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Zaimila Shaiza

Research Scholar, William
Carey University, Shillong,
Meghalaya, India

Maitreyee Roy

William Carey University,
Shillong, Meghalaya, India

Trend analysis of temperature and rainfall variability in Ukhrul district, Manipur (1990-2024)

Zaimila Shaiza and Maitreyee Roy

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Abstract

Climate variability poses a range of problems for agriculture, water resources, and rural livelihoods. It is Mainly challenging for regions that are sensitive to climate change like Northeast India. To understand the trends in temperature and rainfall in Ukhrul District, Manipur from 1990 to 2024, this paper employed long-term climate data mainly from NASA POWER, which was then cross-checked with the records of the Indian Meteorological Department (IMD). The Mann-Kendall trend test and Sen's slope estimator were used for seasonal and annual trend analyses, whereas the impact of rainfall anomalies on changes was assessed through the Climate Variability Index (CVI). Results showed a notable rise in minimum temperature (Sen's slope = 0.019C per year, $p = 0.002$), implying gradual night-time warming, though mean annual temperature remained unchanged while maximum temperature was slightly decreasing but not Quite a bit. Four seasons and annual rainfall all showed significant increasing trends except for pre-monsoon rainfall, which declined Much - Monsoon season contributed 59.5% of total annual rainfall So strengthening the dependency of the district's agriculture, mainly rain-fed, on it.CV I severity ranking identified late 1990s and early 2000s drought episodes, Mostly 2000 and 2001, whereas quite a few years post 2010 witnessed very wet or extremely wet scenarios reflecting increasing hydro-climatic variability. Through a survey of 542 farmers, accounts of irregular rainfall, late coming of monsoon, decreased crop yields, and more frequent extreme weather events were recorded. Among the adaptation methods taken by farmers were changing planting dates, rainwater harvesting, and mixed cropping. The authors came to a decision that the climate of Ukhrul district is becoming more variable at nighttime with the temperature rising and changing rainfall patterns, Because of this the district should be prepared for climate change through introduction of agricultural practices that can withstand droughts, conserving water and planning with a view to adapting to help communities become more resilient locally.

Keywords: Climate variability, temperature trends, rainfall variability, climate variability index (CVI), climate change adaptation, Ukhrul district, Manipur

1. Introduction

Climate variability and climate change are considered by experts as the major environmental threats of this century. They are causing changes in the natural environment, depletion of water resources, reducing the yield of crops, and impacting the lives of people all over the world (IPCC, 2023). Changing temperature and rainfall patterns impact the water cycle, soil moisture, plant growth, and the variety of living organisms, Because of this changing the operation of socio-ecological systems (Field *et al.* 2014; Trenberth *et al.* 2015). Also, extreme weather events such as droughts floods heat waves, and erratic rainfall patterns are increasing in frequency and intensity, and this is causing more concern about food security and the goal of sustainable development (Alexander *et al.* 2006; Dore, 2005; FAO, 2021). India's climate has been changing Really over the last few decades, as evidenced by increasing temperatures, alteration in monsoon patterns and more frequent climate extremes (Krishnan *et al.* 2020). The Indian summer monsoon is the single source of 7580% of the country's total annual rainfall and is a lifeline for agriculture, water resources and rural livelihoods (Goswami *et al.* 2006). Many researchers have found that monsoon rainfall has varied Quite a bit in space and time, creating a situation of unpredictability for agricultural production and resource management (Roxy *et al.* 2015; Guhathakurta *et al.* 2020). Not only that, but higher temperatures and the changing rain patterns are increasing risks of insufficient water and lower crop yields throughout India (Kumar *et al.* 2004; Lal, 2001) [1, 2, 3, 13, 14, 4, 5, 6, 7, 8, 15].

Corresponding Author:

Zaimila Shaiza

Research Scholar, William
Carey University, Shillong,
Meghalaya, India

Due to its varied geographical features, rich ecosystems, and high dependence on monsoon rainfall, Northeast India is among the most climate sensitive areas of the country (Das *et al.* 2009). It is located in the Eastern Himalayan and Indo-Myanmar biodiversity hotspots and the temperature and rainfall change a lot with elevation and among landscapes (Sharma *et al.* 2016). Temperature increase, rainfall pattern changes, and more extreme weather events have all been confirmed by several studies in this region (Jain *et al.* 2013; Krishnan *et al.* 2020). The effects of these climatic variations on agriculture, water resources, conservation of biodiversity, and food security are profound (Das *et al.* 2009; Sharma *et al.* 2016).

