Rainfall Trend Analysis in Mysuru and Bengaluru Districts of Karnataka

Abstract

Climate change is one of the most pressing challenges facing humanity today, with temperature, precipitation, and runoff being key indicators closely linked to its impact. Understanding the spatial variability and temporal trends of rainfall is crucial for effective water resource management and agriculture. This study focuses on analyzing rainfall data from the Mysuru and Bengaluru districts, located in the Southern and Eastern dry zones of Karnataka, respectively. These regions play a pivotal role in the state's agricultural development and overall economic growth. We utilized daily precipitation records from two meteorological stations, spanning the period from 1983 to 2018, to analyze rainfall trends on monthly, seasonal, and annual scales. To assess these trends, we applied both parametric and non-parametric statistical methods, including the simple regression method, Mann-Kendall test, and Sen’s slope estimator. The Mann-Kendall test was used to detect significant trends in the precipitation time series, while Sen’s slope estimator quantified the magnitude of these trends. The findings of this trend analysis are essential for informed water resource planning and management in the region.

Comment [A1]: In abstract parts, outcome of results will be mentioned.

Keywords: *Rainfall;Climate Change; Trend Analysis;Mann-Kendall test; Sen’s slope estimator*

1. Introduction

India's vast geographical expanse and diverse climatic zones lead to significant variations in rainfall, a critical component of the hydrological cycle that underpins agriculture, industry, and domestic consumption. With nearly 50% of the population employed in agriculture, contributing around 18% to GDP, the monsoon season, which provides about 75% of annual rainfall, is vital for the country's agricultural productivity and economic stability(Singh et al. 2020). Karnataka exemplifies this variability, receiving rainfall from both the South-West and North-East monsoons, with stark intra-state disparities. Coastal regions are drenched with heavy rainfall, while inland areas, including Bengaluru and Mysuru, receive considerably less. Bengaluru, with its tropical savanna climate, faces challenges such as urban flooding and water scarcity due to fluctuating rainfall patterns, impacting both its growing urban population and peri-urban agriculture. Mysuru, lying in the rain shadow of the Western Ghats, relies heavily on the monsoon for its agrarian economy, with deviations in rainfall leading to droughts, crop failures, and economic distress(Khan 2024). These variations in rainfall distribution underscore the critical importance of timely and sufficient monsoon rains for the socio-economic stability of regions across Karnataka.

Given the critical importance of rainfall in these regions, it is essential to analyze the rainfall patterns and trends over time to better understand the underlying climatic dynamics. Studying these patterns can provide insights into long-term changes, help in anticipating future trends, and support the development of strategies for mitigating the adverse effects of rainfall variability(Subramanian et al. 2023). This is particularly relevant in the context of climate change, which is expected to exacerbate existing variations and introduce new challenges. Various statistical methods including both parametric and non-parametric methods are present to analyze the trends in rainfall. Parametric methods, such as linear regression, are widely used to model and predict rainfall trends by assuming a linear relationship between time and rainfall.

Linear regression helps in quantifying the rate of change in rainfall over time, providing a straightforward interpretation of trends(Chandler and Scott 2011). However, rainfall data often exhibit non-linear patterns and are subject to anomalies that may not be well-captured by parametric methods alone(Fiddes and Timbal 2016). To complement this, non-parametric methods like Sen's slope estimator and the Mann-Kendall trend test are also utilized. Sen's slope estimator is a robust method that provides a slope of the trend line, offering a measure of the central tendency of the data without making any assumptions about the distribution of data(Collaud Coen et al. 2020). The Mann-Kendall trend test, on the other hand, is a rank-based non-parametric test that is particularly useful for detecting monotonic trends in time series data. It is widely used in climatology and hydrology due to its ability to handle non-normally distributed data and its resilience to missing data and outliers(Totaro et al. 2019).

