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Assessment of long-term rainfall trends in Maharashtra

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सार – यह शोध 120 वर्षों की अवधि (1901-2020) में महाराष्ट्र, भारत की वार्षिक और ऋतुनिष्ट वर्षा पैटर्न की परिवर्तिता, रुझानों और परिवर्तन बिंदुओं का विश्लेषण करने पर केंद्रित है। अध्ययन क्षेत्र को इसके महत्वपूर्ण कृषि महत्व और जलवायु संबंधी तनावों के प्रति भेद्यता के कारण चुना गया था, जो खाद्य उत्पादन और सामाजिक-आर्थिक स्थितियों को प्रभावित करता है। महाराष्ट्र अपने क्षेत्रों में पर्याप्त भिन्नता के साथ विविध वर्षा पैटर्न प्रदर्शित करता है। अनुसंधान भारतीय मौसम विज्ञान विभाग (आईएमडी) से प्राप्त चौहत्तर मौसम संबंधी उप-स्टेशनों से वर्षा के आंकड़ों का उपयोग करता है। प्रवृत्ति विश्लेषण के लिए, मान-केंडल परीक्षण का उपयोग किया गया जो हाइड्रो-जलवायु डेटा श्रृंखला में रुझानों की पहचान करने में अपनी प्रभावशीलता के लिए जाना जाता है। ऐतिहासिक वर्षा समय श्रृंखला में अचानक बदलाव या परिवर्तन बिंदुओं का पता लगाने के लिए, पेटिट परीक्षण और मानक सामान्य समरूपता परीक्षण (एसएनएचटी) का उपयोग किया जाता है। इसके अलावा, अध्ययन में गैर-रैखिकता या क्रमिक सहसंबंध जैसी मान्यताओं की आवश्यकता के बिना वर्षा डेटा में रुझानों की पहचान करने के लिए सेन द्वारा प्रस्तावित नवीन प्रवृत्ति विश्लेषण का उपयोग किया गया है। यह विधि पारंपरिक पैरामीट्रिक और गैर-पैरामीट्रिक परीक्षणों पर लाभ प्रदान करती है, जो विश्वसनीय प्रवृत्ति विश्लेषण परिणाम प्रदान करती है। जबकि कुछ उपकेंद्र लगातार नकारात्मक रुझान प्रदर्शित करते हैं, तथा अन्य विशेष रूप से मॉनसून के मौसम में 1961 के आसपास देखे गए उल्लेखनीय परिवर्तन बिंदुओं के साथ सकारात्मक रुझान प्रदर्शित करते हैं, पोस्ट-चेंज पॉइंट विश्लेषण 1961 के बाद अलग-अलग रुझानों को दर्शाता है, जो विभिन्न मौसमों और उपकेंद्रों में सूक्ष्म समझ की आवश्यकता पर जोर देता है। पुणे पाषाण, शिवाजी नगर, लोहगांव, भीमाशंकर और दापोली सहित विशिष्ट उपकेंद्रों में वर्षा में महत्वपूर्ण नकारात्मक रुझान का अनुभव होता है, जबकि कोल्हापुर, रत्नागिरी, देवगढ़, दहानु और मितभाव मौसम विज्ञान उपकेंद्रों ने सकारात्मक रुझान देखा। यह शोध कृषि योजनाकारों, जल प्रबंधन एजेंसियों, पर्यावरण समूहों और आपातकालीन प्रतिक्रियाकर्ताओं को वर्षा परिवर्तिता में अंतर्दृष्टि प्रदान करके लाभान्वित करता है। यह फसल योजना, सिंचाई, जल प्रबंधन, बुनियादी ढांचे, सूखे से बचाव, पारिस्थितिकी तंत्र संरक्षण और आपदा प्रबंधन का समर्थन करता है। यह महाराष्ट्र के वर्षा के रुझानों और जल संसाधनों और कृषि पर जलवायु प्रभावों का अध्ययन करने के लिए नवीन प्रवृत्ति विश्लेषण का उपयोग करके भारत में एक महत्वपूर्ण अंतर को पाटता है।

ABSTRACT. This research focuses on analyzing the variability, trends, and change points in the annual and seasonal rainfall patterns of Maharashtra, India, over a 120-year period (1901–2020). The study area was chosen due to its significant agricultural importance and vulnerability to climate-related stressors, impacting food production and socioeconomic conditions. Maharashtra exhibits diverse rainfall patterns, with substantial variations across its regions. The research utilizes rainfall data from seventy-four meteorological sub-stations obtained from the Indian Meteorological Department (IMD).

For trend analysis, the Mann-Kendall test is employed, known for its effectiveness in identifying trends in hydro-climatic data series. To detect abrupt shifts or change points in the historical rainfall time series, the Pettitt test and the Standard Normal Homogeneity test (SNHT) are utilized. Additionally, the study employs innovative trend analysis, as proposed by Sen, to identify trends in rainfall data without the need for assumptions such as non-linearity or serial correlation. This method offers advantages over traditional parametric and non-parametric tests, providing reliable trend analysis results. While some substations exhibit consistent negative trends, others display positive trends, with notable change points observed around 1961, particularly during the monsoon season. Post-change point analysis reveals varying trends post-1961, emphasizing the need for nuanced understanding across different seasons and substations. Specific substations, including Pune Pashan, Shivaji Nagar, Lohgaon, Bhimashankar, and Dapoli, experience significant negative trends in rainfall, whereas Kolhapur, Ratnagiri, Devgad, Dahanu, and Mitbhav meteorological substations observed positive trend. This research benefits agricultural planners, water management agencies, environmental groups, and emergency responders by providing insights into rainfall variability. It supports crop planning, irrigation, water management, infrastructure, drought mitigation, ecosystem conservation, and disaster management. It fills a crucial gap in India by using innovative trend analysis to study Maharashtra's rainfall trends and climate impacts on water resources and agriculture.

Key words – Rainfall trend, Mann-Kendall test, Innovative trend analysis

1. Introduction

Rainfall is an indispensable component of the hydrological cycle and changes to its pattern have a direct impact on water resources (Islam. *et al.* 2012). The abrupt shifting pattern of rainfall as a result of climate change is concerning to water resource managers and hydrologists (Gajbhiye S. *et al*. 2015). Srivastava *et al.* (2014) and Islam *et al*. (2012) reported that changes in rainfall amounts and frequency have a direct impact on stream flow, spatiotemporal changes in run-off, surface groundwater reservoirs, and soil moisture conditions. As a result, these changes demonstrated their wide-ranging effects on aquatic and terrestrial ecosystems, biodiversity, agriculture, and food security. The significant fluctuations in rainfall trends make it possible for disastrous catastrophes like floods and drought to occur frequently (Srivastava. *et al.* 2015). Gupta *et al*. (2014) reported that the amount of soil moisture required for crop production in rain-fed areas entirely depends on the amount of rainfall. In India, monsoon rainfall plays a crucial role in agriculture. Rain-fed agriculture occupies 68% of India's total cultivated land, supporting 60% of the livestock population and 40% of the human population (Meshram S. 2017). Therefore, studying climate change, or more specifically, the changes in rainfall occurrences, trends, patterns, and distribution, is the most important way to ensure sustainable water resource management. Hence, significant study on the assessment and quantification of climate change is necessary for the sustainable development of agriculture in India (Meshram S. 2017). Most significantly, a thorough understanding of the rainfall pattern in a changing environment would aid in enhanced decision-making and improve the communities' ability to withstand extreme weather occurrences.

Water resources are nowadays is considered as the prime priority for any type of development programme or planning, including effective water resource management, food production sector, and flood control. The main obstacle to efficient water resource management in Maharashtra is the uneven distribution of rainfall across the state and the pattern of rainfall, which vary greatly across both area and time (Bandyopadhyay, J. & Perveen, S. 2006) The western part of Maharashtra receives a huge amount of rainfall during the monsoon, whereas the central and eastern parts of Maharashtra, which are known as the Marathwada and Vidarbha regions, receive a very less amount of rainfall and frequently experience the worst reality of water scarcity. Besides, the worst consequence of climate change, especially rainfall change, has been the suffering of the agricultural sector in Maharashtra. In addition, hailstorms and high winds have also occurred frequently. As a result, there have been significant losses in crop production, which has decimated the farmers who depend entirely on agriculture (Meshram S. 2017). The changeable weather is disastrous for the farmer community, and as a result, farmers have gone extreme, committing suicide. Therefore, it is important to assess whether there is a trend in the amount of rainfall and a pattern in the variability.

Therefore, it has been vital for researchers studying hydrology, climatology, and meteorology around the world to evaluate variance and changes in pattern as well as the existence of trends in rainfall over wide spatial extents (Yang P. *et al*. 2017, Chatterjee *et al*. 2016, Tian *et al.* 2017, Xia *et al*. 2012, Rao, *et al.* 2014, Talaee, P. 2014). In a number of investigations, researchers used parametric and non-parametric methods (Sonali P. & Kumar D. 2013) such as regression tests (Haan, C. 2002, Piao, *et al*. 2010), Man-Kendall tests (Mann H. 1945, Kendall M. 1973), Kendall rank correlation test (Kendall M. 1975), Sen's slope estimation (Sen, P. 1968, Pingale *et al.* 2014), and Spearman rank correlation test (McGhee J. 1985).The non-parametric test, such as the Mann-Kendall test, was used in this research work to identify the trend in rainfall because it is one of the most universally used methods for trend detection in hydrology, climatology, and meteorology (Batisani N. & Yarnal B. 2010, Tabari H. 2011, Du J. & Shi C. 2012, Singh *et al*. 2008 , Wang *et al.* 2012). Non-parametric tests were used in the

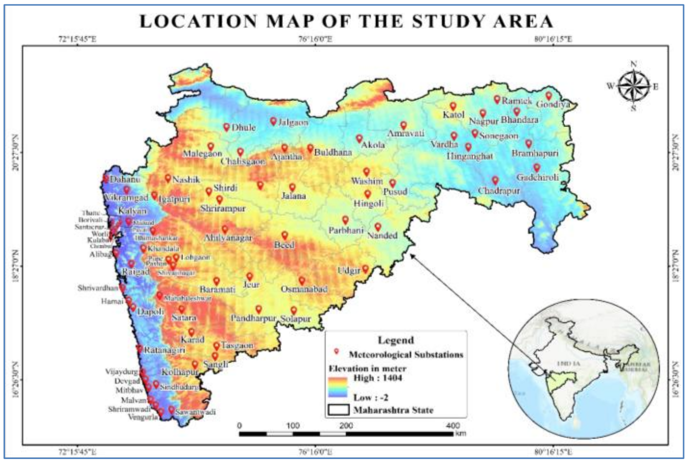

Fig. 1. Location Map of Study Area

present study because they may be applied to independent time series data and are less sensitive to outliers (Mondal *et al.* 2015). However, the change detection analysis in the climatologic and hydrological data series is the important aspect for the trend analysis throughout the world (Zarenistanak *et al*. 2014, Li *et al.* 2014). The Standard Normal Homogeneity Test (SNHT) (Alexandersson & Moberg 1997), Buishand range test (Buishand T.1982), and the Pettitt's test (Pettitt A. 1979) are three methods for detecting changes. In many studies, most of the researcher's trend analysis was carried out before the change point analysis (Mondal *et al*. 2015). This kind of modus operandi can produce deceptive findings since the information received from change point detection analysis is not used for trend analysis (Villarini *et al.* 2009). As a result, Li *et al.* (2014) strongly advised performing the change detection analysis first, followed by the trend analysis. The result outcomes of this method are more reasonable and reliable.

Sen (Şen 2012) innovative trend analysis has been used worldwide for detecting trends in meteorological, hydrological, and environmental variables (Sen 2014, Kisi 2015, Ay & Kisi, 2015, Martinez-Austria *et al.* 2016, Onyutha, C. 2016).Over the non-parametric approach, innovative trend analysis has been universally accepted, like the Mann-Kendal test, Spearman's correlation test, and Sen's slope estimation, for the reason that these non-parametric tests are highly sensitive to distribution assumptions, serial correlation, time series data size, and seasonal cycle. According to Von Storch (Von, 1999) MK test cannot reveal any notable trends in the data series if there is a statistically significant serial correlation in the data series. Sen (Şen, 2012) mentioned that for water resource management to be successful, efficient, and optimal, trends must be identified not just monotonically across time but also independently, with each trend having a high, medium, and low value that can be identified by an innovative trend. Additionally, the innovative trend provides a reliable and effective outcome with reduced error and is not sensitive to serial correlation, non-linearity, or the size of the time series data. As a result, researchers choose innovative trend analysis for detecting trends in hydrological and meteorological investigations (Sonali & Kumar, 2013, Sanikhani *et al.* 2018, Şen Z. 2012, Gedefaw, *et al*. 2018, Kişi, 2018). As a result, in addition to the Mann-Kendall test, the innovative trend was used to detect trends in the present study. There has been very little research in India to detect trends using innovative trend analysis. However, to the best of the authors' knowledge, the use of an innovative trend to detect seasonal rainfall for the state of Maharashtra in India would be the first use.

The trend analysis facilitates understanding present and past climatic changes, so the present research work would be applicable for various stakeholders, including agricultural planners, who can utilize the forecasts to better plan crop cultivation, irrigation, and water management strategies, thus improving agricultural productivity and resilience to changing rainfall patterns. At the same time, government agencies responsible for water resource management can benefit from insights into future rainfall changes to plan infrastructure projects, reservoir management, and drought mitigation strategies effectively.

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Besides that, environmental organizations can use the findings to assess the impact of rainfall changes on ecosystems, biodiversity, and water availability for wildlife, aiding in conservation efforts and sustainable development. It is also useful for emergency response agencies to leverage rainfall forecasts to anticipate and prepare for potential flood events, landslides, and other weather-related disasters, enabling more proactive and effective disaster management measures. The novelty of the present study is that this research will be applicable to various fields. The present study's objective is as follows, which is based on prior research gaps and literature: to analyse trends, change points, and variability in seasonal and annual rainfall for Maharashtra.