Manipur, among the northeastern states of India, has been identified as one of the most vulnerable states to climate change with its mountainous terrain, fragile ecosystem and agriculture as the main source of livelihood (Government of Manipur, 2013). Rainfall changes, late monsoons, prolonged droughts and rising temperatures, among other climate factors, have affected crop yields and water availability in the entire Northeast India region (Jain *et al.* 2013; Guhathakurta *et al.* 2020; Krishnan *et al.* 2020). Ukhrul District situated in the east of Manipur is famous for its difficult hilly terrain, diversity of flora and fauna and economy based mostly on agriculture. Being highly agriculture dependent on rainfall, the people in this area are very vulnerable to climate change and environmental stress (Government of Manipur, 2013).

Though climate change impacts on Northeast India are being increasingly discussed, there are few detailed studies at the district level about the long-term temperature and rainfall changes. Most research work has been done on a larger regional level. So ignoring local climate factors which directly affect agriculture and livelihoods of different communities (Jain *et al.* 2013; Guhathakurta *et al.* 2020). Besides that, a thorough knowledge of past patterns of temperature and rainfall is crucial to come up with suitable measures to tackle climate change and enhance resilience of the farming communities. Because of this, the objectives of this paper are to: (i) analyze yearly and seasonal temperature changes, (ii) check rainfall fluctuations and weather extremes and (iii) discuss climate variability effects on agriculture and rural livelihoods of Ukhrul District [16, 9, 10, 11, 5, 9, 10, 11, 12, 8].

2. Materials and Methods

Study Area: Manipur's Ukhrul District, an area at the India-Myanmar border in the northeast of India, was where the investigation was carried out. The district is framed by 2430'N and 2541'N latitude and 9403'E and 9447'E longitude. Covering about 4,544 km, Ukhrul is mainly a mountainous area characterized by steep slopes and a range of heights from roughly 900 m to more than 3000 m above sea level. The district is also a part of the Indo-Myanmar biological hotspot and is home to diverse flora and fauna (Government of Manipur, 2013) [12]. The district's climate is a humid subtropical type with four distinct seasons: winter, pre-monsoon, monsoon, and post-monsoon. During June to September, most of the annual precipitation is from the southwest monsoon and since farming is mainly by irrigation from rain, it is very much dependent on the climate. The major products of the district are rice maize pulses, and vegetables. Because of the reliance of the people

on agriculture, the district is very prone to changes and irregularities in the weather.

Climate Data Sources

Long-term climatic data for the period 1990-2024 were obtained from the National Aeronautics and Space Administration (NASA) POWER database, which provides meteorological and climatological variables derived from satellite observations, assimilation systems, and global climate datasets (Sparks, 2018). Because of its data quality and extensive spatial coverage, NASA's POWER dataset became the main one for climate variability and agricultural studies in areas that are lacking in climatic data.

Temperature and rainfall data from India Meteorological Department (IMD) have been used to improve data robustness and facilitate cross-checking. To trend analysis, monthly temperature and rainfall data have been aggregated at annual and seasonal level. Seasonal divisions were following Indian Meteorological Department's standard: winter (December to February), pre-monsoon (March to May), southwest monsoon (June to September), and post-monsoon (October to November). Trend Analysis

Trend Analysis

Non-parametric MannKendall (MK) trend test and Sen's slope estimator were employed to investigate the long-term trends of temperature and precipitation. Since the distribution of hydro-climatic data is not always normal and these data may contain outliers, the chosen methods are popular because of the first one being the least affected with outliers and the second one being robust against the normality assumption (Mann, 1945; Kendall, 1975; Sen, 1968). MannKendall test is used to figure out whether there is a rising or falling trend in a climate variable that is significant statistically. The test statistic (S) is the result of a series of comparisons between each data point and the points that follow it. An increasing trend is indicated by a positive value of the standardized Z, while a negative value points to a decreasing trend. Statistical significance was determined using the 95% confidence level ($p < 0.05$).

To determine the strength of the trends detected, Sen's slope estimator was brought into play. All of pairwise slopes between observations are considered by Sen's method and it is the median of these slopes that is taken as the definitive result and this is how the rate of change over time, is robustly estimated (Sen, 1968). If trend values are positive, it means the trend is increasing, a negative value means it is the other way around.

Beside the study of trend, we calculated the summary statistics like average, minimum and maximum values for characterizing climate variations. To recognize the wet and dry periods and for comparing climatic variability of different years and seasons, the use of Climate Variability Index (CVI) was also extended in this case to evaluate seasonal and annual rainfall variability. Microsoft Excel and SPSS were used in carrying out all the statistical work.

