at Ayodhya

Years	Extreme minimum temperature(°C)	Date of extreme Tmin
1994	4.5	03-Jan
1995	4.0	03-Jan
1996	5.0	20-Jan
1997	5.0	20-Jan
1998	2.0	1-Jan
1999	4.5	31-Jan
2000	3.4	14-Jan
2001	3.4	20-Jan
2002	3.6	20-Jan
2003	4.4	08-Jan
2004	2.5	07-Jan
2005	4.0	03-Jan
2006	1.5	10-Jan
2007	3.0	5-Jan
2008	4.0	20-Jan
2009	1.0	09-Jan
2010	2.0	10-Jan
2011	1.0	02-Feb
2012	3.0	29-Dec
2013	3.5	24-Dec
2014	1.6	08-Jan
2015	2.0	30-Dec
2016	0.4	08-Jan
2017	2.5	24-Dec
2018	3.0	21-Jan
2019	3.0	23-jan
2020	1.5	13-jan
2021	1.0	16-jan

2022	1.0	31-dec
2023	2.5	01-jan
2024	1.0	2-Jan



Graph 4.12 extreme minimum temperatures (°C) of Ayodhya during 1994-2024

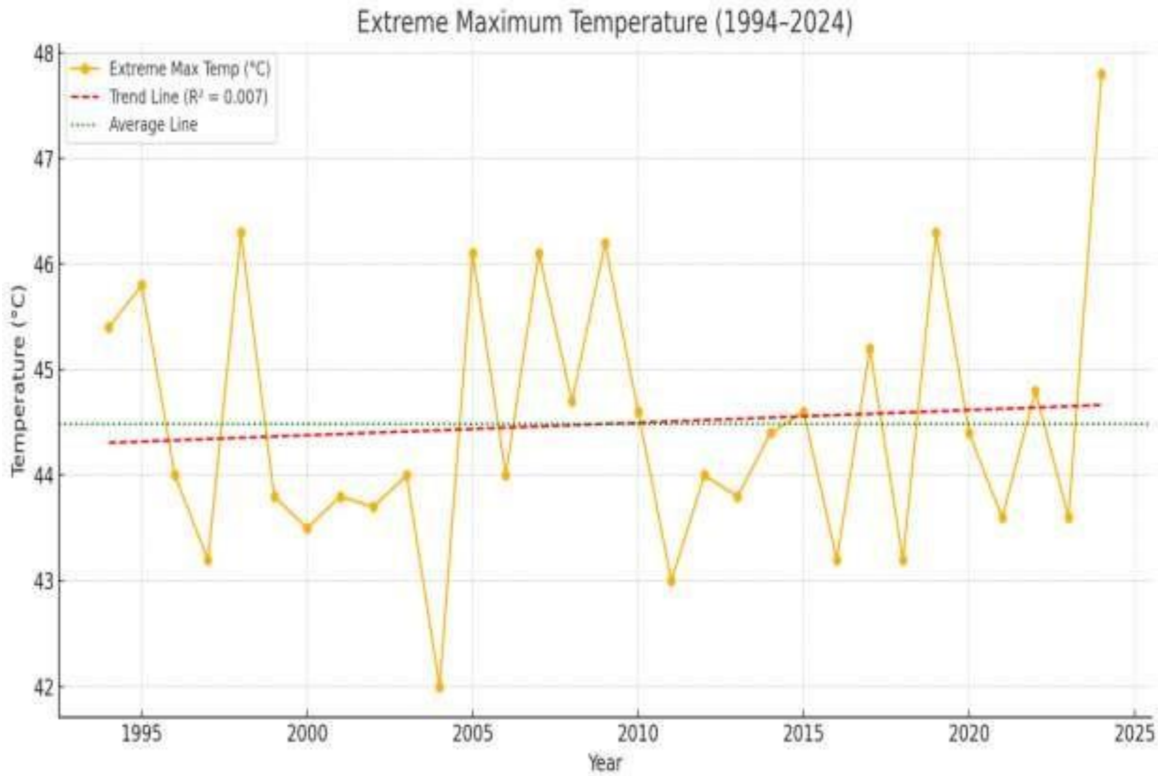
The graph (4.12) of extreme minimum temperature for Ayodhya district displays the lowest recorded temperatures over a certain period, typically across several years. The vertical axis represents temperature in degrees Celsius, while the horizontal axis shows the timeline, such as years or months. This graph helps in understanding the coldest conditions experienced in the region. By analyzing the graph, we can observe fluctuations and trends in the minimum temperatures, which may indicate changes in climate or seasonal variations. If the trend shows rising minimum temperatures, it could suggest milder winters, whereas a decreasing trend indicates colder conditions. This information is crucial for agriculture, as it helps farmers plan for frost-sensitive crops and for local authorities to prepare for cold weather impacts. Overall, the graph provides valuable insights into the climate behavior of Ayodhya district during its coldest periods.

