



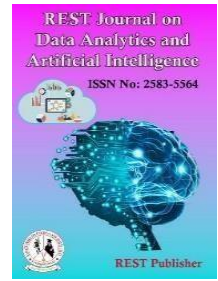
REST Journal on Data Analytics and Artificial Intelligence

Vol: 4(4), December 2025

REST Publisher; ISSN: 2583-5564

Website: <http://restpublisher.com/journals/jdaai/>

DOI: <https://doi.org/10.46632/jdaai/4/4/13>



A Statistical Analysis of Rainfall Patterns in the Subdivisions along the Arabian Coastal Region of India

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Abstract: Understanding changing precipitation patterns is crucial for efficient water resource management and agricultural planning, especially along environmentally sensitive coastal corridors. This study looks at the spatiotemporal dynamics of monthly, seasonal, and annual rainfall in three separate meteorological subdivisions along India's western coast: Konkan and Goa, Coastal Karnataka, and Kerala and Mahe. To robustly quantify these climatological changes, we used classic non-parametric techniques specifically, the Mann-Kendall test and Sen's slope estimator along with the visually intuitive Innovative Trend Analysis (ITA) method. The findings of the study show a striking spatial difference in regional rainfall trends. A significant increase in precipitation in the northern and central coastal regions, which included Konkan and Goa, as well as Coastal Karnataka. While the early monsoon months showed little change, both regions exhibited statistically significant increases during the late monsoon months of August and September. This late-season surge resulted in large increases in both seasonal and annual rainfall totals. In contrast, the southern subdivisions of Kerala and Mahe had a severe drying tendency. This climatological fall was principally caused by acute, statistically significant precipitation shortages in the critical early monsoon months of June and July, which severely reduced both seasonal and yearly totals. Methodologically, the ITA framework significantly supported traditional non-parametric estimators while providing greater sensitivity to modest directional alterations during transitional months. Finally, this study identifies a regionally diverse shift in regional monsoon behavior, emphasizing the critical need for locally tailored, climate-adaptive hydrological measures to meet concurrent trends of late-season amplification and early-season drying. The statistical analysis is performed using R software.

Keywords: Mann Kendall Test, Sen's Test, Innovative Trend method, R-software

1. INTRODUCTION

The west coast of India comprises three contiguous meteorological subdivisions Konkan and Goa, Coastal Karnataka, and Kerala and Mahe flanked by the Arabian Sea and the Western Ghats[1], [2], [3]. This narrow corridor functions as a globally recognized biodiversity hotspot and receives among the highest precipitation totals in the country, locally exceeding 4,000 mm annually. Precipitation onset occurs first in Kerala by late May or early June before advancing northward along the coast.[4], [5], [6]. Intra-seasonal precipitation exhibits pronounced temporal heterogeneity, with coefficient of variation values dropping below 20% during peak monsoon months but exceeding 180% during the dry winter period [4], [7], [8]. Agrarian production across these subdivisions is dominated by kharif crops and vulnerable plantation systems that depend directly on reliable rainfall schedules [9]. Variations in rainfall distribution elevate risks of topsoil erosion and flash flooding during intense wet periods, while prolonged dry spells deplete localized surface reservoirs [2], [6]. Long-term empirical assessments reveal sharp geographic and seasonal divergences among the three coastal subdivisions despite their physical proximity along the Western Ghats.

- Konkan and Goa exhibits a statistically significant upward trend in annual rainfall of +3.2 mm/year over the 1901–2020 period [10], accompanied by significant increases in summer monsoon precipitation[11], [12] and the highest historical frequency of flood years [11].
- Coastal Karnataka demonstrates a significant long-term increase in annual rainfall[1], [13] although recent sub-period records indicate multi-decadal declines during peak monsoon months [4] alongside notable spatial instability at synoptic stations [14]

