# Statistical and Geospatial Insights into Rainfall Dynamics in Gujarat, India

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***Abstract:*** *Rainfall is a critical water resource, particularly in semi-arid and arid regions, where agricultural productivity and socio-economic development are closely tied to its availability. Assessing rainfall variability and long-term trends is essential for informed water resource management and climate adaptation strategies. This study examines spatio-temporal rainfall variability and trends across Gujarat, India, using 25 years (1999–2024) of IMD gridded data for June to October month. Statistical measures—mean, standard deviation, coefficient of variation—and the non-parametric Mann–Kendall test were applied within a GIS framework to assess patterns and visualize trends. Results indicate pronounced spatial heterogeneity: southern districts (Valsad, Navsari, Dang) receive significantly higher rainfall range between 1354mm to 2298mm, while Kutch and northern Gujarat remain drier with rainfall range between 400mm to 700mm and high variability (CV up to 65%). Trend analysis reveals increasing rainfall in northern and southern regions, contrasted by declining trends in Dang and Dahod (p value 0.034).*

***Keywords:*** *Rainfall Variability, Coefficient of Variability, Sustainability, Trend analysis, Mann-Kendall, GIS.*

## 1. INTRODUCTION

The advancement of developing cities or state led to situations where region is grappling with increasing population industrial activity, drought prone regions. Water is often considered economic good when there is scarce supply, its availability is threatened by pollution and thus it commands efficient and sustainable use. Water being important phase of hydrological cycle which directly gets affected by climate change and it is crucial component for earth's climate. Rainfall plays a vital role not only in shaping weather and climate but also in supporting the economic environment of a region. Additionally, it contributes to physical sustainability by sustaining the hydrological cycle and water resources. Rainfall variability has been observed globally across different spatial scales and timeframes, ranging from daily to decadal and even longer-term fluctuations (Aravena & Luckman, 2009). Additionally, spatio-temporal changes in precipitation significantly impact a region's water reserves (Chahine, 1992; Islam et al., 2012). Precipitation is the key driving force in the Earth's hydrological system, and variations in its pattern can directly influence water resources. As a result, numerous researchers worldwide have focused on studying rainfall distribution, variability, and trends (Sun. N et.al. 2025 ,Zeleke et al., 2024).

Weather- and climate-related extreme events present numerous challenges to various assets within a river basin (Deka et al., 2013). Shifts in precipitation patterns have a profound impact on flood and drought hazard management, as well as water resources, from local to regional scales (Pawar, 2022). In recent years, underdeveloped and developing countries with agrarian societies have been severely impacted by the decline in both the quantity and distribution of precipitation. Additionally, the rapid growth of the global population and accelerated economic development have intensified water shortages, making it a critical global issue (Vorosmarty et al., 2000). From this perspective, rivers serve as a primary water source, highlighting the need for micro-level studies on spatio-temporal rainfall patterns to ensure sustainable water resource management (Pathare & Pathare, 2020, 2021; Kharake et al., 2021).

Rainfall quantity and distribution play a vital role in city development, agriculture, and habitation, influencing various aspects of economic growth, environmental sustainability, and human well-being. Thus understanding and managing variations in rainfall quantity and distribution is essential for sustainable development, as it directly impacts water availability, agriculture, infrastructure, and human well-being. Balanced and predictable rainfall supports food security, economic growth, and environmental stability, while irregular patterns can lead to droughts, floods, and resource scarcity. Effective water resource management, climate adaptation strategies, and sustainable planning are crucial in mitigating the risks associated with rainfall variability, ensuring resilience against climate change, and securing the livelihoods of communities worldwide.

## 2. STUDY AREA

Gujarat, located in western India, is the country's ninth-largest state by area and fifth largest by population. It shares its borders with Rajasthan to the north, Madhya Pradesh to the east, and Maharashtra to the south, while its western coastline stretches along the Arabian Sea. Gujarat plays a crucial role in India's economy, contributing significantly to sectors such as manufacturing, petrochemicals, agriculture, and tourism. Gujarat faces irregular monsoons, droughts, and water scarcity, particularly in the Kutch and Saurashtra regions. The primary objective of this study is to analyse rainfall distribution, variations, and trends across all districts of Gujarat to support agriculture, irrigation, and water management efforts in the state. All together using the verified Rainfall Data from IMD rather than focussing any predictive rainfall model.

Gujarat is situated between latitudes 20.1°N and 24.7°N and longitudes 68.4°E and 74.4°E, covering an area of approximately 196,024 km². It comprises diverse physiographic regions, including the Kutch region, Saurashtra plateau, and mainland Gujarat. The state primarily experiences monsoonal rainfall, with the majority of precipitation occurring between June and September. It shares its borders with Rajasthan to the north, Madhya Pradesh to the east, and Maharashtra to the south, while its western and southwestern boundaries are defined by the Arabian Sea. Gujarat also shares an international border with Pakistan to the northwest, separated by the Great Rann of Kutch. States have roughly 2.63% of the country's freshwater resources, whereas 4.86% of the country's population.

The Gujarat State consists of 33 districts. Gujarat has a tropical monsoon climate with variations based on geography: (a)Arid and Semi-Arid Regions – Kutch and North Gujarat receive low and erratic rainfall. (b) Humid and Sub-Humid Zones – South Gujarat and the coastal belt experience higher rainfall due to the Arabian Sea influence. (c) Annual Rainfall – Varies from 250 mm in Kutch to 2,000 mm in South Gujarat, with monsoon rains between June and September. Gujarat has several important rivers, but most of them are seasonal and rely on monsoon rainfall.

