MAUSAM, 77, 1 (January 2026), 129-152

MAUSAM

DOI: https://doi.org/10.54302/e8smr403
Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

UDC No.551.577.3(540.53)

Century-scale rainfall variation over Madhya Maharashtra, India

LABANI SAHA[1], RUTUJA JAGDALE[1], AMIT DHORDE[1*] and RAHUL TODMAL[2]

[1]*Department of Geography, Savitribai Phule Pune University, Pune, Maharashtra, India*

[2]*Vidhya Pratishthan's ASC College, Baramati, Maharashtra, India*

(*Received 29 May 2024, Accepted 7 August 2025*)

***Corresponding author's email: amitdhorde@gmail.com**

सार –आईपीसीसी (2007) के अनुसार वर्ष 2050 तक जल उपलब्धता में 10-30% तक की कमी आने की संभावना है, जिससे मीठे पानी की गंभीर कमी उत्पन्न हो सकती है। मध्य महाराष्ट्र एक मौसम विज्ञान उप- विभाग है, जहाँ प्रमुख रूप से नकदी फसलों एवं अनाज फसलों की खेती की जाती है। हाल के वर्षों में इस क्षेत्र में अत्यधिक वर्षा की घटनाएँ दर्ज की गई हैं, जिसके कारण वर्षा परिवर्तनशीलता के अध्ययन की आवश्यकता उत्पन्न हुई।अतः वर्तमान अध्ययन में 1901 से 2020 की दीर्घकालीन वर्षा प्रवृत्तियों का विश्लेषण पारामीट्रिक एवं अपरामीट्रिक तकनीकों के माध्यम से किया गया। अध्ययन से यह पाया गया कि 1926 के बाद की अवधि में मध्य महाराष्ट्र उप-विभाग में वार्षिक वर्षा में बढ़ती हुई प्रवृत्ति देखी गई। यद्यपि चयनित सभी जिलों में मॉनसून वर्षा में वृद्धि की प्रवृत्ति दर्ज की गई, परंतु उनमें से केवल तीन जिलों (30%) में यह वृद्धि सांख्यिकीय रूप से महत्वपूर्ण पाई गई।इसके विपरीत, सांगली को छोड़कर लगभग सभी अध्ययन किए गए जिलों में शीतकालीन वर्षा में कमी देखी गई। इनमें धुले, अहमदनगर, पुणे एवं कोल्हापुर जिलों में वर्षा में गिरावट सांख्यिकीय रूप से महत्वपूर्ण रही। सभी समय पैमानों (मासिक, मौसमी एवं वार्षिक) पर महत्वपूर्ण परिवर्तन बिंदु (चेंज बिंदु) पाए गए। दस में से छह जिलों में पिछले पाँच वर्षों के दौरान परिवर्तन बिंदुओं का पंजीकरण हुआ। 2100 तक के भविष्य प्रक्षेपण से यह संकेत मिलता है कि इस क्षेत्र में वर्षा की मात्रा एवं परिवर्तनशीलता दोनों में संभावित वृद्धि हो सकती है। अतः इस अवलोकन से यह प्रश्न उत्पन्न होता है कि आने वाले दशकों में इन जिलों में वर्षा की स्थिति कैसी होगी और यह मध्य महाराष्ट्र उप-विभाग की समग्र वर्षा प्रवृत्ति को किस सीमा तक प्रभावित करेगी। साथ ही, अंतः-मौसमी एवं अंतः-ऋतु (इंटर एवं इंट्रा सीज़नल) वर्षा के बदलते स्वरूप पर भी आगे के अनुसंधान की आवश्यकता है, क्योंकि इसका प्रभाव मौसमी या अल्पकालिक फसल प्रतिरूप पर पड़ सकता है।

ABSTRACT. The IPCC (2007) has estimated that the water availability will be reduced by 10-30% up to 2050 causing serious scarcity of freshwater. Madhya Maharashtra, a meteorological subdivision characterised by predominant cash crop and cereal crop cultivation. During the past few years, this region has registered extreme rainfall events which demanded an investigation of rainfall variability. The present study, therefore, attempted to examine long-term (1901-2020) rainfall trends with the application of parametric and nonparametric techniques. The Madhya Maharashtra sub-division is observed with an increasing trend in annual rainfall during the post-1926 period. Although all the selected districts registered an increasing trend in monsoon rainfall, only three of them (30%) are statistically significant. On the contrary, almost all the studied districts reveal declining rainfall in winter, except Sangli. Among them, Dhule, Ahmednagar, Pune and Kolhapur Districts observed a significant decline. Significant change points were found in all the temporal scales (monthly, seasonal and annual). Six out of ten districts are registered with change points in the last 5 years. The future projection till 2100 estimates a potential increase in both the amount and variability of the region's rainfall. So, a question arises from this observation that, what will be the scenario of rainfall in these districts in the coming decades and how much will that contribute in changing the overall trend in rainfall over Madhya Maharashtra sub-division. Also, the changing pattern of the inter and intra seasonal rainfall should draw the attention for further research as this can impact seasonal or short-term cropping patterns.

Key words – Rainfall, Trend analysis, Sequential Mann-Kendall test, Mann-Kendall test, Linear regression.

1. Introduction

Changes in rainfall trends and patterns are directly associated with climatic changes. According to the IPCC (2007) report global surface temperature has increased by 0.74 ± 0.18 °C during the period of 1906–2005. It is believed that implications of such climate will lead to scarcity of freshwater in future. It has also been predicted that, by the middle of the 21st century, the available water and average annual runoff will be reduced up to 10-30% (Roy & Chakravarty, 2021; Barnes, 2007). The changing pattern of rainfall is a topic which needs riveting attention because it affects both, the availability of fresh water and food production (Dore, 2005). One of the very crucial findings of some recent studies shows that there is an increased amount of intense rainfall in many parts of South Asia, but the number of rainy days and total annual precipitation have decreased. (Khan *et al.,* 2000; Shrestha *et al.,* 2000; Mirza, 2002; Lal, 2003; Min *et al.,* 2003; Dash *et al.,* 2007). Number of heavy downpouring events within a short span of time is projected to intensify in near-future (Shaw *et al.,* 2022). Rainfall trends over different parts of India and the country as a whole have always been part of the research. Various studies have found that for a country as a whole, there was no significant long-term trend observed in monsoonal rainfall (Guhathakurta and Rajeevan, 2008; Patra *et al.,* 2012) but the frequency and magnitude of extreme rainfall events are significantly increasing (Goswami *et al.,* 2006). The spatial heterogeneity of the annual maximum intensity of rainfall across India over the past half century is found to have increased considerably (Vinnarasi and Dhanya, 2016). The southern part of the Deccan plateau and the western coast is found to experience a declining trend in extreme hourly precipitation during dry and wet summer monsoon while the same in the northern part of this region is found to increase (Sen Roy, 2009). The warming of the Arabian Sea is responsible for such heterogeneity (Mishra *et al.*, 2020). This warming is accumulating moisture in the Arabian Sea, which is eventually unable to reach the Indian mainland, causing heterogeneity in the changing rainfall pattern over the Indian subcontinent (Mishra *et al.*, 2020). It is also found that the warming increases extreme rainfall in most parts of India. The higher the warming, the greater will be the magnitude of extreme rainfall events over India.

Maharashtra is not only one of the largest states in India but also one of the largest contributors to the country's economy. It has a monsoon climate. By mid-June, most parts of the state come under the influence of a monsoon. July is the wettest month of the year. There is substantial rainfall in August as well. The monsoon weakens during the month of September and hence the rainfall decreases. Progression of the monsoon over the state of Maharashtra is governed by its two branches, *viz*., the Arabian Sea and the Bay of Bengal branches (Ratna, 2012). Potdar *et al.* (2019) have found out that over Maharashtra the annual as well as south-west monsoon rainfall is increasing, however, not statistically significant. Within the monsoon season August rainfall has been found to be increasing significantly at all the four sub-divisions of Maharashtra (Guhathakurta and Rajeevan, 2008). Singh *et al.* (2021) studied the trends and variability of seasonal and annual rainfall time series data for 118 years (1901-2018) for 36 districts of Maharashtra using Mann Kendall (MK), modified Mann-Kendall (MMK), Sen's Slope Estimator (SSE), Spearman's rho (SRC), and simple linear regression (SLR). The study revealed significant decreasing trends in winter and pre-monsoon rainfall in the districts of Maharashtra. Monsoon, post-monsoon, and annual rainfalls had both significantly increasing and decreasing trends in different districts. All the districts were found to have high variability in rainfall. The Western Ghats region of Maharashtra is found to have a decreasing trend in rainfall in June and July and an increasing trend in the months of August and September at a rate of 1.87 mm and 4.92 mm per year respectively (Khadke *et al.,* 2019). The position of the Western Ghats also creates a distinctive rainfall distribution that reduces eastwards (Tadvi, 2016; Barakade and Sule, 2011; Sanjay *et al.,* 2018). However, there is an overall decreasing trend in rainfall over this region (Khadke *et al.,* 2019). The areas that have a deficit in rainfall in the Marathwada sub-division outnumber the areas that have excess rainfall (Kulkarni *et al.*, 2021). A detailed analysis of daily summer monsoon rainfall at 329 rain gauge stations distributed over 35 districts of Maharashtra for the period from 1998 to 2008 shows that the Konkan region receives most of the seasonal rainfall, followed by Vidarbha and Madhya Maharashtra regions respectively (Ratna, 2012). Using only nonparametric tests, Mandale *et al.* (2017) found that there is no significant trend over the Konkan region in the months of June, July, and August. Various districts of Maharashtra have also been studied individually. Position of the Western Ghats and Satpura Ranges in Nandurbar sets the characteristics of rainfall distribution in the district that increases westward (Tadvi, 2016). Solapur district has high variability of rainfall in its western part compared to its eastern part (Barakade and Sule, 2011). In Nashik as well the rainfall decreases from west to east (Sanjay *et al.*, 2018). The state's agriculture is mostly dependent on the south-west monsoon, while various regions of the state experience drought every year (Guhathakurta and Saji, 2013). It has been experiencing drought situations since ages (George and Ramasastri, 1975). There is no notable increase in the monsoonal rainfall in the rain shadow zone of Maharashtra (Todmal, 2023) but the variability of rainfall in this region is high (Todmal, 2020). On account of this condition a notable increase in the withdrawal of groundwater has been found (Todmal, 2023). The region is also predicted to experience meteorological droughts in 2030s (Todmal, 2019). On the other hand, extreme one-day rainfall events have increased significantly in southern Maharashtra, causing an increasing risk of flood in the state (Guhathakurta, *et al.*, 2011; Todmal 2020; Todmal 2023).

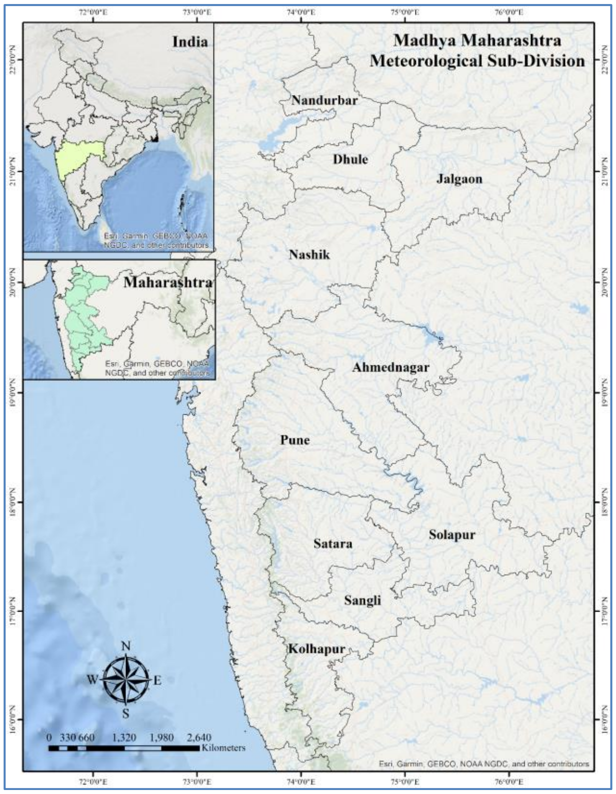


Fig. 1 Study Area

There are only three least agro-potential zones in all over India, one of which fall into Madhya Maharashtra (Todmal 2020). However, from the literature review, the research gap that can be pointed out is that, Madhya Maharashtra, despite being the largest meteorological sub-vision in Maharashtra, has not been studied that extensively as compared to other three sub-divisions. Although, some districts of Madhya Maharashtra had been studied separately (Kulkarni *et al.,* 2021; Barakade and Sule 2011; Sanjay *et al.*, 2018) and major river basins have also been studied previously (Todmal 2019, 2021, 2023), methodologies used in those studies differ from each other. Therefore, in the present study, past 120 years' rainfall variability and its trend has been analysed at both sub-divisional and district scale including all the districts under a uniform methodology, using both parametric and nonparametric tests. Along with that, the near and far-future scenario has also been estimated, which has not been done before.