- Kerala and Mahe displays a consistent, statistically significant decline in both annual and summer monsoon precipitation [12], [15], [16] characterized by notable reductions in June and July rainfall [13], [17] and asymmetric seasonal shifts.
- Intra-seasonal redistribution is evident across all three subdivisions, marked by declining winter precipitation [10], [18], rising August–September rainfall along the central coast [4], [6] and localized increases in post-monsoon totals in southern areas [13], [15]

Methodological Advances in Hydroclimatic Analysis

Evaluating coastal precipitation records requires robust statistical frameworks capable of handling non-normal distributions, serial correlation, and multi-scale non-stationarity [1], [18]

- The Mann-Kendall and Sen's Slope has been used to quantify the monotonic trend directions and magnitudes as it is distribution-free; insensitive to outliers in time series [19], [20], [21], [22], [23]
- The Modified Mann-Kendall (MMK) had been used to correct the variance for lag-1 serial autocorrelation as it eliminates false-positive trend detections in present data [2], [6], [18], [23].
- The Innovative Trend Analysis (ITA) detects trends across low, medium, and high values and is specifically applied to capture the hidden non-monotonic trends missed by MK tests [2], [18], [24]
- The Wavelet Synopsis (DWT) uncovers the localized temporal and cyclical periodicities and is applied to resolve the dominant short-term periodicities under one decade[2], [15], [19].

Despite extensive pan-India analyses, comparative evaluations focusing specifically on the contrasting trends across Konkan and Goa, Coastal Karnataka, and Kerala and Mahe remain limited [13], [16], [21]. Broad multi-basin aggregations often obscure significant sub-seasonal regime shifts operating between adjacent coastal subdivisions [6], [13], [21]. This study conducts a unified trend analysis of monthly, seasonal, and annual rainfall across these three subdivisions to establish precise regional trajectories for climate adaptation and hydrologic planning.

2. STUDY AREA AND DATA DESCRIPTION

Study Area

The three high-rainfall meteorological subdivisions along the West Coast of India facing the Arabian Sea are Konkan & Goa, Coastal Karnataka, and Kerala & Mahe. These subdivisions receive heavy rainfall during the Southwest Monsoon period. The approximate longitude and latitude boundaries are provided in the below

TABLE 1. Location of the Meteorological Subdivision

Meteorological Subdivision	Latitude Range	Longitude Range
Konkan & Goa	15°02' N to 19°17' N	72°50' E to 74°50' E
Coastal Karnataka	12°45' N to 14°53' N	74°05' E to 74°52' E
Kerala & Mahe	8°18' N to 12°48' N	74°52' E to 77°22' E

Data Description

The analysis was conducted using 125 years of data from 1901 to 2025. It is sourced from the Indian Meteorological Department's website. It contains monthly rainfall data over 125 years. This study's analysis included monthly (monsoon season), seasonal, and annual rainfall data.

3. METHODS

Mann Kendall test

The Mann-Kendall test is a non-parametric test that is used to test the significance of trend in the data [25], [26]. The null hypothesis of no trend present in data, is tested against an alternative hypothesis that there is trend present in the data. Let $z_1, z_2, z_3, \dots, z_n$ denote the observations in the time series. Then the test statistic used to test the above hypotheses is

$$U = \operatorname{sgn}(S) \frac{|S|-1}{\sigma} \quad \text{where } S = \sum_{j=1}^n \sum_{i=1}^n \operatorname{sgn}(z_i - z_j), \quad z_i \text{ and } z_j (i < j) \text{ denote the rank of the } i^{\text{th}} \text{ and } j^{\text{th}} \text{ observation}$$

respectively, the sgn function denotes the sign of the term $z_i - z_j$ and is defined as

$$\text{sgn}(z_i - z_j) = \begin{cases} 1, & z_i - z_j > 0 \\ 0, & z_i - z_j = 0 \\ -1, & z_i - z_j < 0 \end{cases}$$

The null hypothesis is rejected if $U < -U_{\alpha/2}$ or $U > U_{\alpha/2}$, where U_{α} is such that $P(U < -U_{\alpha/2}) + P(U > U_{\alpha/2}) = \alpha$

Sens Slope Test

It is a non-parametric technique for identifying patterns in time data [27]. The median for all possible values of u and v respectively is the Sen's estimator of slope $b_{sen} = \frac{z_v - z_u}{v - u}$. A positive b_{sen} value denotes an increasing trend in the data, whereas a negative slope value denotes a declining trend. The trend is considered significant if it does not contain 0 in the confidence interval.