2. Data and methodology

2.1. *Study area and data source*

The state of Maharashtra in India was selected for the study because 61% of its land area is semi-arid and it has highly variable rainfall patterns that have a substantial impact on food production (Barron *et al.*, 2003, Wani *et al.*, 2009). Although the state of Maharashtra is an industrial state in India, agriculture is also an important sector in Maharashtra. Maharashtra is also one of the most socioeconomically vulnerable states in India, as every year a large number of farmers commit suicide due to climate-related stressors such as droughts, hail storms, and monsoon variability (Basu *et al*., 2016). The longitudinal and latitudinal expansion of Maharashtra is between 72° E to 83° E and 15° N to 23° N respectively. Further, Maharashtra has been divided into six regions: the Konkan coastal region in the west, between the Western Ghats and Arabian Sea; Marathwada (Aurangabad region) in the south-east; Vidarbha (Amravati and Nagpur division) towards the eastern side; Nashik in the north-west; and Pune towards the west-central region of Maharashtra. Maharashtra's monsoon season lasts from June to September. Maharashtra's rainfall distribution pattern exhibits significant variation. For example, Central Maharashtra experiences rainfall of about 500 mm, whereas coastal regions, such as the Konkan region, have rainfall of about 6000 mm, and plain areas experience rainfall of about 2500 mm. This demonstrates the wide variance in rainfall seen in the state. Konkan, Central Maharashtra, and Vidarbha regions, the number of rainy days are 75-85, 30-40, and 40-50, respectively. Rainfall varies greatly throughout the state each year, with 31% in Marathwada, 30% in Central Maharashtra, 26% in Vidarbha, and 23% in the Konkan region (NIDM, 2013). IMD has classified seventy-four meteorological sub-stations in Maharashtra (Fig. 1) on the basis of climatic parameters like rainfall, temperature, wind speed, and humidity that have been recorded since 1901. In this study, we obtained rainfall data for 120 years (1901–2020) from seventy-four meteorological sub-stations.

2.2. *Method for trend analysis*

In order to identify trends in long-term rainfall data series, we employed the Mann-Kendal test in this study. The MK test's lesser sensitivity to any abrupt shift makes it primarily useful for identifying trends in hydro-climatic data series (Sharma *et al*., 2019, Yue & Hashino, 2003). It is crucial to assess whether serial correlation exists within the data set in order to carry out this test (Yue, & Wang, 2002).

The MK test was calculated using Eq. 1:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} sgn(K_j - K_i) \tag{1}$$

where,

$$\text{Sgn}(K_j - K_i) = \begin{bmatrix} 1 & if\left(K_j - K_i\right) > 0 \\ 0 & if\left(K_j - K_i\right) = 0 \\ -1 & if\left(K_j - K_i\right) < 0 \end{bmatrix}$$

In a time series, K_i, i = 1, 2, 3, ……….n, the value of S is supposed to be similar as the normal distribution with a mean 0 and while the discrepancy of statistics S has been computed using Eq. 2:

$$\text{Var}(s) = \left[\frac{n(n-1)(2n+5) - \sum_{y=1}^{x} t_y\,(t_y - 1)\,(2t_y + 5)}{18}\right] \tag{2}$$

The Z_{MK} value is used to find out that the time series information is demonstrating a significant trend or not. The Z_{MK} value is computed using Eq. 3:

$$Z_{MK} = \begin{bmatrix} \frac{S-1}{\sqrt{var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{var(s)}} & if\ S < 0 \end{bmatrix} \tag{3}$$

The positive and negative values of Z in a normalized test statistic reflect the increasing and decreasing trend, respectively, while the Z having 0 values reflects a normal distributed data series.

2.3. *Method for change point detection*

In the current study, we used the Pettitt test, which was developed by Pettitt (Pettitt A. 1979), and the Standard Normal Homogeneity test (SNHT), which was introduced by Alexandersson and Moberg (Alexandersson & Moberg 1997), to investigate the presence of abruptly shifting change points in the historical rainfall time series annual and seasonal datasets for the study area.

2.3.1 *Pettitt Test*

The Pettitt test is a rank-based distribution-free test designed to detect significant changes in the mean of a time series. It is more useful when hypothesis testing about the position of a change point is not required. This technique has been widely used to identify changes in meteorological and hydrological data series (Gao, *et al*. 2011, Zhang, & Lu 2009).When the duration of a time series is denoted by t and the shift occurs at m years, the resulting test statistics are given in Eq. (4).The statistic is related to the Mann-Whitney statistic, which has two samples, such as k_1, k_2..., k_m and k_{m+1}, k_{m+2}..., k_n:

$$U_{t,m} = \sum_{i=1}^{m}\sum_{j=t+1}^{t} sgn(K_j - K_i) \quad (4)$$

where,

$$\text{Sgn}(K_j - K_i) = \begin{bmatrix} 1 & if(K_j - K_i) > 0 \\ 0 & if(K_j - K_i) = 0 \\ -1 & if(K_j - K_i) < 0 \end{bmatrix} \quad (5)$$

The test statistic $U_{t,m}$ is calculated from all haphazard variables from 1 to n. The majority of distinctive change points are recognized at the point where the magnitude of the test statistic $|U_{t,m}|$ is highest (Eq. 6).

$$Z_T = Max_{1\le t<m} |U_{t.m}| \quad (6)$$

The probability of shifting year is estimated when $|U_{t,m}|$ is maximum following Eq. 7:

$$P = 1\text{-}\exp\left(\frac{-6Z_T{}^2}{K^2+K^3}\right) \quad (7)$$

If the p-value is less than the significance level α, the null hypothesis is considered to be rejected.

2.3.2. *Standard Normal Homogeneity Test (SNHT)*

This test is used to find change points or abrupt shifts in the time series of hydrologic and climatic information. Equation 8 has been used to detect the change point.

$$T_s = \max T_m \quad ,1\le m < n \quad (8)$$

The change point refers to the point, when T_S attains maximum value in the data series. The T_m is derived using Eq. 9:

$$T_m = \bar{m}z_1 + (n-m)\bar{z_1}, \quad m=1,2,\ldots\ldots n \quad (9)$$

where,

$$\bar{z_1} = \frac{1}{m}\sum_{i=1}^{n}\frac{(M_1-\bar{M})}{s} \quad (10)$$

where, m represents the mean and s represents the standard deviation of the sample data.

2.3.3 *Buishand Range Test*

The Buishand range test is also called as Cumulative Deviation test, which is calculated based on the adjusted biased sums or cumulative deviation from mean. The change point using this test is detected following Eqs. 11 and 12:

$$R_0{}^* = 0 \text{ and } R_m{}^* = \sum_{t=1}^{m} P_t - P_{mcan}) \quad (11)$$

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where,

M = 1,2,………,n

$$R_m{}^{**} = \frac{R_m{}^*}{\sigma}$$

$$S = Max|R_m{}^{**}| - Min|R_m{}^{**}| ,0\le m \le n \quad (12)$$

Methods for innovative trend analysis

The present study finds the rainfall trend in Maharashtra based on historical long-term time series rainfall data. For trend analysis, we used the innovative trend analysis that was proposed by Sen (Şen Z. 2012). The most significant advantage of the innovative trend analysis over the MK test and other parametric and non-parametric statistical tests is that it does not require any assumptions such as non-linearity, serial correlation, or sample counts.

$$S = \frac{1}{n}\sum_{i=1}^{n}\frac{10(\bar{y}-\bar{x})}{n} \quad (13)$$

Method for change rate calculation in rainfall time series data

The simple statistical method of percentage change is used to calculate the change rate of annual and seasonal rainfall for the pre- and post-change points. This method is basic, yet it serves a very useful purpose. It is calculated using Equation 14.

Percentage change (%) over period

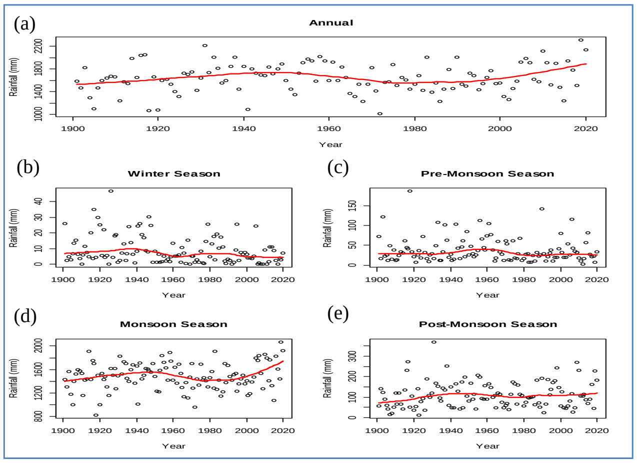
$$= \left(\frac{Average\ rainfall\ of\ post\ change\ point - Average\ rainfall\ of\ pre\ change\ point}{Average\ rainfall\ of\ pre\ change\ point}\right) *100 \quad (14)$$

All mappings in this study were done with the kriging interpolation method in ArcGIS (version 10.3) software.

3. Results and discussion

3.1 *Descriptive Analysis of annual rainfall*

We carried out descriptive statistics of annual rainfall from 1901 to 2020 for seventy-four



Figs. 2(a-e). LOWESS curve on annual and seasonal rainfall from 1901–2020, where the figure shows (a) annual rainfall, (b) winter, (c) pre-monsoon, (d) monsoon, and (e) post-monsoon rainfall of the study area

meteorological sub-stations in Maharashtra. The findings show that the Mahabaleshwar substation at Satara district (4014.4) had the highest average rainfall of all stations, followed by Khandala (3760.5), Sindhudurg (3407.6), Shrivardhan (3358.5), Malvan (3278.9), Sawantwadi (3278.9), Raigad (3246.6), and Ratnagiri (3219.2), respectively. While the minimum average rainfall has been recorded in the sub-station of Shirdi (512.8), which was the lowest in all sub-stations, followed by Baramati (518.2), Shrirampur (554.1), Jeur (567.6), Ahmadnagar (574.0), and Pandharpur (598.5), respectively. The standard deviation of rainfall for the whole of Maharashtra varies from 1205.1 to 153.9mm. The highest variation (standard deviation) in rainfall was observed in Bhimashankar (1205.1mm) meteorological sub-station, followed by Pavai (883.6mm.), Khandala (865.6mm), Pune-Pashan (851.8mm), and Shivaji Nagar (851.8mm), while the minimum variation was recorded in Shirdi (153.9mm), followed by Ahmadnagar (171.7mm) and Tasgaon (176.0mm). The skewness of the rainfall ranges from 0 to 4.9 for all sub-stations in Maharashtra. The lowest skewness was found in Ratnagiri (00), Worli (0.09), and Ramtek (0.1); the highest skewness was observed in Ajantha (4.9), followed by Jalna (3.9) and Pavai (3.9).

The arithmetic mean is not significant (robust) for spatial variation (Duahn & Pandey 2013). In order to decrease spatial variation, a LOWESS, which stands for Locally Weighted Scatterplot Smoothing (LOWESS) regression curve was employed for seasonal rainfall. Several researchers employed this statistical technique and produced good arithmetic mean findings (Taxak 2014, Helsel, & Hirsch, 2002). Fig. 2 represents the LOWESS curve on annual and seasonal rainfall from 1901–2020, where the figure shows (a) annual rainfall, (b) winter, (c) pre-monsoon, (d) monsoon, and (e) post-monsoon rainfall of the study area. The LOWESS curve results show an increasing trend of annual rainfall up to 1948, followed by a declining pattern from 1948 to 1980, and then an increase up to 2020. Rainfall trends during the monsoon season were growing from 1901 to 1949, declining from 1949 to 1978, and increasing again from 1978 to 2020. Pre-monsoon season rainfall trends slightly increased from 1901 to 1962, decreased from 1962 to 1987, and slightly increased from 1987 to 2020.

3.2 *Long Term Pattern and variation of average annual and seasonal rainfall*

We used the coefficient of variation technique to find the variation in rainfall for all meteorological substations. Figs. 3a-e shows the spatial mapping of mean annual and seasonal rainfall variations over Maharashtra using the Kriging interpolation method with a geo-statistical approach. Findings from the spatial mapping of rainfall variation revealed that the climatological subdivisions of western Maharashtra recorded the highest rainfall fluctuation.

