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"Temporal Trails in the Tapestry of Rainfall: A Modern Trend Review"

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Abstract

This study focused on precipitation, a critical meteorological variable, to examine the shifting rainfall patterns in Bengaluru Karnataka. Rainfall is essential to monitor flood surface runoff in this area, but because it happens randomly and unexpectedly, it negatively affects the drainage and Agricultural system and the availability of natural water resources. annual rainfall variability (trend, linear Regression and slope magnitude) was calculated using Parametric and non-parametric analysis from rainfall data collected over 124 years (1901-2024). This study has been carried out by processing annual hydrological data collected from IMD weather stations across Bangalore district from 1901 to 2024The parametric and non-parametric Sen's Slope Estimator and the Mann-Kendall (MK) Test for monotonic trend analysis were used to assess the strength of a trend in time series data.

*The Mann-Kendall te**st** for cumulative rainfall data shows **a** significant increasing trend (**Z** = 2.98, p = 0.0029), indicating that rainfall has been rising over time. The Sen's slope estimator quantifies this increase at approximately 1.76 units per period, with a 95% confidence interval ranging from 0.62 to 2.88. This confirms a consistent upward trend in rainfall. There is a significant increasing trend in cumulative rainfall at the 5% significance level. On average, cumulative rainfall is increasing by about 1.76 mm (or relevant unit) per period. The linear regression equation indicates a slight increasing trend in cumulative rainfall over time, with an average annual increase of approximately 1.94 mm**.** However, the low coefficient of determination (R^2 = 0.0911) shows that only 9.11% of the variation in rainfall is explained by this linear trend. This conclude that rainfall trend is increasing Key words; Rainfall , Linear Regression , Mann Kendall test, Sen's slope Estimator and Trend Analysis*

1. Introduction

Rainfall is a random process; its forecast has always been a challenge for meteorologists globally either of two complexity and technology. Agriculture is the primary occupation of India; rainfall is directly related to the agricultural belt, while agriculture contributes a substantial share to provide the state of a nation. Rainfall is a key input for multiple engineering designs like hydraulic structures, bridges, culverts, canals, stormwater sewers, and road drainage systems. The precise statistical analysis of every region plays a critical role in estimating the respective input value for engineering structure planning and crop planning

In India, rainfall variability during the monsoon season leads to either excess precipitation or severe water scarcity, a situation worsened by climate change. Understanding these patterns is vital for informed decision-making and building resilience against extreme weather events. As rainfall directly influences streamflow, changes in its frequency and distribution impact water availability for domestic, agricultural, industrial, and energy needs. Detailed rainfall trend analysis is essential for managing flood and drought risks, preserving groundwater, and planning for future climate scenarios. Such assessments are also crucial for evaluating the broader impacts of climate change on food and energy security, natural resources, and sustainable development.

Trend analysis of rainfall is essential for understanding climatic shifts and their regional impacts, particularly in areas like Bengaluru(Sharad K Jain et al.,2012). While studies using parametric and non-parametric tests have shown no significant nationwide trend in annual rainfall, localized analysis remains important. Detecting changes in rainfall and streamflow is critical for hydrology and climate science, especially in the face of climate change. This study adopts parametric and non-parametric methods to provide robust insights into rainfall trends specific to Bengaluru , supporting better management of floods, droughts, and extreme weather conditions. The Indian Meteorological office (IMD), orders seasons into four seasons in particular Winter Season (January and February), Pre-storm season (March ., April and May), South West Monsoon(June, July, August and September) and North-East Storm (October, November and December).

