



Trend analysis of rainfall pattern over the Central India during 1901–2010

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Abstract

In the present study, trends of rainfall of the Central India were evaluated in monthly, seasonal, and annual time scales using the Revised Mann-Kendall (RMK) test, Sen's slope estimator, and innovative trend method (ITM). For this purpose, the monthly rainfall data for 20 stations in Madhya Pradesh (MP) and Chhattisgarh (CG) states in Central India during 1901–2010 was used. The Sen's slope estimator was utilized for calculating the slope of rainfall trend line. Based on the obtained results of RMK test, there is no significant trend in the stations for the January and October months. The results also showed that for MP, two out of 15 considered stations indicate significant annual trend, while the CG has four out of five stations with significant trend. The results of applying ITM test indicated that most of the stations have decreasing trends in annual (16 stations), summer (16 stations), and monsoon (11 stations) seasons, while the winter (12 stations) and post monsoon (11 stations) seasons generally show increasing trend. Unlike the RMK, the ITM shows significant increasing trend in rainfall of November and December months. The finding of current study can be used for irrigation and water resource management purpose over the Central India.

Keywords Trend · Rainfall · Mann-Kendall test · Sen's slope estimator · Innovative trend method (ITM) · Central India

Introduction

The researches indicate that the mean global air temperature has increased approximately by 0.6 °C during twentieth century due to increase in atmospheric greenhouse gases (Nazeri Tahroudi et al. 2018). Human activities are considered as the main reason of increasing the atmospheric greenhouse gases, which leads to climate change in different regions across the world. One of the most effective consequences of climate change is changing of amount, types, and spatial and temporal variation of rainfall,

which is more severe in some parts of the earth (Zamani et al. 2018). Rainfall is a main factor of climate, and its variations have a direct effect on agricultural productivity, occurrence of floods, or drought (Abdi et al. 2017). Therefore, investigation on variation of rainfall is a necessary issue in planning and managing of water resources and also designing suitable plans to cope with floods and drought conditions.

Trend analysis is one of the most popular approach, which has widely used by researchers for analyzing the variation of hydro-meteorological variables during the last two decades. Hereunto, many methods have been developed and applied for analyzing the trend of hydro-meteorological variables, which have their own limitations and advantages. Generally, the trend analysis methods are divided into parametric and non-parametric techniques. In the recent years, the non-parametric methods are preferred by researchers for trend analysis because these methods are not sensitive to outliers and can be applied for non-normally distributed series with missing values (Ahmadi et al. 2017). Among the non-parametric methods, the Mann-Kendall (MK) test, which proposed by Mann (1945) and Kendall (1975), is more popular and has suggested by World Meteorological Organization (WMO) for analyzing the trends of hydro-meteorological time series (Kumar et al. 2009).

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The main limitation in applying the MK test on hydro-climatological data sets is the assumption of lack of significant autocorrelation in considered time series, while most of hydro-climatological time series are serially correlated (Dinpashoh et al. 2014). The previous studies revealed that if the effect of autocorrelation does not remove from time series, then the negative autocorrelation leads to underestimate the significance of trends, while the positive autocorrelation leads to overestimate the significance of trends (Hamed and Rao 1998 and Koutsoyiannis 2003). In order to overcome this defect, when the lag-1 autocorrelation was significant, it was removed from time series before applying the MK test. The significant lag-1 autocorrelation coefficient in time series named as short-term persistence (STP). However, in some time series, the autocorrelations with more than one lag are significant and can affect on accuracy of the MK test (Zamani et al. 2017). The significant auto-correlation with more than one, named as long-term persistence (LTP) (Koutsoyiannis and Montanari 2007). Hamed (2008) developed a revised version of MK (RMK) test, which removed the effect of all significant autocorrelation coefficient from time series before performing the MK test. This procedure called trend-free pre-whitening (TFPW) method. Another version of MK test was proposed by Hamed (2008), which takes into account the Hurst phenomenon.

Kumar et al. (2009) compared the performance of four versions of MK test, i.e., classic MK test, MK test after removing the lag-1 autocorrelation, TFPW method, and MK test considering the Hurst coefficient for detecting the trends in streamflow time series recorded in 31 USGS stations in Indiana. The results showed that the autocorrelation structure had not significant effect on the trend of rainfall time series. In addition, it was found that the low flows were more correlated than high flows in Northern Indiana. Heretofore, a numerous studies have been conducted to analyze the trend of hydro-climatological variables using above-mentioned versions of MK test (Yue and Wang 2004; Pal and Al-Tabbaa 2009; De Martino et al. 2013; Jhajharia et al. 2014; Gajbhiye et al. 2016; Amirataee et al. 2016; Zamani et al. 2017; Yan et al. 2017; and many others). The main disadvantage of the MK is involving some assumptions, which are independent structure of the time series, data distribution, and data length.

Recently, a new non-parametric basis method was proposed by Şen (2011) for detection of significant trend in time series, which called as innovative trend method (ITM). In a simple word, the ITM method considers the location of data points in a Cartesian coordinate system and compares them with the 1:1 line as the benchmark (Tabari and Willems 2015). The ITM method is rather simple and is not subject to any preconditions, such as non-normality, autocorrelation, and data length, and also, this method clearly shows the trends of high, medium, and low data (Tosunoglu and Kisi 2017). Although the ITM method is recently proposed, it quickly attracted the attention of researchers, as many studies have conducted by this method.

Tabari and Willems (2015) used the ITM method for analyzing the streamflow trend at eight stations in the northwest of Iran and compared the results of ITM method with MK test. Demir and Kisi (2016) analyzed the trend in annual total rainfall in six provinces in Turkey by MK and ITM tests. Dabanlı et al. (2016) compared the performance of MK and ITM methods for analyzing the trend of relative humidity, temperature, rainfall, and runoff variables in Ergene Basin, Turkey. Tosunoglu and Kisi (2017) analyzed the trend of annual maximum duration (AMD) and annual maximum severity (AMS) using classic MK test, RMK test, and ITM test in nine stations located in Coruh River Basin, Turkey. The results showed that the RMK test provided no significant trend for the other seven stations, while the ITM identified some significant increasing or decreasing trends at these stations. Wu and Qian (2017) analyzed the trends of seasonal and annual rainfall time series at 14 rain gauges in Shaanxi Province, China, applying the ITM, MK, and linear regression methods. Öztopal and Sen (2017) have applied the ITM method for examining the rainfall trend at seven stations in Turkey. Şen (2017a) proposed an over-whitening (O-W) procedure instead of pre-whitening (P-W) procedure for generating independent time series with the same trend line slope. The previous studies used ITM based on graphical evaluation only. Şen (2017b) recently developed a significance test for ITM method and applied on annual total rainfall records of Tigris River Diyarbakir, annual temperature records of Southern New Jersey, and annual discharge time series of Danube River. In the present study, ITM was employed with significance test suggested by Şen (2017b).

