

Climate Variability and Trend Analysis in the Semi-Arid Eastern Plains of Rajasthan: A Case Study of Jaipur District

Dr. Ravi Jhurawat

Assistant Professor, Jawaharlal Nehru Rajkeeya Mahavidyalaya, Port Blair, India

Corresponding Author Email: [ravijhurawat05\[at\]gmail.com](mailto:ravijhurawat05[at]gmail.com)

Abstract: Jaipur District in eastern Rajasthan occupies a semi-arid setting where agriculture and water security depend almost entirely on the monsoon. This study examines long-term trends and variability in rainfall and temperature using data from the Indian Meteorological Department (IMD) and the Water Resources Department, Rajasthan, covering the period 1952 to 2017 for temperature and 1960 to 2017 for block-level rainfall. The non-parametric Mann-Kendall (M-K) test and Sen's Slope Estimator were applied to detect and quantify trends. The UNEP Aridity Index, computed through the Penman-Monteith method for the period 1985 to 2015, was used to assess the changing degree of dryness. Results show that annual rainfall is declining at a rate of 2.448 mm per year, though not yet statistically significant, while mean annual temperature has risen significantly at 0.021 degrees Celsius per year. Spatially, 10 of 14 stations within the district record a negative rainfall trend, with Dudu station alone reaching statistical significance. Aridity increased from the first sub-period (1985-1999) to the second (2000-2015), with three of the five identified drought years falling in the second sub-period. These combined signals - declining rainfall, rising temperature, and deepening aridity - pose a serious risk to rain-fed agriculture across the district. The findings call for climate-sensitive water planning and adaptive agricultural practices at the district level.

Keywords: Climate Variability, Rainfall trend, Temperature trend, Mann-Kendall test, Aridity Index, Semi-arid Rajasthan, Penman-Monteith Method

1. Introduction

Arid and semi-arid regions are among the most sensitive landscapes on earth to changes in climate. The United Nations Convention to Combat Desertification defines desertification as land degradation in these zones resulting from climate variations and human activities (UNCCD, 1994). Where rainfall is low and variable, even modest shifts in the amount or timing of precipitation can intensify droughts, reduce groundwater recharge, and disrupt agriculture (Gosain et al., 2006; Turkes, 1999).

Rajasthan is the largest state in India by area and covers a wide climatic gradient from hyper-arid desert in the west to semi-arid plains in the east. Jaipur District lies within the eastern semi-arid zone and supports a predominantly agrarian population that depends heavily on monsoon rainfall for crop production. Research on Indian rainfall at the national and sub-divisional level has documented mixed and spatially uneven trends. Eastern Rajasthan has been identified as a sub-division with a declining trend in annual and monsoonal rainfall (Guhathakurta and Rajeevan, 2008; Kumar et al., 2010). Understanding how this broad signal plays out at the district and block level is essential for evidence-based water resource management and agricultural planning.

Temperature is equally important. A rise in temperature accelerates evapotranspiration, reduces soil moisture, and increases crop water demand (Arora et al., 2005; Parry et al., 2001). India has recorded a mean annual temperature increase of approximately 0.4 to 0.6 degrees Celsius over the last century, with the warming trend strongest in the post-monsoon and winter seasons (Hingane et al., 1985; Kumar et al., 1994). Whether a similar warming signal is detectable at

the district level in eastern Rajasthan, and how it interacts with rainfall, has not been studied systematically.

This study fills that gap. It analyses rainfall and temperature data for Jaipur District over the period 1952 to 2017, using block-level station data for spatial resolution. The central argument is that the district is undergoing a compounding climate stress: rainfall is declining, temperature is rising significantly, and aridity is deepening - a combination that makes the region increasingly vulnerable to drought and water scarcity. The objectives are: (i) to assess the temporal trend in annual and monthly rainfall and temperature at Jaipur station using the M-K test and Sen's Slope Estimator; (ii) to examine spatial variability in rainfall trend across 14 block-level stations; (iii) to measure rainfall variability through the coefficient of variation; and (iv) to track the changing degree of aridity through the UNEP Aridity Index.

2. Study Area

Jaipur District is located in the eastern part of Rajasthan, India. It lies between approximately 26 degrees 11 minutes and 27 degrees 51 minutes North latitude, and 74 degrees 55 minutes and 76 degrees 50 minutes East longitude. The district is characterised by a semi-arid climate, with most rainfall concentrated in the southwest monsoon season (July to September). The average annual rainfall for the district, based on the IMD station record, is approximately 609.9 mm. The terrain is predominantly flat plain, with some isolated hills. Agriculture is the dominant land use, and given the semi-arid setting, rain-fed farming is highly sensitive to year-to-year variability in rainfall and to long-term changes in climate.

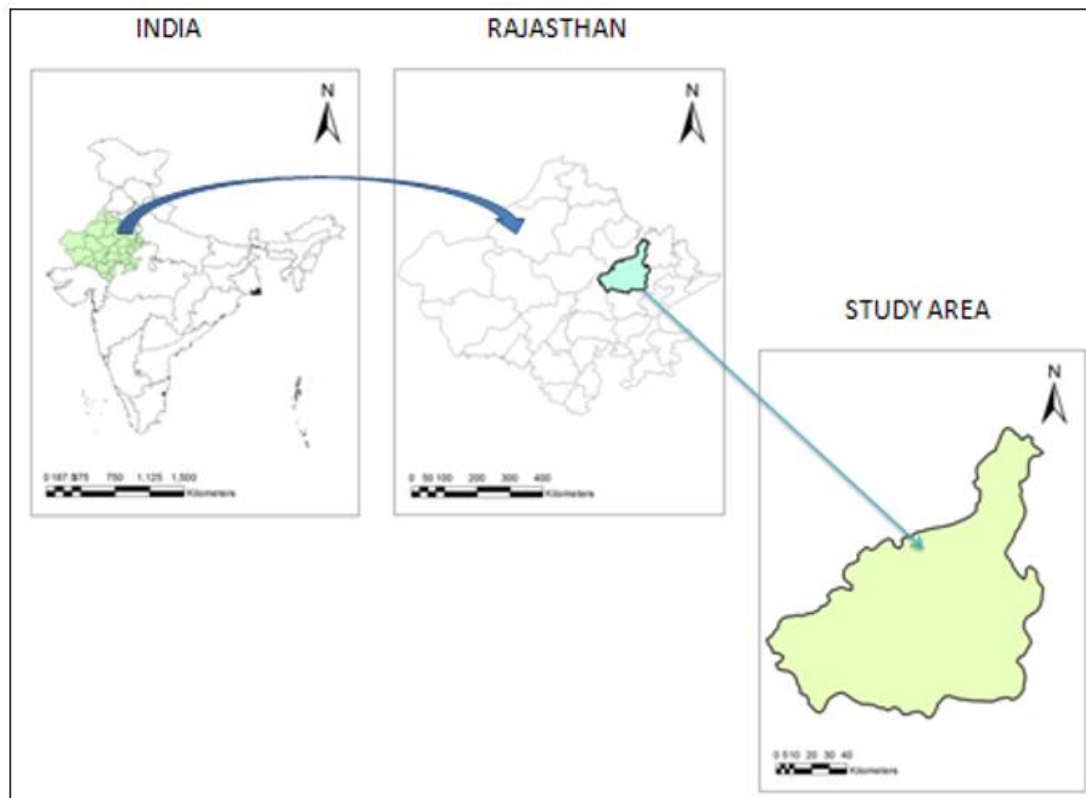


Figure 1: Location Map of Jaipur District

3. Data and Methods

3.1 Data Sources

Secondary climate data were obtained from two agencies. Monthly rainfall, mean maximum temperature, and mean minimum temperature data for 1952 to 2017 were sourced from the Indian Meteorological Department (IMD) for Jaipur station. Block-level annual rainfall data for 14 stations within the district for 1960 to 2017 were obtained from the Water Resources Department, Government of Rajasthan; this agency provides rainfall data only, with no temperature or other climatic parameters at the block level. Additional meteorological parameters required for potential evapotranspiration (PET) computation - mean monthly relative humidity, sunshine hours, and daily wind speed - were available from IMD for 1985 to 2015.

3.2 UNEP Aridity Index

The UNEP (1992) Aridity Index (AI) was used to classify the moisture status of the study area. The index is expressed as:

$$AI = P / PET$$

where P is total annual precipitation (mm) and PET is potential evapotranspiration (mm). A higher AI value indicates more humid conditions, while a lower AI value indicates greater aridity. An AI value between 0.20 and 0.50 corresponds to semi-arid conditions, while values below 0.20 indicate arid conditions (UNESCO, 1979). PET was calculated using the FAO-recommended Penman-Monteith method, which accounts for temperature, relative humidity, sunshine hours, and wind speed (Allen et al., 1998). The AI was computed for each year from 1985 to 2015 (31 years), the period for which all required meteorological inputs were available.