2. LITERATURE REVIEW

Yogananda S. , Shruthi G. , Thimme Gowda P. June 2015 Rain fall trend analysis in Mysore District was analysed by considering 39 years rain fall data (1971-2009) analysed mean rainfall, standard deviation and coefficient of variation for annual, seasonal and weekly Period . monsoon contributes the most (43.7%) to annual rainfall, followed by post-monsoon (28.1%), pre-monsoon (11.0%), and winter (1.2%). The crop-growing period extends from late April to late November, supported by weekly rainfall exceeding 20 mm with moderate variability. Monthly mean rainfall varies significantly, peaking in September and October. Over 39 years, droughts were frequent, with six years experiencing moderate drought, emphasizing the need for adaptive agricultural practices in this semi-arid region. . Arpita Panda, Netrananda Sahu. 21 June 2019 Analysed seasonal rainfall and temperature pattern In Kalahandi, Bolangir and Koraput districts of Odisha,India considering 39 years data(1980–2017) Statistically significant trends are detected for rainfall and also the result is statistically significant at 99% confidence limit during the period of 1980–2017.Rainfall is showing a quite good increasing trend(Sen's slope=4.034)for June to September Season. . Charles B. Chisanga , Edson Nkonde b , Elijah Phiri Kabwe H. Mubanga and Catherine Lwando 15 november 2023 Analysed of rainfall trend (1981-2022) over Zambia,Mann-Kendall test statistic was used at 5 % significant level to compute trends in rainfall at monthly and decadal time. R/RStudio Sen's slope estimator was used to give the magnitude of the observed trends. Decrease in rainfall is expected to affect agriculture, energy, water resources, sanitation and socio- economic aspects. Rainfall pattern shows spatio-temporal variability over Zambia. . Shyam Lochan Bora1,Kalyan Bhuyan , Partha Jyoti Hazarika , Junmi Gogoi and Kuldeep Goswami 10 april 2022 Analysed rain fall trends in NE India(1901-2001) using Mann–Kendall (MK) test test is being widely used for trend detec tion, it has some flaws regarding serial correlation in the time-series data. To overcome this problem modified Mann–Kendall (MMK) and trend free pre-whitening Mann–Kendall (TFPW–MK) tests have been introduced, which provide more reliable results than the MK test .

