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## LONG-TERM PRECIPITATION TRENDS AND VARIABILITY IN KARNATAKA, INDIA: A GEOSPATIAL-STATISTICAL ANALYSIS FOR CLIMATIC ADAPTATION

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### ABSTRACT

The ramifications of climate change are the main emphasis of this study, which looks at the long-term patterns and geographical distribution of precipitation in Karnataka, India, from 1958 to 2020. Seasonal and annual rainfall patterns were examined using TerraClimate data, and Sen's Slope estimator and the Mann-Kendall test were used to find important trends. Karnataka has very variable rainfall, both in terms of location and time. The majority of the yearly precipitation falls during the monsoon season, which runs from June to September, according to the analysis. Because of the Western Ghats' orographic effects, the study area exhibits a notable variance in the distribution of rainfall. Seasonal analysis shows that the post-monsoon and winter seasons have little effect on the state's water supplies, however the southwest monsoon has a major impact. Planning policies, managing water resources, and agriculture are all hampered by this variability.

The results highlight the need for adaptive methods to lessen the negative effects of climate change on Karnataka's water availability and agricultural productivity. Policymakers and other stakeholders can use the study's insightful recommendations to create sustainable water management strategies in response to shifting precipitation patterns.

**Keywords: Precipitation, Spatial and Temporal analysis, Mann-Kendall test, Sen-Slope**

## 1. INTRODUCTION

Environmental variations and land surface-atmosphere interactions are impacted by the pattern of climate change, which is primarily driven by global warming. Policymakers have been plagued by concerns about slow climate change for many years, particularly with regard to temperature and precipitation [1]. IPCC reports indicate that freshwater supplies will become much less available in the future due to climate change [2]. The global mean surface temperature has risen by  $0.6 \pm 0.2$  °C since 1861, and an additional 2 to 4 °C increase is anticipated over the next 100 years, according to IPCC [3]. The hydrology, water quality, and vegetation on Earth are significantly influenced by rainfall [2]. There are two characteristics of precipitation: duration and intensity. Any modification to either of these two factors could result in a major natural hazard [4]. One of the most significant effects of climate change on precipitation is that it can change the timing and volume of precipitation in any given area. This emphasizes the need to forecast precipitation in advance and using historical

data, examine how it has changed over time, paying particular attention to places that are already experiencing water stress. analyze its changing pattern over time using historical data, especially in areas that are already water stressed [3]. Unpredictability, uncertainty, intricacy, and unequal dispersion are characteristics of precipitation. Studying the spatial and temporal properties of precipitation is very important [5].

The impacts of climate change and water management both depend on an understanding of rainfall variability. Researchers were able to ascertain, is there a change in the amount or distribution of seasonal rainfall across the nation by utilizing the trend patterns. Water resource management is essential for nations with cyclical water availability, particularly those like India whose monsoon season affects rainfall. In the ensuing decades, there will likely be a significant change in the land use and population growth patterns of monsoon countries [6]. Rainfall has been both unexpected and not happening when it was

expected, with the agriculture industry appearing to be most negatively impacted [7]. The unpredictability of the weather is wreaking havoc on the farming community, leading a significant number of farmers to resort to extreme means, such as suicide. Indeed, "global warming" is a real thing in our world today, affecting all nations with altered precipitation patterns, accelerated glacier melting, and increasing air temperatures. Raising the sea level as a result is the rivers' increased water discharge [8]. Given India's continued reliance on agriculture, policy makers must take into account how climate change and fluctuations affect the seasonal hydrological cycle. Seasonal rainfall can be significantly impacted by even very slight variations in the regional circulation pattern, even by a few degrees in longitude and latitude [6].

Numerous studies attempt to determine the precipitation trend at both the regional and national levels [9]. Effective planning, design, and management of water resources has shown to benefit from trend analysis since it can be used to detect trends in hydrological variables like discharge, direct runoff, and precipitation, which can provide important information about the likelihood that these variables will change in the future [2]. Large temporal and regional differences in the trend

of rainfall have been documented in India. Of the thirty subdivisions across the nation, half exhibited a rising trend in yearly rainfall, with notable increases observed in coastal Karnataka, Punjab, and Haryana [10].

In India, the monsoon season, which runs from June to September, accounts for more than 80% of the country's annual rainfall [11] and the country received rainfall that was distributed unevenly. There is significant variance in the quantity of rainfall and the number of wet days during the winter, pre-monsoon, and post-monsoon seasons. The results of the snow accumulation experiment indicate that the South Asian Monsoon over the Indian subcontinent has varied noticeably. Furthermore, several Indian areas have reported variations in the quantity and intensity of rainfall, which are directly related to seasonal and yearly rainfall quantities [6]. As a result, rainfall trend analysis is necessary to ascertain if the mean annual rainfall or other rainfall variable is trending upward, downward, or in a constant direction over time. In monsoon season, certain parts of the country receive a lot of precipitation, while others receive much less and often face water scarcity [7]. The nation's economy and the welfare of its citizens will be impacted by any big changes the government makes to the water budget, which will also have a

considerable impact on hydrologic functions [7]. In addition to calculating Karnataka's seasonal, and annual precipitation, this study examines the variations in Karnataka's rainfall over a 62-year period (1958–2020) in both space and time.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Karnataka (**Figure 1**), located on the western coast of India at coordinates 12.97°N 77.50°E, boasts Bengaluru as its capital city. Its borders are shared by the Arabian Sea to the west, Goa and Maharashtra to the north, Telangana to the

east, Tamil Nadu to the southeast, and Kerala to the south. Four different physiographic zones—the coastal plain, hill ranges, the Karnataka Plateau to the east, and the black-soil tract to the northwest—define the terrain of the state [12]. The total land area of Karnataka spans 2,190 sq. km. As per the 2011 Census data, the state's population amounts to 96,21,551 individuals in total [13]. Karnataka comprises 31 administrative districts organized into four distinct administrative regions.