Table 1 shows the UNEP classification scheme used in this study.

Table 1: Climate Types Based on UNEP Aridity Index

AI= P/PE	Climate Type
$0.05 \leq P/PE < 0.20$	Arid
$0.20 \leq P/PE < 0.50$	Semi-arid
$0.50 \leq P/PE < 0.65$	Dry sub-humid
$0.65 \leq P/PE < 0.80$	Semi-humid
$0.80 \leq P/PE < 1.00$	Humid
$1.0 \leq P/PE < 2.0$	Very humid

(Source: UNESCO, 1979)

3.3 Mann-Kendall Test and Sen's Slope Estimator

The non-parametric Mann-Kendall (M-K) test was applied to detect monotonic trends in annual and monthly rainfall and temperature time series. This test is widely used in hydro-meteorological studies because it does not assume a normal distribution and is robust to outliers (Ahmad et al., 2015; Gocic and Trajkovic, 2013). The null hypothesis states that no trend exists in the data series; the alternative hypothesis states that a monotonic trend (increasing or decreasing) is present. The test statistic S is computed from all pairwise comparisons of data values over time. A positive S indicates an upward trend and a negative S indicates a downward trend. Statistical significance is assessed at the 95% confidence level ($\alpha = 0.05$) and at the 90% confidence level ($\alpha = 0.10$). A trend is classified as significant if the p-value falls below the chosen alpha level (Anttila and Toni, 2002).

The magnitude of any detected trend was quantified using Sen's Slope Estimator, a non-parametric method that calculates the median slope across all pairwise data

comparisons (Sen, 1968). A positive slope value indicates the rate of increase per year, while a negative value indicates the rate of decrease per year. The combination of the M-K test and Sen's Slope Estimator provides both direction and magnitude information for each climatic parameter (Gocic and Trajkovic, 2013; Karpouzou et al., 2010).

Rainfall variability was measured using the Coefficient of Variation (CV), expressed as the ratio of standard deviation to mean annual rainfall, multiplied by 100. CV values were classified as follows: less than 20% indicates low variability, 20 to 30% moderate, 30 to 40% high, 40 to 70% very high, and above 70% extremely high variability (Panda and Sahu, 2019).

4. Results and Discussion

4.1 UNEP Aridity Index: A Deepening Dryness

The average aridity index for Jaipur station over the full 31-year period (1985 to 2015) is 0.3205, which falls within the

semi-arid range of the UNEP classification (0.20 to 0.50). However, a comparison between the two sub-periods reveals a clear deterioration in moisture conditions. The average AI for the first sub-period (1985 to 1999) is 0.3581, while for the second sub-period (2000 to 2015) it falls to 0.2884. This decline signals a shift toward drier conditions in the more recent period (Table 2).

Extreme values further illustrate this pattern. The lowest AI of 0.069 was recorded in 2002, far below the semi-arid lower limit, while the highest value of 0.500 was recorded in 1995, at the upper boundary of the semi-arid range. Five drought years, in which the AI fell below 0.20 indicating arid conditions, were identified: 1987, 1999, 2002, 2006, and 2009. Critically, three of these five drought years (2002, 2006, and 2009) fell in the second sub-period (2000 to 2015), indicating that drought frequency has increased in the most recent decades. These findings are consistent with broader national studies that report an increase in drought frequency in many parts of India since the 1990s (Sinha et al., 2015).

Table 2: Results of UNEP Aridity Index for Jaipur Station (1985-2015)

Station	Average Degree of Aridity			Extreme Low Value of AI	Extreme High Value of AI	No. of Year (AI<0.20)
	1985-2015	1985-1999	2000-2015			
Jaipur	0.3205	0.3581	0.2884	0.06903 (2002)	0.5003 (1995)	5 (1987, 1999, 2002, 2006, and 2009)

Source: IMD Data Analysis (1985-2015)

4.2 Annual Rainfall and Temperature Trends

The M-K test results for annual rainfall and mean annual temperature are presented in Table 3. The S-statistic for annual rainfall is -294, indicating a downward trend over the study period. However, the associated p-value of 0.105 is above the significance threshold of 0.05, meaning this trend cannot be confirmed as statistically significant at the 95% confidence level. Sen's Slope Estimator puts the rate of decline at 2.448 mm per year. Over the 65-year record (1952 to 2017), this amounts to a cumulative reduction of approximately 159 mm in annual rainfall - substantial for a semi-arid district with a long-term average of 609.9 mm (Figure 1).

The picture is different for temperature. The S-statistic for mean annual temperature is +908, and the p-value is 0.0001, confirming a highly significant increasing trend at the 95% confidence level. Sen's Slope Estimator shows that temperature has risen at a rate of 0.021 degrees Celsius per year. Over 65 years, this translates to a cumulative increase of approximately 1.37 degrees Celsius (Figure 2), consistent with India-wide warming observations (Kothiyari and Singh, 1996; Sarker and Thapliyal, 1988). The divergence between a declining (though not yet significant) rainfall trend and a strongly significant warming trend points to a closing moisture gap in the district - less water arriving and more being lost to evaporation.

Table 3: Mann-Kendall Test and Sen's Slope Estimator - Annual Rainfall and Temperature

Parameter	S Statistic	Trend at 95% Confidence level			Sen's Slope
		p-value	Alpha (α)	Trend Interpretation	
Rainfall	-294	0.105	0.05	No Trend	-2.448
Temperature	908	0.0001	0.05	Sig. Increasing	0.021

Source: IMD Data Analysis (1952-2017)

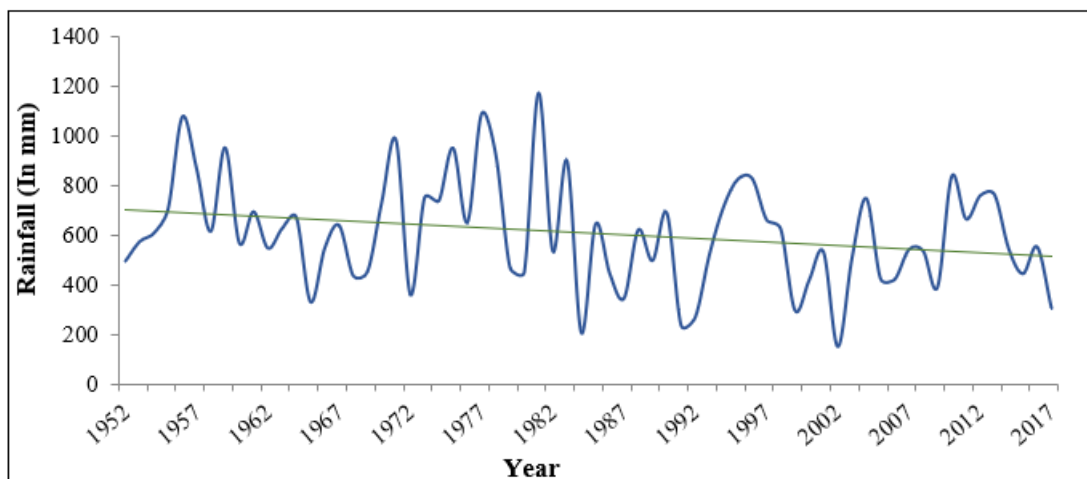


Figure 1: Trend of Annual Rainfall at Jaipur Station (1952-2017) (Source: IMD)

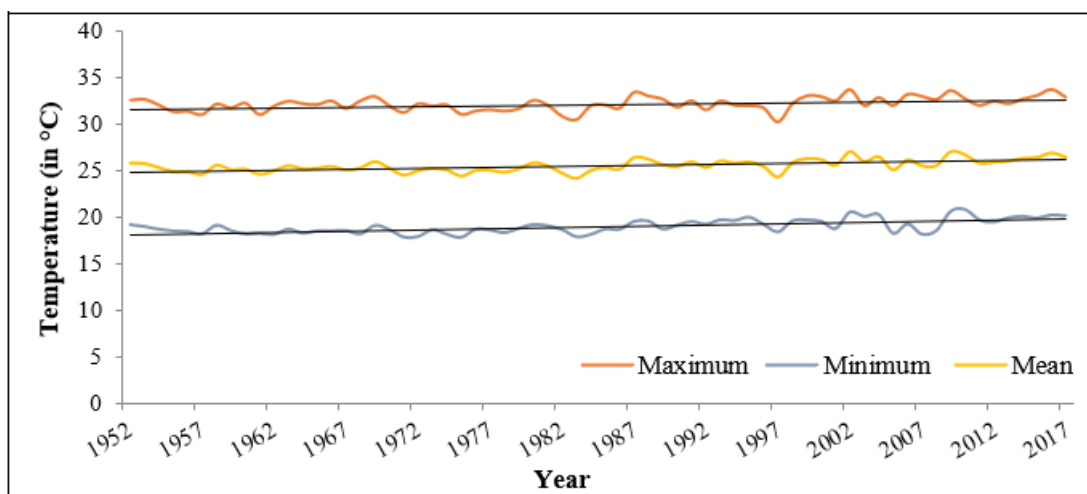


Figure 2: Trend of Mean Annual Temperature at Jaipur Station (1952-2017) (Source: IMD)

