Trend of Seasonal and Annual Rainfall in Semi-arid Districts of Karnataka, India: Application of Innovative Trend Analysis Approach

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Abstract

Trend analysis of rainfall is often carried out in water resources management to understand its distribution over a given region. The cumulative seasonal and annual rainfall derived from monthly datasets spanning 102 years (1901–2002) for 11 districts of the semi-arid Karnataka, India, was used for the trend analysis. The two-step homogeneous test approach was carried out on all the time series. Then, lag-1 autocorrelation was conducted only on homogeneous time series. Only 78.18% of the total time series data was detected as homogeneous, and 95.35% of time series data were found to have insignificant autocorrelation. Then, the Innovative Trend Analysis (ITA) method was applied to 43 homogeneous rainfall time series, MK and SR tests to 41 time series, and mMK test to two time series. The MK and SR tests detected 14.63% of the time series as a significant trend, whereas the ITA method could detect 93.02% of the total time series data. The MK and SR tests captured significant trends for the winter season in two districts, but the two tests detected a significant trend only in one district for the summer season. None could be captured for monsoon season. A significant trend was captured for the post-monsoon season in two districts; however, the tests could detect a significant trend in one district for annual rainfall. The mMK 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.

1 Introduction

The demand for fresh water is ever increasing because of the myriad of needs that are encountered daily in different sectors. Its availability and occurrences result from the quantum of precipitation received during a given period. Even groundwater, which forms a significant source of fresh water in many parts of the world, is recharged by rainfall. Therefore, precipitation is the major component of the hydrologic cycle. One peculiar characteristic of precipitation is that its occurrence is uneven over space and time (Sansom et al. 2017). The precipitation occurrence can lead to flood (drought) when it is excess (scanty). For example, the recent occurrences of devastating floods of 2018 in Kerala (Mishra and Nagaraju 2019) and 2021 in Germany (Fekete and Sandholz 2021) remind how costly precipitation can be when it occurs in excess. On the other extreme, some parts of the United States of America (USA) experienced significant drought during 2020 (Yaddanapudi and Mishra 2022), and 2021 also shows the continuation of the drought in other parts of the USA. It is also known that scanty rainfall leads to meteorological drought (Sajeev et al. 2021; Muthuvel and Mahesha 2021). This drought is often the precursor to agricultural drought (Behrang Manesh et al. 2019) and hydrological drought (Hao et al. 2016). This erratic behaviour of rainfall calls for a proper understanding of rainfall distribution in space and time. Moreover, it is imperative to understand the precipitation trend due to anthropogenic activities and climate alteration in the hydrologic cycle (Zhang et al. 2007; Wu et al. 2013; Yi et al. 2016).

One of the ways to understand the distribution of rainfall patterns over an area of interest is the trend analysis that helps us ascertain how much rainfall amount increases or decreases on a particular time scale. The most widely used nonparametric methods to capture monotonic trends are the Mann-Kendall (MK) and Spearman's rho (SR) methods (Kendall 1938; Mann 1945; Daniel 1990). Some of the recent studies on the use of MK and SR tests for rainfall trend analysis have been reported in the literature (Kalra and Ahmad 2011; Abghari et al. 2013; Gocic and Trajkovic 2013; Formetta et al. 2016; Güner Bacanli 2017; Hajani et al. 2017; Pandey and Khare 2018; Nikzad Tehrani et al. 2019; Raja and Aydin 2019; Gado et al. 2019). However, the MK and SR approaches are limited to the assumptions of the absence of serial correlation (autocorrelation) of a given time series of a variable, normal distribution of the time series, and the sample size of the data. In order to circumvent the requirement of the limiting assumptions, Şen (2012) proposed the innovative trend analysis (ITA) method for carrying out trend investigation of hydrometeorological variables. The ITA method also does not require the prewhitening of time series data prior to applying it. Since then, several studies on the ITA method have been conducted for trend analysis of hydrometeorological variables in different regions. For example, Güçlü (2018a) extended the ITA method to half time series method (HTSM) that could aid the ITA method to detect trend analysis better.

Similarly, the same author proposed double-ITA (D-ITA) and triple-ITA (T-ITA) approaches to use in tandem with ITA to improve trend detection with stability identification (Güçlü 2018b). In yet another study, innovative triangular trend analysis (ITTA) that aids in detecting partial trends within a given time series was applied using the triangular array after splitting a given time series to a pair of equal length sub-series to make a comparison of trends (Güçlü et al. 2020). The extended version of ITA – the Innovative Polygonal Trend Analysis (IPTA) can not only detect trends captured by the traditional methods but also trend transitions of a time scale (weekly, monthly, etc.) of two equal sub-series derived from the original data (Şen et al. 2019). In extending the IPTA, Ceribasi et al. (2021) proposed the Innovative Trend Pivot Analysis Method (ITPAM) to determine the five risk classes using the inherent relationship in data.

Despite the extended versions of the ITA method in literature, the original ITA method (Şen 2012, 2017a) is still widely used for trend analysis of hydrometeorological variables, as evident from recent literature. For instance, Harka et al. (2021) carried out a comparative study of MK, and ITA approaches to detect rainfall trends in Ethiopia's Upper Wabe Shebelle River Basin (UWSRB). The ITA test detected both monotonic and non-monotonic trends that could not have been possible with the MK test. In a similar study of the Bumbu watershed, Papua New Guinea, Doaemo et al. (2022) did a comparative study of rainfall trend analysis using linear regression, Mann-Kendall rank statistics, Sen's Slope, and ITA. In addition, spectral analysis was carried out to remove cyclic components from the rainfall time series. Their findings, however, indicate that all the four methods consistently indicated decreasing trend of annual rainfall. Several other studies on ITA application are reported in the literature (Danandeh Mehr et al. 2021; Şişman and Kizilöz 2021; Mallick et al. 2021; Phuong et al. 2022; Ay 2022). The extended version of ITA - IPTA is the most widely used method to detect trends and trend transitions of different hydrometeorological variables (Şan et al. 2021; Ceribasi and Ceyhunlu 2021; Ahmed et al. 2021; Akçay et al. 2021; Hırca et al. 2022).

The occurrences of flood and drought events in India (Mishra and Nagaraju 2019; Mishra et al. 2021; Jha et al. 2021) cause economic losses and life. Therefore, the need for flood policy (Jameel et al. 2020) and understanding the effect of historical and future drought on crops (Udmale et al. 2020) is necessary for effective water management. There is an urgent need to address these issues because most of the population depends on agriculture as an occupation. In this regard, rainfall trend analysis will help the country with pragmatic decisions and actionable plans in dealing with both floods and drought. The MK test has been widely used to study monthly, seasonal, and annual rainfall trends in India both at the national (Kumar et al. 2010; Nengzouzam et al. 2020; Kaur et al. 2021) and regional levels (Goyal 2014; Gajbhiye et al. 2016; Chatterjee et al. 2016; Meshram et al. 2017; Pandey and Khare 2018; Mehta and Yadav 2021; Gupta et al. 2021).

Recent studies on precipitation trend analysis in India witnessed the ITA method being increasingly applied. Often the ITA method has been compared with MK, SR, and linear regression methods (Sanikhani et al. 2018; Machiwal et al. 2019; Meena et al. 2019; Praveen et al. 2020; Singh et al. 2021a; Saini and Sahu 2021; Aher and Yadav 2021). A few studies are worth mentioning using the ITA and classical trend analysis methods at the national level. The study by Praveen et al. (2020) presented the rainfall trend analysis of all the meteorological sub-divisions of India from 1901 to 2015 at the seasonal and annual scales. It was noticed that the change detection point conducted using the Pettitt test was mostly found to be after 1960 for the meteorological divisions. The application of the MK test revealed the trend to be positive during 1901–1950; however, the trend reduced after 1951. The ITA method detected mostly negative trends even when the MK test detected no trend. Singh et al. (2021) presented a similar study of the same region using gridded rainfall data (1901 to 2019), both seasonal and annual. The ITA method was compared with MK, modified Mann-Kendall (mMK), and the linear regression analysis (LRA) tests.