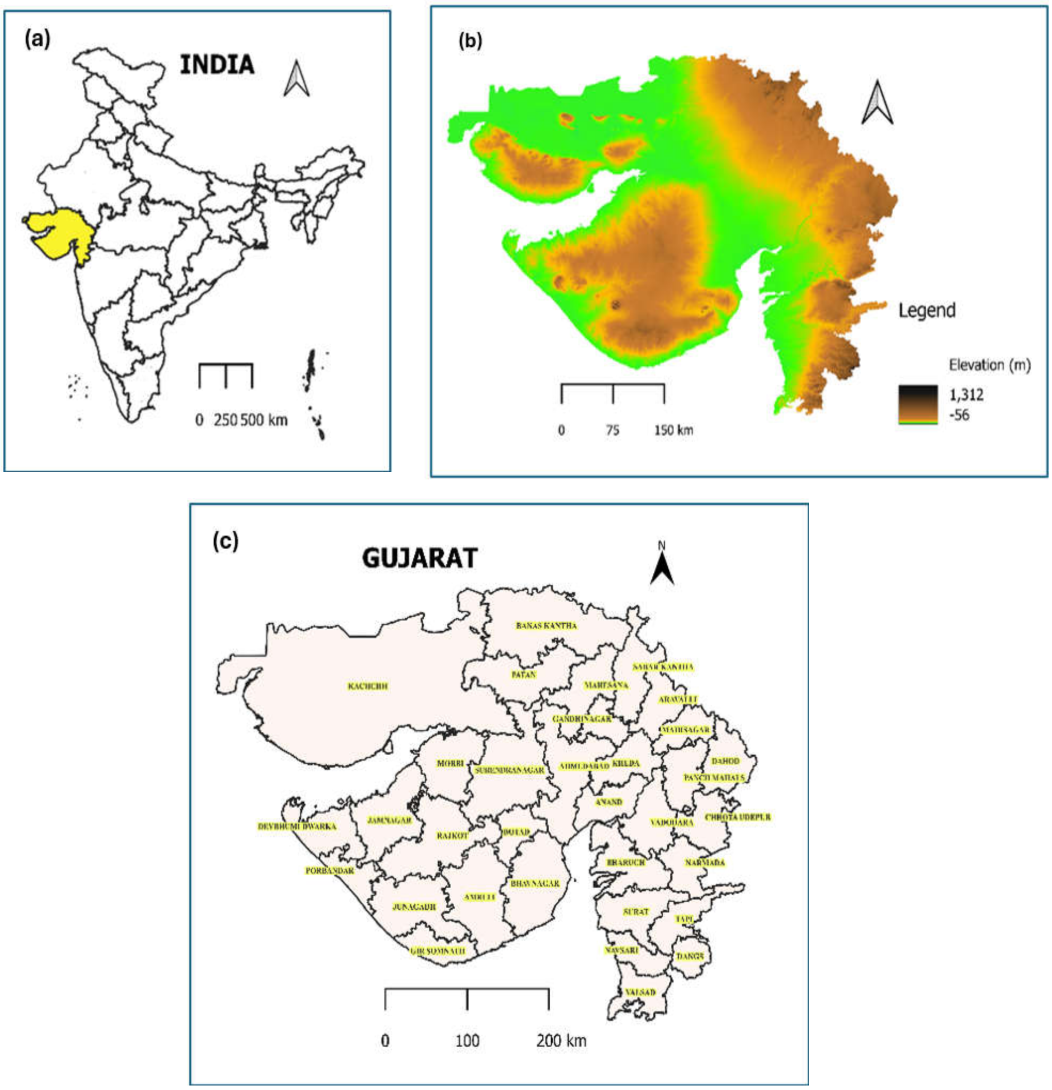


**Figure-1:** *Location Map of the study area: a) Study area location, b) Physiography, c) Districts in Gujarat state*

The major river systems include: (a) Narmada River – One of the most significant rivers, providing irrigation and drinking water through the Sardar Sarovar Dam. (b) Tapi River – Originating from Madhya Pradesh, it supports irrigation and industrial use in South Gujarat. (c) Sabarmati River – Flows through Ahmedabad and has been revitalized with urban riverfront development. (d) Mahi, Damanganga, and Banas Rivers – These contribute to water availability in various regions. The Gujarat state also has numerous smaller rivers and rivulets, but many of them dry up in the non-monsoon months, making groundwater and reservoir storage crucial. However, climate variability, population pressure, and industrial demands necessitate continued innovation in conservation and equitable distribution.

## 3. METHODOLOGY

To analyse the spatial and temporal trends and variability of rainfall across Gujarat, rainfall data was obtained from the High Spatial Resolution (0.25 X 0.25 degree) **Gridded Rainfall Dataset** (Pai et al., 2014) from IMD, New Delhi for a

**25-year period (1999–2024)**. The rainfall data is downscaled for all districts of Gujarat state in QGIS, and the data were exported in tabular form for further statistical analysis. The tabular data were further analysed statistically using Python and Microsoft Excel, Finally, rainfall distribution, correlation coefficients, and Mann-Kendall (MK) trend maps were derived from the obtained results within the GIS environment using Q Gis as shown in Fig 2

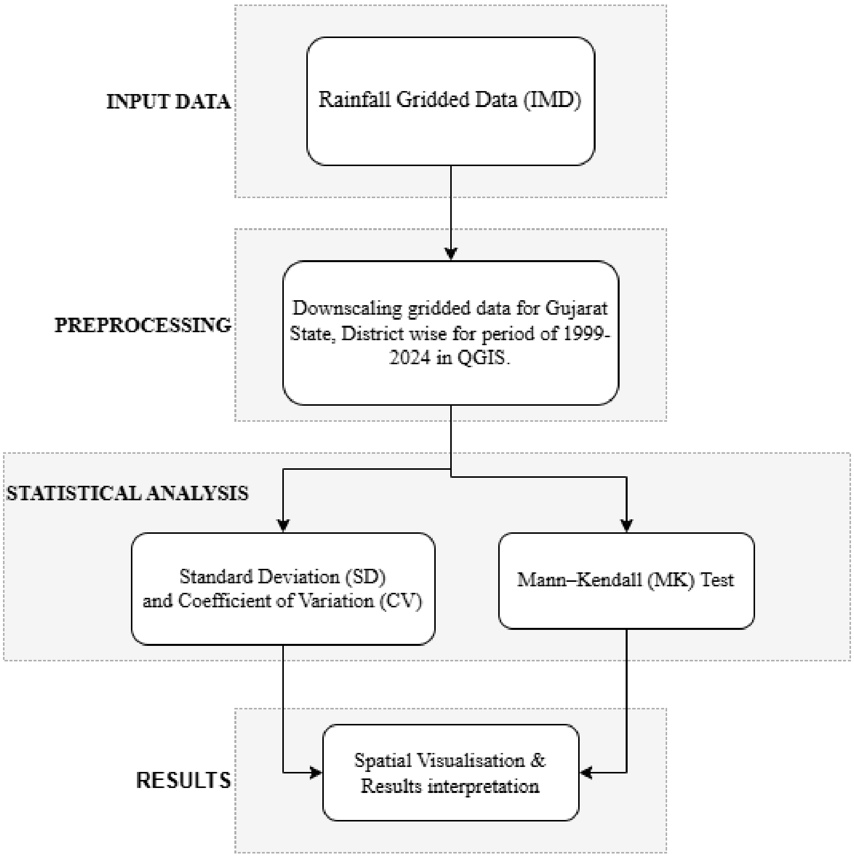


**Figure- 2:** *Methodology flowchart*

Observations indicate that rainfall in Gujarat is predominantly concentrated during the monsoon season (June–October) (NWRWSKD). Therefore, rainfall trends and variability have been examined monthly for both average monthly and Maximum value in Month, with a primary focus on the monsoon months. The rainfall characteristics of the Gujarat were analysed in terms of distribution, variation, and trend using the mean, standard deviation (SD), coefficient of variation (CV), Mann–Kendall (MK) trend test. The corresponding formulas were applied, and the computed results are presented in Tables 1 and 2 for further analysis.
The detailed methodology for assessing rainfall variability and trend analysis is outlined as follows:

### 3.1 Standard Deviation (SD) and Coefficient of Variation (CV):

In this study, the standard deviation (SD) of 25 years of rainfall data was computed using Equation 1 (Aher et al., 2019) and is presented in Table 1.

$$SD = \sqrt{\sum \frac{(x-\bar{x})^2}{n}} \quad \ldots(1)$$

To assess rainfall variability, the coefficient of variation (CV) was computed at both the monthly and seasonal scales for the monsoon period over the selected UGB using Equation 2 (Onyutha, 2021). The results are presented in Table 1.

CV = SD(σ) Mean (μ) ∗ 100

$$CV = \frac{SD(\sigma)}{Mean\ (\mu)} * 100 \quad \ldots(2)$$

The coefficient of variation (CV) values have been categorized based on Hare (1983) into three classes: high variability (CV > 30), moderate variability (20 < CV < 30), and low variability (CV < 20). Additionally, other researchers (Asfaw et al., 2018; Alemu & Bawoke, 2020) have adopted and modified these classifications for variability analysis.

### 3.2 Mann–Kendall (MK) Test

The **Mann–Kendall (MK) test** is a widely used non-parametric method (Mann, 1945; Kendall, 1975) for testing the null hypothesis of no trend against the alternative hypothesis of an increasing or decreasing trend in the time series. It assesses whether a trend is present in a dataset without requiring the data to follow a specific distribution. Prior to applying the Mann–Kendall (MK) trend test to rainfall data, it is essential to assess autocorrelation within the time series to determine the presence of any significant correlation. In this study, serial autocorrelation was evaluated using PAST software, and the results indicate that the rainfall data is not autocorrelated over the specified period. Consequently, the Mann–Kendall (MK) test (Luo et al., 2008) was employed to identify statistically significant trends in rainfall. Accordingly, the monsoon month-wise and seasonal rainfall trends over the Gujarat state were identified using the Mann–Kendall (MK) test statistic (SS), computed based on Equations 3, 4, and 5 (Sharma & Singh, 2017; Asfaw et al., 2018). The results are presented in Table 2.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \quad \ldots(3)$$

where n is the number of data; $X_k$ and $X_j$ are the data values in the time series; k and j (j > k), respectively; and sgn ($X_j - X_k$ ) is the sign function as:

$$sgn(X_j - X_k) = \begin{Bmatrix} +1 if (X_j - X_k) > 0 \\ 0 if (X_j - X_k) = 0 \\ 1 if (X_j - X_k) < 0 \end{Bmatrix} \ldots.(4)$$

When n ≥ 10, S becomes approximately normal distribution with mean = 0 and variance as follows:

$$\sigma_s^2 = \frac{1}{18}[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)] \ldots.(5)$$

where $t$ refers to the extent of any given tie and $\sum_t$ indicates the summation of all ties. The value of Z is computed by Eq. 6 (Partal and Kahya 2006).

$$Z = \begin{cases} \frac{s-1}{\sigma_s} if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{s+1}{\sigma_s} if\ S < 0 \end{cases} \ldots.(6)$$

where Z is the standard normal variate and positive (negative) values of Z indicate increasing (decreasing) trends. A null hypothesis is rejected when |Z|> Z1 − , and a noteworthy trend occurs in the time series. All the results are tested at α = 0.05 (Z = ± 2.056) and α = 0.10 (Z = ± 1.706) significance level (Pawar 2022).

