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# RAINFALL TREND ANALYSIS OF BENGALURU URBAN

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***Abstract**-The study aims to assess the precipitation pattern and different methods for identifying patterns. Non-parametric methods, such as the Mann-Kendall test, were employed for pattern analysis, while Sen's slope was used to determine the magnitude of the trend. Various studies have demonstrated the variability of precipitation worldwide and have also examined the autocorrelation effect in hydrological data. It was observed that precipitation patterns vary across different regions and are influenced by factors such as geography. The Sen's Slope Estimator, along with nonparametric and the Mann-Kendall Test for Monotonic Trend Analysis, was utilized to quantify the strength of trends in monthly, seasonal, and yearly precipitation data. One advantage of this approach is that it does not require the data to be normally distributed or conform to any specific criterion. However, it should be noted that the sample size may be limited due to missing data, which can affect statistical significance. Additionally, the uneven spacing of measurement time points does not impact the analysis. The Mann-Kendall approach has a limitation in that it tends to yield more negative findings for shorter datasets. Therefore, it is recommended to remove known periodic effects from the data before conducting the test. The chi-square test, which compares actual outcomes to predictions, can be employed to examine the relationship between two variables and identify discrepancies between observed and expected values. However, this test requires numerical data, a minimum of 20 observations, and should not be used to compare categories with only two options.*

***Key Words:RAINFALL TREND, RAINFALL PATTERN, FORECAST, AND TEMPERATURE.***

## 1. INTRODUCTION

Bengaluru, known as the 'Silicon Valley of India,' is a rapidly growing city situated at an elevation of 920 meters above mean sea level. Recent floods in various parts of Bengaluru can be attributed to heavy rainfall, urbanization, and encroachment on streams and water bodies. Urban flooding is a consequence of increased impermeable surfaces and rapid urban development. Instead of percolating, water tends to flow towards low-lying areas. Inadequate urban planning may be one of the factors contributing to the recent occurrences of flooding. Local factors, such as changes in the landscape and the lack of green spaces, also impact the rainfall pattern in Bengaluru. The annual rainfall in Bengaluru was recorded as 1050mm in 2018, 950mm in 2019, 1200mm in 2020, and 1500mm in 2021. Conducting a proper analysis of rainfall and implementing improved flood prediction models can help in devising measures to mitigate damage to lives, properties, and other issues like traffic congestion and waterlogging.

### 1.1 Study Area:

Bengaluru District is situated in the southeastern part of Karnataka State, India. It is a rapidly expanding city facing increasing pressure on its water resources due to rapid urbanization and population growth. The city relies on various sources of water, including lakes, rivers, and wells. The primary rivers that supply water to Bengaluru are the Vrishabhavathi, Arkavathi, Kumudvathi, and Kanva rivers. Additionally, the city is supported by several lakes and reservoirs, such as Kalyanisagar, Tippagondanahalli, Hesaraghatta reservoirs, as well as the Bellandur, Agara, and Varthur lakes. The population of Bengaluru is approximately 13.19 million, making it the second-largest city in India. However, the rapid urbanization and population growth have led to water shortages in the city, emphasizing the importance of studying and managing water resources in a sustainable manner. The study area for this research is Bengaluru Urban, Karnataka, India, and its geographical coordinates range from 13.25N, 77.27W to 13.24N, 78.00E and from 12.51S, 77.27W to 12.51S, 78.00E. The district covers an area of 2196 sq km and has a literacy rate of 87.67%. It is divided into 5 taluks, 20 hoblis, and consists of 588 villages. There are 6 urban local bodies within the district. The relevant toposheet OSM-sheet numbers for the area include D43R12-57G/12, D43R15-57/15, D43R16-57G/16, D43R8-57G/8, D43X10-57G/10, D43X13-57H/13, D43X14/14, D43X5-57H/5, D43X6-57H/6, and D43X9-57H/9.

### 1.2 Study Area Location:

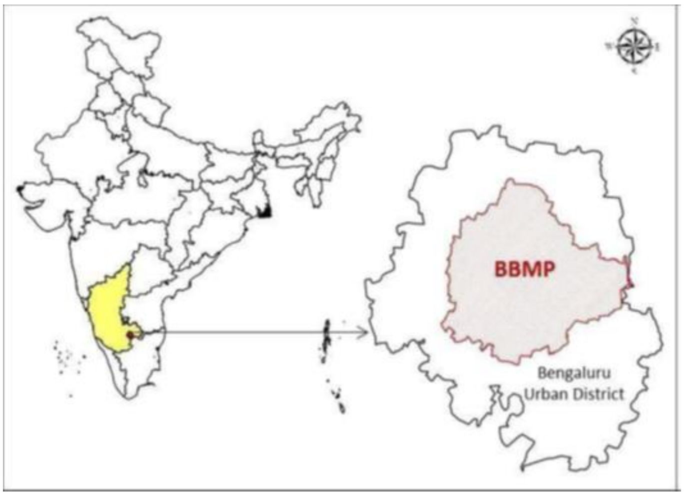


**Fig 1.1: Bengaluru location in India Map**


**Fig 1.2: Bengaluru Map**


**Fig 1.3: Toposheet D43X5**

**1.3 Scope Of Work:**

1. Effective use of rainwater collected in the catchment area during summer.

2. Flood forecasts (early warning system) may help reduce damages to life, property, flooding (inundation) and traffic problems.

3. Use of new technology along with precipitation data to forecast agricultural yield and natural disasters (flood and/or famine).

## 2. OBJECTIVES

**The objectives for the current study are:**

**1.** To analyze the rainfall trend of Bengaluru.
**2.** To analyze the temperature trend of the study area.
**3.** To forecast the rainfall trend for the study area
**4.** To analyze the rainfall pattern of Bengaluru.

## 3. LITERATURE REVIEW

**1. P Guhanthakurta and M Rajeevan, 6 Nov 2007.**

Guhanthakurta and Rajeevan (2007) found that some subdivisions in India experienced a decrease in the contribution of June, July, and September rainfall to the annual rainfall, while the contribution of August rainfall increased in certain subdivisions. They analyzed long-term trends using linear trend analysis and observed significant decreasing trends in Jharkhand, Chattisgarh, and Kerala, while significant increasing trends were found in Gangetic WB, West UP, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Rayalseema, Coastal AP, and North Interior Karnataka.