Innovative Trend Method

Sen proposed a graphical method for trend spotting [28]. The study period is split in half using this manner. The second half's rainfall values are displayed on the y-axis of the time series versus the first half's values on the x-axis. The lower and upper 90% confidence intervals are displayed beside a line that passes through the origin. There is no pattern in the data, as indicated by the dots that are dispersed across the 90% confidence interval surrounding the straight line. There is an increasing trend in the second half of the data compared to the first half if there are points over the upper 90% confidence range. On the other hand, a declining trend in the second half of the data relative to the first half is shown by the points that fall below the lower 90% confidence range.

4. ANALYSIS AND DISCUSSION

Mann Kendall Test

Table 2 details the results of the Mann-Kendall test applied to monthly, seasonal, and annual rainfall datasets across three coastal regions, revealing distinct regional variations in precipitation dynamics. In the Konkan and Goa subdivision, early monsoon months (June and July) exhibit statistically insignificant positive trends. However, a robust increase in rainfall emerges during the late monsoon, with both August ($\tau=0.149$, $p = 0.0138$) and September ($\tau=0.162$, $p = 0.0074$) showing clear, significant positive trajectories. This late-season surge drives highly significant positive trends for both the overall seasonal ($\tau=0.236$, $p < 0.001$) and annual ($\tau=0.231$, $p = 0.0001$) rainfall. Coastal Karnataka mirrors this broader pattern; while June and July show negligible changes, August and September experience significant positive trends ($\tau=0.211$ and $\tau=0.125$, respectively). These late-season increases ultimately push both the seasonal ($p = 0.0164$) and annual ($p = 0.0023$) rainfall accumulations into significant positive territory. Conversely, the Kerala and Goa region displays a striking contrast, characterized by a pronounced drying pattern. Here, the early monsoon months experience highly significant declining trends, particularly in July ($\tau=-0.201$, $p = 0.0008$) and June ($\tau=-0.165$, $p = 0.0065$). Although the late monsoon months in this region show marginal, insignificant increases, the steep early-season deficits dominate the broader temporal scale, resulting in statistically significant negative trends for both seasonal ($\tau=-0.164$, $p = 0.0066$) and annual ($\tau=-0.126$, $p = 0.0374$) rainfall. Overall, the analysis indicates a clear spatial dichotomy along the coast, with rainfall significantly intensifying in the northern and central belts while declining in the southern region.

TABLE 2. Trend Detection Using Mann Kendall Test

Time Period	Test Statistics (τ)	P-Value	Statistical Significance
Konkan and Goa			
June	0.0889	0.1421	Insignificant
July	0.0970	0.1090	Insignificant
August	0.1490	0.0138	Significant
September	0.1620	0.0074	Significant
Seasonal	0.2360	0.0000	Significant
Annual	0.2310	0.0001	Significant
Coastal Karnataka			
June	-0.0219	0.7184	Insignificant

July	0.0245	0.6867	Insignificant
August	0.2110	0.0005	Significant
September	0.1250	0.0389	Significant
Seasonal	0.1450	0.0164	Significant
Annual	0.1840	0.0023	Significant
Kerala and Goa			
June	-0.1650	0.0065	Significant
July	-0.2010	0.0008	Significant
August	0.0332	0.5849	Insignificant
September	0.0755	0.2127	Insignificant
Seasonal	-0.1640	0.0066	Significant
Annual	-0.1260	0.0374	Significant