K. Kumar, S. Verma, R. Sahu, and M. K. Verma 2023 Analysed long-term (1901 ~ 2017) annual and seasonal rainfall trends in India. The sequential Mann-Kendall (SQMK) test is used to estimate the temporal variation of rainfall. analysis revealed that the trends of subdivisions had a short-term periodicity of less than a decade. Non-parametric M-K test, Sen’s slope, and Pettitt’s tests were ap- plied to all subdivisions at seasonal and annual scales at a 95% confidence level. The results of “M-K, Sen’s slopes, and Pettitt’s change point test” for monsoon rainfall Observation analysis of the M-K and Sen’s slope test:. Navneet Kaur, Abrar Yousuf and m. j. Singh July 2021 The trend analysis of historical rainfall data on monthly, annual and seasonal basis for three locations in lower Shivaliks of Punjab, viz., Patiala-ki-Rao (1982-2015), Ballowal Saunkhri (1987-2015) and Saleran (1984-2017) has been done in the present study using linear regression model, Mann Kendall test and Sen’s slope. Nur Islam Saikh, Sunil Saha, Debabrata Sarkar and Prolay Mondal* 24 January 2024 Analysed spatial variation in monthly, seasonally and yearly rainfall patterns in the Kolkata district of West Bengal, India, between 1901 and 2019 (Around 119 years). The trend's reliability and intensity were assessed non-parametrically applying monthly rainfall data series and the Mann Kendall (MK) and Sen's slope estimators . Ibrahim, M.T. Usman, A. Abdulkadir & M.A. Emigilati 21 september 2018 Analysed The precipitation concentration index (PCI) In Savannah Zones of Nigeria Mann–Kendall trend test, Theil–Sen’s slope estimator (β), and relative percentage change methods were adopted for data analysis. The findings reveal that PCI calculated on an annual scale falls into three categories 11–15, 16–20, and PCI > 20. 9. ArpitaPanda, NetranandaSahu, May 2019 Analysed Statistical trend analysis (1980-2017) Kalahandi, Bolangir and Koraput districts of Odisha,India techniques namely Mann–Kendall test and Sen's slope estimate or were used to examine and analyze the problems. The detailed analysis of the data for 37years indicate that the annual maximum temperature and annual minimum temperature have shown an increasing trend, whereas the monsoon's maximum and minimum temperatures have shown a decreasing trend . Gayathri Sudarsan, and Lasitha 2022 Analysed the changing pattern of rainfall in Kerala district (1989-2018). Non-parametric analysis was used to determine the monthly, seasonal, and annual rainfall variability (trend and slope magnitude) from rainfall data spanning 30 years (1989-2018) on a monthly basis. To determine the strength of a trend for time series data, the Mann-Kendall (MK) Test for monotonic analysis of trend and non-parametric Sen's Slope Estimator were utilized . Amrutha Rani. H R and A. S. Ravikumar august 2024 Analysed (1980-2022) of rainfall data in Bangalore Urban using 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. Suresh Kumar Sharma Kiran Gaur ,Durga Prasad Sharma and Pratibha Manohar 2021 Analysed the trends and temperature and rainfall in five divisional headquarters of Rajasthan, namely, Bikaner, Jaipur, Jodhpur, Kota, and Udaipur. historic data of minimum and maximum temperature and rainfall for a period of 49 years from (1971 to 2019) trends and change in magnitude was done using the Mann–Kendall (MK) test and Sen’s slope, respectively.results of the study indicated a significant increase in both minimum and maximum temperature over time for all the five stations.Parth Sinroza and Mohdzuned Mohmedraffi Shaikh may 2021 Analyze the most important climatic variables precipitation and temperature, for analyzing the trend using Mann-kendall test for Ahmedabad district(1979-2014). The average annual precipitation has been found to be in increasing trend alongwith major increasing trend of average minimum temperature. In general, the outcomes of using the Mann-Kendall test showed that the success in detecting the trend for meteorological variables was quite similar.Sunny Agarwal, A.S. Suchithra and Surendra Pal Singh April 2021 Analysed from the IMD data of 1981 2016. The study displays daily, seasonal and annual trend patterns and magnitude of trend slope in precipitation data series for different regions of Andhra Pradesh. The procedures that are adopted to identify the presence of trend are Mann-Kendall and Sen's estimator of slope which are carried out at statistical significance at 95% level of confidence. The month to month precipitation information were utilized to process the yearly and regular time arrangement. The adjustment in extent for a period arrangement is resolved utilizing a nonparametric technique (Sen's estimator) and the factual noteworthiness is breaking down through Mann- Kendall (MK) test. Vishwanatha bhat, Pragathi Somanna P.S Varsha and Harshith 2018 Analysed over 30 years (1975-2005) rainfall data of Belthangady by considering sesonal averages and annual mean using parametric method .increasing slope indicate the increased number of rainy day in pre monsoon or summer days.Bushra praveen, Swapan talukdar, Shahfahad, Susanta Mahato, Jayanta Mondal 2020 Analyse and forecasts the long-term Spatio-temporal changes in rainfall using the data from (1901 to 2015) across India at meteorological divisional level. The Pettitt test was employed to detect the abrupt change point in time frame, while the Mann-Kendall (MK) test and Sen's innovative trend analysis were performed to analyze the rainfall trend. The Artificial Neural Network-Multilayer Perceptron (ANN-MLP) was employed to forecast the upcoming 15 years rainfall across India. Kalahandi, Bolangir and Koraput districts of Odisha,India Serafino Afonso Rui and Mucova 8th April 2025 Analyzing long-term trends in rainfall and temperature in the Metuge district from (1989 to 2022). The Mann–Kendall trend test, a non-parametric method, was used to detect trends, while Sen's slope estimator quantified the magnitude of these trends. The seasonal analysis differentiated trends between the rainy season (October to March) and the dry season (April to September). The Mann–Kendall test revealed a decrease in overall annual rainfall and dry season rainfall, with a decrease of approximately 34.59 mm and 10.57 mm per decade, respectively. A significant decrease in trend was observed in March and the rainy season rainfall, with a decline of 33.83 mm and 42.75 mm per decade. Annual mean and seasonal minimum temperatures showed a significant trend, especially during the rainy season, with an increase of 0.25 °C per decade. The dry season and mean annual minimum temperatures increased by 0.17 °C and 0.2 °C per decade . Arun Mondal & Deepak Khare & Sananda Kundu 9th October 2014 Analysed rainfall trend in India for 141 years (1871–2011) and temperature trend for 107 years (1901–2007). Mann-Kendall (MK) test and Sen's slope. Mann-Whitney-Pettitt (MWP) test was used for probable break point detection in the series, and change percentage was calculated over 30 sub-divisions and 7 broad regions. The results indicate decreasing annual and monsoon rainfall of India in most of the sub-divi sions, and temperature fluctuations were observed in all the places. Sharad K. Jain and Vijay Kumar 10th January 2012 Analysed rainfall, rainy days and temperature over India. Sen's non-parametric estimator of slope has been frequently used to estimate the magnitude of trend, whose statistical significance was assessed by the Mann–Kendall test. Spatial units for trend analysis vary from station data to sub-division to sub-basin/ river basins. There are differences in the results of the various studies, and a clear and consistent picture of rainfall trend has not emerged 20. Jinal Pastagia and Darshan Mehta 2022 Analyse the long-term (1902–2021) temporal trends in seasonal (winter, pre-monsoon, monsoon, and post-monsoon) and annual rainfall for the Rajsamand district of Rajasthan state using the innovative trend analysis (ITA) technique. Due to

