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ANALYSIS OF RAINFALL TREND USING NON PARAMETRIC METHODS FOR WATERSHEDS OF BENGALURU URBAN AREA

Amrutha Rani. H R
Research Scholar, Department of Civil Engineering, UVCE, Bangalore University, Jnanabharathi, Bengaluru 560056, India

A. S. Ravikumar
Professor, Department of Civil Engineering, UVCE, Bangalore University, Jnanabharathi, Bengaluru 560056, India

ABSTRACT

Rainfall plays a crucial role in the hydrological cycle, and changes in its patterns directly impact water resources. These alterations affect hydrological properties and soil characteristics. Analyzing rainfall trends is essential for understanding the impact of climate change on water availability and food security. Numerous studies have investigated rainfall trends at regional and national levels, providing valuable insights into future changes. This study examines 43 years (1980-2022) of rainfall data in Bangalore Urban using the Mann Kendall (MK) and Sen's slope estimator tests. These methods detect variations and long-term monotonic trends in rainfall. Analysis was conducted using XLSTAT software at a 95% significance level. Across 12 rain gauge stations, average annual rainfall ranges from 479.22 mm (Krishnarajapura) to 873.15 mm (Anekal). Krishnarajapura exhibits the highest variability in annual rainfall (coefficient variation of 92.77%), while Anekal shows the lowest (coefficient of variation 29.14%). Sen's slope estimates indicate a positive trend at all stations, suggesting an overall increase in rainfall. However, the Attibele rain gauge station shows a decreasing trend in the pre-monsoon and monsoon periods, and Anekal exhibits a decreasing trend in the monsoon period. The irregular and intensified rainfall patterns, coupled with urban sprawl in Bengaluru Urban, contribute significantly to flooding events.

Keywords: Rainfall, Mann-Kendall test, Sen's slope Estimator, Trend Analysis

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INTRODUCTION

In India, the variability in rainfall patterns during monsoon seasons results in regions experiencing either abundant rainfall or severe water scarcity, exacerbated by climate change (Goswami et al., 2006). A comprehensive understanding of these patterns is crucial for informed decision-making and enhancing community resilience against extreme weather events. Consequently, researchers in India have undertaken numerous initiatives to analyze rainfall trends at both national and regional scales.

Any alteration in precipitation directly influences stream flow, as they are closely related. The amount of rainfall a region receives affects the availability of water for various purposes such as domestic use, agriculture, industry, and hydroelectric power generation. Changes in rainfall frequency and temporal distribution alter stream flow patterns, soil moisture levels, and the depletion of groundwater resources. Conducting a detailed trend analysis of rainfall helps in understanding the challenges associated with floods, droughts, and future water availability under different climate scenarios. Analyzing past trends in meteorological parameters across different spatial and temporal scales is essential for comprehending climate change. This evaluation plays a critical role in assessing its impact on food security, energy security, natural resource management, and sustainable development.

Trend analysis of rainfall is crucial for understanding climate patterns and their impacts on regions like Bengaluru Urban. Researchers have applied non-parametric tests to investigate trends, finding that India overall has not shown a significant increase or decrease in annual average rainfall (Praveen et al., 2020). Detecting trends in rainfall and stream flow is vital for hydrology and climatology, especially in the context of climate change (Amrutha and Sreedhar, 2014). Such studies provide valuable insights into managing floods, droughts, and extreme weather events. The adoption of non-parametric methods in this study aims to yield reliable results on rainfall trends specific to Bengaluru Urban.

STUDY AREA DESCRIPTION

Bengaluru Urban is the most densely populated city which is geographically lies between 12º49’5” N to 13º8’32” N latitude and 77º27’29” E to 77º47’2” E longitude. Bengaluru Urban has four taluks namely, Bengaluru North, Bengaluru South, Bengaluru East and Anekal and surrounded by Bengaluru Rural district in the east and north, Ramanagara district in the west and Krishnagiri district of Tamil Nadu in south. Plate 1 shows the location map of the study area. The city of Bengaluru experiences very favourable weather throughout the year. The city is in the Deccan plateau of southern peninsular India and is situated at an elevation of 949 m above mean sea level. The maximum temperature during summer and winter are 36°C and 17°C respectively. The annual average rainfall is 859 mm with different rainy seasons covering nine months of the year. June to October is the rainy season accounting for 64% of the total annual rainfall in the SW monsoon period and 324 mm during the NE monsoons (November – December). Bengaluru urban have three valleys namely Vrishabhavathi flows from north to south and confluence with river Arkavathi near Ganalu, Karnataka Taluk, Ramanagara District. KC and Hebbal flows towards east and joins Dhakshina Pinakini river near Nagondanahalli and Mallasandra, Bengaluru respectively. The study area has 12 raingauge stations Anekal, Attibele, Chikkajala, Jigani, Kadugodi Plantation, Kengeri, Krishnarajapura, Sarjapur, Tavareke, Tippagondanahalli, Uttarahalli and Varthur.

