

GEOSPATIAL ANALYSIS OF RAINFALL TRENDS AND VARIABILITY OVER ARID REGIONS OF TELANGANA STATE, INDIA: A CASE STUDY

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Abstract

Climate change, particularly the unpredictability of rainfall, has received considerable global attention due to its significant impact on livelihoods, health, and future sustainability. Understanding how the climate is changing is essential for enhancing adaptability. The extent of variability in climate components differs by location. Examining the spatial-temporal dynamics of meteorological variables is thus critical for analyzing climate-induced changes and recommending practical adaptation strategies, especially in developing countries like India, where rainfed agriculture is predominant. This study investigates long-term precipitation changes in the humid and sub-humid zones of Telangana's Saroor Nagar, Hayat Nagar, Uppal, and Ghatkesar Mandals. A trend analysis of seasonal rainfall-pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-December), and winter (January-February) and annual rainfall is conducted at regional and temporal scales. Annual rainfall ranges from 512-1478 mm in Saroor Nagar, 426-1548 mm in Hayat Nagar, 429-1268 mm in Uppal, and 409-1473 mm in Ghatkesar. The Mann-Kendall test, applied at the 5% significance level, assesses rainfall trends from 2008 to 2020, revealing both increasing and decreasing trends. The inverse distance weighted (IDW) interpolation technique is used to assess spatial rainfall patterns. IDW results help identify rainfall variability across space and time, particularly in areas with limited or low-quality data. These spatial maps offer valuable insights for water resource planning in the face of climate change.

Keywords: Climate Variability; Geomatics; Mann-Kendall's test; Sen's Slope; Trend Analysis

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Introduction

Climate change is rapidly becoming one of the most widely discussed global issues. It can occur in various forms, over different time periods, and across multiple regions (Parek and Prajapati, 2015). Extreme weather events and significant shifts in weather pattern distribution have long posed threats to both the environment and human society. In recent decades, however, growing evidence suggests that these changes are increasingly influenced by anthropogenic sources. Climate change refers to variations in climatic or meteorological parameters such as precipitation, temperature, solar radiation, wind speed, relative humidity, and other related factors. In contrast, changes specifically in surface temperature are defined as global warming or cooling (Back and Bretherton, 2005). Due to its direct and indirect impacts on major sectors—including hydrometeorological, ecological, biological, and socioeconomic systems—climate change has garnered significant attention from the scientific community (IPCC, 2001, 2007, 2013). The effects of climate change typically become evident over long periods, but it has now emerged as a critical global concern. Consequently, quantifying climate change has become essential. Trend analysis serves as a key method for identifying both spatial variability and temporal shifts in climate-related indicators (Swain *et al.*, 2015). Among the various techniques available for time series and trend analysis, the Mann-Kendall (MK) test is a widely used non-parametric tool for detecting climate trends (Mann, 1945; Kendall, 1955). The MK trend test, a rank correlation test between two groups of observations, was proposed by Kendall. It is widely used in hydrological and climatological time-series data to detect significant trends (Modarres and Silva, 2007). In India, numerous studies have applied the MK test. Jhaharia *et al.* (2009) used it to analyze the temporal characteristics of pan evaporation. Burn *et al.* (2011) applied the MK test along with wavelet transformation to investigate local-scale climate change and hydrological trends in annual precipitation. Bora *et al.* (2022) and Kakkar *et al.* (2022) identified significant long-term changes in rainfall patterns, indicating climate shifts in India. Jyothy *et al.* (2021) analyzed the impact of climate change on seasonal rainfall trends in Andhra Pradesh and Telangana using non-parametric and innovative trend analysis methods. Shashikant Verma *et al.* (2022) examined rainfall and temperature trends in the state of Chhattisgarh, India. In Odisha, India, Mondal *et al.* (2012) explored long-term changes in rainfall patterns.

Patle *et al.* (2013) analyzed crop data from 1981 to 2011 to assess temporal fluctuations in climatic conditions and potential evapotranspiration. Duhan and Pandey (2013a) studied seasonal and annual rainfall trends in Haryana and Madhya Pradesh. Trend analysis was also conducted for all 33 urban areas in Rajasthan using the Mann-Kendall test and Sen's slope estimator (Pingale *et al.*, 2014). Suryavanshi *et al.* (2014) employed the MK test to analyze trends in historical climate variables for the Betwa River basin in India. Shrestha *et al.* (2016) investigated trends and variability in climate variables over the Koshi River watershed from 1975 to 2010 and found that extreme climate events are becoming more frequent, increasing vulnerability and raising significant policy concerns. According to the literature review, most previous studies on rainfall trends in India have been conducted at the national, state, or basin level, while trend analysis at the mandal or watershed level has largely been overlooked. The present study focuses on a region located in the Musi sub-basin, part of the Krishna River basin. It aims to analyze rainfall trends in the Saroor Nagar, Hayat Nagar, Uppal, and Ghatkesar mandals of Telangana's Ranga Reddy district, where a 197 sq. km increase in impervious surface area was observed between 2009 and 2020. This, combined with recent increases in high-intensity, short-duration, and unevenly distributed rainfall, has led to frequent flooding (Shiva Chandra and Reshma, 2022; Vaddiraju and Savitha, 2022). In recent years, localized rainfall events have been observed, where certain areas receive rainfall while adjacent areas remain dry. There has also been an increase in the number of rainy days compared to earlier periods. With further urban expansion likely—since these mandals border Hyderabad, which is undergoing rapid growth in infrastructure, information technology, and education sectors—local climate patterns are expected to change further. Given these conditions and the looming threat of regional climate change, a comprehensive understanding of the temporal and spatial patterns of rainfall in the study area is critical for effective water resource planning and management.