2. Data and methodology

2.1. *Study area*

Madhya Maharashtra is the largest (1.13 lakh km^2) meteorological sub-division in Maharashtra, occupying 36% of the state's area. According to the census of India 2011, out of the 112 million population of Maharashtra, 42 million resides in Madhya Maharashtra. The elongated shaped region falls on the leeward side of the Western Ghats which brings three types of climates to that region (IMD 2005) and causes lower rainfall conditions with high variability (Guhathakurta and Saji, 2013; Todmal, 2021). The high variability is due to the orographic effect governed by the Western Ghats (Gadgil, 2020). According to Köppen's climate classification, the eastern and the majority of the region fall under the dry semi-arid climate (Bsh). The middle part experiences tropical savanna hot climate (Aw). The south-western most corner that is close to Konkan falls under the tropical monsoon climate (Am). Therefore, only four districts, *i.e.*, Pune, Satara, Sangli, and Kolhapur come under all these three types of climatic regions. The Western Ghats, along with its gaps, create a unique rainfall distribution in Maharashtra causing the Madhya Maharashtra sub-division to have the lowest mean rainfall (<60 cm). The region gets 83% of its annual rainfall in the south-west monsoon (IMD, 2005). Six out of its ten districts face periodic droughts, of which Pune is the most chronically drought prone (IMD, 2005). There is a 14% probability that the annual rainfall will be less than 75% of normal in this sub-division (IMD, 2005). On the other hand, Kolhapur has the maximum number of years (13) to receive excessive rainfall, two pairs of them being successive years (IMD, 2005; Todmal, 2020). This caused flooding in the district. Overall, the Madhya Maharashtra sub-division (Fig. 1) has a very high variability in rainfall in terms of spatial and temporal scale and the intensity of the rainfall as well.

2.2. *Data acquisition*

Rainfall data for all 10 districts of the Madhya Maharashtra sub-division were obtained for the period of 1901-2020. This dataset were acquired from the online data library of the India Meteorological Department (IMD). This data has used IMD station datasets as available and spatially classified them into district, sub-division and all-India series. It first prepares the district series by taking simple arithmetic mean of monthly rainfall of the available stations in the district for a particular month. Sub-division series has been prepared using the district area weighted method and the all-India series has been prepared using the sub-division area weighted method. In the present study the district series has been used for the districts in the Madhya Maharashtra sub-division. The data were further classified into monthly, annual, and seasonal sets. For the seasonal set, four seasons were considered with respect to the study area, *i.e.*, winter (January-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-December).

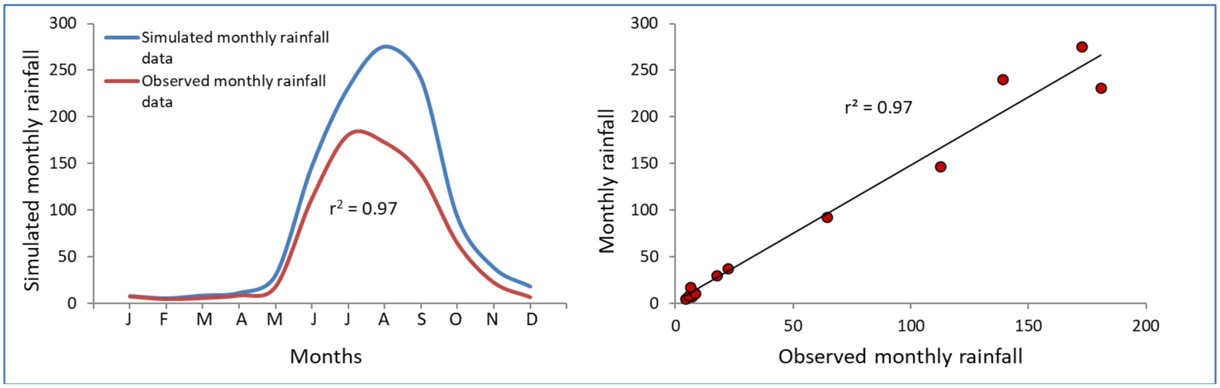


Fig. 2. Average annual cycles of simulated model (REMO-2009) and observed rainfall data over the study area for the period between 1976 and 2005

The estimated rainfall data of the regional climate model (RCM) REMO (Regional Model) with 0.44 X 0.44 (~50 km) resolution were acquired from the Earth System Grid Federation (ESGF), DKRZ, Germany (https://esgf-data.dkrz.de), and Indian Institute of Tropical Meteorology (IITM), Pune (http://cccr.tropmet.res.in). The REMO-2009 model is based on the Representative Concentration Pathway 4.5 scenario and recently considered in the Fifth Assessment Report of IPCC. The Coordinated Regional Climate Downscaling Experiment (CORDEX) project under World Climate Research Programme (WCRP) aims at producing an improved set of regional climate change projections for different domains across the globe. South Asia (SA) is one of such domains which include Maharashtra. In the present work, future projections of the regional climate model REMO-2009 (Saeed *et al., 2012*; Kumar *et al., 2013*) under MPI-ESM-LR-REMO 2009 CORDEX SA simulation are used. It was developed by the Max Planck Institute for Meteorology, Germany, forced with the CMIP5 general circulation model (GCM) MPI-ESM-LR. The dynamical downscaling method using high-resolution limited-area RCMs utilizes the outputs provided by CMIP5 (AOGCMs) as lateral boundary condition (*i.e*., driving AOGCMs including winds, temperature, water vapour and surface pressure) to provide physically consistent spatiotemporal variations of climatic parameters at spatial scales much smaller than the AOGCMs' grid. In the present investigation, one ensemble member is considered.

This investigation considered 1976–2015 as a base period. The simulated REMO-2009 model data for the Madhya Maharashtra subdivision were validated (Fig. 2). It is pertinent to mention here that validation of the REMO model was carried out which suggested that this model is very well suited for the present study area. For this, the observed rainfall data (between 1976 and 2005) obtained from the India Meteorological Department (https://www.imdpune.gov.in) were compared with the historical simulated model data for the same period.

2.3. *Statistical analyses*

Two fundamental components of any kind of trend analysis are the magnitude and statistical significance of the trend of the given data (Kulkarni *et al.*, 2021). There are plenty of types of statistical techniques which are broadly characterised as parametric and non-parametric tests (Dhorde *et al.*, 2017). In parametric tests, the data are assumed to be normally distributed while in non-parametric tests the data are assumed to be distribution-free. Parametric Tests assume normality of data. However, data is not always normally distributed which may cause type I error. Therefore, both parametric and non-parametric tests are employed, and the results are further compared. The World Meteorological Organisation (WMO), in their technical note no. 79 (Mitchell *et al.*, 1966), has mentioned some standard statistical tests as a guideline to be followed while studying climatic fluctuations. Those guidelines have both Moving average and MK Tau as standard nonparametric tests. They have also suggested Student's *t* test as a standard parametric test for analysing long-term climatic variation. Hence, the most frequently used parametric tests are SLR analysis and *t* test and the most widely used nonparametric tests are Mann-Kendall (MK) test and Sequential Mann-Kendall (SQMK). The significance level of the statistical tests, which are frequently used, are 1%, 5% and 10%. In the present study, 95% confidence level is used. To understand the variability of the rainfall, district-wise mean ($\bar{x}$), standard deviation (SD), and coefficient of variation (CV) of monthly, seasonal and annual rainfall were calculated. The statistical tests that are employed in the present study are as follows:

2.3.1. *Simple linear regression (SLR)*

Since SLR is a parametric test, the two variables i.e., time and rainfall values (in mm) in the correlation are assumed to be independent of each other. The equation is given by

$$Y = a + bX$$

where, Y is rainfall values, X is time, b is the slope and a is the intercept. The sign of b determines the upward (positive) or downward (negative) direction of the trend and the value of b determines the magnitude of the trend. The test of significance is performed at 95% confidence level. The *t* test is given by

$$t = r\sqrt{\frac{(n-2)}{(1-r^2)}}$$

2.3.2. *Mann-Kendall Test (MK)*

Nonparametric tests are widely used on long-term data because generally they stay unaffected by any abruptly high or low (outliers) observations in the data set and hence represents more of a monotonic trend (Patra *et al.*, 2012). The MK test actually performs in that aspect along with a test of significance (Dhorde *et al.*, 2017). Mann (1945) first introduced a nonparametric test against the trend and Kendall further in 1975 added the statistical distribution of the test (Patra *et al.*, 2012). The significance level is kept at p = 0.05. The test statistics are as follows:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sig(X_j - X_i)$$

where, X_j *and* X_i are annual rainfall values in the years *j* and *i*, $j > i$, respectively and *n* is the number of years. The value of *sig* is computed as

$$sig(X_j - X_i) = \begin{cases} 1 \; if \; (X_j - X_i) > 0 \\ 0 \; if \; (X_j - X_i) = 0 \\ -1 \; if \; (X_j - X_i) < 0 \end{cases}$$

with the larger positive and negative values of *S* we can derive a consistent increasing and decreasing trend respectively. The variance (*var*(*S*)) of MK test is calculated as

$$var(S) = \frac{1}{18}[n(n-1)(2n+5)]$$

For larger samples (*n >10)*, the test statistics (Z) is calculated as follows:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & \ldots if \; S > 0 \\ 0 & \ldots if \; S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & \ldots if \; S < 0 \end{cases}$$

The null hypothesis (H_0) is that there is no trend present in the data set and the alternative hypothesis (H_α) is that there is a statistically significant trend in the data set. H_0 is rejected if $Z_{mk} > Z_{1-\alpha/2}$, where, Z is the table value of standard normal distribution and α is the significance level. Value of Z is ±1.96 when α=0.05. To understand the magnitude of the trend MK Tau (τ) was also calculated as follows:

$$\tau = 0 \pm t_g\sqrt{\frac{4n+10}{9n(n-1)}}$$

where, t_g is the chosen probability value in Gaussian normal distribution. In the present study it is at 0.05 point. Greater the value of τ, greater is the magnitude of the trend.

2.3.3. *Sen's Slope Estimator (SSE)*

SSE (Sen, 1968) another nonparametric slope estimator, applied to the monotonic data set to find out the trend of the same. In other words, it is used to define the magnitude of the trend line (Patra *et al.*, 2012). As said in the title of the article (Sen, 1968) it is an estimate of "Regression Coefficient based on Kendall's Tau". The calculation of the slope starts with calculating the median of each pair of data set which is as follows

$$Q_i = \frac{X_j - X_k}{j-k} \; for \; i = 1,2 \ldots, n$$

Here, j and k are two consecutive years (time) in which j is the following time and k is the preceding year and X_j and X_k are respective data values i.e., in this case, amount of rainfall. Now, to acquire the slope value, the median of all these Q_i values is calculated as

$$Q_{med} = \begin{cases} Q_{\left[\frac{(n+1)}{2}\right]} & \ldots if \; n \; is \; odd \\ \frac{Q_{\left[\frac{n}{2}\right]} + Q_{\left[\frac{(n+2)}{2}\right]}}{2} & \ldots if \; n \; is \; even \end{cases}$$

The sign of Q_{med} determines the direction of the slope while the value of it depicts the magnitude of same.

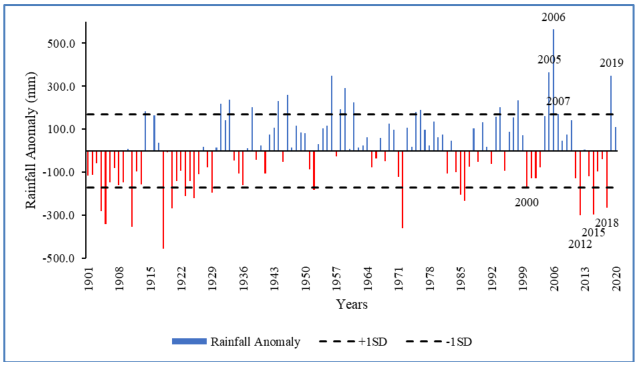


Fig. 3. Rainfall anomaly over Madhya Maharashtra during the study period

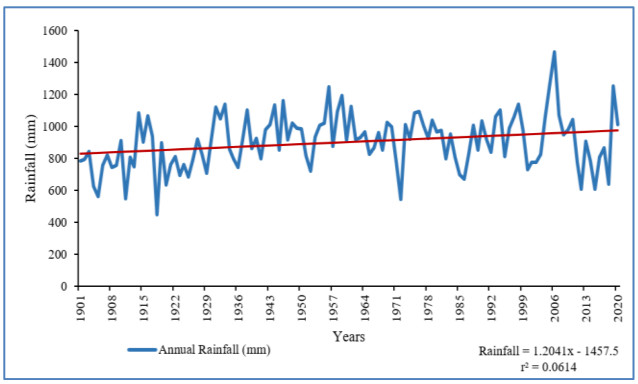


Fig. 4. SLR of annual rainfall over Madhya Maharashtra

In case of SSE, the statistical significance of the test is derived by calculating the nonparametric confidence interval as

$$C_\alpha = Z_{1-\frac{\alpha}{2}} \times \sqrt{var(S)}$$

where, var(S) is the variance of SSE

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

The SSE variance is MK's variance minus the "standard correction for tied observations" (Sen, 1968). Here, n=number of data points, t_p= elements which are tied (equal) for p=1, 2..., q. The $Z_{1-\alpha/2}$ is obtained from standard normal distribution table at 95% confidence level. Now the Confidence interval is computed as

Upper limit $\qquad M_1 = \frac{n-C_\alpha}{2}$

Lower limit $\qquad M_1 = \frac{n+C_\alpha}{2}$

The test is statistically different than zero (0) if there is no zero between M_1 and M_2, which means, if the sign of both the limits are same, the test is significant.

2.3.4. *Sequential Mann-Kendall Test (SQMK)*

The SQMK test is used to detect significant change points, also called mutation point, in a monotonous trend (Sneyers, 1990). The test statistics t_i of the test is defined as

$$t_i = \sum_{j=1}^{i} n_i$$

where, counting and indication of n_i = the number of cases $x_i > x_j$. the values are X_i ($i=1,2...n$) and X_j ($j=1,2..., i-1$). The mean E(t) and Variance var(t_i) are computed as:

$$E(t) = \frac{n(n-1)}{4}$$

$$var(t_i) = \frac{i(i-1)(2i+5)}{72}$$

Two series i.e., one forward series U and one backward series U' are computed from the data set. The forward series is calculated from the original time series and the backward series is calculated in the same way but from the end of the original series (Bisai *et al.*,, 2014). When both the series cross each other, deviate and go beyond the critical value ±1.96 (at p=0.05) the trend is called statistically significant (Kulkarni *et al.*, 2021). The sequential forward series values are calculated as

$$U = \frac{t_i - E(t)}{\sqrt{var(t_i)}}$$

If one of these reduced variables (U and U') become greater than the threshold of the chosen level of significance, the H_0 is rejected.