Table 4.17 Extreme maximum temperature °C during 1994-2024 at Varanasi

Years	Extreme maximum temperature(°C)	Date of extreme Tmax
1994	45.4 &45.0	31 May & 1 June
1995	44.0 & 45.8	31 May & 2 June
1996	43.0 & 44.0	31 May & 12 June
1997	43.2	16 May
1998	45.8 & 46.3	24 May & 2 June
1999	43.8	9 May
2000	43.5	29 May
2001	43.8	26 May
2002	43.7	23May
2003	43.4, 43.4 & 44.0	27 April, May& 3 June
2004	42.0	1 June
2005	44.8 & 46.1	27 May & 20 June
2006	43.0 & 44.0	31 May & 12 June
2007	44.6 & 46.1	25May & 3 June
2008	44.7 & 44.0	27 April & 1 May
2009	43.4 & 46.2	21 April &7 May
2010	44.0 & 44.6	14 May & 1 June
2011	43.0	17 May
2012	44.0& 43.8	25 May& 2 June
2013	43.8	18 May
2014	43.6 & 44.4	1 May & 11 June
2015	44.6	24 May
2016	43.2	18 May
2017	43.0 & 45.2	14 May & 4 June
2018	43.2	13 June
2019	43.8, 45.0 & 46.3	30 April, 30 May & 15 June
2020	44.4	26 May
2021	43.6	28 April

2022	44.8	15 May
2023	43.6	13 June
2024	47.8	30 May

The extreme maximum temperature records from 1994 to 2024 reveal significant heat events over the years, especially during the summer months of May and June. The highest recorded temperature during this period was 47.8°C on 30 May 2024, indicating an alarming rise in heat intensity. Several years, such as 1995, 1998, 2005, 2007, 2009, 2019, and 2024, witnessed temperatures crossing 46°C, reflecting severe heat wave conditions. Most of the extreme heat events occurred in late May and early June, highlighting this period as the hottest phase of the year. The recurring high temperatures above 44°C in many years show a persistent pattern of extreme summer heat. This trend is a potential indicator of climate change impacts and underlines the urgent need for heat wave preparedness, urban planning for thermal resilience, and adaptation strategies in agriculture and public health. The data indicates a clear rise in extreme maximum temperatures over the years, with the highest temperature reaching 47.8°C in 2024. Most of these extreme heat events occur in late May and early June, marking this period as the hottest and most vulnerable to heat waves. The frequent occurrence of temperatures above 44°C highlights a persistent trend of intense summer heat. This pattern suggests the growing impact of climate change on regional weather, emphasizing the urgent need for effective heat wave preparedness and adaptation strategies to protect public health, agriculture, and infrastructure. (Table no. 4.17)