4.3 Monthly Rainfall Trends

Monthly analysis reveals a more nuanced pattern within the annual signal (Table 4). A negative trend in monthly rainfall was recorded in 7 of 12 months: January, July, August, September, October, November, and December. Of these, only August shows a statistically significant decreasing trend ($S = -386$, $p = 0.03$) at the 95% confidence level. Sen's Slope Estimator confirms that August rainfall has declined at a rate of 1.605 mm per year - the steepest monthly rate of decrease recorded across the year. July and September also show notable negative slopes (-0.629 and -0.380 mm per year respectively), though these fall short of statistical significance.

A positive trend was observed in the remaining 5 months: February, March, April, May, and June. Of these, only April achieved statistical significance at the 90% confidence level ($S = 309$, $p = 0.085$). The significance of this seasonal pattern lies in the contribution of each month to total annual rainfall. July, August, and September together account for well over 90% of the district's annual precipitation. A sustained decline in these monsoon-core months therefore carries far greater practical consequence than trends in the drier months. The positive trend in April and other pre-monsoon months contributes very little to annual totals and does not compensate for losses in monsoon months. This seasonal asymmetry - gains in months that contribute minimally, losses in the months that matter most - points to a structural weakening of the monsoon in this district (Figure 3 and Figure 4).

Table 4: Mann-Kendall Test and Sen's Slope Estimator - Monthly Rainfall

Month	S Statistic	Trend at 95% Confidence level			Trend at 90% Confidence level			Sen's Slope
		Alpha(α)	p-value	Trend Interpretation	Alpha(α)	p-value	Trend Interpretation	
Jan	-242	0.05	0.17	No Trend	0.1	0.177	No Trend	-0.008
Feb	58	0.05	0.74	No Trend	0.1	0.746	No Trend	0.000
Mar	57	0.05	0.74	No Trend	0.1	0.748	No Trend	0.000
Apr	309	0.05	0.08	No Trend	0.1	0.085	Sig. Increasing	0.019
May	142	0.05	0.43	No Trend	0.1	0.433	No Trend	0.026
Jun	32	0.05	0.86	No Trend	0.1	0.864	No Trend	0.044
Jul	-167	0.05	0.35	No Trend	0.1	0.358	No Trend	-0.629
Aug	-386	0.05	0.03	Sig. Decreasing	0.1	0.033	-----	-1.605

Sep	-191	0.05	0.29	No Trend	0.1	0.293	No Trend	-0.380
Oct	-81	0.05	0.65	No Trend	0.1	0.652	No Trend	0.000
Nov	-74	0.05	0.65	No Trend	0.1	0.650	No Trend	0.000
Dec	-41	0.05	0.79	No Trend	0.1	0.794	No Trend	0.000

Source: IMD Data Analysis (1952-2017)

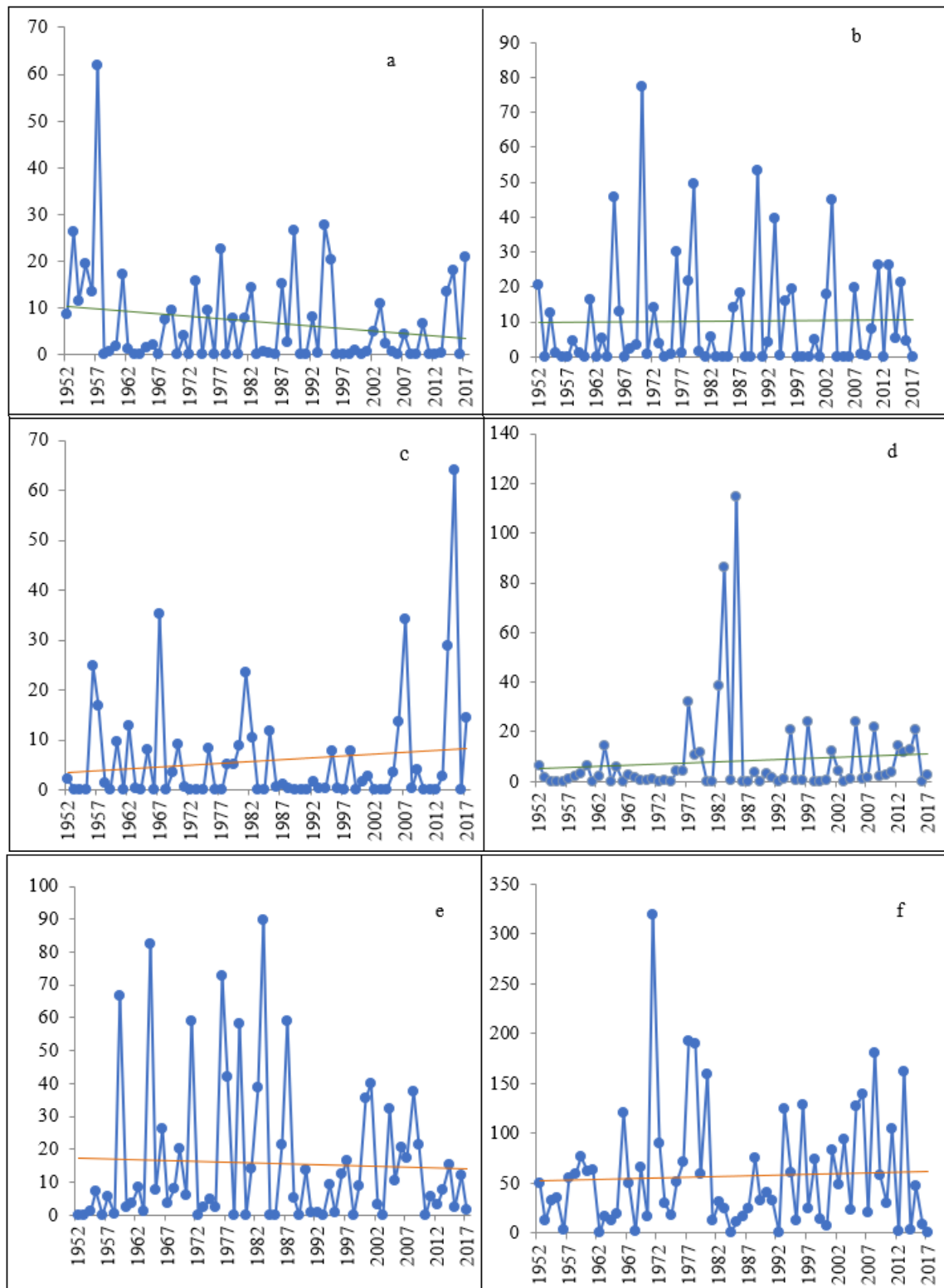


Figure 3: Trend of Monthly Rainfall - January to June

Note: X - axis represents rainfall(mm); Fig 3.3a January, 3.3b February, 3.3c March, 3.3d April, 3.3e May, 3.3f June.
Source: IMD