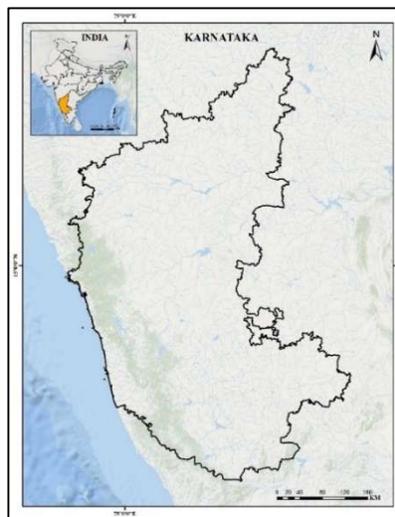


Figure 1 Study Area Map

Karnataka experiences a subtropical climate characterized by four distinct seasons: the southwest monsoon (June through September), the post-monsoon (October through December), and winter (January and February). Daily temperatures range from the

mid-80<sup>0</sup> F (around 30 °C) in winter to the low 100<sup>0</sup> F (about 40 °C) in summer. Precipitation varies across the state, with drier regions receiving approximately 20 inches (500 mm) of annual rainfall, while the wettest coastal areas receive up to 160 inches (4,000 mm).

The majority of rainfall occurs during the southwest monsoon, with a lesser contribution from the northeast monsoon during the post-monsoon season. Winter is notably dry. Agriculture forms the backbone of the state's economy, with rice being the primary food crop cultivated on the coastal plain, sorghum (jowar) and millet (ragi) came next.

## 2.2 Methodology

We retrieved the amount of rainfall from multidimensional visual data that we downloaded from the TerraClimate website

using the Arc GIS software application tool. TerraClimate provides a dataset of monthly rainfall in the study area from 1958 to 2020 (<http://www.climatologylab.org>). Time-varying data and high geographic resolution are required for global ecological and hydrological study, and these data offer vital contributions. Using the aggregated monthly dataset, the study of the long-term rainfall analyze trend, annual, and seasonal geographic distribution was produced (**Figure 1a**).

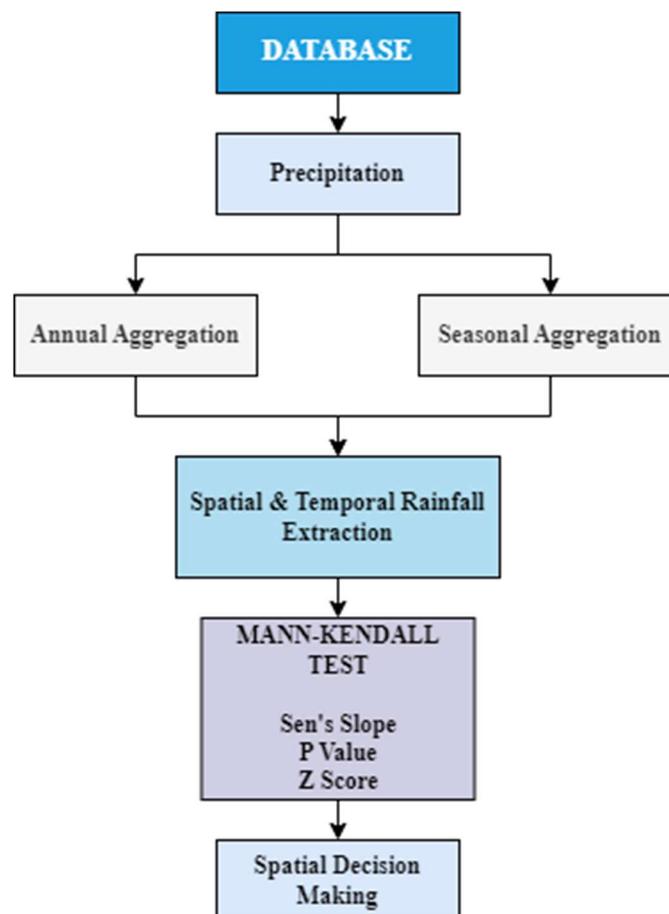


Figure 1 a) Flow chart of the Research

For a span of 62 years (1958 – 2020), monthly rainfall is extracted as numerical tables using the Aggregate Multidimensional Raster (Spatial Analyst) tool. Next, by classifying the months as summer, monsoon, post-monsoon, and winter seasons, the mean annual and seasonal quantity of rainfall in mm was determined. Various statistical techniques can be employed for trend analysis in an application, contingent on the characteristics of the distributed data. Utilizing the Aggregate Multidimensional Raster tool, the mean for every year was computed in order to ascertain the total precipitation for each year. With Subset Multidimensional Raster, values for later month-wise temporal statistics are obtained. Seasonal and annual evaluations of the long-term trend analysis were conducted. The amount of rainfall trend in the study area was examined using Sen's Slope, a widely used Mann-Kendell test.

### 2.2.1 Mann-Kendall Test – Magnitude of Trend

The MK test is the non-parametric test that is most frequently used to identify monotonic patterns in climate data [14, 15]. Statistically significant trends in rainfall time series data were found in this work using the non-parametric MK test. According to the test's alternative hypothesis (Ha), the rainfall time

series data exhibits a monotonic trend that can be either positive or negative. The null hypothesis (H0) asserts that the data shows no trend over time. To determine Mann-Kendall test, the equations (1) are: [16]

$$S = \sum_{i=0}^{n-1} \sum_{j=i+1}^n \text{sign}(x_j - x_i) \quad (1)$$

The number of data points is denoted by n, data values in the time series i are denoted by  $X_i$ , and data values in the time series j ( $j > i$ ) are denoted by  $X_j$ . The sign function is displayed as  $\text{sgn}(2)$ .  $(X_j - X_i)$  [15]

$$\text{sgn}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -0 & \text{if } (X_j - X_i) < 0 \end{cases} \quad (2)$$

The numbers n, q, and  $t_p$  in the following equation represent the number of data points, tied groups, and data values, respectively, in the group [16].