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its ability to provide results in graphical form, the ITA approach is a very useful tool for detecting pat terns in rainfall time series data. This technique is also used to detect trends as 'low,' 'medium,' and 'high,' which should be considered in future studies on floods 'high' and drought 'low', respectively. Based on the above study, it is observed that no trend is detected for the annual season, a positive trend is detected in the winter season and a negative trend is detected for pre-monsoon and post-monsoon sea sons in some regimes respectively

3 . STUDY AREA AND DATA USED

Bangalore lies in the southeast of the South Indian state of Karnataka at an average elevation of 920 m (3,020 ft). It is positioned at 12.97°N 77.56°E and covers an area of 1741 km^2 (673 mi^2). The majority of the city of Bangalore lies in the Bangalore Urban district of Karnataka and the surrounding rural areas are a part of the Bangalore Rural district. The region comprising the Bangalore Urban and Rural districts is known as the Bangalore (region). The Government of Karnataka has carved out the new district of Ramanagara from the old Bangalore Rural district. Bangalore has two unique Topography terrains—North Bangalore taluk and the South Bangalore taluk. The North Bangalore taluk is a relatively more level plateau and lies between an average of 839 to 962 meters above sea level. The middle of the taluk has a prominent ridge running NNE-SSW. The highest point in the city, Doddabettahalli, (962m) is on this ridge. There are gentle slopes and valleys on either side of this ridge. The low-lying area is marked by a series of water tanks varying in size from a small pond to those of considerable extent, but all fairly shallow. 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).

The Monthly rainfall data of rain gauge stations in Bengaluru spanning years (1901-2024) were sourced from IMD, Bengaluru. After rigorous consistency checks confirming their reliability, the data were analysed to compute essential statistical metrics such as average rainfall, coefficient of variation, standard deviation, kurtosis coefficient, and skewness coefficient