The minimum fluctuation was observed in Ahmadnagar (15.5%) meteorological substation, followed

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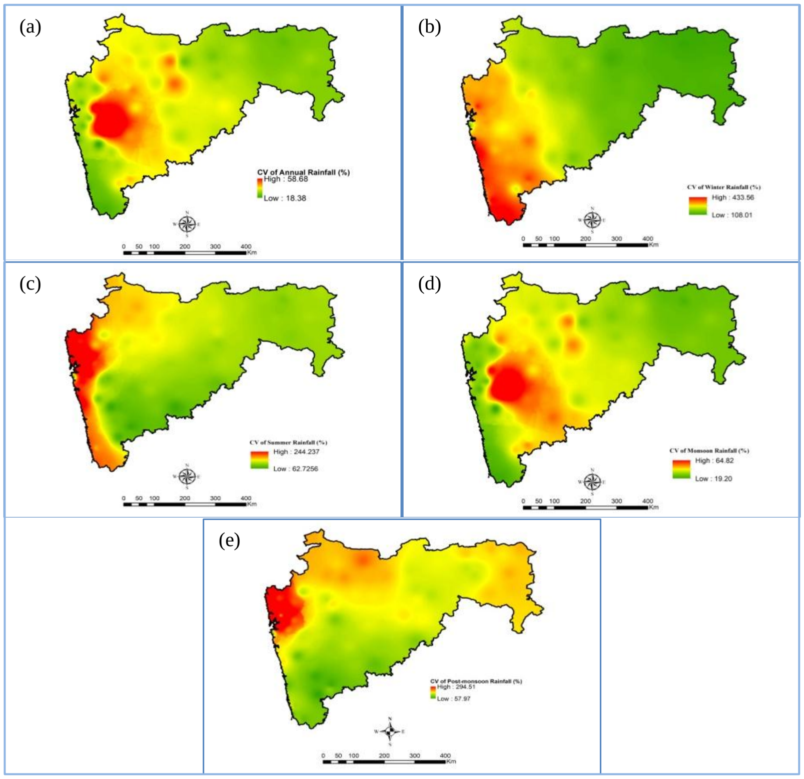
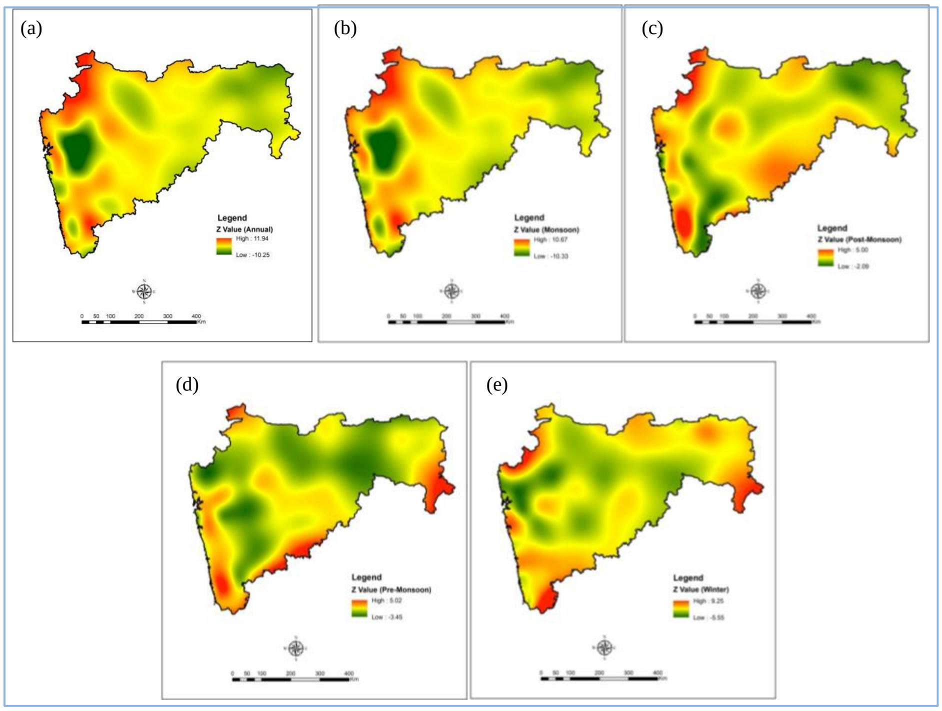


Figs. 3(a-e). Meteorological substation wise spatial variations using the coefficient of variation (CV) in annual and seasonal rainfall where figure (a) shows annual, (b) winter, (c) summer, (d) monsoon, and (e) post monsoon rainfall pattern

by substations like Malegaon (18.3%), Mitbhav (19.5%), Shirdi (19.5%), Vijaydurg (19.7%), Shrivardhan (19.7%), and Vikramgad (19.9%). This result indicates that these stations have been experiencing a very consistent rainfall trend for the last 120 years. While the highest rainfall variation was found in Pusud and Shrirampur (58.7%), followed by Mahabaleshwar (58.7%), Borivali (45.1%), and Pune-Pashan (39.4%), indicating the irregular occurrence of the rainfall throughout the year.

The present analysis of the distribution and variation of rainfall in Maharashtra reveals that the winter season had considerably less precipitation than the other seasons from 1901 to 2020. The maximum variation of rainfall was observed in Mitbhav and Shirdi stations (434.3%), followed by Hinganghat (398.6%), Solapur (395.2%), Devgad (378.9%), and Sindhudurg (373.08%), indicating the unstable incidence of rainfall at these meteorological stations. More consistent rainfall with low variations was observed in Ahmadnagar (101.03%), followed by Nanded (107.9%), Ratnagiri (113.2%), and Harnai (113.5%). The findings indicate that while rainfall in the summer did not see a substantial variance, the north-western region of Maharashtra experienced the most variability. The far east and south-east of Maharashtra saw the least fluctuation in rainfall.

According to research on the divergent distribution of rainfall across Maharashtra during the monsoon season, Mahabaleshwar (64.8%) has the maximum fluctuation, followed by Pusud and Shrirampur (64.4%). Ahmadnagar (15.4%) and Malegaon (19.1%) had the lowest fluctuations. Whereas, the highest rain fall variation in the post - monsoon season was found in Punjab (36.1% and



Figs. 4(a-e). Z value of the MK test on annual and seasonal rainfall from 1901–2020, where the figure shows (a) annual rainfall, (b) monsoon, (c) post-monsoon, (d) pre-monsoon, and (e) winter rainfall of the study area.

138.6%), followed by the Gujarat region (31.3% and 127.6%), indicating unstable rainfall incidences (Figs. 3(d, e).

The spatial rainfall variation analysis aligns with known drought-prone regions of Maharashtra, particularly in Marathwada and parts of Vidarbha**,** such as Beed, Osmanabad, Hingoli, and Wardha districts. These regions show high coefficients of variation**,** indicating unstable and erratic monsoon rainfall patterns. The lower mean annual rainfall and greater inter-annual fluctuation exacerbate the vulnerability of these areas to frequent agricultural droughts. Long-term analysis highlights that even minor monsoon shortfalls significantly affect soil moisture and crop yield due to the lack of supplementary irrigation**,** underscoring the climate-sensitive nature of these zones. Conversely, recent extreme rainfall events and floods in southern Maharashtra, especially in Kolhapur, Sangli, and Satara, suggest a trend of localized heavy downpours. Although the annual average rainfall in these districts may not appear highly variable, short-duration intense rainfall events have increased in frequency. This is reflected in the high seasonal coefficient of variation and suggests a shift towards more extreme rainfall episodes, contributing to urban and riverine flooding. These findings are crucial for infrastructure planning, disaster preparedness, and reservoir operation in the region.

3.3. *Meteorological sub-stations wise trends of Annual and Seasonal Rainfall*

For seventy-four meteorological sub-stations in Maharashtra, from 1901 to 2020, we used the non-parametric Mann-Kendall test to calculate the annual and seasonal rainfall trend (Table 1). At the same time, Fig. 4 shows the Z value of the MK test on annual and seasonal rainfall from 1901-2020, where the figure shows (a) annual rainfall, (b) monsoon, (c) post-monsoon, (d) pre-monsoon, and (e) winter rainfall of the study area. The annual column shows the five colour shades of green to red based on the intensity of the z value of the Mann-

TABLE 1

Results of the MK test (Z) and the percentage change estimation for annual and seasonal rainfall for the period of 1901–2020.

Meteorological Sub-stations	Annual	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Overall	0.46	-2.24	-0.58	0.49	0.99
Ahamadnagar	-0.02	-2	-1.96	0.2	0.57
Ajantha	-1.94	-3.05	-2.44	-1.76	0.37
Akola	-0.02	-1.39	-1.02	-0.01	0.86
Alibag	-2.73	-1.55	-2.44	-1.53	-1.12
Amravati	0.18	-1.37	-1.83	0.4	0.51
Aurangabad	0.31	-2.84	-0.27	0.28	0.86
Baramati	2.45	-2.57	-2.15	2.9	0.38
Beed	1.36	-2.66	-0.12	0.85	0.41
Bhandara	-2.89	-1.24	-0.84	-3.16	-0.28
Bhimashankar	-7.52	-4.5	0.85	-7.64	0.97
Borivali	3.35	-3.33	0.1	3.33	2.09
Brahmapuri	-1.01	-1.98	-0.74	-0.81	0.04
Buldhana	-0.07	-2.83	-2.34	0.55	0.38
Chalisgaon	-0.36	-3.27	-0.96	-0.36	0
Chandrapur	-1.35	-2.05	-1.24	-0.95	0.58
Chembur	3.35	-3.33	0.06	3.31	2.07
Dahanu	5.04	-1.27	-0.69	5.21	1.84
Dapoli	-2.72	-2.47	-0.46	-2.79	0.2
Devgad	4.88	-1.56	-0.61	4.52	0.51
Dhule	0.69	-3.31	-0.65	0.83	0.24
Gadchiroli	-0.57	-1.14	0.4	-0.43	0.04
Gondiya	-3.64	-1.66	-1.26	-3.26	-0.97
Harnai	-2.16	-2.37	-0.96	-2.45	0.62
Hinganghat	-1.73	-2.17	-1.36	-1.03	-0.45
Hingoli	-0.51	-2.63	-1.28	-0.36	0.51
Igatpuri	2.43	-3.5	-1.96	2.64	0.73
Jalna	-1.6	-3.97	-1.72	-1.37	-0.15
Jalgaon	-0.37	-2.56	-2.31	-0.06	0
Jeur	0.35	-3.82	-1.03	0.59	0.73
Kalyan	1.19	-4.49	-0.19	1.18	1.79
Karad	1.95	-0.49	-1.33	2.53	0.02
Katol	-1.21	-1.77	-2.09	-0.75	-0.78
Khandala	1.33	-4.52	0.3	1.51	1.19
Kolhapur	6.02	-0.63	-2.2	6.55	-1.35
Kulaba	2.99	-5.04	-0.23	2.94	2.42
Lohgaon	-7.74	-2.53	-2.79	-7.94	-0.7
Mahableshwar	0.71	-2.38	0.13	0.78	0.91
Malegaon	3.21	-2.46	-1.35	3.67	0.62
Malvan	1.42	-0.52	0.68	1.06	0.74
Mitbhav	4.86	-1.56	-0.27	4.43	0.5
Mulund	3.33	-3.15	0.03	3.33	2.11
Nagpur	-2.11	0.22	-0.69	-2.08	-0.8
Nanded	-0.34	-2.45	-0.57	-0.38	0.88
Nashik	3.84	-2.21	-2.14	3.56	1.43
Osmanabad	0.64	-2.01	-0.6	-0.04	1.73
Pandharpur	0.92	-2.02	-1.18	0.5	0.18
Parbhani	0.18	-1.45	-0.03	0.07	0.82
Pavai	2.83	-3.3	-0.17	3.01	2.3
Pune_Pashan	-7.94	-3.25	-2.6	-8.25	-1.02

Table 1 continued

Meteorological Sub-stations	Annual	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Pusud	-0.34	-3.47	-2.66	0.32	0.39
Raigad	3.09	-0.27	0.97	3.31	1.09
Ramtek	-2.08	-1.01	-1.55	-1.69	-0.77
Ratnagiri	4.97	-0.4	0.12	4.88	1.27
Sangli	2.38	-0.27	-0.63	2.88	0.13
Santacruz	3.35	-3.06	0.03	3.3	2.09
Satara	2.81	-2.15	-0.57	2.92	0.19
Sawantwadi	1.42	-0.52	0.68	1.06	0.74
Shirdi	0.68	-4.69	-1.23	0.94	-0.13
Shivaji_Nagar	-7.94	-3.25	-2.6	-8.25	-1.02
Shrirampur	2.33	-3.11	-0.23	2.04	1.09
Shriramwadi	2.88	-2.49	0.48	2.8	1.4
Shrivardhan	-1.57	-0.31	-0.9	-1.71	0.53
Sindhudurg	1.1	-2.14	1.88	0.2	2.88
Solapur	0.62	-1.84	1.57	0	0.97
Sonegaon	-2.94	-1.19	-0.73	-2.58	-1.2
Tasgaon	0.4	-0.46	-1.57	1.43	-0.75
Thane	3.35	-3.33	0.1	3.33	2.09
Udgir	-1.32	-2.48	0.02	-1.96	1.9
Vardha	-2.31	-1.86	-1.82	-1.81	-0.69
Vengurla	2.89	-2.49	0.68	2.75	1.59
Vijaydurg	4.62	-2.42	-0.38	4.35	0.42
Vikramgad	1.16	-1.15	-3.01	1.43	0.55
Washim	0.36	-2.88	-2.2	0.65	0.02
Worli	3	-4.96	-0.21	2.93	2.4

TABLE 2.1

The annual abrupt change point year for the meteorological sub-stations using SNHT test, Pettitt test and Buishihand's range test.

	Annual					
	Pettit Test		**SNHT Test**		**Buishand's test**	
Sub-Station	Year	P value	Year	P value	Year	P value
1_Overall	1964	0.4627	2018	0.0259	2004	0.2643
Ahamadnagar	1926	0.9651	2019	0.2307	1913	0.9448
Ajantha	1963	0.0065	1963	0.0951	1963	0.1160
Akola	1930	1.0000	1930	0.8542	1930	0.8871
Alibag	1958	0.0001	1958	0.0065	1958	0.0232
Amravati	1930	0.9166	1930	0.6758	1930	0.8676
Aurangabad	1930	0.6330	2019	0.1386	1930	0.5174
Baramati	1972	0.0504	1972	0.0645	1972	0.0072
Beed	1946	0.2065	1946	0.5009	1946	0.2008
Bhandara	1971	0.0112	1971	0.0367	1971	0.0044
Bhimashankar	1950	0.0000	1950	0.0000	1950	0.0000
Borivali	1952	0.0191	2004	0.0017	1952	0.0024
Brahmapuri	1961	0.0960	1961	0.5379	1961	0.3995
Buldhana	1963	0.6406	1913	0.8571	1963	0.7425
Chalisgaon	1970	0.1373	2019	0.1718	1970	0.3102
Chandrapur	1961	0.0985	1961	0.5685	1961	0.3865
Chembur	1951	0.0342	2004	0.0017	1951	0.0020
Dahanu	1952	0.0000	1952	0.0000	1952	0.0000
Dapoli	1964	0.0002	2015	0.0093	1964	0.0092
Devgad	1947	0.0001	2006	0.0002	1947	0.0000