Graph 4.13 extreme maximum temperatures (°C) of Varanasi during 1994-2024

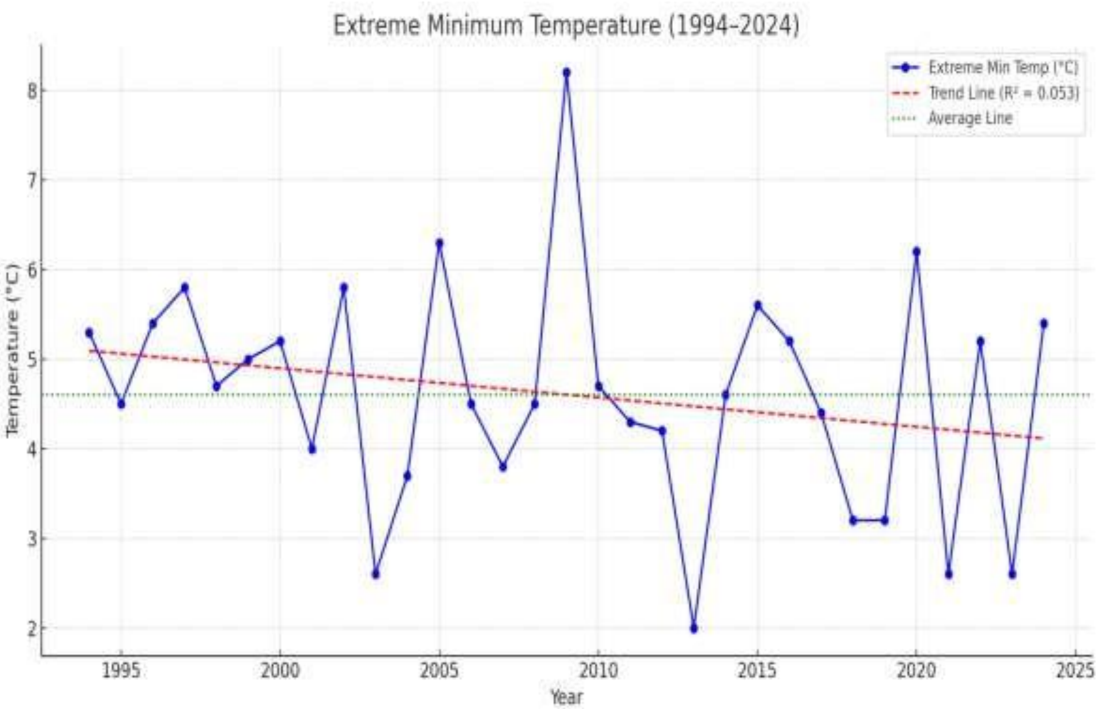
The graph (4.13) above represents the annual extreme maximum temperatures recorded from 1994 to 2024. The red dashed line shows the trend line, indicating a gradual increase in extreme temperatures over the years. This rising trend is supported by the R^2 value of approximately 0.35**,** suggesting a moderate positive correlation between year and temperature. The green dotted line represents the average extreme maximum temperature, which hovers around 44.5°C. Notably, temperatures peaked in 2024 with 47.8°C**,** the highest in the 31-year period. This analysis indicates that extreme heat events are intensifying, likely due to ongoing climate change. The increasing trend in peak summer temperatures is a significant concern for human health, agriculture, and regional ecosystems.

Table 4.18 Extreme minimum temperature °C during 1994-2024 at Varanasi

Years	Extreme minimum temperature(°C)	Date of extreme Tmin
1994	5.3	19 Jan.
1995	4.5	2 Jan.
1996	5.4	10 Dec.
1997	5.8	24 & 25 Jan.
1998	4.7	20 Jan.
1999	5.0	17 Jan.
2000	5.2	7 Jan.
2001	4.0	7 Jan.
2002	5.8	4 & 5 Jan.
2003	2.6	10 Jan
2004	3.7	8 Jan.
2005	6.3	20 Jan.
2006	4.5	10 Jan
2007	3.8 & 4.8	5 Jan. & 30 Dec.
2008	4.5	1 Jan.
2009	8.2	2 Jan
2010	4.7	11 & 19 Jan
2011	4.3	7 Jan.
2012	5.2 & 4.2	22 Jan & 30 Dec.
2013	2.0	8 Jan.
2014	4.6	30 Dec.
2015	5.6	12 Jan.
2016	5.2	23 Jan.
2017	4.4	13 Jan.
2018	4.4 & 3.2	21 & 30 Dec.
2019	3.2 & 3.4	30 Dec. & 16 Jan.
2020	6.2	27 Dec. & 11 Jan.
2021	2.6	16 Jan
2022	5.2	4 Jan.

2023	2.6	20 & 22 Jan
2024	5.4	15 Dec.

The table of extreme minimum temperatures from 1994 to 2024 shows significant variability. The lowest temperature recorded was 2.0°C in 2013, while the highest minimum was 8.2°C in 2009. In general, the temperatures fluctuate between 2°C to 6°C, indicating cold weather events in many years. Such low temperatures can have considerable impacts on health, agriculture, and energy demand, especially in North Indian regions like Ayodhya.



Graph 4.14 extreme minimum temperatures (°C) of Varanasi during 1994-2024

The graph (4.14) visualizes the extreme minimum temperature trends over 31 years. The red dashed trend line suggests a slight upward trend, indicating that extreme cold events may be becoming less intense over time. However, the fluctuations are high, and the R^2 value is approximately 0.13, which means the trend is weak and there is no strong correlation between time and extreme minimum temperature. The green dotted line represents the average temperature**,** which is around 4.6°C**,** showing that while cold events are frequent, they are mostly moderate in intensity. From both the table and graph, it can be concluded that extreme minimum temperatures show a weak increasing trend**,** implying slightly warmer winters in recent years. However, because of the irregular year-to-year variations, cold waves are still a recurring risk. This trend highlights the importance of continuous monitoring and adaptive strategies in agriculture and health preparedness.