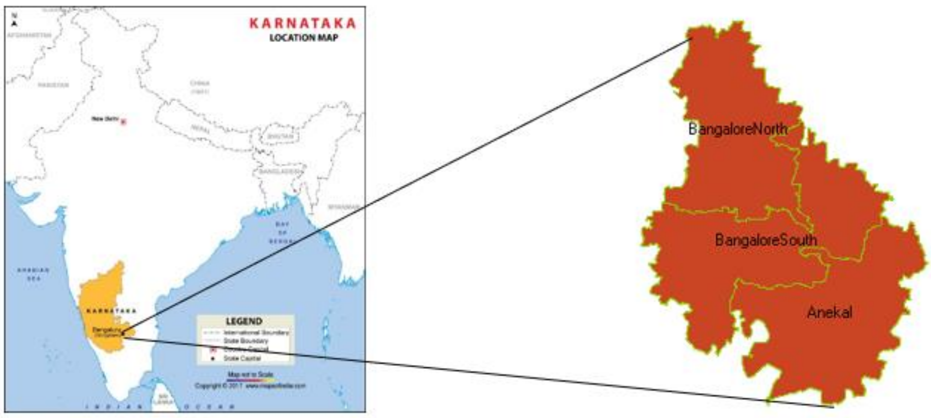

Fig.1 Location Map of Study Area

4. Methodology

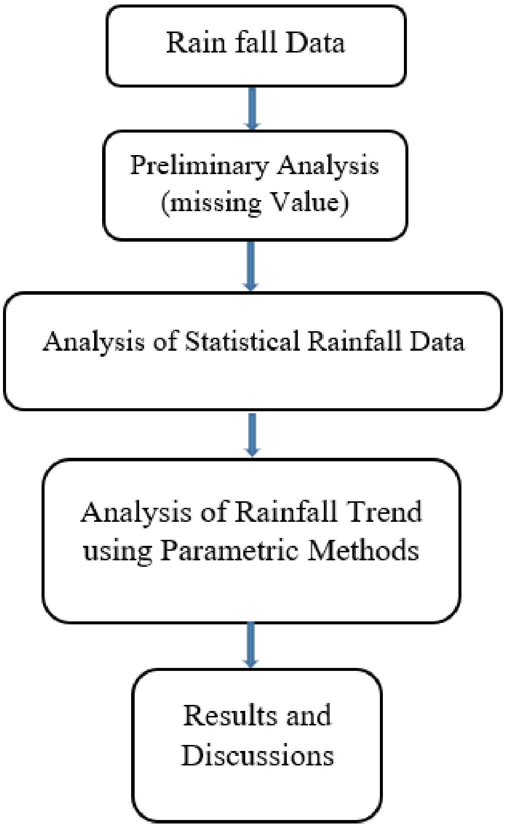

Fig.2 Shows Methodology to Adopt Trend Analysis

4.1. Parametric Methods:

4.1.1. Linear Regression:

Regression analysis Regression analysis is a statistical technique used to estimate the relationship between a dependent variable and one or more independent variables and is often used to test for linear trends by developing an inner relationship between time and the variable of interest, such as rainfall . In regression analysis, the assumption of normality is critical to the validity of many statistical tools, including correlation, regression, and parameter tests, because their accuracy depends on the normal distribution of the data . Linear regression is crucial in rainfall trend analysis for identifying and quantifying relationships between rainfall and other variables over time. It helps determine if there's a statistically significant trend (increasing, decreasing, or no trend) in rainfall patterns, which is vital for water resource management, agriculture planning, and understanding climate change impacts. This method fits a linear equation to the rainfall data to assess the trend. A positive slope indicates an increasing trend, while a negative slope indicates a decreasing trend.

4.1.2. Linear Regression Formula:

$$y = b + cx \qquad \text{(eq.1)}$$

Where,

y is the dependent variable (rainfall in this case).

x is the independent variable (time, often the year).

b is the intercept (the value of y when x is zero).

c is the slope (the rate of change of y with respect to x).

If c>0: Increasing trend and If c<0: Decreasing trend.

4.2. Non-parametric Methods

4.2.1. Mann-Kendall (MK) Test

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 Kendal test gives the Z value ,P value and S Values based on this value we can predict weather trend and also we can done the hypothesis test The Mann - Kendall test equation is as follows:

S: The Mann-Kendall statistic, calculated based on the number of increasing and decreasing data point pairs. Positive value indicates increasing trend and Negative value Indicates Decreasing trend.

Z: Standardized test statistic used to determine significance. If **Z > 0**: upward trend. If **Z < 0**: downward trend.

p-value: Determines the significance of the trend. If **p < 0.05**: statistically significant trend.

4.2.1.1 Test Statistic (SSS)

The Mann-Kendall statistic SSS is calculated using the formula:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sng(Rj - Ri) \qquad \text{(eq.2)}$$

Where:

n: Number of data points (e.g., years or months in the rainfall series)

Ri,Rj: Rainfall values in years i and j

sgn: Sign function defined as:

$$\operatorname{sgn}(Rj - Ri) = \begin{cases} +1, if Rj - Ri \succ 0 \\ 0, if Rj - Ri = 0 \\ -0, if Rj - Ri \prec 0 \end{cases} \qquad \text{(eq.3)}$$

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:

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{n(n-1)(2n+5) - \sum_{j=1}^{q} tj(tj-1)(2tj+5)/18}} \\ \dfrac{s-1}{\sqrt{n(n-1)(2n+5) - \sum_{j=1}^{q} tj(tj-1)(2tj+5)/18}} \end{cases}$$

(eq.4)

Where

n: Number of data points (e.g., years or months in the rainfall series) ,S: statics Value

4.2.2. Sen's Slope Estimator:

Sen's slope, also known as Sen's slope estimator, is a non-parametric method used to determine the trend or slope of a time series data, particularly useful in rainfall analysis to identify increasing or decreasing rainfall trends over time. It is often used in conjunction with the Mann-Kendall test for trend analysis. In Trend analysis 95% Confidence Interval is considered .The slope is significantly greater than 0, confirming an upward trend and Negative or less than zero confirming decreasing trend

$$Qk = (Rj - Ri)/(j - i) \quad \text{for all } 1 \le i \prec j \le n \qquad \text{(eq.2)}$$

Where:

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

n: Total number of data points.

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.