Study Area

The study region includes the mandals of Saroor Nagar and Hayatnagar (Ranga Reddy district) and Uppal and Ghatkesar (Medchal-Malkajgiri district), all located near Hyderabad City in the northern and eastern parts of the city. These areas have experienced significant development, particularly due to their proximity to Hyderabad,

with substantial growth in transportation infrastructure. Public transport systems such as the METRO, MMTS, and RTC now connect these mandals to the city center in under 30 min. The population in these mandals has surged, driven by migration from neighboring districts such as Warangal and Nalgonda, as people seek better educational and employment opportunities. The study area is situated between 17°20'41.7" and 17°27'17.4" North latitude and 78°30'57.9" and 78°40'51.4" East longitude. The location of the study area is shown in Figure 1.

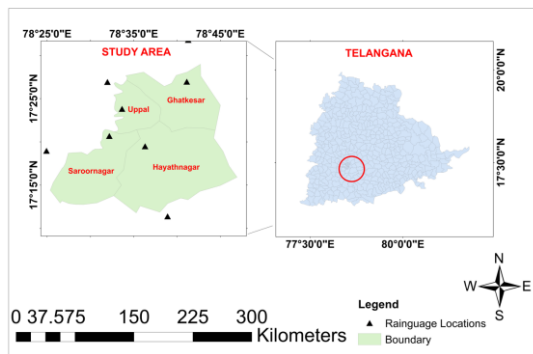


Figure 1. Study Area

Daily precipitation data for Saroor Nagar, Hayat Nagar, Uppal, and Ghatkesar mandals over a 12-year period (2008-2020), along with administrative boundaries, were obtained from the District Collectorate. Daily rainfall data were aggregated into monthly, seasonal, and annual values, and statistical parameters such as mean, median, standard deviation, and variance were calculated. The geographical and temporal variability of precipitation was analyzed on both annual and seasonal scales. Autocorrelation in rainfall refers to the relationship between rainfall observations recorded at the same location over time. If rainfall is autocorrelated, it indicates that past rainfall values can help predict future ones, which may affect how rainfall patterns are modeled or analyzed. In the absence of autocorrelation, the analysis becomes simpler and more direct, with no need to account for temporal correlations between events. Basic statistical methods can then be applied to identify trends without adjusting for autocorrelation. The methodology adopted in the present study is illustrated in Figure 2.

Rainfall Variability Index

The rainfall variability index (RVI) is a tool used to assess and classify monthly or annual rainfall data into five categories: very dry, dry,

normal, moist, and very wet. The index is calculated using the following equation:

$$RV_i = (P_i - \mu) / \sigma \quad (1)$$

where RV_i is the rainfall variability index for year i , P_i is the annual rainfall for the year i , μ is the mean annual rainfall, and σ is the standard deviation for the period 2008 to 2020.

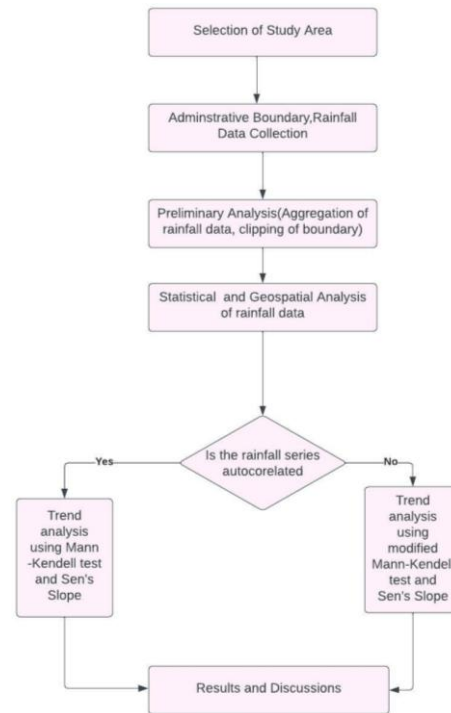


Figure 2. Methodology adopted in this study

Mann-Kendall's Test

The MK test is employed in this study to detect trends in rainfall at the 5% significance level. Non-parametric methods are preferred over parametric methods for identifying trends in hydro-meteorological data (Hirsch, 1982; Helsel and Hirsch, 2002). When autocorrelation is not significant, the M-K test, being rank-based and distribution-free, has greater power than other tests (Duhan and Pandey, 2013b). The M-K test was applied after pre-whitening all meteorological parameters during the pre-monsoon, monsoon, and post-monsoon seasons to reduce the impact of autocorrelation in the dataset (Mohammad and Jha, 2014). The standardized MK test Z-value for determining the statistical significance of a trend in a time series is as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (2)$$

$$\text{sgn}(x_j - x_k) = \begin{cases} 1, & x_j - x_k > 0 \\ 0, & x_j - x_k = 0 \\ -1, & x_j - x_k < 0 \end{cases} \quad (3)$$

$$\text{var}(s) = [n(n-1)(2n-5) - \sum_{y=1}^x t_y(t_y-1)(2t_y+5)]/18 \quad (4)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad (5)$$

where n is the sample size, x_i and x_j are data values with $k = 1, 2, \dots, n-1$, and $j = k+1, \dots, N$; S and

Z are test statistics; t_y represents the number of data values in the y group. In the normalised test statistic, positive and negative Z values indicate increasing and decreasing trends, respectively, while a Z value of 0 indicates a normally distributed data series.

Sen's Slope Estimator Test

A linear trend is commonly detected using Sen's slope estimator test (Sen, 1968) as illustrated below (Sen, 1968).

$$T_k = \frac{x_j - x_i}{j - i} \quad \text{for } k = 1, 2, 3, \dots, N \quad (6)$$