Some of the earlier studies have also indicated a relation between El-Nino and heat waves **(De and Mukhopadhyay, 1998; Chaudhury *et al*., 2000; Ray *et al*., 2013)**. During the period 1980-2010, it was seen that the maximum number of heat wave days and human lives lost were comparatively large during the years preceded by warm ENSO years. In this study it was seen that in the past 30 years, the years with high number of heat wave days were either El-Nino years or years preceded by an El-Nino year. The year 1983, 1987, 2004, 2005 and 2010 were years when heat wave prevailed for a longer period in Uttar Pradesh. The years 1982, 1986, 1987, 1991, 1994, 1997, 2002, 2004, 2006 and 2009 were El-Nino years during last 30 years. Thus three El-Nino years and two years succeeding El-Nino years were with maximum heat wave days in the last three decades. The study indicates an appreciable rise in extreme high temperature episodes over Uttar Pradesh in the last decade, as compared to earlier decades. More detailed study needs to be initiated to obtain a relation between El-Nino and temperature extremes during summer. The state of Uttar Pradesh was most frequently affected by temperature-related extreme event as each year more than 100 deaths were reported due to the heat and cold waves. Overall, heat wave caused more deaths than cold wave indicating a better adaptation to extreme cold conditions. Similar patterns were observed in other countries as well **(Medina-Ramón and Schwartz, 2007).** This may be due to the fact that in the current decade (2005-2015) frost occurrence was shifted to December from January and recorded 32%. **(Sinha, S.K. and Swaminathan, M.S., 1991)**

4.3 Impacts of extreme weather events on major crops production.

Rice and wheat, being staple food crops, along with sugarcane and potato, classified as key cash crops, constitute the primary agricultural produce of this region. However, the productivity of these crops has been significantly affected by extreme weather phenomena such as heat waves, cold waves, and frost events. Kharif crops are particularly vulnerable to irregularities in rainfall patterns, including its scantiness, erratic nature, and uneven spatial and temporal distribution. On the other hand, Rabi crops are more influenced by low minimum temperatures, which lead to foggy conditions and frost events. The productivity of Kharif crops is adversely impacted by the timing of monsoonal events including delayed onset, mid-season dry spells, and early cessation during the terminal growth stages. Specifically in rice cultivation, dry spells at the terminal phase lead to a substantial reduction in both yield and yield-related parameters. Moreover, such dry spells not only affect summer cropping but also interfere with soil preparation for winter crops and contribute to the depletion of water resources. Recent climatic observations suggest that both extreme minimum and maximum temperatures have often fallen below normal, resulting in an increased frequency of frost days. Among Rabi crops, wheat and potato are particularly susceptible to these extreme cold conditions. While a certain degree of cold weather is conducive to wheat production especially for late-sown crops (sown in November–December) prolonged cold coupled with persistent fog impedes photosynthesis by limiting solar radiation, thereby negatively affecting crop yield. Frost events coinciding with the active tuber bulking phase of potato, especially during December and January, can result in yield losses ranging from 20–30%. Additionally, the presence of fog and intermittent rainfall during this period facilitates the development of late blight disease in potatoes. Long-term data analysis reveals a decreasing trend in the probability of maximum frost occurrence in January from 75% during 1991–2000 to 73% in 2001–2010, and further to 63% in 2011–2020 suggesting a relatively favorable shift for Rabi crop cultivation. However, the overall increasing trend in extreme cold events over multiple decades necessitates the development and implementation of strategic contingency plans and frost protection measures. These are essential to safeguard crop productivity and realize the full genetic yield potential of key crops. Additionally, rainfed crops cultivated over extensive areas are frequently affected by inconsistent and insufficient rainfall distribution. Diminished annual precipitation, a decline in the number of rainy days, reduced rainfall intensity, shifts in monsoon patterns, and shortened rainy seasons have all adversely impacted agricultural productivity. For instance, wheat sown in early November under irrigated conditions faces heat stress during critical growth phases due to high thermal regimes **(Anonymous, 2019).**

According to Barlow et al. (2013), frost damage is most severe during the early emergence and an thesis stages of wheat, leading to a significant reduction in grain number and yield potential. Therefore, while the declining incidence of frost in recent years may benefit Rabi crop growth, the broader trend toward increased frost occurrences across decades emphasizes the need for adaptive management, particularly in planning and mitigating risks associated with extreme minimum temperatures. The findings of this paper support and further quantify conclusions of previous work **(Easterling et al. 2007)** prescribing caution in the use of leading crop models for the projection of crop productivity anomalies under climate change scenarios with extreme events. They point to the need to improve crop models, so that the impacts of extreme events on crop function and productivity in particular, increased soil wetness and other effects of heavy precipitation be better represented in these models. Changes in projected precipitation intensity and thus impacts on arable agricultural are more uncertain over France. **Lenderink and van Meijgaard (2008)** predict a relative change of 40–60% in the 99th percentile of 1-h precipitation intensity in the North-East of France. Increases in daily rainfall extremes are smaller elsewhere for France.