Studies on rainfall variations across India have identified significant temporal and spatial trends. Guhathakurta and Rajeevan (2008) observed decreasing contributions to annual rainfall from June, July, and September in several regions, while August showed an increase. Krishnakumar et al. (2009) reported a notable decrease in southwest monsoon rainfall in Kerala, with minor increases during winter and summer. Kumar et al. (2010) found an increasing trend in annual rainfall in half of India's sub-divisions, despite a national decrease in monsoon rainfall. Amrutha and Shreedhar (2014) pointed out spatial variability in Belgaum, Karnataka, while Swain et al. (2015) noted significant decreases in southwest monsoon rainfall in Raipur. Mehta and Yadav (2021) and Kakkar et al. (2022) applied the Mann-Kendall test and Sen’s Slope estimator to reveal significant shifts in rainfall trends, particularly in East and West Rajasthan, and Sikkim, with recent changes leading to increased landslides and floods. These findings emphasize the complex, region-specific nature of rainfall variability in India and the utility of nonparametric methods like the Mann-Kendall test and Sen’s Slope estimator in trend analysis.

By applying these methods, the study aims to identify significant trends and changes in the rainfall patterns of Bengaluru and Mysuru districts over the past few decades. The outcomes of this analysis will provide valuable information for policymakers, urban planners, and agricultural stakeholders, enabling them to devise informed strategies for managing water resources, planning agricultural activities, and mitigating the impacts of extreme weather events. Understanding the trends in rainfall is not only crucial for current planning and development but also for adapting to future climatic conditions in these rapidly growing and economically significant regions.

2. Methodology

2.1 Study Area

Karnataka is situated in the central part of western Peninsular India, between latitudes 11° 40' N and 18° 27' N, and longitudes 74° 5' E and 78° 33' E. The state spans an area of 19.1 million hectares, representing 5.8% of India's total geographical area. The state has five agroclimatic zones, with the Southern dry zone covering 1.739 million hectares and receiving annual rainfall between 670.60 mm and 888.60 mm, primarily during the Kharif season from the South-West monsoon. The Eastern dry zone spans 1.808 million hectares with rainfall ranging from 679 mm to 888.9 mm (Rani et al. 2023). For this study, Mysuru district, located at 12.30°N 74.65°E with 785 mm of average rainfall, is analyzed under the Southern dry zone, while Bengaluru district, at 12.97°N 77.56°E, is studied under the Eastern dry zone to assess rainfall variations over time.

Daily rainfall data for two meteorological stations, GKVK in Bengaluru district and Naganahalli in Mysuru district, Karnataka, were collected for the period 1983 to 2018 (36 years) from the AICRP on Agro-Meteorology, GKVK, UAS, Bengaluru. The data were recorded using a standard rain gauge and measured in millimeters, providing a reliable basis for the analysis.

Fig.1:MapshowingBengaluruandMysurudistrictsofKarnataka

2.2 Trend analysis of rainfall for two meteorological stations

Trend analysis involves fitting a specific trend line or curve to time series data to identify patterns over time. In this study, a linear trend was fitted to the rainfall data from two meteorological stations. Typically, trends in time series are assessed using either parametric methods, such as regression analysis, or non-parametric methods like the Mann-Kendall trend test, with the magnitude of the trend determined using Sen's slope estimator.

2.2.1Linear regression

The Linear Trend equation is a mathematical representation used to model and predict the behavior of a time series over a period. It is expressed as:

$$Y_t = a + mt$$

Where, Y_t is the value of the dependent variable (e.g., rainfall) at time *t*, *a* is the intercept, representing the value of Y_t when *t*=0, *m* is the slope, indicating the rate of change in Y_t per unit time and *t* is the time.The linear trend equation assumes that the change in the variable of interest is constant over time. It is useful in identifying and quantifying long-term trends in time series data, such as increasing or decreasing patterns in climate variables like rainfall(Chandler and Scott 2011).