**2. ArunRana, CintiaBertacchi, Uvo, Lars Bengtsson, P.ParthSarth, 15 June 2010.**

Rana et al. (2010) investigated rainfall trends in Delhi and Mumbai from 1951 to 2004. They used statistical methods such as the Man-Kendall rank statistics and linear regression to analyze monthly, seasonal, and yearly precipitation data. The study also examined the relationship between southwest monsoon precipitation and global climatic phenomena using climatic indices.

**3. Vijay Kumar, Sharad K. Jain &Yatveer Singh, 26 May 2010.**

Kumar et al. (2010) studied the trends in monthly, seasonal, and annual rainfall in India over a period of 135 years (1871–2005). They employed Sen's estimator and the non-parametric Mann- Kendall test to determine the magnitude and statistical significance of the trends in 30 sub- divisions. The study highlighted the importance of precipitation trends for India's food security and economy.

**4. ArunMondal, SanandaKundu, AnirbanMukhopadhyay, Jan 2012.** Mondal et al. (2012) analyzed 40 years of daily rainfall data (1971–2010) to assess the monthly variability of rainfall. They used the modified Mann-Kendall test and Sen's slope estimator to detect trends. The results indicated both rising and decreasing precipitation trends in different months, suggesting overall insignificant changes in the area.

**5. SanandaKundu Deepak KhareArunMondal P K Mishra, 7 January 2015.**

Kundu et al. (2015) examined the changed rainfall trend in Madhya Pradesh, India, using monthly rainfall data from 1901 to 2011. They applied the Mann-Kendall test, Sen's slope estimator, and other statistical methods to analyze spatial distribution, temporal variation, and break points in the series. The study observed a decreasing trend in the spatial distribution of annual and monsoon rainfall.

**6. S Pal, D Mazumdar and P K Chakraborty Sep, 2015.**

Pal et al. (2015) observed a decreasing tendency in summer monsoon rainfall and an increasing trend in pre-monsoon and post-monsoon months in India over the last century. The study identified districts with significant increasing trends in September rainfall and highlighted the potential risks of over-precipitation causing floods and impacting crop growth.

**7. SaritaGajbhiye ,ChandrashekharMeshram, RasoulMirabbasi and S K Sharma,1 June 2015.**

Gajbhiye et al. (2015) analyzed historical rainfall data from 1901 to 2002 and 1942 to 2002 in the Sindh river basin, India. They employed the Mann-Kendall test, Sen's slope estimator, and spatial interpolation techniques to identify trends and analyze spatial patterns. The study indicated a significant increasing trend in seasonal and annual rainfall in the Sindh basin during the period 1901–2002.

**8. SanandaKundu, Deepak Khare, ArunMonda, P K Mishra, 7 January 2015.**

Kundu et al. (2015) investigated the changed rainfall trend in Madhya Pradesh using monthly rainfall data from 1901 to 2011. They utilized the Mann-Kendall test, Sen's slope estimator, and other statistical tests to analyze trends and break points. The study observed a spatial distribution with a decreasing trend and identified a break point in the series around 1978.

**9. SaritaGajbhiyeMeshram, Vijay P Singh and ChandrashekharMeshram, 11 April 2016)**

GajbhiyeMeshram et al. (2016) examined the spatial and temporal precipitation variability in Chhattisgarh State, India. They analyzed monthly precipitation data for 102 years (1901–2002) and detected significant decreasing trends in June and September rainfall. The study highlighted the importance of understanding precipitation trends for sustainable water resource management.

**10. Mohammad Atiqur Rahman, Lou Yunsheng, Nahid Sultana, 12 September 2016.**

Atiqur Rahman et al. (2016) analyzed 60-year monthly rainfall data from Bangladesh to identify trends. They employed modified Mann-Kendall and Spearman's rho tests, as well as Sen's slope estimators, to detect long-term annual, dry season, and monthly trends. Sequential Mann-Kendall analysis was used to identify potential trend turning points. Spatial variations of the trends were examined through inverse distance weighting (IDW) interpolation. Additionally, an Auto Regressive Integrated Moving Average (ARIMA) model was utilized for country mean rainfall and for data from two specific stations that exhibited the highest and lowest trends in the Mann-Kendall and Spearman's rho tests.

**11. Amar Bahadur Pal, Deepak Khare, P K Mishra, Lakhwinder Singh, December-2017.**

The study has been carried out to investigate and assess the significance of the potential trend of three variables viz. rainfall, temperature and runoff over the Rangoon watershed in Dadeldhura district of Nepal**.** Mann-Kendall test and Sen's slope estimate test were applied to identify the existing trend direction and to detect the trend direction and magnitude of change over time. The most important findings are, i) There is warming trends over the Rangoon watershed as Mann-Kendall statistic (Z-value) for most of the maximum temperature values are positive, ii) Rainfall and runoff affected by fluctuations every year though the annual rainfall showing a rising trend whereas runoff showing a falling trend.

**12. K. VenkataSai, Asha Joseph, 24 August 2018.**

VenkataSai et al. (2018) collected the annual trends of rainfall have been studied over pattam- -be region using rainfall data for 35 years (1983-9017). Mann-Kendall analysis and Sen's slope estimator are used for the trend analysis. The results of the trend analyst's using sen's slope estimator was revealed that the annual rainfall was observed as falling trend (south-west monsoon, & North-east monsoon) 8 rising trend. In summer season. The winter season does not showed any trend as the estimated sen's slope was zero.

**13. HadiSanikhani, Ozgur Kisi, RasoulMirabbasi, Sarita-GajbhiyeMeshram. 3 Aug 2018.**

HadiSanikhani et al. (2018) For this purpose, the monthly rainfall data for 20 stations in Madhya Pradesh (MP) and Chhattisgarh (CG) states in Central India during 1901–2010 was used. Revised Mann-Kendall (RMK) test, Sen’s slope estimator, and innovative trend method (ITM), The Sen’s slope estimator was utilized for calculating the slope of rainfall trend line. The ITM shows significant increasing trend in rainfall of November and December months.