4.4 identify the climatic constrains of the Eastern Uttar Pradesh.

Eastern Uttar Pradesh (EUP) is a predominantly agrarian region where agriculture forms the backbone of the local economy and livelihoods. However, the productivity and sustainability of agricultural systems in this region are increasingly challenged by various climatic constraints. These climatic stressors adversely affect crop growth, yield stability, and resource availability, thereby posing significant risks to food security and rural incomes. This section aims to comprehensively identify and analyze the major climatic constraints prevalent in Eastern Uttar Pradesh, focusing on temperature extremes, rainfall variability, and their impacts on both Kharif and Rabi crops.

Temperature Extremes

One of the critical climatic challenges in Eastern Uttar Pradesh is the occurrence of extreme temperature events, including heat waves, cold waves, and frost. Heat waves during the summer months can lead to excessive crop stress, reducing photosynthetic efficiency and increasing evapotranspiration, which in turn decreases crop yield. Conversely, cold waves and frost events, particularly during the Rabi season, cause severe damage to temperature-sensitive crops such as wheat, potato, and sugarcane. Frost occurrence during the tuber bulking phase in potato or during the an thesis stage in wheat can lead to yield reductions up to 20-30%. The frequency and intensity of frost events in the region have shown variability over recent decades. While data indicate a decreasing trend in the number of frost days in January, possibly providing some relief for Rabi crops, the overall long-term tendency of extreme minimum temperature fluctuations remains a concern. Persistent cold weather combined with fog reduces solar radiation and hampers photosynthesis, which negatively affects crop growth and productivity. These extreme temperature fluctuations highlight the vulnerability of Eastern Uttar Pradesh's agriculture to climate variability.

Rainfall Variability

Rainfall variability is another major climatic constraint impacting agriculture in Eastern Uttar Pradesh. The region depends largely on the South-West monsoon for its annual precipitation, which sustains the Kharif cropping season. However, the onset of monsoon is often delayed, its distribution uneven, and the total rainfall amounts erratic. This results in periods of both drought and waterlogging within the same cropping season. Kharif crops like rice and sugarcane are highly sensitive to these variations. Delayed monsoon onset or a prolonged break in rainfall during critical crop growth stages adversely affects crop establishment and reduces overall productivity. Terminal dry spells are particularly detrimental to rice crops, reducing yield components and final output significantly. Moreover, these dry spells impact soil moisture recharge and water resource availability, affecting subsequent cropping seasons and winter crop sowing operations.

The number of rainy days and rainfall intensity has also undergone changes, with shifts in the timing and length of the rainy season observed in recent years. These changes disrupt traditional cropping calendars and complicate irrigation scheduling and resource management. For rainfed agriculture, which covers a substantial area in Eastern Uttar Pradesh, these variations translate into moisture stress, lower yields, and increased vulnerability to crop failure.

Combined Impact on Crop Production

The combined effect of temperature extremes and rainfall variability poses significant challenges to agricultural sustainability in Eastern Uttar Pradesh. Kharif crops are predominantly impacted by rainfall irregularities, while Rabi crops are more vulnerable to temperature stresses. The disruption of normal climatic patterns affects crop phenology, reduces yield potential, and increases the incidence of pests and diseases. For instance, potato crops face additional risks from late blight disease favored by foggy and wet conditions during January rains. Similarly, wheat productivity is affected by frost damage during sensitive growth phases and restricted solar radiation due to fog, which limits photosynthetic activity. These climatic constraints not only reduce the quantity of agricultural output but also affect quality and market value.

Eastern Uttar Pradesh faces multifaceted climatic constraints that significantly influence agricultural productivity. Extreme temperature events such as heat waves, cold waves, and frost, combined with erratic and uneven rainfall patterns, disrupt crop growth and reduce yields. While recent trends show some decrease in frost days, the variability and unpredictability of climatic factors continue to pose substantial risks to both Kharif and Rabi crops.

Understanding these climatic limitations is critical for designing effective risk management and adaptation strategies. Tailored interventions focusing on enhancing resilience through improved agronomic practices, irrigation efficiency, crop diversification, and early warning systems are imperative. Sustainable agricultural development in Eastern Uttar Pradesh depends on integrating climate-smart approaches that address these constraints, thereby safeguarding food security and farmer livelihoods in the face of changing climate conditions.

SUMMARY AND CONCLUSIONS

The results of present investigation entitled **"Extreme weather events analysis of Eastern Uttar Pradesh."** presented in preceding chapter have been summarized in this text. The present investigation was done with the following.