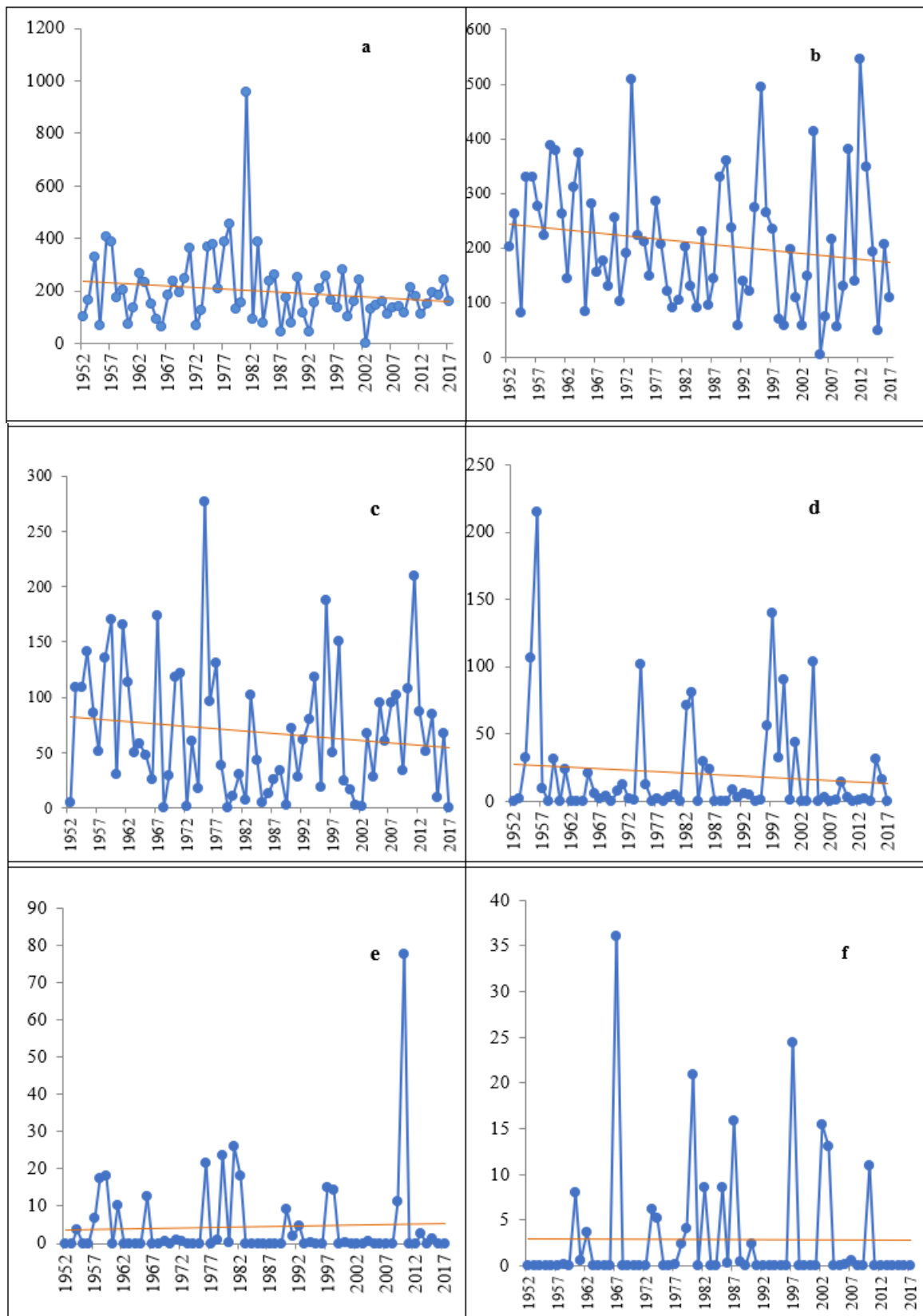


Figure 4: Trend of Monthly Rainfall - July to December

Note: X - axis represents rainfall(mm); Fig 3.4a July, 3.4b August, 3.4c September, 3.4d October, 3.4e November, 3.4f December. Source: IMD.

4.4 Monthly Temperature Trends

All 12 months of the year show a positive (warming) trend in mean maximum temperature, mean minimum temperature, and mean monthly temperature (Table 5). This is a strong and

consistent signal. Significant warming in mean maximum temperature was detected in 6 months: May, August, September, October, November, and December, with S-statistic values of 363, 442, 546, 517, 518, and 499 respectively. Mean minimum temperature shows significant

warming in 9 months: the same 6 months as mean maximum temperature, plus February ($S = 531$), March ($S = 765$), and April ($S = 674$). Mean monthly temperature shows significant warming in 8 months.

Sen's Slope values for mean minimum temperature are consistently higher than those for mean maximum temperature across most months (Table 6). For example, in October, the mean minimum temperature slope is 0.044 degrees Celsius per year compared to 0.026 degrees Celsius per year for mean maximum temperature. This asymmetric warming pattern, where minimum temperatures rise faster than maximum temperatures, narrows the diurnal temperature range and has implications for crop respiration, nighttime cooling, and pest dynamics. It mirrors findings from national-level studies in which mean minimum temperature has contributed more than mean maximum temperature to overall warming in India (Kumar et al., 1994). The pre-monsoon and post-monsoon seasons show the steepest warming slopes (Figure 5 and Figure 6).

Table 5: Mann-Kendall Test Results - Monthly Temperature

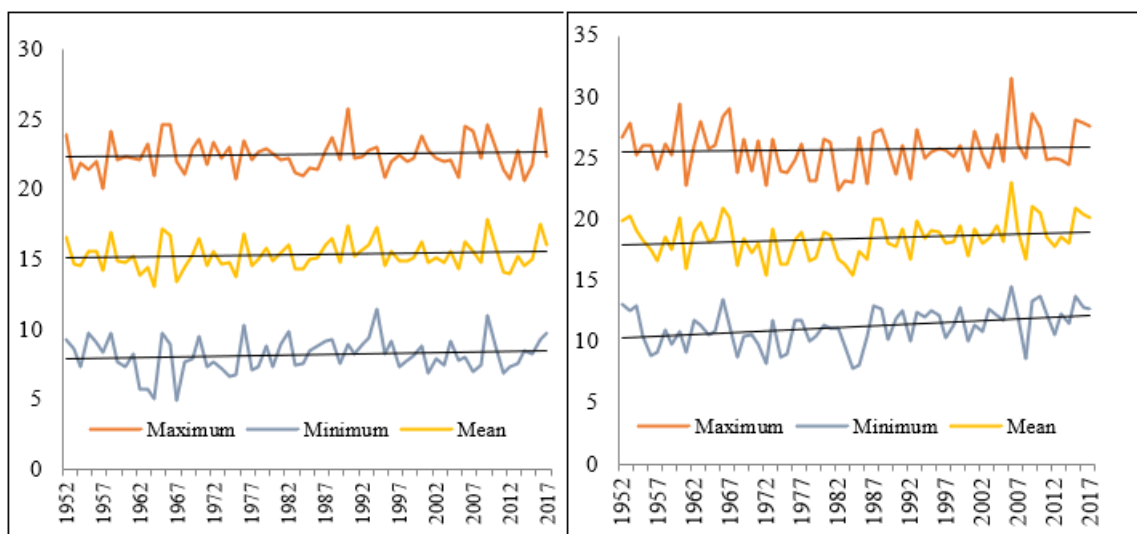
Month	Mean Maximum Temperature	Mean Minimum Temperature	Mean Average Temperature
	Sen's slope	Sen's slope	Sen's slope
January	0.003	0.004	0.007
February	0.005	0.032	0.016
March	0.011	0.033	0.021
April	0.018	0.037	0.027
May	0.017	0.040	0.028
June	0.005	0.008	0.005
July	0.012	0.007	0.009
August	0.017	0.014	0.014
September	0.029	0.025	0.027
October	0.026	0.044	0.035
November	0.020	0.041	0.028
December	0.019	0.019	0.017

Source: IMD Data Analysis (1952-2017).

Table 6: Sen's Slope Estimator Results - Monthly Temperature

Month	Alpha(α)	Mean Maximum Temperature			Mean Minimum Temperature			Mean Monthly Temperature		
		S Statistic	p-value	Trend Interpretation	S Statistic	p-value	Trend Interpretation	S Statistic	p-value	Trend Interpretation
January	0.05	84	0.646	No Trend	103	0.572	No Trend	187	0.303	No Trend
February	0.05	56	0.761	No Trend	531	0.003	Sig. Increasing	287	0.113	Sig. Increasing
March	0.05	158	0.385	No Trend	765	0.0001	Sig. Increasing	426	0.019	Sig. Increasing
April	0.05	289	0.111	No Trend	674	0.0001	Sig. Increasing	519	0.004	Sig. Increasing
May	0.05	363	0.045	Sig. Increasing	729	0.0001	Sig. Increasing	565	0.002	Sig. Increasing
June	0.05	118	0.517	No Trend	193	0.287	No Trend	110	0.546	No Trend
July	0.05	212	0.243	No Trend	270	0.135	No Trend	213	0.241	No Trend
August	0.05	442	0.015	Sig. Increasing	591	0.001	Sig. Increasing	526	0.004	Sig. Increasing
September	0.05	546	0.003	Sig. Increasing	747	0.0001	Sig. Increasing	722	0.0001	Sig. Increasing
October	0.05	517	0.004	Sig. Increasing	989	0.0001	Sig. Increasing	870	0.0001	Sig. Increasing
November	0.05	518	0.004	Sig. Increasing	686	0.000	Sig. Increasing	724	0.0001	Sig. Increasing
December	0.05	499	0.006	Sig. Increasing	405	0.025	Sig. Increasing	545	0.003	Sig. Increasing