**14. Rajakumara H.N, Ganesha Raj K, Ramesh K S, Vidya A, Ajey Kumar V G, November 2019.**

H. N Rajakumara et al. (2019) studied Vrishabhavathi valley is a part of river Arkavathi. It covers parts of Bengaluru Urban and Ramanagara districts with an area of 381.46 sq. kms. Disturbance to human activities and damages to properties has been observed in Vrishabhavathi valley region due to heavy rainfall especially in heavy rain events. Rainfall data analysis has been carried out statistically and graphically on Vrishabhavathi valley from 1970 to 2018. Rainfall analysis was made on converting daily rainfall data to monthly average data and seasonal analysis of rainfall has made for three different monsoon seasons Pre- monsoon, South- West and North- East monsoon, distribution and frequency of rainfall has been analyzed and results are represented graphically. From the annual rainfall study it is observed that less rainfall variations till 1990 and rainfall pattern seem to be increasing constantly from 1990’s onwards till 2018, particularly in the months of August, September and October.

**15. M SatyaSwarupa Rani, R Asha, G M V Prasadrao, 01 August 2020.**

SatyaSwarupa Rani et al. (2020) analyzed the trend of rain fall events in prakasam district of Andhra state in which the data consists of annual precipitation time series from 1991-2019. Initially study concerns with analysis of data base using descriptive statics, later trend change was detected by using non parametric tests. The results indicate an increased trend in June and monsoon season, with a decreased trend in July & winter season at 50% level of significance.

**16. JavedMallick, SwapanTalukdar, MajedAlsubih, Roquia Salam, Mohd Ahmed, Nabil Ben Kahla and Md. Shamimuzzaman, 25 October 2020.**
The study is designed to analyse the annual rainfall variability and trend in 30 meteorological stations of the Asir region for the period of 1970–2017 using the Mann-Kendall (MK) test,Modified Mann Kendall (MMK) test, trend free pre-whitening Mann-Kendall (TFPW MK) test, and the innovative trend analysis (ITA). The trend detection techniques was performed using the correlation coefficient. The future rainfall trend based on the historical rainfall pattern was investigated by using distended fluctuation analysis (DFA). Results of the MK test showed that 20 stations in the study area observed a negative trend, and out of these, nine stations had significant negative trends at the significance level of 0.01.Based on the findings of the tests and their performance, the MMK test appeared as the best performing technique among the MK test family, while ITA appeared as the best trend detection technique among the four techniques because it outperformed ($p < 0.01$) the others. Results of DFA showed that 23 stations (10 were significant) had recorded declining future rainfall trends based on past trends. The results of the present study would help the planners and policy makers to make accurate and easy decisions on irrigation, climatic, and water resource management in the Asir region of Saudi Arabia.

**17. Pavithra C J, Balakrishna H B, ShivakumarNaikal H S, July-2021.**
C J Pavithra et al. (2021) in this study the rainfall data was collected from Karnataka State Natural Disaster Monitoring Cell for the period of 50 years using Thiessen Polygon Method. Based on monthly rainfall data it is observed highest rainfall was occurred in September and South-West monsoon contributes highest. Since all the valleys are located spatially adjacent to each other, they experience similar monthly and seasonal rainfall pattern and shows an increasing trend.

**18. K AAhire, R C Kothwale, P D Hange, Bhagyashri R, Jalgoankar, A D Patil, J P Shewale, December 31, 2021.**
A Ahire et al. (2021) in this the Rainfall data from the satara district was analysed for monthly and annual rainfall trends for 21 years (2000-2020). The monthly and annual rainfall data was obtained from the Mahaagri website. The study revealed that tehsils in the east, such as manahatav and phaltans are prone to drought, in the west receive excess rain.

**19. K KChowdari, March 16th, 2022.**
K KChowdari collected the curoulative seasonal and annual rain fall derived from monthly datasets spanning 102 years (1901 - 2009) for 11 districts of the semi-arid Karnataka. The Innovative trend (analysis) method was applied to 43 homogeneous rainfall time series, MK and SR tests to 41 time series & MK test to two time series. The Mk test revealed a positive trend for the post- monsoon season in a district. The ITA method could capture a significant trend for all the seasons in most districts.

**20. Bushra Praveen, SwapanTalukdar, Shahfahad, SusantaMahato, JayantaMondal, Pritee Sharma, Abu Reza Md. Towfiqul Islam, Atiqur Rahman.**
Praveen et al. (2022) in this 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 analyse the rainfall trend. The Artificial Neural Network-Multilayer Perceptron (ANN-MLP) was employed to forecast the upcoming 15 years rainfall across India. Rainfall trend pattern for whole country by using the geo-statistical technique like Kriging in ArcGIS environment. The results derived from ECMWF ERA5 reanalysis data exhibit that increasing/ decreasing precipitation convective rate, elevated low cloud cover and inadequate vertically integrated moisture divergence might have influenced on change of rainfall in India.