Interestingly, the ITA method could detect trends beyond traditional approaches. An increasing trend was observed for the monsoon and annual rainfall in the northwest and peninsular India; however, the northeast central portion of the nation experienced a negative trend. Most of the zones, however, experienced decreasing winter rainfall. Extracting the rainfall events from anomalous rainfall time series (1871–2016), Saini and Sahu (2021) carried out a unique (not raw rainfall time series) study for the same meteorological zones of India using the MK, ITA, and LRA methods. Though the study is unique in terms of data input and detailed, refined trend analysis, the ITA test captured other trends similar to the above mentioned studies.

The ITA method can be used to capture the trend in hydrometeorological time series data overcoming the assumptions of traditional trend analysis approaches. However, the requirement of time series homogeneity cannot be neglected (Şen 2012). However, there are limited studies on using the ITA approach on homogeneous rainfall time series in the Indian context. If homogeneity tests are not carried out, there are chances of accepting false trends, which might not have occurred.

Karnataka stands only next to Rajasthan state in India to be the most drought-prone area (Jayasree and Venkatesh 2015), receiving a little over 700 mm of mean annual rainfall. The northern region of the state, Rajasthan and northern-central Maharashtra constitute 72% of India's total pearl millet production (Singh et al. 2017). The region is also home to some of the largest crop-producing districts in Karnataka. The districts in this region lie on the Western Ghats' leeward side, making them drought-prone. Furthermore, nearly 90% of the inhabitants in the semi-arid region of Karnataka - over and above 11 districts are dependent on agriculture as an occupation (Jayasree and Venkatesh 2015).

From the literature, it is evident that no such study on the ITA method for precipitation trend analysis has been reported for this region. Hence, the present investigation is focused on: (a) to carry out homogeneity tests of seasonal and annual rainfall time series of each district within the region, (b) to determine the serial correlation of each time series, and (c) to compare the trend of seasonal and annual rainfall using the MK, mMK, SR, and ITA approaches.

2 Study Area

The semi-arid region, also known as North Interior Karnataka, lies between 14.26 °N to 18.49 °N latitude and 74.07 °E to 77.71 °E longitude, with an elevation of about 100 to 1100 m above msl (Fig. 1). It has 11 districts, namely Bagalkot, Belagavi (Belgaum), Ballari (Bellary), Bidar, Vijayapura (Bijapur), Dharwad, Gadag, Kalaburagi (Gulbarga), Haveri, Koppal, and Raichur. The region makes up 84,560 km^2, which is about 44% of the area of the state. The population is over 23 million (about 40%) (https://www.census2011.co.in/district.php). There are four seasons in the state of Karnataka in a year: January and February- winter, March to May- summer, June to September- monsoon, and October to December- post-monsoon. The temperature ranges between 5–25°C during the winter and 20–40°C during the summer. Though the temperature drops during the monsoon, the rise in humidity level could cause the weather to be unpleasant. The post-monsoon and winter seasons are generally pleasant. The district of Raichur experienced the lowest mean of total annual rainfall at 564 mm, while the district of Dharwad experienced the highest mean of total annual rainfall at 2233 mm (1901–2002). The region receives about 80% of the total annual rainfall during the southwest monsoon (June - September). The most commonly grown crops in the region are paddy, jowar, sugarcane, cotton, and finger millet (ragi).

Figure 1 Study area map of 11 semi-arid districts in northern Karnataka

3 Data And Methods

3.1 Data used

The monthly rainfall data of 11 districts (Fig. 1) of semi-arid Karnataka were retrieved from the India water portal (http://www.indiawaterportal.org/metdata) spanning 102 years (1901–2002). The monthly rainfall data at the district level have been applied for trend analysis for different regions across India (Chatterjee et al. 2016; Meshram et al. 2017; Pandey and Khare 2018; Sharma and Goyal 2020; Mahato et al. 2021). Each monthly time series dataset was further summed up to obtain seasonal and annual rainfall time series.

3.2 Methods

3.2.1 Homogeneity tests

A homogeneity test is conducted to check whether inhomogeneity in a time series is present due to human intervention. In the current study, the two-step approach proposed by Wijngaard et al. (2003) is applied to ascertain the deviation from absolute homogeneity of the time series. In the first step, the seasonal and annual rainfall data subjected to four standard statistical tests are (a) the Von Neumann ratio test (VNRT) (von Neumann 1941), (b) the Pettitt test (PT) (Pettitt 1979), (c) the standard normal homogeneity test (SNHT) (Alexandersson 1986), and (d) the Buishand range test (BRT) (Buishand 1982). In the second step, the following three classes are obtained based on the outcome of the four tests rejecting the null hypothesis when there is inhomogeneity:

(1) Category A: 'useful' — when three or all tests fail to accept the alternative hypothesis.

(2) Category B: 'doubtful' — when two tests accept the alternative hypothesis.

(3) Category C: 'suspect' — when one or none tests fail to accept the alternative hypothesis.

In this study, only the time series of category A was considered for further analysis at a 5% level of significance.

3.2.2 Serial correlation test

One of the assumptions of the classical trend analysis methods like the MK and SR tests is that the time series should have no significant serial correlation (lag-1) that influences the strength of trend analysis. The autocorrelation function (ACF) in the R programming language (R Core Team 2022) was used to determine a significant lag-1 correlation at a 95% confidence level.

3.2.3 Trend analysis

The Mann-Kendall (MK), Spearman's rho (SR) tests (Kendall 1938; Mann 1945; Daniel 1990), and Sen's slope estimator (SSE) (Sen 1968) are applied to the homogeneous (category A) and lag-1 serially independent time series of seasonal and annual rainfall to capture monotonic trend embedded in rainfall time series (Gocic and Trajkovic 2013; Formetta et al. 2016; Güner Bacanli 2017; Hajani et al. 2017; Pandey and Khare 2018; Gado et al. 2019). The modified MK (mMK) method Yue and Wang (2004) reported was applied to homogeneous and significant lag-1 serially dependent time series. This method was used to remove the influence of autocorrelation on the MK test by Monte Carlo simulation using the effective sample size (ESS). The MK test was subsequently applied to the autocorrelation eliminated time series obtained at a 5% significance level. The MK and SR tests indicate whether the trend is decreasing or increasing. If the magnitudes of MK and SR are positive (negative), then the trend is increasing (decreasing). The SSE represents the magnitude of a trend is increasing (decreasing) if it is positive (negative). The modifiedmk R package (Patakamuri and O'Brien 2020) was used to carry out the MK, mMK, SR, and SSE tests at 5 and 10% significance levels.

The innovative trend analysis (ITA) (Şen 2012a, 2017b) was conducted on the homogeneous rainfall time series, irrespective of the significance of the autocorrelation of the time series. The ITA test is independent of autocorrelation, normality, and data length. Two equal sub-series are obtained from the original rainfall time series to conduct ITA. Next, the two segregated datasets are arranged in increasing order. Then, the first sub-series data are placed on the x-axis and the second on the y-axis of the Cartesian coordinate system. The coordinates lying on the 45° line indicate the absence of a trend, below indicate a negative trend, and above indicate an increasing trend. The ITA test can also identify obscure trends, which is impossible with traditional methods because such methods can detect only monotonic trends (Şen 2012). The trendchange R package was applied to detect trends using the ITA method (Patakamuri and Das 2019) at 5 and 10% significance levels.

4 Results And Discussion

Each arid district of Karnataka consists of five time series, four for seasonal and one for annual. Hence, there are 55 time series for the 11 districts of Karnataka.

4.1 Homogeneity tests of seasonal and annual rainfall

All the 55 time series of the 11 districts were subject to four homogeneity tests, as shown in Table 1. For the winter season, the rainfall time series data of the Ballari and Haveri districts were doubtful. However, all the time series data of the summer season were in the useful category. The time series data of Bagalkot, Vijayapura, and Dharwad districts were doubtful for monsoon season. On the other hand, for the post-monsoon season, the rainfall of the Bidar and Vijayapura districts was identified to be in the suspect category. Also, the annual rainfall of Bagalkot, Vijayapura, and Dharwad fall into the suspect category. The rainfall of Bagalkot, Gadag, and Kalaburagi districts falls into the doubtful category. All the rainfall time series falling in the doubtful or suspect category were discarded from further analysis. Hence, 78.18% (43/55) of the total time series data were used for further analysis.