$$\text{VAR}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p-5)] \quad (3)$$

When the sample size n is greater than 30, the standard normal test statistic ZS is computed as follows (3) [15]

$$Q_i = \frac{x_j - x_k}{j - k} \quad (4)$$

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

Positive  $Z_s$  (4,5) values represent growing patterns, whereas negative  $Z_s$  values represent declining trends. At the  $\alpha$  significance level, the trend of rainfall was examined. If  $|Z_s| > |Z_{1-\alpha/2}|$ , a strong trend in the rainfall is seen [15]. Here,  $P=\alpha/2$  is computed using the conventional normal distribution, and the associated value  $Z(1-\alpha/2)$  is used to indicate this. There were five distinct test significance thresholds used:  $\alpha=0.001$ ,  $\alpha=0.01$ ,  $\alpha=0.05$ ,  $\alpha=1$ , and  $\alpha>1$  [16], [15]

### 2.2.2 Sen's Slope – Significance of Trend

Sen's Slope is a non-parametric method for estimating the volume of meteorological time series data. Equation (6) is used to present a linear trend model that Sen's Slope employs [15], [17]:

$$f(t) = Q_t + B \quad (6)$$

The slope is denoted as  $Q_t$  and the constant as  $B$  in the equation above. Initially, the slope of each pair of data values that must be computed in order to get the slope estimate  $Q_t$  [17]

$$Q_t = \frac{x_j - x_i}{j - i} \quad (7)$$

where the data values at time  $j$  and  $i(j>i)$  are denoted by the variables  $x_j$  and  $x_i$ , respectively. Sen's estimator of slope is the median of these  $N$  values of  $T_i$  [16]. Sen's estimator is calculated as  $Q_{med}=T(N+1)/2$  in the case of an odd number of  $N$ , and as  $Q_{med}=[T(N/2)+T(N+2)/2]/2$  in the case of an even number of  $N$ . Ultimately,  $Q_{med}$  is calculated using a two-sided test with a  $100(1-\alpha)\%$  confidence interval. A non-parametric test can then be used to determine the true slope. In the time series, an upward or increasing trend is indicated by a positive value of  $Q_i$ , and a downward or declining trend is shown by a negative value [16].

[16].

## 3. RESULTS AND DISCUSSION

### 3.1 Spatial Rainfall Distribution

Long-term monthly, seasonal, and annual trend studies were examined using spatial analysis, a sort of geographical inquiry, on monthly rainfall data from 1958 to 2020 [18]. The four seasons recognized by the Indian Metrological Department are winter (January to February), summer (March to May), monsoon (rainy) season (June to September), and post-monsoon (October to December), with minor local variations [19].

#### 3.1.1 Annual Distribution of Rainfall

Karnataka's annual precipitation ranges significantly from 945.47 mm to 1857.81 mm, with an average of 1299.14 mm and a standard deviation of 211.22 mm, according to an examination of rainfall data collected between 1958 and 2020. In 2012, the region experienced the lowest recorded annual rainfall of 945.47 mm (Figure 2, 3).

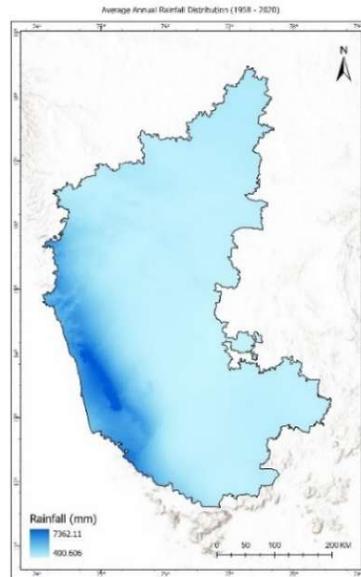


Figure 2 Average Annual Rainfall (1958-2020)

This can be ascribed to factors including weak monsoon activity and possible El Niño conditions, which frequently result in insufficient rainfall [20]. In contrast, a strong monsoon season that was likely driven by La Niña conditions, which generally increase monsoon rainfall, could be linked to the greatest rainfall ever recorded in 1961, which came to 1857.81 mm. Even with this large variation, annual precipitation does not show

a statistically significant trend, suggesting that a variety of causes contribute to the fluctuation from year to year rather than a distinct long-term increase or decrease [21]. partially responsible for this heterogeneity are geographic variables. Because of the Western Ghats, a prominent mountain range, rainfall is orographic, with larger amounts on the windward side and smaller amounts on the leeward side [22].

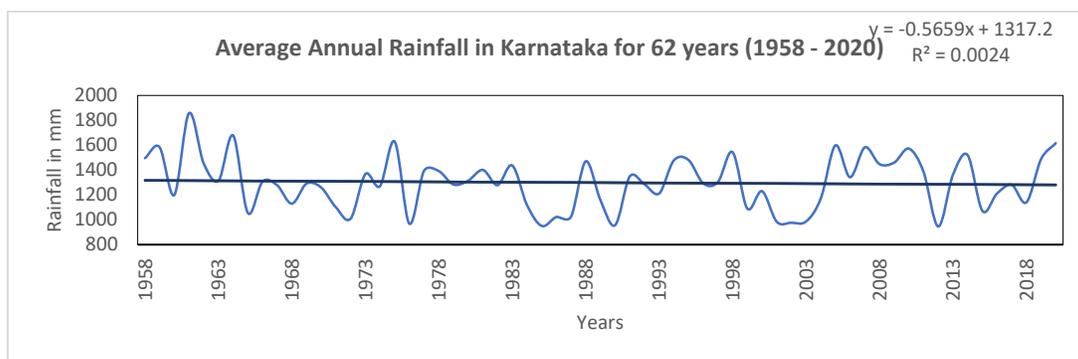


Figure 3: Graphical representation of annual average rainfall in Karnataka

## 3.2 Seasonal Analysis of Rainfall

### 3.2.1 The Winter Season

The winter season in Karnataka provides only 0.25 percent of the total annual rainfall, according to an analysis of statistics on winter rainfall from 1958 to 2020 (Fig.4,8). This means that the season is essentially precipitation-free. When considering the state as a whole, southern Karnataka has had comparatively greater winter rainfall. Some years had marginally higher winter rainfall than others: 1984, 1978, 1979, 1968, and 2008 with 11.44 mm, 11.63 mm, 12.44 mm, 15.13

mm, and 15.47 mm, respectively. But there was no precipitation in 1973 or 1974, while the remaining years saw winter precipitation of less than 10 mm. Due to the region's meteorological conditions, which mostly affect southern India, the Northeast Monsoon has a negligible impact in Karnataka, this minimal winter rainfall can be explained. The majority of the yearly rainfall is caused by the powerful Southwest Monsoon, which runs from June to September, making winters extremely dry [23].