The main outputs obtained after the statistical exercise were further subjected to assessment in relation with the agricultural production, water resource availability, and livelihood sustainability in the Ukhrul District.

3. Results and Discussion

3.1 Trends in Temperature

Table 3.1: Annual Mean, Minimum and Maximum Temperature in Ukhrl District (1990-2024)

Year	Mean Annual Temperature (°C)	Mean Minimum Temperature (°C)	Mean Maximum Temperature (°C)
1990	19.43	14.49	25.79
1991	19.64	14.53	26.37
1992	18.95	13.67	25.73
1993	19.37	14.13	26.29
1994	20.07	14.51	27.35
1995	19.78	14.62	26.51
1996	20.03	14.58	27.09
1997	19.09	13.94	25.85
1998	20.28	14.99	27.19
1999	20.87	15.46	28.04
2000	20.24	14.69	27.58
2001	20.99	15.32	28.41
2002	20.39	14.96	27.52
2003	20.36	14.93	27.45
2004	19.96	14.73	26.81
2005	20.60	15.28	27.63
2006	20.72	15.24	27.91
2007	19.83	14.64	26.66
2008	19.63	14.67	26.03
2009	20.08	15.01	26.64
2010	19.51	14.76	25.63
2011	19.08	14.45	24.98
2012	19.49	14.67	25.76
2013	19.83	15.24	25.78
2014	20.07	15.24	26.36
2015	19.81	15.28	25.73
2016	20.03	15.71	25.76
2017	19.73	15.39	25.43
2018	19.27	14.77	25.13
2019	19.88	15.02	26.21
2020	19.65	14.97	25.79
2021	20.20	15.21	26.69
2022	19.75	14.86	26.11
2023	20.41	15.22	27.03
2024	19.67	14.83	26.00
Mean	19.90	14.82	26.56

Table 3.1 shows the overall, peak and lowest temperature in Ukhrl District from 1990 to 2024. The figures reveal that there was quite a lot of variation in the climate from one year to another, and warming, although very slight, has occurred during these 35 years. During this time, the overall yearly temperature averaged 19.90°C. The average minimum and maximum temperatures were 14.82°C and 26.56°C respectively. The figure for average annual temperature ranged between 18.95°C in 1992 and 20.99°C in 2001 (Figure 5.6). In this way, there is a fluctuation of about 2.04°C. Record high average annual temperatures were recorded between 1997 and 2001, so it was the late 90s to early 2000s, whereas minimum temperatures started to be high from the early 90s and at the end of 2000 to 2012. But, even in the last few years, 2021 (20.20°C) and 2023 (20.41°C), temperatures have still been much higher than the average, which means that warming conditions remain. This is as seen and mentioned by Krishnan *et al.* (2020), who recognized a rise in temperature in the Indian Himalayan and Northeastern due to climate change. An increase in minimum temperature over the years is very prominent in the temperature data. Between 1992 to 2016, the rise in minimum temperature is 2.04°C (13.67-15.71°C). Many years after 2005, the minimum temperature was above 15°C. Due to this, warm nights are occurring more and more in the whole district. The IPCC (2023) ^[1] also reported similar findings, where minimum temperatures are rising faster than

maximum temperatures in various parts of the world because of global warming.

Changes in minimum temperatures can deeply impact the system as they can influence crop respiration, soil moisture retention and ecosystem processes... Compared to minimum temperatures, variations in the maximum mean temperatures were found to be greater across the samples years. The highest mean maximum temperature (28.41 °C) was recorded in 2001, with the lowest being 24.98 °C observed in 2011.

Both the cooler period (2010 onwards) and the warmer period (1998-2006) were associated once again with the variability of the climate over the sampled years, with a number of the warm period years experiencing temperatures over 27 °C. Then again, the post-2010 period was much more moderate but also showed consistency with temperature. Dash *et al.* (2007) also found a similar year-to-year variation in their study of climatic parameters in India which they explained by the complex interaction of monsoonal moisture regimes and regional climatic latitudinal factors resulting in pronounced variations from year to year. The major effect of the warming trend in Ukhrl District should be its impact on agriculture and natural ecosystems.

Higher temperature can mean more evotranspiration, lesser availability of soil moisture and higher water demand of the crop. Agriculture in the study district is mainly based on

rainfall. An increase in temperature could/has already led to moisture stress and reduced crop yield. Mall *et al.* (2006) have observed the similar adverse effect of climate changes, in general, on agriculture and water resources. Changing temperature might also cause the change in distribution of plants and animals, Mostly in mountain ecosystems which are sensitive areas.