Table 1
Homogeneity test of the seasonal and annual rainfall of semi-arid region of Karnataka

District	Winter	Summer	Monsoon	Post monsoon	Annual
Bagalkot	useful	useful	**doubtful**	useful	**suspect**
Belagavi	useful	useful	useful	useful	useful
Ballari	**doubtful**	useful	useful	useful	useful
Bidar	useful	useful	useful	**suspect**	useful
Vijayapura	useful	useful	**doubtful**	**suspect**	**suspect**
Dharwad	useful	useful	**doubtful**	useful	**suspect**
Gadag	useful	useful	useful	useful	**doubtful**
Kalaburagi	useful	useful	useful	useful	**doubtful**
Haveri	**doubtful**	useful	useful	useful	useful
Koppal	useful	useful	useful	useful	useful
Raichur	useful	useful	useful	useful	useful
Note: “doubtful” and “suspect” categories were discarded for further analysis.					

Table 1 Homogeneity test of the seasonal and annual rainfall of semi-arid region of Karnataka

4.2 Lag-1 correlation tests of seasonal and annual rainfall

Out of the 43 time series data carried out for lag-1 correlation, 95.35% (41/43) time series data was found to have insignificant autocorrelation (Table 2). The datasets of the post-monsoon and annual rainfall of the Belagavi district were found to have a significant ($p < 0.05$) lag-1 correlation. Therefore, the modified Mann Kendall (mMK) was applied to these two time series rainfall data.

Table 2
Lag-1 correlation test of seasonal and annual rainfall of semi-arid region of Karnataka

District	Winter	Summer	Monsoon	Post monsoon	Annual
Bagalkot	No	No	-	No	-
Belagavi	No	No	No	Yes	Yes
Ballari	-	No	No	No	No
Bidar	No	No	No	-	No
Vijayapura	No	No	-	-	-
Dharwad	No	No	-	No	-
Gadag	No	No	No	No	-
Kalaburagi	No	No	No	No	-
Haveri	-	No	No	No	No
Koppal	No	No	No	No	No
Raichur	No	No	No	No	No
Note:”No” means significant lag-1 correlation does not exist, “Yes” means lag-1 correlation exists.					

Table 2 Lag-1 correlation test of the seasonal and annual rainfall of semi-arid region of Karnataka

4.3 Trend analysis of seasonal and annual rainfall

4.3.1 Trend analysis of winter rainfall

For the winter season, the MK and SR tests detected an insignificantly decreasing (negative) trend in seven of the nine districts with homogeneous rainfall time series (Table 3). On the other hand, the rainfall of the Koppal and Raichur districts shows a significantly decreasing trend at a 10% significance level. The ITA method, however, detected decreasing trend in all the nine districts at a 5% level of significance. The magnitudes of Sen’s slope for Koppal and Raichur districts are significantly decreasing at 0.0002 and 0.0003 mm/year (Table 4, Fig. 2), respectively. The slopes of the ITA method indicate that the Vijayapura district experienced the least decreasing trend, whereas Dharwad experienced the highest decreasing trend among all the districts. The ITA slope ranges − 0.008 to − 0.07 mm/year (Fig. 3).

Table 3
Trend indication of seasonal and annual rainfall of the semi-arid districts of Karnataka

District	Winter			Summer			Monsoon			Post monsoon			Annual		
	MK	Spearman	ITA	MK	Spearman	ITA	MK	Spearman	ITA	MK	Spearman	ITA	MK	Spearman	ITA
Bagalkot	−	−	−*	+	+	+*	NA	NA	NA	+**	+**	+*	NA	NA	NA
Belagavi	−	−	−*	+	+	+*	−	−	+*	+/+*	+	+*	−/−	−	+*
Ballari	NA	NA	NA	−	−	+*	−	−	−	+	+	+*	+	+	+*
Bidar	−	−	−*	+	+	+*	−	−	+*	NA	NA	NA	+	+	+*
Vijayapura	−	−	−*	+	+	+*	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dharwad	−	−	−*	−	−	+*	NA	NA	NA	+	+	−*	NA	NA	NA
Gadag	−	−	−*	−	−	−	−	−	+	−	−	−*	NA	NA	NA
Kalaburagi	−	−	−*	+**	+**	+*	+	+	+*	+*	+*	+*	NA	NA	NA
Haveri	NA	NA	NA	−	−	+*	−	−	−*	+	+	+*	−	−	−*
Koppal	−**	− **	−*	−	−	+*	+	+	+*	+	+	+*	+	+	+*
Raichur	−**	− **	−*	+	+	+*	+	+	+*	+	+	+*	+*	+*	+*

Note: **−** indicates negative trend; **+** indicates positive trend; * indicates 5% significance level; ** indicates 10% significance level; NA indicates no analysis was carried out.

Table 4
Magnitude of trends of the winter rainfall

District	Sen's slope	ITA slope	Slope of SD (SSD)	Correlation ($\rho y_1 y_2$)	Lower CL	Upper CL
Bagalkot	0	−0.01*	0.0009	0.98	−0.002	0.002
Belagavi	−0.00004	−0.01*	0.001	0.93	−0.002	0.002
Ballari	NA	NA	NA	NA	NA	NA
Bidar	0	−0.06*	0.009	0.91	−0.02	0.02
Vijayapura	0	−0.008*	0.001	0.96	−0.003	0.003
Dharwad	0	−0.07*	0.003	0.98	−0.005	0.005
Gadag	0	−0.03*	0.001	0.99	−0.002	0.002
Kalaburagi	−0.0004	−0.03*	0.002	0.97	−0.005	0.005
Haveri	NA	NA	NA	NA	NA	NA
Koppal	−0.0002**	−0.03*	0.002	0.95	−0.003	0.003
Raichur	−0.0003**	−0.02*	0.001	0.98	−0.002	0.002

Note: * indicates 5% significance level; ** indicates 10% significance level; NA indicates no analysis was carried out.

Table 3 Trend indication of seasonal and annual rainfall of the semi-arid districts of Karnataka

Table 4 Magnitude of trends of the winter rainfall

Figure 2 Sen's slope map of seasonal and annual rainfall

Figure 3 ITA slope map of seasonal and annual rainfall

4.3.2 Trend analysis of summer rainfall

The MK and SR tests for the districts (5/11; 45.45%) of Bagalkot, Belagavi, Bidar, Vijayapura, and Raichur show an insignificant increasing (positive) trend of rainfall, whereas the districts (5/11; 45.45%) of Ballari, Dharwad, Gadag, Haveri, and Koppal show insignificant decreasing trend at 95% confidence interval (Table 5). The district (9.1%) of Kalaburagi is the only one to experience a significantly increasing trend at a 90% confidence interval as per the MK and SR tests (Fig. 2). Out of the 11 districts with homogeneous rainfall, except the district of Gadag, the remaining districts (90.91%) show a significantly increasing trend at a 5% significance level as per the ITA method (Table 3). Gadag is the only district to show an insignificantly decreasing trend using the ITA method. The Sen's slope of Kalaburagi is 0.18 mm/year. The ITA slope lies in the range 0.13–0.38 mm/year, in which the district of Koppal shows the least positively significant trend of 0.13 mm/year (Fig. 3). Moreover, Belagavi and Vijayapura districts show the highest positively significant trend of 0.38 mm/ year.