Sen's Slope Test

Table 3, quantifies the magnitude of rainfall trends utilizing Sen's slope estimator across three distinct coastal subdivisions. In the Konkan and Goa region, the early monsoon months of June and July exhibit positive but statistically insignificant changes in rainfall. However, a pronounced and significant upward shift occurs during the late monsoon, with rainfall increasing at a rate of 1.5608 units in August ($p = 0.0138$) and 1.2340 units in September ($p = 0.0074$). This late-season surge contributes to substantial and highly significant positive slopes for both the seasonal ($b_{sen} = 4.5597$, $p = 0.0000$) and annual ($b_{sen} = 4.9598$, $p = 0.0001$) aggregations. Coastal Karnataka demonstrates a comparable temporal pattern; while June and July record negligible variations, August and September show significant positive slopes of 1.9364 ($p = 0.0005$) and 0.7857 ($p = 0.0389$), respectively. Consequently, the overarching seasonal (2.6294, $p = 0.0164$) and annual (3.7464, $p = 0.0023$) precipitation trajectories for this subdivision are characterized by significant upward trends. Conversely, the Kerala and Mahe region is defined by a significant drying pattern driven primarily by severe early-season deficits. Rainfall in June and July decreases substantially in this area, recording significant negative slopes of -1.3282 ($p = 0.0065$) and -1.6708 ($p = 0.0008$). Although August and September show marginal, statistically insignificant positive slopes, the severity of the early-season decline dominates the broader temporal scales, resulting in significant overall negative trends for both seasonal (-2.4188, $p = 0.006595$) and annual (-2.1474, $p = 0.03746$) rainfall.

TABLE 3. Trend Detection Using Sens Slope Test

Time Period	Sen's Slope	Test Statistics (z)	P-Value	Confidence Interval	Statistical Significance
Konkan and Goa					
June	0.7415	1.4682	0.1420	(-0.0791, 1.5434)	Insignificant
July	1.1565	1.6027	0.1090	(-0.0428, 2.3982)	Insignificant
August	1.5608	2.4627	0.0138	(0.5810, 2.6561)	Significantly Increasing
September	1.2340	2.6782	0.0074	(0.5223, 1.9667)	Significantly Increasing
Seasonal	4.5597	3.9031	0.0000	(2.6593, 6.4229)	Significantly Increasing
Annual	4.9598	3.8220	0.0001	(2.8015, 7.1321)	Significantly Increasing
Coastal Karnataka					
June	-0.1940	-0.3606	0.7184	(-0.9925, 0.6589)	Insignificant
July	0.3076	0.4033	0.6867	(-0.9044, 1.6411)	Insignificant
August	1.9364	3.4913	0.0005	(1.0055, 2.8800)	Significantly Increasing
September	0.7857	2.0658	0.0389	(0.1760, 1.3800)	Significantly Increasing
Seasonal	2.6294	2.4008	0.0164	(0.8447, 4.5622)	Significantly Increasing
Annual	3.7464	3.0453	0.0023	(1.6714, 5.8824)	Significantly Increasing
Kerala and Mahe					
June	-1.3282	-2.7209	0.0065	(-2.0979, -0.5444)	Significantly Decreasing
July	-1.6708	-3.3270	0.0008	(-2.5413, -0.8578)	Significantly Decreasing
August	0.1923	0.5463	0.5849	(-0.3888, 0.7186)	Insignificant
September	0.4147	1.2463	0.2127	(-0.1431, 0.9645)	Insignificant
Seasonal	-2.4188	-2.7166	0.0065	(-3.9339, -1.0860)	Significantly Decreasing
Annual	-2.1474	-2.0807	0.0374	(-4.0458, -0.4103)	Significantly Decreasing