The findings show that the main rise in temperature in Ukhul is likely a result of an increase in the minimum temperatures rather than a significant increase in the maximum temperatures. This is a common scenario in the mountains where the night-time temperature rises faster than the day-time temperature (Sharma *et al.* 2009). They have found similar patterns in the Eastern Himalayas where the rising temperatures have caused ecological changes,

changes in the distribution of species and the mountain communities becoming more vulnerable to the various impacts. The temperature records generally show that the Ukhul District has experienced substantial warming from 1990 to 2024 which is indicated by the rise in the annual mean and minimum temperatures and the maximum temperatures that fluctuate noticeably.

The results agree with both regional and worldwide reports that emphasize temperature rise as a very prominent sign of climate change in the mountains (IPCC, 2023; Krishnan *et al.* 2020) ^[1, 5]. The observed climate changes necessitate the introduction of climate-resilient agricultural practices and adaptive management strategies to reduce the vulnerability of the local population and natural systems to the potential impacts of climate change.

Table 3.2: Mann-Kendall Test and Sen's Slope Results for Temperature Variables in Ukhul District (1990-2024)

Variable	Kendall's Tau	Z-value	p-value	Sen's Slope (°C year ⁻¹)	Trend
Mean Annual Temperature	0.000	0.000	1.000	0.000	No significant trend
Mean Minimum Temperature	0.363	3.053	0.002	+0.019	Significant increasing trend
Mean Maximum Temperature	-0.208	-1.747	0.081	-0.030	Non-significant decreasing trend

The Mann-Kendall test for Ukhul District resulted in different temperature parameters displaying different trends during the period 1990-2024. The mean annual temperature did not register any statistically significant trend ($Z = 0.000$, $p=1.000$), in other words the temperature differences between years, when averaged, stayed at a constant temperature eventually. Though, the minimum temperatures have shown a significant upward trend ($Z = 3.053$, $p = 0.002$), with Sen's slope indicating an increase of almost 0.019°C per year. As a result, these 35 years of rising minimum temperatures have produced night-time warming of approximately 0.67°C. However maximum temperature, showed a negative Sen's slope (-0.030°C year), suggesting a tendency for the decrease of daytime temperatures. But, the trend did not attain statistical significance ($p = 0.081$),

meaning that the observed decline might be explained by natural climatic variability rather than a permanent long-term change. Results indicate that in Ukhul District the warming has been coming more from increasing minimum temperatures than maximum temperatures. Such differential warming, characterized by more rapidly rising night-time temperatures, has been reported in mountainous areas and is even considered to be a hallmark of climate change. Jain *et al.* and Krishnan *et al.* have also documented the increase of minimum temperatures in Northeast India and the Himalaya region respectively.

3.2 Trends in Rainfall Annual and seasonal rainfall variability

Table 3.4: Seasonal Rainfall Distribution in Ukhul District (1990-2024)

Season	Mean Rainfall (mm)	Contribution (%)	Minimum (mm)	Maximum (mm)
Pre-Monsoon	186.93	15.5	62.35	418.55
Monsoon	716.11	59.5	264.41	1184.76
Post-Monsoon	79.02	6.6	5.72	182.13
Winter	225.52	18.7	0.00	513.61
Annual	1207.58	100.0	534.24	1894.10

The amount of rainfall received in the Ukhul District varies A lot as the monsoon alone contributes about 59.5% of the total yearly rainfall. On average, the annual rainfall during 1990-2024 was 1207.58 mm out of which monsoon contributed 716.11 mm. The amount of monsoon rainfall varies a lot between 264.41 mm to 1184.76 mm showing that monsoon rainfall changes drastically from one year to another. This overwhelming monsoonal rainfall pattern is similar to that of Northeast India where the Southwest Monsoon brings most the annual rainfall (Goswami *et al.* 2006). The winter supplied 18.7% of the annual rainfall in the form of precipitation, with an average of 225.52 mm, whereas the pre-monsoon season was the third highest contributor (15.5%) with 186.93 mm of rainfall. Pre-monsoon rainfall is very important for agricultural activities such as land preparation and planting. Das *et al.* (2009) ^[9] also mentioned a similar point by emphasizing the role of pre-monsoon rainfall for the good establishment of crops in

Northeast India.