DATA AND METHODS

The daily rainfall data from 12 rain gauge stations in Bengaluru Urban spanning 43 years (1980-2022) were sourced from WRDO, Bengaluru. After rigorous consistency checks confirming their reliability, the data were analyzed to compute essential statistical metrics such as average rainfall, coefficient of variation, standard deviation, kurtosis coefficient, and skewness coefficient. Additionally, the data were categorized into three distinct climatic seasons: monsoon (June-September), pre-monsoon (April-May), and post-monsoon (October-November).

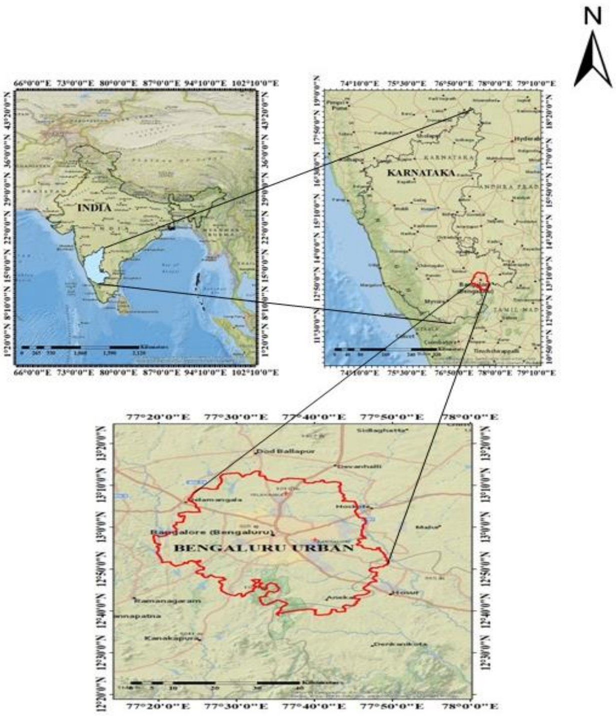


Plate 1 Location map of Bengaluru Urban

Table 1 Geographical details of rain gauge stations of Bengaluru Urban

Sl. No	Name of the Rain gauge Station	Latitude (N)	Longitude (E)
1	Anekal	12.709^0	77.699^0
2	Attibele	12.779^0	77.77^0
3	Chikkajala	13.169^0	77.634^0
4	Jigani	12.778^0	77.643^0
5	Kadugodi Plantation	12.993^0	77.751^0
6	Kengeri	12.899^0	77.482^0
7	Krishnarajapura	13.017^0	77.704^0
8	Sarjapura	12.857^0	77.786^0
9	Tavarekere	12.965^0	77.402^0
10	Tippagondanahalli	12.968^0	77.335^0
11	Uttarahalli	12.907^0	77.552^0
12	Varthur	12.939^0	77.741^0

Thiessen's polygons have been plotted to knew the influencing rain gauge stations. Fig. 1 shows the Thiessen's polygon of Bengaluru urban.

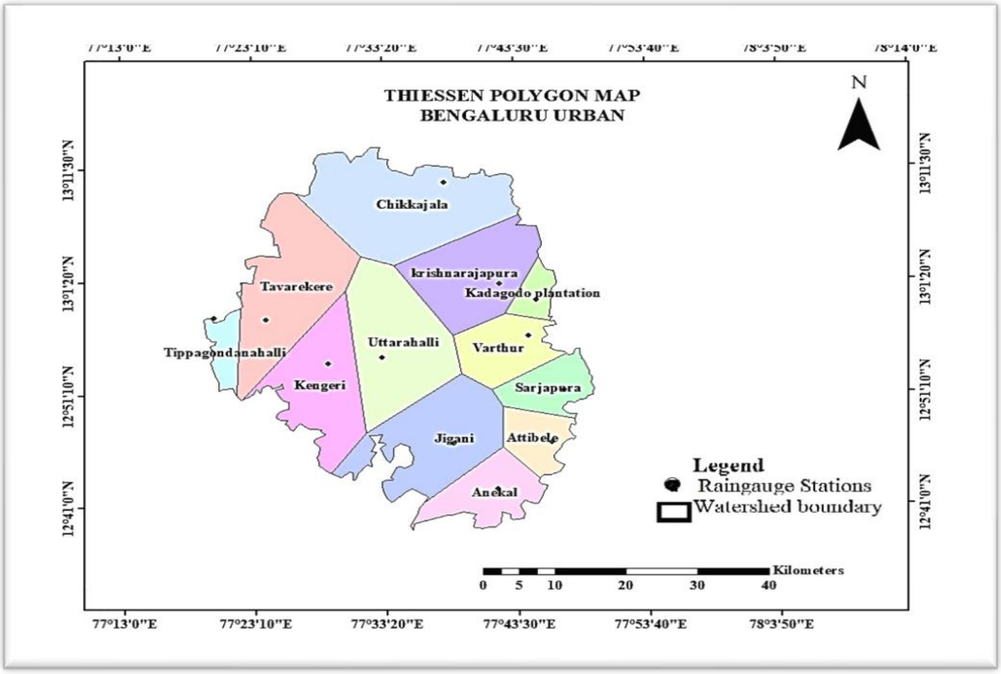


Fig.1 Thiessen polygon of raingauge stations of Bengaluru urban

Fig. 2 explain the methodology adopted to carry out the trend analysis using Mann-Kendall and Sen's Slope estimator methods.