Table 2.1 continued

Dhule	1930	0.3772	2018	0.0418	1930	0.2400
Gadchiroli	1961	0.1503	1905	0.8268	1961	0.7893
Gondiya	1949	0.0001	1961	0.0011	1961	0.0004
Harnai	1964	0.0021	2015	0.0146	1964	0.0284
Hinganghat	1961	0.0514	1961	0.2421	1961	0.0952
Hingoli	1990	0.4382	2001	0.4371	1990	0.2887
Igatpuri	1929	0.0038	1929	0.0024	1929	0.0191
Jalna	1949	0.3863	1963	0.8478	1963	0.4187
Jalgaon	1929	0.6766	1929	0.6629	1929	0.4905
Jeur	1926	0.2244	1926	0.2196	1926	0.2212
Kalyan	1930	0.2307	2018	0.1201	1941	0.1709
Karad	1925	0.1986	2018	0.0005	1925	0.0913
Katol	1961	0.1078	1961	0.1730	1961	0.1526
Khandala	1930	0.4967	2016	0.1350	1953	0.1007
Kolhapur	1936	0.0000	1933	0.0000	1936	0.0000
Kulaba	1952	0.0388	2003	0.0073	1952	0.0028
Lohgaon	1950	0.0000	1950	0.0000	1950	0.0000
Mahableshwar	2004	0.5055	2015	0.0025	2004	0.2493
Malegaon	1942	0.0056	1961	0.0084	1961	0.0011
Malvan	1930	0.3700	2018	0.0003	1930	0.1522
Mitbhav	1947	0.0002	2006	0.0003	1947	0.0000
Mulund	1952	0.0155	2004	0.0129	1952	0.0019
Nagpur	1961	0.0266	1949	0.0656	1949	0.0274
Nanded	1930	0.3882	1999	0.3243	1990	0.2425
Nashik	2002	0.0043	2003	0.0000	2002	0.0000
Osmanabad	1946	0.4382	1946	0.7614	1946	0.4166
Pandharpur	1925	0.7686	1914	0.8280	1957	0.3786
Parbhani	1932	0.6081	1930	0.8939	1932	0.6936
Pavai	1952	0.0279	2009	0.0000	2003	0.0006
Pune_Pashan	1950	0.0000	1950	0.0000	1950	0.0000
Pusud	1963	0.8427	2013	0.8739	1930	0.5856
Raigad	1952	0.0134	2018	0.0201	1952	0.0013
Ramtek	1981	0.0537	1981	0.1281	1981	0.0335
Ratnagiri	1945	0.0001	1982	0.0001	1981	0.0000
Sangli	1945	0.0380	1945	0.0580	1949	0.0164
Santacruz	1952	0.0121	2004	0.0014	1952	0.0007
Satara	1972	0.0207	2018	0.0102	1972	0.0021
Sawantwadi	1930	0.3700	2018	0.0003	1930	0.1457
Shirdi	1926	0.2461	2018	0.0549	1926	0.3679
Shivaji_Nagar	1950	0.0000	1950	0.0000	1950	0.0000
Shrirampur	1926	0.0894	2019	0.0189	1926	0.0458
Shriramwadi	1944	0.0051	2018	0.0003	1944	0.0041
Shrivardhan	1963	0.0175	1958	0.1044	1958	0.0381
Sindhudurg	2008	0.4753	2009	0.0581	2008	0.3942
Solapur	1931	0.3019	1931	0.6364	1946	0.2522
Sonegaon	1961	0.0029	1961	0.0130	1961	0.0028
Tasgaon	1929	0.3273	2018	0.0749	1929	0.2673
Thane	1952	0.0191	2004	0.0011	1952	0.0018
Udgir	1963	0.0689	1963	0.1549	1963	0.1095
Vardha	1962	0.0204	1961	0.1497	1961	0.0310
Vengurla	1944	0.0051	2018	0.0003	1944	0.0040
Vijaydurg	1947	0.0005	2005	0.0009	1947	0.0000
Vikramgad	1929	0.0226	1929	0.0158	1929	0.0463
Washim	1930	0.8052	1930	0.8102	1952	0.5532
Worli	1952	0.0315	2003	0.0090	1952	0.0029

TABLE 2.2

The monsoon and post-monsoon abrupt change point year for the meteorological sub-stations using SNHT test, Pettitt test and Buishihand's range test

Sub-Station	Monsoon						Post-Monsoon					
	Pettit Test		SNHT Test		Buishand's test		Pettit Test		SNHT Test		Buishand's test	
	Year	P value	Year	P value	Year	P value	Year	P value	Year	P value	Year	P value
1_Overall	2004	0.3700	2018	0.0344	2004	0.2583	1926	0.2357	1914	0.2687	1926	0.4577
Ahamadnagar	1926	1.0000	2019	0.1759	1987	0.9799	1926	0.4031	2018	0.3875	1926	0.5070
Ajantha	1970	0.0145	1970	0.1882	1963	0.1614	1923	1.0000	2018	0.9250	1926	0.9182
Akola	1945	1.0000	1930	0.9332	1930	0.9436	1923	0.5959	1923	0.5247	1923	0.5151
Alibag	1957	0.0039	1957	0.1946	1957	0.0525	1963	0.1633	1963	0.2702	1963	0.0973
Amravati	1930	0.6381	1930	0.5617	1930	0.7217	1947	0.7826	1908	0.6230	1923	0.5600
Aurangabad	1925	0.5766	2019	0.0753	1925	0.6729	1926	0.4031	1926	0.5956	1929	0.4067
Baramati	1972	0.0123	1978	0.0086	1972	0.0009	1928	0.3423	2018	0.2824	1928	0.3800
Beed	1946	0.1458	1946	0.3723	1946	0.2310	1926	0.6381	2018	0.3382	1926	0.5841
Bhandara	1964	0.0100	1942	0.0379	1964	0.0037	1999	0.3128	2001	0.1866	2001	0.3128
Bhimashankar	1950	0.0000	1950	0.0000	1950	0.0000	1926	0.2652	1956	0.6010	1956	0.3130
Borivali	1952	0.0123	2004	0.0012	1952	0.0011	1926	0.0703	1911	0.6744	1926	0.7683
Brahmapuri	1961	0.1381	1961	0.7316	1961	0.5094	1999	0.7854	1914	0.6514	1999	0.7226
Buldhana	1987	1.0000	1997	0.8842	1987	0.6456	1923	0.9560	1902	0.5471	1937	0.8093
Chalisgaon	1970	0.1276	2019	0.0680	1970	0.3558	1926	0.8340	1926	0.8515	1930	0.8109
Chandrapur	1961	0.2638	1961	0.6883	1961	0.5868	1923	0.7111	1923	0.7668	1923	0.7887
Chembur	1951	0.0212	2004	0.0012	1951	0.0014	1926	0.0804	1911	0.6966	1926	0.7563
Dahanu	1952	0.0000	1952	0.0000	1952	0.0000	1926	0.1908	1909	0.6666	1914	0.8230
Dapoli	1964	0.0002	2015	0.0027	1963	0.0099	1926	0.7084	1926	0.6858	1926	0.6488
Devgad	1947	0.0002	2006	0.0001	1947	0.0000	1926	0.2542	2018	0.0021	1926	0.2437
Dhule	1941	0.3306	2018	0.0955	1941	0.1473	1999	0.9196	2018	0.4162	1923	0.8023
Gadchiroli	1961	0.1485	1905	0.5259	1961	0.7042	1981	1.0000	2013	0.9398	1940	0.9576
Gondiya	1949	0.0002	1949	0.0055	1961	0.0019	1999	0.3144	1999	0.2544	1999	0.3115
Harnai	1963	0.0011	2015	0.0064	1963	0.0201	1926	0.6130	1926	0.6117	1926	0.6809
Hinganghat	1961	0.2100	1961	0.3957	1961	0.2185	1999	0.3790	1999	0.2879	1999	0.4639
Hingoli	1990	0.5188	1990	0.5676	1990	0.2849	2001	1.0000	2001	0.9219	2001	0.8749
Igatpuri	1929	0.0044	1929	0.0035	1929	0.0103	1926	0.2737	1961	0.6164	1961	0.2583
Jalna	1993	0.4816	1993	0.8462	1970	0.4357	2001	0.8485	2018	0.3153	1926	0.8460
Jalgaon	1929	0.4989	1929	0.4898	1929	0.5895	2001	0.6951	1909	0.7884	1963	0.7568
Jeur	1926	0.6255	1926	0.5454	1926	0.3897	1929	0.2124	2018	0.1066	1929	0.2988
Kalyan	1941	0.2269	2018	0.1677	1941	0.1800	1926	0.2019	1911	0.6000	1926	0.6865
Karad	2003	0.1078	2003	0.0014	2003	0.0152	1928	0.3993	2018	0.1698	1928	0.6660
Katol	1961	0.2396	1961	0.4196	1961	0.4115	1999	0.8957	2013	0.8845	1999	0.9146
Khandala	1953	0.3647	2016	0.1610	1953	0.0744	1926	0.3525	2018	0.2675	1961	0.8408
Kolhapur	1933	0.0000	1933	0.0000	1933	0.0000	1977	0.0718	1977	0.2074	1977	0.1199
Kulaba	1952	0.0207	2002	0.0079	1952	0.0024	1926	0.0366	1926	0.3426	1926	0.3300
Lohgaon	1950	0.0000	1950	0.0000	1950	0.0000	1956	0.0639	2018	0.0668	1956	0.1027
Mahableshwar	2003	0.4989	2015	0.0019	2003	0.2545	1926	0.4185	1926	0.5424	1926	0.6421
Malegaon	1961	0.0007	1961	0.0005	1961	0.0003	1930	0.2569	1930	0.3453	1930	0.4213
Malvan	1930	0.6740	2018	0.0008	1930	0.1910	1915	0.4483	2018	0.0117	1992	0.2375
Mitbhav	1947	0.0003	2006	0.0001	1947	0.0000	1926	0.2159	2018	0.0014	1926	0.2629
Mulund	1952	0.0087	2004	0.0136	1952	0.0016	1926	0.0670	1911	0.6740	1926	0.7592
Nagpur	1949	0.0235	1949	0.0885	1949	0.0317	1999	0.4669	2001	0.2810	2001	0.4493
Nanded	1930	0.3808	1992	0.3644	1990	0.2448	1950	0.8897	2018	0.6834	1958	0.4817
Nashik	2002	0.0034	2003	0.0000	2002	0.0001	1926	0.1214	1930	0.1406	1930	0.2684
Osmanabad	1946	0.5647	1946	0.7265	1946	0.4506	1926	0.1952	2018	0.0481	1972	0.1480
Pandharpur	1957	0.8311	1961	0.8144	1961	0.3955	1926	1.0000	2018	0.3908	1973	0.5772

Table 2.2 continued

Parbhani	1930	0.7165	1930	0.9625	1932	0.8086	1954	0.5391	1923	0.8140	1954	0.3850
Pavai	1952	0.0250	2004	0.0009	1952	0.0025	1926	0.0533	2009	0.0000	2008	0.0088
Pune_Pashan	1950	0.0000	1950	0.0000	1950	0.0000	1956	0.0518	2018	0.0620	1956	0.0908
Pusud	1930	0.8167	1930	0.6991	1930	0.5928	1957	0.8253	2006	0.8154	1957	0.6306
Raigad	1952	0.0070	1952	0.0125	1952	0.0012	1926	0.3525	1909	0.5946	1926	0.6716
Ramtek	1981	0.2008	1981	0.3595	1947	0.0793	1999	0.6007	2001	0.3889	1978	0.3603
Ratnagiri	1946	0.0001	1980	0.0002	1980	0.0000	1926	0.2112	1926	0.2309	1926	0.1686
Sangli	1952	0.0082	1954	0.0118	1958	0.0015	1928	0.8282	2016	0.1919	1930	0.7731
Santacruz	1952	0.0070	2004	0.0010	1952	0.0003	1926	0.0622	1911	0.6619	1926	0.7546
Satara	1972	0.0131	2003	0.0011	1973	0.0006	1928	0.4031	2018	0.2840	1928	0.7064
Sawantwadi	1930	0.6740	2018	0.0008	1930	0.1942	1915	0.4483	2018	0.0125	1992	0.2355
Shirdi	1987	0.6662	2019	0.0831	1987	0.2504	1926	0.4342	1926	0.4626	1926	0.3711
Shivaji_Nagar	1950	0.0000	1950	0.0000	1950	0.0000	1956	0.0518	2018	0.0585	1956	0.0915
Shrirampur	1946	0.2307	2019	0.0019	1946	0.0310	1926	0.1071	1926	0.1272	1926	0.2572
Shriramwadi	1944	0.0054	2018	0.0008	1944	0.0053	1926	0.1476	2018	0.0218	1992	0.0947
Shrivardhan	1958	0.0194	1970	0.1193	1970	0.0456	1926	0.6431	1911	0.7162	1926	0.4721
Sindhudurg	2009	0.6355	2009	0.0872	2009	0.6102	1926	0.0023	1926	0.0032	1930	0.0049
Solapur	1990	0.4012	1991	0.5124	1937	0.2390	1972	0.4989	2018	0.2190	1972	0.5189
Sonegaon	1961	0.0100	1961	0.0299	1961	0.0077	1999	0.2171	1999	0.1043	1999	0.2692
Tasgaon	1958	0.0967	1958	0.3024	1958	0.1153	1979	0.5165	2018	0.0259	1999	0.6012
Thane	1952	0.0123	2004	0.0013	1952	0.0016	1926	0.0703	1911	0.6807	1926	0.7686
Udgir	1959	0.0212	1959	0.0330	1959	0.0262	1972	0.0967	1972	0.1884	1972	0.0552
Vardha	1961	0.0689	1961	0.2462	1961	0.0851	1999	0.2195	1999	0.1628	1999	0.4239
Vengurla	1944	0.0055	2018	0.0006	1944	0.0056	1926	0.1245	2018	0.0227	1992	0.0717
Vijaydurg	1946	0.0013	2006	0.0009	1946	0.0000	1926	0.3919	2018	0.0144	1926	0.3310
Vikramgad	1929	0.0212	1929	0.0141	1929	0.0329	1926	0.2332	1909	0.8205	1961	0.4325
Washim	1952	0.6280	1952	0.5071	1952	0.3229	1923	1.0000	1923	0.9278	1923	0.7960
Worli	1952	0.0177	2002	0.0066	1952	0.0019	1926	0.0366	1926	0.3491	1926	0.3251

TABLE 2.3

The pre-monsoon and winter abrupt change point year for the meteorological sub-stations using SNHT test, Pettitt test and Buishihand's range test.