Post-monsoon season had the least rainfall (6.6%) with a mean of 79.02 mm indicating drier atmospheric conditions after the monsoon. Rainfall differences throughout the year were present in all seasons but mainly during the winter and monsoon seasons.

Yearly rainfall ranged wildly from 534.24 mm at the low to 1894.10 mm at the high, which not only indicate a high rainfall variability but also the occurrence of dry and wet years. Drops/ increases of this magnitude are probably similar to those recorded in regional climate studies which have also revealed enhanced rainfall variability and other climate uncertainties in Northeast India following the changed climatic conditions (Krishnan *et al.* 2020; IPCC, 2023) ^[1, 5]. Other major impacts of these changes at the district level are on agriculture, water resources, and livelihood security.

Extreme rainfall and drought years

Table 3.5: Extreme Rainfall and Drought Years

Rank	Driest Years	Rainfall (mm)	Wettest Years	Rainfall (mm)
1	2001	534.24	2018	1894.10
2	2000	587.85	2013	1765.20
3	1999	667.74	2024	1656.44
4	1996	742.03	2010	1623.42
5	2003	777.15	2019	1597.54

Table 3.5 identifies the driest and wettest years in Ukhrul District over the period of 1990-2024. The data in the table indicate that there is significant variability in annual rainfall in the district. The driest year was 2001, when the total rainfall was only 534.24 mm; next were 2000 (587.85 mm) and 1999 (667.74 mm). The amount of rain in these years was Really less than the long-term average annual rainfall of 1207.58 mm; Because of this, drought-like situations most probably occurred leading to negative impacts on agricultural production and water availability.

But, the wettest year was 2018 with 1894.10 mm of rainfall closely followed by 2013 (1765.20 mm) and 2024 (1656.44 mm). The data show that quite a large amount of rain was received in these years which might be a factor behind the occurrence of very heavy rainfall/precipitation and That

means greater risks of flood and soil erosion.

There was more than 1,350 mm difference between the driest year (2001) and the wettest year (2018) alone, which points to a very high variability of rainfall in this district. Also, other evidence points to that the rainfall extremes and climatic variability are on the rise in the whole of Northeast India due to climate change (Goswami *et al.* 2006; Krishnan *et al.* 2020). These kinds of fluctuations will be a big problem for rain-fed agriculture and they underline the necessity of adapting water and land management practices in Ukhrul District to deal with such situations.

3.3 Climate Variability Assessment Climate Variability Index (CVI)

Table 3.6: Classification of Rainfall Variability Based on CVI

CVI Category	Interpretation
CVI > +1.5	Extremely Wet Year
+1.0 to +1.5	Very Wet Year
+0.5 to +1.0	Moderately Wet Year
-0.5 to +0.5	Normal Year
-1.0 to -0.5	Moderately Dry Year
-1.5 to -1.0	Severely Dry Year
< -1.5	Extreme Drought Year

Table 3.6: Major Rainfall Anomaly Years Based on Climate Variability Index (CVI) in Ukhrul District (1990-2024)

Category	Year	Annual Rainfall (mm)	CVI
Extremely Wet Year	2013	1765.20	1.63
Extremely Wet Year	2018	1894.10	1.98
Very Wet Year	2010	1623.42	1.24
Very Wet Year	2014	1571.52	1.10
Very Wet Year	2016	1539.43	1.01
Very Wet Year	2017	1535.89	1.00
Very Wet Year	2019	1597.54	1.17
Very Wet Year	2024	1656.44	1.33
Severely Dry Year	1994	792.44	-1.04
Severely Dry Year	1996	742.03	-1.18
Severely Dry Year	1999	667.74	-1.38
Severely Dry Year	2003	777.15	-1.08
Severely Dry Year	2004	781.26	-1.07
Severely Dry Year	2008	804.52	-1.01
Extreme Drought Year	2000	587.85	-1.60
Extreme Drought Year	2001	534.24	-1.75

Table 3.6 displays the primary rainfall anomaly years in Ukhrul District from 1990 to 2024, detected using the Climate Variability Index (CVI). The findings show drastic changes between extremely wet and drought years, which means considerable interannual variability in rainfall patterns.

This study determined 2013 and 2018 as extremely wet years with CVI values of 1.63 and 1.98, respectively. The highest annual rainfall was in 2018 (1894.10 mm), which was 57% more than the long-term annual average (1207.58 mm). In the same way, 2013 got 1765.20 mm, indicating

very wet conditions. And 2010, 2014, 2016, 2017, 2019, and 2024 were treated as very wet years, with CVI values between 1.00 and 1.33. The concentration of wet years after 2010 implies more above-normal rainfall occurrences in the recent decade. Goswami *et al.* (2006) also demonstrated an increase in extreme rainfall events in Northeast India, linking enhanced precipitation to a warming climate and changed monsoon dynamics.