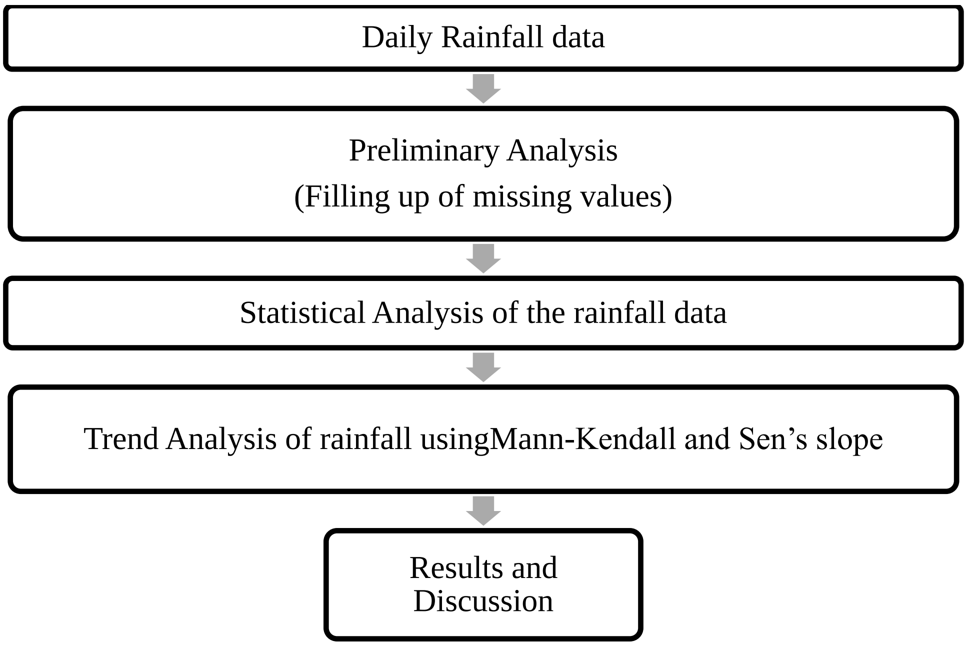


Fig.2 Methodology followed for trend analysis

Mann-Kendall Trend Test

Mann, 1945 and Kendall, 1975 established Mann-Kendall (MK) test which is a non-parametric test which are widely used statistical test for analysing the trends in the data series based on relative ranking. It statistically checks the monotonic upward and downward trends of climate data series over the time. The World Meteorological Organisation (WMO) recommended this test to detect trend for a set of hydrological data. The Mann - Kendall test equation is as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn\left(x_j - x_i\right) \tag{1}$$

where x_j and x_i are the time series and N is the number of data points in the time series. The sgn function can be further expressed as:

$$Sgn\left(x_j - x_i\right) = \begin{cases} +1, & (x_j > x_i) > 0 \\ 0, & (x_j = x_i) = 0 \\ -1, & (x_j < x_i) < 0 \end{cases} \tag{2}$$

A positive S value indicates an upward trend, while a negative value indicates a downward trend. The variance of rainfall is calculated to obtain the Z value which is as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\dfrac{n(n-1)(2n+5)-\sum_{j=1}^{q} t_j\left(t_j-1\right)\left(2t_j+5\right)}{18}}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S-1}{\sqrt{\dfrac{n(n-1)(2n+5)-\sum_{j=1}^{q} t_j\left(t_j-1\right)\left(2t_j+5\right)}{18}}} & if\ S < 0 \end{cases} \tag{3}$$

Sen’s Slope Estimator

The non parametric Sen’s slope estimator developed by Sen (1968) used to predict the magnitude of hydrological time series data. In this test, the trend is assumed to be linear and represents the quantification of the time change. The Sen’s Slope equation for a number of N data sample pairs is as follows:

$$Q_i = \frac{(x_j - x_k)}{j-k} \text{ for } i = 1, 2, 3 \ldots\ldots N \tag{4}$$

where x_j and x_k are data values at time j and k (J>k), respectively. If there are n values of x_j in the time series, there will be N= n(n-1)/2 slope estimates.

RESULTS AND DISCUSSION

Numerous studies on time series data have consistently revealed trends that either decrease or increase over time. Trend analysis employs a variety of methods, including both parametric and non-parametric approaches. Parametric methods like linear regression, graphical methods, and least squares are frequently utilized. Non-parametric tests such as the Mann-Kendall test and Sen's slope estimator are particularly favoured and widely applied for identifying trends in climatic parameters.