3. Results and discussions

3.1. *Analyses of rainfall over the study area*

The mean annual rainfall over the entire Madhya Maharashtra sub-division as a whole is 903 mm. with a SD of ±169 and CV of 19% (Appendix Fig. 1). Rainfall anomaly (Fig. 3) of the study period shows that there were 18 years that had annual rainfall above 1SD of the mean and 16 below the same. The overall trend of rainfall in the study area is increasing with an r^2 of 0.06. (Fig. 4). Increasing trend is very weak but statistically significant at 95% confidence level (calculated t = 2.778). July rainfall contributes the highest amount to the annual

TABLE 1

Seasonal and monthly rainfall distribution

Seasons	Contribution to the annual rainfall (%)	Months	Contribution to the annual rainfall (%)	Contribution to the seasonal rainfall (%)	CV of monthly rainfall (%)
Monsoon	84.2	June	16.8	19.9	37.6
		July	29.0	34.5	30.3
		August	21.4	25.4	36.8
		September	17.0	20.2	40.3
Post-monsoon	11.2	October	7.8	69.9	66.3
		November	2.7	24.4	130.1
		December	0.6	5.6	197.2
Winter	0.5	January	0.3	68.0	228.1
		February	0.2	31.9	199.5
Pre-monsoon	4.1	March	0.4	10.1	165.3
		April	1.1	26.5	96.9
		May	2.6	63.4	94.7

rainfall with least variability. On the other hand, the lowest contributor is the month of February (Table 1). January is found with the highest variability. Seasonally, around 84% of the annual rainfall occurs in monsoon, followed by post-monsoon and pre-monsoon seasons. The lowest rainfall occurs in the winter season (Table 1). In India four months, *i.e.*, June, July, August and September constitute the monsoon season and all four of them have quite low CV (%).

Distribution of Mean monsoonal rainfall among these four months is quite homogeneous (Table 1). July contributes the highest (~34%), followed by August (~25%), September (~20%) and June (~19%). During the rest of the seasons this distribution is quite heterogeneous. For example, in the post-monsoon season, around 70% of the rainfall precipitates in October itself, and in November and December only 24% and 5% rainfall is recorded. Likewise, around 68% of the winter rainfall and around 63% of the pre-monsoon rainfall occurs in only January and May respectively. October and November are the months of retreating monsoon which brings rain to the Coromandel coast and adjacent continental part of the peninsula. Comparatively, the month of December gets no major source of rainfall. In winter, though the mean rainfall is very low (~43 mm), but in January the region sources some rainfall from the remnants of the Western disturbances which bring rain towards the eastern part of the study area. From the findings, that comply with previous studies (Todmal, 2020), it can be inferred that the study area is characterised by high rainfall with lower variability and vice versa.

3.1.1. *Monthly variability of rainfall*

For most of the months, rainfall is within the range of 1SD from the mean. Only in April, May, July and August there is an exception (Table 2). In all these four months Kolhapur has been getting rainfall above this range. Along with Kolhapur, Sangli in April and Satara in July and August also receive rainfall higher than 1SD of the mean. During both July and August, Ahmednagar, Sangli and Solapur receive rainfall below the range of 1SD from the mean. In July, Dhule is the only addition.

In both, January and February months (Table 2) the mean rainfall is comparatively higher and CV is comparatively lower in Jalgaon and Solapur than the remaining districts. This is the effect of Western disturbances reaching the interior part of the peninsula. As such Jalgaon, which is more of a drought prone area, gets the highest amount of rainfall in both months. From the month of March (Table 2), the southern districts start getting comparatively higher rainfall while the northern and western districts still receive scanty rainfall. This picture of mean rainfall gets reflected in the CV of rainfall in March. The western and northern districts undergo high variability of rainfall while Jalgaon and the southern districts experience very low variability. By the month of April, this scenario gets more intensified, such that there forms almost a clear-cut north-south division among the states in terms of both mean rainfall and CV. From Pune and Solapur, all the districts to the north of them undergo scanty rainfall and very high variability (more than 100%). To the south of Pune and Solapur, districts get higher mean rainfall, with CV ranging between 93 and

TABLE 2

Variability in monthly rainfall

District	January		February		March		April	
	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)
Ahemadnagar	3	268	1.4	272	3.5	250	5.7	171
Dhule	3.6	261	1.7	266	2.8	235	2.1	205
Jalgaon	5	210	3.3	220	4.4	202	1.8	236
Nandurbar	3.6	478	0.8	305	1.2	253	1.5	227
Nashik	2.4	248	1.1	230	2.3	268	4.6	159
Pune	1.6	268	0.7	356	2.5	255	7.9	134
Satara	2.2	374	1	301	4.2	176	16	113
Sangli	2.3	362	0.9	375	5	182	20.5	99
Kolhapur	1.9	278	0.9	359	6.9	182	26.2	93
Solapur	4.2	246	2	251	4.3	180	10.7	121
District	**May**		**June**		**July**		**August**	
	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)
Ahemadnagar	17.3	137	110	49	100.7	51	87	64
Dhule	8.9	210	116.9	57	168.2	39	122.7	57
Jalgaon	8.7	177	128.3	51	200.3	32	176.7	50
Nandurbar	6.8	285	135	69	282.8	40	214.5	55
Nashik	16	142	155.1	53	311.1	38	238.9	43
Pune	22.4	140	168.7	47	323.5	40	226.5	45
Satara	34.8	95	208.1	51	416.7	41	287.5	46
Sangli	44.7	104	104.6	58	136.9	47	99.8	57
Kolhapur	50.2	95	289.4	46	589.9	39	381.5	46
Solapur	22.7	131	100.3	47	91.5	59	96.6	70
District	**September**		**October**		**November**		**December**	
	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)	$\bar{x}$ (mm)	CV (%)
Ahemadnagar	150.9	54	66.5	85	26.8	157	6.2	249
Dhule	119.3	62	36.6	112	17.4	184	5.3	226
Jalgaon	138.8	60	40.4	124	19.1	183	6.7	208
Nandurbar	149	67	32.9	120	12.2	206	3.9	267
Nashik	177.7	53	61.8	95	23.8	160	4.4	218
Pune	168.3	44	80.7	79	27.4	147	5	243
Satara	177.3	44	95.7	77	34.5	132	6.8	248
Sangli	123.9	58	96.5	67	27.5	132	6.1	238
Kolhapur	168.7	49	114.5	63	32.2	129	6.4	252
Solapur	165.6	56	82.5	80	26.2	135	6.4	232
Legend		>($\bar{x}$+1SD)			<($\bar{x}$-1SD)			

99%. This situation persists until the month of May. By the month of June, which is called the onset month of Indian monsoon, the situation reverses as the western districts like Nandurbar, Nashik, Pune, Satara and Kolhapur start getting higher rainfall (above 199 mm), the eastern districts like Dhule, Jalgaon, Ahmednagar, Solapur, Sangli get around 90-199 mm. In September, which is the last month of monsoon, once again the western and southern districts like Nashik, Pune, Satara and Kolhapur get more than 165 mm of rainfall with medium to higher consistency. The northern districts (Nandurbar, Dhule and Jalgaon) and the eastern districts (Ahmednagar, Solapur and Sangli) receive comparatively low rainfall. In the months of October and November rainfall decreases while CV increases from south to northwards. In December, all the districts record very low rainfall with very high variability.

TABLE 3

Variability of monthly rainfall

Districts	Winter		Pre-monsoon		Monsoon		Post-monsoon	
	x̄	CV (%)	x̄	CV (%)	x̄	CV (%)	x̄	CV (%)
Ahemadnagar	4.4	200	26.5	100	448.7	28	99.4	65
Dhule	5.3	193	13.9	125	527	27	59.3	85
Jalgaon	8.3	151	15	123	644.2	25	66.2	89
Nandurbar	4.9	368	9.5	172	781.3	30	49	94
Nashik	3.5	185	23	108	882.7	25	90	77
Pune	2.3	212	45.6	114	887	26	113.1	67
Satara	3.2	276	55	67	1089.4	27	137	63
Sangli	3.8	247	78.9	64	466.3	31	131	56
Kolhapur	2.8	226	83.3	63	1429.5	29	153.2	54
Solapur	6.3	173	37.8	75	453.9	29	115.1	64
	Legend		(blue)	>(x̄+1SD)		(red)	<(x̄-1SD)	

3.1.2. *Seasonal variability of rainfall*

In winter and post-monsoon, the districts receive rainfall within the range of 1SD from mean. Fluctuation is found only in the pre-monsoon and monsoon seasons (Table 3). Moreover, in the monthly scenario, Kolhapur is the only district to receive rainfall greater than 1SD being accompanied by Sangli in pre-monsoon and Satara in monsoon. In pre-monsoon, only Nandurbar goes below this range while in monsoon, four districts, *viz*., Ahmednagar, Dhule, Sangli and Solapur receive rainfall below 1SD.

The seasonal mean monsoon rainfall in the study area is around 761 mm. In monsoon, half of the ten districts receive rainfall which is less than the mean of Madhya Maharashtra. This includes districts such as Ahmednagar, Dhule, Jalgaon, Sangli and Solapur with four of them receiving lower than 1SD of the mean rainfall (Table 3). Nandurbar, Nashik, Pune, Satara and Kolhapur receive rainfall above mean. Such a pattern of distribution of monsoon rain can be related to the proximity to the Western Ghats (Todmal *et al.*, 2018). In Maharashtra, monsoon rainfall first increases from the coasts to the maximum contour of the Western Ghats and on the leeward side, it first decreases eastwards for a certain stretch and then gradually increases towards the far east of the state (Patwardhan and Asnani 2000). In both post-monsoon and pre-monsoon seasons, the southern districts, *viz*., Pune, Satara, Sangli, Kolhapur and Solapur, receive rains higher than the seasonal mean rainfall of Madhya Maharashtra with CV < 100% (except in Pune in pre-monsoon). It suggests the occurrence of heavy rainfall events during pre and post monsoon period (Todmal, 2020). For the northern districts, *viz*., Ahmednagar, Dhule, Jalgaon, Nandurbar and Nashik, the scenario is reversed in pre-monsoon as the CV is above 100%. In winter, all the districts have very high variability with five of the districts, *viz*., Ahmednagar, Dhule, Jalgaon, Nandurbar and Solapur, having more than the seasonal mean rainfall in Madhya Maharashtra.

3.1.3. *Annual variability of rainfall*

The distribution of mean annual rainfall over the districts of Madhya Maharashtra follows almost the same pattern as monsoon. Kolhapur receives the highest mean annual rainfall (>1285 mm), followed by Satara (1035-1285 mm). The districts that receive rainfall below 609.36 mm are Dhule, Ahmednagar and Solapur. Jalgaon and Sangli get 609-734 mm and Nandurbar, Nashik and Dhule get 734-1035 mm mean annual rainfall. The pattern of the distribution of CV over the districts also follows the same pattern of monsoon, having Jalgaon with lowest CV (<23.4%). Nandurbar has the highest variability in mean annual rainfall. (>27.8%). Kolhapur, along with having the highest mean annual rainfall, has medium variability (24.5-24.6%) in it. The spatial distribution of rainfall is attributed by the position of Western Ghats. The districts closest to Western Ghats *i.e*., Satara and Kolhapur receive highest rainfall (Guhathakurta and Saji, 2013). On the other hand, districts like Dhule, Ahmednagar and Solapur, that receive the lowest rainfall, fall into the rain shadow zone of Western Ghat which leads to the development of semi-arid type of climate in these districts (Guhathakurta and Saji, 2013). This eventually results in putting Solapur and Sangli districts into low agro-potential zones (Todmal, 2020).