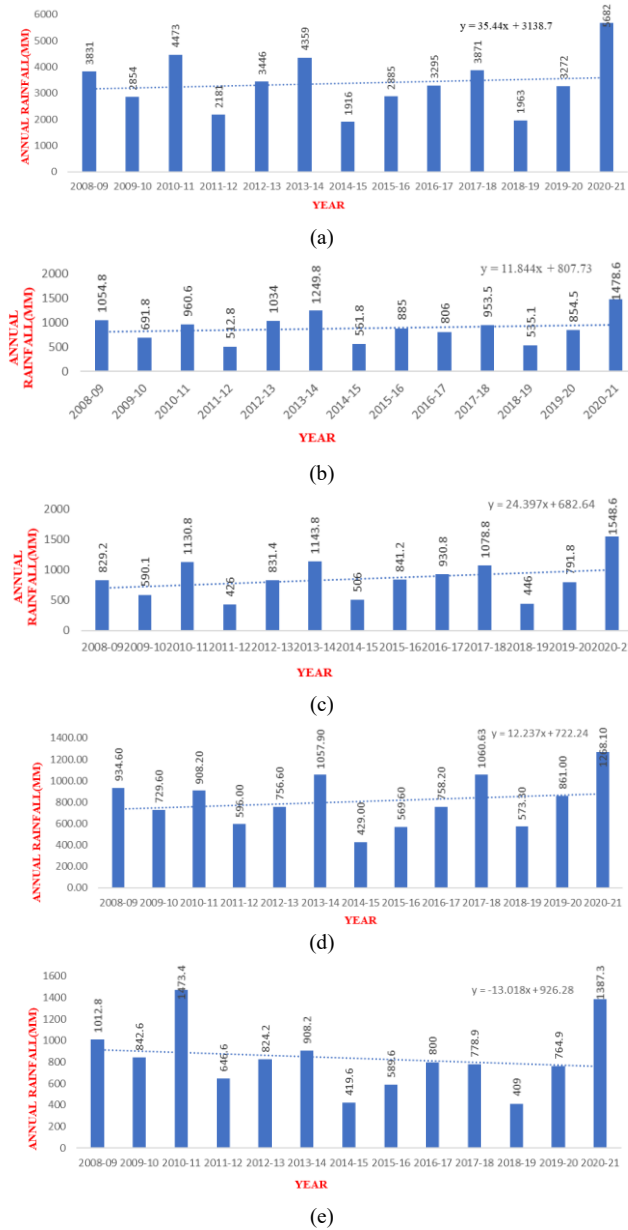


Figure 3. Annual rainfall in the study area: (a) aggregate of all mandals, (b) Saroor Nagar, (c) Hayatnagar, (d) Uppal, (e) Ghatkesar

where x_i and x_j denote the data values at times i ($j > i$) and j ($j > i$), respectively. The median of these N values of T_k , as shown in the following equation, is Sen's estimator of the slope (Q).

$$Q_k = T_{(N+1)/2}, \text{ where } N \text{ is odd.} \quad (7)$$

$$Q_k = 1/2[T_{N/2} + T_{(N+2)/2}], \text{ where } N \text{ is even} \quad (8)$$

Results and Discussions

A preliminary statistical analysis of the rainfall series was conducted prior to the trend analysis, including the estimation of key statistical parameters. The mean, standard deviation, and coefficient of variation were calculated for each mandal from 2008 to 2020. Minimum annual rainfall ranged from 409 mm to 512.80 mm, while maximum rainfall varied from 1268.10 mm to 1548.60 mm during the same period. Monsoon rainfall accounted for 74% to 77% of the total rainfall across all four mandals. Figure 3 presents a twelve-year time series of annual rainfall for the entire study area as well as for each mandal, while Table 1 and Table 2 summarize the data.

The analysis shows that annual rainfall in Saroor Nagar Mandal ranges from 512.80 mm/year to 1478.60 mm/year, with a mean of 891.71 mm/year and a standard deviation of 281.98 mm/year. Monsoon rainfall accounts for 74.42% of the total rainfall, followed by post-monsoon rainfall at 17%, pre-monsoon at 8%, and winter rainfall contributing less than 1%. In Hayat Nagar Mandal, annual rainfall ranges from 426 mm/year to 1578 mm/year, with a mean of 853.42 mm/year and a standard deviation of 322.11 mm/year. Monsoon rainfall accounts for 74.30% of the total, followed by post-monsoon rainfall at 17.34%, pre-monsoon at 7.14%, and winter rainfall contributing 1.24%.

Annual rainfall in Uppal Mandal ranges from 429 mm/year to 1268 mm/year, with a mean of 807.90 mm/year and a standard deviation of 237.80 mm/year. Monsoon rainfall accounts for 77.05% of the total, followed by pre-monsoon rainfall at 13.59%, winter rainfall at 8.08%, and post-monsoon rainfall at 1.28%. In Ghatkesar Mandal, annual rainfall ranges from 409 mm/year to 1473 mm/year, with a mean of 835.16 mm/year and a standard deviation of 317.38 mm/year.

Table 1. Rainfall Statistics

Saroor Nagar	Annual	Annual Mean	Pre-Mon	Mon	Post-Mon	Winter
Min	512.80	42.73	10.60	329.80	31.80	0.00
Max	1478.60	123.22	162.00	922.40	476.60	34.70
Mean	891.71	74.22	67.77	663.60	151.68	4.59
SD	281.98	23.53	52.13	191.55	134.01	10.70
CV	31.62	31.70	76.92	28.87	88.36	233.08
Hayat Nagar	Annual	Annual Mean	Pre-Mon	Mon	Post-Mon	Winter
Min	426.00	35.50	8.40	266.00	4.80	0.00
Max	1548.60	129.05	167.40	966.80	485.50	73.80
Mean	853.42	71.12	60.98	634.08	148.00	10.36
SD	322.11	26.84	53.56	222.17	141.67	20.23
CV	37.74	37.74	87.83	35.04	95.73	195.20
Uppal	Annual	Annual Mean	Pre-Mon	Mon	Post-Mon	Winter
Min	429.00	35.75	0.00	243.40	0.00	0.00
Max	1268.10	105.68	433.10	871.60	45.00	226.60
Mean	807.90	67.33	109.82	622.49	10.34	65.25
SD	237.80	19.82	124.71	180.43	17.81	66.16
CV	29.43	29.43	28.98	113.55	172.30	101.41
Ghatkesar	Annual	Annual Mean	Pre-Mon	Mon	Post-Mon	Winter
Min	409.00	34.08	0.00	246.80	0.00	0.00
Max	1473.40	122.78	123.80	1025.00	502.20	51.00
Mean	835.16	69.60	43.95	627.15	153.08	10.99
SD	317.38	26.45	43.48	244.11	162.07	17.43
CV	38.00	38.00	98.94	38.92	105.88	158.57