Table 1 statistics of Annual rainfall Bengaluru

Sl no	Month	Max(mm)	Avg(mm)	SD	Cv	Skew	Kurtosis
1	January	101.80	4.36	10.89	249.98	6.17	51.32
2	February	89.902	7.44	17.25	231.86	2.94	8.47
3	March	115.40	11.48	21.02	183.03	2.71	8.18
4	April	323.80	50.04	52.05	104.02	2.06	6.27
5	May	305.50	118.36	57.93	48.94	0.69	0.38
6	June	255.50	84.79	50.54	59.61	1.11	1.11
7	July	350.20	111.10	62.18	55.97	1.12	1.60
8	Aug	387.10	139.92	85.41	61.05	0.98	0.32
9	September	516.60	187.13	106.07	56.68	0.90	1.02
10	October	522.20	164.57	101.69	61.79	1.02	1.46
11	November	296.40	62.06	63.74	102.69	1.59	2.20
12	December	119.20	16.89	23.09	136.71	2.09	4.39

The above table 1 shows rainfall variation on a monthly basis was assessed for all 124 years annual rain fall using the Mann-Kendall and Sen’s slope estimator methods. Table 1 presents the statistical analysis of annual rainfall data from 1901 to 2024 at a 95% confidence level. Seasonal analysis divides the annual precipitation data

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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, 2024).

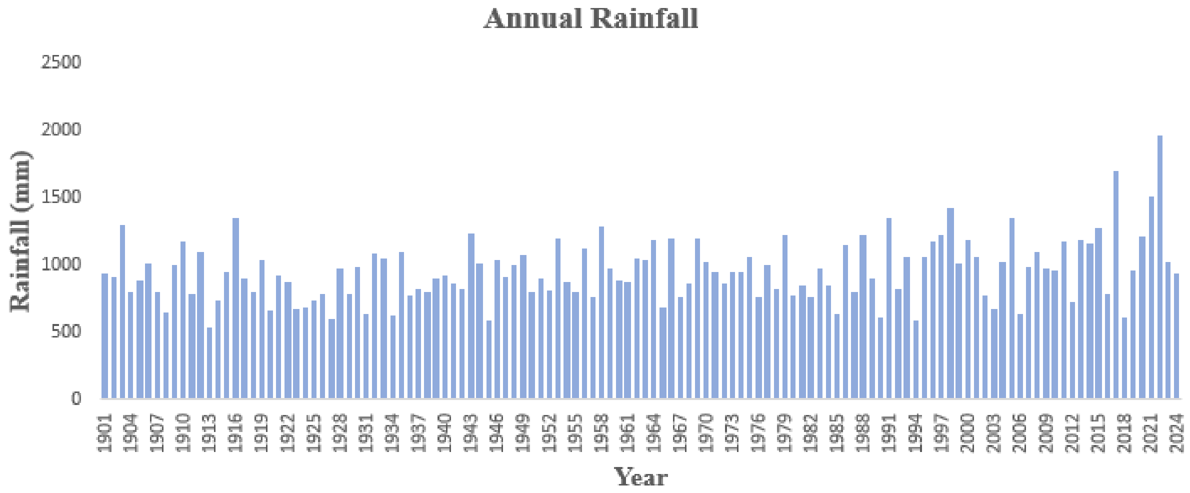

Fig.3 Annual Rainfall

The above figure 3 , the values typically falling between 600 mm and 1,200 mm in the early decades, the annual rainfall data for Bengaluru over the 124-year period (1901–2024) demonstrates notable inter-annual variability. Rainfall fluctuated moderately between the 1970s and the early 2000s. Nonetheless, there has been a discernible upward trend over the past 20 years, particularly after 2010. The most notable aspect is the dramatic increase in 2022, which became the wettest year on record with rainfall exceeding 2,000 mm. More years with above-average rainfall and more fluctuations are seen between 2015 and 2024, indicating growing climatic variability. This pattern confirms the results of a notable rise in precipitation identified by Mann-Kendall and Sen's slope analysis. The graph indicates a steady rise in rainfall overall.