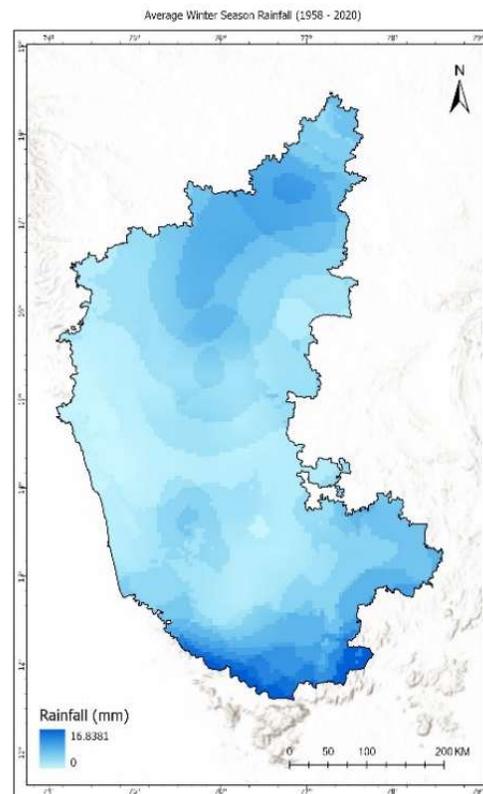


Figure 4 Average Winter Rainfall (1958-2020)

### 3.2.2 The Summer Season

Geographic variations and distinct seasonal patterns are revealed by analyzing rainfall data in Karnataka from 1958 to 2020 (Fig.5,9). The summer season exhibits a strong seasonal pattern in precipitation, accounting for a mere 9.77 percent of the yearly rainfall. Between these extremes were the records for summer rainfall in 1961, which was the greatest at 253.90 mm, and 1983, which was the lowest, with other years' figures falling in between. The limited summer rainfall in Karnataka is caused by the monsoonal climate of the region, where the majority of the annual precipitation occurs during the Southwest Monsoon season (June to September) [24]. Due to the severe heat causing rapid water loss from soil and vegetation, summertime evapotranspiration

increases the already existing water scarcity by further lowering the amount of available moisture [25]. The Western Ghats, which cause orographic rainfall, are the main geographical factor responsible for Karnataka's highest rainfall in the southwestern regions. Because of the Ghats' natural barrier, which causes moist air from the Arabian Sea to rise and cool, heavy rainfall falls on the windward side of the mountain range [26][27]. Conversely, Karnataka's leeward side and other regions receive much less rainfall, which adds to the lopsided spatial distribution seen for the past 62-year. The extremes of the annual rainfall—1857.81 mm in 1961 and 945.47 mm in 2012 further highlight the unpredictability caused by topographical factors and monsoon processes.

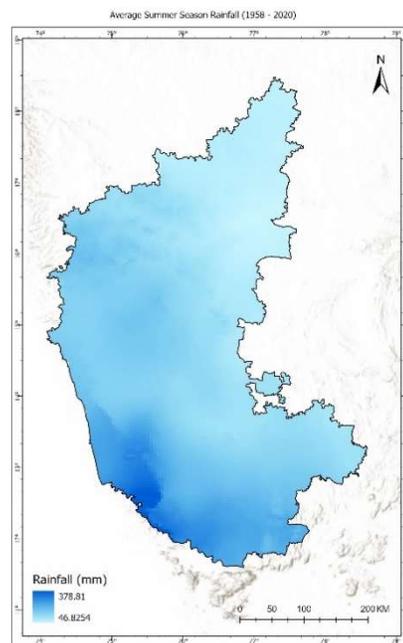
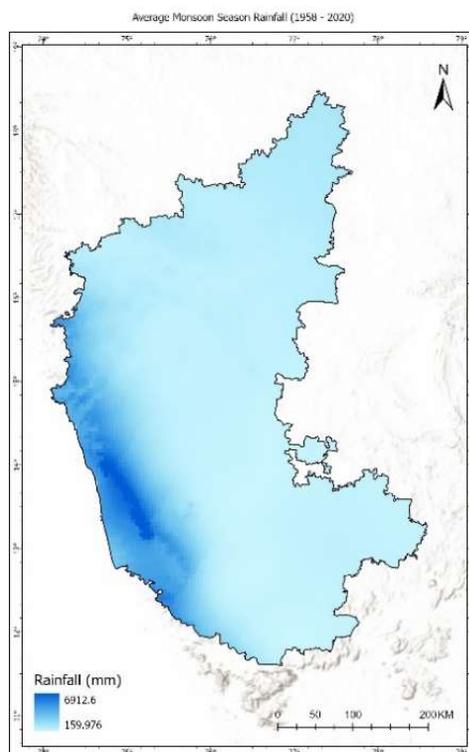


Figure 5: Average Summer Rainfall (1958-2020)

### 3.2.3 The Monsoon Season

The monsoon season contributes the most to the state's annual precipitation, making up 75.56 percent of the total, according to an examination of monsoon rainfall data in Karnataka from 1958 to 2020 (**Figure 6, 10**). Rainfall during this season is mostly focused in the Western Ghats region, where orographic influences are important in augmenting precipitation [24]. In 1961, the maximum recorded monsoon rainfall was 1403.91 mm, while in 2002, the minimum recorded amount was 602.29 mm. During the monsoon season, rainfall is distributed as follows: Of the entire

monsoon rainfall, 19.37 percent falls in June, 38.50 percent in July, 24.52% in August, and 17.58 percent in September. The state receives very little rainfall in the non-monsoon months, especially in the winter and summer, with the winter providing only 0.25 percent and the summer 9.77 percent of the yearly total. In addition to significantly increasing water availability during the monsoon months, this high concentration of rainfall causes uneven annual rainfall distribution, which in turn causes water shortages during non-rainy periods (Meshram *et al.*, 2017).