Table 2. Summary of descriptive statistics for the entire study area (average of all mandals)

Statistics	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Mean(mm)	847.05	70.63	636.83	115.77	22.80
SD (mm)	289.82	68.47	209.57	113.89	28.63
CV	34.20	94.31	32.95	115.56	172.06

Monsoon rainfall contributes 75.09%, followed by post-monsoon at 18.33%, pre-monsoon at 5.26%, and winter rainfall at 1.32%. Figure 4 shows the spatial variation of rainfall across all mandals. As observed from the maps, annual rainfall varies from 807.91 mm to 876.94 mm per year, with the highest rainfall recorded in the Saroor Nagar area, which is more urbanized than the other mandals. During the pre-monsoon season, Saroor Nagar and Uppal received higher rainfall, ranging from 43.95 mm to 67.76 mm. Monsoon rainfall ranges from 622.49 mm to 642.02 mm, indicating relatively uniform distribution across the mandals. The post-monsoon season recorded rainfall between 109.82 mm and 153.07 mm, while winter rainfall ranged from 8.14 mm to 11.19 mm. The maps clearly show that urban areas receive more rainfall compared to less urbanized regions, indicating the impact of urbanization on rainfall patterns and intensity, likely due to changes in wind patterns and increased temperatures.

Coefficient of variation

The coefficient of variation (CV) in annual rainfall is highest in Ghatkesar Mandal at 38%, followed by Hayatnagar at 37.74%, Saroor Nagar at 31.62%, and lowest in Uppal at 29.43%. During the pre-monsoon season, Ghatkesar reported the maximum variation at 98.94%, followed by Hayatnagar at 87.83%, Saroor Nagar at 76.92%, and Uppal at 76.92%. In the monsoon season, Uppal

recorded the highest CV at 113.55%, followed by Ghatkesar at 38.92%, Hayatnagar at 35.04%, and Saroor Nagar at 28.87%. During the post-monsoon season, Uppal again showed the highest variation at 172.30%, followed by Ghatkesar at 105.88%, Hayatnagar at 95.73%, and Saroor Nagar at 88.36%. In the winter season, Saroor Nagar reported the highest CV at 233.08%, followed by Hayatnagar at 195.20%, Ghatkesar at 158.57%, and Uppal at 101.41%. The spatial variation of the coefficient of variation for all seasons is shown in Figure 5. As seen from the maps, over 50% of the area exhibits a CV of 34-36% during annual rainfall. During the pre-monsoon season, most of the area shows a CV between 75-85%; during the monsoon season, between 44-55%; and during the post-monsoon season, between 104-115%. The high CV in Ghatkesar and Uppal, particularly during the pre-monsoon and winter seasons, can be attributed to unpredictable rainfall patterns and factors such as wind direction and temperature fluctuations, which cause significant variability. Uppal's extreme CV during the post-monsoon season suggests that rainfall is highly unpredictable due to local climatic conditions. In contrast, Saroor Nagar's relatively low CV across seasons may result from its urbanized environment, where more consistent rainfall patterns are influenced by urban heat islands and altered wind flow. These variations highlight the impact of geographical location and urbanization on rainfall distribution.