3.2. *Trend Analysis of the monthly, seasonal and annual rainfall*

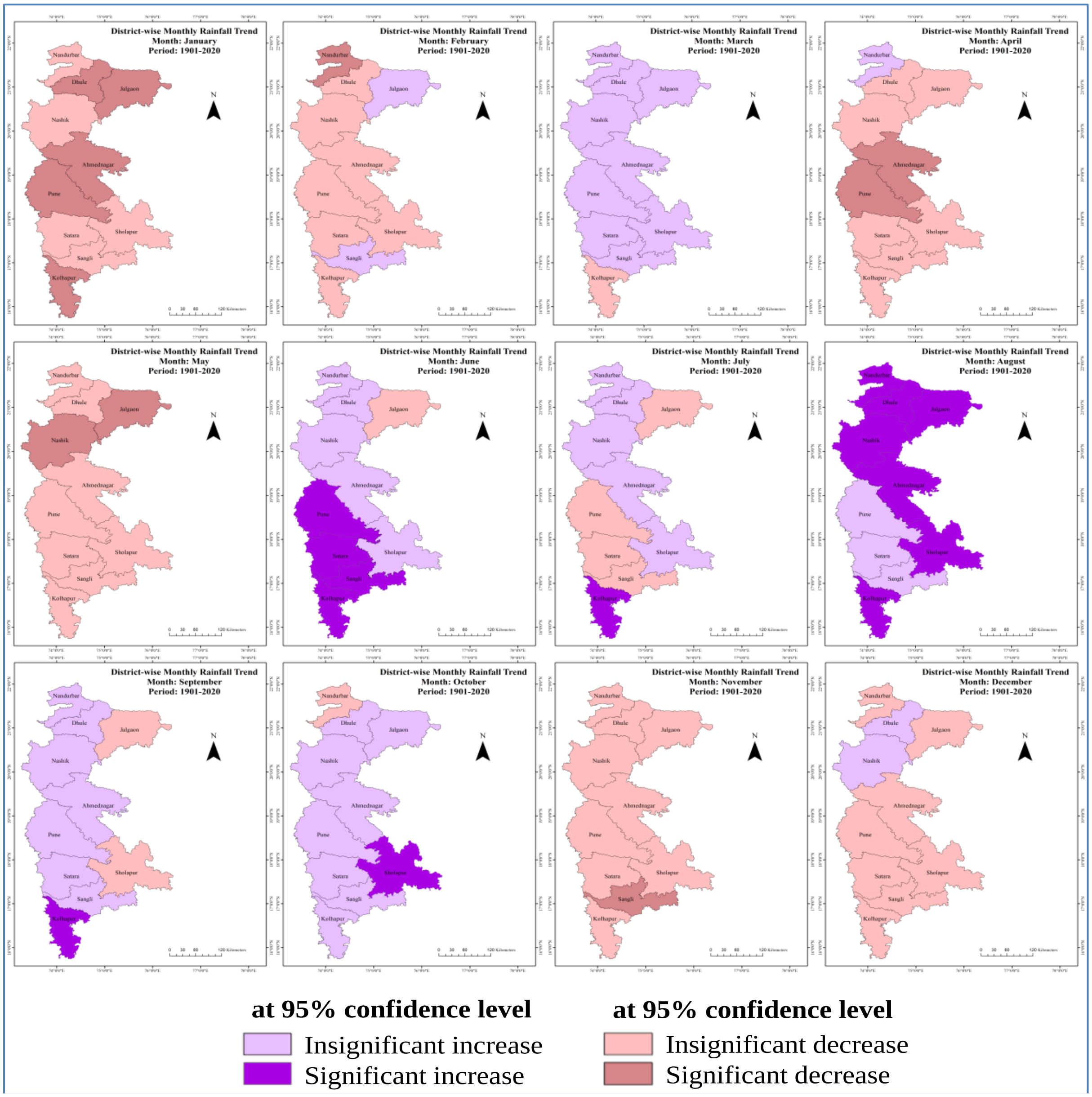


Fig. 5. SLR analysis of mean monthly rainfall

3.2.1. *Monthly rainfall trend analysis*

From the parametric test (Fig. 5) we can see that in January the rainfall is significantly decreasing in Dhule, Jalgaon, Ahmednagar, Pune and Kolhapur districts. Nandurbar is the only district that has a significant decreasing trend in February. In March, only Kolhapur has got a decreasing trend. Except for that, all the other districts are having an increasing trend. However, none of the districts have significant rainfall. Ahmednagar and Pune have a significant decreasing trend in April. Jalgaon and Nashik have shown a significant decreasing trend in rainfall in May. Most of the districts in all the months except July exhibit an increasing trend. For the month of June, a significant increasing trend can be observed in Pune, Satara, Sangli, Kolhapur. In the months of July and September, only Kolhapur district has a significant increasing trend . In August it is observed that Nandurbar, Dhule, Jalgaon, Nashik and Ahmednagar show a significantly increasing rainfall trend. Solapur district depicted a significant increasing trend in October. In the month of November, all the districts have witnessed decreasing trends with only Sangli having a significant decline. In December, only Dhule and Nashik had an increasing trend, none of them being statistically significant.

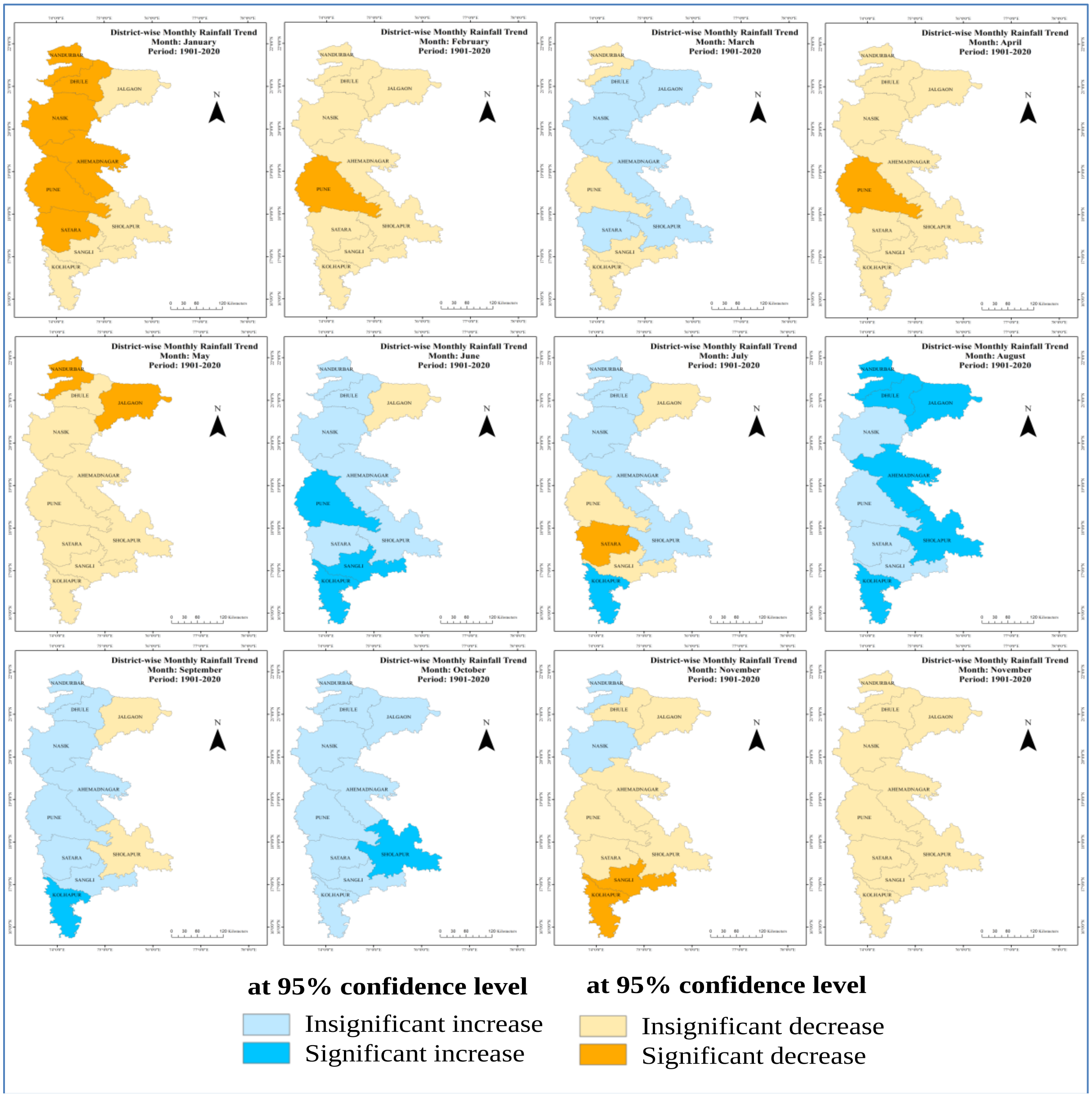


Fig. 6. MK Analysis of monthly rainfall

In nonparametric tests, the results of MK test show same outcome as the SSE. In both tests, statistically significant decreasing trend is unique in the months of January, February, April, May and November (Fig. 6). Also, statistically increasing trend is unique in the months of June, August, September and October (Fig. 6). In the month of July, there is a coexistence of both statistically significant increasing and decreasing trends (Fig. 6). In the month of January, all the districts witnessed decreasing trend. Among them, six districts, *viz*., Ahmednagar, Dhule, Nandurbar, Nashik, Pune and Satara, are found to have statistically significant decreasing trend. In February, the only district with an increasing trend (statistically insignificant) is Kolhapur. All the remaining districts are having a decreasing trend, with only Pune having a statistically significant decreasing trend. In March, four districts, *viz*., Nandurbar, Pune, Sangli and Kolhapur are observed with decreasing trend, while the rest six have increasing trend. None of them are statistically significant. In April, all the districts are found with a decreasing trend having only Pune with a statistically significant decreasing trend (τ = -0.131) (Appendix Table 1). In May, all the districts are showing a decreasing trend having only Jalgaon and Nandurbar with

TABLE 4

District-wise years of considerable change point at monthly, seasonal and annual scale

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Monsoon	Post-monsoon	Winter	Pre-monsoon	Annual
Ahemadnagar				1973				1993			1978				1922		
Dhule					1950			1953			1928		1944		1902		1930
Jalgaon					1927	2004		1944			1920				1933	1964	1908
Nandurbar					1923			1949	**1978***				1930		1903	1975	1925
Nashik				1968											1902	1979	**1970***
Pune				**1906***	1996		1912	1931					1913		1902	**1968***	1913
Satara				**1912***		1979	2011				1999				1902	2005	
Sangli			1940	**1912***	2001	1967	2006	1946			1987		1930			**1972***	1927
Kolhapur			1959	**1912***		1939	1922	1933	1936	1916	1979		1926			1995	1925
Sholapur								1961							1902		1927

**Denotes statistically significant change point*

statistically significant decreasing trend. In June, all the districts, except Jalgaon, are recorded increasing trend with three districts, *viz*., Pune, Sangli and Kolhapur registering statistically significant increasing trend. In the month of July, four districts are found with decreasing trend (Fig. 6), among them, Satara is the only district with statistically significant decreasing trend. Among all the other districts, which depicted an increasing trend, Kolhapur is the only one with statistically significant increasing trend. In August, when all the districts recorded increasing trends, six of them, viz., Ahmednagar, Dhule, Jalgaon, Nandurbar, Kolhapur and Solapur witnessed significantly rising trends. The τ in this month ranges from 0.044 in Satara to 2.230 in Dhule (Appendix Table 2). In September, only Jalgaon and Solapur are observed with decreasing trend which are not statistically significant. The only trend found to be statistically significant is in Kolhapur with an increasing direction. In October, all the districts witnessed increasing trend with only Solapur recording statistically significant trend. In November, only Nandurbar and Nashik registered decreasing trends, statistically insignificant. The only two districts that were observed with statistically significant trends were Sangli and Kolhapur, both of them registering declining trends. None of the districts are observed to have any statistically significant trend in December.

Despite having good sync in the results of the direction and significance of the trends, the magnitude of the trend has varied across the two tests. The slope value (Q_{med}) has come to 0 in all the districts in the months of January, February, March and December (Appendix Table 3-4). As the Z_s against these slopes are $\neq 0$, thus the null hypothesis cannot be accepted. Hence, this can be inferred as extremely low magnitude trend. On the other hand, the magnitude in MK test (τ) in these four months has varied between 0.001 and 0.236 (irrespective of the direction). In MK test the highest magnitude of change is found in August in Dhule (τ = 2.230) (Appendix Table 2) district while according to SSE it is Kolhapur (Q_{med} = 2.40581) (Appendix Table 4). Both of them happen to be statistically significant as well. With the help of SQMK, an idea of the initiation year of these trends has been visualised. It helps in understanding the temporal status of a trend, whether it is running for a longer term, or has just begun. For the months of January, February and December (Table 4) none of the districts have any considerable change points. Significant change points are found in April and September. In April, four statistically significant change points are found *i.e*., in Pune, Satara Sangli and Kolhapur (Table 4). First, in Pune, the first change point occurs in 1906 where the reduced variable U = -2.0665 which is greater than the threshold value. This mutation point is statistically significant. From this point on, a statistically significant increasing trend was initiated, which eventually got altered at the next change point in 1979 with a significantly decreasing trend. Satara (U'= -1.9744), Sangli (U'= -2.27812708) and Kolhapur (U'= -2.35668319) share the same year, *i.e*., 1912 when statistically significant change point was registered, from there onwards an upward trend was observed. In 1998 over Satara and in 1992 over Sangli and Kolhapur, the next important change point was detected from where a decreasing trend started (Table 4). The only change point in September that is found to be a statistically significant mutation point is in 1978 in Nandurbar district (U'=2.29192709) (Table 4). The clearest significantly increasing trend is found in Kolhapur with only a single change point in 1936. For the rest of the months there is existence of too many change points but none of them are statistically significant.