Table 5
Magnitude of trends of the summer rainfall

District	Sen's slope	ITA slope	Slope of SD (SSD)	Correlation ($\rho y_1 y_2$)	Lower CL	Upper CL
Bagalkot	0.12	0.37*	0.034	0.96	−0.07	0.07
Belagavi	0.06	0.38*	0.02	0.99	−0.03	0.03
Ballari	−0.02	0.18*	0.02	0.98	−0.03	0.03
Bidar	0.09	0.16*	0.02	0.97	−0.03	0.03
Vijayapura	0.20	0.38*	0.03	0.96	−0.05	0.05
Dharwad	−0.21	0.17*	0.02	0.99	−0.05	0.05
Gadag	−0.25	−0.01	0.02	0.98	−0.05	0.05
Kalaburagi	0.18**	0.31*	0.02	0.96	−0.04	0.04
Haveri	−0.06	0.34*	0.04	0.98	−0.07	0.07
Koppal	−0.1	0.13*	0.02	0.99	−0.03	0.03
Raichur	0.14	0.35*	0.02	0.98	−0.03	0.03
Note: * indicates 5% significance level; ** indicates 10% significance level.						

Table 5 Magnitude of trends of the summer rainfall

4.3.3 Trend analysis of monsoon rainfall

Out of the eight districts with homogeneous time series for monsoon rainfall, none showed a significant trend using the MK and SR tests at 5% and 10% significance levels (Table 3). However, the ITA method captured significant positive and negative trends for five (62.5%) and one (12.5%) of the eight districts, respectively, at a 5% significance level. Only Ballari and Gadag districts experienced insignificantly decreasing and increasing trends using the ITA method, respectively. Belagavi, Ballari, Bidar, Gadag, and Haveri districts show a negatively insignificant trend, whereas Kalaburagi, Koppal, and Raichur indicate a positively insignificant trend. Using the ITA method, the Haveri district experienced the most decreasing trend at 1.07 mm/year, whereas Belagavi at 0.86 mm/year shows the most increasing trend (Table 6). Bidar district had the least increasing trend at 0.2 mm/year.

Table 6
Magnitude of trends of the monsoon rainfall

District	Sen's slope	ITA slope	Slope of SD (SSD)	Correlation ($\rho y_1 y_2$)	Lower CL	Upper CL
Bagalkot	NA	NA	NA	NA	NA	NA
Belagavi	−0.77	0.86*	0.22	0.94	−0.43	0.43
Ballari	−0.009	−0.01	0.03	0.99	−0.07	0.07
Bidar	−0.02	0.20*	0.05	0.98	−0.1	0.1
Vijayapura	NA	NA	NA	NA	NA	NA
Dharwad	NA	NA	NA	NA	NA	NA
Gadag	−0.74	0.08	0.08	0.98	−0.16	0.16
Kalaburagi	0.16	0.45*	0.03	0.99	−0.07	0.07
Haveri	−1.53	−1.07*	0.16	0.96	−0.32	0.32
Koppal	0.2	0.38*	0.04	0.98	−0.08	0.08
Raichur	0.23	0.37*	0.03	0.99	−0.05	0.05
Note: * indicates 5% significance level; ** indicates 10% significance level; NA indicates no analysis was carried out.						

Table 6 Magnitude of trends of the monsoon rainfall

4.3.4 Trend analysis of post-monsoon rainfall

Out of nine districts with homogeneous post-monsoon rainfall, the MK and SR tests detected an increasing trend for two districts (Bagalkot at 90% and Kalaburagi at 95% confidence intervals) (Table 3). The mMK test was applied to the post-monsoon rainfall for the Belagavi district because it had a significant lag-1 correlation ($p < 0.05$). Therefore, the rainfall for the Belagavi district turned out to have an increasing trend ($p < 0.05$). The Belagavi, Ballari, Bidar, Vijayapura, Dharwad, Haveri, Koppal, and Raichur districts show an insignificantly increasing trend ($p < 0.1$). In contrast, the district of Gadag shows an insignificantly decreasing trend using the MK and SR tests. The ITA method detected a significant ($p < 0.05$) trend in all the nine districts. The Bagalkot, Belagavi, Ballari, Kalaburagi, Haveri, Koppal, and Raichur districts experienced increasing trends, while Dharwad and Gadag showed decreasing trends using the ITA method. The Sen's slopes of Bagalkot, Belagavi, and Kalaburagi are 0.47, 0.25, and 0.63 mm/year, respectively (Table 7, Fig. 2). The Ballari district shows the least increasing ITA slope (0.06 mm/year), and the highest increasing ITA slope (0.62 mm/year) is shown by the Kalaburagi district. Dharwad and Gadag districts show decreasing ITA slope at 0.05 mm/year (Table 7, Fig. 3).

Table 7
Magnitude of trends of the post-monsoon rainfall

District	Sen's slope	ITA slope	Slope of SD (SSD)	Correlation ($\rho y_1 y_2$)	Lower CL	Upper CL
Bagalkot	0.47**	0.52*	0.03	0.97	−0.06	0.06
Belagavi	0.25	0.21*	0.04	0.97	−0.08	0.08
Ballari	0.09	0.06*	0.02	0.99	−0.04	0.04
Bidar	NA	NA	NA	NA	NA	NA
Vijayapura	NA	NA	NA	NA	NA	NA
Dharwad	0.003	−0.05	0.02	0.99	−0.04	0.04
Gadag	−0.04	−0.05	0.02	0.99	−0.04	0.04
Kalaburagi	0.63*	0.62*	0.03	0.98	−0.06	0.06
Haveri	0.08	0.10*	0.03	0.98	−0.06	0.06
Koppal	0.14	0.12*	0.03	0.98	−0.06	0.06
Raichur	0.34	0.26*	0.02	0.99	−0.03	0.03

Note: * indicates 5% significance level; ** indicates 10% significance level; NA indicates no analysis was carried out.

Table 7 Magnitude of trends of the post-monsoon rainfall

4.3.5 Trend analysis of annual rainfall

Out of the six districts with homogeneous annual rainfall, only Raichur experienced an increasing trend ($p < 0.05$) using the MK and SR tests (Table 3). Even after the annual rainfall of the district of Belagavi (significant lag-1 correlation at $p < 0.05$) was subjected to the mMK test apart from the two tests, the district experienced an insignificant trend. Belagavi and Haveri districts experienced an insignificant decreasing trend. In contrast, Ballari, Bidar, and Koppal districts show an insignificant increasing trend using the MK, SR, and mMK tests. The ITA method detected significant increasing/decreasing trends in all six districts. The Belagavi, Ballari, Bidar, Koppal, and Raichur districts were found to have a significantly increasing trend, whereas Haveri had a significant decreasing trend using the ITA method ($p < 0.05$). The Sen's slope of the Raichur district indicates an increasing trend (0.88 mm/year) (Table 8, Fig. 2). The ITA slope of the Ballari district shows the least increasing trend (0.19 mm/year), whereas the Belagavi district shows the most increasing trend (1.44 mm/year) (Table 8, Fig. 3). The magnitude of the slope of the Haveri district shows decreasing trend (0.68 mm/year).

Table 8
Magnitude of trends of the annual rainfall

District	Sen's slope	ITA slope	Slope of SD (SSD)	Correlation ($\rho y_1 y_2$)	Lower CL	Upper CL
Bagalkot	NA	NA	NA	NA	NA	NA
Belagavi	−0.44	1.44*	0.22	0.94	−0.44	0.44
Ballari	0.06	0.19*	0.05	0.98	−0.09	0.09
Bidar	0.86	1.12*	0.09	0.96	−0.19	0.19
Vijayapura	NA	NA	NA	NA	NA	NA
Dharwad	NA	NA	NA	NA	NA	NA
Gadag	NA	NA	NA	NA	NA	NA
Kalaburagi	NA	NA	NA	NA	NA	NA
Haveri	−1.31	−0.68*	0.05	0.99	−0.11	0.11
Koppal	0.36	0.6*	0.06	0.98	−0.11	0.11
Raichur	0.88*	0.96*	0.05	0.98	−0.11	0.11
Note * indicates 5% significance level; ** indicates 10% significance level; NA indicates no analysis was carried out.						