2.2.2 Sen's Slope estimator

Sen's estimator has been widely used for determining the magnitude of trend in hydrometeorological time series. In this method, the slopes (T_i) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j - k} \quad for\ i = 1,2, \dots, N$$

where $x_j$and $x_k$are data values at time *j* and *k* (*j* >*k*) respectively. The median of these *N* values of T_i *is* Sen's estimator of slope which is calculated as

$$\beta = \begin{Bmatrix} T_{\frac{N+1}{2}} & N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N\ is\ even \end{Bmatrix}$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series. The trend line for all the three seasons and annually were computed for the two meteorological stations and compared with a non-parametric Mann- Kendall trend test.

2.2.3 Mann-Kendall trend test

The non-parametric Mann-Kendall trend test was used to determine the rainfall trend. Significance was tested stating that there is no trend in the series as null hypothesis (H_0) against the alternative hypothesis (H_1) that there is a negative, non-null or positive trend. It was tested at 95 per cent significance level. Since rainfall pattern shows the trend, the appropriate non-parametric test will be Mann- Kendall test. It is appropriate because its statistic is based on the sign of differences, not directly based on values of random variable and it is also less affected by the fluctuations. Monotonic trend in any time series data can be detected by the application of Mann- Kendall (non-parametric) test(Patle et al. 2016).

The test statistic S is calculated using the formula

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

$$sgn(x_j - x_k) = \begin{Bmatrix} +1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{Bmatrix}$$

where n is the number of observed data series, x_j and x_k are the values in periods j and k respectively, j > k. For n ≥10, the sampling distribution of S is given by

$$z = \begin{Bmatrix} \frac{s-1}{\sqrt{Var(s)}} if\ s > 0 \\ 0 \quad if\ s = 0 \\ \frac{s+1}{\sqrt{Var(s)}} if\ s < 0 \end{Bmatrix}$$

where Var(S) is determined as

$$Var(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

3. Results and discussion

3.1 Descriptive Statistics

3.1.1 Descriptive Statistics of Monthly Total Rainfall

The analysis of monthly total rainfall for Bengaluru district over the 36-year period from 1983 to 2018 reveals significant variability. The minimum monthly total rainfall recorded during this period was 0 mm in most years except for 2005. The highest monthly rainfall observed was 540.90 mm in 1991. The lowest average monthly rainfall was 44 mm in 1990, followed by 48.24 mm in 2012. Conversely, the highest average monthly rainfall was 114.53 mm in 2005, with the next highest being 110.70 mm in 1991. The coefficient of variation (CV) for monthly total rainfall in Bengaluru ranged from a minimum of 68.71% in 2010 to a maximum of 145.21% in 1989. These values indicate substantial fluctuation in rainfall patterns over the years.

For Mysuru district, the monthly total rainfall data over the same 36-year period exhibits a similar pattern of variability. The minimum monthly rainfall recorded was 0 mm in most years, except for 1986. The highest monthly total rainfall was 448.8 mm, recorded in 2005. The lowest mean monthly rainfall was 19.61 mm in 2016, followed by 30.35 mm in 2013. The highest mean rainfall was 90.49 mm in 2005, with the next highest being 89.30 mm in 2000. The coefficient of variation for monthly total rainfall in Mysuru was highest at 160.66% in 2016 and lowest at 85.18% in 1986. This indicates that rainfall in Mysuru was even more variable than in Bengaluru over the study period.

3.1.2 Descriptive Statistics of Seasonal Rainfall

Comment [A2]: according to the Meteorological Convention, i.e., monsoon, post-monsoon, pre-monsoon, and winter, using proper mentioning of months for better understanding.

The descriptive statistics for total seasonal rainfall in Bengaluru district over the 36-year period from 1983 to 2018 highlight notable variations across the Pre-Monsoon, Monsoon, and Post-Monsoon seasons. On average, Bengaluru received 174.19 mm of rainfall during the Pre-Monsoon, 505.85 mm during the Monsoon, and 232.77 mm during the post-monsoon season.