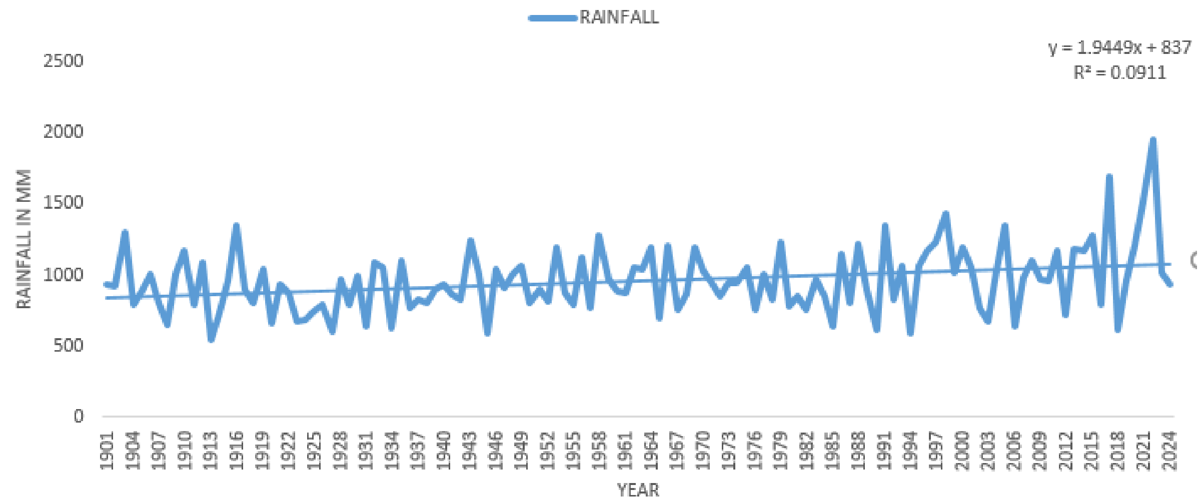

Fig.4 Rainfall Trend Analysis

The figure 4 ,shows the trend and variability of Bengaluru's annual rainfall over a span of 124 years. Rainfall has been trending slightly upward over time, according to a linear regression line fitted to the data. The trend line's equation is:

Rainfall (mm) = 1.944x + 837

This indicates an annual rainfall increase of roughly 1.94 mm on average. But according to the coefficient of determination (R2 = 0.0911), the linear trend only accounts for 9.11% of the variation in rainfall, indicating a weak relationship and year-to-year variation in rainfall.

Notably, there have been some notable sharp peaks in recent years, especially around 2022, when one of the highest rainfall values ever recorded occurred. The data indicates that extreme rainfall events have become more frequent in recent decades, which may be a result of climate change, even though the trend strength is weak.

Table 2. Annual rainfall data using Mann–Kendall and Sen's slope estimator method

Sl no	Month	Z value	P Values	Sens slop
1	**January**	-1.94	0.04	0
2	**February**	0.127	0.89	0
3	**March**	0.76	0.44	0.126
4	**April**	1.71	0.08	0.12
5	**May**	2.14	0.032	0.32
6	**June**	2.42	0.015	0.26
7	**July**	0.65	0.51	0.079
8	**Aug**	1.06	0.28	0.19
9	**September**	1.57	0.11	0.41
10	**October**	0.99	0.31	0.21
11	**November**	0.95	0.34	0.09
12	**December**	0.85	032	0.08

The above table 2 refers the Rainfall for the months of May (p = 0.032, Sen's slope = 0.32 mm/month) and June (p = 0.015, Sen's slope = 0.26 mm/month) increased significantly, according to the Mann-Kendall analysis, suggesting an increase in pre-monsoon and early monsoon rainfall. Although not statistically significant, April's trend showed a near-significant increase (p = 0.08), indicating a potential upward shift. On the other hand, January showed a significant downward trend (Z = -1.94, p = 0.04), and Sen's slope showed no actual monthly gain, pointing to drier winters. Though slight positive Sen's slope values indicate weak increasing tendencies, the remaining months (February, March, July, and December) did not exhibit any statistically significant trends. All things considered, the findings point to changing rainfall patterns in Bengaluru, with increases in early rainy seasons and decreases in dry months

SUMMARY

In this study spanning 124 years, annual rainfall data from various rain gauge stations of Bengaluru was analyzed using parametric and non-parametric methods for annual rainfall to detect trends. The Mann-Kendall te**st** for cumulative rainfall data shows **a** significant increasing trend (**Z =** 2.98, $p = 0.0029$), indicating that rainfall has been rising over time. The Sen's slope estimator quantifies this increase at approximately 1.76 units per period, with a 95% confidence interval ranging from 0.62 to 2.88. This confirms a consistent upward trend in rainfall. There is a significant increasing trend in cumulative rainfall at the 5% significance level. On average, cumulative rainfall is increasing by about 1.76 mm (or relevant unit) per period. The linear regression equation indicates a slight increasing trend in cumulative rainfall over time, with an average annual increase of approximately 1.94 mm**.** However, the low coefficient of determination ($R^2 = 0.0911$) shows that only 9.11% of the variation in rainfall is explained by this linear trend. This conclude that rainfall trend is increasing.