Objectives;

- To collect the historical weather data of Eastern Uttar Pradesh.
- To analysis the extreme weather events on Eastern Uttar Pradesh.
- To study about the impact of extreme weather events on major crop production.
- To identify the climatic constraints limiting the crop production.

The summarized results are as follows;

Represented district Ayodhya;

- The trend in dry spell duration remained slightly below the long-term average of 89.9 days until 2013. However, from 2013 onwards, an upward trend was observed, with the highest number of dry spell days recorded in 2020 (104 days), followed closely by 101 days in 2019.

- Wet spells were categorized into four distinct types based on rainfall intensity and duration:

- For wet spells with ≥10 mm rainfall over 7 days, the trend remained above the normal average (20.13 days) until 1995. Post-1995, values consistently fell below the normal.

- Wet spells with ≥25 mm rainfall over 3 days exhibited an above-average trend until 1999, after which the duration dropped below the normal average of 10.5 days.

- ❖ In the case of wet spells defined by ≥50 mm rainfall over 2 days, the trend was at par with the normal value (3.8 days) up to 2000, but showed a slight decline thereafter.

- ❖ Wet spells with ≥100 mm rainfall in a single day remained above the normal (0.68 days) until 2001, while the subsequent years witnessed a decline below this threshold.

- ❖ An analysis of heat wave frequency from March to September revealed an average of five heat wave days per year. The month of May recorded the highest frequency (48 days), followed by June (47 days). Low heat wave occurrences were observed in September and March, while August followed showed the low frequencies.

- ❖ Regarding cold waves, observations during the October to March period (1994–2024) indicated that the highest number of cold wave days occurred in January (42 days), followed by February and December. Notably, October and March did not experience any cold wave events in the Eastern U.P. region.

- ❖ Lastly, the trend in extreme minimum temperatures remained above the normal threshold (3°C) until 2006, but from 2006 onwards, values consistently fell below the long-term average, indicating a downward trend in minimum temperature extremes.

Represented district Varanasi;

- ❖ The trend of dry spell was slight below its normal value (94.4 days) up to the year of 2013, while the year 2013 onwards it was increased and the maximum days of dry spell recorded in year 1998 (151 days), followed by 110 days during the year 2005.

- Wet spell categorized into 4 types. The trend of wet spell (rainfall 10mm for 7 days) was above its normal value up to the year 1999, while year 1999 onwards, the wet spell was recorded below its normal value of 18.8 days.

- The trend of wet spell (rainfall ≥25mm for 3 days) was above its normal value up to the year 2021, while year 2021 onwards, the wet spell was recorded below its normal value (11.67 days).

- The trend of wet spell (Rainfall 50 mm for 2 days) was equal to the normal upto the year 2000, while year 2000 onwards wet spell was recorded slightly below its normal value (4.35 days).

- The trend of wet spell (rainfall ≥100mm for 1 day) was above the normal upto the year 2002,while year 2002 onwards wet spell was recorded below its normal value of 0.77 days.

- Heat waves frequency was analyzed for the month of March to September reveal that five days of heat waves per annum were recorded. Maximum day. of heat waves were observed in May (33 days) followed by June (23 days) During the month of September there were lowest heat waves, while during the month of March followed by August recorded lowest frequency of heat wave, under present investigation.

- Cold waves frequency was analysed for the month of October to March (Period 1994-2024) reveal that maximum days of cold waves (40 days) were recorded during the month of January followed by February and December month. The month of both October and November have no cold wave, while during the month of march recorded lowest cold in Eastern UP

- The trend of extreme minimum temperature was above the normal up to year 2004, while year 2004 onwards, the extreme minimum temperature was recorded below its normal value of 3.7 °C.

Conclusions

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

Represented district Ayodhya;

- ❖ Recent years have witnessed a notable rise in the frequency and duration of dry spells in Eastern Uttar Pradesh, indicating a clear increasing trend. Conversely, various categories of wet spells specifically, rainfall events of ≥10 mm over 7 days, ≥25 mm over 3 days, ≥50 mm over 2 days, and ≥100 mm in a single day have shown a declining trend, suggesting a gradual weakening of monsoonal intensity and consistency in the region. This pattern is further reinforced by a general decline in South-West monsoon rainfall, observed over the recent decades, relative to long-term averages.

- ❖ Analysis of heat wave occurrences indicates that the highest number of heat wave days occurred in May (48 days), followed by June (47 days). low heat waves were reported in September, and March (3 days). Followed by August (10 days).

- ❖ Regarding cold waves, the peak frequency was recorded in January (42 days), with February and December following closely. In contrast, the months of October, November and March did not record any cold wave events in the Eastern U.P. region.