Source: IMD Data Analysis (1952-2017)



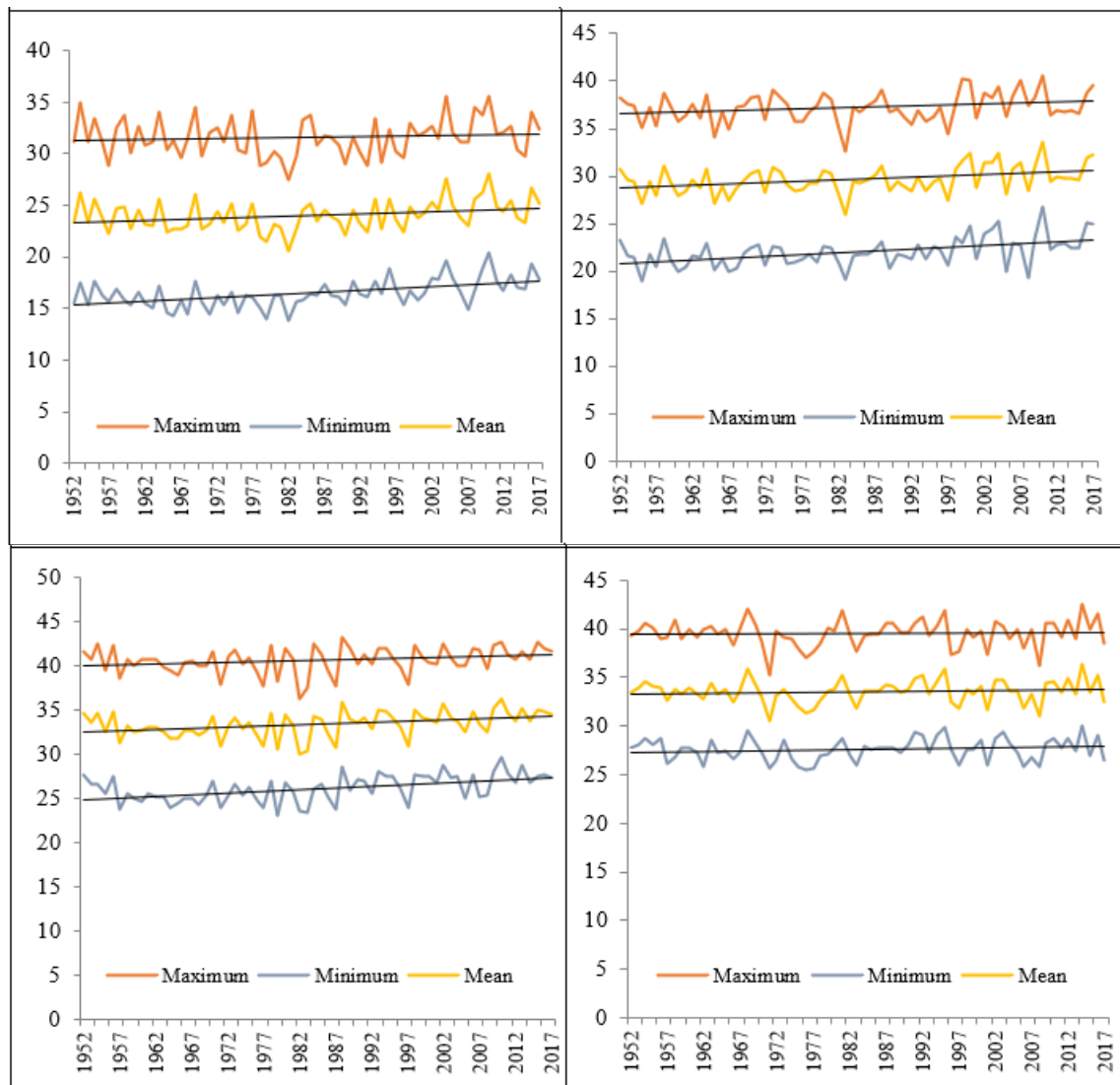
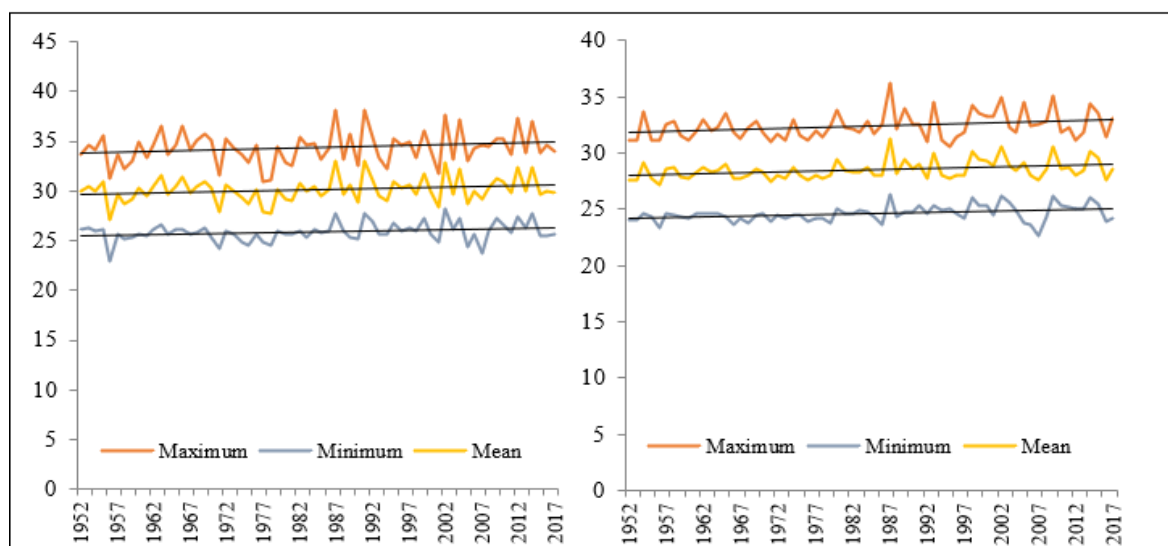


Figure 5: Trend of Monthly Mean Maximum, Minimum and Mean Temperature - January to June

Note: X - axis represents Temperature (in °C); Fig 3.5a January, 3.5b February, 3.5c March, 3.5d April, 3.5e May, 3.5f June.
Source: IMD.