Sub-Station	Pre-Monsoon						Winter					
	Pettit Test		SNHT Test		Buishand's test		Pettit Test		SNHT Test		Buishand's test	
	Year	P value	Year	P value	Year	P value	Year	P value	Year	P value	Year	P value
1_Overall	1963	0.1941	1963	0.5569	1963	0.3076	1948	0.0038	1948	0.0024	1948	0.0043
Ahamadnagar	1971	0.0067	1978	0.1075	1971	0.0412	1955	0.0221	1926	0.0034	1948	0.0022
Ajantha	1971	0.0044	1963	0.4940	1963	0.1818	1948	0.0071	1929	0.0440	1948	0.0103
Akola	1968	0.1782	2016	0.9627	1962	0.7187	1948	0.1348	1948	0.2776	1948	0.1169
Alibag	1958	0.0055	1958	0.3783	1958	0.1554	1998	0.0209	1998	0.1996	1998	0.2217
Amravati	1968	0.0124	1968	0.1932	1968	0.1314	1948	0.0067	1948	0.0150	1948	0.0218
Aurangabad	1982	1.0000	1918	0.9999	1953	0.9863	1982	0.1407	1929	0.0123	1929	0.0106
Baramati	1978	0.0087	1978	0.0665	1978	0.0645	1948	0.1390	1948	0.3190	1948	0.1049
Beed	1962	0.5742	1901	0.7077	1988	0.9627	1948	0.0456	1947	0.4852	1947	0.1449
Bhandara	1971	0.2765	1971	0.7038	1971	0.5099	1948	0.0476	1948	0.3803	1948	0.3897
Bhimashankar	1974	0.2973	1903	0.2490	1971	0.3099	1948	0.0019	1901	0.0447	1958	0.0127
Borivali	1985	1.0000	1903	0.2942	1998	0.8284	1948	0.2269	1926	0.0576	1945	0.0106
Brahmapuri	1971	0.2780	1901	0.4610	1971	0.3586	1948	0.0763	1901	0.0223	1948	0.0487
Buldhana	1968	0.0014	1963	0.1710	1963	0.0812	1987	0.0312	1929	0.1766	1929	0.0391
Chalisgaon	1957	0.2988	1991	0.9079	1991	0.5927	1948	0.0085	1929	0.4584	1948	0.1660
Chandrapur	1945	0.3975	2019	0.6678	1971	0.3543	1947	0.0327	1944	0.0829	1947	0.0379
Chembur	1942	0.9712	1903	0.2890	1998	0.8318	1948	0.2269	1926	0.0582	1945	0.0112
Dahanu	1962	1.0000	1903	0.6839	1971	0.7659	1948	0.0004	1946	0.0045	1946	0.0035
Dapoli	1962	0.2569	1903	0.5105	1962	0.3726	1948	0.0900	1948	0.1077	1948	0.0345

Table 2.3 continued

Devgad	1966	0.2737	2009	0.9919	1962	0.9484	1968	0.5414	1965	0.7550	1965	0.5324
Dhule	1978	0.6180	1971	0.2560	1971	0.1268	1962	0.0584	1926	0.1414	1948	0.0262
Gadchiroli	1959	1.0000	1901	0.2142	2013	0.9530	1950	0.0768	1944	0.1042	1944	0.0736
Gondiya	1971	0.0290	1971	0.2553	1971	0.0896	1948	0.0342	1948	0.1268	1948	0.1150
Harnai	1962	0.2208	1903	0.8944	1998	0.9124	1948	0.0992	1928	0.1962	1948	0.0496
Hinganghat	1968	0.1199	1968	0.1793	1968	0.0665	1950	0.0177	1950	0.3649	1950	0.2021
Hingoli	1963	0.1134	1901	0.4270	1963	0.2151	1950	0.0022	1947	0.0226	1947	0.0070
Igatpuri	1967	0.0007	1975	0.0863	1975	0.1458	1948	0.0082	1948	0.2009	1948	0.0921
Jalna	1971	0.2195	1918	0.7421	1971	0.4014	1952	0.0005	1929	0.0061	1948	0.0035
Jalgaon	1978	0.0596	1995	0.6375	1962	0.1438	1948	0.1276	1929	0.0422	1929	0.0495
Jeur	1982	0.0258	1974	0.1182	1974	0.0621	1948	0.0143	1947	0.0283	1948	0.0112
Kalyan	1998	0.4669	1903	0.2290	1998	0.8725	1948	0.0301	1948	0.0252	1948	0.0047
Karad	1988	0.0082	1901	0.0010	1966	0.0165	1948	0.3700	1902	0.0011	1941	0.4606
Katol	1971	0.0073	1971	0.0370	1971	0.0183	1948	0.0131	1948	0.0846	1948	0.0522
Khandala	1962	0.8282	1903	0.2380	1903	0.9996	1948	0.0022	1948	0.0106	1948	0.0047
Kolhapur	1978	0.0025	1982	0.0059	1978	0.0080	1965	0.0865	1901	0.2340	1948	0.1281
Kulaba	1963	1.0000	1903	0.5292	1943	0.7425	1948	0.0106	1948	0.0096	1948	0.0026
Lohgaon	1967	0.0010	1967	0.0024	1967	0.0017	1948	0.0214	1948	0.2644	1948	0.1670
Mahableshwar	1941	0.7630	1903	0.3569	1966	0.3856	1948	0.0028	1948	0.0293	1948	0.0306
Malegaon	1963	0.2383	1903	0.1975	1938	0.2625	1960	0.0882	1903	0.8355	1948	0.5806
Malvan	1942	0.6130	1962	0.9299	1962	0.6703	1948	0.7547	1962	0.8850	1962	0.7531
Mitbhav	1966	0.3882	2009	0.9945	1942	0.9179	1968	0.5414	1965	0.7519	1965	0.5330
Mulund	1918	1.0000	1903	0.3091	1998	0.7922	1948	0.3004	1926	0.0629	1945	0.0120
Nagpur	1971	0.5983	1971	0.7189	1971	0.4003	2005	0.7658	2005	0.6916	1948	0.6568
Nanded	1982	0.2088	1901	0.0854	1970	0.5724	1952	0.0126	1952	0.0394	1952	0.0127
Nashik	1974	0.0063	1974	0.3695	1974	0.2547	1928	0.1177	1926	0.5393	1948	0.3762
Osmanabad	1963	0.0472	1901	0.2873	1967	0.5147	1952	0.0877	1947	0.0255	1947	0.0056
Pandharpur	1963	0.0652	1901	0.0516	1963	0.3641	1948	0.1044	1901	0.3125	1947	0.3929
Parbhani	1968	0.7273	1901	0.2830	1918	0.9232	1952	0.0366	1947	0.1874	1947	0.1572
Pavai	1985	1.0000	1903	0.1589	1918	0.8525	1948	0.2569	1926	0.0580	1945	0.0116
Pune_Pashan	1967	0.0019	1967	0.0813	1967	0.0444	1948	0.0092	1948	0.0438	1948	0.0255
Pusud	1971	0.0000	1971	0.0066	1971	0.0048	1952	0.0007	1950	0.0224	1950	0.0046
Raigad	1962	0.5886	1903	0.9568	1962	0.8164	1948	0.1214	1961	0.1984	1961	0.0686
Ramtek	1971	0.0221	1971	0.1752	1971	0.1895	1948	0.1214	1987	0.3406	1987	0.2214
Ratnagiri	1962	0.7084	1998	0.8562	1989	0.7673	1948	0.0439	1948	0.1253	1948	0.0589
Sangli	1962	0.1071	1978	0.5132	1978	0.3652	1948	0.8485	1947	0.6326	1947	0.3611
Santacruz	1985	1.0000	1903	0.0000	1903	0.4881	1948	0.3700	1926	0.1292	1945	0.0219
Satara	1966	0.3491	1901	0.0493	1982	0.2691	1948	0.0639	1948	0.1870	1948	0.1105
Sawantwadi	1942	0.6130	1962	0.9266	1962	0.6764	1948	0.7547	1962	0.8883	1962	0.7591
Shirdi	1971	0.0832	1962	0.6188	1962	0.2914	1959	0.0010	1948	0.0133	1948	0.0046
Shivaji_Nagar	1967	0.0019	1967	0.0810	1967	0.0422	1948	0.0092	1948	0.0426	1948	0.0238
Shrirampur	1974	0.6431	1918	0.7947	1962	0.5381	1951	0.0600	1929	0.3699	1929	0.1897
Shriramwadi	1935	0.7084	1961	0.9408	1961	0.7206	1948	0.2515	2012	0.7122	1948	0.5613
Shrivardhan	1962	0.1782	1903	0.7046	1962	0.8904	1948	0.0694	1948	0.1475	1948	0.0670
Sindhudurg	1942	0.0270	1942	0.2728	1942	0.1918	1948	0.2652	1945	0.3198	1945	0.0809
Solapur	1932	0.7602	1901	0.8915	1932	0.6577	1947	0.2088	1947	0.8063	1947	0.3325
Sonegaon	1968	0.4107	1968	0.4557	1968	0.1236	1950	0.0301	1950	0.2289	1950	0.1168
Tasgaon	1982	0.0350	1995	0.0198	1994	0.0556	1928	1.0000	1906	0.1556	1948	0.3512
Thane	1985	1.0000	1903	0.2865	1998	0.8296	1948	0.2269	1926	0.0591	1945	0.0116
Udgir	1963	0.6977	1963	0.9791	1963	0.9000	1947	0.0033	1947	0.1161	1947	0.0435
Vardha	1968	0.0541	1968	0.1648	1968	0.0473	1950	0.0131	1950	0.4413	1950	0.2521
Vengurla	1935	0.6205	1961	0.9514	1961	0.7483	1948	0.2515	2012	0.7097	1948	0.5661
Vijaydurg	1966	0.4069	2006	0.9967	1962	0.9454	1965	0.3439	1965	0.5795	1965	0.3902
Vikramgad	1962	0.0003	1962	0.0523	1962	0.0141	1950	0.0000	1948	0.0030	1948	0.0025
Washim	1968	0.0036	1949	0.1250	1949	0.0281	1952	0.0007	1948	0.0215	1948	0.0101
Worli	1963	1.0000	1903	0.5571	1938	0.7737	1973	0.0187	1961	0.1343	1961	0.0511

TABLE 3

The monsoon season abrupt change point year for the meteorological sub-stations using SNHT test, Pettitt test and Buishand′s range test.

Sub-Station	Change point based on Pettit test	Pettit test P Value	Change point based on SNHT test	SNHT test P Value	Change point based on Buishand′s test	Buishand′s test p Value	Selected change point (Year)
1_Overall	2004	0.37	2018	0.0344	2004	0.2583	2018
Ahamadnagar	1926	1	2019	0.1759	1987	0.9799	2019
Ajantha	1970	0.0145	1970	0.1882	1963	0.1614	1970
Akola	1945	1	1930	0.9332	1930	0.9436	1930
Alibag	1957	0.0039	1957	0.1946	1957	0.0525	1957
Amravati	1930	0.6381	1930	0.5617	1930	0.7217	1930
Aurangabad	1925	0.5766	2019	0.0753	1925	0.6729	2019
Baramati	1972	0.0123	1978	0.0086	1972	0.0009	1972
Beed	1946	0.1458	1946	0.3723	1946	0.231	1946
Bhandara	1964	0.01	1942	0.0379	1964	0.0037	1964
Bhimashankar	1950	0	1950	0	1950	0	1950
Borivali	1952	0.0123	2004	0.0012	1952	0.0011	1952
Brahmapuri	1961	0.1381	1961	0.7316	1961	0.5094	1961
Buldhana	1987	1	1997	0.8842	1987	0.6456	1987
Chalisgaon	1970	0.1276	2019	0.068	1970	0.3558	2019
Chandrapur	1961	0.2638	1961	0.6883	1961	0.5868	1961
Chembur	1951	0.0212	2004	0.0012	1951	0.0014	1951
Dahanu	1952	0	1952	0	1952	0	1952
Dapoli	1964	0.0002	2015	0.0027	1963	0.0099	1964
Devgad	1947	0.0002	2006	0.0001	1947	0	1947
Dhule	1941	0.3306	2018	0.0955	1941	0.1473	2018
Gadchiroli	1961	0.1485	1905	0.5259	1961	0.7042	1961
Gondiya	1949	0.0002	1949	0.0055	1961	0.0019	1949
Harnai	1963	0.0011	2015	0.0064	1963	0.0201	1963
Hinganghat	1961	0.21	1961	0.3957	1961	0.2185	1961
Hingoli	1990	0.5188	1990	0.5676	1990	0.2849	1990
Igatpuri	1929	0.0044	1929	0.0035	1929	0.0103	1929
Jalna	1993	0.4816	1993	0.8462	1970	0.4357	1993
Jalgaon	1929	0.4989	1929	0.4898	1929	0.5895	1929
Jeur	1926	0.6255	1926	0.5454	1926	0.3897	1926
Kalyan	1941	0.2269	2018	0.1677	1941	0.18	1941
Karad	2003	0.1078	2003	0.0014	2003	0.0152	2003
Katol	1961	0.2396	1961	0.4196	1961	0.4115	1961
Khandala	1953	0.3647	2016	0.161	1953	0.0744	1953
Kolhapur	1933	0	1933	0	1933	0	1933
Kulaba	1952	0.0207	2002	0.0079	1952	0.0024	1952
Lohgaon	1950	0	1950	0	1950	0	1950
Mahableshwar	2003	0.4989	2015	0.0019	2003	0.2545	2015
Malegaon	1961	0.0007	1961	0.0005	1961	0.0003	1961
Malvan	1930	0.674	2018	0.0008	1930	0.191	2018
Mitbhav	1947	0.0003	2006	0.0001	1947	0	1947
Mulund	1952	0.0087	2004	0.0136	1952	0.0016	1952
Nagpur	1949	0.0235	1949	0.0885	1949	0.0317	1949
Nanded	1930	0.3808	1992	0.3644	1990	0.2448	1990
Nashik	2002	0.0034	2003	0	2002	0.0001	2002
Osmanabad	1946	0.5647	1946	0.7265	1946	0.4506	1946
Pandharpur	1957	0.8311	1961	0.8144	1961	0.3955	1961
Parbhani	1930	0.7165	1930	0.9625	1932	0.8086	1930
Pavai	1952	0.025	2004	0.0009	1952	0.0025	1952