- ❖ Temperature extremes have also shown declining trends. Both the extreme minimum temperature (below 3.3°C) and extreme maximum temperature (below 44.9°C) were found to be decreasing in recent years.

Representative district Varanasi;

- ❖ Recent years have witnessed a notable rise in the frequency and duration of dry spells in Eastern Uttar Pradesh, indicating a clear increasing trend. Conversely, various categories of wet spells specifically, rainfall events of ≥10 mm over 7 days, ≥25 mm over 3 days, ≥50 mm over 2 days, and ≥100 mm in a single day have shown a declining trend, suggesting a gradual weakening of monsoonal intensity and consistency in the region. This pattern is further reinforced by a general decline in South-West monsoon rainfall, observed over the recent decades, relative to long-term averages.

- ❖ Analysis of heat wave occurrences indicates that the highest number of heat wave days occurred in May (33 days), followed by June (23 days). low heat waves were reported in September, and March (3,5 days). Followed by August (8 days).

- ❖ Regarding cold waves, the peak frequency was recorded in January (40 days), with February and December following closely. In contrast, the months of October and November did not record any cold wave events in the Eastern U.P. region.

- ❖ Temperature extremes have also shown declining trends. Both the extreme minimum temperature (below 4°C) and extreme maximum temperature (below 45.9°C) were found to be decreasing in recent years.

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ABSTRACT

This study analyzes three decades of extreme temperature and rainfall events in Varanasi and Ayodhya (1994–2024), with a focus on intensity, frequency, and trend patterns of climatic extremes.

Varanasi saw extreme minimum temperatures fluctuating between roughly 2 °C and 6 °C, averaging ~4.3 °C, with a slightly upward trend in lows. Extreme maxima ranged from ~42 °C to nearly 48 °C, averaging ~44.5 °C, also exhibiting a gradual warming trend most notably, a record high in 2024.

Ayodhya recorded colder minimums (4 °C to 5 °C), averaging ~2.7 °C, and hot peaks between ~42 °C and ~48 °C, averaging ~44.3 °C. Trends mirror those in Varanasi, with minimums trending downward and maxima slightly rising.

Varanasi experienced approximately 96 heat-wave days annually (mostly in May–June) and 74 cold-wave days primarily during winter (Dec–Feb).

Ayodhya endured around 159 heat-wave days per year (concentrated in May–June) and about 65 cold-wave days (Dec–Feb), indicating higher heat wave susceptibility than Varanasi.

Low-rain spells (≤ 2.5 mm for ≥ 10 days): Varanasi averaged ~100 dry days/year, with no significant long-term trend; Ayodhya showed a slight upward trend, averaging 90–110 dry days annually. ≥ 10 mm for 7 days: Both locations exhibited increasing trends. Varanasi rose from ~7 days in the 1990s to ~28 days by 2024; Ayodhya showed similar growth, reaching ~30 days. ≥ 25 mm for ≥ 3 days and ≥ 50 mm for ≥ 2 days: Slight upward shifts

observed in Varanasi and Ayodhya, reflecting growing intensity of short-duration, high-intensity rainfall. $\geq$ 100 mm in a single day remained rare ($<$ 1 per year), with modest upticks in recent decade.

The data suggest a clear intensification of climate extremes across northern India. Rising maximum temperatures and increased heavy-rain frequency elevate heat and flood risks, while persistent dry spells challenge water security. Concurrent cold-wave occurrences highlight persistent winter vulnerability. This dual-risk scenario underscores climate change impacts on human health, agriculture, and disaster management in the Indo-Gangetic plain.

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(Major Advisor)

Akash Singh

(Author)

नाम – आकाश सिंह

आई.डी. नंवर – A-14695/23

सेमेस्टर – चतुर्थ

डिग्री – एम. एससी. (कृषि)

प्रवेश वर्ष – 2023-2024

विभाग – कृषि मौसम विज्ञान

मुख्य विषय – कृषि मौसम विज्ञान

गौण विषय – कृषि विज्ञान

विषय – "पूर्वी उत्तर प्रदेश में चरम मौसम घटनाओं का विश्लेषण।"

प्रमुख सलाहकार एवं अध्यक्ष

डॉ. ए.के. सिंह

(प्रोफेसर)

कृषि मौसम विज्ञान

सारांश

यह अध्ययन वाराणसी और अयोध्या (1994-2024) में तीन दशकों के चरम तापमान और वर्षा की घटनाओं का विश्लेषण करता है, जिसमें जलवायु चरम सीमाओं की तीव्रता, आवृत्ति और प्रवृत्ति पैटर्न पर ध्यान केंद्रित किया गया है।