**3.1Literature Summary:**
The literature papers mentioned above have conducted rainfall trend analyses on various areas using different methodologies. One commonly used method is the Thiessen polygon test, which calculates the mean areal precipitation for a catchment based on rain gauge observations. This method is considered more accurate than the arithmetic method. However, it does not account for topographic influences. The advantage of the Thiessen polygon test is that polygons only need to be created once, but its disadvantage is the lack of consideration for topographic effects.
To estimate the magnitude of trend in time series data, the Mann-Kendall (MK) Test for monotonic analysis of trend and the nonparametric Sen's Slope Estimator were used. The Mann- Kendall test has several advantages: it does not assume a specific data distribution, it is not affected by missing data except for the reduction in sample points, it is not affected by irregular time point spacing, and it is not affected by the length of the time series. However, the Mann- Kendall test is not suitable for data with periodicities or seasonal effects. It is recommended to remove known periodic effects before conducting the test, and longer time series yield more effective trend detection results.
The chi-square test, a statistical test used to compare observed and expected results, was also employed. It is advantageous for testing associations between variables and identifying differences between observed and expected values. However, the test has certain limitations such as the inability to use percentages, the requirement of numerical data, the difficulty in comparing categories of two, the need for a minimum of 20 observations, and invalidity if any expected values are below 5.
The Pettitt test, a non-parametric test, has been utilized in hydroclimatological studies to detect abrupt changes in the mean of a variable's distribution. Its main advantage is the absence of prior assumptions about the data distribution, with the exception that the data must be continuous. However, the Pettitt test may be inefficient in detecting breaks when dealing with extreme values.
The Implicit Association Test (IAT) measures the strength of associations between concepts and evaluations. The trend (linear) regression analysis method uses an equation to analyze the relationship between two or more quantitative variables to predict one from the other. The primary advantages of linear regression are its simplicity, interpretability, scientific acceptance, and widespread availability. On the other hand, it

fails to fit complex datasets properly due to its assumption of a linear relationship, which is a disadvantage.
The Thiel-Sen slope estimator is known for its efficiency and robustness against outliers. It can provide accurate estimates for skewed and heteroskedastic data, and it performs well even for normally distributed data in terms of statistical power compared to least squares regression. However, the usual method for estimating the slope using least squares regression is not valid when the data does not fit a straight line and is sensitive to outliers.

## 4. METHODOLOGY

**Methodology of Rainfall Trend Analysis using Polynomial Fit**

Rainfall trend analysis using polynomial fit is a commonly employed method for detecting changes in precipitation patterns over time. The process involves fitting a polynomial function to the rainfall data and utilizing the coefficients of the function to determine the trend.
To perform polynomial fit analysis using Origin software, you can utilize the Polynomial Fit tool located in the Analysis menu. This tool allows you to select the degree of the polynomial function and provides access to the results of the analysis, including the coefficients of the polynomial function and the R-squared value.
The methodology for rainfall trend analysis using polynomial fit with Origin software typically encompasses several steps. These include data collection, data pre-processing (if required), polynomial fitting, trend analysis, and prediction using the software. Origin software offers robust tools for data analysis and visualization, making it well-suited for conducting rainfall trend analysis using polynomial fit. The degree of the polynomial can be determined using statistical methods such as cross-validation or Akaike Information Criterion (AIC). For trend analysis, statistical measures like R-squared, Root Mean Square Error (RMSE), or Mean Absolute Error (MAE) can be utilized in Origin software. These measures help assess the goodness of fit and quantify the accuracy of the trend analysis.
Rainfall trend analysis using polynomial fit with Origin software finds application in various climate research endeavors. It is particularly useful for analyzingthe trend in rainfall over time and predicting future rainfall based on the trend analysis.

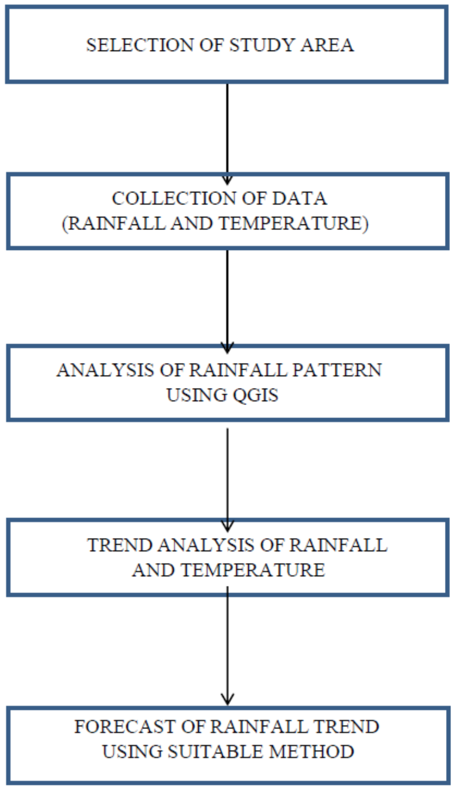


**Fig.4: FLOWCHART OF METHODOLOGY**

## 5. RESULT AND DISCUSSIONS

**5.1Rainfall Trend Analysis:**

The polynomial fit analysis performed using Origin software produced an R-squared value of 0.9458 for the annual rainfall data. The R-squared value, also known as the coefficient of determination, indicates the proportion of the variance in the dependent variable (rainfall) that can be explained by the independent variable (time).
An R-squared value of 0.9458 suggests that approximately 94.58% of the variation in annual rainfall can be explained by the polynomial fit equation. This high value indicates a strong relationship between time and rainfall patterns, with the fitted curve closely aligning with the majority of the data points. The high R-squared value signifies that the polynomial equation used in the analysis effectively captures the underlying trend in the data. Consequently, the polynomial fit provides a reliable approximation of the annual rainfall pattern, enabling trustworthy trend analysis and predictions.

Polynomial Fit (24-04-2023 12:11:30)

Notes

Input Data

Parameters

| | | Value | Standard Error |
|---|---|---|---|
| ANNULL RAINFALL | Intercept | 0 | -- |
| | B1 | -8.12763 | 10.69461 |
| | B2 | 0.00431 | 0.00532 |

Statistics

| | ANNULL RAINFALL |
|---|---|
| Number of Points | 20 |
| Degrees of Freedom | 18 |
| Residual Sum of Squares | 1.36898E6 |
| R-Square(COD) | 0.94581 |
| Adj. R-Square | 0.93979 |

Summary

| | Intercept | | B1 | | B2 | | Statistics |
|---|---|---|---|---|---|---|---|
| | Value | Error | Value | Error | Value | Error | Adj. R-Square |
| ANNULL RAINFALL | 0 | -- | -8.12763 | 10.69461 | 0.00431 | 0.00532 | 0.93979 |