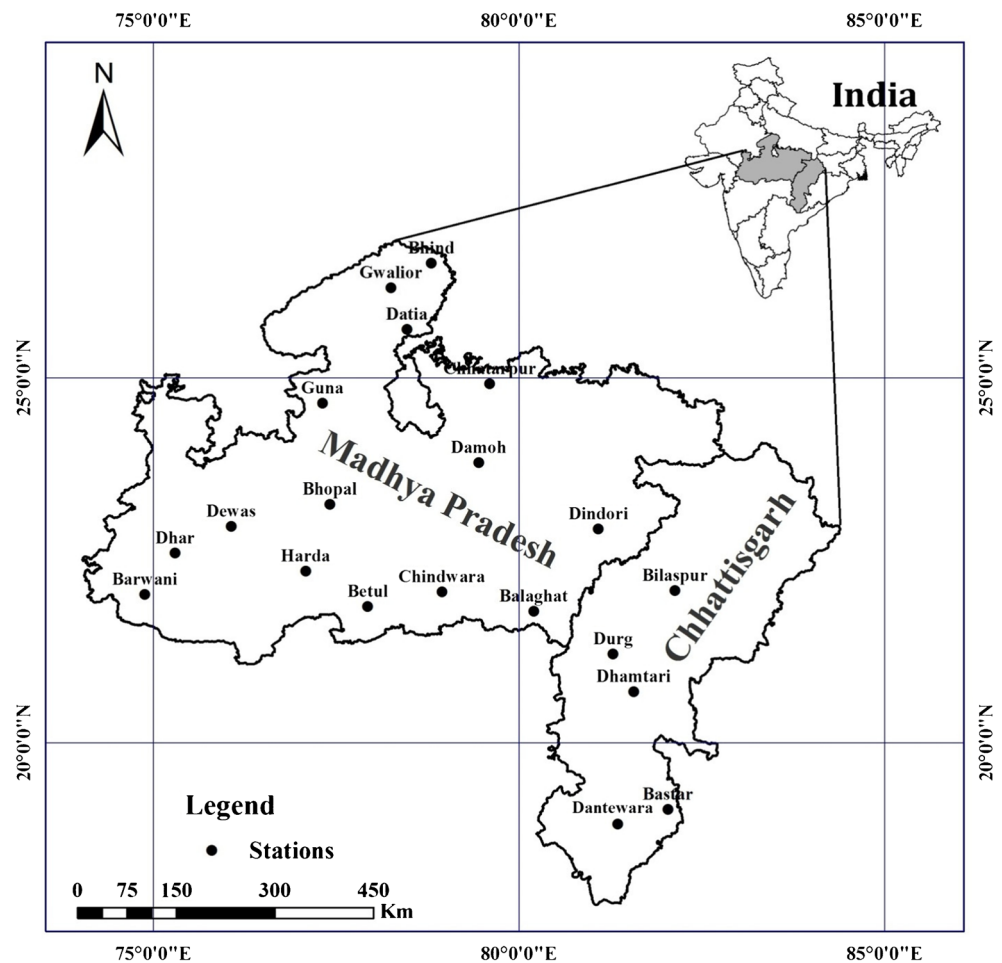
The literature review shows that no study has been published yet on analyzing the rainfall trend in Central India by ITM method. Therefore, the main objectives of the present study are as follows: (i) to identify the possible trends of rainfall time series of Central India using recently developed ITM; (ii) to detect the monotonic trends in monthly, seasonal, and annual rainfalls using Revised Mann-Kendall (RMK) technique by eliminating all significant auto-correlation coefficients; and (iii) to estimate the trend line slopes of rainfall time series by conducting the Theil-Sen approach (TSA) (Theil 1950; Sen 1968) over the Central India.

Material and methods

Study area

The states of Madhya Pradesh (MP) and Chhattisgarh (CG) are located at central part of India with an area of 443,000 km² (Fig. 1). This area is situated between 74° 02' E to 84° 20' E longitude and 17° 46' N to 26° 36' N latitude. The land use of about 35% of the study area is as rainfed agriculture, which provides the main economic source of about 80% of the

Fig. 1 Location map of the study area and studied stations



population. The principal crops in MP and CG states are rice, wheat, and maize. The cropping patterns in MP and CG states depend on spatial distribution of rainfall; for example, rice is the popular crop in the east MP, while the short duration, drought-tolerant crops like pearl millet are dominant in northern MP.

This area has a **tropical-subtropical climate**, which is under the **monsoon** influence. There are four predominant seasons: winter (December to February), summer (March to May), monsoon (June to September), and post-Monsoon (October to November). The average annual rainfall is about 1200 mm. In general, rainfall decreases from east to west and increase towards south. In the most parts of the study area, the rainfall falls in the monsoon months; however, the northern part of the area receives considerable rainfall in December and January (Mirabbasi et al. 2018). The spatial distribution of mean annual rainfall is shown in Fig. 2.

Data used

In the present study, monthly rainfall data of the 20 stations distributed uniformly over MP and CG states for a 110-year period (1901 to 2010) were used for analyzing the rainfall

trend in monthly, seasonal, and annual time scales. The rainfall data were obtained from India Meteorological Department (IMD). Locations of the considered stations are presented in Fig. 1, and the station characteristics are given in Table 1.

The Revised Mann-Kendall test

The common MK test that called the classic version of MK test (Mann 1945;

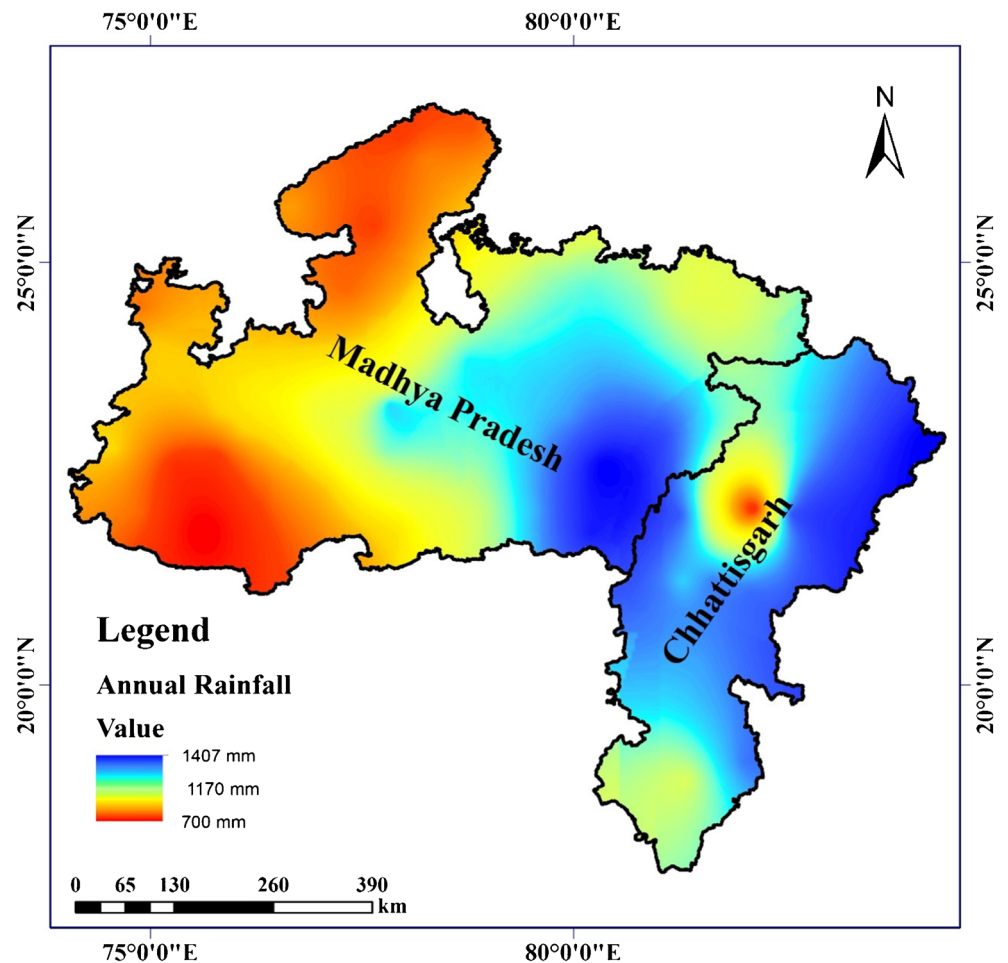
Kendall 1975) has been applied in many studies related to trend identification of climatological and hydrological variables. Suppose that we have a time series with length equals to N for a given period, the S statistic can be obtained as follows:

$$\forall j > i \rightarrow S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N sgn(X_j - X_i) \tag{1}$$

where X_j is the j th observation in the time series and $sgn(X)$ is the sign function and can be defined as:

$$sgn(X) = \begin{cases} 1 & \text{for } X > 0 \\ 0 & \text{for } X = 0 \\ -1 & \text{for } X < 0 \end{cases} \tag{2}$$

Fig. 2 Spatial distribution of mean annual rainfall (mm) over the Central India



The mean of S ($E(S)$) is equal to zero and the variance of S ($V(S)$) can be calculated as:

$$V(S) = \frac{N(N-1)(2N+5) - \sum_{i=1}^N t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

where t_i is the number of similar values for i th observation and N is the numbers of data. Finally, based on computation of S , the MK statistic (Z) can be calculated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & \text{for } S < 0 \end{cases} \quad (4)$$

In this study, the null hypothesis (H_0) indicated that there is no any significant trend in studied time series and opposite hypothesis (H_1) denotes availability of significant trend over the data. If $|Z|$ is lower than 1.645 (10% significant level) or 1.96 (5% significant level) or 2.33 (1% significant level), then we can accept the H_0 . Otherwise, we reject the H_0 and H_1 will be accepted.