Table 8 Magnitude of trends of the annual rainfall

5 Comparative Analysis Of The Ita With Mk, Mmk And Sr Tests

Out of the 43 homogeneous rainfall time series, only six showed significant trends using the MK and SR methods. Since two time series showed significant lag-1 correlation ($p < 0.05$), only 14.63% of the time series (6/ (43 − 2) = 0.1463) reveal significant trend using the two tests. Only a district out of the two shows a significant trend. However, the ITA method could detect 93.02% of the total time series (40/43 = 0.9302). This outcome could be because the classical trend test methods like the MK and SR detect only monotonic (decreasing/ increasing) trend in time series. In contrast, the ITA method can capture obscure trends that are not easily captured by the traditional methods (Şen 2012). Though no categorisation of verbal clusters as reported in Şen (2012) was carried out in this study, visual inspections of the scatter plots of the ITA method could give us insights into the trend behaviour of seasonal and annual rainfall. The scatter points above/below the 1:1 (45°) line indicate an increasing/decreasing/ trend.

The trends of the MK, SR, and ITA tests match for the Bagalkot district irrespective of whether the trend is significant or not. On visual inspection, the low and medium clusters of rainfall of the second half of the series (1952–2002) follow decreasing trend (Fig. 4a) in regard to the first half of the data (1901–1951). However, the same clusters of the second half of the parent series for summer and post-monsoon seasons follow an increasing trend (Fig. 4b-c).

Figure 4 Innovative trend analysis of Bagalkot and Belagavi districts

For the Belagavi district, except monsoon and annual rainfall trends, the direction of trends in winter, summer, and post-monsoon match each other using the MK, SR, and ITA tests irrespective of whether the trend is significant or insignificant. In Fig. 4f-h, the ITA method detected a monotonic insignificant decreasing trend, whereas the MK and SR tests detected otherwise for the corresponding time scales. If visually inspected, it is seen that more scatter points lie on the line parallel to 1:1 in both the figures. It suggests that the MK and SR tests failed to detect more scatter points on the upper side of the 1:1 line than the ITA method.

For the summer in the Ballari district, the MK and SR detected an insignificantly decreasing trend. However, the ITA method captured the medium cluster of rainfall lying on the upper triangular side, indicating a significantly increasing trend (Fig. 5a). All the methods detected insignificantly decreasing trends for the monsoon season as reflected by scatter points lying slightly downward along the 1:1 line (Fig. 5b). For post-monsoon and annual rainfall of the district, all the trend methods have the same direction of trend (increasing) though only the ITA method has a significant trend (Fig. 5c-d).

Figure 5 Innovative trend analysis of Ballari and Bidar districts

There is an opposing direction of the trend for the Bidar district between traditional and innovative methods in the monsoon season. In contrast, the trend direction matches winter, summer, and annual scales. However, only the ITA method indicates significance in all the tested seasonal and annual rainfall (Fig. 5e-h). Though the trend directions for the winter and summer seasons of Vijayapura and Dharwad districts are the same using the MK, SR, and ITA tests, only the ITA method captured the trend (Figs. 6a-d). For the post-monsoon season of Dharwad, the trend direction is insignificantly increasing using the MK and SR tests but significantly decreasing using the ITA (Fig. 6e). The Gadag district experienced decreasing trend for winter and post-monsoon seasons using all three methods, but only the ITA test captured a significant trend (Figs. 6f,7a). The trend direction in all the seasons of the Kalaburagi district matches for all three methods; however, the classical methods could capture a significant trend (10% significance level) only for the summer season (Table 3). On the other hand, ITA could detect a significant trend in all the seasons (Fig. 7b-e).

Figure 6 Innovative trend analysis of Vijayapura, Dharwad and Gadag districts

Figure 7 Innovative trend analysis of Gadag, Kalaburagi and Haveri districts

Except for the summer season in the Haveri district, the trend direction of monsoon, post-monsoon, and annual rainfall is the same. As with other districts, ITA captured a significant trend for all the mentioned seasons and annually (Figs. 7f-h,8a). For the Koppal district, except for the summer season trend, all other seasons and annual rainfall showed the same trend direction using all three methods. The two traditional methods could capture a significant trend in the winter season, whereas the ITA captured a significant trend in all the seasons (Fig. 8b-f). For the Raichur district, the trend direction matches for all the seasons and annual scale. The trend is significant for winter and annual rainfall using the MK and SR tests, but the ITA could detect a significant trend for all seasonal and annual scales (Figs. 8g-9c). The comparisons carried out for all seasonal and annual rainfall of the 11 districts using the ITA and traditional methods reveal that the ITA approach was indeed able to capture the monotonic trends detected by the traditional methods and the obscure trends. The outcome of the current study corroborates with the findings reported in recent literature (Marak et al. 2020; Singh et al. 2021b, a).

Figure 8 Innovative trend analysis of Haveri, Koppal and Raichur districts

Figure 9 Innovative trend analysis of Raichur district

6 Conclusions

In this study, trend analysis was investigated using the MK, mMK, SR, and the ITA methods for the seasonal and annual rainfall of 11 semi-arid districts in Karnataka for 102 years (1901–2002) of data. Only 78.18% (43/55) of the total time series data were homogeneous based on a two-step approach that involved four statistical methods and classification of the methods into three categories. Out of the 43 homogeneous time series data, 95.35% (41/43) time series data were found to have insignificant autocorrelation. The post-monsoon and annual rainfall of the Belagavi district were found to have a significant ($p < 0.05$) lag-1 correlation; however, the mMK test showed an increasing trend for the post-monsoon season only. The MK and SR tests detected 14.63% of the time series (6/ (43 − 2) = 0.1463) as a significant trend. However, the ITA method could detect 93.02% (40/43 = 0.9302) of the total time series. The MK and SR tests could capture a significant trend for the winter season in Koppal and Raichur districts. The two tests could detect significant trend only in the Kalaburagi district for the summer season. No trend could be captured for the monsoon season. The significant trend in Bagalkot and Kalaburagi districts could be captured for the post-monsoon season. The tests could detect a significant trend in the Raichur district for annual rainfall; however, the ITA captured a significant trend for all the seasons in most districts.

Declarations

Data availability

The datasets generated during and/or analysed during the current study are available in the India water portal repository, http://www.indiawaterportal.org/metdata

Compliance with Ethical Standards

The authors declare that they have no known conflict of interest.