Table 3 continued

Pune_Pashan	1950	0	1950	0	1950	0	1950
Pusud	1930	0.8167	1930	0.6991	1930	0.5928	1930
Raigad	1952	0.007	1952	0.0125	1952	0.0012	1952
Ramtek	1981	0.2008	1981	0.3595	1947	0.0793	1947
Ratnagiri	1946	0.0001	1980	0.0002	1980	0	1980
Sangli	1952	0.0082	1954	0.0118	1958	0.0015	1958
Santacruz	1952	0.007	2004	0.001	1952	0.0003	1952
Satara	1972	0.0131	2003	0.0011	1973	0.0006	1973
Sawantwadi	1930	0.674	2018	0.0008	1930	0.1942	2018
Shirdi	1987	0.6662	2019	0.0831	1987	0.2504	2019
Shivaji_Nagar	1950	0	1950	0	1950	0	1950
Shrirampur	1946	0.2307	2019	0.0019	1946	0.031	1946
Shriramwadi	1944	0.0054	2018	0.0008	1944	0.0053	1944
Shrivardhan	1958	0.0194	1970	0.1193	1970	0.0456	1958
Sindhudurg	2009	0.6355	2009	0.0872	2009	0.6102	2009
Solapur	1990	0.4012	1991	0.5124	1937	0.239	1937
Sonegaon	1961	0.01	1961	0.0299	1961	0.0077	1961
Tasgaon	1958	0.0967	1958	0.3024	1958	0.1153	1958
Thane	1952	0.0123	2004	0.0013	1952	0.0016	1952
Udgir	1959	0.0212	1959	0.033	1959	0.0262	1959
Vardha	1961	0.0689	1961	0.2462	1961	0.0851	1961
Vengurla	1944	0.0055	2018	0.0006	1944	0.0056	1944
Vijaydurg	1946	0.0013	2006	0.0009	1946	0	1946
Vikramgad	1929	0.0212	1929	0.0141	1929	0.0329	1929
Washim	1952	0.628	1952	0.5071	1952	0.3229	1952
Worli	1952	0.0177	2002	0.0066	1952	0.0019	1952

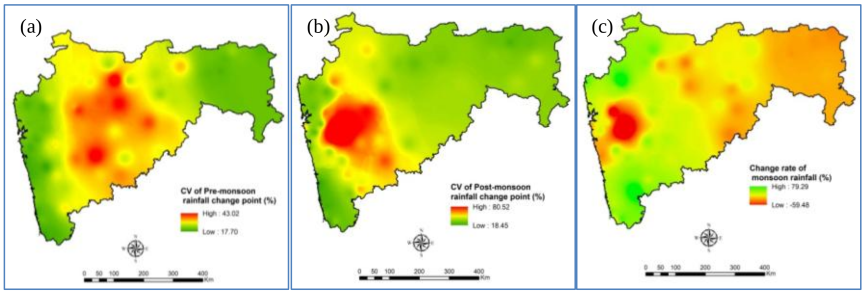
Kendall test at the 0.05 significance level, which indicates that the darker the shade of green color, higher the positive z value, and the orange to red colour indicates a higher negative z value. Out of seventy-four meteorological sub-stations, thirty meteorological sub-stations found a negative trend. The highest negative trend was found in Bhimashankar (-7.52), Lohgaon (-7.74), Pune Pashan (-7.94), and Shivaji Nagar (-7.94). The z value of the MK test ranges from 0 to -4, which could be found in twenty-three meteorological sub-stations, *i.e*., Ahamadnanr, Ajantha, Akola, Alibag, Bhandara, Brahmapuri, Buldhana, Chalisgaon, Chandrapur, Dapoli, Gadchiroli, Gondia, Harnai, Hinganghat, Hingoli, Jalna, Jalgaon, Katol, Nagpur, Nanded, Pusud, Ramtek, and Shrivardhan (orange colour in Table 1).

The z value with a positive trend varies from 0 to 6. Out of a positive sub-station z value of 2 to 6, which were observed in the sixteen meteorological sub-stations, this implies the increasing nature of rainfall over these stations, which are found at these meteorological sub-stations: Baramati, Borivali, Chembur, Dahanu, Devagad, Igatpuri, Kolhapur, Malegaon, Mitbhav, Mulund, Nashik, Pavai, Raigad, Ratnagiri, Thane, and Vijaydurg. While the Kolhapur meteorological sub-station recorded highly positive trend of more than 6 of z value (very dark shade of green color in Table 1), which indicates the significant increase of rainfall over time in this meteorological sub-station.

The two meteorological sub-stations (Sindhudurg and Solapur) for the pre-monsoon season recorded a highly positive trend in rainfall with >1 of z value (Table 1). Only Nagpur meteorological sub-station for the winter season recorded a positive rainfall trend (0.22). In the monsoon season, the highest negative trends (-8.25) were observed at Shivaji Nagar and Pune Pashan Sub-station, whereas Kolhapur meteorological sub-station noticed the highest positive trend with a z value of 6.55.

3.4 *The Change Point Detection analysis for annual and seasonal rainfall*

Table 1 of the aforementioned analysis provided an explanation for the detection of a few meteorological sub-stations with a significant negative trend and a z value greater than −2. However, a number of scholars asserted that using the MK test on all hydro-climatic datasets would not reveal the true trend. It is therefore highly advised that change detection approaches be used prior to applying the MK test. For this reason, we used change detection techniques such as the Pettitt test, the SNHT



Figs. 5(a-c) Spatial variation of rainfall measured using the coefficient of variation for the pre-change point, where figure (a) shows monsoon rainfall; the post-change point, where figure (b) shows monsoon rainfall; and spatial changes in the rate of rainfall, where figure (c) shows monsoon rainfall.

test, and the Buishand's range test to identify the abrupt change point in the rainfall datasets across 74 meteorological sub-stations (Table 2). Table 2 indicates that all meteorological sub-stations' annual and seasonal rainfall had an abrupt change point, which was identified using the three change detection techniques such as the Pettitt test, the SNHT test, and the Buishand's range test. Furthermore, we selected the change point for monsoon season rainfall in each meteorological sub-stations based on the performances (p value) of these tests (Table 3). As a result, it appears from these abrupt change points that there was no monotonous trend in the rainfall datasets.

According to the change point year for monsoon season for all meteorological sub-stations, 1950 was the change point year for Bhimashankar, Lohgaon, Pune Pashan, and Shivaji Nagar, while 1930 was the change point year for Akola, Amravati, Parbhani, and Pusud. The significant thing is that 2019 was a change-point year for Ahamadnagar, Aurangabad, Chalisgaon, and Shirdi sub-stations.

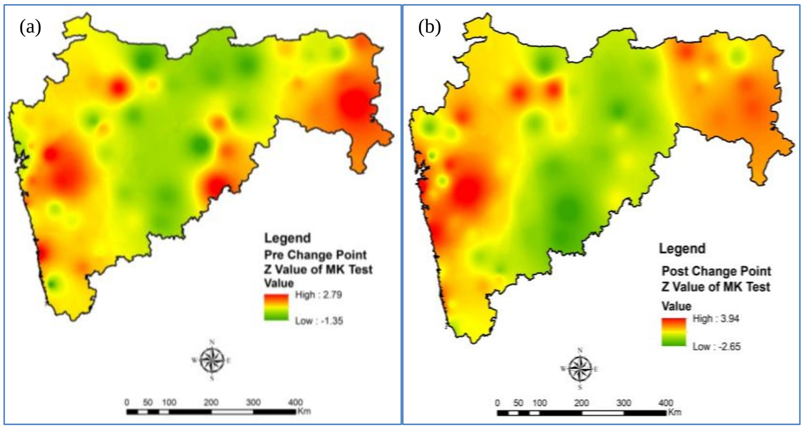
We focused on monsoon season rainfall change point variation analysis so that we computed the monsoon rainfall variation pre- and post-change point-wise for all meteorological sub-stations in Maharashtra to explore the dynamics of the intensity of monsoon season rainfall variations after the change point. So Fig. 5 illustrates the spatial variation of rainfall measured using the coefficient of variation for the pre-change point, where fig. (a) shows monsoon rainfall; the post-change point, where figure (b) shows monsoon rainfall; and spatial changes in the rate of rainfall. Thus, this rainfall variation study based on change points can be regarded as a means of verifying the applicability of change point methods and facilitating future research. In order to substantiate this claim, we computed and prepared a spatial map of monsoon season rainfall variation for the pre-change point using the coefficient of variation method.

Results show the highest fluctuation of the pre-change point in the Ajantha meteorological sub-station, with the maximum coefficient of variation (43.08). Below that, the maximum coefficient of variation was noticed in the meteorological sub-stations like Jeur (42.4), Jalna (40.1), Shrirampur (37.6), Parbhani (36.6), Aurangabad (35.8), Baramati (34.6), Solapur (33.6), and Ahamadnagar (32.4), whereas the minimum coefficient of variation was observed in the Mahableshwar (17.7), Shriramwadi (17.7), Vengurla (17.7), Shrivardhan (17.8), Vijaydurg (17.9), Dapoli (18.6), Harnai (18.6), Malvan (18.9), and Sawantwadi (18.9) meteorological sub-stations in Maharashtra.

The Pune Pashan and Shivaji Nagar meteorological sub-stations had the highest coefficient of variation (80.6), indicating the most post-change point variability in the research area. The values of Lohgaon (75.1), Ahamadnagar (50.6), Pandharpur (45.5), Nashik (41.6), Bhimashankar (43.4), and Baramati (40.2) were found to have the highest coefficient of variation below that. Ratnagiri (18.4), Vijaydurg (19.2), Sindhudurg (19.4), and Shriramwadi (19.6) meteorological sub-stations in Maharashtra were found to have the lowest coefficient of variation.

3.5 *Rainfall change rate analysis*

In this study, we computed the rainfall change rate for the monsoon season rainfall in each of the meteorological sub-stations in Maharashtra based on the calculation between the rainfall data of the pre- and post-change point phase. Fig. 5 (c) depicts the spatial mapping of the rainfall change rate for monsoon season rainfall. Results show that the meteorological substation of Kolhapur observed the highest change rate (79.4%) in monsoon season rainfall. Below that, meteorological sub-stations like Nashik (60.6%), Sawantwadi (39.4%), Malvan (39.4%), Dahanu (37.4%), and Dhule (34.1%)



Figs. 6(a&b). Z value of the MK test, where figure (a) shows the monsoon rainfall pre-change point and figure (b) shows the monsoon rainfall post-change point

also noticed the highest change rate in monsoon season rainfall. while Lohgaon (59.5%), Pune Pashan (58.3%), Shivaji Nagar (58.3%), Bhimashankar (51.01%), Ajantha (16.2%), and Udgir (15.5%) recorded the highest negative change rate in monsoon rainfall. Furthermore, Akola, Buldhana, and Parbhani recorded the minimum change rate of monsoon rainfall.

3.6 *Change point wise monsoon season rainfall trend analysis*

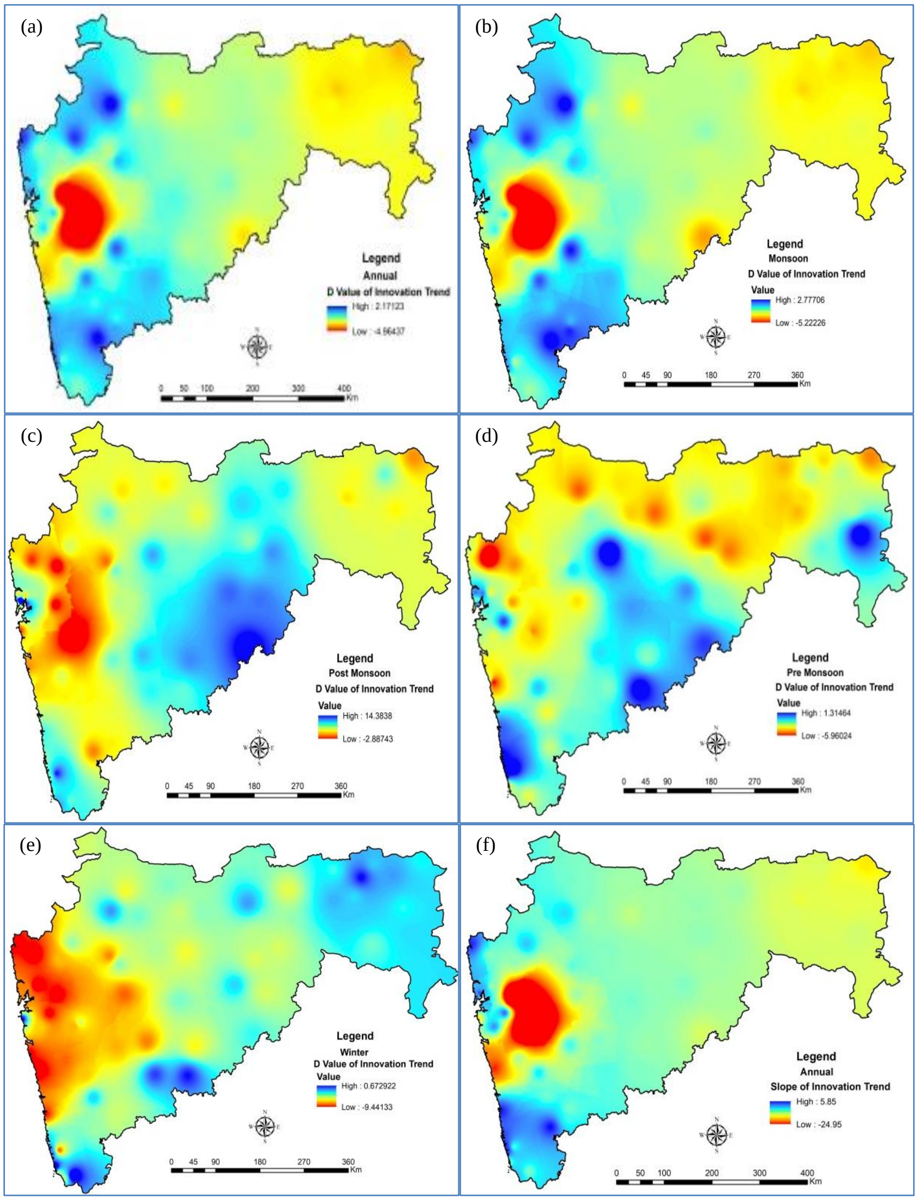
We used the MK test on datasets of pre- and post-change points of monsoon rainfall in each meteorological sub-station in Maharashtra. Table 4 represents the monsoon rainfall trend for pre- and post-change points in all meteorological sub-stations. At the same time, fig. 6 represents the Z value of the MK test, where fig.6(a) shows the monsoon rainfall pre-change point and fig.6(b) shows the monsoon rainfall post-change point. Results indicate that the highest negative trend in pre-change point was observed at Parbhani, with a greater negative Z value of -1.36. Besides that, Jalgaon (-1.33), Sindhudurg (-1.26), Amravati (-1.01), and Osmanabad (-0.7) also noticed a negative trend. While the highest positive trend in pre-change point was observed at Gadchiroli with a greater positive Z value of 2.8, Bhimashankar (2.43), Ratnagiri (2.34), Udgir (2.29), Chalisgaon (2.15), Shivaji Nagar (1.96), and Pune Pashan (1.96) also saw positive trends. At Mahableshwar meteorological substation, no trend was observed in the pre- change point.