The basic assumption in most of trend analysis studies using classic MK test is that the samples have not significant

autocorrelations. However, some hydrological series may have significant auto-correlation coefficients (Dinpashoh et al. 2014). By considering a time series with positive auto-correlation coefficients, the probability of existing trend using MK test is increased. In such situation, the null hypothesis (i.e., the absence of trend) is rejected, while the truth is that the null hypothesis must not reject (Dinpashoh et al. 2014). Hamed and Rao (1998) introduced the revised version of MK test. In RMK test, the effect of all auto-correlation coefficients is eliminated from the time series. The RMK can be used for time series that the one or several auto-correlation coefficients are significant. Firstly, the revised variance ($V(S)^*$) is computed as follows:

$$V(S)^* = V(S) \frac{n}{n^*} \quad (5)$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2)r_i \quad (6)$$

where r_i is the i lagged the auto-correlation coefficient and $V(S)$ can be obtained using Eq. (3). In order to compute the Z statistic of RMK in Eq. (4), $V(S)$ is replace by $V(S)^*$. The Z statistic value that calculated using the mentioned equation

Table 1 Summary of the geographical information of the studied stations and basic statistics of monthly rainfall (1901–2010)

State	Station	Latitude (°N)	Longitude (°W)	Altitude (m)	Min. value (mm)	Max. value (mm)	Mean, μ (mm)	Standard deviation, σ (mm)	CV ^a	SC ^a
Madhya Pradesh	Balaghat	21.8	80.2	289	0	813.601	113.892	159.905	1.404	1.514
	Barwani	22.0	74.8	176	0	552.119	70.025	107.627	1.536	1.630
	Betul	21.8	77.9	653	0	623.26	81.408	116.511	1.431	1.619
	Bhind	26.5	78.8	140	0	635.308	68.716	114.702	1.669	2.020
	Bhopal	23.2	77.4	483	0	903.8	89.624	141.909	1.583	1.826
	Chhatarpur	24.9	79.6	299	0	826.691	93.341	147.327	1.578	1.859
	Chindwara	22.1	78.9	677	0	725.2	92.693	129.043	1.392	1.508
	Damoh	23.8	79.4	365	0	922.4	98.985	151.396	1.529	1.782
	Datia	25.6	78.4	247	0	698.17	75.612	124.843	1.651	1.959
	Dewas	22.9	76.0	533	0	596.125	78.128	118.817	1.520	1.618
	Dhar	22.6	75.3	560	0	537.816	64.428	102.092	1.584	1.756
	Dindori	22.9	81.0	674	0	674.755	108.891	151.790	1.393	1.520
	Guna	24.6	77.3	484	0	537.003	70.238	109.792	1.563	1.755
	Gwalior	26.2	78.2	197	0	694.522	71.969	120.006	1.667	2.006
	Harda	22.3	77.0	282	0	683.4	78.744	117.97	1.498	1.707
Chhattisgarh	Bastar	19.1	82.1	543	0	655.892	105.097	129.936	1.236	1.207
	Bilaspur	22.1	82.1	265	0	539.184	63.477	88.092	1.387	1.912
	Dantewara	18.8	81.3	344	0	595.2	91.154	110.869	1.216	1.207
	Dhamtari	20.7	81.5	314	0	660.456	103.822	139.439	1.343	1.369
	Durg	21.2	81.2	277	0	653.076	100.076	137.116	1.370	1.357

^a CV variation coefficient, SC skewness coefficient

should compare with Z of normal standard distribution at α significant level (Khalili et al. 2016).

In this study, the slope of trend line (β) is calculated using Sen’s slope estimator formula (Theil 1950; Sen 1968) as follows:

$$\forall j > i \rightarrow \beta = \text{median} \left[\frac{X_j - X_i}{j - i} \right]. \tag{7}$$

The positive value of β denotes the positive trend and vice versa.

The innovative trend method

ITM was introduced by Şen (2011) and applied for trend identification of hydro-meteorological variables (Şen 2013; Kisi 2015). In order to apply the ITM on any given time series, the data should be split into two separate sub-series. Then the data of each sub-series is sorted in ascending order. In the next step, the first half and second half of time series is placed on X and Y axis, respectively (Fig. 3). With respect to Fig. 3, for the data are accumulated on 45° axis, we can say the given time series have not any trend. For the data that are stand in upper triangular region, we expect that the time series has increasing trend. Furthermore, for the data that located in lower triangular region, the decreasing trend can be found. By application of ITM, the trend of low, medium, and high time series values of any hydro-

meteorological variables can be identified and investigated (Şen 2011; Kisi 2015). In this study, the ITM recently proposed by Şen (2017b) was used.

Results and discussions

The RMK and ITM were used for identifying possible trends in monthly, seasonal, and annual rainfall data obtained from 20 stations, India for the period 1901–2010. Table 2 reports the Z statistics of the RMK test for the monthly data of each station for the 10,