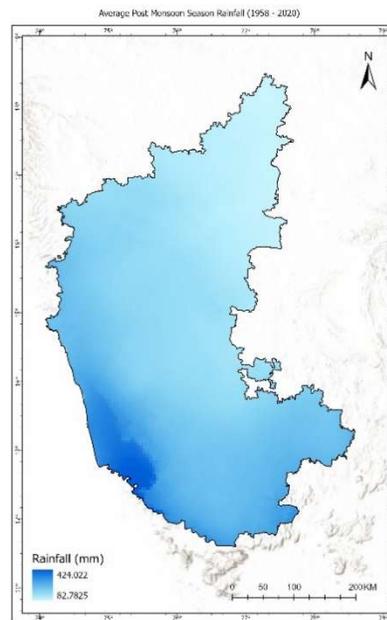


**Figure 6: Average Monsoon Rainfall (1958-2020)**

### 3.2.4 The Post Monsoon Season

The post-monsoon season, which accounts for 14.43% of the yearly rainfall in Karnataka from 1958 to 2020, is critical for agricultural activity in the Indian peninsula (**Figure 7, 11**). After the main rainy season, the post-monsoon period helps to maintain water levels until the following monsoon and supplies essential moisture for some crops [28]. The post-monsoon rainfall in the southern regions of Karnataka ranges from medium to maximum;

the highest reported amount was 334.35 mm in 2019 and the lowest was 65.2 mm in 1988. The other years' rainfall totals fall within this range, suggesting that regional climate conditions have an impact on variability. The inter-annual variability of the monsoon and the existence or absence of cyclonic disturbances have an impact on the variability in post-monsoon rainfall, as seen by the highest in 2019 and the lowest in 1988 [29].



**Figure 7: Average Post-Monsoon Rainfall (1958-2020)**

The state of Karnataka receives the most rainfall during the monsoon season, which runs from June to September (75.6%), and the post-monsoon season (14.37%), which runs from October to December. The winter season (0.25%), which runs from January to February, receives the least amount of rainfall,

while the summer season (9.73%), which runs from March to May, receives the third highest. The heatmap (**Figure 12**) shows the monthly mean rainfall in the state of Karnataka from 1958 to 2020. The blue strips show the monthly mean rainfall; the higher the rainfall, the darker the shade; the lower the rainfall, the

lighter the shade. The first four months (January, February, March, and April) and the final two months (November, December) are when the drier weather is most prevalent. The color grade, which shows irregular and uncommon rainfall within the study area, reveals the recurring dryness inside the research area. The region's copious rainfall between June and December significantly contributes to both agricultural productivity and its vast biodiversity of flora and wildlife. The state's agriculture economy depends on this pattern of precipitation, which also guarantees the availability of water for home and industrial usage [30]. The heavy

concentration of rain in a short period of time presents difficulties, though. The state is more vulnerable to flooding, which raises the danger of crop destruction, soil erosion, and deteriorating infrastructure [31]. In addition, the dry weather in January through April and November through December makes water scarcity problems worse, which affects drinking water supply and agriculture. In order to ensure sustainable development and resilience against climatic variability, this bimodal distribution of rainfall calls for effective water management methods to limit the negative effects of both excessive rainfall and extended dry periods [32].