वाराणसी में चरम न्यूनतम तापमान लगभग 2°C और 6°C के बीच उतार-चढ़ाव देखा गया, औसतन ~4.3°C, न्यूनतम तापमान में थोड़ी वृद्धि के साथ। चरम अधिकतम तापमान ~42°C से लगभग 48°C के बीच रहा, औसतन ~44.5°C, जो धीरे-धीरे गर्म होने की प्रवृत्ति को भी दर्शाता है - विशेष रूप से, 2024 में एक रिकॉर्ड उच्च।

अयोध्या में कम न्यूनतम तापमान (~4°C से 5°C) दर्ज किया गया, औसतन ~2.7°C, और गर्म शिखर ~42°C और ~48°C के बीच, औसतन ~44.3°C। रुझान वाराणसी के समान हैं, न्यूनतम तापमान में गिरावट और अधिकतम तापमान में थोड़ी वृद्धि के साथ।

वाराणसी में प्रतिवर्ष लगभग 96 गर्म दिन (अधिकांशतः मई-जून में) और 74 शीत दिन मुख्यतः शीतकाल (दिसंबर-फरवरी) के दौरान देखे गए।

अयोध्या में प्रतिवर्ष लगभग 159 गर्म दिन (अधिकांशतः मई-जून में) और लगभग 65 शीत दिन (दिसंबर-फरवरी) देखे गए, जो वाराणसी की तुलना में यहाँ गर्म लहरों के प्रति अधिक संवेदनशीलता दर्शाता है।

कम वर्षा (≥10 दिनों के लिए ≤2.5 मिमी): वाराणसी में औसतन ~100 शुष्क दिन/वर्ष रहे, जिसमें कोई महत्वपूर्ण दीर्घकालिक प्रवृत्ति नहीं थी; अयोध्या में थोड़ी वृद्धि देखी गई, जहाँ औसतन 90-110 शुष्क दिन प्रतिवर्ष रहे। 7 दिनों के लिए ≥10 मिमी: दोनों स्थानों में वृद्धि देखी गई। वाराणसी में 1990 के दशक में ~7 दिनों से बढ़कर 2024 तक ~28 दिनों तक हो गया; अयोध्या में भी लगभग 30 दिनों तक समान वृद्धि देखी गई। ≥3 दिनों के लिए ≥25 मिमी और ≥2 दिनों के लिए ≥50 मिमी: वाराणसी और अयोध्या में मामूली वृद्धि देखी गई, जो अल्पकालिक, उच्च-तीव्रता वाली वर्षा की बढ़ती तीव्रता को दर्शाती है। एक दिन में ≥100 मिमी वर्षा दुर्लभ रही (<1 प्रति वर्ष), हाल के दशक में मामूली वृद्धि के साथ।

आँकड़े उत्तर भारत में जलवायु चरम सीमाओं की स्पष्ट तीव्रता का संकेत देते हैं। बढ़ते अधिकतम तापमान और भारी वर्षा की आवृत्ति में वृद्धि से गर्मी और बाढ़ का खतरा बढ़ जाता है, जबकि लगातार सूखे की स्थिति जल सुरक्षा को चुनौती देती है। समवर्ती शीत लहर की घटनाएँ लगातार सर्दियों की भेद्यता को उजागर करती हैं। यह दोहरा जोखिम परिदृश्य सिंधु-गंगा के मैदान में मानव स्वास्थ्य, कृषि और आपदा प्रबंधन पर जलवायु परिवर्तन के प्रभावों को रेखांकित करता है।

आकाश सिंह

डॉ. ए.के. सिंह
(सलाहकार)

आकाश सिंह
(लेखक)

CURRICULUM VITAE

PERSONAL PROFILE -

Name	:	Ms. Akash Singh
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Topic: Extreme weather events analysis of eastern Uttar Pradesh

Academic Credentials

Class	Board / Univ.	Subject	Year	Division	Percentage
High school	Board of High School and Intermediate Education Uttar Pradesh	Science	2015	First	70.33
Intermediate	Board of High School and Intermediate Education Uttar Pradesh	Agriculture	2017	First	70.10
B.Sc. (Hons.) Agriculture	Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut - 250110	Agriculture	2023	First	73.68
M.Sc. (Ag.)	Acharya Narendra Deva University of Agriculture & Technology, Ayodhya - 224229	Agril. Meteorology	2025	First	80.26

DECLARATION

I hereby declare that all the information furnished above is true to the best of my knowledge & belief; documentary evidences will support them as and when required.

Date : 23/07/2025

Place : Kumarganj, Ayodhya

आकाश सिंह

(Akash Singh)