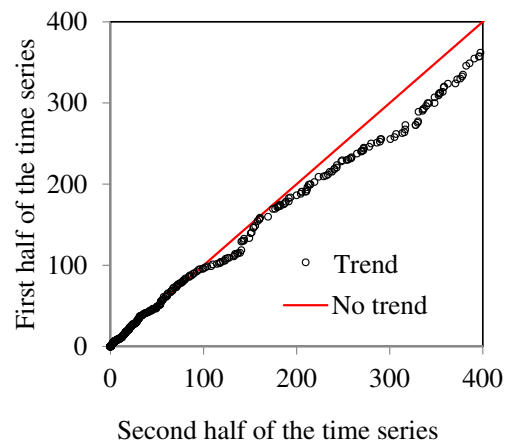


Fig. 3 Schematic view of data accumulation around 1:1 axis in ITM

Table 2 The Z statistic values of monthly rainfall using RMK for study region (1901–2010)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madhya Pradesh	Balaghat	0.245	-1.142	-0.266	-0.252	-0.230	-1.640	-1.204	0.385	-0.829	0.178	0.533	-1.607
	Barwani	-0.720	-1.440	-0.601	-1.933	-0.894	-0.158	-1.227	2.684^b	-1.093	1.284	-0.449	-0.716
	Betul	0.704	-0.517	-0.101	-0.871	0.744	-1.408	-1.707	1.397	-0.054	0.638	0.000	-1.768
	Bhind	-1.121	-1.048	0.234	-0.343	1.375	1.186	-1.423	-0.350	-0.354	1.119	-0.722	-0.736
	Bhopal	0.832	-0.023	1.681	0.125	0.827	0.121	-1.578	1.335	-2.441^b	1.331	-0.058	0.218
	Chhatarpur	-0.165	-0.964	0.779	0.344	2.376^b	0.860	-2.596^b	-1.201	-1.444	1.128	-0.814	0.005
	Chindwara	-0.246	-1.756	-0.642	-1.506	0.008	-1.821	-1.785	-0.090	-0.850	0.021	-0.284	-1.902
	Damoh	-0.124	-1.713	-1.436	-0.559	0.773	0.731	-2.110^a	-0.690	-1.775	0.176	-1.143	-0.355
	Datia	-1.108	-0.515	0.858	0.554	1.165	1.010	-2.395^b	-0.025	-0.612	0.642	-1.016	-0.409
	Dewas	-0.335	-1.107	-0.753	-0.924	-1.043	-0.938	-2.188^a	2.219^a	-1.784	0.607	-1.991^a	-1.963^a
	Dhar	-0.368	-0.770	0.743	-1.334	-0.243	0.085	-0.772	2.575^b	-0.431	1.049	-0.405	-0.328
	Dindori	0.152	-2.271^b	-1.416	-0.605	0.000	-1.501	-1.924	-1.335	-1.258	-0.163	0.492	-1.900
	Guna	-0.550	-0.423	0.711	0.010	0.871	1.558	-1.976^a	1.490	-1.462	1.020	-0.748	-0.621
	Gwalior	-0.729	-0.714	1.099	0.663	2.033^a	1.635	-2.203^a	0.419	-0.468	1.420	-0.163	-0.374
	Chhattisgarh	Harda	-0.321	-0.428	-0.378	-1.537	-0.623	-0.984	-0.809	1.661	-1.372	0.328	-1.154
Bastar		1.231	-1.266	0.804	-0.821	2.183^a	0.261	-0.220	1.470	-2.229^a	0.803	0.173	-1.578
Bilaspur		-1.183	0.310	1.878	0.597	2.694^b	1.055	2.322^b	1.361	0.932	1.402	1.145	-1.520
Dantewara		1.013	-2.425^b	-0.707	-2.978^b	-0.085	0.354	0.819	3.159^b	-2.136^a	1.165	-0.572	-1.007
Dhamtari		0.166	-1.867	0.119	-1.560	0.413	-1.000	-1.035	-1.201	-2.508^b	-0.251	-0.057	-1.723
Durg	-0.147	-2.608^b	-0.445	-1.356	-0.323	-1.558	-1.593	-0.700	-1.914	-0.726	-0.804	-1.739	

Numbers in bold indicate significant values at the 10% level ($Z_{10\%} = \pm 1.645$)

^a Significant at the 5% level ($Z_{5\%} = \pm 1.96$)

^b Significant at the 1% level ($Z_{1\%} = \pm 2.58$)

5, and 1% significant levels. Rainfall data generally shows negative trends (either statistically significant or insignificant) in most

of the months. Rainfall trend shows highly spatial variation. As it can be seen from Table 2, there is no significant trend in the all

Table 3 Values of Z statistics for seasonal and annual rainfall using RMK for study region

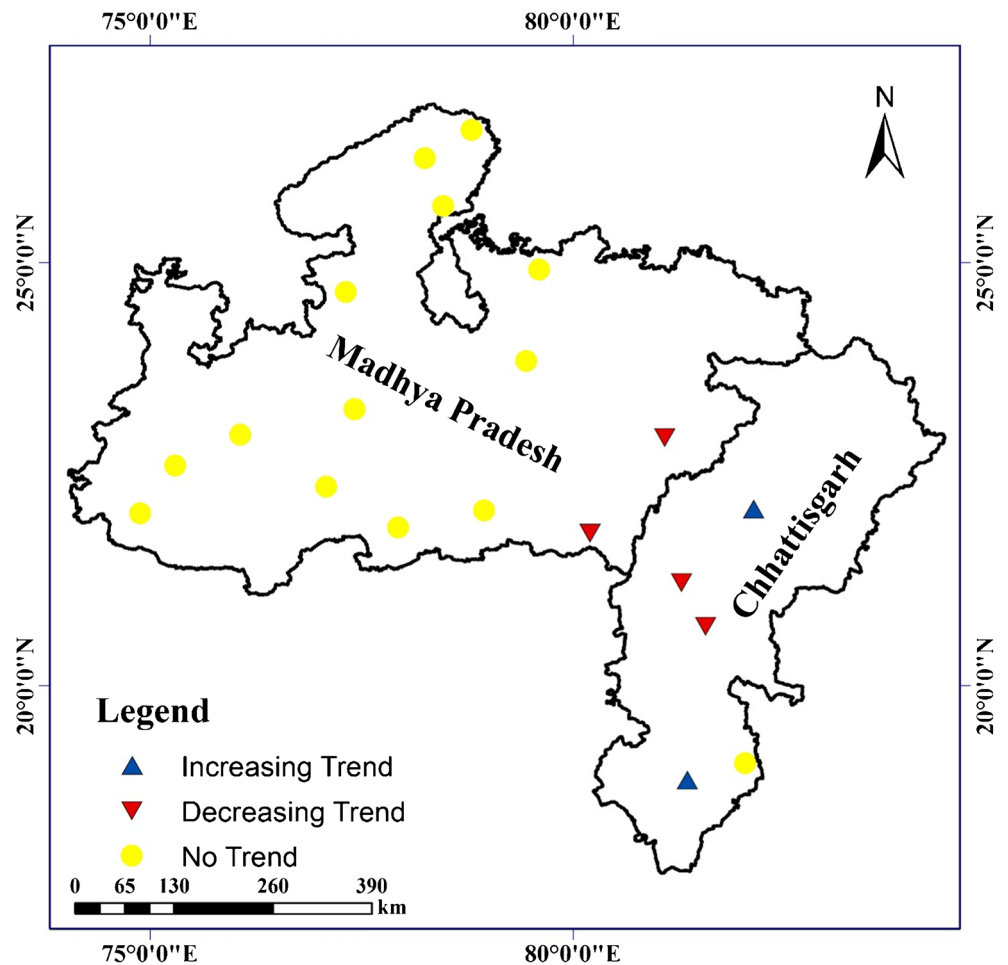
State	Station	Annual	Summer	Winter	Monsoon	Post-monsoon
Madhya Pradesh	Balaghat	-2.289^a	-0.457	-0.473	-2.178^a	0.411
	Barwani	0.170	-1.174	-1.470	0.150	0.708
	Betul	-0.573	-0.013	-0.049	-0.672	-0.028
	Bhind	-0.532	1.570	-0.917	-0.780	1.100
	Bhopal	-0.914	1.020	1.416	-1.524	0.181
	Chhatarpur	-1.207	1.183	-0.196	-1.239	0.770
	Chindwara	-1.617	-0.648	-0.932	-1.793	-0.261
	Damoh	-1.271	-0.196	-0.387	-1.075	-0.220
	Datia	-0.765	1.971^a	-0.553	-0.987	0.705
	Dewas	-1.540	-0.954	-0.762	-1.565	-1.387
	Dhar	0.703	-0.132	-1.307	0.744	0.682
	Dindori	-2.567^a	-0.935	-0.938	-2.586^b	0.049
	Guna	0.207	1.237	-0.147	-0.145	0.266
	Gwalior	-0.387	2.341^b	-0.194	-0.832	1.421
	Chhattisgarh	Harda	-0.852	-0.543	-0.351	-0.754
Bastar		-0.170	0.974	-0.586	-0.328	0.979
Bilaspur		1.825	1.842	-0.927	2.064^a	1.553
Dantewara		1.705	-1.348	-1.764	1.576	1.263
Dhamtari		-2.236^a	-0.269	-0.984	-2.107^a	0.093
Durg	-2.761^b	-1.126	-1.390	-2.568^a	-0.245	

Numbers in bold indicate significant values at the 10% level ($Z_{10\%} = \pm 1.645$)

^a Significant at the 5% level ($Z_{5\%} = \pm 1.96$)

^b Significant at the 1% level ($Z_{1\%} = \pm 2.58$)

Fig. 4 Spatial distribution map of annual rainfall trend determined by RMK test over Central India during 1901–2010



stations for the January and October months. Two stations Balaghat and Bhind have not experienced significant trend in

monthly rainfall. The Chindwara, Damoh, Dindori, Dantewara, Dhamtari, and Durg stations have significant decreasing trends in

Table 4 Values of trend line slope of monthly rainfall time series calculated by Sen estimator