3.2.2. *Seasonal rainfall trend analysis*

Seasonally (Fig. 7) it was observed that for monsoon months, rainfall showed a significant increasing trend in

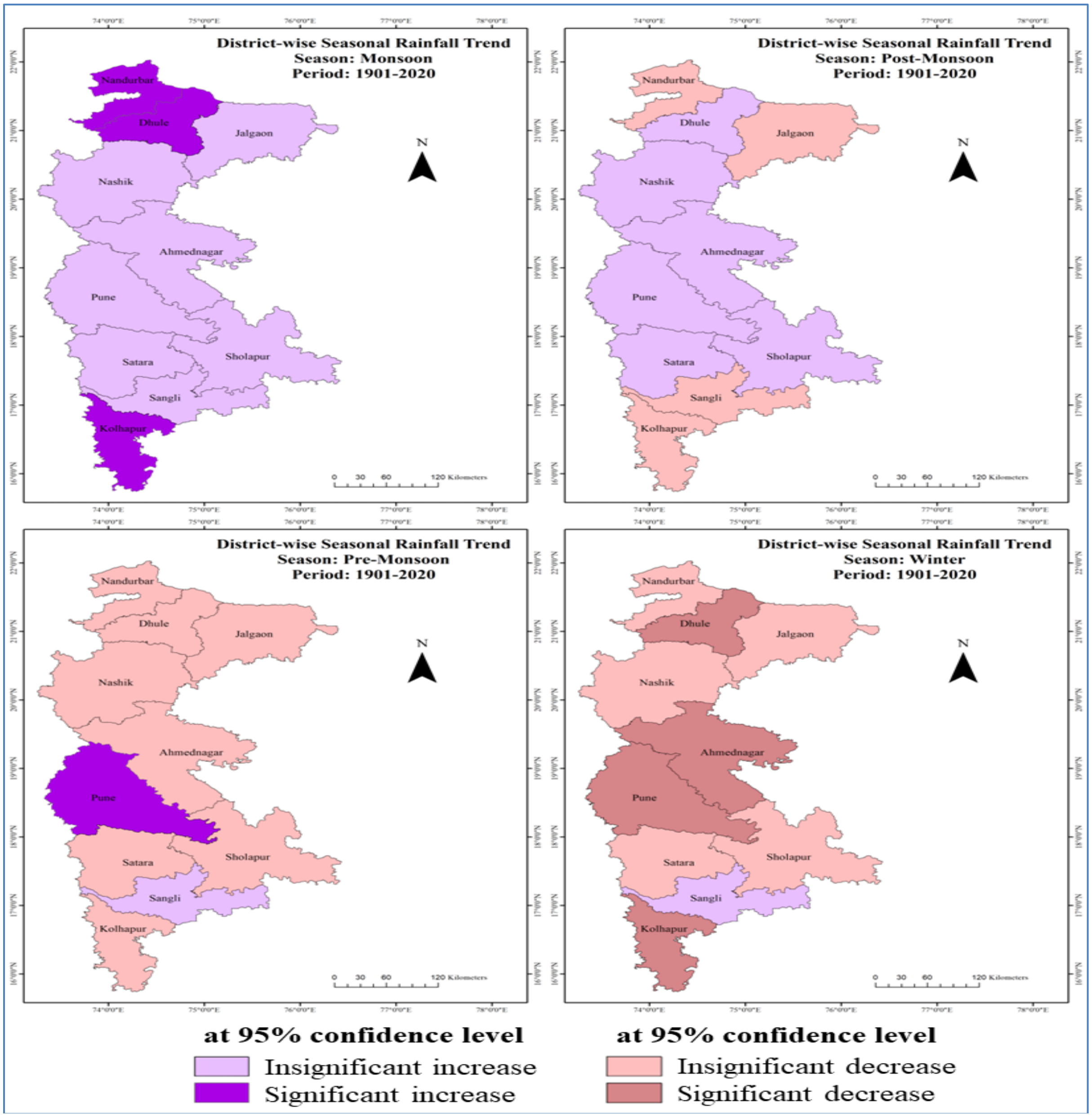


Fig. 7. SLR analysis of seasonal rainfall

Nandurbar, Dhule and Kolhapur, but no other district in monsoon months registered any significant increasing or decreasing trend. Although, in overall Madhya Maharashtra, monsoon rainfall has been significantly increasing at a rate of 1.3 mm per year. In the post-monsoon months, no significant trend, whether increasing or decreasing, can be observed for any district or the overall stud region. Nandurbar, Jalgaon, Kolhapur and Sangli are showing decreasing trend and rest are showing an increasing trend. In case of pre-monsoon months, only Pune district witnessed a significant increasing trend in rainfall. For the rest, only Sangli showed an increasing trend which was not statistically significant. Rest of the districts recorded insignificant decreasing trend. Dhule, Ahmednagar, Pune and Kolhapur districts have shown significant decreasing trend in rainfall for winter while Nandurbar, Jalgaon, Nashik, Satara and Solapur showed statistically insignificant decreasing trend. Sangli is the only district in winter which is showing an increasing trend, though not statistically significant. Overall, there is a significant decreasing trend in winter rainfall.

In seasonal rainfall as well, the MK test results (Fig. 8) have come exactly as the SSE, which is a little different

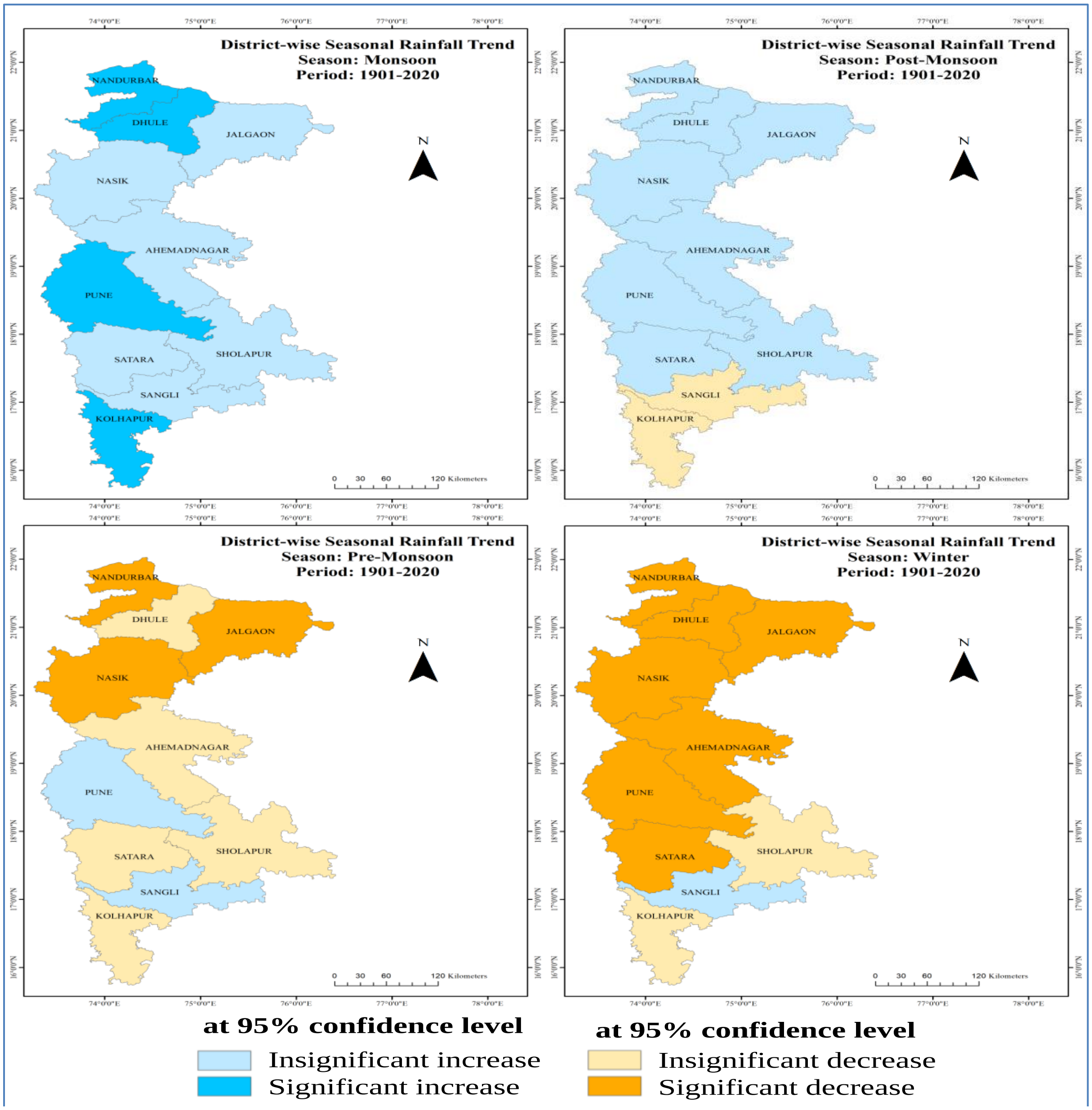


Fig. 8. MK analysis of seasonal rainfall

from the SLR analysis. In the nonparametric tests, for mean seasonal rainfall, statistically significant increasing trends were found in monsoon while statistically significant decreasing trends were detected in winter and pre-monsoon. In monsoon, the districts with statistically significant increasing trend are Dhule, Nandurbar, Pune and Kolhapur. From the Q_{med} (6.28372) (Appendix Table 6) values we can infer that among these four districts, Kolhapur has the strongest increasing trend. According to MK test Pune has the weakest increasing trend while according to SSE Dhule has the weakest increasing trend. In winter, the districts with statistically significant decreasing trend were Ahmednagar, Dhule, Jalgaon, Nandurbar, Nashik, Pune and Satara. The slope value of two districts, *i.e.*, Dhule and Nandurbar amongst these seven have come 0. Since the $Z_s \neq 0$, the null hypothesis cannot be accepted, meaning that the trend is too weak. Overall, in winter, a total of four districts have been found with slope value 0, and that includes Kolhapur also, which has the highest slope value for statistically significant mean monsoon rainfall trend. Other than that, Satara also falls under this criterion. In pre-monsoon, the three districts with statistically significant decreasing trend were Jalgaon, Nandurbar, Nashik. Amongst them, Nandurbar

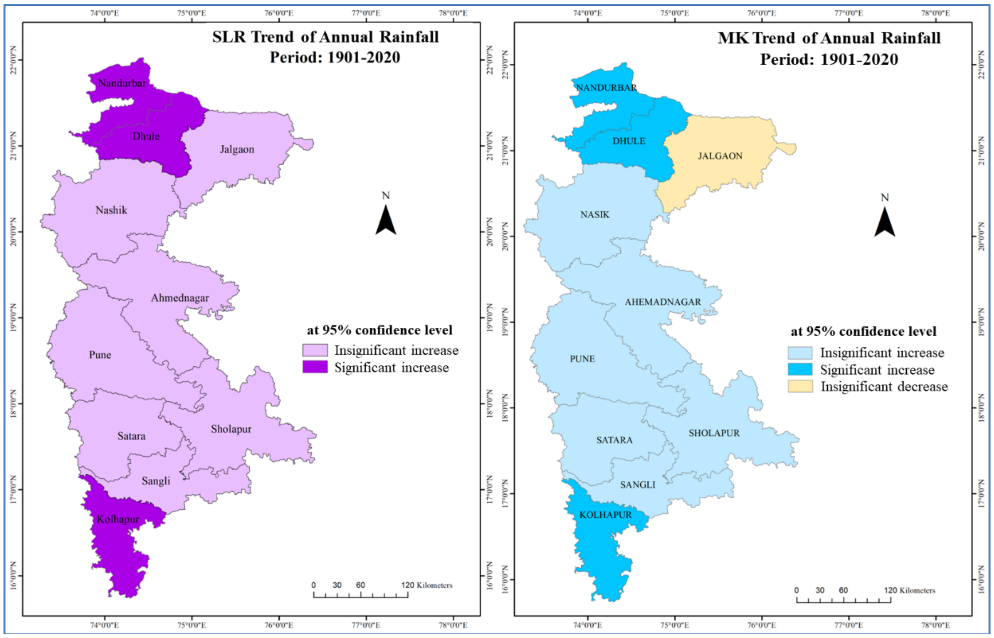


Fig. 9. SLR and MK analysis of annual rainfall

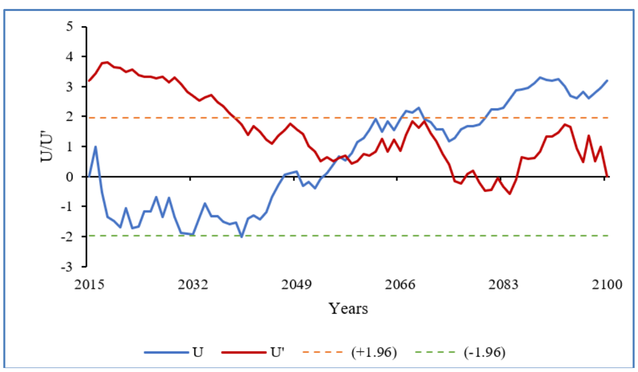


Fig. 10. SQMK analysis of future rainfall trend of Madhya Maharashtra

registered the strongest statistically significant trend and Nashik recorded the weakest according to MK analysis. According to SSE, the scenario is exactly reversed. In post-monsoon season, all the districts except Sangli and Kolhapur are observed with having a mildly increasing trend, but none of them are statistically significant.

Significant change point is found only in pre-monsoon season in Pune and Sangli (Table 4). In Pune, the Change point that occurred in 1968, was a significant one, as in this change point U = 2.00091. 1968 onwards, there is a development of significantly decreasing trend that persisted until recently. In case of Sangli, the year is 1972, in which, a statistically significant change point has been detected with U = 2.241157. From that year onwards, Sangli also witnessed the development of a significant decreasing trend till the end of the study period.

No significant change point was found in any other season. In monsoon, significantly increasing trend, with a clear change point preceding the change, was found in Dhule (1944), Nandurbar (1930), Pune (1913), Sangli (1930) and Kolhapur (1926) (Table 4). In winter, all the districts recorded decreasing trend, with most of the districts having statistically significant trend, that initiated as early as 1902-1903 (Dhule, Nandurbar, Nashik, Pune, Satara and Solapur) (Table 4). In post-monsoon, no trend can be clearly identified (Table 4).

3.2.3. *Annual rainfall trend analysis*

The mean annual rainfall over entire Madhya Maharashtra is showing an increasing trend (Fig. 9). Amongst them, only Nandurbar, Dhule and Kolhapur are observed with significantly increasing trend. For the rest, it is insignificant. Same results were obtained in both the MK test and SSE, with Nandurbar, Dhule and Kolhapur having statistically significant increasing trends in terms of mean annual rainfall (Fig. 9).