Innovative Trend Method

Table 4 presents the findings from the Innovative Trend Analysis (ITA), providing a comparative perspective that largely corroborates the earlier Mann-Kendall (MK) and Sen's slope results while offering additional sensitivity to subtle shifts. For the Konkan and Goa subdivision, the ITA method confirms the robust upward trajectories during the late monsoon, categorizing August, September, seasonal, and annual rainfall as "Increasing". This perfectly aligns with the statistically significant positive trends identified in the traditional tests. The accompanying ITA plot in Figure 1 visually reinforce this, displaying data points for these periods noticeably elevated above the 1:1 no-trend line. Notably, while the MK and Sen's tests found June's positive shift to be statistically insignificant, the ITA method distinctly classifies June as "Increasing" (Slope ITA = 0.5507). Similarly, in Coastal Karnataka, the ITA strictly agrees with the significant late-season surges, denoting August, September, seasonal, and annual rainfall as "Increasing". This upward dynamic is visually supported by Figure 2, where scatter points for these timeframes clearly aggregate above the upper confidence limits. For the early monsoon in this subdivision, the ITA classifies June as "Decreasing," providing a more definitive directional indicator than the insignificant negative values derived from the previous tests. In the Kerala and Mahe subdivision, the ITA method strongly validates the pronounced regional drying pattern. June, July, seasonal, and annual rainfall are all unambiguously classified as "Decreasing," directly corroborating the highly significant negative slopes established by the MK and Sen's estimators. Figure 3 clearly illustrates these severe deficits, with data points clustering well below the 1:1 reference line. Interestingly, a minor divergence between the methodologies emerges in August for this southern region; whereas Sen's slope indicated a marginal, statistically insignificant positive change, the ITA method captures a "Decreasing" trend indicator (-0.2268) and slope (-0.1571). Overall, the visual and tabular results from the ITA methodology successfully validate the broader spatial dichotomy rainfall intensification along the northern and central coasts versus a drying trend in the south while simultaneously demonstrating a heightened sensitivity in detecting trend directions during the transitional early monsoon months.

TABLE 4. Trend Analysis Using Innovative Trend Analysis (ITA) method

Series	Slope ITA	Trend Indicator	SD Slope	Lower Confidence limit	Upper Confidence Limit	Trend
Konkan and Goa						
June	0.5507	0.5103	0.0464	-0.0761	0.0761	Increasing
July	-0.0361	-0.0204	0.0624	-0.1024	0.1024	No Trend
August	1.2240	1.1742	0.0506	-0.0829	0.0829	Increasing
September	0.6504	1.1611	0.0508	-0.0834	0.0834	Increasing
Seasonal	2.3889	0.5364	0.1266	-0.2076	0.2076	Increasing
Annual	2.1978	0.4609	0.1424	-0.2335	0.2335	Increasing
Coastal Karnataka						
June	-0.4033	-0.2953	0.052034	-0.085336	0.085336	Decreasing
July	0.0486	0.0266	0.056553	-0.092746	0.092746	No Trend
August	2.2077	2.1255	0.070284	-0.115265	0.115265	Increasing
September	0.3929	0.8224	0.037725	-0.061868	0.061868	Increasing
Seasonal	2.246	0.4771	0.154333	-0.253106	0.253106	Increasing
Annual	2.1691	0.4008	0.229021	-0.375594	0.375594	Increasing
Kerala and Mahe						
June	-1.4322	-1.2916	0.044433	-0.072871	0.072871	Decreasing
July	-1.7819	-1.4848	0.031746	-0.052064	0.052064	Decreasing
August	-0.1571	-0.2268	0.056505	-0.092669	0.092669	Decreasing
September	0.3539	0.9178	0.020021	-0.032835	0.032835	Increasing
Seasonal	-3.0172	-0.8908	0.142303	-0.233376	0.233376	Decreasing
Annual	-4.2143	-0.8567	0.152627	-0.250308	0.250308	Decreasing