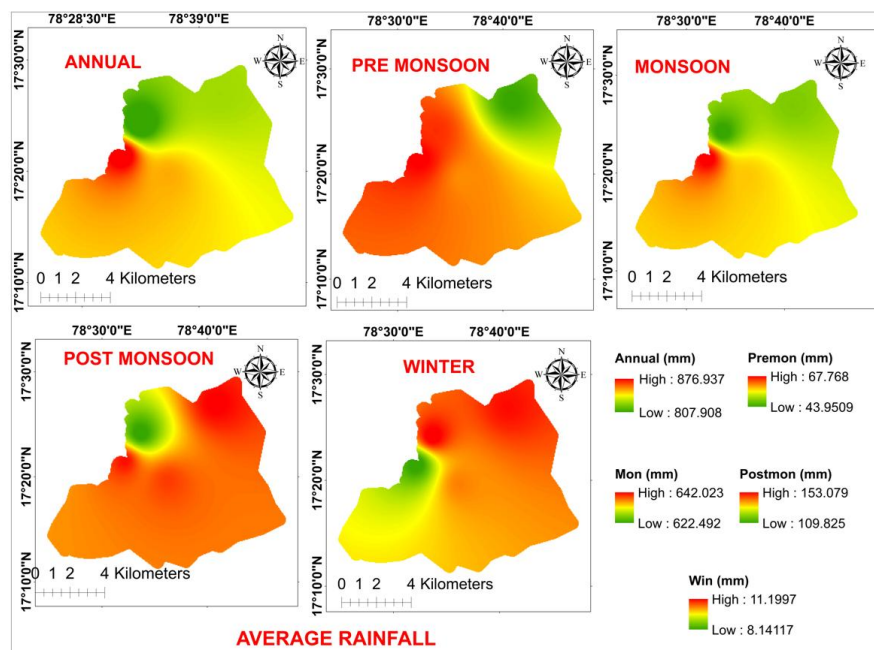


Figure 4. Spatial variation of rainfall across all mandals

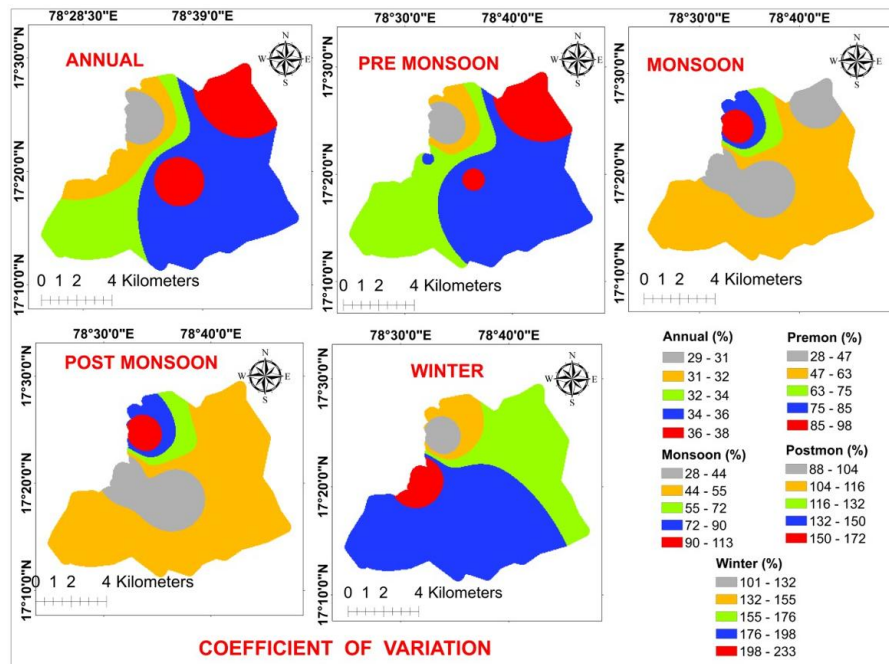


Figure 5. Spatial variation of rainfall across all mandals

Rainfall Variability

Rainfall variability across the study area as a whole and by mandal from 2008 to 2020 is shown in Figure 6. The overall rainfall variability is negative, indicating below-average rainfall during six of the years in this period. The year 2014 was the driest, with a RVI of -1.36, indicating a very dry climatic year, while 2020 was the wettest, with an RVI of +2.12. The negative RVI may be due to reduced monsoon activity or regional drought conditions, while the positive RVI in 2020 may result from increased moisture levels or strong monsoons.

Mandal Wise analysis of RVI

Saroor Nagar experienced negative rainfall variability in 7 out of the 12 years studied. The year 2011 was a very dry climatic year with a RVI of -1.34, while 2020 was a very wet year with an RVI of +2.08. Hayat Nagar recorded negative rainfall variability in 8 out of 12 years. The driest year was 2011, with an RVI of -1.33, and the wettest was 2020, with an RVI of +2.16. Uppal showed negative rainfall variability in 7 out of 12 years, with 2014 being the driest year (RVI -1.59) and 2020 the wettest (RVI +1.94). Ghatkesar recorded negative rainfall variability in 8 out of 12 years, with 2018 as the driest (RVI -1.34) and 2010 as the wettest (RVI +2.01). The RVIs for each mandal and for the entire study area are shown in Figure 6.

Trend Analysis

The MK test is used to determine whether the rainfall data series over the study area exhibits a statistically significant monotonic increasing or decreasing trend. While the MK test assesses the presence of a trend, Sen's slope estimates its magnitude.

MK Trend and Sen's Slope of Saroor Nagar

As seen in Table 3, the pre-monsoon season shows a significantly increasing trend, with a Z-value of +21.94 and Sen's slope of +3.508. In contrast, the monsoon season exhibits a significantly decreasing trend, with a Z-value of -13.94 and Sen's slope of -14.933. The post-monsoon and winter seasons indicate increasing trends, though statistically insignificant. Annual rainfall shows no discernible trend, with a Z-value of 0. Seasonal trend graphs are presented in Figure 7.

MK Trend and Sen's Slope of Hayat Nagar

As seen in Table 4, an insignificant increasing trend is observed for annual rainfall and all seasons. The strongest trend appears in annual rainfall, with an S-value of 22.510, followed by the monsoon season with an S-value of 12.863. Seasonal trend graphs are shown in Figure 8.



Figure 6. Rainfall variability index: (a) All four mandals, (b) Saroor Nagar, (c) Hayatnagar, (d) Uppal, (e) Ghatkesar

Table 3. Summary of statistics for Saroor Nagar

Series/Test	Kendall's tau	p-value	Z Value	Sen's slope
Annual	0.000	0.952	0.00	1.068
Pre Mon	0.282	0.204	21.94	3.508
Mon	-0.179	0.435	-13.94	-14.933
Post Mon	0.051	0.858	0.18	1.175
Winter	0.185	0.402	0.77	0.000



Figure 7. Rainfall trends in Saroor Nagar mandal

Table 4. Summary statistics for Hayatnagar

Series\Test	Kendall's tau	p-value	Z Value	Sen's slope
Annual	0.179	0.435	0.79	22.510
Pre Mon	0.256	0.252	1.16	4.500
Mon	0.154	0.510	0.67	12.863
Post Mon	0.039	0.855	0.12	1.092
Winter	0.105	0.640	0.40	0.000

MK Trend and Sen's Slope of Uppal

As seen in Table 5, the Z-value is positive for the annual, pre-monsoon, post-monsoon, and winter seasons, indicating an increasing, though insignificant, trend. The monsoon period shows no trend. The strongest trend is observed for annual rainfall, with an S-value of 11.070, followed by the pre-monsoon season with an S-value of 4.234. Seasonal trend graphs are shown in Figure 9.

MK Trend and Sen's Slope of Ghatkesar

As seen in Table 6, there is an insignificant decreasing trend in annual rainfall and across all seasons. The monsoon season shows the strongest decline, with an S-value of -19.356, followed by annual rainfall with an S-value of -12.975. Seasonal trend graphs are shown in Figure 10. The spatial variation of the MK test Z-values and Sen's slope is presented in Figure 11.