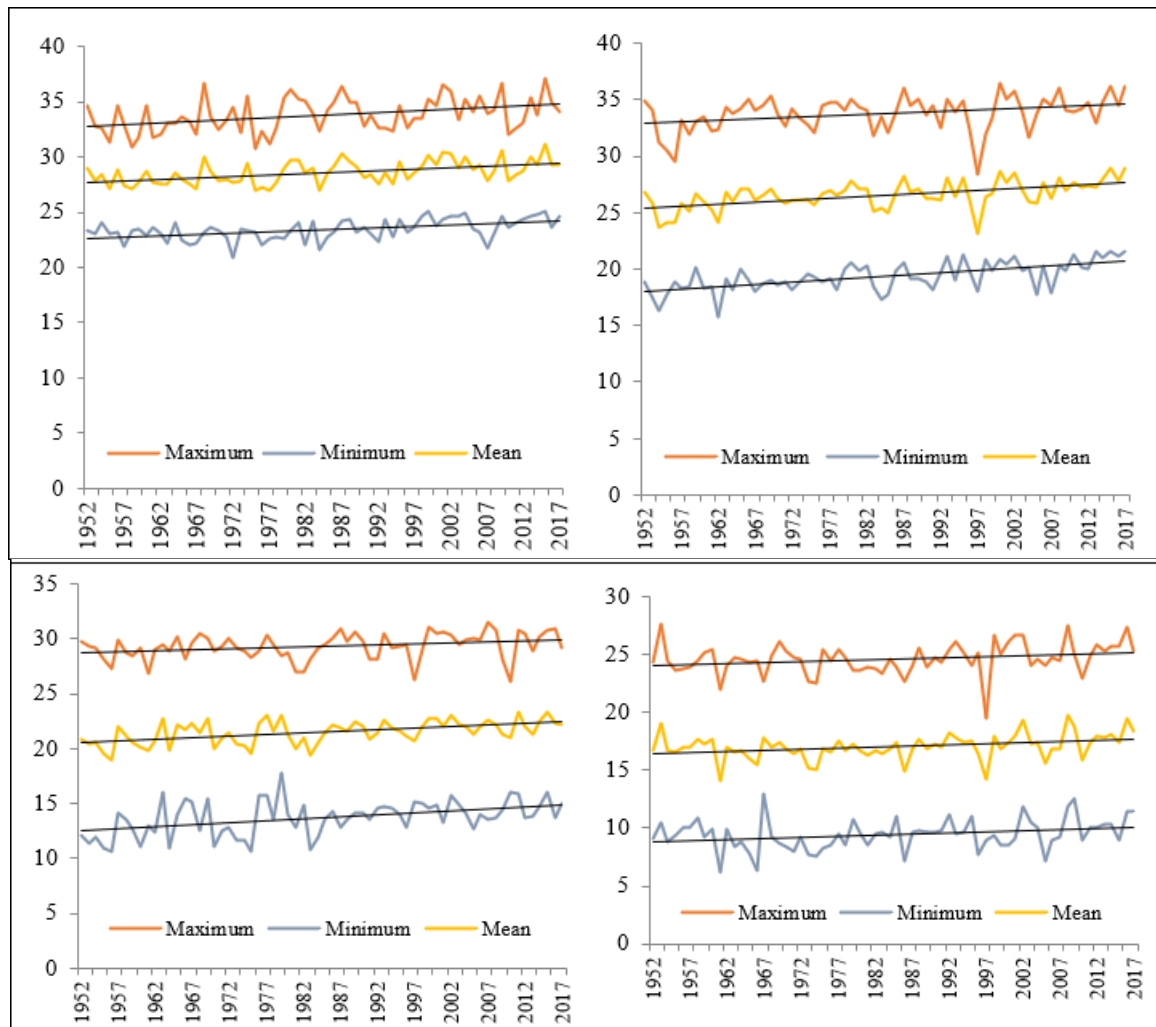


Figure 6: Trend of Monthly Mean Maximum, Minimum and Mean Temperature - July to December

Note: X - axis represents Temperature (in °C); Fig 3.6a July, 3.6b August, 3.6c September, 3.6d October, 3.6e November, 3.6f December. Source: IMD.

4.5 Spatial Rainfall Trend Across Block-Level Stations

The M-K test was applied to block-level annual rainfall data for 14 stations across Jaipur District for the period 1960 to 2017 (Table 7). A negative trend in rainfall was recorded at 10 of 14 stations. However, statistical significance at the 95% confidence level was achieved at only one station - Dudu ($S = -311$, $p = 0.038$), with a Sen's Slope of -3.038 mm per year, the highest rate of rainfall decline across the entire district. Several other stations show considerable negative S-statistic values that fall just short of significance: Chomu (-185), Jaipur (-179), Chaksu (-159), Naraina (-149), Amber (-131), and Phagi (-118). The consistent negative direction across 10 stations, even without reaching statistical significance in most cases, strengthens the conclusion that most of the district is on a declining rainfall trajectory.

An upward trend was recorded at 4 stations: Bairath, also known as Viratnagar ($S = 145$, Sen's Slope = 2.063 mm per year), Jamwa Ramgarh ($S = 87$), Kotputli ($S = 65$), and Sambhar ($S = 12$). None of these positive trends reached statistical significance. Bairath, located in the northern part of the district, records both the highest long-term average rainfall (635.42 mm) and the strongest positive Sen's Slope among the 14 stations. Spatially, there is a contrast between the northern and eastern stations, which tend toward slight increases or weaker negative trends, and the central and western stations, which show stronger decreasing trends. This differentiation has direct implications for planning: farmers in the western and central zones face greater and more rapidly worsening rainfall stress than those in the north and east (Figure 7 and Figure 8).

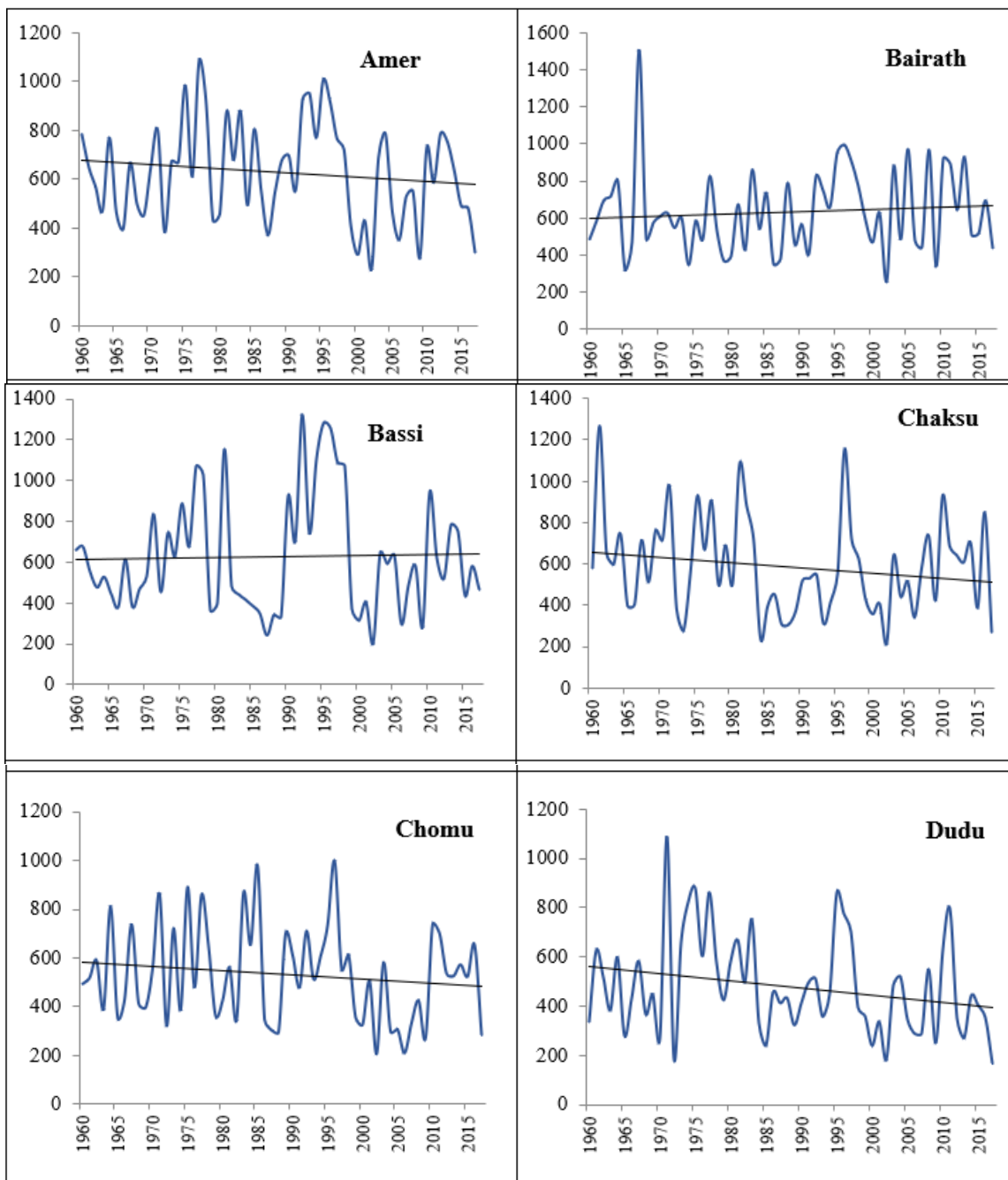
Table 7: Mann-Kendall Test and Sen's Slope Estimator - Block-Level Annual Rainfall

Station	S Statistic	Trend at 95% Confidence level			Trend at 90% Confidence level			Sen's Slope
		α	p-value	TI	α	p-value	TI	
Amber	-131	0.05	0.383	*	0.1	0.383	*	-1.617
Bairath	145	0.05	0.334	*	0.1	0.334	*	2.063
Bassi	-33	0.05	0.83	*	0.1	0.83	*	-0.562
Chaksu	-159	0.05	0.289	*	0.1	0.289	*	-1.914
Chomu	-185	0.05	0.217	*	0.1	0.217	*	-1.829
Dudu	-311	0.05	0.038	***	0.1	0.038	***	-3.038

Jaipur	-179	0.05	0.232	*	0.1	0.232	*	-2.053
Jamwa Ramgarh	87	0.05	0.564	*	0.1	0.564	*	0.939
Kotputli	65	0.05	0.668	*	0.1	0.668	*	0.772
Naraina	-149	0.05	0.321	*	0.1	0.321	*	-1.635
Phagi	-118	0.05	0.433	*	0.1	0.433	*	-1.379
Phulera	-2	0.05	0.995	*	0.1	0.995	*	-0.019
Sambhar	12	0.05	0.941	*	0.1	0.941	*	0.08
Sanganer	-101	0.05	0.502	*	0.1	0.502	*	-0.869

Notes: TI means Trend Interpretation, * No Trend, *** Significant Decreasing Trend

Source: Water Resource Department Rajasthan Data Analysis (1960-2017).