**Table 1 :** *Summary of the monthly and seasonal rainfall statistics (1999-2024)*

| District | JUNE | | | JULY | | | AUGUST | | | SEPTEMBER | | | OCTOBER | | | Monsoon | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MEAN (mm) | SD(mm) | CV (%) | MEAN (mm) | SD(mm) | CV (%) | MEAN (mm) | SD(mm) | CV (%) | MEAN (mm) | SD(mm) | CV (%) | MEAN (mm) | SD(mm) | CV (%) | MEAN (mm) | SD(mm) | CV (%) |
| Ahmedabad | 98 | 68 | 69 | 278 | 124 | 45 | 230 | 151 | 66 | 134 | 104 | 78 | 14 | 23 | 164 | 784 | 244 | 31 |
| Amreli | 156 | 136 | 88 | 262 | 222 | 85 | 166 | 152 | 92 | 159 | 121 | 76 | 28 | 29 | 105 | 770 | 451 | 59 |
| Anand | 100 | 90 | 110 | 313 | 152 | 205 | 269 | 194 | 139 | 143 | 110 | 130 | 15 | 22 | 69 | 839 | 283 | 34 |
| Aravalli | 85 | 50 | 169 | 316 | 159 | 198 | 283 | 198 | 143 | 149 | 116 | 129 | 15 | 27 | 54 | 848 | 281 | 33 |
| Banaskantha | 61 | 52 | 117 | 253 | 206 | 123 | 193 | 160 | 121 | 107 | 98 | 110 | 15 | 27 | 54 | 630 | 250 | 40 |
| Bharuch | 143 | 138 | 103 | 346 | 170 | 203 | 266 | 190 | 140 | 186 | 128 | 146 | 22 | 26 | 86 | 963 | 322 | 33 |
| Bhavnagar | 125 | 106 | 118 | 223 | 120 | 185 | 164 | 114 | 144 | 141 | 108 | 130 | 19 | 25 | 78 | 671 | 216 | 32 |
| Botad | 121 | 94 | 129 | 220 | 119 | 185 | 188 | 151 | 124 | 140 | 112 | 125 | 21 | 35 | 59 | 689 | 252 | 37 |
| Chotaudepur | 127 | 93 | 137 | 330 | 147 | 224 | 321 | 227 | 141 | 191 | 123 | 155 | 21 | 23 | 90 | 990 | 322 | 32 |
| Dahod | 90 | 54 | 166 | 254 | 102 | 249 | 272 | 187 | 146 | 161 | 102 | 159 | 19 | 23 | 81 | 795 | 266 | 33 |
| Dangs | 180 | 155 | 116 | 484 | 201 | 241 | 403 | 242 | 167 | 235 | 110 | 212 | 53 | 52 | 103 | 1354 | 455 | 34 |
| Dwarka | 104 | 94 | 110 | 288 | 257 | 112 | 239 | 259 | 92 | 153 | 186 | 82 | 15 | 26 | 60 | 799 | 521 | 65 |
| Gandhinagar | 77 | 48 | 158 | 322 | 184 | 175 | 263 | 166 | 158 | 129 | 105 | 123 | 15 | 27 | 57 | 807 | 280 | 35 |
| Gir Somnath | 170 | 100 | 171 | 429 | 334 | 128 | 249 | 250 | 100 | 167 | 150 | 112 | 21 | 26 | 78 | 1036 | 400 | 39 |
| Jamnagar | 102 | 84 | 121 | 255 | 163 | 157 | 228 | 198 | 115 | 147 | 168 | 87 | 18 | 32 | 56 | 749 | 321 | 43 |
| Junagadh | 167 | 112 | 149 | 391 | 282 | 139 | 245 | 226 | 108 | 189 | 170 | 111 | 31 | 39 | 79 | 1023 | 380 | 37 |
| Kutch | 59 | 57 | 102 | 182 | 151 | 120 | 156 | 146 | 107 | 89 | 92 | 96 | 14 | 25 | 54 | 493 | 223 | 45 |
| Kheda | 94 | 67 | 141 | 303 | 150 | 201 | 276 | 187 | 148 | 147 | 112 | 131 | 13 | 23 | 59 | 834 | 266 | 32 |
| Mehsana | 74 | 45 | 163 | 295 | 165 | 179 | 243 | 171 | 142 | 112 | 102 | 110 | 14 | 25 | 55 | 738 | 248 | 34 |
| Mahisagar | 87 | 57 | 153 | 297 | 146 | 204 | 283 | 203 | 139 | 153 | 121 | 126 | 15 | 25 | 59 | 835 | 280 | 34 |
| Morbi | 113 | 91 | 123 | 260 | 218 | 119 | 195 | 185 | 105 | 127 | 121 | 105 | 22 | 35 | 62 | 717 | 417 | 58 |
| Narmada | 177 | 127 | 139 | 430 | 230 | 187 | 360 | 255 | 141 | 236 | 163 | 144 | 27 | 24 | 112 | 1230 | 444 | 36 |
| Navsari | 289 | 268 | 108 | 704 | 302 | 233 | 471 | 271 | 174 | 303 | 183 | 166 | 38 | 39 | 97 | 1805 | 490 | 27 |
| Panchmahal | 106 | 71 | 150 | 301 | 135 | 222 | 305 | 201 | 152 | 154 | 111 | 139 | 18 | 29 | 64 | 885 | 270 | 30 |
| Patan | 66 | 47 | 138 | 241 | 179 | 135 | 207 | 160 | 129 | 98 | 92 | 106 | 14 | 29 | 49 | 626 | 224 | 36 |
| Porbandar | 131 | 97 | 135 | 335 | 265 | 127 | 242 | 232 | 104 | 161 | 174 | 92 | 21 | 35 | 61 | 891 | 407 | 46 |
| Rajkot | 133 | 101 | 132 | 273 | 167 | 164 | 214 | 181 | 118 | 168 | 149 | 113 | 25 | 31 | 79 | 813 | 350 | 43 |
| Sabarkantha | 86 | 51 | 168 | 303 | 163 | 186 | 272 | 191 | 142 | 137 | 117 | 116 | 16 | 29 | 53 | 812 | 261 | 32 |
| Surat | 220 | 184 | 119 | 481 | 199 | 242 | 362 | 255 | 142 | 242 | 151 | 160 | 31 | 34 | 92 | 1337 | 361 | 27 |
| Surendranagar | 99 | 70 | 141 | 237 | 142 | 166 | 188 | 148 | 127 | 120 | 100 | 119 | 15 | 23 | 65 | 658 | 281 | 43 |
| Tapi | 180 | 144 | 125 | 413 | 152 | 272 | 349 | 216 | 162 | 213 | 107 | 199 | 33 | 31 | 105 | 1188 | 360 | 30 |
| Vadodara | 121 | 112 | 108 | 329 | 148 | 222 | 289 | 198 | 146 | 169 | 122 | 139 | 18 | 24 | 79 | 927 | 330 | 36 |
| Valsad | 350 | 276 | 127 | 912 | 393 | 232 | 625 | 327 | 191 | 356 | 218 | 164 | 53 | 44 | 122 | 2298 | 604 | 26 |

**Table 2 :** *Monthly and seasonal rainfall trends over Gujarat State ('p' value , font: Green = Rising Trend, Red= Decreasing Trend, White= No trend)*