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Figures

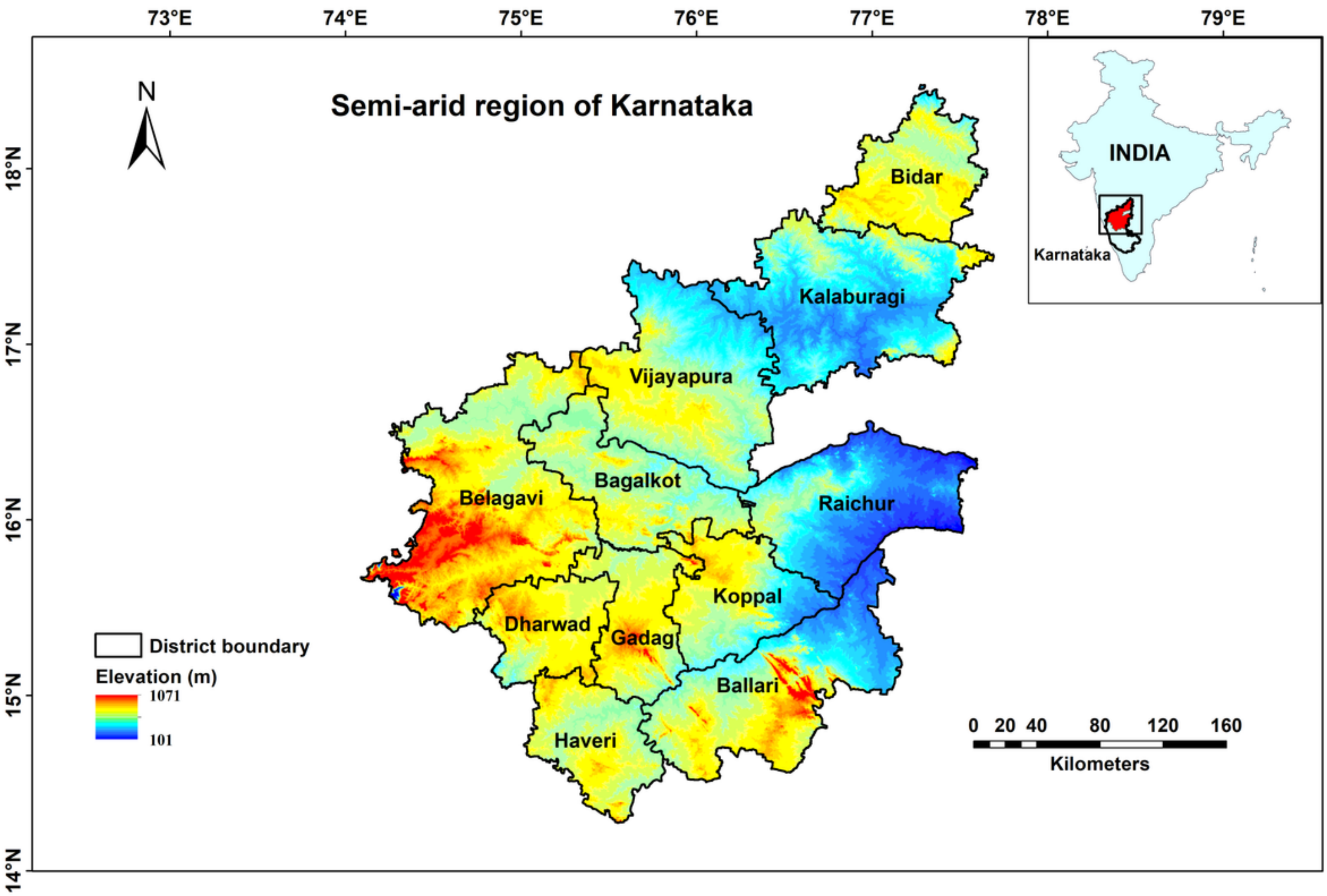

Figure 1

Study area map of 11 semi-arid districts in northern Karnataka

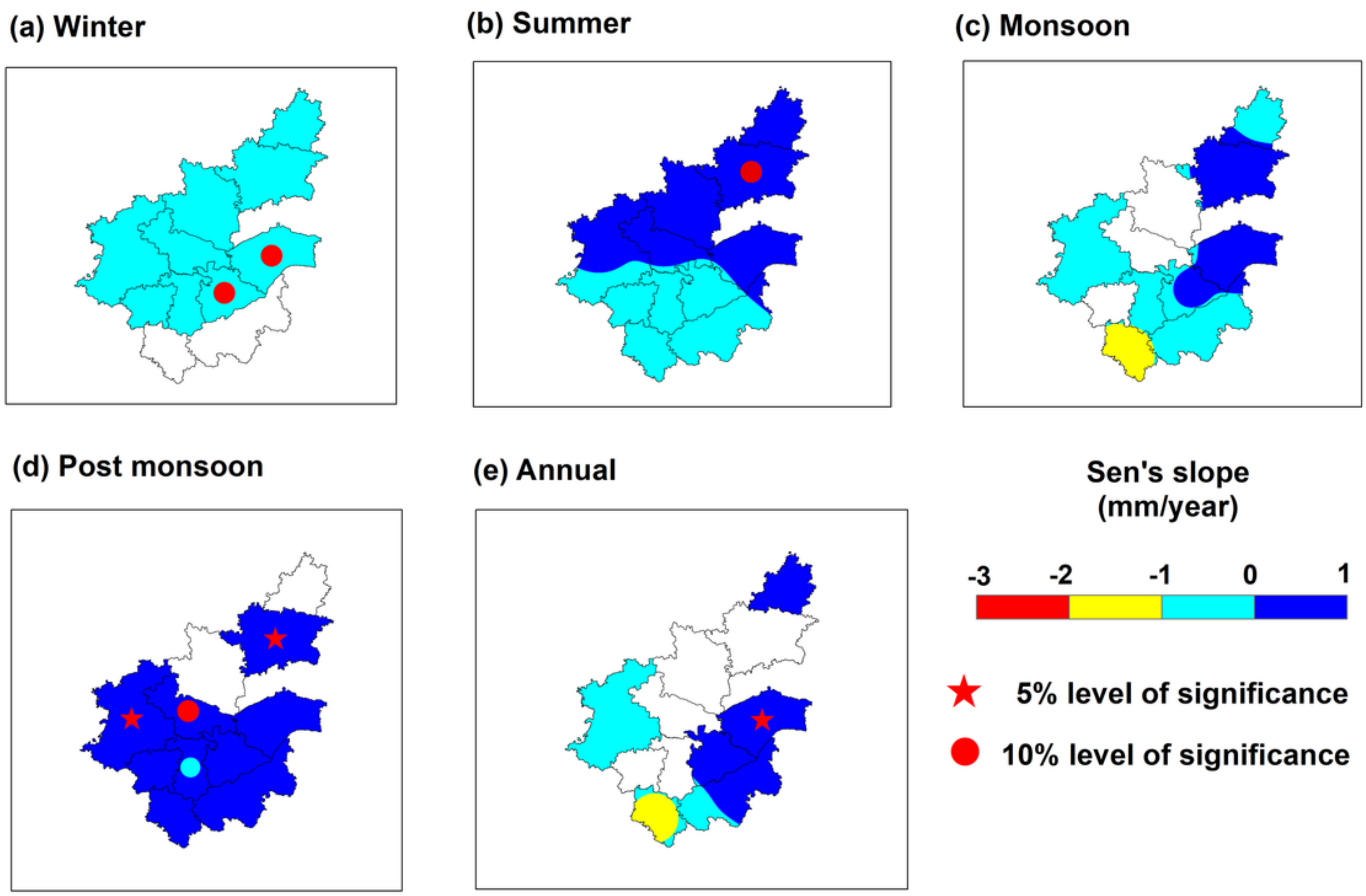

Figure 2

Sen’s slope map of seasonal and annual rainfall

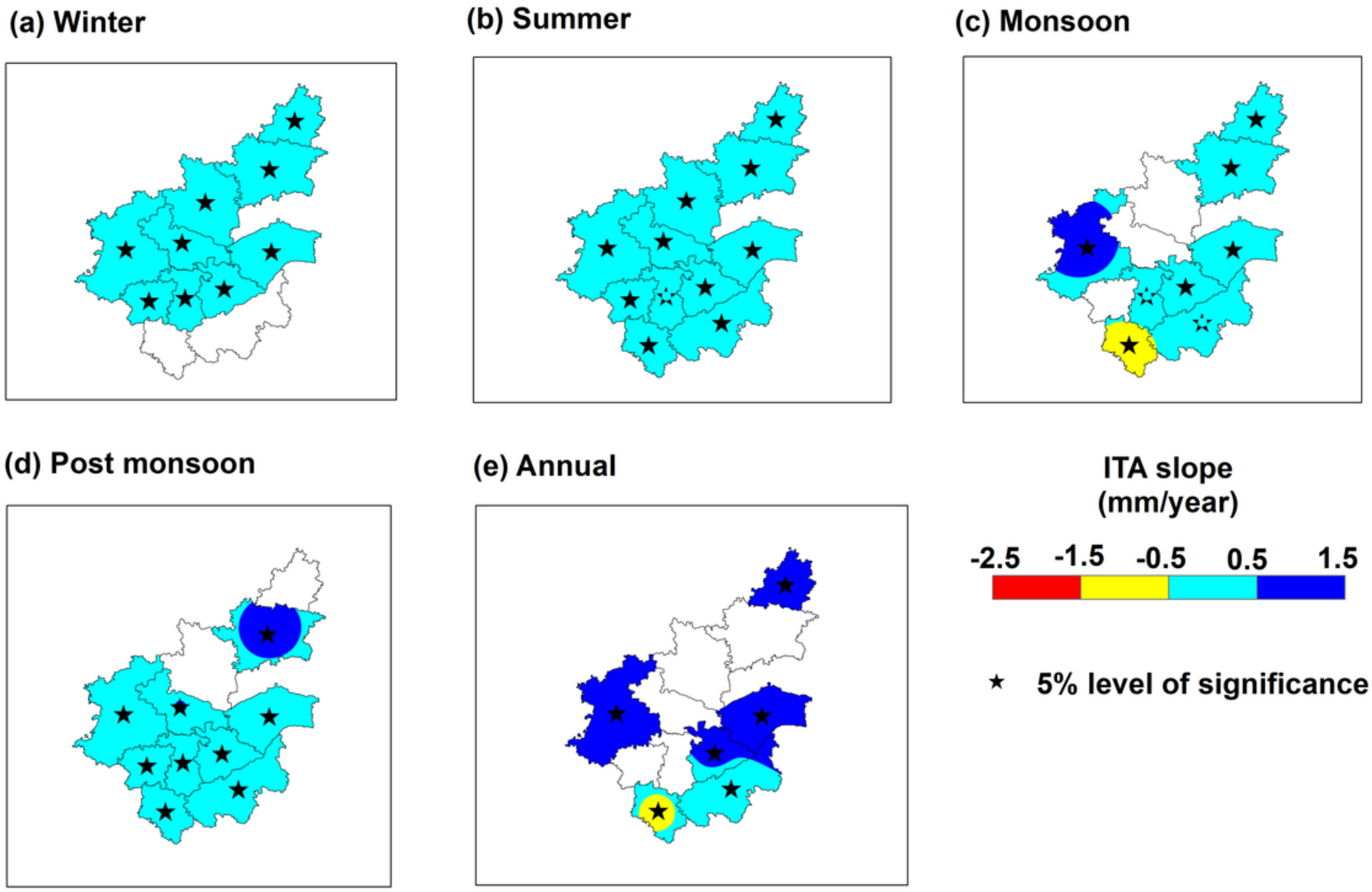

Figure 3

ITA slope map of seasonal and annual rainfall