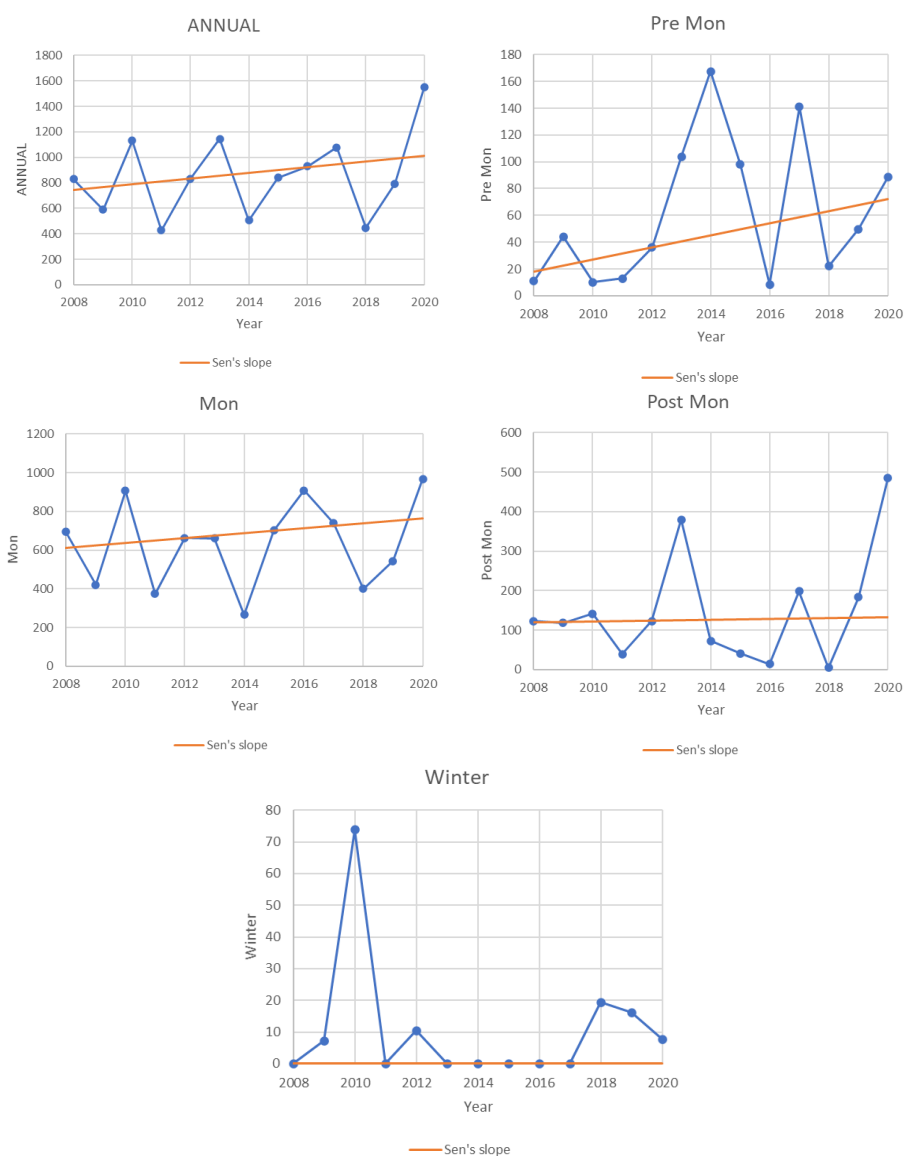


Figure 8. Rainfall trends in Hayatnagar mandal

Table 5. Summary statistics for Uppal

Series/Test	Kendall's tau	p-value	Z Value	Sen's slope
Annual	0.128	0.590	0.55	11.070
Pre Mon	0.077	0.765	0.31	4.234
Mon	0.013	0.951	0.00	0.067
Post Mon	0.105	0.652	0.38	0.00
Winter	0.065	0.760	0.24	0.507