| Districts | June | July | August | September | October | Monsoon |
|---|---|---|---|---|---|---|
| Ahmedabad | 0.3780 | 0.6916 | 0.7914 | 0.0641 | 0.4013 | 0.48726 |
| Amreli | 0.4023 | 0.0856 | 0.8948 | 0.1029 | 0.1339 | 0.34588 |
| Anand | 0.2171 | 1.0000 | 0.8948 | 0.0939 | 0.2577 | 0.51469 |
| Aravalli | 0.1718 | 0.5371 | 0.4536 | 0.0308 | 0.5278 | 0.3662 |
| Banaskantha | 0.7914 | 0.6916 | 0.5666 | 0.0473 | 0.7881 | 0.59898 |
| Bharuch | 0.1956 | 0.8955 | 0.6662 | 0.0409 | 0.0684 | 0.39531 |
| Bhavnagar | 0.4275 | 0.4806 | 0.8255 | 0.0856 | 0.2011 | 0.42606 |
| Botad | 0.7914 | 0.3546 | 0.7243 | 0.0707 | 0.8597 | 0.58215 |
| Chotaudepur | 0.2901 | 0.1125 | 0.5968 | 0.0580 | 0.6411 | 0.36171 |
| Dahod | 0.0343 | 0.5666 | 0.5371 | 0.1583 | 0.7382 | 0.42892 |
| Dangs | 0.0308 | 0.5085 | 1.0000 | 0.3546 | 0.2704 | 0.45485 |
| Dwarka | 0.5968 | 0.0473 | 0.5666 | 0.0383 | 0.2996 | 0.33171 |
| Gandhinagar | 0.4275 | 0.8255 | 0.8255 | 0.0093 | 0.2851 | 0.4966 |
| Gir Somnath | 0.3106 | 0.0641 | 0.8948 | 0.0641 | 0.0894 | 0.3066 |
| Jamnagar | 0.9297 | 0.1229 | 0.7914 | 0.1339 | 0.8252 | 0.58262 |
| Junagadh | 0.2901 | 0.0246 | 0.9297 | 0.1125 | 0.0308 | 0.29953 |
| Kutch | 0.5085 | 0.2517 | 0.4023 | 0.0219 | 0.5960 | 0.37807 |
| Kheda | 0.2011 | 0.2517 | 0.6916 | 0.0524 | 0.4529 | 0.35195 |
| Mehsana | 0.2704 | 0.8948 | 0.9648 | 0.0343 | 0.6198 | 0.57884 |
| Mahisagar | 0.2901 | 0.4275 | 0.5085 | 0.0219 | 0.2996 | 0.33149 |
| Morbi | 0.6277 | 0.6593 | 0.4536 | 0.0856 | 1.0000 | 0.58725 |
| Narmada | 0.1125 | 0.0246 | 0.5371 | 0.0017 | 0.1394 | 0.18507 |
| Navsari | 0.0778 | 0.1860 | 0.9297 | 0.0195 | 0.3211 | 0.32884 |
| Panchmahal | 0.1718 | 0.6277 | 0.7914 | 0.0383 | 0.7200 | 0.49184 |
| Patan | 0.6277 | 0.6593 | 0.8600 | 0.0343 | 0.4200 | 0.54229 |
| Porbandar | 0.7576 | 0.0473 | 0.8255 | 0.0383 | 0.8944 | 0.53462 |
| Rajkot | 0.5085 | 0.1583 | 0.6593 | 0.1229 | 0.1860 | 0.349 |
| Sabarkantha | 0.5666 | 0.6916 | 0.6277 | 0.0120 | 0.6294 | 0.52745 |
| Surat | 0.1125 | 0.7243 | 0.9297 | 0.0120 | 0.3657 | 0.45086 |
| Surendranagar | 0.1029 | 0.3321 | 0.8600 | 0.0778 | 0.3660 | 0.36978 |
| Tapi | 0.0219 | 0.1229 | 0.8948 | 0.0308 | 0.5815 | 0.35236 |
| Vadodara | 0.0707 | 0.8600 | 0.7243 | 0.0426 | 0.3848 | 0.4385 |
| Valsad | 0.2901 | 0.0173 | 0.9297 | 0.0343 | 0.3321 | 0.34271 |

# 4. RESULTS AND DISCUSSIONS

## 4.1 Descriptive Statistical Analysis:

The mean maximum monsoon rainfall of the Gujarat state is 2298 mm with SD of 604 mm recorded at Valsad District, whereas the mean minimum rainfall is observed at 493mm (Kutch) and the lowest SD of 216 mm (Bhavnagar). The mean maximum and minimum monsoonal monthly rainfall over Gujarat state ranges between 912 mm (Valsad) and 13mm (Kheda) respectively (Table 1). The spatial distribution of Gujarat state shows that the southeastern part receives highest rainfall than the western, central and northern part (Fig 3). It is due to its **geographical location and proximity to the Western Ghats and the Arabian Sea**. Southern Gujarat is closer to the Arabian Sea, which is the main source of moisture during the Southwest Monsoon (June–October). Moist winds from the sea bring heavy rainfall to this region. The southern part of Gujarat lies nearer to the Western Ghats, which enhances **orographic rainfall** — where moist winds are forced to rise due to the mountains, cooling and condensing to form rain clouds. The southwest monsoon winds hit Southern Gujarat directly, while by the time they reach Northern Gujarat, they have already lost some of their moisture, resulting in comparatively less rainfall. Southern Gujarat lies in a more **humid tropical zone**, while Northern Gujarat falls in a **semi-arid to arid zone**, making it naturally drier.

The distribution of rainfall in the peak monsoon month i.e. July & August remarked that Valsad, Navsari, Dangs, Surat, Narmada, Gir-Somnath, Tapi, Junagadh, Bharuch, Porbandar, Vadodara and Chotaudepur districts received significantly higher rainfall, as the

Southwest Monsoon advances. The distribution of rainfall in Kutch, Botad, Bhavnagar, Surendranagar and Patan were significantly Low. The overall monsoon season rainfall indicates the Saurashtra Peninsula, Kutch and northern Gujarat receives significantly less rainfall compared to south and Southwest Gujarat. The study also encounters that the rainfall pattern decreases in the direction of northwest of Gujarat. (Fig.3 a-f).