Overall, in Madhya Maharashtra, significant increasing trend in the mean annual rainfall has been found at a rate of 1.2 mm per year. 1926 is the change point which is the approximate year of initiation of this statistically significant increasing trend in mean annual rainfall (Fig. 10). District-wise, the year of change point for statistically significant trend in the mean annual rainfall has occurred within the first three decades (1901-1930). From this, it can be inferred that the current trend in rainfall has been quite persistent over the study area.

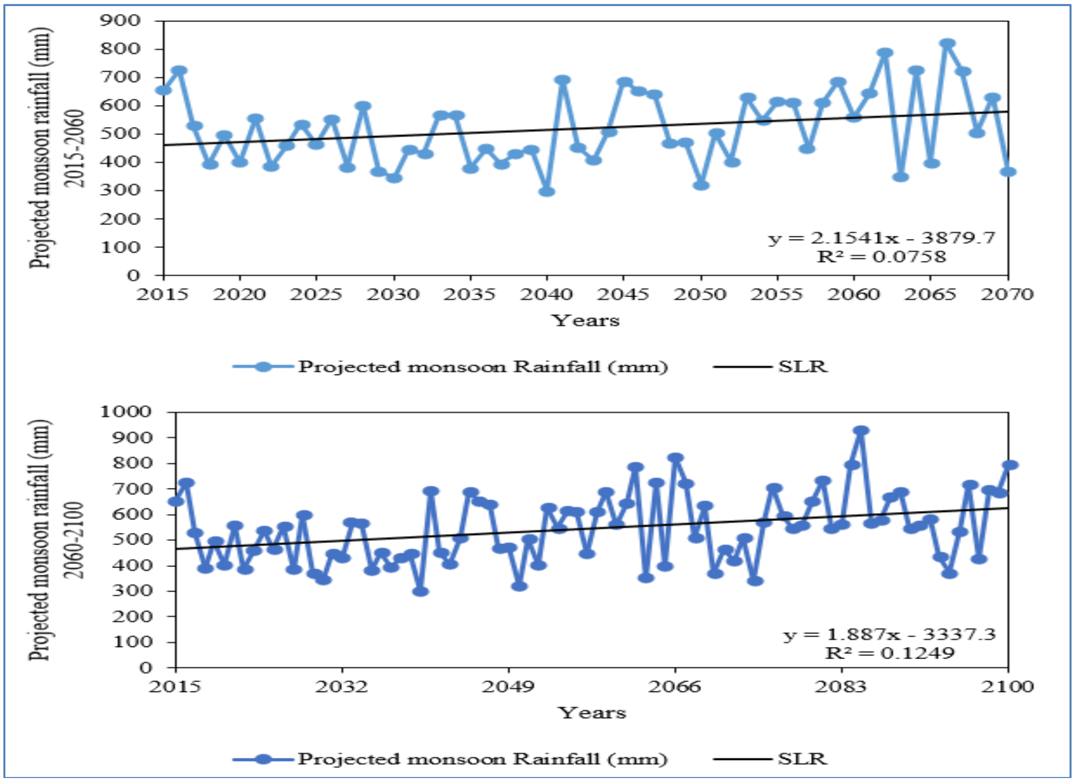


Fig. 11. Near-term and long-term SLR of future climate of Madhya Maharashtra

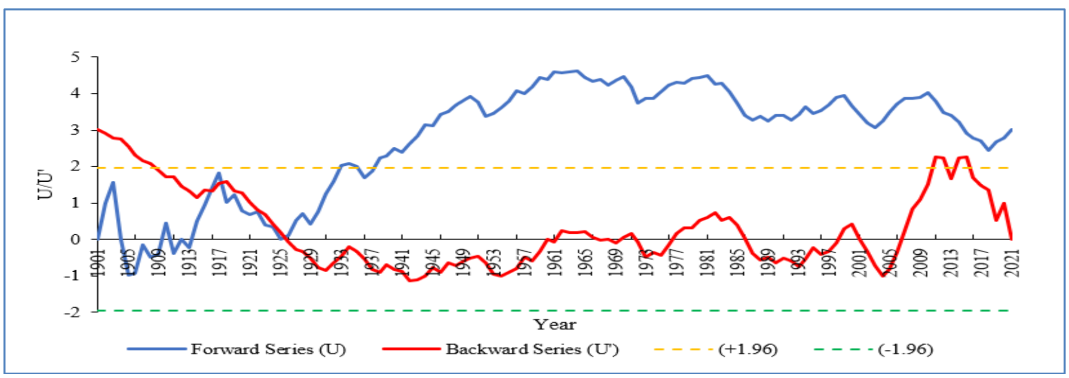


Fig. 12. SQMK analysis of the mean annual rainfall in the entire Madhya Maharashtra

The only statistically significant change point found in the annual Rainfall scenario was for Nashik in 1970 (U= 2.33711246, U'= 2.10365268) which is the initiation of a decreasing trend (Table 4). Over Dhule, Pune and Kolhapur (Table 4) there is only one mutation point for each which are, 1930, 1913 and 1925 respectively, from where the forward and backward curves have diverged, signifying an increasing trend for each of the cases. Over Nandurbar district, for the initial years, many statistically insignificant mutation points were observed (1914, 1915, 1916, 1918, 1919 and 1923). 1925 is the initiation of an increasing trend which is statistically significant (Table 4). Rest of the districts have too many change points to be identified with any clear trend at all. An important observation that can be traced from the SQMK test of the annual rainfall of the districts is that, except Dhule, Nandurbar, Pune and Kolhapur all the other districts have got at least one change point within the last decade. Many of them possess their latest change point in the last 5 years as well. *So, a question forms from this observation is that, what will be the scenario of rainfall trend in these districts in coming decades and how much will that contribute in changing the overall trend in rainfall over Madhya Maharashtra sub-division as a whole.* Although the trend of annual rainfall of past 120 years in these districts are not significant, seasonally the scenario varies.

TABLE 5

Comparison of the b of SLR and Q_{med} of SSE

DISTRICT	JAN		FEB		MAR		APR	
	b	Q_{med}	b	Q_{med}	b	Q_{med}	b	Q_{med}
Ahemadnagar	-0.0598	0	-0.0121	0	0.0361	0	-0.0597	-0.00872
Dhule	-0.0526	0	-0.0074	0	0.0159	0	-0.0053	0
Jalgaon	-0.0654	0	0.0048	0	0.0278	0	-0.0103	0
Nandurbar	-0.0819	0	-0.014	0	0.001	0	0.0001	0
Nashik	-0.0285	0	-0.0038	0	0.024	0	-0.0267	-0.00143
Pune	-0.0251	0	-0.0101	0	0.0184	0	-0.0729	-0.0225
Satara	-0.0376	0	-0.0045	0	0.0035	0	-0.0811	-0.02624
Sangli	-0.0216	0	0.0006	0	0.0063	0	-0.1023	-0.051
Kolhapur	-0.0313	0	-0.0018	0	-0.0021	0	-0.1046	-0.0644
Sholapur	-0.0422	0	-0.0129	0	0.0299	0	-0.0385	0
District	**MAY**		**JUN**		**JUL**		**AUG**	
	b	Q_{med}	b	Q_{med}	b	Q_{med}	b	Q_{med}
Ahemadnagar	-0.0619	-0.02879	0.0891	0.035364	0.0223	0.119677	0.4427	0.415692
Dhule	-0.0388	0	0.0856	0.166226	0.2596	0.261351	0.6296	0.635545
Jalgaon	-0.0977	-0.0153	-0.1735	-0.21781	-0.1357	-0.15847	0.5929	0.550882
Nandurbar	-0.0441	0	0.2242	0.1525	0.2457	0.256718	1.1413	0.928583
Nashik	-0.1209	-0.04034	0.1704	0.068615	0.0555	0.105902	0.5574	0.480377
Pune	-0.1161	-0.05539	0.417	0.436993	-0.0718	-0.04365	0.4498	0.390536
Satara	-0.0948	-0.08081	0.6116	0.34259	-0.7684	-0.99442	0.4002	0.217426
Sangli	-0.0952	-0.08034	0.3814	0.3009	-0.3138	-0.28031	0.1852	0.241003
Kolhapur	-0.1079	-0.11367	1.4839	1.432207	1.4	1.670096	2.2297	2.40581
Sholapur	-0.0324	-0.00559	0.0831	0.06721	0.1018	0.176569	0.3865	0.359444
District	**SEP**		**OCT**		**NOV**		**DEC**	
	b	Q_{med}	b	Q_{med}	b	Q_{med}	b	Q_{med}
Ahemadnagar	0.0652	0.062454	0.2593	0.193705	-0.1094	-0.0066	-0.0289	0
Dhule	0.2233	0.253114	0.0617	0.048645	-0.0577	0	0.0148	0
Jalgaon	-0.0922	-0.038	0.0522	0.057252	-0.0581	0	-0.0052	0
Nandurbar	0.2182	0.193622	-0.0206	0.019651	-0.0227	0	-0.0034	0
Nashik	0.1923	0.095445	0.0914	0.148305	-0.0297	0	0.0006	0
Pune	0.247	0.250926	0.231	0.176154	-0.1049	-0.0385	-0.0145	0
Satara	0.2481	1.0502	0.2926	0.181395	-0.1528	-0.08279	-0.0297	0
Sangli	0.1747	0.153847	0.192	0.109819	-0.1878	-0.08598	-0.0578	0
Kolhapur	0.8836	0.853844	0.205	0.13622	-0.2095	-0.1	-0.0603	0
Sholapur	-0.0884	-0.15464	0.4122	0.267702	-0.152	-0.01175	-0.064	0
District	**Monsoon**		**Post-Monsoon**		**Winter**		**Pre-Monsoon**	
	b	Q_{med}	b	Q_{med}	b	Q_{med}	b	Q_{med}
Ahemadnagar	1.8292	0.546233	-0.0469	0.088324	-0.0766	-0.00526	-0.043	-0.06194
Dhule	1.1981	0.990243	0.0189	0.04949	-0.0601	0	-0.0298	-0.00889
Jalgaon	0.1912	0.031206	-0.011	0.00904	-0.0606	-0.01195	-0.0802	-0.04221
Nandurbar	0.9753	1.565207	0.8816	0.010301	-0.0323	0	-0.1236	-0.02795
Nashik	0.6195	0.697736	0.1208	0.128199	-0.0718	-0.00371	-0.0853	-0.075
Pune	1.0419	1.139349	0.1116	0.101364	-0.0352	-0.00339	0.4148	0.020135
Satara	0.4916	0.039242	0.1099	0.043095	-0.042	-0.00132	-0.1725	-0.15968
Sangli	0.4812	0.506479	-0.0226	-0.10056	0.0063	0	0.2073	0.068178
Kolhapur	5.9972	6.283732	-0.0644	-0.02909	-0.0331	0	-0.2144	-0.21962
Sholapur	0.483	0.498079	0.1964	0.134826	-0.0492	-0.00085	-0.041	-0.02431

In the study, both parametric and nonparametric tests were employed and the results of both types of tests have synced quite magnificently. To find out such sync between the parametric and nonparametric tests, in terms of both the magnitude and direction of the trend, *b* of the SLR model and Q_{med} of the SSE model are compared in the Table 5. Both the parameters from the two models have synced very well in all the months in all the districts except the one in October in Nandurbar. The sign has altered, *i.e*., for SLR model the slope is in negative and for SSE model, the slope is in positive direction but the magnitude of slope in both the tests is very close. The minor gap between these two models at this point can be attributed to the obvious effect of an outlier in a post-monsoon month. Also, in October, none of the tests reveal the existence of any significant trend in Nandurbar district. Hence, this gap can be considered negligible. In the monthly analysis, March and December show perfect sync between the tests as there is no significant trend in these two months. Also, in September and October, there are examples of such sync. In September, Kolhapur and in October Solapur are the only districts that registered significant trend in both the tests.

3.3. *Climate Change Prediction in the Study Area*

The long-term future (from 2015 to 2100) trend in monsoon rainfall over the Madhya Maharashtra sub-division has been obtained from REMO-2009 model which shows a significantly increasing trend at a rate of 1.8 mm per year in the region. However, applying SQMK, it was found that 2059 will be a year of change point within this period (Fig. 11). Although, no significant change in the trend has been found to precede or follow the change point. To understand the near-term future scenario, multiple years were tested. It is found that till 2070, there is a significant increasing trend at a rate of 2.1 mm per year (Fig. 12). Both parametric and nonparametric tests were employed on both the sets of near and distant future scenario. The results are same in nonparametric tests as well, which denotes that the water availability through monsoon rainfall in Madhya Maharashtra is going to increase in both near and distant future. Previous studies (Sandeep *et al.,* 2017; Todmal, 2019; Todmal, 2021) corroborate this result. Although TERI (2014) has estimated marginal increase in annual rainfall over the study area, it is not statistically considerable. It can be observed that the selected climate projection models estimate a higher frequency of years with low rainfall between 2030 and 2040. The findings emerged from the study undertaken by TERI (2014),

Todmal (2021) and Todmal (2023) are in good agreement with these results. The CV is also estimated to increase up to 24.5% in the near-term future. The long-term future scenario is almost identical with the near-term future conditions. From this result, we can infer that the variability in the monsoon rainfall, that at present constitutes around 84% of the region's rainfall, will increase along with the possibility of extreme rainfall conditions.

4. Conclusions

The location of the Western Ghats in Maharashtra has caused a unique distribution pattern of rainfall over the state. Madhya Maharashtra, being adjacent to the Western Ghats on its leeward side, receives the least amount of rainfall among all the sub-divisions. All of the districts of these sub-divisions have experienced at least once drought event. Along with that, some of its districts have also been experiencing flood situations since the last few years. Overall, rainfall has been quite erratic over the sub-division causing a decay in the ground water storage. The present study attempted to find the trends in rainfall for the past 120 years and project future rainfall till the next century at both near and far-future scales. The investigation highlights various important aspects of both current and future scenarios.