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madhya Pradesh	Balaghat	0.002	-0.024	-0.001	-0.003	-0.005	-0.427	-0.453	0.111	-0.241	0.014	0.000	-0.002
	Barwani	0.000	0.000	0.000	-0.002	-0.002	-0.042	-0.380	0.707	-0.319	0.063	0.000	0.000
	Betul	0.003	-0.001	0.000	-0.004	0.009	-0.276	-0.616	0.418	-0.017	0.042	0.000	-0.002
	Bhind	-0.015	-0.009	0.000	0.000	0.018	0.141	-0.568	-0.139	-0.100	0.012	0.000	0.000
	Bhopal	0.005	0.000	0.007	0.000	0.012	0.015	-0.631	0.481	-0.905	0.036	0.000	0.000
	Chhatarpur	-0.002	-0.019	0.006	0.000	0.035	0.157	-1.120	-0.682	-0.400	0.042	0.000	0.000
	Chindwara	0.000	-0.023	-0.002	-0.017	0.000	-0.377	-0.535	-0.023	-0.250	0.001	0.000	-0.002
	Damoh	0.000	-0.044	-0.011	-0.002	0.011	0.158	-0.863	-0.279	-0.498	0.005	0.000	0.000
	Datia	-0.015	-0.004	0.004	0.000	0.014	0.126	-0.969	-0.007	-0.179	0.010	0.000	0.000
	Dewas	0.000	0.000	0.000	0.000	-0.008	-0.190	-0.701	0.689	-0.638	0.021	-0.003	0.000
	Dhar	0.000	0.000	0.000	0.000	0.000	0.012	-0.226	0.699	-0.120	0.025	0.000	0.000
	Dindori	0.001	-0.111	-0.037	-0.010	0.000	-0.339	-0.615	-0.414	-0.277	-0.013	0.000	-0.003
	Guna	-0.005	0.000	0.001	0.000	0.015	0.192	-0.544	0.440	-0.358	0.029	0.000	0.000
	Gwalior	-0.008	-0.003	0.003	0.001	0.037	0.203	-0.837	0.160	-0.127	0.029	0.000	0.000
	Harda	0.000	0.000	0.000	-0.002	-0.003	-0.190	-0.279	0.452	-0.424	0.010	0.000	0.000
	Chhattisgarh	Bastar	0.002	-0.005	0.016	-0.061	0.142	0.059	-0.067	0.364	-0.536	0.155	0.000
Bilaspur		-0.066	0.019	0.078	0.014	0.092	0.163	0.683	0.322	0.210	0.033	0.000	-0.038
Dantewara		0.000	-0.010	-0.003	-0.149	-0.003	0.066	0.237	0.770	-0.488	0.231	-0.007	0.000
Dhamtari		0.000	-0.012	0.000	-0.081	0.022	-0.243	-0.414	-0.342	-0.621	-0.028	0.000	0.000
Durg		0.000	-0.028	-0.003	-0.043	-0.008	-0.342	-0.515	-0.185	-0.451	-0.064	0.000	0.000

Table 5 Values of Sen’s slope for seasonal and annual rainfall (1901–2010)

State	Station	Annual	Summer	Winter	Monsoon	Post-monsoon
Madhya Pradesh	Balaghat	-1.548	-0.034	-0.043	-1.417	0.040
	Barwani	0.100	-0.028	-0.005	0.107	0.065
	Betul	-0.392	-0.001	-0.003	-0.486	-0.002
	Bhind	-0.393	0.071	-0.043	-0.563	0.045
	Bhopal	-0.602	0.037	0.066	-0.995	0.006
	Chhatarpur	-1.326	0.059	-0.019	-1.413	0.051
	Chindwara	-1.274	-0.051	-0.063	-1.106	-0.041
	Damoh	-1.001	-0.011	-0.030	-0.834	-0.014
	Datia	-0.647	0.066	-0.030	-0.739	0.024
	Dewas	-1.035	-0.025	-0.012	-0.960	-0.150
	Dhar	0.448	-0.002	-0.007	0.460	0.038
	Dindori	-1.890	-0.083	-0.107	-1.724	0.003
	Guna	0.101	0.048	-0.007	-0.108	0.013
	Gwalior	-0.292	0.096	-0.009	-0.592	0.065
Chhattisgarh	Harda	-0.619	-0.020	-0.009	-0.445	-0.125
	Bastar	-0.123	0.126	-0.022	-0.154	0.191
	Bilaspur	1.629	0.178	-0.095	1.199	0.066
	Dantewara	0.989	-0.158	-0.049	0.738	0.303
	Dhamtari	-1.854	-0.031	-0.037	-1.547	0.015
	Durg	-2.103	-0.100	-0.058	-1.633	-0.037

February, while the Bhopal and Bilaspur show significant increasing trends in March. The Barwani and Dantewara show significant decreasing trend in rainfall of April. There is a significant

increasing trend in May for the Chhatarpur, Gwalior, Bastar, and Bilaspur. In June and November, only a significant decreasing trend exists for the Chindwara and Dewas, respectively. Betul,

Table 6 Detailed trend parameters of ITM test for the monthly rainfall of Durg station (significant at the 10% level)

Time	Slope, <i>s</i>	Intercept, <i>a</i>	Std. dev., σ	Correlation, $\rho_{y y_2}$	Slope std. dev., σ_s	Sign. level	Lower CL	Upper CL	Hypothesis	Decision	Type of trend
Jan	-0.01527	9.32	11.08153	0.9641	0.00515	0.10	-0.00849	0.00849	Ha	Yes	Decreasing
Feb	-0.06776	12.404	9.98967	0.9961	0.00154	0.10	-0.00254	0.00254	Ha	Yes	Decreasing
Mar	-0.00540	12.245	12.39519	0.9908	0.00292	0.10	-0.00482	0.00482	Ha	Yes	Decreasing
Apr	-0.07340	22.28	15.96021	0.9870	0.00446	0.10	-0.00736	0.00736	Ha	Yes	Decreasing
May	-0.00028	18.2	13.16632	0.9636	0.00616	0.10	-0.01016	0.01016	Ho	No	No trend
Jun	-0.22372	201.12	72.43642	0.9823	0.02364	0.10	-0.03901	0.03901	Ha	Yes	Decreasing
Jul	-0.78082	386.49	99.36391	0.9642	0.04607	0.10	-0.07601	0.07601	Ha	Yes	Decreasing
Aug	-0.18719	346.25	80.53199	0.9907	0.01909	0.10	-0.03149	0.03149	Ha	Yes	Decreasing
Sep	-0.48816	228.3	74.91192	0.9812	0.02517	0.10	-0.04153	0.04153	Ha	Yes	Decreasing
Oct	-0.19783	60.085	44.24685	0.9811	0.01490	0.10	-0.02458	0.02458	Ha	Yes	Decreasing
Nov	0.02749	4.242	11.78368	0.9018	0.00905	0.10	-0.01494	0.01494	Ha	Yes	Increasing
Dec	0.04935	4	8.95858	0.9681	0.00392	0.10	-0.00647	0.00647	Ha	Yes	Increasing
Annual	-1.96300	1305	184.37507	0.9858	0.05382	0.10	-0.08880	0.08880	Ha	Yes	Decreasing
Monsoon	-1.67989	1162.2	163.36138	0.9790	0.05809	0.10	-0.09584	0.09584	Ha	Yes	Decreasing
Summer	-0.07908	52.73	25.60721	0.9629	0.01209	0.10	-0.01995	0.01995	Ha	Yes	Decreasing
Winter	-0.03369	12.73	17.47815	0.9677	0.00770	0.10	-0.01271	0.01271	Ha	Yes	Decreasing
Post monsoon	-0.17034	64.32	44.76401	0.9840	0.01390	0.10	-0.02293	0.02293	Ha	Yes	Decreasing