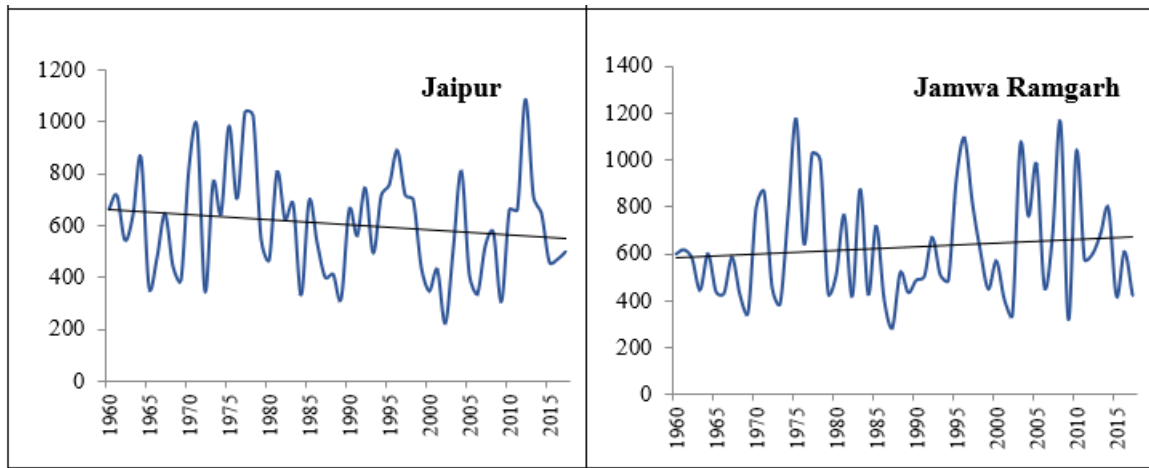


Figure 7: Trend of Annual Rainfall at Block-Level Stations

Note: X-axis represent year and Y-axis rainfall (mm). Source: Water Resource Department Rajasthan.

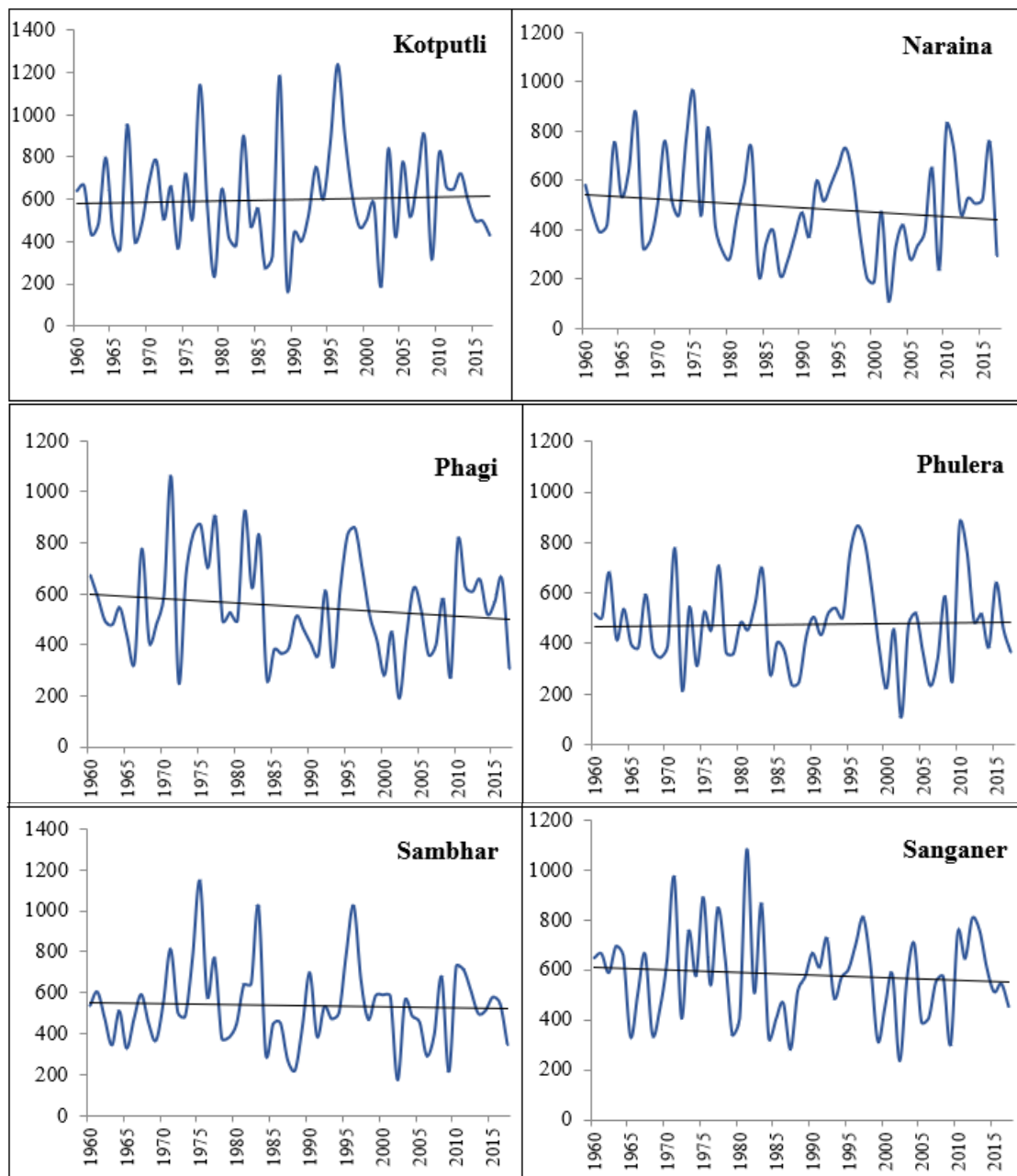


Figure 8: Trend of Annual Rainfall at Block-Level Stations

Note: X-axis represent year and Y-axis rainfall (mm). Source: Water Resource Department Rajasthan.

4.6 Spatial and Temporal Rainfall Variability

The coefficient of variation was calculated for each of the 14 stations to measure temporal variability in annual rainfall (Table 8). All stations recorded CV values above 30%, placing them in the "high variability" category. Two stations - Bassi (CV = 45.54%) and Dudu (CV = 41.88%) - fall in the "very high variability" category. CV values range from 30.72% at Sanganer to 45.54% at Bassi. The uniformly high variability across all stations underlines the precarious nature of rain-fed farming in the district: even if the long-term mean were stable, the year-to-year swings in rainfall are large enough to cause recurrent crop failure and water stress.

Monthly rainfall variability is even more extreme (Table 9). Eleven of 12 months show CV values above 100%, placing them in the "extremely high variability" category. Only July

(CV = 69.10%) and August (CV = 58.21%) fall below this threshold - precisely the months that deliver the bulk of annual rainfall. November records the highest CV (248.96%), followed by December (234.01%) and April (227.60%). The extreme variability in non-monsoon months reflects the sporadic and unpredictable nature of winter western disturbances and pre-monsoon thunderstorms in this region.

Spatially, the eastern part of the district receives more rainfall than the western part. Bairath (635.42 mm), Amber (628.5 mm), and Jamwa Ramgarh (628.01 mm) are the highest-receiving stations, while Phulera (473.94 mm), Dudu (478.29 mm), and Naraina (491.46 mm) are the lowest. The spatial gradient of approximately 161 mm between the highest and lowest receiving stations is significant for a single district, and highlights the need for localised planning rather than uniform district-wide approaches.

Table 8: Coefficient of Variation and Long-Term Average Rainfall at Block-Level Stations

Station	CV (%)	Avg. Rainfall (mm)	Station	CV (%)	Avg. Rainfall (mm)
Amber	32.26	628.5	Jamwa Ramgarh	36.88	628.01
Bairath	35.68	635.42	Kotputli	38.51	597.43
Bassi	45.54	626.13	Naraina	39.25	491.46
Chaksu	39.71	585.45	Phagi	35.27	549.29
Chomu	37.21	531.71	Phulera	35.62	473.94
Dudu	41.88	478.29	Sambhar	35.85	535.68
Jaipur	33.55	605.5	Sanganer	30.72	578.23
Jaipur (IMD data)	35.95	609.9			

Source: Water Resource Department Rajasthan Data Analysis (1960-2017).