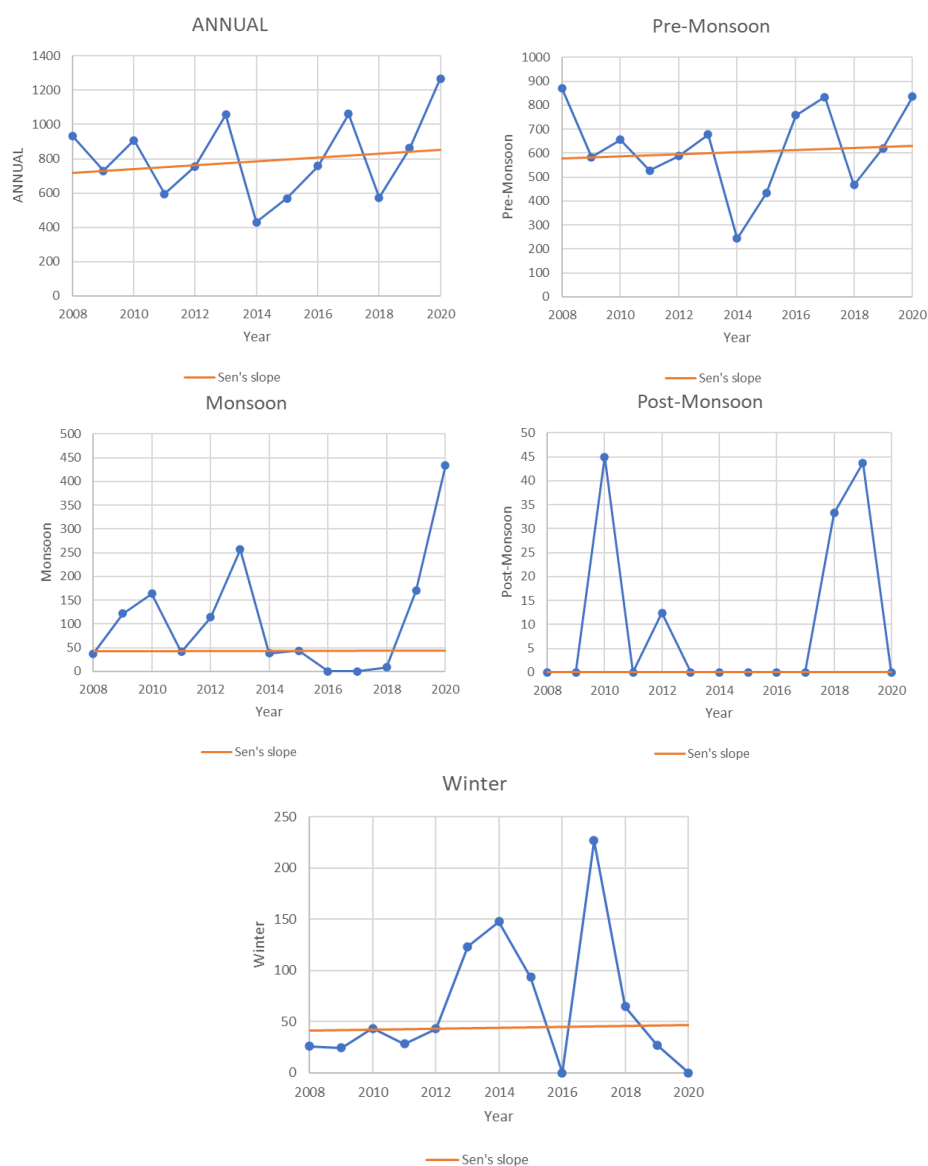


Figure 9. Rainfall trends in Uppal mandal

Table 6. Summary statistics for Ghatkesar

Series\Test	Kendall's tau	p-value	Z Value	Sen's slope
Annual	-0.282	0.204	-1.28	-12.975
Pre Mon	-0.170	0.425	-0.74	-1.025
Mon	-0.205	0.367	-0.92	-19.356
Post Mon	-0.090	0.667	-0.37	-3.738
Winter	-0.064	0.779	-0.21	0.000