The maximum rainfall recorded in these seasons was 328.60 mm, 835.50 mm, and 693.10 mm, respectively. The minimum recorded rainfall was 52.60 mm for both the Pre-Monsoon and Post-Monsoon seasons, while it was 252.50 mm for the Monsoon season. The coefficient of variation (CV), which measures the relative variability in rainfall, was lowest during the post-monsoon season at 166.93%. This indicates that the post-monsoon rainfall was more consistent compared to the other seasons. For Mysuru district, the total seasonal rainfall statistics also show significant variability over the same 36-year period. The average rainfall for the Pre-Monsoon season was 175.38 mm, for the Monsoon season 289.46 mm, and for the post-monsoon season 204.82 mm. The highest rainfall recorded during these seasons was 365.20 mm, 514.10 mm, and 521.20 mm, respectively. The lowest rainfall values were 32.90 mm for the Pre-Monsoon, 84.50 mm for the Monsoon, and 36.90 mm for the post-monsoon seasons. The coefficient of variation was highest during the Pre-Monsoon season at 255.31%, indicating a greater inconsistency in rainfall during this season. In contrast, the Monsoon season had a relatively lower CV of 172.92%, suggesting more stable rainfall patterns during this period.

Overall, both Bengaluru and Mysuru districts experienced significant variations in seasonal rainfall, with the Monsoon season consistently receiving the highest average rainfall in both districts. However, the variability in rainfall was more pronounced in Mysuru, particularly during the Pre-Monsoon season, whereas Bengaluru displayed more consistent rainfall during the post-monsoon season.

3.1.3 Annual Excess and Deficit rainfall for Bengaluru and Mysuru Districts

The annual excess and deficit rainfall analysis for Bengaluru and Mysuru districts over the 36-year period (1983-2018) reveals distinct patterns in rainfall variability. In Bengaluru, the occurrence of excess rainfall was more frequent, with significant years of surplus rainfall, indicating a tendency towards wetter years. However, the district also experienced several years of deficit rainfall, highlighting periods of drought or lower-than-average precipitation. In Bengaluru district, the maximum deficit was observed in 1991, while 2005 saw the maximum excess rainfall (Fig. 2). In contrast, Mysuru exhibited a more balanced distribution of excess and deficit rainfall years, though the overall trend leaned slightly towards deficit years. This suggests that while Mysuru experienced both wet and dry years, the frequency of below-average rainfall was slightly higher, potentially impacting agricultural activities and water resource management in the district. The maximum deficit was observed in 2016, while 2005 had the highest excess rainfall in Mysuru (Fig. 3).

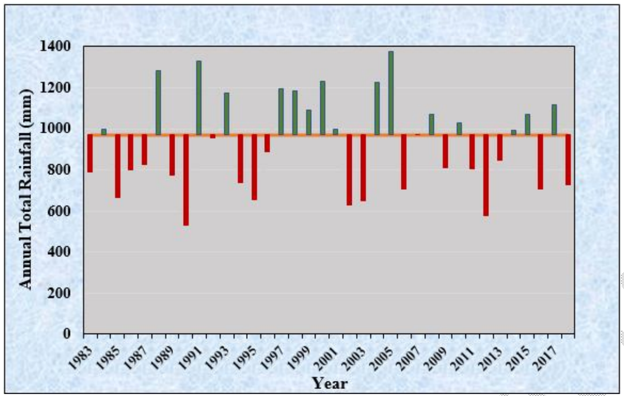

Fig.2:AnnualExcessandDeficitRainfallwithrespecttoNormalAverageRainfallforBengaluru Districtfrom1983-2018.

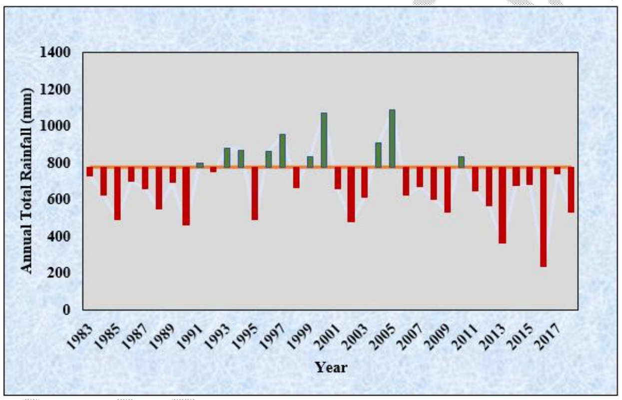

Fig.3:AnnualExcessandDeficitRainfallwithrespecttoNormalAverageRainfallforMysuru Districtfrom1983-2018.