Table 9: Month-wise Coefficient of Variation of Rainfall

(Source: IMD Data Analysis, 1952-2017)

Month	CV (%)	Month	CV (%)
January	153.59	July	69.10
February	156.00	August	58.21
March	188.91	September	86.25
April	227.6	October	193.03
May	138.89	November	248.96
June	103.68	December	234.01

Source: IMD Data Analysis (1952-2017).

5. Conclusion

This study presents a comprehensive analysis of climate variability and trend for Jaipur District across a 65-year record. Three convergent signals emerge from the data. First, annual rainfall is declining at 2.448 mm per year, with 10 of 14 block-level stations recording negative trends. Although the overall district-level trend has not yet crossed the threshold of statistical significance, the consistent direction and magnitude of the signal across stations, combined with a statistically significant decline in the critical month of August (the steepest monthly decline at 1.605 mm per year), points to a genuine and ongoing weakening of monsoon-season rainfall. Second, mean annual temperature has risen significantly at 0.021 degrees Celsius per year, a warming signal that holds for all 12 months and for all three temperature parameters measured. The faster rise in mean minimum temperature compared to mean maximum temperature narrows the diurnal range with cascading effects on agricultural productivity and water demand. Third, the UNEP Aridity Index declined from the first to the second sub-period, and three of the five drought years identified over the 31-year record were concentrated in the period 2000 to 2015.

Taken together, these three signals confirm that Jaipur District is undergoing compound climate stress. Less precipitation and higher evapotranspiration rates reduce the effective moisture available to crops and groundwater systems. High inter-annual and intra-annual rainfall variability, documented uniformly across all 14 stations, compounds this risk by making any given year's rainfall outcome highly unpredictable. The finding that the western and central parts of the district face both lower average rainfall and stronger declining trends than the north and east calls for spatially differentiated policy responses.

Policy implications are direct. District and block-level water resource planning should incorporate the rainfall decline signal rather than relying on historical averages. Drought-resilient crop varieties and water-efficient irrigation practices should be promoted, particularly at stations with the strongest declining trends such as Dudu, Chomu, and Chaksu. Rainwater harvesting infrastructure - both traditional systems such as tanka and johad, and modern check dams - should be expanded to buffer against high inter-annual variability. Climate monitoring at the block level should be strengthened, as the spatial heterogeneity in rainfall trends within the district makes sub-district data essential for targeted intervention.

References

- [1] Ahmad, I., Tang, D., Wang, T., Wang, M., & Wagan, B. (2015). Precipitation trends over time using Mann-Kendall and Spearman's rho tests in Swat River Basin, Pakistan. *Advances in Meteorology*, 2015, 1-15. <https://doi.org/10.1155/2015/431860>

- [2] Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. Food and Agriculture Organization of the United Nations.
- [3] Anttila, T. S. A. M. P., & Toni, T. R.-A. (2002). Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates (Issue 31). Finnish Meteorological Institute.
- [4] Arora, M., Goel, N. K., & Singh, P. (2005). Evaluation of temperature trends over India. *Hydrological Sciences Journal*, 50(1), 81-93. <https://doi.org/10.1623/hysj.50.1.81.56330>
- [5] Aziz, J. J., Ling, M., Rifai, H. S., Newell, C. J., & Gonzales, J. R. (2002). MAROS: A decision support system for optimizing monitoring plans. *Ground Water*, 41(3), 355-367.
- [6] Gocic, M., & Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and Planetary Change*, 100, 172-182. <https://doi.org/10.1016/j.gloplacha.2012.10.014>
- [7] Gosain, A. K., Rao, S., & Basuray, D. (2006). Climate change impact assessment on hydrology of Indian river basins. *Current Science*, 90(3), 346-353.
- [8] Guhathakurta, P., & Rajeevan, M. (2008). Trends in the rainfall pattern over India. *International Journal of Climatology*, 28, 1453-1469. <https://doi.org/10.1002/joc>
- [9] Hingane, L. S., Kumar, K. R., & Murty, V. R. (1985). Long-term trends of surface air temperature in India. *Journal of Climatology*, 5, 521-528.
- [10] Jain, S. K., Kumar, V., & Saharia, M. (2013). Analysis of rainfall and temperature trends in northeast India. *International Journal of Climatology*, 33, 968-978. <https://doi.org/10.1002/joc.3483>
- [11] Karpouzios, D. K., Kavalieratou, S., & Babajimopoulos, C. (2010). Trend analysis of precipitation data in Pieria region, Greece. *European Water*, 30, 31-40.
- [12] Kothyari, U. C., & Singh, V. P. (1996). Rainfall and temperature trends in India. *Hydrological Processes*, 10, 357-372.
- [13] Kumar, K. R., Krishna, K., & Pant, G. B. (1994). Diurnal asymmetry of surface temperature trends over India. *Geophysical Research Letters*, 21(8), 677-680.
- [14] Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal*, 55(4), 484-496. <https://doi.org/10.1080/02626667.2010.481373>
- [15] Mondal, A., Kundu, S., & Mukhopadhyay, A. (2012). Rainfall trend analysis by Mann-Kendall test: A case study of North-Eastern part of Cuttack district, Orissa. *International Journal of Geology, Earth and Environmental Sciences*, 2(1), 70-78.
- [16] Panda, A., & Sahu, N. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*, 20, 1-10. <https://doi.org/10.1002/asl.932>
- [17] Parry, M., Arnell, N., McMichael, T., Nicholls, R., Martens, P., Kovats, S., Livermore, M., Rosenzweig, C., Iglesias, A., & Fischer, G. (2001). Millions at risk: Defining critical climate change threats and targets. *Global Environmental Change*, 11, 181-183.
- [18] Partal, T., & Kahya, E. (2006). Trend analysis in Turkish precipitation data. *Hydrological Processes*, 20, 2011-2026. <https://doi.org/10.1002/hyp.5993>
- [19] Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. *Proceedings of the Royal Society of London*, 193(1032), 120-145.
- [20] Roy, S. S., & Balling, R. C. (2004). Trends in extreme daily precipitation indices in India. *International Journal of Climatology*, 24, 457-466. <https://doi.org/10.1002/joc.995>
- [21] Sarker, R. P., & Thapliyal, V. (1988). Climatic change and variability. *Mausam*, 39(2), 127-138.
- [22] Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63(324), 1379-1389.
- [23] Sinha, A., Kathayat, G., Cheng, H., Breitenbach, S. F. M., Berkelhammer, M., Mudelsee, M., Biswas, J., & Edwards, R. L. (2015). Trends and oscillations in the Indian summer monsoon rainfall over the last two millennia. *Nature Communications*, 6, 6309. <https://doi.org/10.1038/ncomms7309>
- [24] Tabari, H., & Talaee, P. H. (2011). Analysis of trends in temperature data in arid and semi-arid regions of Iran. *Global and Planetary Change*, 79(1), 1-10. <https://doi.org/10.1016/j.gloplacha.2011.07.008>
- [25] Thenmozhi, M., & Kottiswaran, S. V. (2016). Analysis of rainfall trend using Mann-Kendall test and the Sen's slope estimator in Udumalpet of Tirupur district in Tamil Nadu. *International Journal of Agricultural Science and Research*, 6(2), 131-138.
- [26] Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. *Geographical Review*, 38(1), 55-94.
- [27] Turkes, M. (1999). Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. *Journal of Engineering and Environmental Science*, 23, 363-380.
- [28] UNCCD. (1994). Elaboration of an international convention to combat desertification in countries experiencing serious drought and/or desertification. United Nations.
- [29] UNESCO. (1979). Map of the world distribution of arid regions: Explanatory note. United Nations Educational, Scientific and Cultural Organization.
- [30] Upadhyay, R. G., Ranjan, R., & Negi, P. S. (2015). Climatic variability and trend at Ranichauri, Uttarakhand. *Journal of Agrometeorology*, 17(2), 241-243.
- [31] Vittal, H., Karmakar, S., & Ghosh, S. (2013). Diametric changes in trends and patterns of extreme rainfall over India from pre-1950 to post-1950. *Geophysical Research Letters*, 40, 3253-3258. <https://doi.org/10.1002/grl.50631>
- [32] Xu, Z., Tang, Y., Connor, T., Li, D., Li, Y., & Liu, J. (2017). Climate variability and trends at a national scale. *Scientific Reports*, 7, 3258. <https://doi.org/10.1038/s41598-017-03297-5>