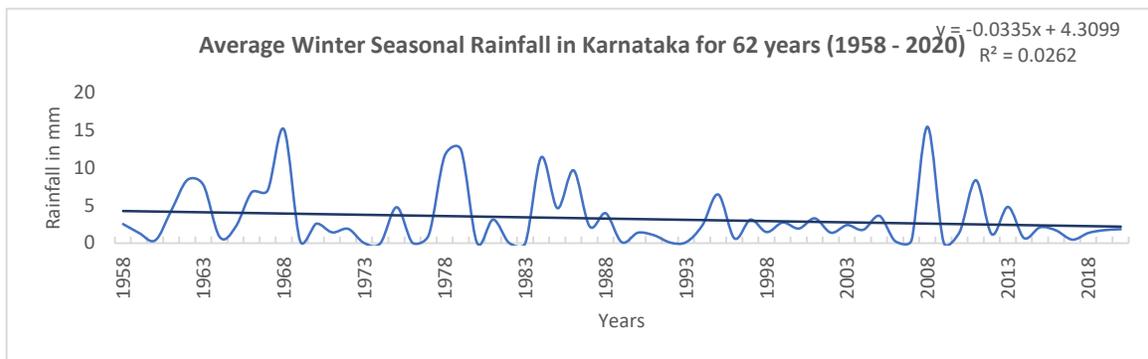


Figure 8: Graphical representation of average summer rainfall in Karnataka

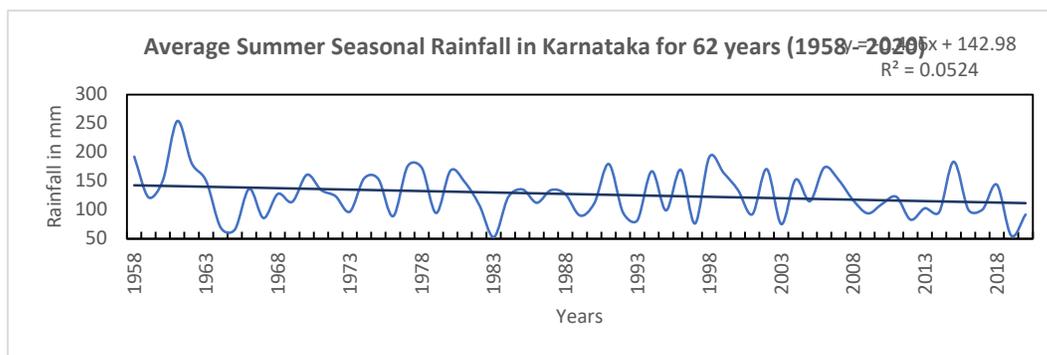


Figure 9: Graphical representation of average winter rainfall in Karnataka

### 3.3 Trend Analysis of Rainfall

The findings of the trend analysis using Sen's Slope technique and the Mann-Kendall trend test are covered in this section (**Table 1**). Every test was taken into consideration at the

5% significance level. Analyzing various time series data has shown that the trend for both temperature and rainfall is either declining or increasing [33].

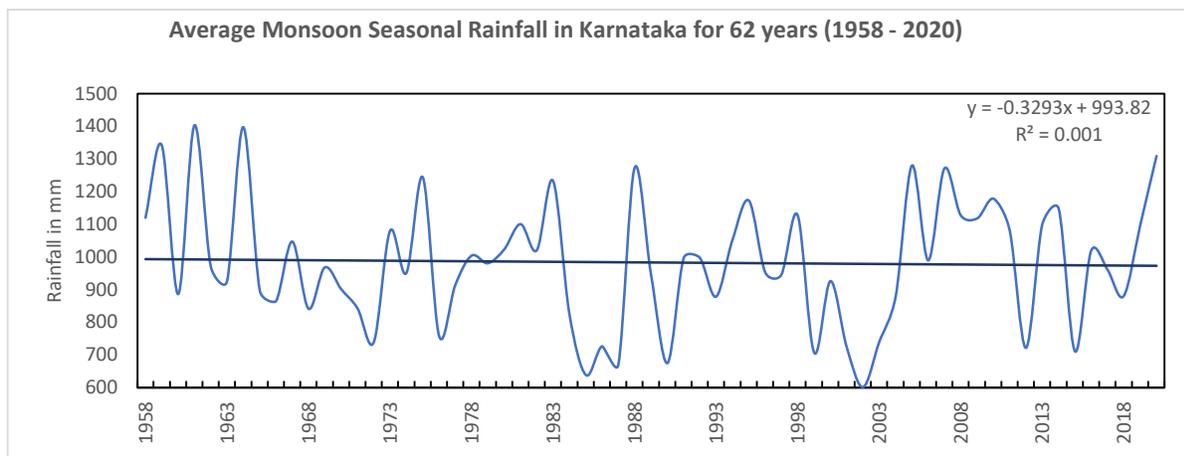


Figure 10: Graphical representation of average monsoon rainfall in Karnataka

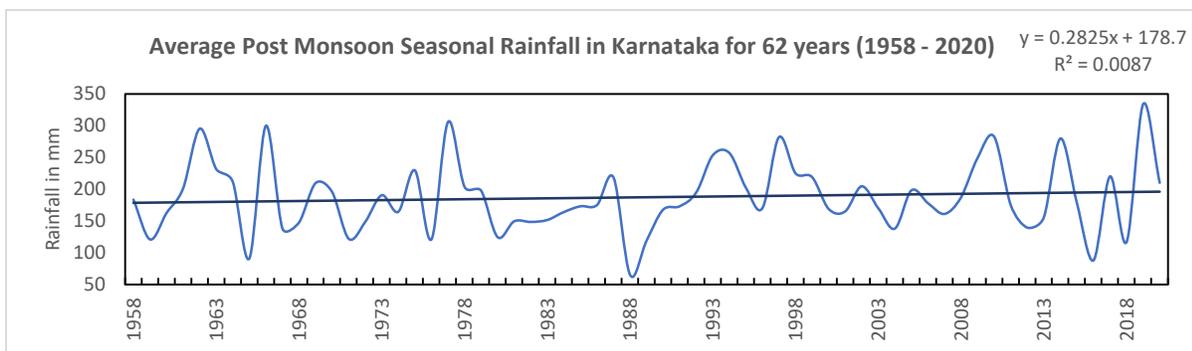


Figure 11: Graphical representation of average post-monsoon rainfall in Karnataka

Table 1: District-level analysis of Sen's Slope, P value, and Z score of Rainfall for Annual, Summer, Monsoon, Post Monsoon, and Winter seasons in Karnataka