3.2Trend Analysis on Annual and Seasonal Rainfall

3.2.1Trend analysis on Annual rainfall for Bengaluru and Mysuru Districts

Trend analysis was carried out to check the presence of trend in the annual rainfall across two meteorological stations located in Bengaluru and Mysuru during the period of 36 years from 1983 to 2018. Trend analysis was carried out using nonparametric test (Mann-Kendall). From Table 1, we can infer that for both the districts, annual rainfall shows no trend since Kendall's tau test statistic value has the p value more than the 0.05 (level of significance) value.

Table 1:Estimated Trend values in Annual Rainfall for Bengaluru and Mysuru districts

District	Intercept (S.E)	Slope (S.E)	R^2	Kendall's tau value	Sen's Slope	p-value
Bengaluru	929.294 (79.831)	- 0.260 (3.763)	0.000	0.000	0.061	1.000
Mysuru	737.673 (62.441)	- 3.028 (2.943)	0.030	-0.095	-2.577	0.421

3.2.2Trend analysis on Monthlyrainfall for Bengaluru and Mysuru Districts

Trend analysis was conducted on monthly rainfall data for both Bengaluru and Mysuru districts. The slope, intercept, standard error (S.E.), and Mann-Kendall estimates are provided in Tables 2 and 3, respectively. The analysis revealed that there was no discernible trend in rainfall over the months for either district.

Table 2: Estimated Trend values in Monthly Rainfall for Bengaluru district

Month	Intercept (S.E)	Slope (S.E)	Kendall's tau value	Sen's Slope	p-value
January	3.031 (1.275)	-0.067 (0.060)	-0.154	0.000	0.154
February	14.412 (15.553)	-0.012 (0.733)	0.024	0.000	0.861
March	15.817 (11.177)	0.186 (0.527)	0.104	0.020	0.391
April	31.833 (17.788)	1.018 (0.838)	0.149	0.851	0.205
May	67.711 (16.687)	1.977 (0.787)	0.236	1.625	0.043
June	101.754 (19.889)	-0.967 (0.937)	-0.079	-0.392	0.504
July	103.234 (21.870)	-0.194 (1.031)	-0.001	-0.004	1.000
August	123.061 (27.648)	0.489 (1.303)	0.053	0.439	0.653
September	230.652 (34.812)	- 2.184 (1.641)	-0.165	-2.080	0.160
October	172.482 (43.613)	-0.294 (2.056)	-0.069	-0.859	0.558
November	45.670 (18.081)	0.335 0.852)	0.015	0.061	0.902

December	19.634 (6.168)	-0.311 (0.291)	-0.134	-0.166	0.166

Table 3: Estimated Trend values in Monthly Rainfall for Mysuru district

Month	Intercept (S.E)	Slope (S.E)	Kendall's tau value	Sen's Slope	p-value
January	14.12 (7.424)	-0.465 (0.350)	-0.133	0.000	0.331
February	3.718 (4.995)	0.132 (0.235)	0.063	0.000	0.636
March	13.884 (13.072)	0.196 (0.616)	0.020	0.000	0.876
April	50.863 (14.285)	0.099 (0.699)	0.006	0.015	0.967
May	117.124 (18.360)	-0.645 (0.865)	-0.090	-0.616	0.445
June	86.755 (15.267)	-1.202 (0.720)	-0.142	-0.691	0.225
July	65.835 (11.712)	-0.819 (0.552	-0.211	-0.811	0.072
August	57.372 (15.838)	0.423 (0.746)	0.012	0.105	0.924
September	133.385 (17.469)	-1.315 (0.823)	-0.209	-1.915	0.074
October	134.581 (34.837)	0.516 (1.642)	0.068	0.660	0.567
November	38.900 (20.472)	0.546 (0.965)	0.042	0.141	0.723
December	20.844 (6.414)	-0.494 (0.302)	-0.082	0.000	0.508