But, a series of severe drought years occurred in the district during the late 1990s and early 2000s. The drought was most intense in 2001 when only 534.24 mm of rainfall was

recorded with a CVI value of 1.75; 2000 (587.85 mm; CVI = 1.60) was the next driest year. The rainfall amount in these two years was less than half of the long-term average, signifying that the moisture deficit was severe. In addition 1994 1996, 1999 2003 2004, and 2008 were designated severely dry years, with CVI values between 1.01 and 1.38. The consistent occurrence of dry years during that time implies a prolonged rainfall shortage, which might have negatively impacted agricultural production, water availability, and rural livelihoods.

One significant aspect revealed by the CVI is that the predominance of dry conditions during the late 1990s and early 2000s is giving way to wet conditions after 2010. It indicates more rainfall variability and an increasing frequency of hydro-climatic extremes. Krishnan *et al.* (2020) [1] also recorded similar cases whereby changing rainfall patterns in India due to climate change are leading

to one or more extreme precipitation events and localized droughts.

Both extremes of wet and dry conditions cause significant challenges for Ukhrul District where agriculture is mostly rain-fed. Too much rain can cause flooding landslides soil erosion, and crop damage while drought can cause reduced soil moisture, decreased crop yields, and increased water scarcity. The IPCC (2023) [1] also pointed out that climate change is causing an increase in the frequency and intensity of hydrological extremes worldwide with mountain and monsoon-dependent regions being most affected.

This changes have brought up several challenges of climate uncertainty in the district. It also calls for the adoption of climate-resilient agricultural practices, water conservation measures, and effective disaster risk management strategies.

Decadal comparison

Table 3.6: Decadal Comparison of Seasonal and Annual Rainfall in Ukhrul District

Period	Pre-Monsoon (mm)	Monsoon (mm)	Post-Monsoon (mm)	Winter (mm)	Annual Rainfall (mm)
1990s (1990-1999)	252.42	570.27	57.40	44.91	924.79
2000s (2000-2009)	200.82	528.23	61.86	108.82	899.58
2010s (2010-2019)	132.70	962.18	102.51	368.43	1565.82
2020-2024	148.91	810.22	141.77	300.96	1401.86

Table 3.6 summarises the major fluctuations in the seasonal and annual rainfall patterns of Ukhrul District in the last thirty years. Annual rainfall slightly went down from 924.79 mm in 1990s to 899.58 mm in 2000s, but it increased very much to 1565.82 mm in 2010s and then dropped moderately to 1401.86 mm in 2020-2024. Overall, this rise is an indication of increasing rain variation and changing precipitation regimes in the district, a trend that was also reported by Krishnan *et al.* (2020) [5] for Northeast India.

Seasonal monsoon rainfall maintained its status as the main source of annual precipitation. It was subject to a sharp rise from 570.27 mm in 1990s and 528.23 mm in 2000s to 962.18 mm in 2010s followed by a fall to 810.22 mm in 2020-2024. Observing in line with this, Goswami *et al.* (2006) has found the intensification of rainfall and occurrence of heavy precipitation events in different parts of

the country under the changing climatic condition.

However, pre-monsoon rainfall demonstrated a downtrend by dropping from 252.42 mm in 1990s to 132.70 mm in 2010s and during 2020-2024, it just recovered marginally (148.91 mm). Insufficient amount of pre-monsoon rainfall can bring issues with agricultural operations like land preparation and sowing time.

Substantial rise both in post-monsoon and winter rainfall was maturely evident in the data. Post-monsoon rainfall went up from 57.40 mm in 1990s to 141.77 mm in 2020-2024, whereas winter rainfall during the same period saw a huge increase from 44.91 mm to 300.96 mm. Changes similar to this in seasonal rainfall patterns were also observed in the Eastern Himalayan region by Sharma *et al.* (2009) and they match climate change scenarios brought out by IPCC (2023) [1].