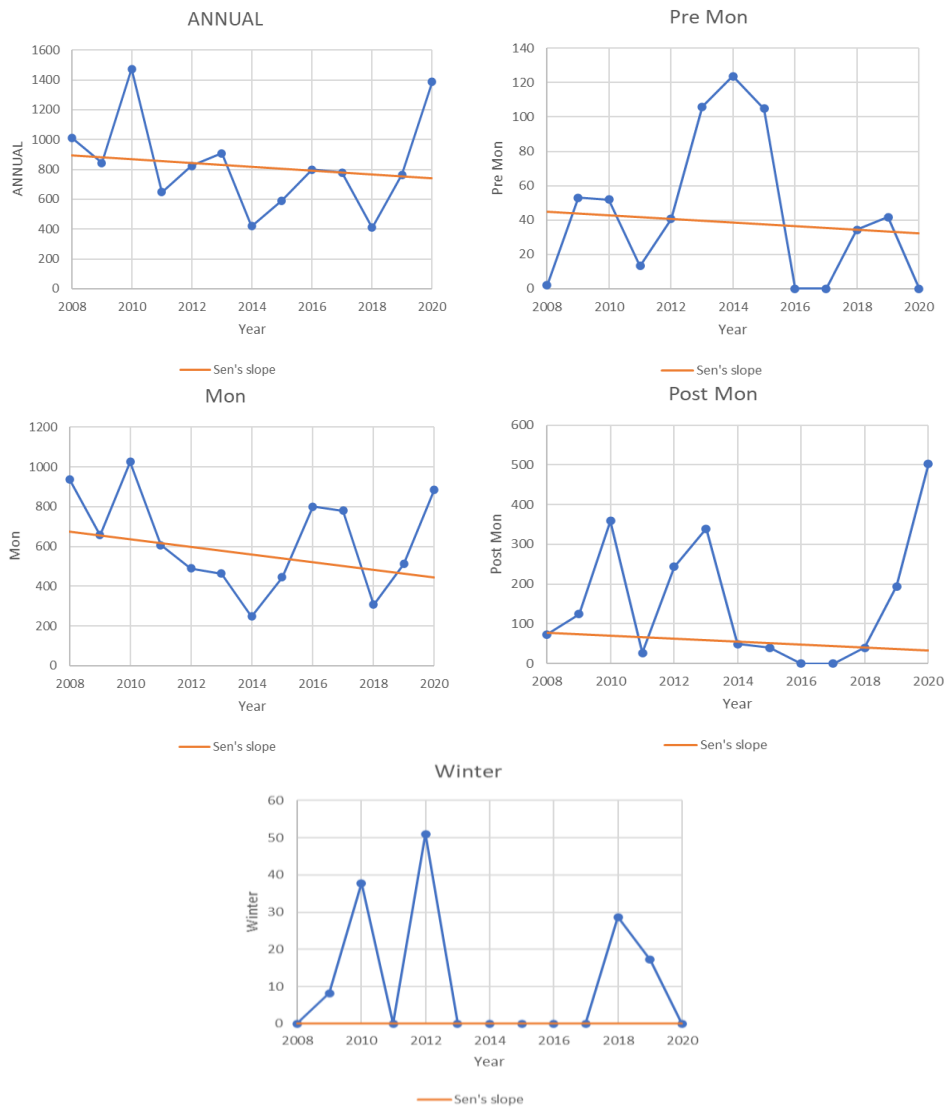


Figure 10. Rainfall trends in Ghatkesar mandal

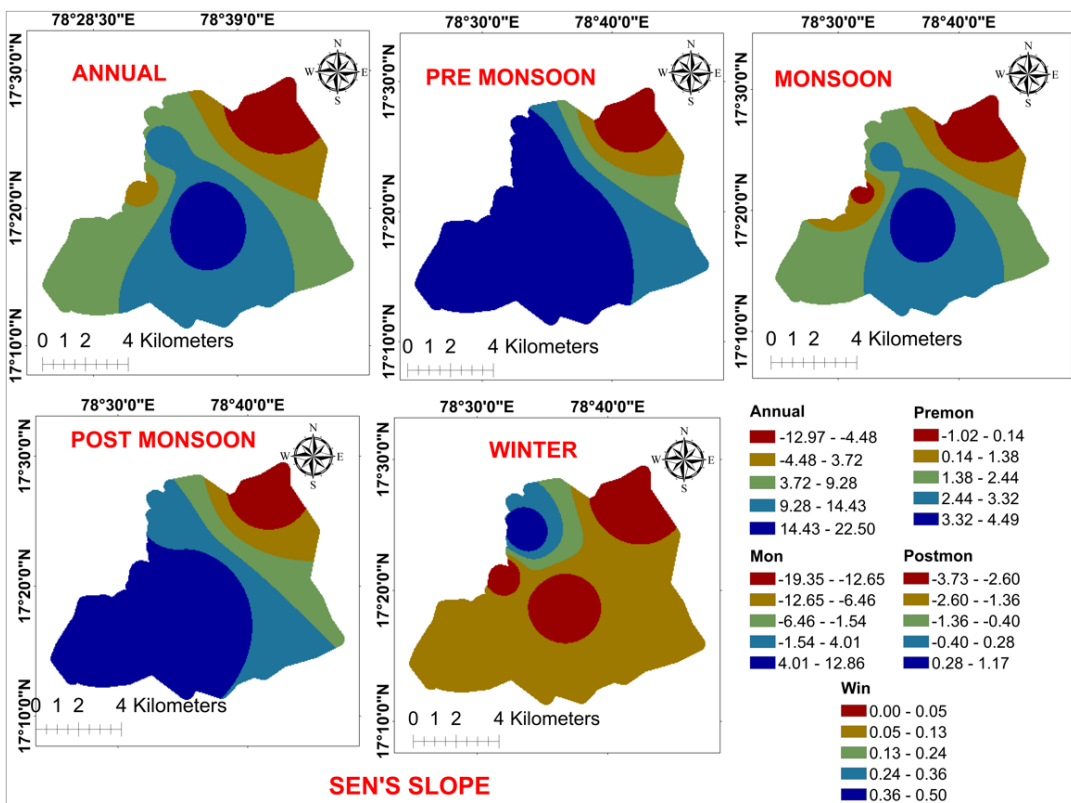
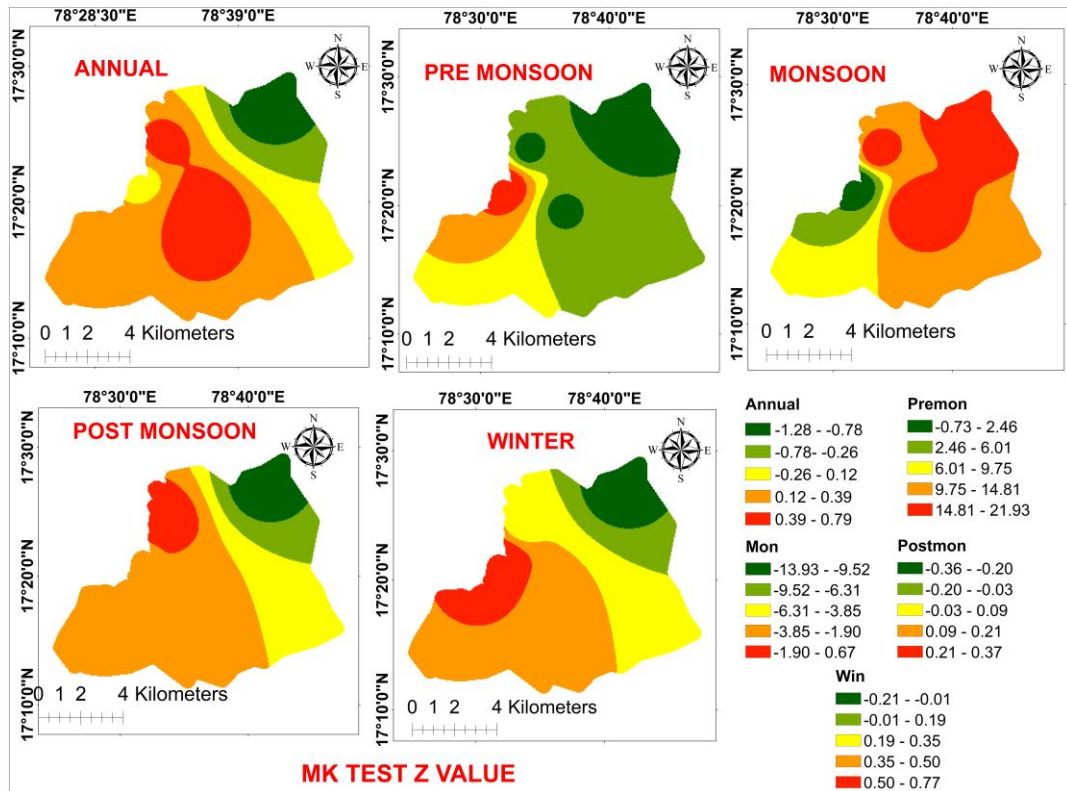


Figure 11. Spatial variation of Mann–Kendall test Z-values and Sen's slope

Conclusions

This study analyzed rainfall trends from 2008 to 2020 in Telangana's humid and sub-humid zones, focusing on Saroor Nagar, Hayat Nagar, Uppal, and Ghatkesar. Annual rainfall varied significantly, with Saroor Nagar receiving the highest and Ghatkesar the lowest amounts. Monsoon rainfall accounted for the majority (74%-77%), followed by post-monsoon (17%-18%), pre-monsoon (5%-14%), and winter rainfall (<2%). Urbanization influenced precipitation, with Saroor Nagar experiencing increased rainfall likely due to urban heat island effects. Rainfall variability was highest in Ghatkesar, particularly during the pre-monsoon season (CV: 98.94%), while winter rainfall remained highly erratic. Nearly half the years exhibited negative rainfall variability, with 2014 being the driest (RVI: -1.36) and 2020 the wettest (RVI: +2.12). Trend analysis indicated a significant increase in pre-monsoon rainfall in Saroor Nagar and a decline in monsoon rainfall, suggesting shifting precipitation patterns. Hayat Nagar and Uppal showed increasing trends across all seasons, though statistically insignificant, whereas Ghatkesar exhibited an overall decreasing trend. These findings underscore the risks posed by rising rainfall variability and declining monsoon precipitation to water management and agriculture. Future research should incorporate climate models and remote sensing techniques, while adaptive measures such as enhanced rainwater harvesting and groundwater recharge should be prioritized for sustainable water resource management.

Data Availability

The data supporting the findings of this study are available within the article.

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Competing Interests/Conflict of Interest

The Authors declare no conflicts of interest.

Author Contributions

Study conception, design, material preparation, data collection and analysis were conducted by Shiva Chandra Vaddiraju. The manuscript was written and approved by Dr. Shiva Chandra Vaddiraju.

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