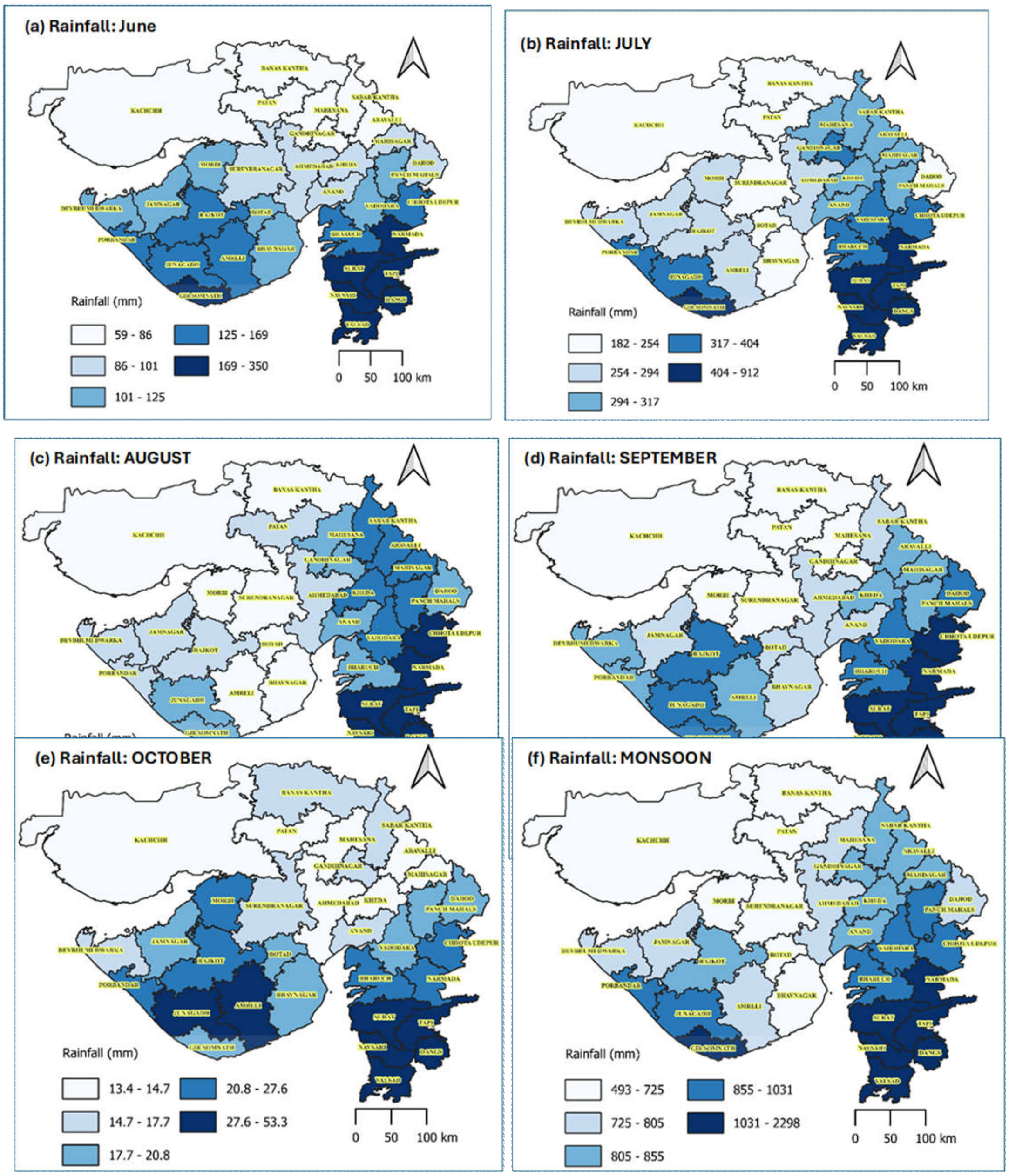


**Figure. 3** *Monthly and seasonal rainfall distribution over the Gujarat State*

### 4.2 Analysis of Rainfall Variability:

The variability of monsoon rainfall is a significant climate change indicator that impacts agricultural growth and yield in the Gujarat State. According to (Biswas et.al. 2019), the CV is an important statistical metric for the comprehending rainfall fluctuations in agrarian cultures, where rainfall volatility has negative fluctuations in agrarian cultures, where rainfall volatility has a negative impact on crop production and crop type. The investigation of Rainfall variability at district level is therefore crucial component of the current study, The spatial scale of monsoon and monthly rainfall variability is shown in fig.4 (a-f). In the month of June, Gir Somnath district has the highest rainfall variability (170%) followed by districts such as Aravalli (168%) , Sabarkantha

(167%), Dahod (165%), Mehsana (162%) and Gandhinagar (158%) (Fig 4a, table 1). In July the rainfall variability ranges from 271% (Tapi) to 45% (Ahmedabad) (Fig 4b, Table 1). In August rainfall variability ranges from 191% (Valsad) to 66% (Ahmedabad) (Fig 4c, Table 1). I September the rainfall variability ranges from 212% (Dangs) to 76% (Amreli) (Fig 4d, Table 1). The October month shows rainfall variability range from 164% (Ahmedabad) to 49% (Patan) (Fig 4e, Table 1). The Gujarat state shows varying percentages of monsoon rainfall, ranging from 65% in Dwarka district to 26% in Valsad District (Fig 4 f, Table 1). It demonstrates medium to high rainfall variability is present in the Gujarat State across the districts. According to Conrad (1941). There is negative correlation between CV and rainfall circumstances, meaning that more rainfall variation results in greater rainfall fluctuation and vice versa.