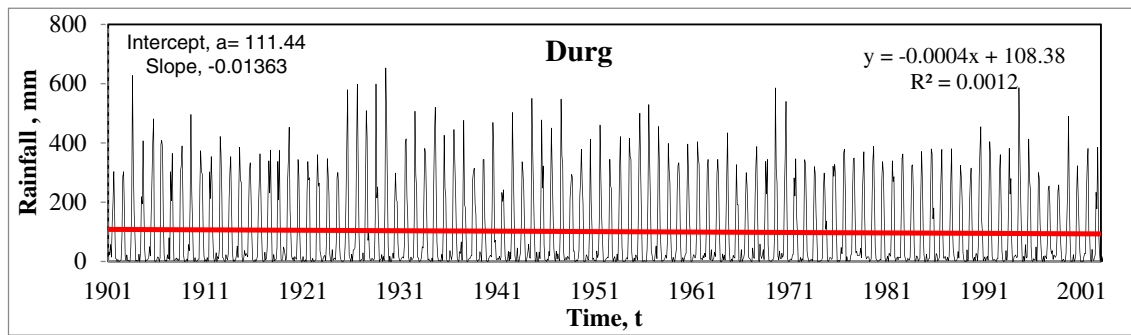


Fig. 5 Time series and the intercept and slope parameters of the ITM for the Durg station

Chhatarpur, Chindwara, Damoh, Datia, Dewas, Dindori, Guna, and Gwalior stations indicate significantly decreasing trends for July, while the Bilaspur station shows significantly increasing trend for this month. Bhopal, Dewas, Bastar, Dantewara, Dhamtari, and Durg stations have significantly decreasing trends in September, while the Betul, Chindwara, Dewas, Dindori, Harda, Dhamtari, and Durg stations show significantly increasing trends in December. In general, based on the RMK test, significantly decreasing trend generally occurs in rainfall of post monsoon, winter, and summer months except August, while the monsoon period (except April) generally shows significantly increasing trend.

A summary of the RMK test results is provided in Table 3 for the annual and seasonal rainfall data of 20 stations. In

summer season, only three stations (Datia, Gwalior, and Bilaspur) indicate significantly increasing trend, while others do not have a significant trend. However, it can be said that the Bhind has nearly significant trend for this season. Only Dantewara has a significantly decreasing trend in winter season rainfall, while the Barwani and Bhopal have nearly significant trends (negative for the first one and positive for the latter). In monsoon season, five stations (Balaghat, Chindwara, Dindori, Dhamtari, and Durg) out of 20 considered stations indicate a significant negative trend, while the Bilaspur shows significant increasing trend in rainfall. In this season, there are nearly significant trends for the Bhopal (decreasing), Dewas (decreasing), and Dantewara (increasing).

Table 7 Slope, S, values of monthly rainfall using ITM test for study region (1901–2010)

State	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madhya Pradesh	Balaghat	-0.004	-0.124^b	0.015^a	-0.016^b	-0.009	-0.359^b	-0.701^b	0.114^b	-0.322^b	-0.178^b	0.064^b	0.130^b
	Barwani	-0.001	0.001	0.008^b	-0.004^b	0.010^a	-0.036	-0.320^b	0.942^b	-0.435^b	0.053^b	0.004	0.016^b
	Betul	-0.001	0.007	0.006	0.009^b	0.021^b	-0.439^b	-0.908^b	0.393^b	-0.135^b	-0.198^b	-0.014	0.035^b
	Bhind	-0.031^b	-0.013^b	0.024^b	-0.004	0.056^b	0.106^b	-0.433^b	0.157^b	-0.221^b	0.185^b	0.017^b	-0.012^b
	Bhopal	0.052^b	0.008^b	0.059^b	-0.001	0.036^b	0.034	-0.954^b	0.853^b	-0.972^b	0.105^b	0.027^b	0.068^b
	Chhatarpur	-0.018	-0.039^b	0.013^b	-0.003	0.055^b	0.094^b	-1.120^b	-0.255^b	-0.345^b	0.175^b	0.012	0.017^b
	Chindwara	-0.029^b	-0.060^b	0.016	-0.026^b	0.004	-0.424^b	-0.738^b	0.071	-0.266^b	-0.196^b	0.002	0.085^b
	Damoh	-0.015^b	-0.068^b	-0.005	-0.073^b	0.001	-0.224^b	-0.781^b	-0.187^b	-0.488^b	-0.198^b	0.028^b	0.049^b
	Datia	-0.041^b	-0.009^b	0.032^b	-0.004^b	0.037^b	0.141^b	-0.728^b	0.297^b	-0.347^b	0.129^b	0.009	-0.003
	Dewas	0.013^b	0.002	0.005^a	0.003^b	-0.005	-0.149^b	-0.928^b	0.847^b	-0.756^b	-0.012	-0.136^b	0.029^b
	Dhar	0.001	-0.001	0.016^b	0.001	-0.003	-0.048^a	-0.213^b	0.816^b	-0.274^b	0.066^b	-0.010	0.008
	Dindori	-0.002	-0.195^b	-0.058^b	-0.029^b	0.007	-0.270^b	-0.677^b	-0.363^b	-0.284^b	-0.171^b	0.044^b	0.125^b
	Guna	-0.009^b	0.006^a	0.045^b	-0.001	0.023^b	0.236^b	-0.605^b	0.635^b	-0.504^b	0.086^b	-0.007	0.008^a
	Gwalior	-0.020^b	-0.003	0.029^b	0.006^b	0.058^b	0.155^b	-0.605^b	0.412^b	-0.307^b	0.155^b	0.051^b	0.001
Harda	-0.015^b	-0.068^b	-0.005^a	-0.073^b	0.001	-0.224^b	-0.781^b	-0.187^b	-0.488^b	-0.198^b	0.028^b	0.049^b	
Chhattisgarh	Bastar	0.030^b	-0.056^b	0.061^b	-0.118^b	0.142^b	0.216^b	-0.405^b	0.221^b	-0.618^b	0.025	-0.009	0.032^b
	Bilaspur	-0.036^b	-0.006	0.121^b	0.033^b	0.158^b	0.213^b	0.526^b	0.545^b	0.065	0.091^b	0.043^b	-0.050^b
	Dantewara	0.027^b	-0.077^b	-0.025^b	-0.179^b	0.018^b	0.225^b	0.134^b	0.830^b	-0.395^b	0.266^b	-0.024	0.025^b
	Dhamtari	0.012	-0.035^b	0.034^b	-0.113^b	0.045^b	-0.045^a	-0.675^b	-0.313^b	-0.695^b	-0.173^b	0.042^b	0.034^b
	Durg	-0.015^b	-0.068^b	-0.005	-0.073^b	0.001	-0.224^b	-0.781^b	-0.187^b	-0.488^b	-0.198^b	0.028^b	0.049^b