**Fig.5: Polynomial fit of rainfall trend**

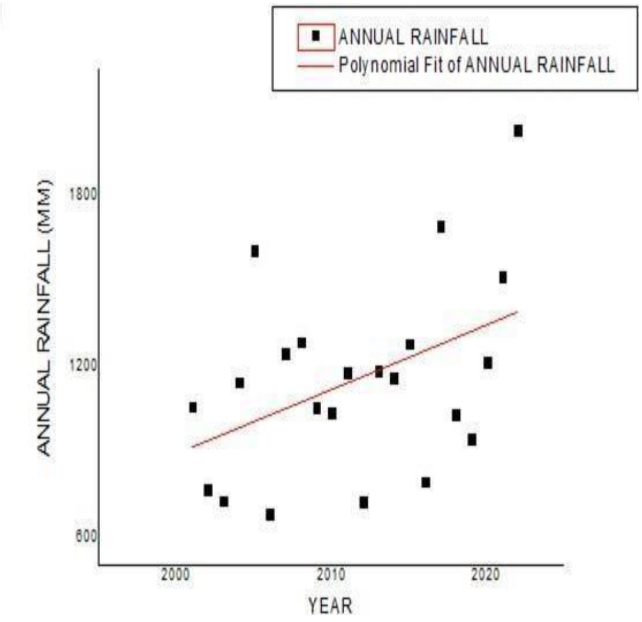


**Fig.5.1: Graph represents rainfall trend**

**5.2 Change of trend in temperature**

In the analysis conducted using Origin software, the annual temperature change was examined through polynomial fit, resulting in an impressive coefficient of determination (R-squared) of 0.99991. This exceptionally high R-squared value indicates an excellent fit of the polynomial curve to the temperature data, demonstrating a strong relationship between the independent variable (time) and the dependent variable (temperature).

With an R-squared value of 0.99991, approximately 99.991% of the variability in the annual temperature change can be explained by the selected polynomial fit equation. This high value signifies that the polynomial equation effectively captures the underlying trend and pattern present in the temperature data. The close alignment between the polynomial fit and the observed data points further supports the reliability and accuracy of the analysis.

The outstanding R-squared value of 0.99991 attests to the suitability of the polynomial fit model for approximating the annual temperature change. Such a precise representation enables the identification and characterization of long-term temperature trends, which are crucial for comprehending the dynamics of climate change and its potential implications on various aspects of our environment, society, and economy.

Statistics

| | B |
|---|---|
| Number of Points | 27 |
| Degrees of Freedom | 25 |
| Residual Sum of Squares | 1.51687 |
| R-Square(COD) | 0.99991 |
| Adj. R-Square | 0.9999 |

Summary

| | Intercept | | B1 | | B2 | | Statistics |
|---|---|---|---|---|---|---|---|
| | Value | Error | Value | Error | Value | Error | Adj. R-Square |
| B | 0 | -- | 0.00863 | 0.00609 | 1.80719E-6 | 3.05232E-6 | 0.9999 |

ANOVA

| | | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|---|
| B | Model | 2 | 16060.49313 | 8030.24656 | 132348.95589 | 0 |
| | Error | 25 | 1.51687 | 0.06067 | | |
| | Total | 27 | 16062.01 | | | |

Polynomial Fit (21-04-2023 14:27:52)

Notes

| | |
|---|---|
| Description | Perform Polynomial Fitting |
| User Name | Admin |
| Operation Time | 21-04-2023 14:27:52 |
| Equation | y = Intercept + B1*x^1 + B2*x^2 |
| Report Status | New Analysis Report |
| Weight | No Weighting |

Input Data

| Input X Data Source | Input Y Data Source | Range |
|---|---|---|
| [Book1]Sheet1!year | [Book1]Sheet1!B | [1:27] |

Parameters

| | | Value | Standard Error |
|---|---|---|---|
| B | Intercept | 0 | -- |
| | B1 | 0.00863 | 0.00609 |
| | B2 | 1.80719E-6 | 3.05232E-6 |

Statistics

| | B |
|---|---|
| Number of Points | 27 |
| Degrees of Freedom | 25 |

**Fig.5.2: Polynomial fit of temperature trend**

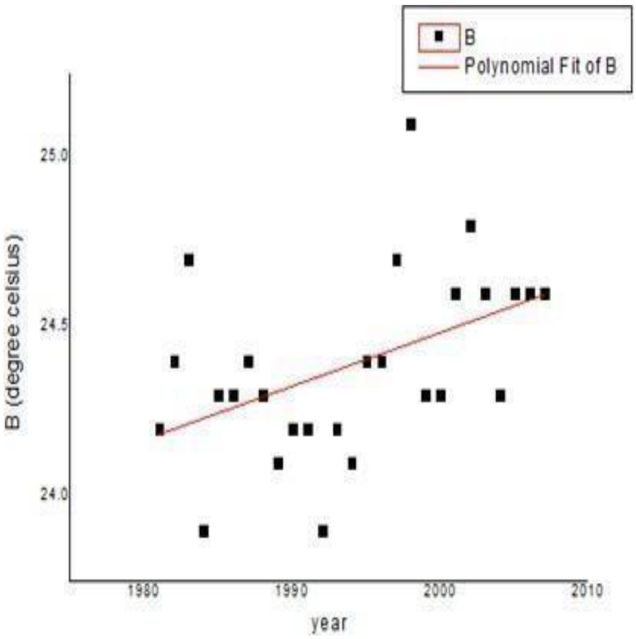


**Fig.5.2.1: Graph represents temperature trend**

**5.3 Forecast the rainfall trend for the study area:**

To forecast the annual data from 2023 to 2060 and identify an increasing trend, a polynomial equation of the form y = Intercept + $B1x^1$+ $B2x^2$ was employed. This equation enables the examination of both linear and quadratic trends over time. After analyzing the available data, it was determined that there exists a clear upward trend in the variable under investigation.

Using the Origin software, the previous years' data were fitted to the polynomial equation, and the resulting coefficients were utilized to forecast the future values of the variable of interest for the next 37 years, spanning from 2023 to 2060. The increasing trend revealed by the polynomial fit equation suggests that the variable is projected to steadily rise as time progresses. This forecast holds significant implications for various domains, including climate science, economics, and infrastructure planning.