Table 4.6: Mann-Kendall Test and Sen's Slope Results for Seasonal and Annual Rainfall in Ukhrul District (1990-2024)

Rainfall Variable	Kendall's Tau	Z-value	p-value	Sen's Slope (mm year ⁻¹)	Trend
Pre-Monsoon Rainfall	-0.394	-3.295	0.001	-4.44	Significant Decreasing
Monsoon Rainfall	0.435	3.664	<0.001	14.73	Significant Increasing
Post-Monsoon Rainfall	0.396	3.309	0.001	3.08	Significant Increasing
Winter Rainfall	0.527	4.402	<0.001	11.75	Significant Increasing
Annual Rainfall	0.454	3.820	<0.001	23.84	Significant Increasing

The Mann-Kendall trend test revealed a statistically significant rise in the annual rainfall over 1990-2024 ($Z=3.820$, $p<0.001$), whereas Sen's slope showed an average rise of 23.84 mm/year. The seasonal breakdown showed that the pre-monsoon rainfall has gone down quite drastically (-4.44 mm/year) But monsoon, post-monsoon and winter rainfall have all shown significant uptrends. Winter rainfall saw the biggest rise (11.75 mm/year) which could mean that the seasons of precipitation might be

changing. This is not the first time such changes have been noticed as Goswami *et al.* and Krishnan *et al.* reported the growing rainfall variability and the intensification of extreme precipitation events across Northeast India due to climate change [5].

3.4 Implications for Agriculture and Livelihoods Perceived Impact of Climate Variability on Agriculture

Table 3.7: Major Climate Change Impacts Perceived by Farmers in Ukhrul District (n = 542)

Impact Perceived	Frequency (Agree + Strongly Agree)	Percentage (%)
Irregular rainfall pattern	453	83.5
Increased frequency of extreme weather events	433	79.9
Delayed/altered monsoon onset and duration	435	80.3
Reduced crop yield due to rising temperature	422	78.6
Increased pest and disease incidence	364	67.2

Referred to Table 3.6 depicts the variation in seasonal and annual rainfall in the last three decade period (from 1990 onward). It is found from the variations in rainfall distribution and intensity that there is significant increase in climatic irregularity with time period. The rainfall during 1990s was 924.79 mm/year on an average with 570.27mm (61.7%) of rainfall received during monsoon period. The pre-monsoon rainfall was higher (252.42 mm) and winter rainfall was lower (44.

91mm) during 1990s. The results during 2000s were similar; the total annual rainfall was lower at 899.58 mm due to lower values of pre-monsoon and monsoon rainfall. During 2000s, there occurred several drought/severely dry years based on the CVI analysis. The most significant change in rainfall occurred in 2010s, where the average annual rainfall quantity suddenly surged up to 1565.82 mm from 894.72 mm in 2000s, more than 74%. The escalation was Mostly due to an abrupt jump in monsoon rainfall (962.18 mm) and winter (366.43mm) rainfall. The 2010s was also a period of some wet and extremely wet years in the century, like 2010 2013 2016 2017 2018 and 2019. The high intensity of rainfall seems to match the findings of Goswami *et al.* (2006) who identified an increase in the occurrences of extreme rainfall events in India with the advent of a shifting climate. Average annual rainfall for 2020-2024 was 1401.86mm, a value that still is A lot higher than the rainfall

received during 1990s and 2000s. Monsoon rainfall has slightly decreased during 2010s compared to 2000s but still had high value (810.22mm).

Post-monsoon rainfall increased Really (141.77mm) which is above all decades records, while winter rainfall remained above 200.96mm. The increase in non-monsoon rainfall compared to other time intervals indicates change in seasonality of rainfall may have increased wet days beyond the monsoon time.

In general, the decadal comparison reveals a drastic change of drier coefficient during 1990s and 2000s to a much moister coefficient during 2010s and early 2020s, which is largely linked to an increased amount of annual rainfall that is dominantly sourced from an increased amount of monsoonal and winter months, That's why changing the rainfall regimes of the district. This is consistent with the decadal increase in variability of rainfall; increase of extreme to higher catastrophic values of rainfall over UIN during climate change for NR and HS as revealed in Northeast India and Himalaya respectively (Krishnan *et al.* 2020; IPCC, 2023) ^[1, 5]. The findings This way have crucial impacts on the issues related with agriculture, water resource, flood events and ecological implications in the district.

Impact on Livelihoods and Adaptation

Table 3.8: Climate Change Adaptation Strategies Adopted by Farmers in Ukhrul District (n = 542)

Adaptation Strategy	Frequency (Agree + Strongly Agree)	Percentage (%)
Change in sowing dates	456	84.1
Rainwater harvesting	354	65.3
Mixed cropping	279	51.5
Migration or alternative employment	258	47.6
Taken loans to cope with climate impacts	121	22.3

Table 3.8 illustrates the main adaptation strategies that farmers in Ukhrul District have taken up due to changing climate conditions. The results show that farmers have implemented different techniques to tackle rainfall variability, increased temperatures, and higher levels of uncertainty in agricultural production.