Numbers in bold indicate significant values at the 10% level

^a Significant at the 5% level

^b Significant at the 1% level

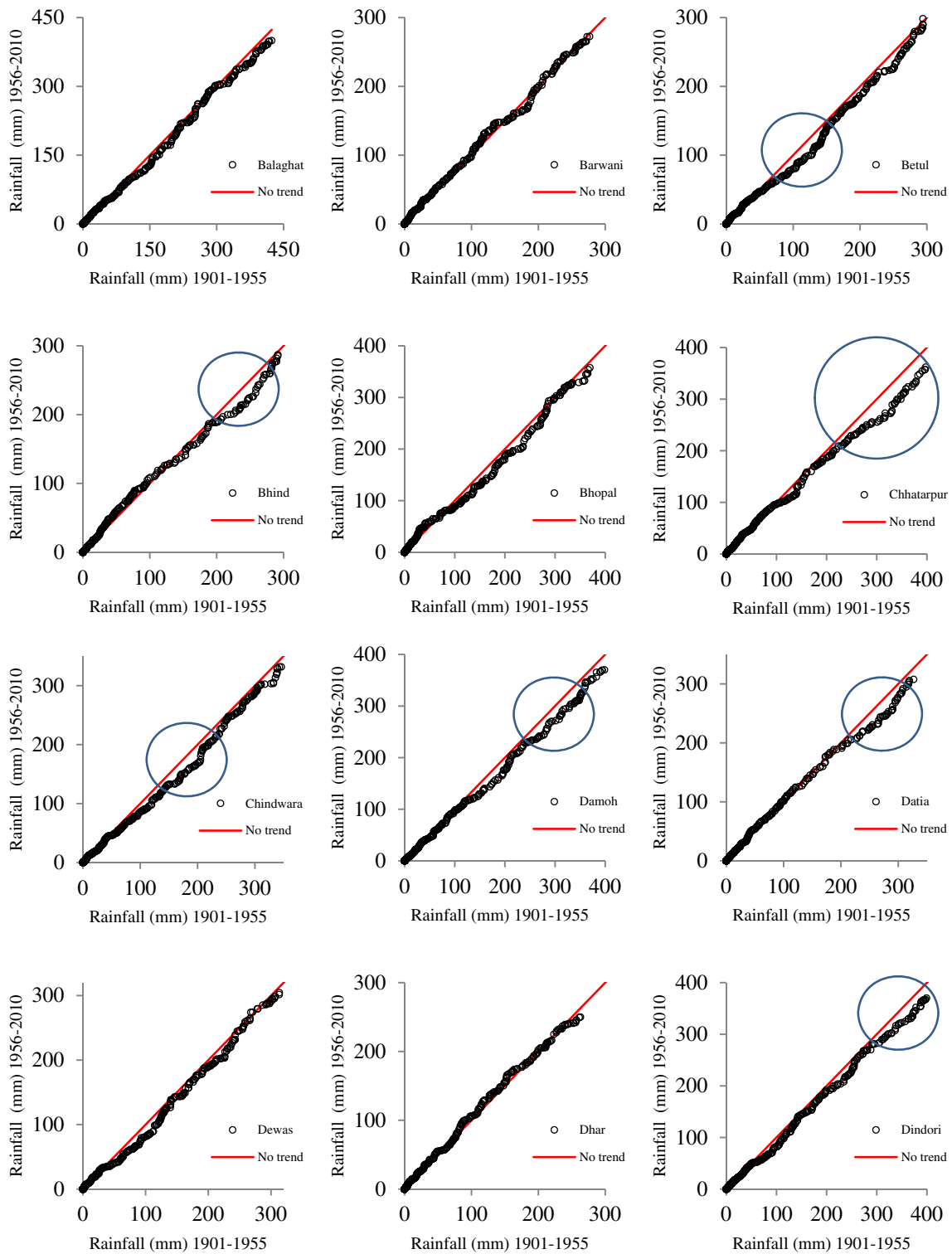


Fig. 6 Innovative trend plot for rainfall data of selected stations in Central India (1901–2010)

There is no significant trend in post monsoon season, while the Gwalior and Bilaspur have nearly significant (increasing) trends. From Table 3, it is observed that CG state has a higher rainfall variation than the MP. In CG, four out of five considered stations indicate significant annual trends, while MP has

only two out of 15 considered stations having significant trends. The type of trend of annual rainfall determined by RMK test is shown in Fig. 4. It is observed from the figure that the north eastern part of MP and center of CG generally have significant decreasing trends. In seasonal scale, also for

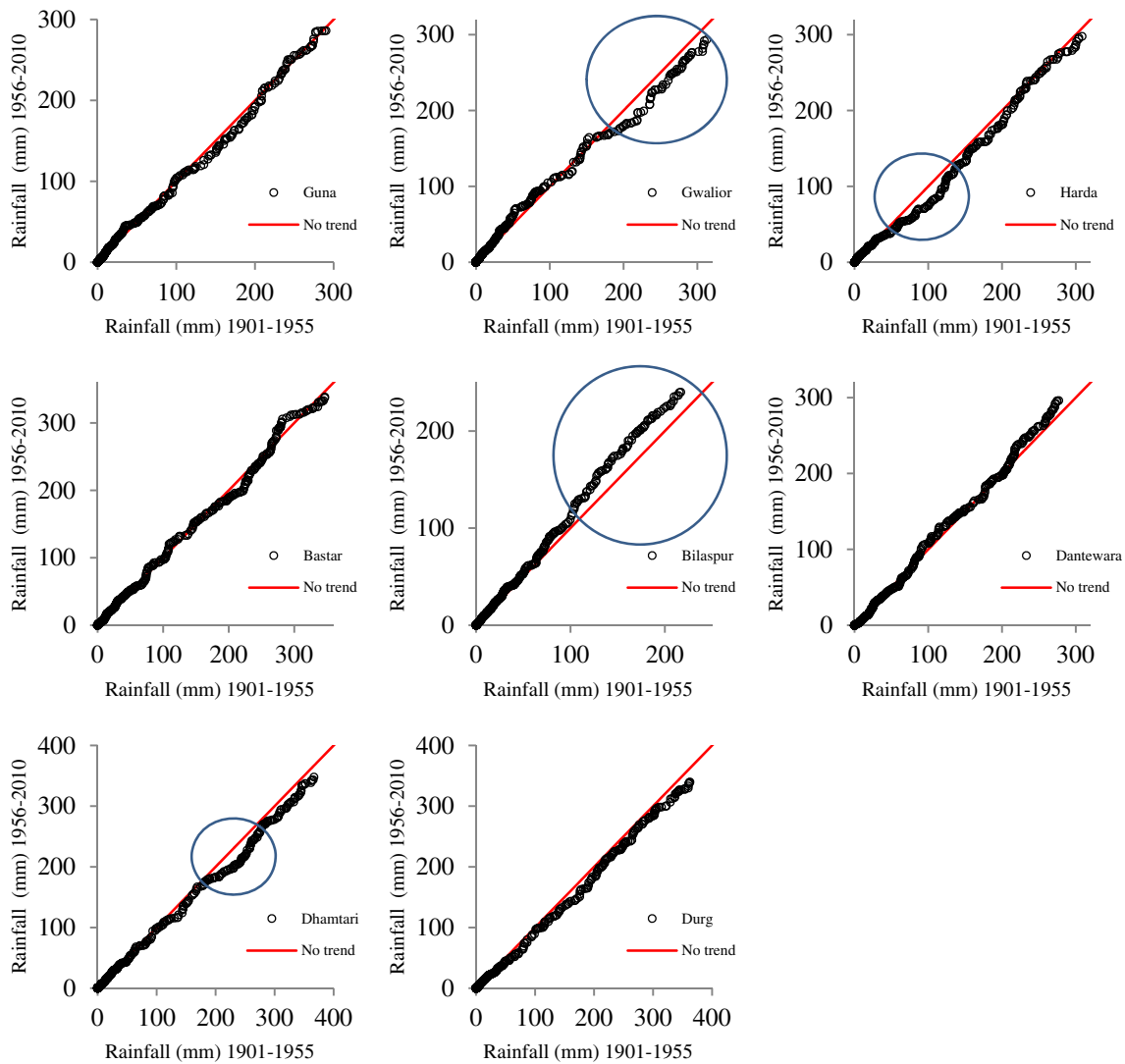


Fig. 6 continued.

CG, five out of 20 cases have significant trends, while for MP, only five out of 60 cases show significant trends.

Trend magnitudes (Sen’s slope values) of the monthly rainfall data are shown in Table 4. Most of the stations have no remarkable slope in rainfall of November and December. In January, nine stations have no trend, while the five/six stations have positive/negative slope. In accordance with the RMK test, the rainfalls generally show decreasing slope in February (13 out of 20 stations in which no trend exists in six stations), April (11 out of 20 stations in which no trend exists in seven stations), July (18 stations), and September (19 stations), while a positive slope is generally observed for the March (seven out of 20 stations in which no trend exists in seven stations), May (11 stations), June (11 stations), August (12 out of 20 stations in which no trend exists in 3 stations), and October (17 stations). Table 5 reports the slope values of trend line for the seasonal and annual rainfall data of 20 considered stations across Central India. Negative rainfall slope

ranges from 0.123 mm/year at Bastar station to 2.103 mm/year at Durg station in the annual rainfall series. It means that the annual rainfall of Bastar and Durg stations decreased about 1.1 and 19.2%, respectively, during the studied 110-year period. Most of the stations have negative slope in annual (15 stations), summer (12 stations), winter (19 stations), and monsoon (16 stations) seasons, while the post-monsoon (14 stations) season generally shows positive slope in rainfall.