Analysis of annual rainfall

Statistical analysis of annual rainfall provides crucial insights into the parameters and distribution necessary for designing and managing water resources projects (Luis et al., 2000).

These statistics enable the extraction of essential information from the data and the characterization of hydrologic variables vital for rainfall analysis.

The study also examines shape parameters such as the coefficient of skewness and kurtosis coefficient (Bharath and Venkatesh, 2022), detailed in Table 2. Annual average rainfall varied notably, ranging from 479.22 ± 444.58 mm (Krishnarajapura) to 873.15 ± 254.43 mm (Anekal), accompanied by coefficients of variation of 92.77% and 29.14%, respectively.

The standard deviation of annual rainfall ranges from 254.43 (Anekal) to 554.03 (Kengeri), with coefficients of variation of 29.14% and 62.28%, respectively. The kurtosis coefficients for most stations are negative, suggesting distributions flatter than normal. Notably, Kengeri exhibits a kurtosis coefficient exceeding 3, indicating a higher frequency of low rainfall values compared to high values. Skewness coefficients are mostly positive across stations, indicating frequent occurrence of low rainfall and rare instances of high rainfall. Some stations have skewness coefficients near zero, suggesting data distributions approaching normality.

Time series analysis of rainfall

The daily rainfall data from influencing rain gauge stations spanning 43 years (1980-2022) has been analyzed. Figures 4 to 14 depict monthly and seasonal rainfall patterns for Anekal, Attibele, Chikkaajala, Jigani, Kadagodo Plantation, Kengeri, Krishnarajapura, Sarjapura, Tavarekere, Tippagondanahalli, Uttarahalli, and Varthur stations. The average annual rainfall across Bengaluru Urban ranges from 479.22 mm (Krishnarajapura) to 889.52 mm (Kengeri).

Table 2 Rainfall statistics of rain gauge station of Bengaluru Urban area

Sl. No	Name of the Rain gauge Station	Max (mm)	Avg. (mm)	SD (mm)	Cv	Skew	Kurtosis
1	Anekal	1494.5	873.15	254.43	29.14	0.26	-0.36
2	Attibele	1284.5	620.79	305.85	49.26	-0.0045	-0.58
3	Chikkajala	2035.7	619.62	551.41	88.99	0.42	-0.66
4	Jigani	1888	759.29	498.40	65.64	0.22	-0.44
5	Kadagodo plantation	2028.2	628.03	505.57	80.50	0.86	0.75
6	Kengeri	3204.2	889.52	554.03	62.28	1.52	6.32
7	Krishnarajapura	1359.7	479.22	444.58	92.77	0.52	-0.88
8	Sarjapura	1422.2	555.45	346.92	62.45	0.30	-0.01
9	Tavarekere	1383.8	679.63	267.22	39.31	0.57	-0.01
10	Tippagondanahalli	1631.7	618.61	383.39	61.97	0.08	-0.19
11	Uttarahalli	1584	783.23	445.53	56.88	0.05	-0.77
12	Varthur	1254.8	582.42	389.89	66.94	-0.11	-0.92

TREND ANALYSIS OF RAINFALL

The rainfall variation on a monthly basis was assessed for all 12 rain gauge stations using the Mann-Kendall and Sen’s slope estimator methods. Table 3 presents the statistical analysis of annual rainfall data from 1981 to 2022 at a 95% confidence level. Seasonal analysis divides the annual precipitation data into monsoon, post-monsoon, and pre-monsoon seasons. According to historical and predictive periods, a positive Sen’s slope value for rainfall series indicates an upward or increasing trend (Ashwad et al., 2020), while a negative value indicates a downward or decreasing trend. Most annual series exhibit an increasing trend in rainfall data (Amrutha Rani and Shreedhar, 2014). Specifically, the Attibele station shows a decreasing trend in the pre-monsoon and monsoon periods, and the Anekal station exhibits a decreasing trend in the monsoon period, while the remaining stations show positive trends.