Nevertheless, it is crucial to acknowledge that forecasting future trends inherently involves a certain level of uncertainty. External factors such as policy changes, technological advancements, or natural events can influence the actual trajectory of the variable. Consequently, the forecasted values should be interpreted with caution and regularly updated as new data becomes available. By leveraging the polynomial fit equation and conducting a forecast of the annual data for the next 37 years, decision-makers and researchers can gain valuable insights into the expected trajectory of the variable. This information can aid in making informed decisions, formulating appropriate strategies, and preparing for potential challenges associated with the increasing trend.

In conclusion, the polynomial fit equation y = Intercept + $B1x^1$+ $B2x^2$ offers a forecast of the variable from 2023 to 2060, highlighting an increasing trend. This projected trend can serve as a basis for future planning and decision-making processes.

| Equation from the trend analysis test run | Rainfall in mm | | Year | |
|---|---|---|---|---|
| y = Intercept + B1*x^1 + B2*x^2 | 1023.36 | | 2000 | x1=0.50505 |
| | 1025.549899 | | 2001 | x2=Year |
| | 1027.741475 | | 2002 | |
| PERCENTAGE ERROR | 1029.934728 | | 2003 | |
| 0.895468433 | 1032.129659 | | 2004 | |
| | 1034.326267 | | 2005 | |
| | 1036.524553 | | 2006 | |
| | 1038.724516 | | 2007 | |
| | 1040.926156 | | 2008 | |
| | 1043.129474 | | 2009 | |
| | 1045.334469 | | 2010 | |
| | 1047.541141 | | 2011 | |
| | 1049.749491 | | 2012 | |
| | 1051.959519 | | 2013 | |
| | 1054.171223 | | 2014 | |
| | 1056.384605 | | 2015 | |
| | 1058.599665 | | 2016 | |
| | 1060.816401 | | 2017 | |
| | 1063.034816 | | 2018 | |
| | 1065.254907 | | 2019 | |
| | 1067.476676 | | 2020 | |
| | 1069.700122 | | 2021 | |
| | 1071.925246 | | 2022 | |
| | 1074.152047 | | 2023 | |
| | 1076.380525 | | 2024 | |
| | 1078.610681 | | 2025 | |
| | 1080.842514 | | 2026 | |
| | 1083.076025 | | 2027 | |
| | 1085.311213 | | 2028 | |
| | 1087.548078 | | 2029 | |
| | 1089.786621 | | 2030 | |

| | |
|---|---|
| 1092.026841 | 2031 |
| 1094.268739 | 2032 |
| 1096.512313 | 2033 |
| 1098.757566 | 2034 |
| 1101.004495 | 2035 |
| 1103.253102 | 2036 |
| 1105.503387 | 2037 |
| 1107.755348 | 2038 |
| 1110.008987 | 2039 |
| 1112.264304 | 2040 |
| 1114.521298 | 2041 |
| 1116.779969 | 2042 |
| 1119.040318 | 2043 |
| 1121.302344 | 2044 |
| 1123.566047 | 2045 |
| 1125.831428 | 2046 |
| 1128.098486 | 2047 |
| 1130.367222 | 2048 |
| 1132.637635 | 2049 |
| 1134.909725 | 2050 |
| 1137.183493 | 2051 |
| 1139.458938 | 2052 |
| 1141.73606 | 2053 |
| 1144.01486 | 2054 |
| 1146.295337 | 2055 |
| 1148.577492 | 2056 |
| 1150.861324 | 2057 |
| 1153.146833 | 2058 |
| 1155.43402 | 2059 |
| 1157.722884 | 2060 |

**Fig.5.3:Rainfall forecast validation**

**5.4Rainfall Pattern Analysis of Bengaluru:**

Rainfall pattern analysis involves the study of precipitation trends and variations over a specific region or area. By examining the distribution, frequency, and intensity of rainfall events, scientists and researchers can gain insights into the climatic conditions and understand how precipitation patterns may be changing over time.In recent years, rainfall pattern analysis has become increasingly important due to concerns about climate change and its potential impact on water resources, agriculture, and ecosystems. By analyzing historical rainfall data and comparing it with current observations, researchers can identify any shifts or anomalies in the rainfall patterns.One aspect of rainfall pattern analysis is the examination of long-term trends. This involves analyzing data collected over several decades to identify any significant changes in the amount or timing of rainfall. For example, an increase or decrease in the average annual rainfall can provide insights into shifts in regional climate conditions.Another aspect involves studying short-term variations and extreme events. This includes analyzing rainfall anomalies such as droughts, floods, or unusually heavy rainfall episodes. Understanding these extreme events is crucial for developing effective strategies to manage water resources and mitigate the impacts of climate-related disasters.