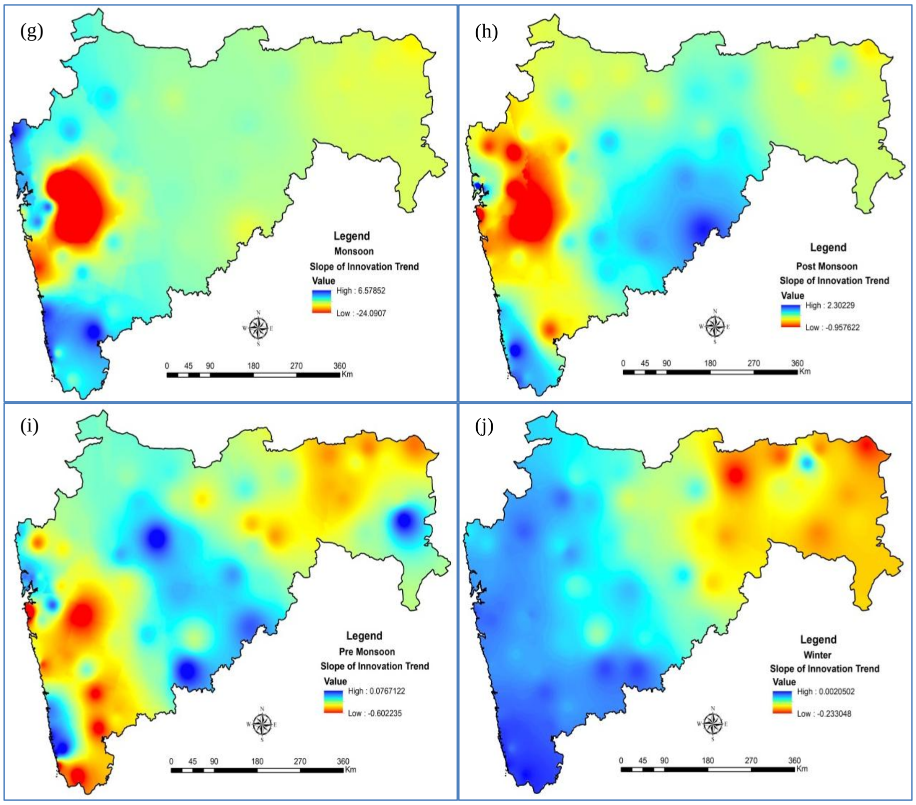
Results show that the highest negative trend at the post-change point was observed at Osmanabad, with a greater negative Z value of -2.66. Besides that, Solapur (-2.25), Washim (-2.08), Jalgaon (-1.94), Beed (-1.7), and Kalyan (-1.46) also noticed a negative trend. Whereas the highest positive trend in post-change point was noticed at Alibag with the greater Z value of 3.97, Lohgaon 2.74, Pune Pashan 2.47, Shivaji Nagar 2.47, and Harnai 2.17. At Ahamadnagar, Dhule, Malvan, and Sawantwadi meteorological substations, no trend was observed at the post-change point.

3.7 *Innovative trend analysis for seasonal rainfall*

Several scholars claimed that non-parametric statistical technique, such as the Mann-Kendall test, had many limitations, including the occurrence of serial correlation within data sets, non-linearity, and, most crucially, sample size, all of which might influence the result. Therefore, Sen 55 proposed an innovative trend method to tackle the aforementioned disadvantages, particularly the problem of sample size. According to Sen55, an innovative trend can successfully identify a trend in any sample size when serial correlation is present. Therefore, we employed an innovative trend to determine the annual and seasonal rainfall trend (pre-monsoon, monsoon, post-monsoon, and winter) in 74 meteorological sub-stations across Maharashtra (Supplementary Table 1 to 4). In order to compare the intensity of the trend attained by the MK test, we calculated the innovative trend's D value. Fig. 7(a–j) shows the spatial mapping for annual and seasonal rainfall utilizing D values and the Sen Slope value of the innovative trend.

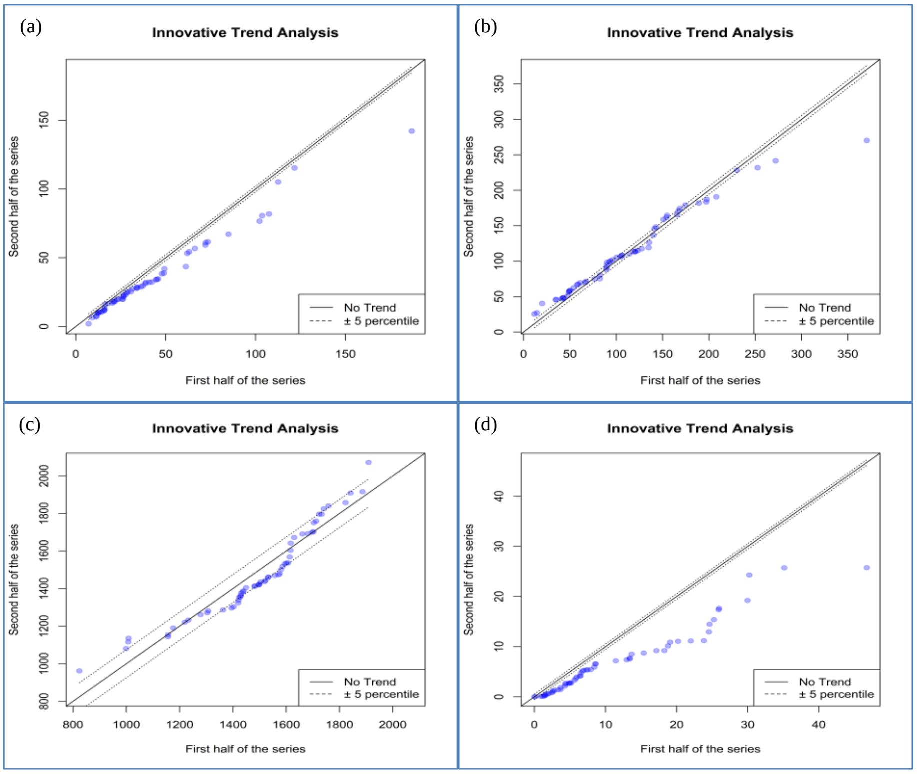
However, the Supplementary Table 1 to 4 displayed the slope value and D value of the innovative trend for seasonal rainfall in all meteorological sub - stations in


(a)
Legend
Annual
D Value of Innovation Trend
High : 2.17123
Low : -4.96437
0 50 100 200 300 400 Km
(b)
Legend
Monsoon
D Value of Innovation Trend
Value
High : 2.77706
Low : -5.22226
0 45 90 180 270 360 Km
(c)
Legend
Post Monsoon
D Value of Innovation Trend
Value
High : 14.3838
Low : -2.88743
0 45 90 180 270 360 Km
(d)
Legend
Pre Monsoon
D Value of Innovation Trend
Value
High : 1.31464
Low : -5.96024
0 45 90 180 270 360 Km
(e)
Legend
Winter
D Value of Innovation Trend
Value
High : 0.672922
Low : -9.44133
0 45 90 180 270 360 Km
(f)
Legend
Annual
Slope of Innovation Trend
High : 5.85
Low : -24.95
0 50 100 200 300 400 Km



Figs. 7(a-j). The spatial variation of 'D' value of innovative trend for (a) annual, (b) monsoon, (c) post-monsoon, (d) pre-monsoon, (e) winter, and The spatial variation of the slope of the innovative trend for (f) annual, (g) monsoon, (h) post-monsoon, (i) pre-monsoon, and (j) winter

Maharashtra. Sen Slop's results show a negative trend in Bhimashankar, Dapoli, Harnai, Lohgaon, Pune Pashan, Shivaji Nagar, and Shrivardhan meteorological substations in Maharashtra during the monsoon season. During the same season, a positive trend was observed at the meteorological substations at Kolhapur, Dahanu, Devgad, Khandala, Mitbhav, Raigad, Ratnagiri, and Vijaydurg. The results were nearly comparable to the findings of the MK test, but the magnitudes of the trend were different, which stated that the region experienced a strong negative trend Fig. 7(a-j). During the pre-monsoon season, meteorological substations in Alibag, Karad, Kolhapur, Lohgaon, Malvan, Pune Pashan, Sawantwadi, and Shivaji Nagar detected a negative trend, whereas during the same season, Aurangabad, Gadchiroli, Sindhudurg, and Solapur substations observed a positive trend. Alibag, Bhimashankar, Igatpuri, Lohgaon, Pune Pashan, Shivaji Nagar, and Vikramgad substations showed a negative trend during the post-monsoon season, while Pavai, Parbhani, Shriramwadi, Sindhudurg, Udgir, and Vengurla meteorological substations showed a positive trend. The results of the MK test and innovative trend analysis were nearly equal; however, there were a few meteorological substations where no significant trend was discovered using the MK test, but in the case of the innovative trend, those regions showed a negative trend. Fig. 8 represents Season-wise Innovative Trends in Maharashtra from 1901-2020. Innovative trend analysis shows that in Maharashtra, a downward trend in rainfall was noted over the winter (fig. 8). Fig. 9-12 shows a meteorological substation-wise innovative trend analysis of the pre-monsoon, monsoon, post-monsoon, and winter

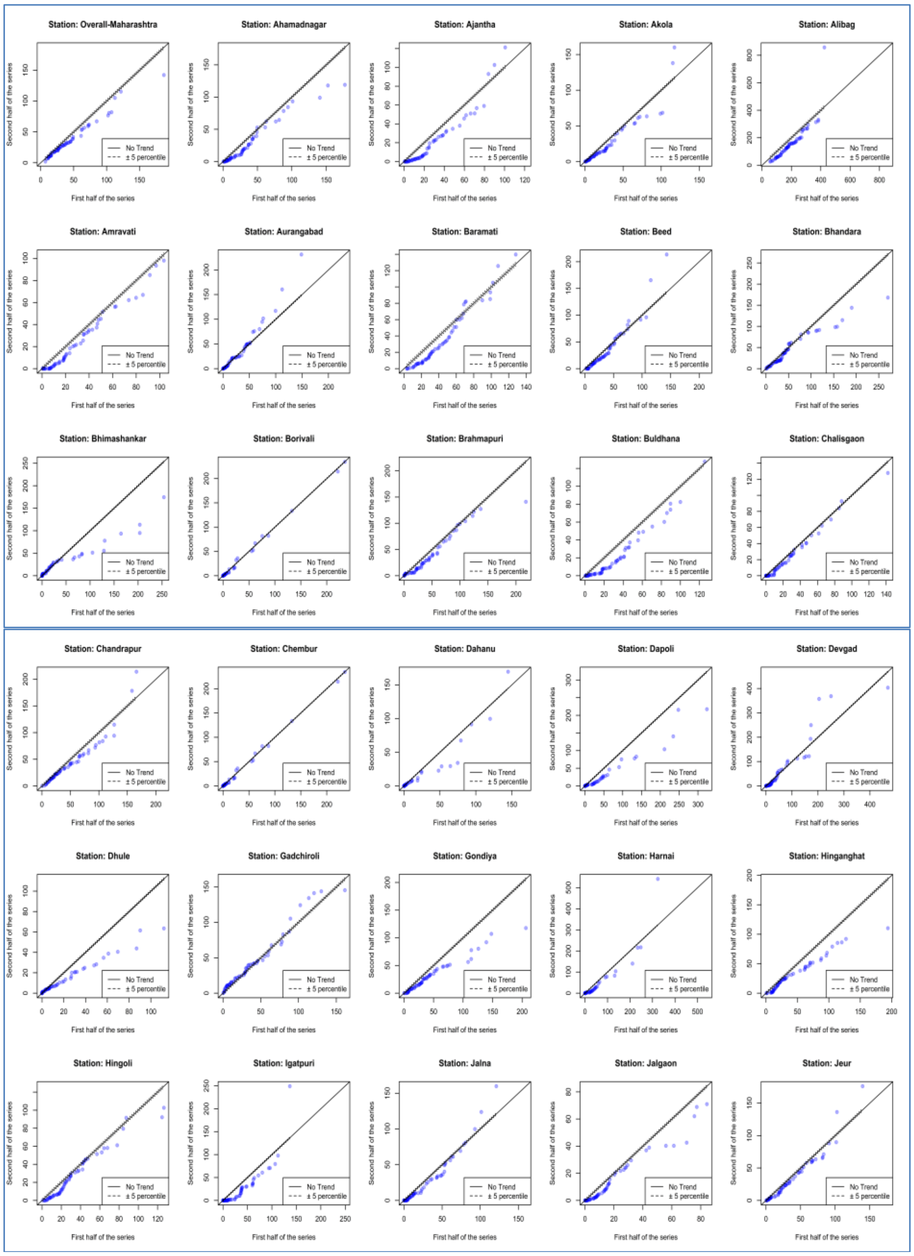


Figs. 8(a-d). Season-wise Innovative Trends in Maharashtra from 1901-2020 (a) indicate pre-monsoon, (b) show post-monsoon, (c) represent monsoon, and (d) show winter.Data: Pre-Monsoon season

seasons. According to innovative trend analysis, during the pre-monsoon season, Dhule, Hinganghat, Buldhana, Lohgaon, Nagpur, and Vardha meteorological substations observed a negative rainfall trend (Fig. 9). According to the innovative trend analysis, Baramati, Dahanu, Kolhapur, Khandala, Satara, and Santacruz meteorological substations experienced positive rainfall trends during the monsoon season between 1901 and 2020, whereas Bhimashankar, Lohgaon, and Shivaji Nagar exhibited negative trends (Fig. 10)The negative deviation observed in these stations could be attributed to multiple factors, such as rapid urbanization**,** land use/land cover (LULC) changes**,** and urban heat island effects**,** particularly around Pune district (where Lohgaon and Shivaji Nagar are located). These factors may influence local convective processes and rainfall patterns. Additionally, orographic effects and microclimatic variations in the Western Ghats region (such as Bhimashankar) may also contribute to reduced monsoonal rainfall in recent decades. These findings highlight the importance of integrating local environmental changes into long-term climatic trend assessments.