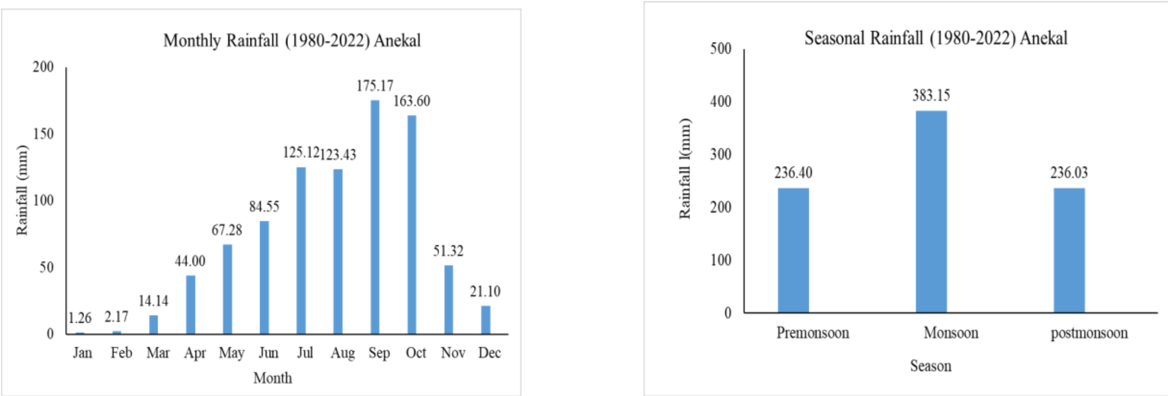


Fig.4 Mean monthly rainfall and mean seasonal rainfall (mm) of Anekal (1980-2022)

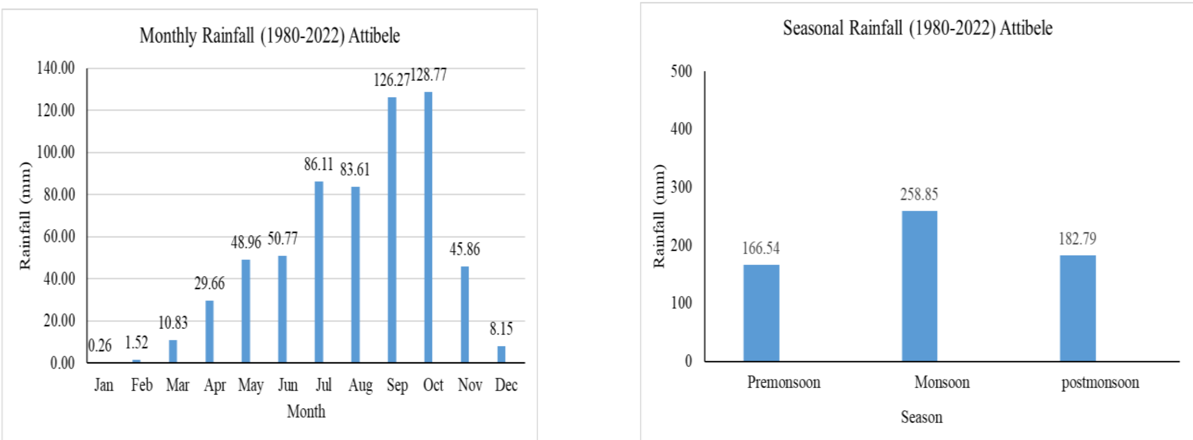


Fig.5 Mean monthly rainfall and mean seasonal rainfall (mm) of Attibele (1980-2022)

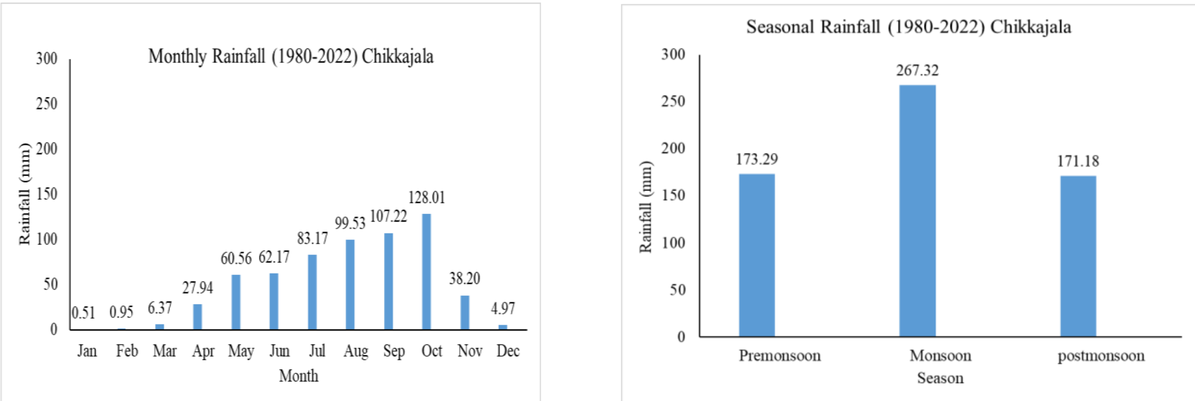


Fig.6 Mean monthly rainfall and mean seasonal rainfall (mm) of Chikkajala (1980-2022)