Gajbhiye et al. (2016) recently applied MK and Sen’s slope estimator for analyzing trends in rainfall data obtained from six stations in India. They also found that most of the stations had a negative trend in July and September, and no trend was found for the November and December in monthly rainfalls. They also found positive trends for the March, May, June, August, and October. They identified decreasing trends in all stations for the annual and monsoon seasons.

Gupta et al. (2017) have used the MK test to investigate the trend of monthly rainfall in upstream districts of the Hirakud

reservoir, India. They also reported significant decreasing trend in September rainfall in most of the considered stations.

As an example, detailed trend parameters of ITM are given in Table 6 for the monthly rainfall of Durg station at the 10% significant level. As seen from the table, slope values are generally not within the lower and upper CL limits, which indicate significant trend for this station. The rainfall data generally show significantly decreasing trend except May (no trend), November (increasing), and December (increasing) months at the level of 10%. The intercept and slope values of the monthly rainfall time series are illustrated in Fig. 5 for the Durg station. Summary of the ITM results for the monthly rainfall of all stations at different significant levels (10, 5, and 1%) is provided in Table 7. Similar to the RMK, rainfall data generally shows negative trends in most of the months. The monthly rainfalls generally show significantly decreasing trend in January (11 out of 20 stations and no significant trend is found in five stations), February (12 out of 20 stations and no significant trend is found in five stations), April (13 out of 20 stations and no significant trend exists in three stations), June (10 out of 20 stations and no significant trend exists in 2 stations), July (18 stations), and September (19 stations), while a significant increasing trend generally exists for the March (14 out of 20 stations), May (12 out of 20 stations and no significant trend exists in six

stations), August (13 out of 20 stations), and October (10 out of 20 stations and no significant trend exists in two stations). Unlike the RMK test, the ITM shows significant increasing trend in November and December months. Scatterplot representation of the monthly rainfalls' trend for each station is presented in Fig. 6. Trends parts are circled in the Fig. 6 for better diagnosis. Based on the Fig. 6, a decreasing trend was clearly seen for the high rainfall values of Bhind, Chhatarpur, Damoh, Datia, Dindori, and Gwalior stations, while an increasing trend exists for the Bilaspur station. Medium rainfall values of the Chindwara and Dhamtari stations and low-medium rainfall values of the Betul and Harda stations have decreasing trends in the second half of the whole monthly time series. Summary of the ITM results is given in Table 8 for the seasonal and annual rainfalls. Similar to the RMK test, most of the stations show decreasing trends in annual (16 stations), summer (16 stations), and monsoon (11 stations) seasons, while the winter (12 stations) and post-monsoon (11 stations) seasons generally show increasing trend.

Similar trends were generally obtained for monthly, annual, and seasonal rainfalls from the RMK and ITM tests. However, in some cases, different results (e.g., monthly rainfall in November and December) were provided by the two methods. The basic reason for this difference may be the fact that the

Table 8 Slope, *S*, values of seasonal and annual rainfall using ITM test for study region

State	Station	Annual	Summer	Winter	Monsoon	Post-monsoon
Madhya Pradesh	Balaghat	-1.389	-1.268^b	-0.009	0.002	-0.114^b
	Barwani	0.236^b	0.151^a	0.014^b	0.015^b	0.057^b
	Betul	-1.223^b	-1.088^b	0.036^a	0.040^b	-0.212^b
	Bhind	-0.168	-0.391^b	0.077^b	-0.057^b	0.202^b
	Bhopal	-0.686^b	-1.038^b	0.094^b	0.127^b	0.132^b
	Chhatarpur	-1.415^b	-1.626^b	0.065^b	-0.041^b	0.186^b
	Chindwara	-1.561^b	-1.357^b	-0.007	-0.004	-0.194^b
	Damoh	-1.963^b	-1.680^b	-0.079^b	-0.034^b	-0.170^b
	Datia	-0.486^b	-0.637^b	0.065^b	-0.053^b	0.138^b
	Dewas	-1.087^b	-0.986^b	0.003	0.044^b	-0.147^b
	Dhar	0.357^b	0.281^b	0.013^b	0.008^a	0.056^b
	Dindori	-1.874^b	-1.594^b	-0.080^b	-0.073^b	-0.127^b
	Guna	-0.086	-0.237^b	0.067^b	0.005	0.079^b
	Gwalior	-0.068	-0.345^b	0.093^b	-0.022^b	0.206^b
	Harda	-1.963^b	-1.680^b	-0.079^b	-0.034^b	-0.170^b
Chhattisgarh	Bastar	-0.479^b	-0.587^b	0.085^b	0.006	0.016
	Bilaspur	1.704^b	1.349^b	0.312^b	-0.092^b	0.134^b
	Dantewara	0.824^b	0.794^b	-0.187^b	-0.025^b	0.241^b
	Dhamtari	-1.882^b	-1.728^b	-0.034	0.011	-0.131^b
	Durg	-1.963^b	-1.680^b	-0.079^b	-0.034^b	-0.170^b

Numbers in bold indicate significant values at the 10% level

^a Significant at the 5% level

^b Significant at the 1% level

ITM investigates the variation of second half of the time series with respect to first half of the time series, while the RMK evaluates whole time series. The ITM, however, provides useful information about trends of any variable without any restrictions (e.g., non-normality, serial correlation, and data number) (Şen 2017b).

Rainfall is an essential climatic parameter, which directly affects agricultural production and water resource availability. It is also effective on urban water supply and water uses in industrial, residential, and agricultural purposes. From the present study, it was observed that most of the considered stations have significant decreasing trend in rainfall. This may cause greater extraction of ground water for irrigating crops and decreasing of groundwater level, facing drought problems, and reducing soil moisture (Mirabbasi and Eslamian 2010). On the other hand, increasing trend in some stations may cause flood due to high intensity of rainfall. Therefore, change in rainfall should be carefully taken into consideration for the water management in long-term catchment scale.

Conclusions

In this study, the trends of rainfall over the MP and CG states (Central India) using 110-year data were evaluated by RMK, Sen's slope estimator, and ITM. Similar trends were generally obtained for monthly, annual, and seasonal rainfalls from the RMK and ITM tests. In some cases, however, different trends (e.g., monthly rainfalls in November and December) were detected by these methods. By application of RMK test, there are not significant trend in the stations for the January and October months. Using RMK, in CG state, four out of five considered stations indicate significant annual trend, while in MP, only two out of 15 considered stations have significant trends. In seasonal scale, for CG, five out of 20 considered time series show significant trend, while in MP state, only five out of 60 series show significant trends. Based on Sen's slope estimator, the maximum trend slope belongs to Dantewara station in August for CG, and the trend slope of most of stations is equal to zero in November and December. By application of ITM, similar to the RMK test, most of the stations show decreasing trends in annual (16 stations), summer (16 stations), and monsoon (11 stations) series, while the winter (12 stations) and post-monsoon (11 stations) seasons generally show increasing trend. Unlike the RMK test, the ITM shows significant increasing trend in November and December months. This difference between the two methods might be due to the fact that ITM investigates the trends by comparing variation of second half of the time series with respect to first half of the time series, while whole time series are considered in the RMK method. The main advantage of ITM is analyzing trends by providing graphical information

and without any restrictions, such as non-normality, serial correlation, and number of data. The presented study employed ITM significance test recently proposed by Şen (2017b) to rainfall time series for the first time. The findings of current research and advantage of recently developed ITM can be used for irrigation and water resource planning and management purpose over the Central India.

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