3.2.3 Trend analysis on Seasonal rainfall for Bengaluru and Mysuru Districts

3.2.3.1 Bengaluru District

The estimated trend values in seasonal rainfall for Bengaluru district, as presented in Table 4, reveal varying patterns across different seasons. The trend analysis indicates a significant positive trend in the Pre-Monsoon season, with an intercept of 115.362 mm (±49.703 mm) and a slope of 3.180 mm/year (±2.343 mm/year). The Kendall's tau value of 0.335, a positive Sen's slope of 3.543 mm/year, and a p-value of 0.0042 indicate that this increasing trend is statistically significant. For the Monsoon season, the trend analysis shows a slight negative trend with an intercept of 558.702 mm (±20.360 mm) and a slope of -2.857 mm/year (±0.960 mm/year). Kendall's tau value of -0.155 and a Sen's slope of -2.485 mm/year suggest a decreasing trend, but with a p-value of 0.1864, this trend is not statistically significant. In the post-monsoon season, the analysis shows a very weak and insignificant trend, with a Sen's slope of 0.500 mm/year, and a high p-value of 0.7541.

Table 4: Estimated Trend values in Seasonal Rainfall for Bengaluru District

Season	Intercept (S.E)	Slope (S.E)	Kendall's tau value	Sen's Slope	p-value
Pre-Monsoon	115.362 (49.703)	3.180 (2.343)	0.335	3.543	0.0042
Monsoon	558.702 (20.360)	-2.857 (0.960)	-0.155	-2.485	0.1864
Post-Monsoon	237.787 (48.148)	- 0.271 (2.269)	0.038	0.500	0.7541

3.2.3.2Mysuru District

From Table 5, it was observed that Pre-Monsoon and Post-Monsoon season had no trend. But for the Monsoon season, there is a more noticeable negative trend, with an intercept of 343.347 mm (±32.333 mm) and a slope of -2.912 mm/year (±1.524 mm/year). Kendall's tau value of -0.231 and a Sen's slope of -3.238 mm/year indicate a decreasing trend that is statistically significant, as evidenced by the p-value of 0.048.

Table 5: Estimated Trend values in Seasonal Rainfall for Mysuru District

Season	Intercept (S.E)	Slope (S.E)	Kendall's tau value	Sen's Slope	p-value
Pre-Monsoon	181.871 (23.691)	- 0.350 (1.117)	-0.044	- 0.610	0.713
Monsoon	343.347 (32.333)	-2.912 (1.524)	-0.231	-3.238	0.048
Post-Monsoon	194.352 (40.856)	0.568 (1.936)	0.034	0.441	0.774

For two districts it was observed that post-monsoon had no trend. Bengaluru had an increasing trend in Pre-Monsoon season and in Mysuru, Monsoon season had a decreasing trend. A similar pattern of variation in the trends during annual and seasonal rainfall is supported by various recently published works on trend by Jain et al. (2013) and Thakural et al. (2018).

Conclusion

The annual average rainfall for Bengaluru was 928.81 mm and it was 681.65 mm for Mysuru district. Bengaluru had higher average annual rainfall compared to Mysuru. The average seasonal rainfall was more during Monsoon seasons for both the districts. Excess annual rainfall was observed for Bengaluru district with maximum excess was observed in 2005 whereas more deficit annual rainfall was observed for Mysuru district with maximum deficit was observed in 2016. Neither district exhibited a significant trend in annual rainfall. For seasonal rainfall, a positive trend was observed in the Pre-Monsoon season of Bengaluru (3.543 mm/year), while a negative trend was noted in the Monsoon season of Mysuru (-3.238 mm/year).Future research could model different rainy spells using Markov Chains to study drought indices. The pattern of rainfall can be described using Hidden Markov Models. Based on these rainfall amounts and patterns, agricultural activities can be better planned.

Reference

Comment [A3]: Incorporate references of nonparametric and parametric tests.

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