The findings of the study reveal that, in the study area, rainfall patterns are not only changing intra-seasonally, but also inter-seasonally. On one hand, monsoon rainfall has been significantly increasing while on the other hand, winter rainfall has been significantly decreasing over Madhya Maharashtra. However, there is no typical spatial pattern of it that can be observed. Such a scenario will not only damage the winter cultivation in the study region, but also bring disastrous floods in monsoon. Besides this, the changing pattern of intra-seasonal rainfall, specifically in monsoon, shall impact the corresponding cropping pattern. The significant increase in monsoon rainfall is mainly because of the significantly increasing rainfall in August. As a result, most of the floods are occurring in August in the form of heavy rainfall events. For example, Kolhapur in 2019 and 2021 experienced life-threatening floods in the first week of August and last week of July, respectively. The near and distant future projections of the monsoon rainfall in the overall study region also indicate a significantly increasing trend. However, this increase may be associated with an increase in extreme rainfall events. Therefore, the study suggests a pentad-scale rainfall trend analysis of monsoon rainfall in the most vulnerable districts for a clearer understanding of the situation and robust planning for agricultural production and to manage regional food security challenges. Along with that the present study prepares the premise for further research on changing the short-term or seasonal cropping patterns that will best suit the changing rainfall pattern. The study also recommends a proper assessment of the availability of this excess water in monsoon and plan a judicial allocation of the same in the deficit regions. If the excess monsoon water recharge is channelled properly, the need for ground water for winter irrigation can be reduced. Thereby, a more sustainable cultivation practice can be achieved in the non-monsoon months.

Acknowledgements

The authors are grateful to the Department of Geography, Savitribai Phule Pune University for providing infrastructural facilities required for carrying out this research. The present Ph.D. is funded by University Grants Commission as a Junior Research Fellowship provided to the first author. We are grateful to University Grants Commission for granting the fellowship. We would also like to thank India Meteorological Department for providing the data. The authors would also like to thank the anonymous reviewers whose suggestions greatly helped to improve the quality of the manuscript.

Authors' Contributions

Amit Dhorde: Conceptualised
Labani Saha: Conceptualized and analysis. (*email-slaboni010@gmail.com*).
Rutuja Jagdale: Analysis. (*email-14rjagdale@gmail.com*).
Rahul Todmal: Analysis and the future prediction was exclusively performed by Dr. Rahul Todmal (*email-todmalrahul@gmail.com*).
The draft was revised multiple times by all the authors.

Disclaimer: The contents and views presented in this research article/paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Barakade, A. J. and Sule, B. M., 2011, "Rainfall Variability in Solapur District of Maharashtra: A Geographical Study", *Review Of Research*, **1**, 2, 1–4.

Barnes, D., 2007, "Climate change and water", *PACE - Process and Control Engineering*, **60**, 8, 8. doi : https://doi.org/10.1525/9780520943933-008.

Bisai, D., Chatterjee, S., Khan, A. and Barman., N. K., 2014, "Application of Sequential Mann-Kendall Test for Detection of Approximate Significant Change Point in Surface Air Temperature for Kolkata Weather Observatory, West Bengal, India", *International Journal of Current Research*, **6**, 2, 5319–5324.

Dash, S. K., Jenamani, R. K., Kalsi, S. R. and Panda, S. K., 2007, "Some evidence of climate change in twentieth-century India" *Climatic Change*, **85**, 3–4, 299–321. https://doi.org/10.1007/s10584-007-9305-9.

Dhorde, A. G., Korade, M. S. and Dhorde, A. A., 2017, "Spatial distribution of temperature trends and extremes over Maharashtra and Karnataka States of India", *Theoretical and Aplied Climatology*, **130**, 191-204. https://doi.org/10.1007/s00704-016-1876-9.

Dore, M. H. I., 2005, "Climate change and changes in global precipitation patterns: What do we know?", *Environment International*, **31**, 8, 1167–1181. https://doi.org/10.1016/j.envint.2005.03.004.

Gadgil, S., Srinivasan, J., Nanjundiah, R. S., Kumar, K. K., Munot, A. A., and Kumar, K. R., 2002, "On forecasting the Indian summer monsoon: the intriguing season of 2002", *Current Science*, **83**, 4, 394-403. https://www.jstor.org/stable/24106837.

George, C. J. and Ramasastri, K. S., 1975, "Agricultural drought of 1972 Kharif season", *MAUSAM*, **26**, 1, 89-96. https://doi.org/10.54302/mausam.v26i1.2032.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., and Xavier, P. K., 2006, "Increasing trend of extreme rain events over India in a warming environment", *Science*, **314**, 5804, 1442-1445. https://doi.org/10.1126/science.1132027.

Guhathakurta, P. and Rajeevan, M., 2008, "Trends in the rainfall pattern over India", *International Journal of Climatology: A Journal of the Royal Meteorological Society*, **28**, 11, 1453-1469. https://doi.org/10.1002/joc.1640.

Guhathakurta, P., and Saji, E., 2013, "Detecting changes in rainfall pattern and seasonality index vis-à-vis increasing water scarcity in Maharashtra", *Journal of Earth System Science*, **122**, 3, 639-649. https://doi.org/10.1007/s12040-013-0294-y

Guhathakurta, P., Sreejith, O. P. and Menon, P. A., 2011, "Impact of climate change on extreme rainfall events and flood risk in India", *Journal of Earth System Science*, **120**, 359-373. https://doi.org/10.1007/s12040-011-0082-5

IMD, 2005, "Climate of Maharashtra", Issued by National Climate Centre, India Meteorological Department, Pune.

Khadke, P. A., Sanap, H. S. and Karande, S. V., 2019, "Trend analysis of Annual , Seasonal and South-west Monsoon rainfall on Sahyadri in Maharashtra", *RESEARC REVIEW International Journal of Multidisciplinary*, **04**, 03, 508–511.

Khan, T. M. A., Singh, O. P., Aktar, F. and Sarker, M. A., 2000, "Recent Sea Level and Sea Surface Temperature Trends Along the Bangladesh Coast in Relation to the Frequency of Intense Cyclones", *Marine Geodesy*, **23**, 4, 103–116. https://doi.org/10.1080/014904101753227851

Kulkarni, S., Gedam, S. and Dhorde, A., 2021, "District Wise Comparative Analysis of Rainfall Trends in Konkan-Goa and Marathwada Meteorological Subdivision of India", *Applied Ecology and Environmental Sciences*, **9**, 10, 885–894. https://doi.org/10.12691/aees-9-10-6

Kumar, K. N., Rajeevan, M., Pai, D. S., Srivastava, A. K. and Preethi, B., 2013, "On the observed variability of monsoon droughts over India", *Weather Climate Extremes*, **1**, 42-50. https://doi.org/10.1016/j.wace.2013.07.006

Lal, M., 2003, "Global climate change : India ' s monsoon and its variability", *Journal of Environmental Studies and Policy*, **6**, 1, 1–34.

Mandale, V. P., Mahale, D. M., Nandgude, S. B., Gharde, K. D. and Thokal, R. T., 2017, "Spatio-Temporal Rainfall Trends in Konkan Region of Maharashtra State", *Advanced Agricultural Research & Technology Journal*, **1**, 1, 61–69.

Mann, H. B., 1945, "Nonparametric Tests Against Trend", *Econometrica*, **13**, 3, 245–259. http://www.jstor.com/stable /1907187.

Min, S. K., Kwon, W. T., Park, E. H. and Choi, Y., 2003, "Spatial and temporal comparisons of droughts over Korea with East Asia", *International Journal of Climatology*, **23**, 2, 223–233. https://doi.org/10.1002/joc.872.

Mirza, M. M. Q., 2002, "Global warming and changes in the probability of occurrence of floods in Bangladesh and implications", *Global Environmental Change*, **12**, 2, 127–138. https://doi.org/10.1016 /S0959-3780(02)00002-X.

Mishra, A. K., Dwivedi, S. and Das, S., 2020, "Role of Arabian Sea warming on the Indian summer monsoon rainfall in a regional climate model" *International Journal of Climatology*, **40**, 4, 2226–2238. https://doi.org/10.1002/joc.6328.

Mitchell, J. M., Dzerdzeevskii, B., Flohn, H., Hofmeyr, W. L., Lamb, H. H., Rao, K. N. and Wallen, C. C, 1966, "Technical Note No. 79", World Meteorological Organization, Geneva, 43-53.

Patra, J. P., Mishra, A., Singh, R. and Raghuwanshi, N. S., 2012, "Detecting rainfall trends in twentieth century (1871-2006) over Orissa State, India", *Climate Change*, **111**, 3, 801–817. https://doi.org/10.1007/s10584-011-0215-5

Patwardhan, S. K. and Asnani, G. C., 2000, "Meso-scale distribution of summer monsoon rainfall near the Western Ghats (India)", *International Journal of Climatology*, **20**, 5, 575-581. https://doi.org/10.1002/(SICI)1097-0088(200004)20: 5%3C575: :AID-JOC509%3E3.0.CO;2-6.

Potdar, S. S., Kulkarni, S., Patil, P., Pawar, R. P., Jakhalekar, V. V. and Nade, D. P., 2019, "The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa regions in India", *International Journal of Water*, **13**, 3, 293–309. https://doi.org/ 10.1504/ijw.2019.10021791.

Ratna, S. B., 2012, "Summer monsoon rainfall variability over Maharashtra, India", *Pure and Applied Geophysics*, **169**, 1–2, 259–273. https://doi.org/10.1007/s00024-011-0276-4.

Roy, S. and Chakravarty, N., 2021, "Rainfall analysis by using Mann-Kendall trend, Sen's slope and variability at six Stations of Andaman & Nicobar islands", *Research Square* (2021). https://doi.org/10.21203/rs.3.rs-265913/v1.

Saeed, F., Hagemann, S. and Jacob, D., 2012, "A framework for the evaluation of the South Asian summer monsoon in a regional climate model applied to REMO", *International Journal of Climatology*, **32**, 430-440.

Sandeep, V. M., Bapuji Rao, B., Bharathi, G., Rao, V. U. M, Pramod, V. P., Chowdhary, P. S., Patel N. R. and Vijaya Kumar, P., 2017, "Projecting future changes in water requirement of grain sorghum in India', *Journal of Agrometeorology*, **19**, 217–225. https://doi.org/10.54386/jam.v19i3.630.

Sanjay, C., Bhasker, P., Damodare, S. L. and Abhale, A. P., 2018, "Statistical analysis of seasonal rainfall variability in Nasik district by using GIS interpolation technique" *Journal of Pharmacognosy and Phytochemistry*, **7**, 4, 2072–2077.

Sen, P. K., 1968, "Estimates of the Regression Coefficient Based on Kendall's Tau" *Journal of the American Statistical Association*, **63**, 324, 1379–1389. https://doi.org/10.1080/01621459. 1968.10480934

Sen Roy, S., 2009, "A spatial analysis of extreme hourly precipitation patterns in India", *International Journal of Climatology: A Journal of the Royal Meteorological Society*, **29**, 3, 345-355. https://doi.org/10.1002/joc.1763

Shaw, R., Luo, Y., Cheong, T. S., Abdul Halim, S., Chaturvedi, S., Hashizume, M., Insarov, G. E., Ishikawa, Y., Jafari, M., Kitoh, A., Pulhin, J., Singh, C., Vasant, K. and Zhang, Z., ,2022, Asia. In H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (Eds.). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, 1457–1579. doi:10.1017/9781009325844.012.

Shrestha, A. B., Wake, C. P., Dibb, J. E. and Mayewski, P. A., 2000, "Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters", *International Journal of Climatology*, **20**, 3, 317–327. https://doi.org/10.1002/(SICI)1097-0088(20000315)20:3< 317::AID-JOC476>3.0.CO;2-G.

Singh, R., Sah, S., Das, B., Vishnoi, L., Pathak, H., 2021, "Spatio-temporal trends and variability of rainfall in Maharashtra, India: Analysis of 118 years", *Theoretical and Applied Climatology*, **143**, 3–4, 883–900. https://doi.org/10.1007/s00704-020-03452-5.

Sneyers, R., 1990, "Techical Note No. 143", World Meteorological Organization, Geneva.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L., 2007, IPCC fourth assessment report (AR4). Climate change, 374.

Tadvi, V. R., 2016, "A Geographical Study of Rainfall Variability in Nandurbar District", *International Journal of Science and Research*, **5**, 2, 416–418. https://doi.org/10.21275 /v5i2.nov161053.

TERI, 2014, "Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra: Maharashtra State Adaptation Action Plan on Climate Change (MSAAPC)", The Energy and Resources Institute, New Delhi, Report No. 2010GW01, 2014.

Todmal, R. S., Korade, M. S., Dhorde, A. G., and Zolekar, R. B., 2018, "Hydro-meteorological and agricultural trends in water-scarce Karha Basin, western India: current and future scenario", Arabian Journal of Geosciences, **11**, 1-12. https://doi.org/ 10.1007/s12517-018-3594-3

Todmal, R. S., 2019, "Droughts and agriculture in the semi-arid region of Maharashtra, western India", *Weather, Climate, and Society*, **11**, 4, 741-754. https://doi.org/10.1175/WCAS-D-18-0131.1.