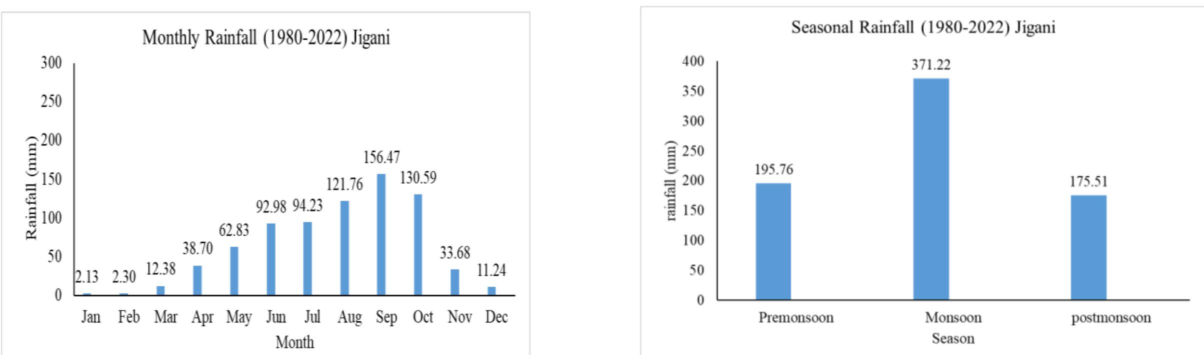
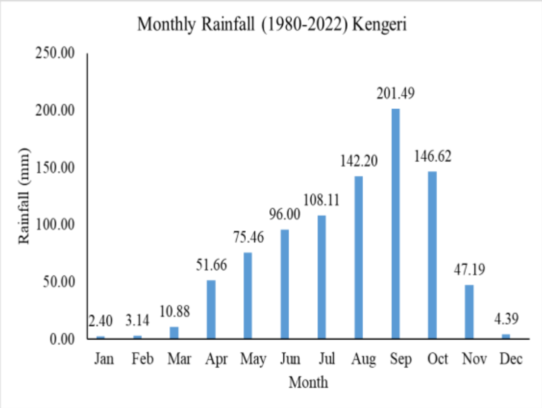


Fig.7 Mean monthly rainfall and mean seasonal rainfall (mm) of Jigani (1980-2022)



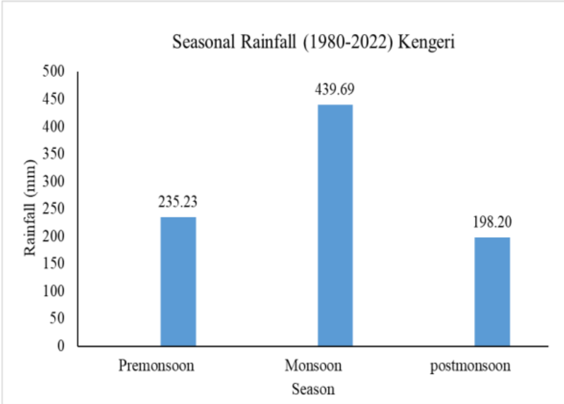
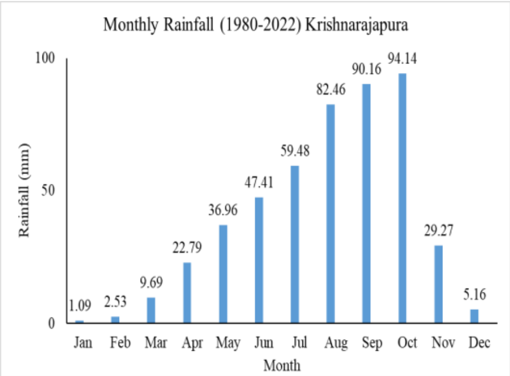


Fig.8 Mean monthly rainfall and mean seasonal rainfall (mm) of Kengeri (1980-2022)



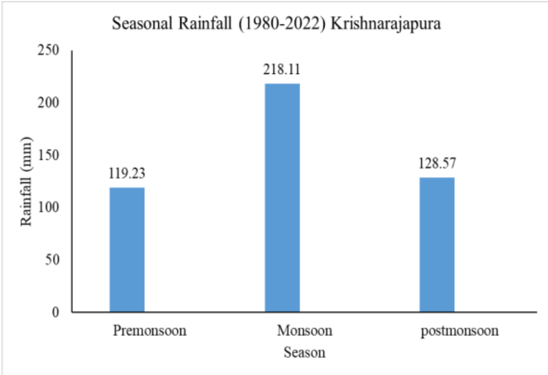
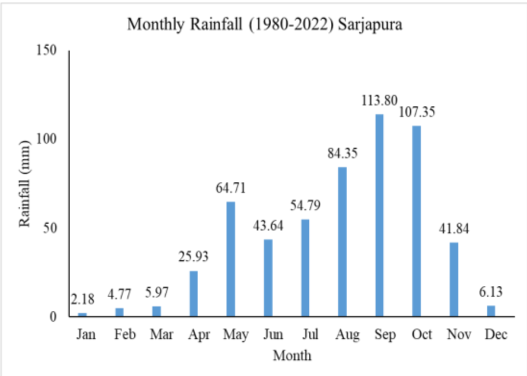


Fig.9 Mean monthly rainfall and mean seasonal rainfall (mm) of Krishnarajapura(1980-2022)