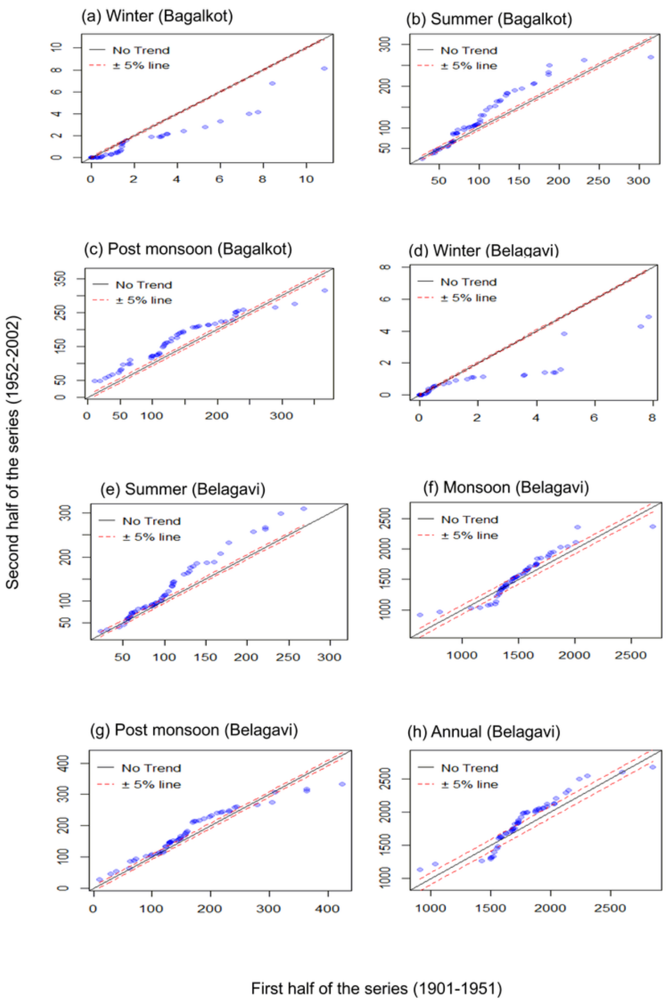

Figure 4

Innovative trend analysis of Bagalkot and Belagavi districts

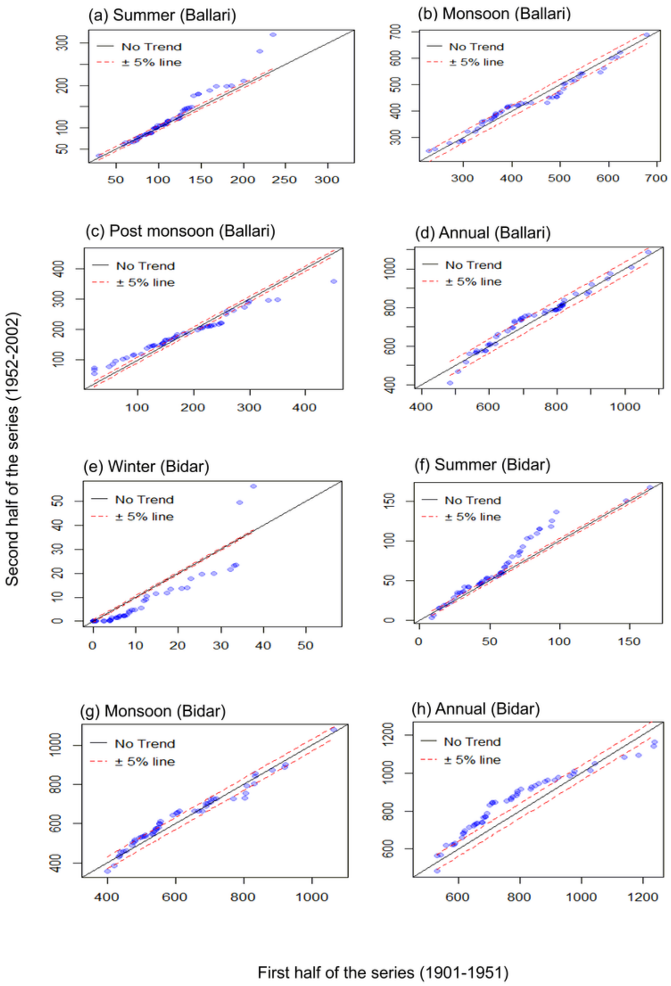

Figure 5

Innovative trend analysis of Ballari and Bidar districts

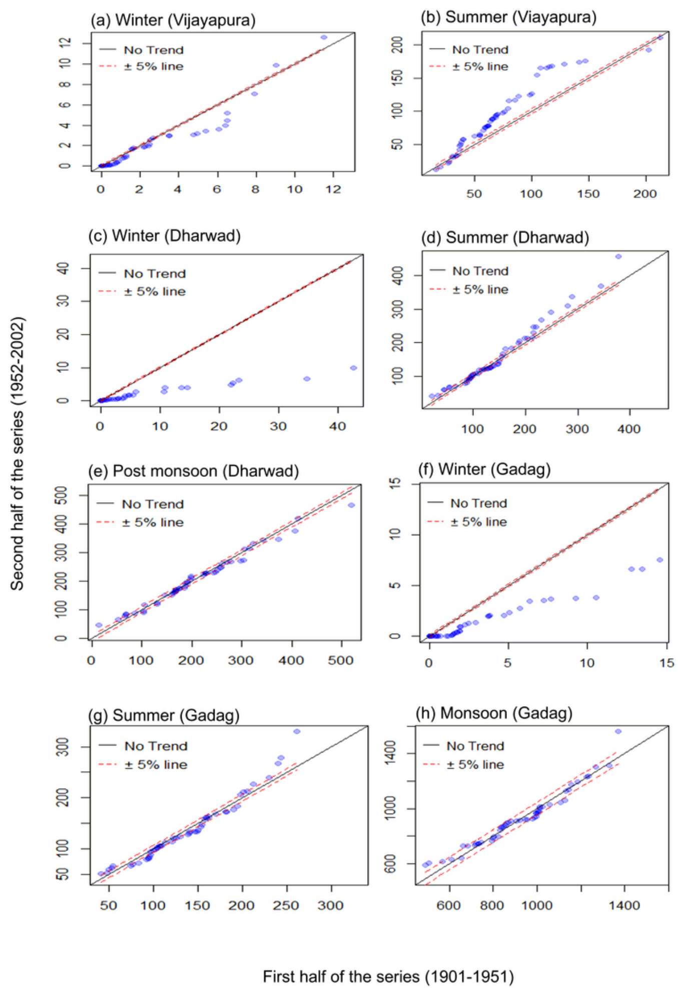

Figure 6

Innovative trend analysis of Vijayapura, Dharwad and Gadag districts

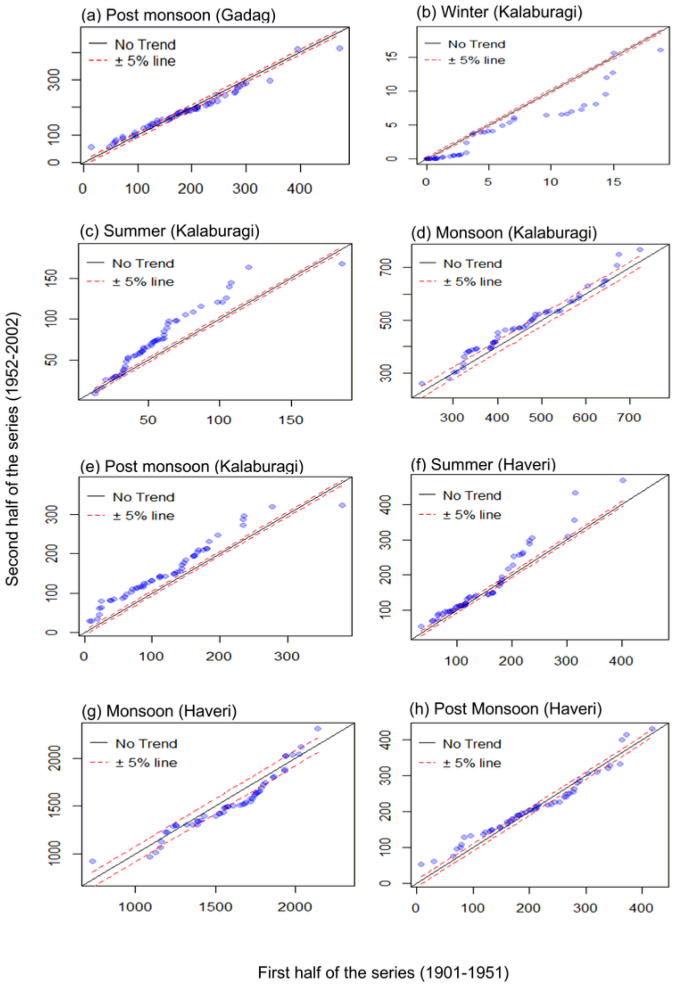

Figure 7