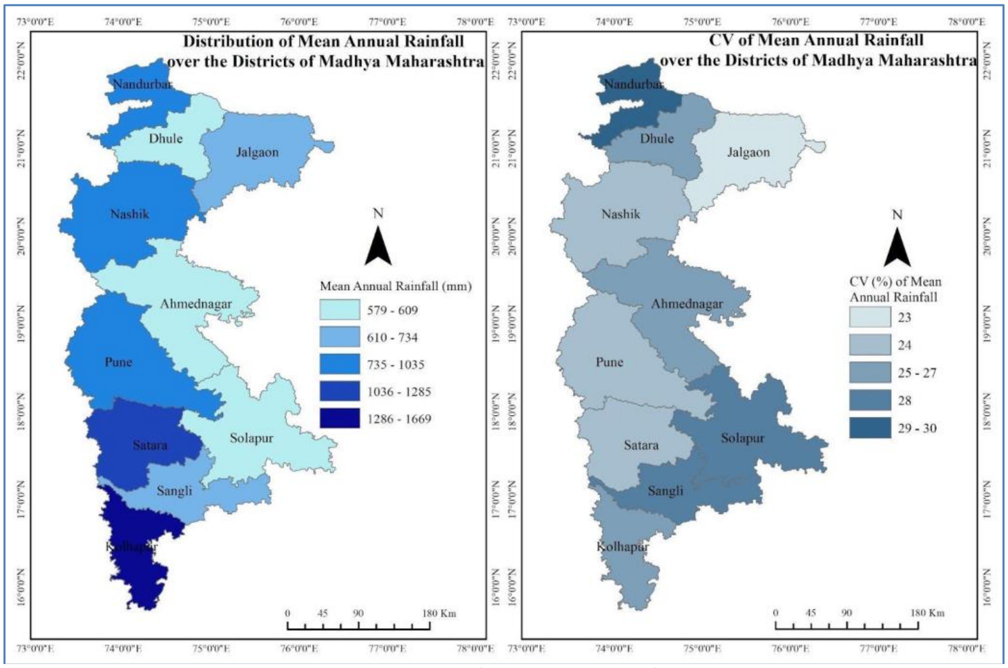
Todmal, R. S., 2020, "Understanding the hydrometeorological characteristics and relationships in the semiarid region of Maharashtra (western India): implications for water management", Acta Geophysica, **68**, 1, 189-206. https://doi.org/ 10.1007/s11600-019-00386-z.

Todmal, R. S., 2021, "Future climate change scenario over Maharashtra, Western India: Implications of the Regional Climate Model (REMO-2009) for the understanding of agricultural vulnerability", *Pure and Applied Geophysics*, **178**, 1, 155-168. https://doi.org/10.1007/s00024-020-02642-6.

Todmal, R. S., 2023, "Assessment of hydro-climatic trends in a drought-prone region of Maharashtra (India) with reference to rainfed agriculture", *Regional Environmental Change*, **23**, 2, 62. https://doi.org/10.1007/s10113-023-02044-z.

Vinnarasi, R., Dhanya, C. T., 2016, "Changing characteristics of extreme wet and dry spells of Indian monsoon rainfall", *Journal of Geophysical Research Atmospheres*, **121**, 5, 2146–2160. https://doi.org/doi:10.1002/2015JD024310.

Appendix



Supplementary Fig. 1. Spatial Variability of normal annual rainfall over Madhya Maharashtra

TABLE 1

MK Test of mean monthly rainfall (January-June)

District	JAN		FEB		MAR	
	Z_{mk}	τ	Z_{mk}	τ	Z_{mk}	τ
Ahmednagar	-2.707	-0.182	-1.561	-0.107	0.107	0.007
Dhule	-2.228	-0.150	-1.070	-0.075	1.092	0.075
Jalgaon	-1.652	-0.108	-0.854	-0.057	1.665	0.109
Nandurbar	-2.232	-0.154	-1.591	-0.113	-0.164	-0.012
Nasik	-2.095	-0.140	-1.695	-0.116	0.989	0.066
Pune	-3.018	-0.206	-2.123	-0.148	-0.019	-0.001
Satara	-3.432	-0.236	-1.497	-0.104	0.099	0.006
Sangli	-0.545	-0.038	-0.525	-0.037	-0.721	-0.047
Kolhapur	-1.299	-0.090	0.187	0.013	-0.227	-0.015
Solapur	-1.504	-0.102	-1.045	-0.071	1.420	0.092

District	APR		MAY		JUN	
	Z_{mk}	τ	Z_{mk}	τ	Z_{mk}	τ
Ahmednagar	-1.838	-0.116	-1.357	-0.084	0.218	0.014
Dhule	-1.004	-0.067	-1.235	-0.079	0.869	0.054
Jalgaon	-1.284	-0.084	-2.212	-0.139	-1.261	-0.078
Nandurbar	-1.098	-0.075	-2.140	-0.140	0.753	0.047
Nasik	-1.311	-0.083	-1.941	-0.121	0.293	0.018
Pune	-2.091	-0.131	-1.545	-0.096	2.178	0.135
Satara	-0.960	-0.060	-1.268	-0.079	1.309	0.081
Sangli	-1.400	-0.087	-1.125	-0.070	2.606	0.161
Kolhapur	-1.597	-0.099	-1.186	-0.073	4.360	0.269
Solapur	-0.134	-0.008	-0.204	-0.013	0.642	0.040
Legend		**> (+1.960)**			**< (-1.960)**	

TABLE 2

MK Test of mean monthly rainfall (July-December)

DISTRICT	JUL		AUG		SEP	
	Z_{mk}	τ	Z_{mk}	τ	Z_{mk}	τ
Ahmednagar	0.780	0.048	2.863	0.177	0.320	0.020
Dhule	1.415	0.088	3.609	2.230	1.266	0.078
Jalgaon	-0.817	-0.051	2.599	0.161	-0.191	-0.012
Nandurbar	0.828	0.051	3.377	0.209	0.860	0.053
Nasik	0.401	0.025	1.926	0.119	0.420	0.026
Pune	-0.152	-0.010	1.486	0.092	1.202	0.074
Satara	-2.218	-0.137	0.715	0.044	1.050	0.065
Sangli	-1.803	-0.112	1.819	0.112	0.855	0.053
Kolhapur	2.579	0.159	4.904	0.303	4.072	0.252
Solapur	1.291	0.080	2.239	0.138	-0.492	-0.031
DISTRICT	**OCT**		**NOV**		**DEC**	
	Z_{mk}	τ	Z_{mk}	τ	Z_{mk}	τ
Ahmednagar	1.583	0.098	-1.046	-0.066	-1.649	-0.110
Dhule	1.010	0.063	-0.567	-0.037	-1.268	-0.085
Jalgaon	1.325	0.082	-0.725	-0.047	-1.179	-0.079
Nandurbar	0.727	0.045	0.319	0.021	-0.605	-0.042
Nasik	1.370	0.085	0.089	0.006	-0.727	-0.048
Pune	1.347	0.083	-1.381	-0.086	-1.279	-0.084
Satara	1.109	0.069	-1.638	-0.102	-0.539	-0.036
Sangli	0.674	0.042	-2.216	-0.138	-1.586	-0.106
Kolhapur	0.817	0.051	-2.061	-0.128	-1.086	-0.072
Solapur	2.019	0.125	-0.804	-0.050	-1.138	-0.075

Legend

(red)	> (+1.960)	(green)	< (-1.960)

TABLE 3

SSE for mean monthly rainfall (January-June)

DISTRICT	JAN		FEB		MAR	
	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}
Ahmednagar	-2.7067	0	-1.5608	0	0.10659	0
Dhule	-2.2282	0	-1.0699	0	1.0915	0
Jalgaon	-1.6517	0	-0.85435	0	1.6647	0
Nandurbar	-2.2319	0	-1.5907	0	-0.16383	0
Nasik	-2.0946	0	-1.6954	0	0.9893	0
Pune	-3.0186	0	-2.1228	0	-0.01881	0
Satara	-3.4316	0	-1.4973	0	0.099046	0
Sangli	-0.54499	0	-0.52542	0	-0.72149	0
Kolhapur	-1.2986	0	0.18672	0	-0.22724	0
Solapur	-1.5041	0	-1.0446	0	1.4201	0

TABLE 3 Continued

DISTRICT	APR		MAY		JUN	
	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}
Ahmednagar	-1.8382	-0.00872	-1.3572	-0.02879	0.21775	0.035364
Dhule	-1.0036	0	-1.2349	0	0.86875	0.166226
Jalgaon	-1.284	0	-2.2121	-0.0153	-1.2611	-0.21781
Nandurbar	-1.0977	0	-2.1402	0	0.75306	0.1525
Nasik	-1.3106	-0.00143	-1.9408	-0.04034	0.2926	0.068615
Pune	-2.0907	-0.0225	-1.545	-0.05539	2.1775	0.436993
Satara	-0.95968	-0.02624	-1.268	-0.08081	1.3088	0.34259
Sangli	-1.4	-0.051	-1.1251	-0.08034	2.6063	0.3009
Kolhapur	-1.597	-0.0644	-1.1863	-0.11367	4.3596	1.432207
Solapur	-0.13388	0	-0.20415	-0.00559	0.64192	0.06721

Legend

	[red]	> (+1.960)	[green]	< (-1.960)

TABLE 4

SSE for mean monthly rainfall (July-December)

DISTRICT	JUL		AUG		SEP	
	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}
Ahmednagar	0.78028	0.119677	2.8625	0.415692	0.31982	0.062454
Dhule	1.4154	0.261351	3.6088	0.635545	1.2657	0.253114
Jalgaon	-0.81658	-0.15847	2.5994	0.550882	-0.19053	-0.038
Nandurbar	0.82791	0.256718	3.3774	0.928583	0.85966	0.193622
Nasik	0.40148	0.105902	1.9258	0.480377	0.41963	0.095445
Pune	-0.15197	-0.04365	1.4857	0.390536	1.2022	0.250926
Satara	-2.2183	-0.99442	0.7145	0.217426	1.0502	1.0502
Sangli	-1.8033	-0.28031	1.8191	0.241003	0.85514	0.153847
Kolhapur	2.579	1.670096	4.9039	2.40581	4.0715	0.853844
Solapur	1.2906	0.176569	2.2388	0.359444	-0.49221	-0.15464
DISTRICT	**OCT**		**NOV**		**DEC**	
	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}
Ahmednagar	1.5832	0.193705	-1.0461	-0.0066	-1.6494	0
Dhule	1.0096	0.048645	-0.56664	0	-1.2675	0
Jalgaon	1.3249	0.057252	-0.72496	0	-1.179	0
Nandurbar	0.72696	0.019651	0.31924	0	-0.6053	0
Nasik	1.37	0.148305	0.089117	0	-0.72679	0
Pune	1.3473	0.176154	-1.3809	-0.0385	-1.2787	0
Satara	1.1092	0.181395	-1.6381	-0.08279	-0.53904	0
Sangli	0.67367	0.109819	-2.2162	-0.08598	-1.5857	0
Kolhapur	0.81658	0.13622	-2.0614	-0.1	-1.0859	0
Solapur	2.0188	0.267702	-0.80421	-0.01175	-1.1382	0
Legend	[red]	> (+1.960)		[green]	< (-1.960)	

TABLE 5

MK Test of mean seasonal rainfall

DISTRICT	Monsoon		Post-Monsoon		Winter		Pre-Monsoon	
	Z_{mk}	τ	Z_{mk}	τ	Z_{mk}	τ	Z_{mk}	τ
Ahmednagar	1.477	0.0913	0.504	0.0312	-3.018	-0.19484	-1.626	-0.101
Dhule	2.949	0.1822	0.506	0.0314	-2.706	-0.1768	-0.724	-0.045
Jalgaon	0.086	0.0055	0.073	0.0046	-2.483	-0.15685	-2.008	-0.124
Nandurbar	2.740	0.1693	0.256	0.0160	-3.442	-0.22876	-2.426	-0.152
Nasik	1.273	0.0787	1.003	0.0621	-2.416	-0.15531	-1.994	-0.123
Pune	2.003	0.1238	0.585	0.0363	-3.779	-0.24823	0.265	0.017
Satara	0.082	0.0052	0.166	0.0104	-3.243	-0.21268	-1.885	-0.117
Sangli	1.420	0.0878	-0.542	-0.0336	0.287	0.019212	0.506	0.031
Kolhapur	5.315	0.3283	-0.202	-0.0126	-1.059	-0.07022	-1.860	-0.115
Solapur	1.320	0.0817	0.805	0.0499	-1.553	-0.0994	-0.377	-0.023

Legend

(red) > (+1.960) (green) < (-1.960)

TABLE 6

SSE for mean seasonal rainfall

DISTRICT	Monsoon		Post-Monsoon		Winter		Pre-Monsoon	
	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}
Ahmednagar	1.47	0.546233	0.50356	0.088324	-3.0181	-0.00526	-1.6264	-0.06194
Dhule	2.9487	0.990243	0.50582	0.04949	-2.7063	0	-0.72437	-0.00889
Jalgaon	0.086193	0.031206	0.072585	0.00904	-2.4829	-0.01195	-2.0077	-0.04221
Nandurbar	2.74	1.565207	0.25633	0.010301	-3.4421	0	-2.4259	-0.02795
Nasik	1.2725	0.697736	1.0026	0.128199	-2.4157	-0.00371	-1.9938	-0.075
Pune	2.0029	1.139349	0.58521	0.101364	-3.7789	-0.00339	0.26539	0.020135
Satara	0.081657	0.039242	0.16558	0.043095	-3.2432	-0.00132	-1.8849	-0.15968
Sangli	1.4199	0.506479	-0.54212	-0.10056	0.28684	0	0.50582	0.068178
Kolhapur	5.3145	6.283732	-0.20187	-0.02909	-1.0587	0	-1.86	-0.21962
Solapur	1.3201	0.498079	0.80523	0.134826	-1.5529	-0.00085	-0.37654	-0.02431

Legend

(red) > (+1.960) (green) < (-1.960)