If rainfall trends are increasing in Bangalore, it can lead to serious urban challenges such as flooding, infrastructure damage, waterlogging, traffic disruptions, and even public health risks.

CONCLUSIONS

In this study spanning 124 years, annual rainfall data from various rain gauge stations of Bengaluru was analyzed using parametric and non-parametric methods for annual rainfall to detect trends. The Mann-Kendall test for cumulative rainfall data shows **a** significant increasing trend (**Z =** 2.98, $p = 0.0029$), indicating that rainfall has been rising over time. The Sen's slope estimator quantifies this increase at approximately 1.76 units per period, with a 95% confidence interval ranging from 0.62 to 2.88. This confirms a consistent upward trend in rainfall. There is a significant increasing trend in cumulative rainfall at the 5% significance level. On average, cumulative rainfall is increasing by about 1.76 mm (or relevant unit) per period. The linear regression equation indicates a slight increasing trend in cumulative rainfall over time, with an average annual increase of approximately 1.94 mm**.** However, the low coefficient of determination ($R^2 = 0.0911$) shows that only 9.11% of the variation in rainfall is explained by this linear trend. This conclude that rainfall trend is increasing.

If rainfall trends are increasing in Bangalore, it can lead to serious urban challenges such as flooding, infrastructure damage, waterlogging, traffic disruptions, and even public health risks.

METHODS TO IMPLEMENT IN RESPONSE TO RAINFALL TREND

1**. Improve Urban Drainage Systems**- Bangalore's storm water drainage systems need to be upgraded and expanded in order to handle the increased rainfall. Natural water flow requires the restoration of traditional Rajakaluves and the removal of encroachments. Blockages can be avoided with routine cleaning and upkeep. Runoff can be decreased with sustainable solutions like rain gardens and permeable pavement. Planning for drainage needs to be accompanied by real-time monitoring and integrated with urban development.

2. **Rejuvenate Lakes and Water Bodies**- Rejuvenating lakes helps manage excess rainfall by acting as natural buffers and reducing urban flooding. Restoring lake catchment areas and removing encroachments ensure natural inflow and outflow. Preventing sewage entry and treating inflows improves water quality. Interlinking lakes can distribute overflow and reduce pressure on individual water bodies. Community participation and continuous monitoring are key to sustaining lake ecosystems.

3. Adopt Sustainable Urban Planning- By incorporating green infrastructure such as rain gardens and permeable pavements, sustainable urban planning aids in the management of increased rainfall. By encouraging eco-friendly zoning and prohibiting construction in flood-prone areas, it guarantees appropriate land use. Compact, transitoriented development enhances climate resilience and lessens urban sprawl. Community involvement in planning and rainwater management enhances long-term sustainability.

4. Flood-Resilient Infrastructure- Roads, bridges, and buildings that are designed to withstand high rainfall and waterlogging are examples of flood-resilient infrastructure. It consists of flood barriers in high-risk areas, elevated buildings, and better stormwater drainage. Surface runoff is decreased through the use of permeable materials and subterranean water storage. By taking these steps, flood damage is reduced, livelihoods are safeguarded, and recovery from extreme weather events is accelerated.

5.Promote Rainwater Harvesting- Rainwater harvesting lessens reliance on groundwater by collecting and storing rainwater from open spaces or rooftops for later use. By reducing surface runoff during periods of intense rainfall, it helps prevent urban flooding. Water security is improved when it is used in residences, educational institutions, and public buildings. Public awareness and government incentives are essential for widespread adoption.

6. Community Awareness & Participation- Resilience and readiness are increased when communities are educated about flood risks and sustainable practices. Involving the public in drainage system design and upkeep guarantees that local needs are met. Ownership is encouraged by involving the public in waste management, rainwater collection, and lake conservation. Campaigns, workshops, and school initiatives promote community support and long-term behavioral change.

7. Data-Driven Decision Making- Planners can prioritize interventions and identify vulnerable areas by using precise rainfall and flood data. Early warning systems and real-time monitoring are made possible by advanced analytics and GIS mapping. Effective resource allocation and locally specific infrastructure design are made possible by data. Long-term urban resilience and climate adaptation plans are enhanced by ongoing data collection and analysis

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