Districts	Annual			Winter			Summer			Monsoon			Post Monsoon		
	S_SL	P_V	Z_S	S_SL	P_V	Z_S	S_SL	P_V	Z_S	S_SL	P_V	Z_S	S_SL	P_V	Z_S
Bagalkot	-1.02	0.32	0.98	0.00	0.75	0.32	-0.95	0.00	3.00	0.17	0.82	0.23	0.34	0.45	0.75
Ballari	0.70	0.45	0.75	0.00	0.77	0.30	-0.08	0.71	0.37	0.57	0.45	0.75	0.26	0.48	0.71
Belagavi	-5.15	0.03	2.17	0.00	0.75	0.32	-1.41	0.00	3.16	-3.11	0.09	1.70	0.31	0.61	0.51
Bengaluru (Rural)	1.66	0.10	1.63	0.00	0.68	0.41	0.10	0.73	0.34	1.02	0.10	1.66	0.13	0.73	0.34
Bengaluru (Urban)	1.62	0.21	1.26	-0.01	0.70	0.38	0.15	0.65	0.45	1.11	0.14	1.46	0.06	0.87	0.17
Bidar	0.40	0.77	0.30	0.00	0.96	0.05	-0.17	0.36	0.92	0.66	0.62	0.50	0.22	0.43	0.78
Chamarajanagara	0.35	0.76	0.31	0.00	0.91	0.11	-0.36	0.41	0.83	0.39	0.46	0.74	0.12	0.46	0.15
Chikkaballapura	1.39	0.11	1.59	0.00	0.76	0.30	0.13	0.59	0.55	0.95	0.10	1.65	0.19	0.70	0.38
Chikkamagaluru	1.53	0.71	0.37	0.00	0.99	0.01	-0.44	0.32	0.98	1.93	0.51	0.65	0.34	0.58	0.56
Chitradurga	0.42	0.44	0.77	0.00	0.87	0.16	-0.18	0.51	0.65	0.36	0.39	0.85	0.20	0.56	0.58
Dakshina Kannada	4.68	0.43	0.78	0.00	0.94	0.08	-0.53	0.53	0.63	4.71	0.43	0.79	0.93	0.31	1.01
Davanagere	-0.02	0.99	0.01	0.00	0.89	0.14	-0.36	0.20	1.27	0.15	0.74	0.33	0.14	0.75	0.32
Dharwad	-2.28	0.12	1.55	0.00	0.81	0.24	-1.20	0.01	2.78	-1.08	0.36	0.91	0.03	0.92	0.09
Gadag	-0.63	0.48	0.71	0.00	1.00	0.01	-0.88	0.01	2.56	0.24	0.79	0.26	0.16	0.78	0.28
Hassan	0.92	0.56	0.58	0.00	0.90	0.13	-0.29	0.46	0.74	1.44	0.31	1.02	0.34	0.58	0.56
Haveri	-1.33	0.24	1.19	0.00	0.80	0.26	-0.79	0.03	2.11	-0.92	0.34	0.95	0.06	0.90	0.13
Kalburgi	0.62	0.70	0.38	0.00	0.75	0.32	-0.28	0.27	1.10	0.74	0.59	0.53	0.31	0.38	0.88
Kodagu	3.92	0.39	0.87	-0.01	0.79	0.27	-0.10	0.89	0.14	4.14	0.30	1.04	0.54	0.44	0.77
Kolar	1.07	0.22	1.23	0.00	0.71	0.37	0.18	0.45	0.76	0.97	0.12	1.54	0.26	0.59	0.53
Koppal	0.05	0.94	0.07	0.00	0.90	0.12	-0.48	0.10	1.65	0.48	0.49	0.69	0.11	0.75	0.32
Mandya	0.45	0.64	0.46	-0.01	0.67	0.43	-0.12	0.73	0.34	0.48	0.37	0.89	0.08	0.83	0.21

Mysuru	0.76	0.58	0.56	-0.01	0.72	0.36	-0.24	0.59	0.55	0.83	0.29	1.07	0.40	0.48	0.71
Raichur	0.71	0.43	0.30	0.00	0.80	0.05	-0.16	0.50	0.92	0.59	0.51	0.50	0.26	0.45	0.78
Ramanagara	1.03	0.35	0.94	-0.01	0.78	0.27	0.10	0.75	0.32	0.81	0.20	1.29	0.00	0.99	0.01
Shivamogga	-1.95	0.61	0.61	0.00	0.89	0.89	-0.61	0.15	0.15	-1.91	0.64	0.64	0.34	0.57	0.57
Tumakuru	0.78	0.30	1.03	0.00	0.83	0.22	-0.01	0.96	0.05	0.63	0.24	1.19	0.19	0.64	0.47
Udupi	1.82	0.82	0.23	0.00	0.44	0.78	-0.72	0.31	1.01	1.38	0.88	0.15	0.59	0.45	0.76
Uttara Kannada	-8.29	0.10	1.63	0.00	0.80	0.26	-1.02	0.03	2.16	-7.17	0.16	1.40	0.10	0.92	0.09
Vijayanagara	0.19	0.77	0.30	0.00	0.80	0.26	-0.33	0.19	1.30	0.41	0.55	0.60	0.12	0.74	0.33
Vijayapura	-0.29	0.77	0.30	0.00	0.66	0.44	-0.71	0.01	2.44	0.59	0.58	0.56	0.31	0.48	0.71
Yadgir	0.81	0.57	0.57	0.00	0.77	0.30	-0.20	0.39	0.87	0.71	0.46	0.74	0.30	0.40	0.84

### 3.3.1 Annual trend analysis

Deforestation, changes in land use, and variations in the monsoon patterns of the Western Ghats could be occurring in Uttar Kannada, which exhibits a decreasing trend with a Sen slope of -8.29. On the other hand, Dakshina Kannada may benefit from more variable weather patterns, more vegetation, and better watershed management techniques due to its growing trend and Sen slope of 4.68 [34]. The notable patterns in precipitation observed in Karnataka over the last six decades in districts such as Belgavi (0.030) and Davanagere (0.991) can be ascribed to a multitude (P value) of natural and man-made variables. Differential rainfall patterns result from the state's varied geography, which

includes the Deccan Plateau and Western Ghats, interacting with monsoonal changes [35]. A time series' Z score can be used to identify patterns within it. Belgavi has a score of -2.17, whereas Bengaluru Rural has the highest score of 1.625, which indicates a trend change in favor of the positive. The statistical validation shows that Karnataka's rainfall trends have increased statistically significantly during the preceding 62 years, with a confidence level of 3.78%. This high degree of certainty highlights how strong the changes have been, which are probably the result of anthropogenic effects and climate variability changing local precipitation patterns [36].