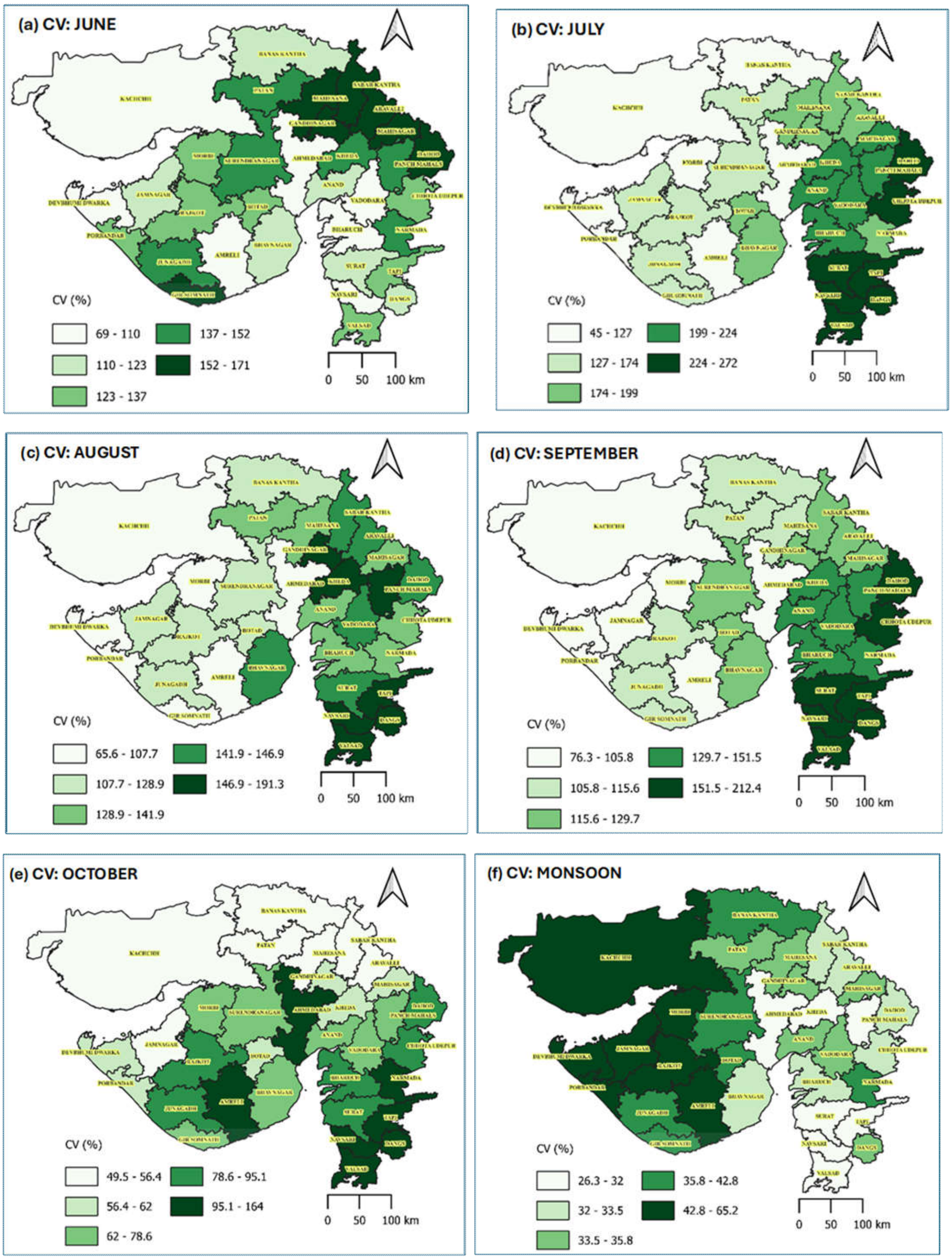


**Figure -4:** *Monthly and seasonal rainfall variability over Gujarat state.*

### 4.3 Analysis of Rainfall trend by MK Test:

The MK test has been used to determine the kind of rainfall trend over the Gujarat State for the period of (1999-2024) 25 years. The S- statistics is considered in identifying the trend (Rising Trend (S>0), Decreasing Trend (S<0), no trend (S=0) and "p" value is considered to assess how statistically significant the trend is. In general, a significant rising trend is observed in the study area which specifies the increase in rainfall quantity (Table 2). The spatial distribution of Gujarat, monsoon months and seasonal rainfall trend is shown in table 2 and figure 5 a-f. For the month of June, district such as Dahod, Dang and Tapi showed decreasing rainfall trend (Table 2 and Fig. 5a). For the month of July, there is seen increasing rainfall trend in the Narmada, Dwarka, Porbandar, Junagadh and Valsad district (Table 2 and Fig. 5b). For the month of August there appears no significant changes in rainfall trend (Table 2 and Fig 5c). For the month of September there is significant rising trend of rainfall observed in Kutch, Patan, Banaskantha, Mahesana Gandhinagar, Sabarkantha, Aravalli, Mahisagar, Panchmahal, Vadodara, Narmada, Surat, Tapi, Valsad, Rajkot, Dwarka, Porbandar District (Table 2 and Fig 5d). for the month of October there is rise in rainfall trend in Junagadh district. (Table 2 and Fig 5e).

In the monsoon season over Gujarat state, there is insignificant decrease in rainfall in Dang and Dahod districts. It is also found that the Northern part of Gujarat has seen significant rise in rainfall trend. The south Gujarat and the Saurashtra Region of Gujarat also observed the rising trend of rainfall over the monsoon season.