Innovative trend analysis of Gadag, Kalaburagi and Haveri districts

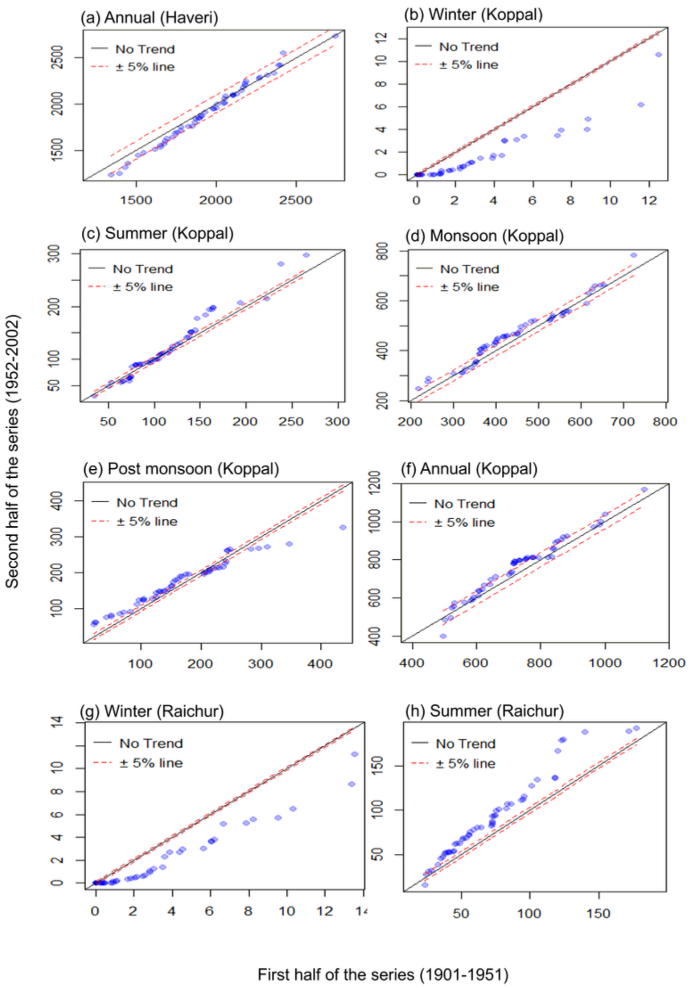

Figure 8

Innovative trend analysis of Haveri, Koppal and Raichur districts

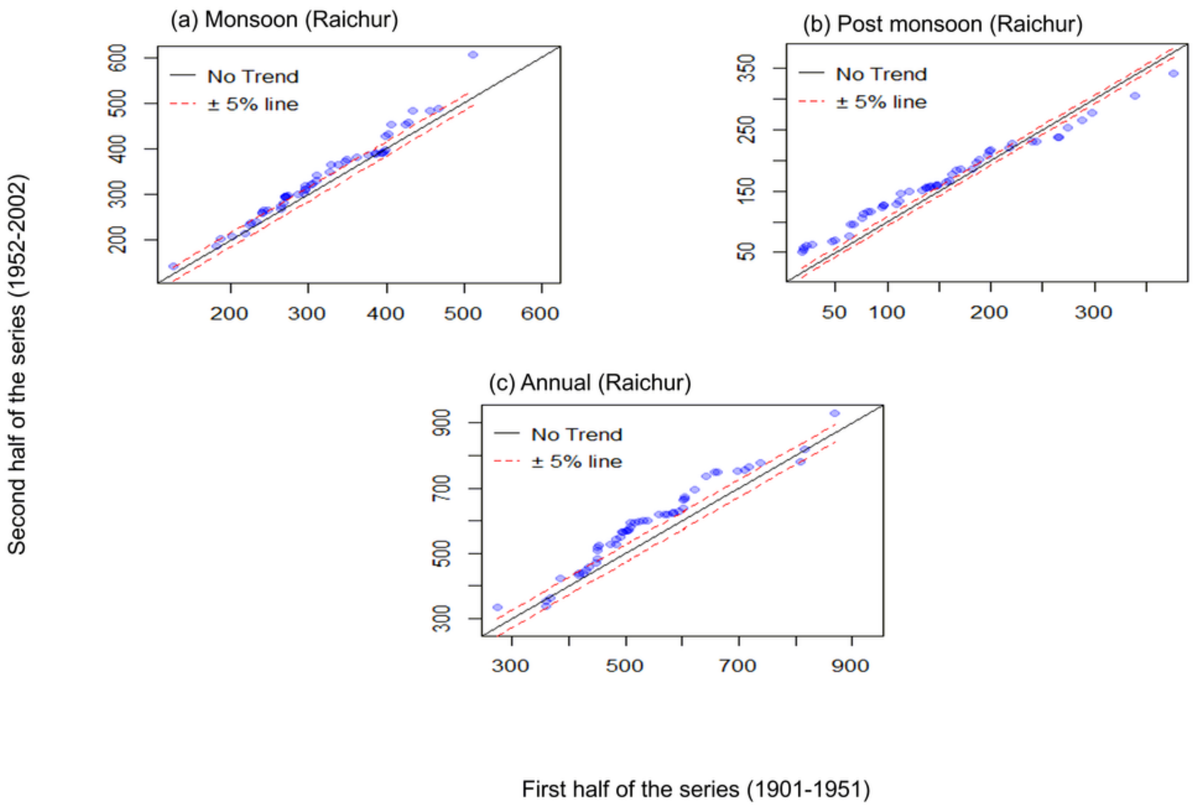

Figure 9

Innovative trend analysis of Raichur district

Supplementary Files

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- SupplementTable.pdf