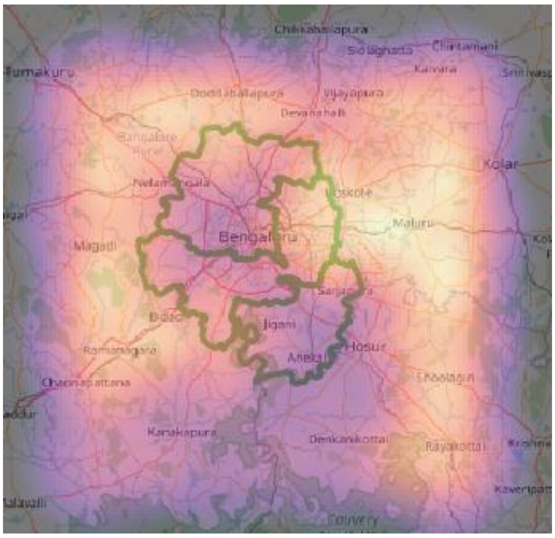


**Fig.5.4: Rainfall Pattern for the Year 2001**

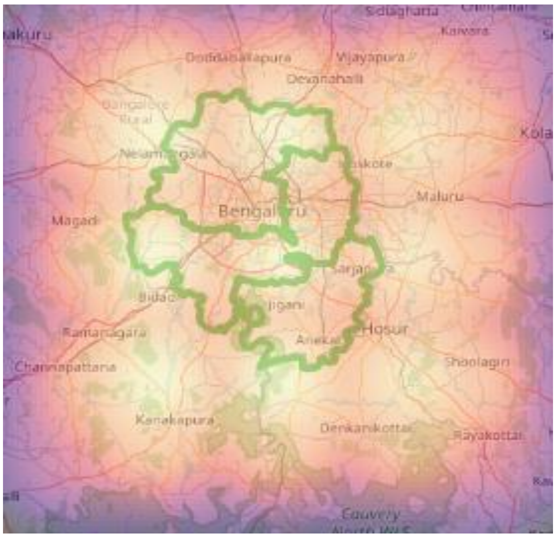


**Fig.5.4.1: Rainfall Pattern for the Year 2021**

**5.5 DISCUSSIONS:**

The rainfall trend in Bengaluru urban was analyzed using the equation $y = \text{Intercept} + B1x^1 + B2x^2$, where y represents the rainfall values, x represents the time in years, Intercept represents the constant term, B1 represents the coefficient for the linear term, and B2 represents the coefficient for the quadratic term. Similarly, the temperature trend was analyzed using the equation $y = \text{Intercept} + B1x^1 + B2x^2$.

Based on these equations, future rainfall values were forecasted up to the year 2060. The forecasted values provide an estimation of the expected rainfall pattern in Bengaluru urban over the coming years. The forecasted values can be utilized for various purposes, such as water resource management, urban planning, and infrastructure development.

To analyze the rainfall pattern using QGIS, geographic information system (GIS) software, data on rainfall distribution and spatial variations in Bengaluru urban were considered. By mapping the rainfall data onto a spatial framework in QGIS, it becomes possible to visualize the rainfall pattern across the region, identify areas with high or low rainfall, and observe any spatial trends or variations in the rainfall distribution.

By combining the forecasted rainfall values with the spatial analysis capabilities of QGIS, a comprehensive understanding of the future rainfall pattern in Bengaluru urban can be obtained. This information can assist in making informed decisions related to water management, agriculture, and urban planning, taking into account the anticipated changes in rainfall over time.

Overall, by employing the rainfall trend equation and leveraging the capabilities of QGIS for spatial analysis, the future rainfall forecast and analysis of rainfall patterns in Bengaluru urban can provide valuable insights for planning and decision-making purposes.

## 6. CONCLUSION

The increasing trend in rainfall, coupled with the scarcity of fresh water, highlights the importance of effective water resources management and monitoring techniques in Bengaluru urban. Despite the overall increase in rainfall, it is crucial to ensure the optimal utilization of this natural resource to address the water scarcity issue and meet the growing water demands of the city.

To tackle this challenge, the involvement of various stakeholders becomes essential. Citizens, engineers, professionals, decision-makers, and policy-makers all have important roles to play in implementing suitable water resources management strategies. Here are some key considerations for effective management:

**1. Conservation and Efficiency**: Encouraging water conservation practices among citizens and promoting water-efficient technologies can help reduce overall water consumption. This may include initiatives such as rainwater harvesting, wastewater recycling, and efficient irrigation techniques.

**2. Infrastructure Development**: Investing in infrastructure projects for water storage, treatment, and distribution can enhance water availability and ensure reliable access to clean water. This may involve constructing reservoirs, water treatment plants, and distribution networks to effectively manage the available water resources.

**3. Monitoring and Data Analysis**: Implementing robust monitoring systems to track rainfall patterns, water availability, and consumption can provide valuable insights for decision-making. Advanced technologies such as remote sensing, IoT-based sensors, and data analytics can aid in real-time monitoring and informed decision-making.

**4. Integrated Water Management**: Adopting an integrated approach to water management involves considering the entire water cycle, including surface water, groundwater, and wastewater. This holistic approach ensures the sustainable use of water resources and minimizes wastage.

**5. Stakeholder Engagement**: Collaboration and engagement with all stakeholders, including the public, industry, and government agencies, are crucial for successful water resources management. This can involve awareness campaigns, public participation programs, and policy dialogues to create a shared responsibility and promote sustainable water practices.

By implementing these strategies and techniques, Bengaluru urban can make optimum use of the increasing rainfall to address the water scarcity issue. It requires a collective effort from all stakeholders to ensure the long-term availability and sustainability of fresh water resources in the city.

**6.1 Limitations of the study**

When conducting a study on rainfall and temperature trends in Bengaluru, researchers should be aware of several limitations. These limitations can impact the accuracy and interpretation of the results. Here are some common limitations to consider:

**1. Data Availability and Quality**: The availability and quality of historical weather data for Bengaluru may vary. Missing or incomplete data can introduce biases and affect the accuracy of trend analysis. It is important to use reliable data sources and ensure data quality through proper validation and quality control procedures.

**2. Spatial Variability:** Bengaluru is a large city with diverse topography and land cover. Weather conditions can vary within different regions of the city. Limited weather stations may not capture the full spatial variability of rainfall and temperature patterns. Care should be taken to consider the representativeness of the selected weather stations.

**3. Urbanization and Urban Heat Island Effect**: Rapid urbanization in Bengaluru can lead to the urban heat island effect, where urban areas experience higher temperatures compared to surrounding rural areas. Urban infrastructure and land use changes can influence temperature trends. The impact of urbanization on temperature should be considered when analyzing trends.

**4. Land Use Changes:** Changes in land use, such as deforestation, urbanization, or agricultural practices, can affect local climate patterns. These changes may introduce biases in the analysis of rainfall and temperature trends. It is important to consider the influence of land use changes and their potential impact on the study area.

**5. Short-Term Variability**: Weather patterns exhibit natural short-term variability, including annual, seasonal, and daily fluctuations. These short-term variations can mask long-term trends in the data. It is crucial to consider the influence of short-term variability when interpreting the results of the study.

**6. Climate Change Attribution**: Distinguishing the effects of long-term climate change from other factors, such as natural climate variability or local environmental changes, can be challenging. Proper attribution of observed changes to climate change requires careful analysis and consideration of multiple factors.