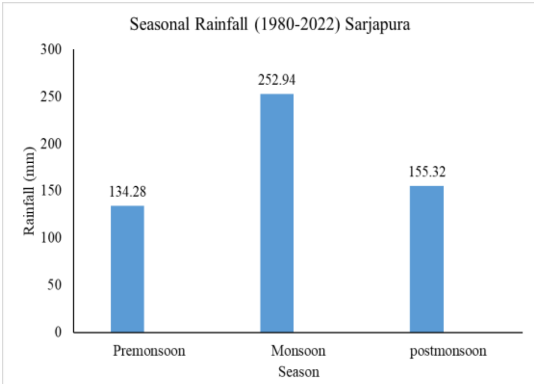
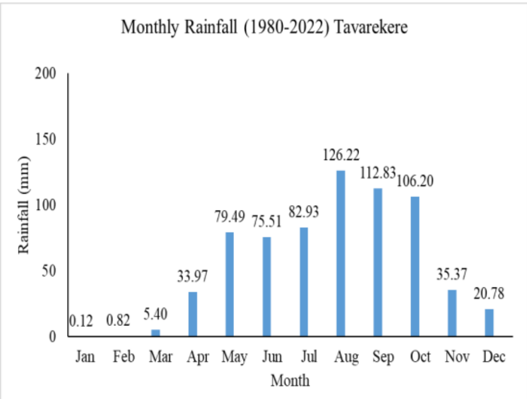


Fig.10 Mean monthly rainfall and mean seasonal rainfall (mm) of Sarjapura (1980-2022)



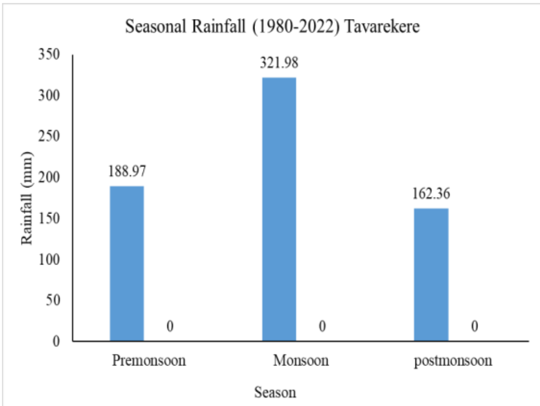


Fig.11 Mean monthly rainfall and mean seasonal rainfall (mm) of Tavarekere (1980-2022)

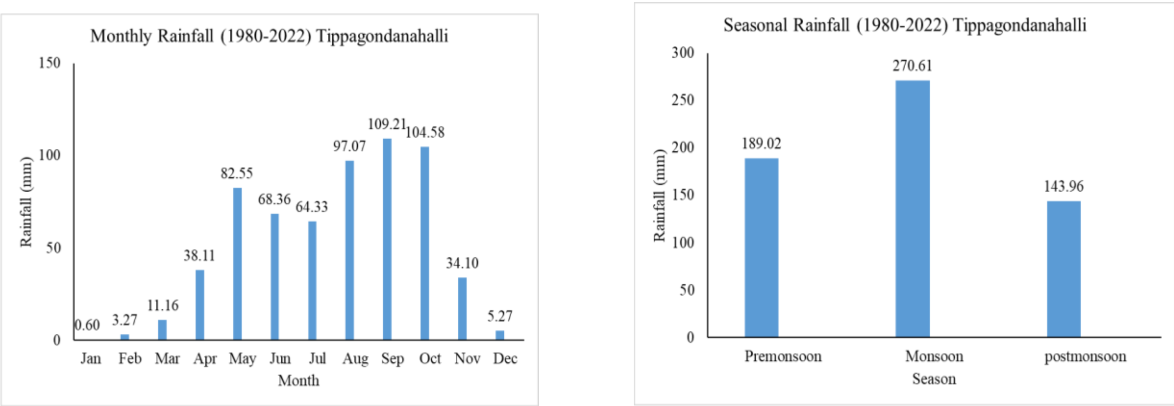


Fig.12 Mean monthly rainfall and mean seasonal rainfall (mm) of Tippagondanahalli (1980-2022)