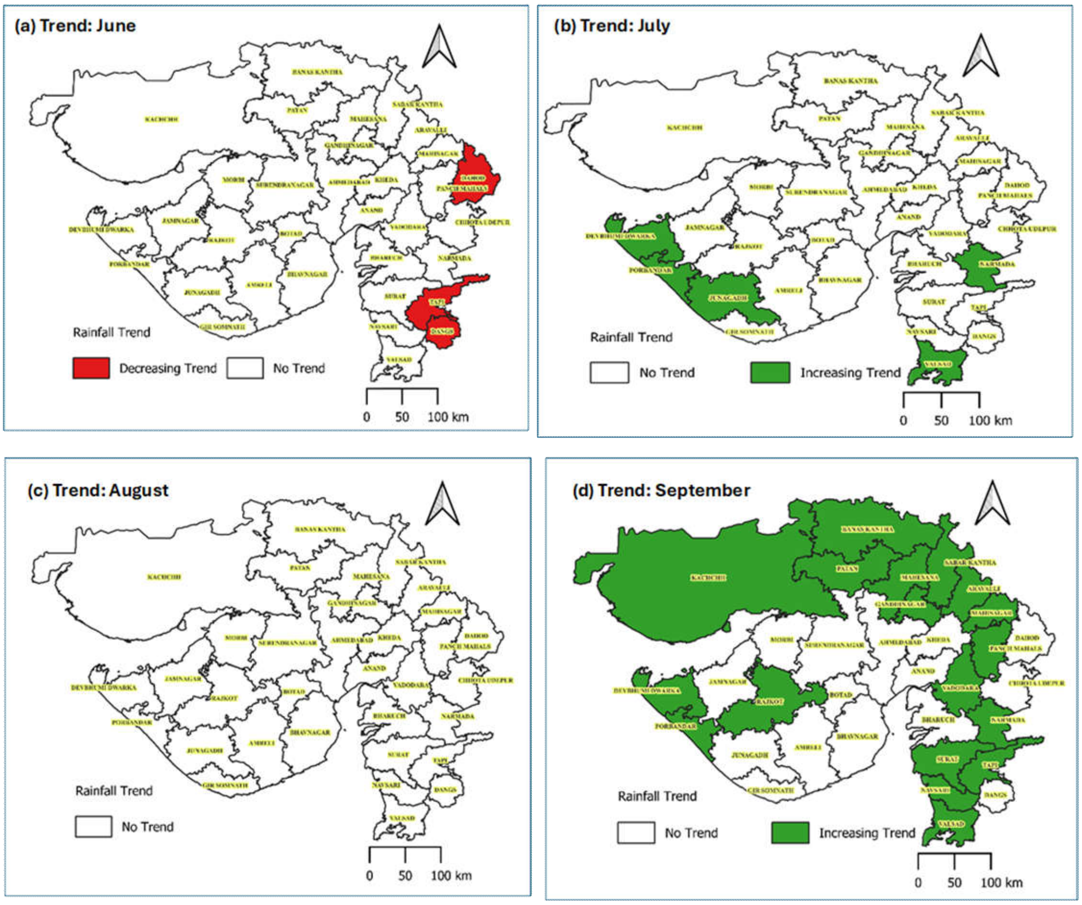


**Figure-5 (a-d):** *Monthly and seasonal rainfall trends over the Gujarat state based on MK test*

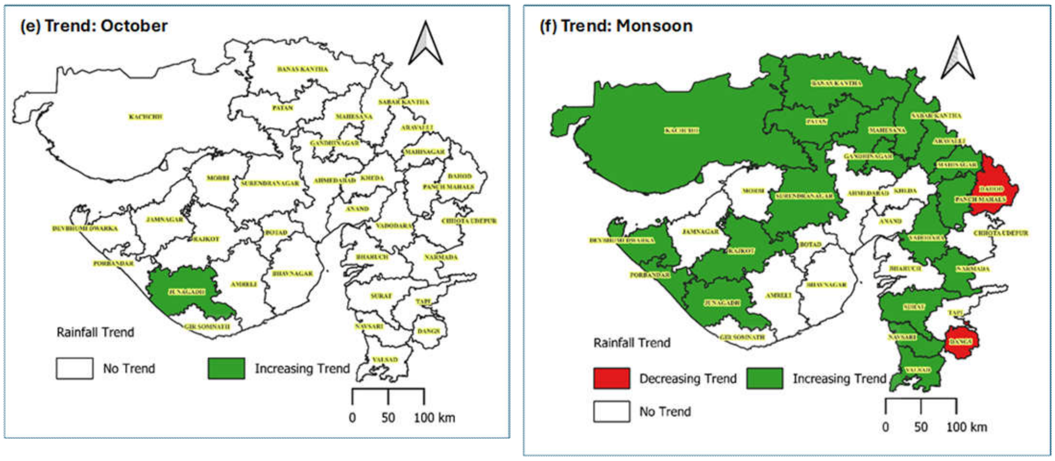


**Figure-5 (e-f):** *Monthly and seasonal rainfall trends over the Gujarat state based on MK test*

## 5. IMPLICATION OF THE STUDY

Rainfall variability is one of the major factors influencing the spatio temporal fluctuations in the availability of water resources, which has an immediate impact on agricultural output and water resources in the river catchment of the arid and semi- arid regions. Climate change causes rainfall unpredictability to increase, resulting in localised or worldwide floods and droughts that impact agro-based economics (Mall et.al.2006). furthermore, changed rainfall patterns negatively impacts irrigation and groundwater recharge in semi-arid regions (like Saurashtra and North Gujarat). the Gujarat state exhibits notable differences in rainfall pattern, with the south and north-western regions receiving higher levels than Saurashtra and southwest regions. Certainly, due to Climate change and change in rainfall approach. Thus, present research on the distribution, variability and trend of rainfall over Gujarat state will be helpful in understanding the ground response to rainfall i.e. rainfall induced flood scenario and managing water resources across Gujarat state.

## 6. CONCLUSION

The main objective of the existing study is to evaluate the total 33 districts- wise (of Gujarat state) rainfall distribution, variability and trend of rainfall over the Gujarat state for the period of 1999-2024. Analysis can be concluded as:

### 6.1 Rainfall Distribution and Statistical Insights:

The analysis of 25 years of rainfall data (1999–2024) reveals pronounced spatial heterogeneity across Gujarat. Southern districts such as Valsad (2298 mm), Navsari (1805 mm), and Dang (1354 mm) recorded the highest mean monsoon rainfall, while Kutch (493 mm), Patan (626 mm), and Banaskantha (630 mm) received significantly lower rainfall. Valsad's rainfall is over 4.5 times that of Kutch, highlighting stark regional disparities.

Standard deviation (SD) and coefficient of variation (CV) further underscore rainfall anomalies. Valsad, despite high rainfall, shows a CV of 26%, indicating relatively stable rainfall, whereas districts like Dwarka (65%), Rajkot (43%), and Vadodara (36%) exhibit high variability, suggesting erratic rainfall patterns.

**6.2 Spatial Heterogeneity and Physiographic Influence:**

Rainfall distribution aligns closely with Gujarat's physiography and monsoon dynamics. Southern Gujarat's proximity to the Arabian Sea and Western Ghats facilitates orographic rainfall, with moist monsoon winds rising and condensing over elevated terrain. This explains the high rainfall in districts like Valsad and Navsari.
In contrast, northern and northwestern Gujarat (e.g., Kutch, Mehsana, Banaskantha) lies in semi-arid zones, farther from moisture sources. By the time monsoon winds reach these regions, much of the moisture has dissipated, resulting in lower rainfall and higher variability.

**6.3 Rainfall Variability and Anomalies:**

Rainfall variability, measured via CV, is a critical indicator of climate instability. In June, districts like Gir Somnath (170%), Aravalli (168%), and Sabarkantha (167%) show extreme variability, posing challenges for early sowing and water storage. July sees the highest CV in Tapi (271%), while August variability peaks in Valsad (191%).
Such anomalies suggest that while some districts receive high rainfall, its distribution is inconsistent, complicating agricultural planning and water management.

**6.4 Rainfall Trends and Statistical Significance:**

Using the Mann–Kendall (MK) test, rainfall trends were assessed for statistical significance. Notable findings include:

- Increasing trends in Narmada ($p = 0.0017$), Junagadh ($p = 0.0246$), Valsad ($p = 0.0173$), and Kutch ($p = 0.0219$).
- Decreasing trends in Dang ($p = 0.0308$) and Dahod ($p = 0.0343$).
- September shows widespread rising trends across northern Gujarat, including Mehsana, Patan, Banaskantha, Sabarkantha, and Mahisagar, indicating a shift in monsoon intensity toward these regions.

These trends are statistically significant ($p < 0.05$), suggesting real climatic shifts rather than random fluctuations.

**6.5 Integrated Implications for Agriculture, Water Planning, and Climate Adaptation:**

The observed rainfall variability and trends have direct implications:

- Agriculture: High CV districts face crop failure risks due to unpredictable rainfall. Adaptive cropping strategies and drought-resistant varieties are essential.
- Water Resource Planning: Rising rainfall in northern districts necessitates flood control infrastructure, while declining trends in Dang and Dahod call for rainwater harvesting and groundwater recharge.
- Climate Adaptation: District-level trend data can inform resilience planning, including early warning systems, irrigation scheduling, and disaster preparedness.

The integration of statistical analysis with physiographic context provides a robust framework for understanding Gujarat's evolving rainfall dynamics and supports informed decision-making across sectors.

**Limitations:** The study is limited to Gujarat State completely rely on downscaled gridded rainfall dataset to district level, the spatial variation can be studied in more detail in village and taluka level using high resolution dataset, such datasets are not available.

**Future scope:** Rainfall variability and trend can be studies at micro level (village level) using High resolution datasets. Trend forecast using forecasting techniques for high resolution rainfall datasets shall be useful for understanding future trends and improve resilience.

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