**7. Statistical Significance**: Statistical analysis is essential to determine the significance of observed trends. Care must be taken to ensure that the detected trends are not simply due to random fluctuations or outliers in the data. Proper statistical methods should be applied to assess the significance of the trends.

**8. Extrapolation**: Extrapolating trends into the future based solely on historical data carries inherent uncertainties. Climate models and additional analyses may be needed to project future rainfall and temperature trends accurately, considering the complex interactions of various factors.

**9. Contextual Factors**: Understanding contextual factors such as socio-economic development, land management practices, and policy interventions is crucial to interpreting the results. These factors can influence the vulnerability and adaptive capacity of the region to climate change and should be considered in conjunction with the trend analysis.

Acknowledging and addressing these limitations will help ensure that the study provides reliable and meaningful insights into rainfall and temperature trends in Bengaluru. It is important to exercise caution and communicate the findings in the appropriate context, considering the uncertainties associated with the analysis.

**6.2 Scope for the future work**

Absolutely! The research scopes you've outlined cover important areas that can significantly enhance our understanding of climate dynamics in Bengaluru and inform effective decision-making. By addressing these aspects, future studies can contribute to the development of sustainable strategies and policies for climate resilience. The interdisciplinary approach that integrates climate science, urban planning, water resource management, socio-economic analysis, and stakeholder engagement is crucial for addressing the complex challenges associated with climate change. Continued research in these areas will provide valuable insights into the impacts of climate change on Bengaluru and facilitate the development of appropriate adaptation and mitigation measures.

**1. Climate Change Impact Assessment**: Conduct a comprehensive investigation into the specific effects of climate change on the rainfall and temperature patterns in Bengaluru. Evaluate the potential implications of projected changes in climate variables on crucial aspects such as water resources, agriculture, urban planning, and public health within the region.

**2. Urban Heat Island Mitigation**: Explore and analyze various approaches and measures aimed at mitigating the urban heat island effect in Bengaluru. Assess the effectiveness of interventions such as urban planning strategies, implementation of green infrastructure, cool roof initiatives, and other relevant measures in reducing temperatures and improving the city's overall resilience to heat stress.

**3. Extreme Events Analysis**: Conduct an in-depth examination of extreme weather events, including but not limited to intense rainfall, heat waves, and droughts, in Bengaluru. Investigate the frequency, duration, and intensity of these events to gain insights into potential changes in their patterns and associated risks. Analyze historical data and employ statistical methods to identify trends and evaluate the impacts of extreme events on various sectors, such as infrastructure, agriculture, public health, and emergency management.

**4. Climate Modelling**: Utilize advanced climate models to simulate and project future climate scenarios specifically for Bengaluru. Incorporate relevant climate model outputs with local- scale data, such as topography, land cover, and urbanization, to enhance the accuracy and resolution of rainfall and temperature projections. Assess potential changes in seasonal patterns, extreme events, and long-term trends to inform adaptation and mitigation strategies. Validate the model outputs against historical data to ensure reliability and explore uncertainties associated with the projections. Collaborate with climate scientists, meteorologists, and local stakeholders to ensure the effective utilization of climate modeling results in decision-making processes.

**5. Water Resource Management**: Conduct a comprehensive study to understand the implications of changing rainfall patterns on water availability and quality in Bengaluru. Analyze the impacts on surface water reservoirs, groundwater recharge, and urban water supply systems. Assess the vulnerability of existing water infrastructure to climate change- induced shifts in rainfall patterns. Explore innovative strategies for sustainable water resource management, including rainwater harvesting, water conservation measures, and efficient water use practices. Investigate the potential of implementing decentralized water management systems and integrating nature-based solutions for water storage and purification. Collaborate with water resource experts, hydrologists, and local authorities to develop adaptive water management plans that consider future climate conditions and ensure long-term water security for the city.

**6. Urbanization and Land Use Change**: Conduct a comprehensive analysis to examine the relationship between urbanization, land use change, and alterations in rainfall patterns and temperatures in Bengaluru. Investigate the impact of rapid urbanization on local microclimates and the urban heat island effect. Assess how changes in land cover, such as the expansion of impervious surfaces, affect rainfall distribution and intensity. Analyze the role of green spaces, including parks, urban forests, and green infrastructure, in mitigating the urban heat island effect and influencing temperature patterns. Evaluate the effectiveness of urban planning policies and regulations in promoting sustainable land use practices and preserving natural areas. Collaborate with urban planners, environmental scientists, and policymakers to develop strategies that balance urban development with the preservation of green spaces, promote sustainable land use practices, and enhance the resilience of the urban environment to climate change impacts.

**7. Socio-Economic Impacts**: Study the socio-economic consequences of changing rainfall and temperature patterns in Bengaluru. Assess the implications for sectors such as agriculture, water management, infrastructure, and public health. Analyze vulnerabilities and explore adaptation strategies for affected communities.

**8. Climate Resilience Plannin**g: Develop climate resilience strategies and policies for Bengaluru based on an in-depth understanding of rainfall and temperature trends. Integrate climate data into urban planning, infrastructure design, and disaster preparedness frameworks to enhance the city's resilience to climate change.

**9. Ecosystem Response**: Investigate the impacts of changing climate variables on Bengaluru's ecosystems, including vegetation, biodiversity, and ecological processes. Study the relationships between rainfall, temperature, and ecosystem functioning to inform conservation and restoration efforts.

**10. Stakeholder Engagement and Policy Interventions**: Involve stakeholders from various sectors, including government agencies, urban planners, researchers, and local communities, to develop collaborative approaches for climate adaptation and mitigation. Explore policy interventions, awareness campaigns, and capacity-building initiatives to foster climate resilience in Bengaluru.

By addressing these research scopes, future studies can make significant contributions to advancing our understanding of Bengaluru's climate dynamics. Through in-depth investigations into rainfall and temperature trends, the impacts of climate change, and the effectiveness of mitigation and adaptation measures, researchers can generate valuable insights for evidence- based decision-making.

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