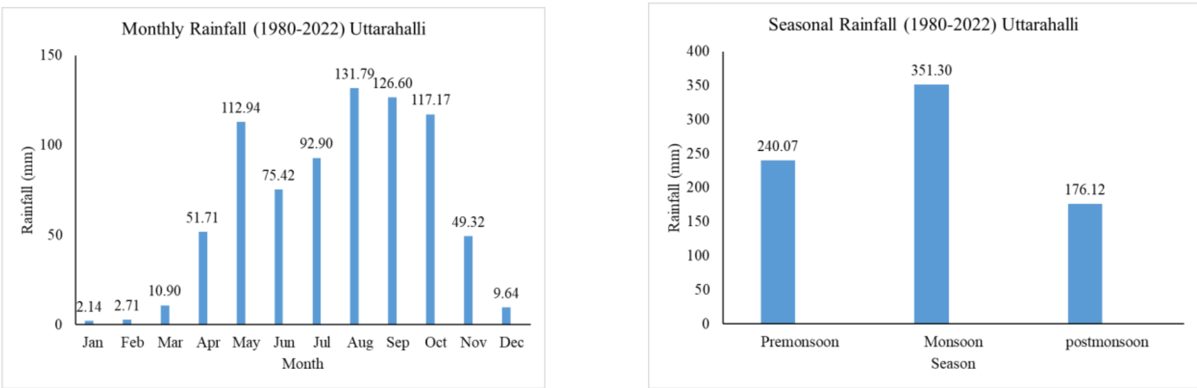


Fig.13 Mean monthly rainfall and mean seasonal rainfall (mm) of Uttarahalli (1980-2022)

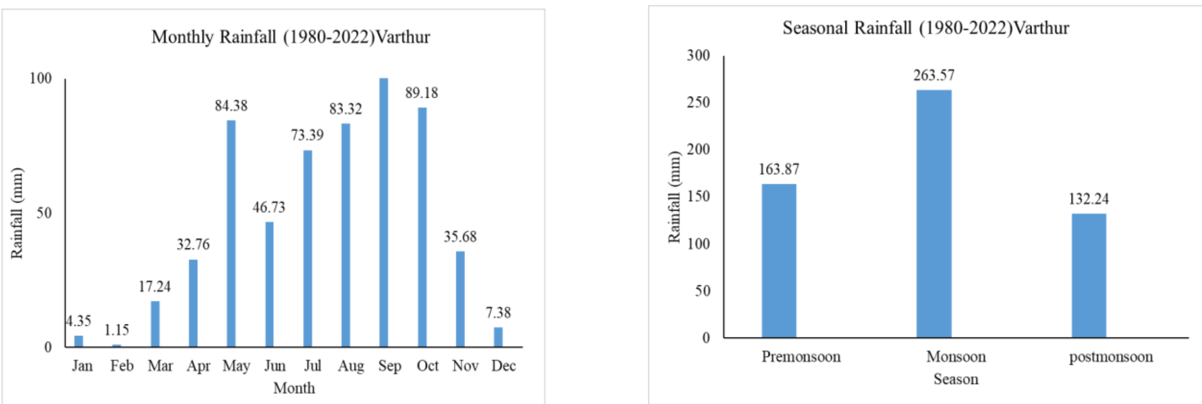


Fig.14 Mean monthly rainfall and mean seasonal rainfall (mm) of Varthur (1980-2022)

Table 3 Annual rainfall data using Mann–Kendall and Sen's slope estimator method

SI. NO	Name of the Raingauge stations	Total		Pre-Monsoon		Monsoon		Post Monsoon	
		p value	Sen's slope	p value	Sen's slope	p value	Sen's slope	p value	Sen's slope
1	Anekal	0.933	0.393	0.884	0.200	0.645	-1.011	0.379	1.900
2	Attibele	0.967	0.077	0.362	-1.379	0.818	-0.441	0.530	0.925
3	Chikkajala	0.000	23.250	0.0001	6.379	0.001	8.356	0.001	5.469
4	Jigani	0.001	20.258	0.000	7.397	0.029	8.010	0.014	4.800
5	Kadugodi plantation	0.346	6.111	0.1562	1.519	0.285	2.411	0.515	0.492
6	Kengeri	0.0001	22.709	0.0001	7.339	0.007	7.860	0.002	4.884
7	Krishnarajapura	0.0001	25.643	0.0001	7.014	0.0001	9.936	0.0001	4.925
8	Sarjapura	0.164	5.486	0.164	1.696	0.509	1.606	0.586	0.506
9	Tavarekere	0.009	9.341	0.015	1.849	0.379	1.696	0.194	1.720
10	Tippagondanahalli	0.0002	19.074	0.0002	5.870	0.018	5.876	0.004	3.980
11	Uttarahalli	0.006	16.659	0.012	5.434	0.015	4.476	0.035	2.907
12	Varthur	0.001	15.967	0.019	3.470	0.002	7.911	0.014	3.55

CONCLUSIONS

In this study spanning 43 years, annual rainfall data from three valleys in Bengaluru Urban was analyzed using non-parametric methods for pre-monsoon, monsoon, and post-monsoon periods to detect trends. The analysis revealed that the Attibele rain gauge station exhibited a negative Sen's slope, indicating a decreasing trend during the pre-monsoon season. Conversely, the remaining stations showed a positive trend during this period. Similarly, during the monsoon season, Anekal and Attibele stations displayed negative trends, while all stations showed a positive trend during the post-monsoon season. These findings from the rainfall trend analysis are valuable for devising improved strategies for water management, ensuring water security, addressing flood risks during the monsoon season, optimizing cropping practices, and promoting sustainable development of natural resources in and around Bengaluru Urban.

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