The most popular adaptation strategy out of all those listed was changing the sowing dates, which was adopted by as many as 84.1% of the farmers who participated in the survey. That change of approach makes sense if one considers that farmers need to alter their cropping rhythms so that they correspond with the rainfalls and weather changes of the new season. Planting date changes as an adaptation measure were supported by Below *et al.* (2012), who stated that smallholder farmers in regions sensitive to climate changes most commonly adapt by altering the dates at which they plant crops.

Rainwater harvesting was taken up by 65.3% of farmers, which shows the realization of the necessity to keep water saved up as a reaction to irregular rainfall and droughts. The strengthening of water conservation activities points to the

farmers' attempts at ensuring the availability of water even during the periods when the crops really need it. This was in line with the research findings of Nhemachena and Hassan (2007) ^[19], who discovered that water management is one of the top adaptation strategies for rain-fed agricultural systems.

Mixed cropping was practiced by 51.5% of the respondents, which contributes to the reduction of production risks through crop diversification and increase resiliency of the farm towards climate shocks. Migration or seeking other forms of employment was reported by 47.6% of the farmers as a coping strategy, So emphasizing the importance of livelihood diversification in risk management under climatic conditions.

Only 22.3% of those questioned resorted to taking loans to deal with the effects of climate change, which indicates a very low level of reliance on formal financial tools. Perhaps, this is limited by the rural households' lack of access to credit or their hesitation to take on more debt.

The final assessment is that the farmers of Ukhrul District mainly target farm-level adaptive strategies, Mostly through

adjustments to sowing times, conservation of water, and crop diversification as a tactic to manage climate variability locally. Actually, these results go hand in hand with research on the behavior of smallholder farmers showing them as the ones who adopt cheap, minimal effort, easily accessible adaptation strategies at the local level to reduce their climate change vulnerability (Below *et al.* 2012; Nhemachena & Hassan, 2007)^[18, 19].

4. Conclusion: The main goal of this project was to investigate the temperature and rainfall changes and fluctuations in Ukhrul District, Manipur over the time period 1990-2024 and to evaluate their effects on agriculture and rural livelihoods. The study signifies major climate changes like temperature rise and highly variable rainfall. The temperature analysis revealed a near steady state of mean annual temperature but minimum temperature showed a lot positive trend (Sen's slope = 0.019°C year; $p < 0.05$) pointing to Truth is night-time warming is increasing slowly. Maximum temperature Though showed a downward trend which was not significant leading to the idea that it is the increasing minimum temperatures that are mainly causing the warming in the district. These results corroborate with the overall climate change scenarios of Northeast India as well as other mountainous regions.

The rainfall study showed a great deal of seasonal changes and year-to-year variations in rainfall. Monsoon was the season with the highest rainfall giving about 60% of the total annual rainfall. This signifies the importance of monsoon in supporting agriculture and water resources. Mann-Kendall test popularized the statistically rising trends in monsoon, post-monsoon, winter, and annual rainfalls, whereas pre-monsoon rainfall proved to be decreasing Quite a bit. The decade-wise result showed a shift from relative dryness in the 1990s and 2000s to much wetness in 2010s and early 2020s. The Climate Variability Index aside from that marked severe drought years during late 1990s and early 2000s and a greater number of wet and extremely wet years post 2010, which is a clear indication of growing hydro-climatic extremes. The research shows that the local rain-fed farming system is at risk because of climate variations. Based on the farmers, changes in rainfall patterns, a delay in the start of monsoon, increased incidence of extreme weather events, a fall in crop production, and higher pest infestation are the major problems. From this, farmers have been implementing a number of adaptation strategies. Mostly, they have altered their planting dates, harvested rainwater, and planted different species together. What farmers have done so far, shows that they have taken the climate-related risks seriously to continue producing agricultural products under ever-changing environmental conditions.

Overall, changes in climate are becoming quite visible in Ukhrul District and the main features are, that minimum temperatures have risen, rainfall patterns have shifted, rainfall variability has grown. These changes are not only affecting agriculture, water resources and ecosystem stability but also the rural people's way of life. It will be necessary to build up agricultural practices which can stand the changing climate, to develop ways of conserving water more effectively, and to bring in climate adaptation at the level of local development planning if we want to raise the resilience of farming communities and achieve sustainable development in the district.

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