### 3.3.2 Winter trend analysis:

Numerous variables can be contributed to the observed Sen slope of -0.01 in Mysuru and 0.00 in Ballari, which indicates an increasing tendency in rainfall during the previous 62 years. The minor negative trend observed in Mysuru could be attributed to the impact of deforestation, land use changes, and urbanization on local microclimates. On the other hand, regional climate stability and regular farming methods may have an impact on Ballari's steady trend [37]. Over the previous 62 years, Karnataka has seen a statistically significant rise in winter rainfall, as shown by the positive significance (P value) of 0.438 in Udupi and 0.995 in Gadag. While Gadag's trend indicates changes in atmospheric circulation and land-use practices, Udupi's coastline topography makes it more susceptible to changes in monsoonal and post-monsoonal rainfall patterns [38]. Based on 62 years of data, Karnataka's winter rainfall trends have increased statistically, as evidenced by the Z scores of -0.44 in Vijayapura and 0.891 in Shivamogga, supported by a 55.23% confidence level. The negative Z score for Vijayapura indicates a downward tendency, which may be impacted by regional changes in land use and agricultural activities that alter precipitation patterns. On the other hand, Shivamogga's positive Z score is indicative of advantageous

geographic features, including its closeness to the Western Ghats, which enhance orographic rainfall and contribute to higher winter precipitation [39].

### 3.3.3 Summer trend analysis:

The Sen slopes of -1.41 in Belgavi and 0.18 in Kolar, which show a notable increase in the patterns of rainfall in Karnataka during the previous 62 years, can be ascribed to a number of regional and human variables. The deforestation, increased agricultural production, and changes in watershed management that impact regional hydrology could be the cause of Belgavi's downward trend. On the other hand, regional climate changes that increase rainfall distribution and reforestation activities could have an impact on Kolar's growing tendency [40]. P values of 0.002 in Belagavi and 0.962 in Tumakuru show that Karnataka's winter rainfall trends have significantly increased during the previous 62 years. Changes in farming techniques and better water management are probably what have contributed to Tumakuru's increase, whereas regional climate fluctuations and the effects of deforestation may be the driving forces behind Belagavi's trend [36]. In Karnataka, summer rainfall trends have significantly increased during the previous 62 years, as indicated by the Z scores of -3.16 in Belagavi and 0.759 in

Kolar, with a confidence level of 91.46%. Belagavi's significantly negative  $Z$  score indicates a considerable decline in summer rainfall, which could be brought on by changes in the local climate and human activity altering local precipitation patterns. On the other hand, Kolar's positive  $Z$  score indicates elements that contribute to more summer precipitation, such as enhanced agricultural techniques and regional climate variability [41].

#### 3.3.4 Monsoon Trend Analysis:

There are specific geographical and human causes to blame for the Sen slopes of -3.11 in Belgavi and 0.97 in Kolar, which show different trends in rainfall over the last 62 years in Karnataka. Belgavi may be experiencing a major decline due to land use changes that upset local hydrological cycles, deforestation, and intensified agriculture. Conversely, the upward trend observed in Kolar is probably due to effective reforestation initiatives, better water management strategies, and regional climate variables that promote increased precipitation [42]. The  $P$  values of 0.877 in Udipi and 0.090 in Belagavi show that the patterns of monsoon rainfall in Karnataka during the previous 62 years have been positively significant. While Udipi's coastline location likely boosts its responsiveness to monsoonal swings and

consistent precipitation patterns, Belagavi's trend may be caused by regional climate changes and variations in monsoon strength [43]. In Karnataka, the monsoon rainfall trends over the previous 62 years appear to have significantly improved, as indicated by the  $Z$  scores of -1.70 in Belgavi and 1.661 in Bengaluru Rural, with a confidence level of 14.12%. Although Bengaluru Rural's high  $Z$  score can be explained by advantageous local geographic characteristics or agricultural techniques that increase monsoon precipitation, Belgavi's negative  $Z$  score might point to regional climate variability or land-use changes negatively impacting monsoonal patterns [44].

#### 3.3.5 Post Monsoon Trend Analysis

The Sen slopes of 0.93 in Dakshina Kannada and 0.00 in Ramnagara, which show an increase in rainfall during the previous 62 years, can be ascribed to different land-use patterns and regional climate variations. Ramnagara's steady trend indicates that local hydrological conditions have not changed much, while Dakshina Kannada's notable increase could be the consequence of improved vegetation cover and advantageous monsoonal patterns [45].  $P$  values of 0.991 in Ramnagara and 0.313 in Dakshina Kannada show that post-monsoon rainfall trends in Karnataka have significantly increased over

the previous 62 years. The trend in Dakshina Kannada can be explained by the region's coastal location and the impact of retreating monsoon systems, whereas the increase in Ramnagara can be the consequence of more targeted land-use changes and localized climate changes [46]. A positive significant trend in post-monsoon rainfall during the past 62 years in Karnataka is shown by the Z scores of 0.012 in Ramnagara and 1.008 in Dakshina Kannada, with a confidence level of 63.58%. Based on local climate conditions and land-use patterns, Ramnagara's minimal Z score indicates stability in post-monsoon precipitation. As a result of regional monsoonal dynamics and maritime impacts, Dakshina Kannada, on the other hand, may be more susceptible to increased post-monsoon rainfall due to its coastal location and positive Z score [47].

#### 4. CONCLUSION

Analyzing the precipitation trends in Karnataka over the past 62 years reveals significant regional variability due by both geographical and anthropogenic factors. Districts like Belgavi and Kolar, which have different local conditions, show opposing trends. Belgavi has a decrease in rainfall, probably as a result of deforestation and increased agriculture, while Kolar has an increase in rainfall that is attributed to

efficient reforestation and water management techniques[36]. Sen's Slope, P values, and Z scores are used in the statistical analysis to show how intricately land-use changes and regional climate variables interact to influence monsoonal and post-monsoonal rainfall patterns [48].

These results highlight the vital need for sustainable land-use practices and region-specific water management strategies to lessen the negative effects of climatic variability on local hydrological cycles. To improve soil moisture levels and water retention, policymakers should give priority to afforestation, reforestation, and sustainable agriculture methods [49]. In addition, to overcome precipitation variability and guarantee a steady supply of water for home and agricultural use, strong frameworks for water conservation and management must be established. The study's understanding of long-term rainfall patterns offers a useful starting point for creating climate-adaptive plans that would protect the state's water resources and agricultural output from the effects of continuing climate change [50].

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