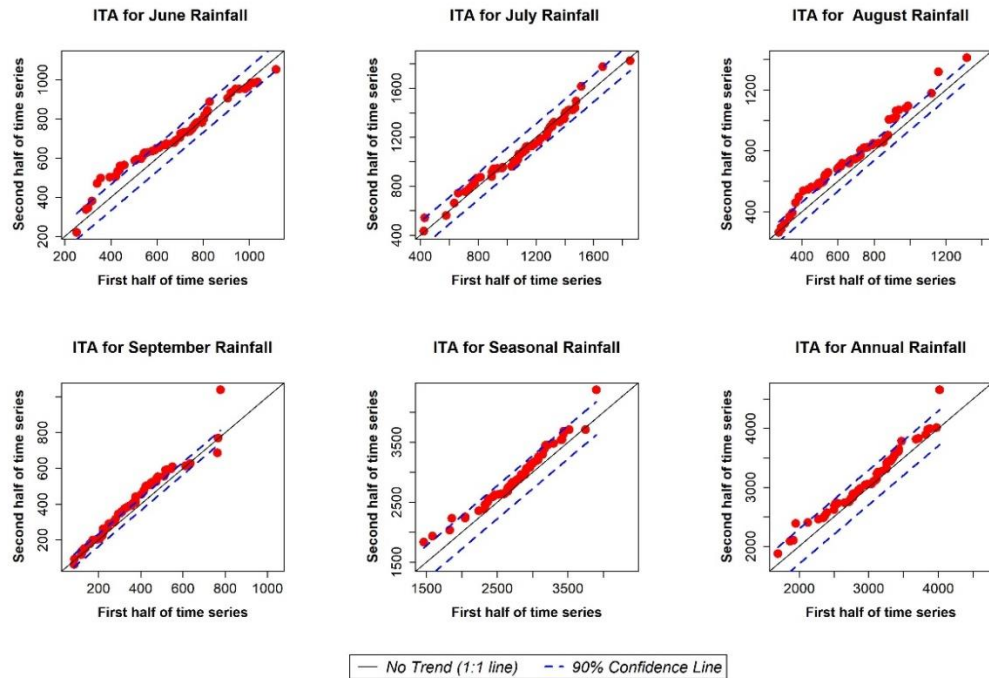


FIGURE 1. Innovative Konkan and Goa Subdivision Trend Analysis for

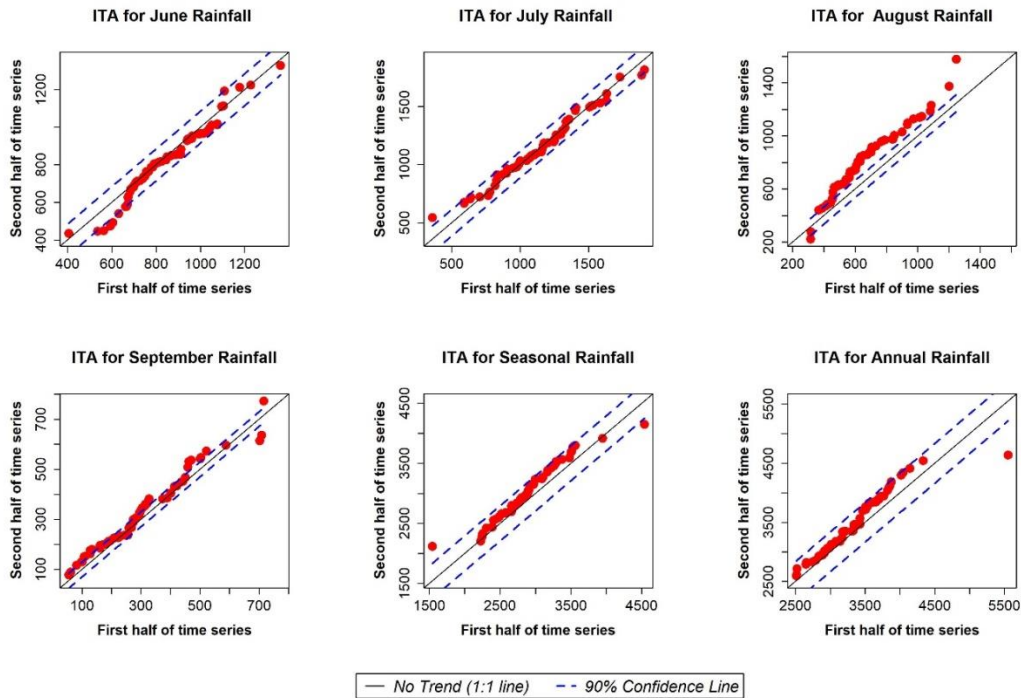


FIGURE 2. Innovative Trend Analysis for Coastal Karnataka Subdivision

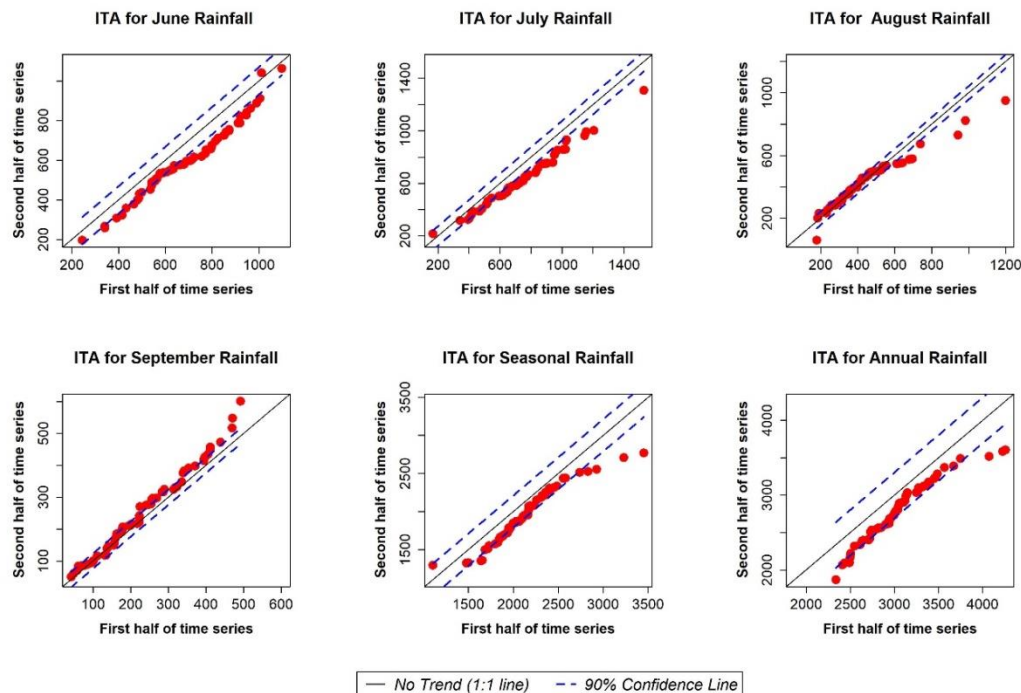


FIGURE 3. Innovative Trend Analysis for Coastal Kerala and Mahe Subdivision

5. CONCLUSION

In conclusion, the comprehensive trend analysis reveals a striking spatial and temporal dichotomy in precipitation patterns along the western coast. The northern and central subdivisions, encompassing Konkan and Goa as well as Coastal Karnataka, are experiencing a pronounced intensification of rainfall, driven primarily by robust, statistically significant surges during the late monsoon months of August and September. This late-season amplification ultimately dictates the seasonal and annual accumulations, indicating a definitive shift toward wetter overall conditions in these regions. Conversely, the southern coastal stretch of Kerala and Mahe demonstrates a starkly contrasting climatological trajectory. This subdivision is undergoing a significant drying phase, characterized by acute precipitation deficits during the critical early monsoon months of June and July, which decisively suppress both seasonal and annual rainfall totals. Methodologically, the deployment of the Innovative Trend Analysis (ITA) alongside traditional non-parametric tests such as the Mann-Kendall and Sen's slope estimators provided a highly consistent yet nuanced validation of these regional dynamics. While the classical tests successfully established the statistical significance and magnitude of the primary trends, the ITA framework exhibited a heightened sensitivity to subtle transitional shifts, capturing directional changes during the early monsoon that the traditional methods deemed insignificant. Together, these findings underscore a complex, heterogeneous transformation in regional monsoon behavior. Such distinct geographic divergences, where adjacent coastal belts simultaneously face intensifying late-season rainfall and emergent early-season drying trends, highlight the necessity for localized, adaptive strategies in regional water resource management and agricultural planning.

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