3.8 *Micro level rainfall change rate analysis*

In the present research work, we attempted to analyze the annual rainfall change rate for seventy-four meteorological sub-stations in Maharashtra from 1901–2020. We computed the change rate by calculating the departure of year-wise average rainfall from long-term average rainfall. The heat map was used to depict the dynamics of year-by-year rainfall change rates for all meteorological substations (Fig. 13).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Station: Bhimashankar
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Station: Brahmapuri
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Station: Chandrapur
Station: Chembur
Station: Dahanu
Station: Dapoli
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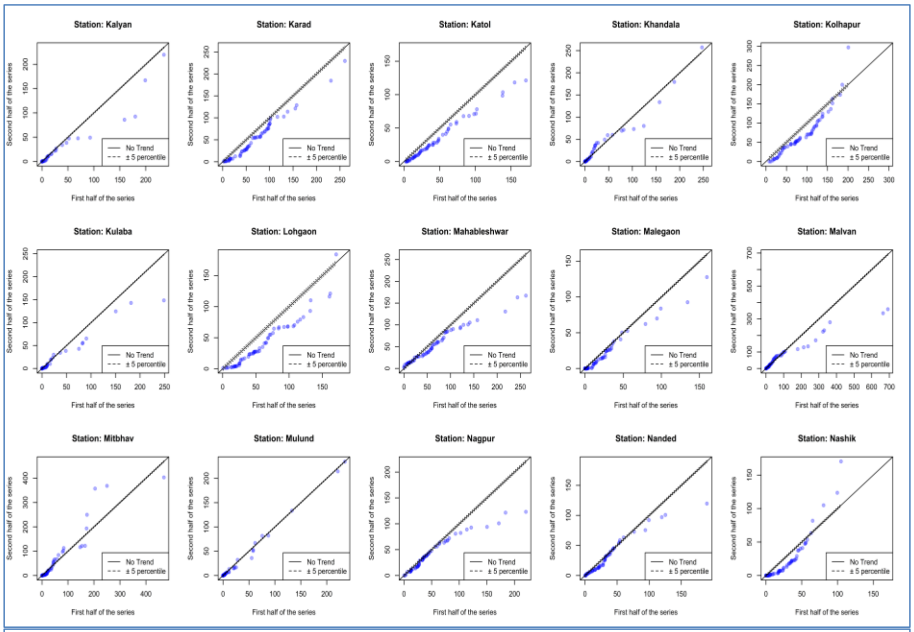
Station: Dhule
Station: Gadchiroli
Station: Gondiya
Station: Harnai
Station: Hinganghat
Station: Hingoli
Station: Igatpuri
Station: Jalna
Station: Jalgaon
Station: Jeur
Second half of the series
First half of the series
No Trend
± 5 percentile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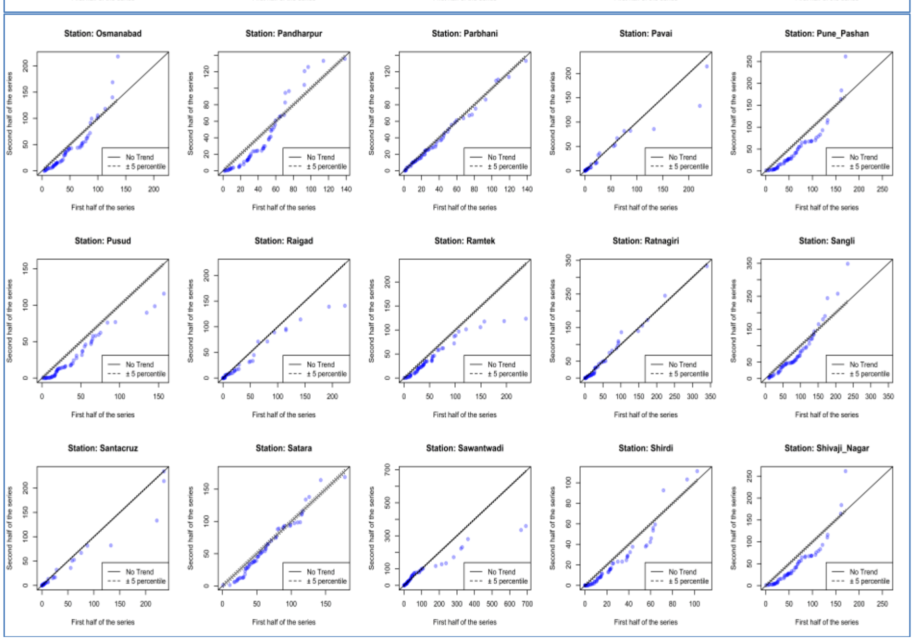
Station: Malegaon
Station: Malvan
Station: Mitbhav
Station: Mulund
Station: Nagpur
Station: Nanded
Station: Nashik
Second half of the series
First half of the series
No Trend
± 5 percentile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Station: Sangli
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Station: Shivaji_Nagar
Second half of the series
First half of the series
No Trend
± 5 percentile

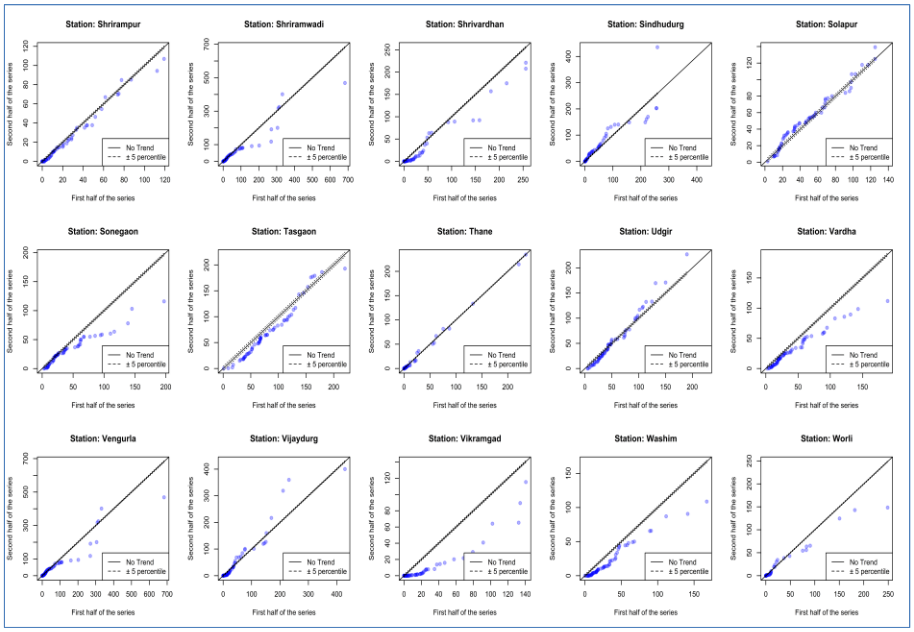

Fig. 9. Meteorological substation-wise innovative trend analysis of pre-monsoon rainfall Data

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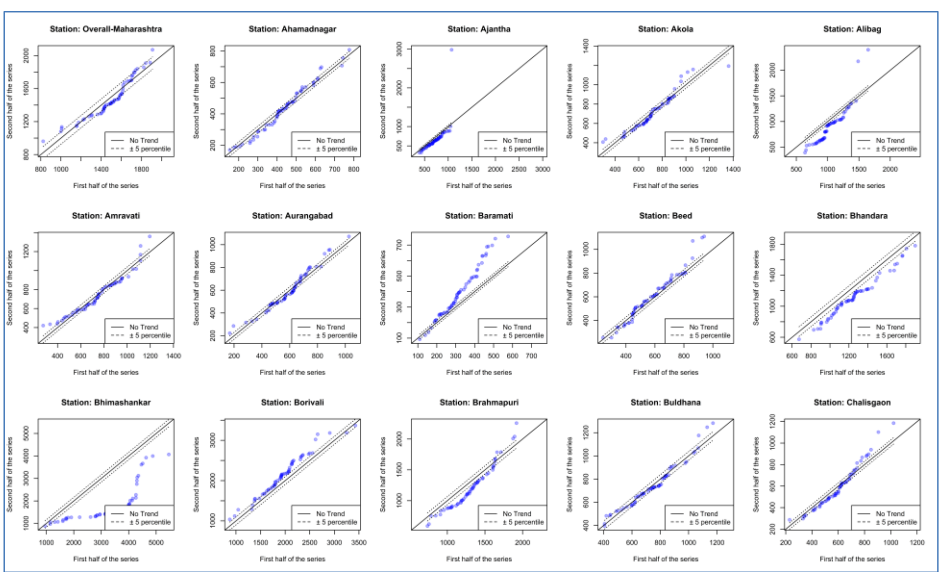

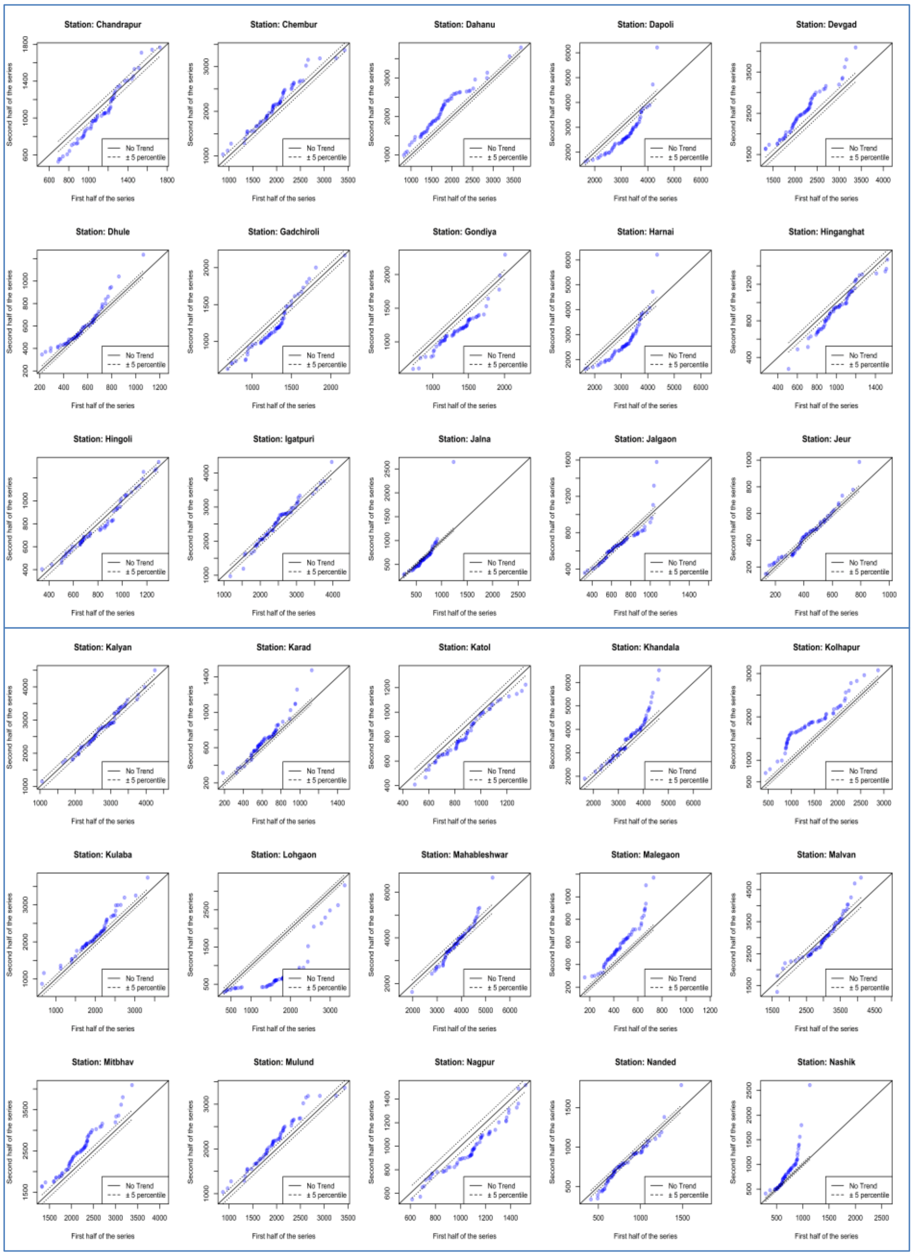
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Station: Malegaon
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Station: Nanded
Station: Nashik
Second half of the series
First half of the series
No Trend
± 5 percentile

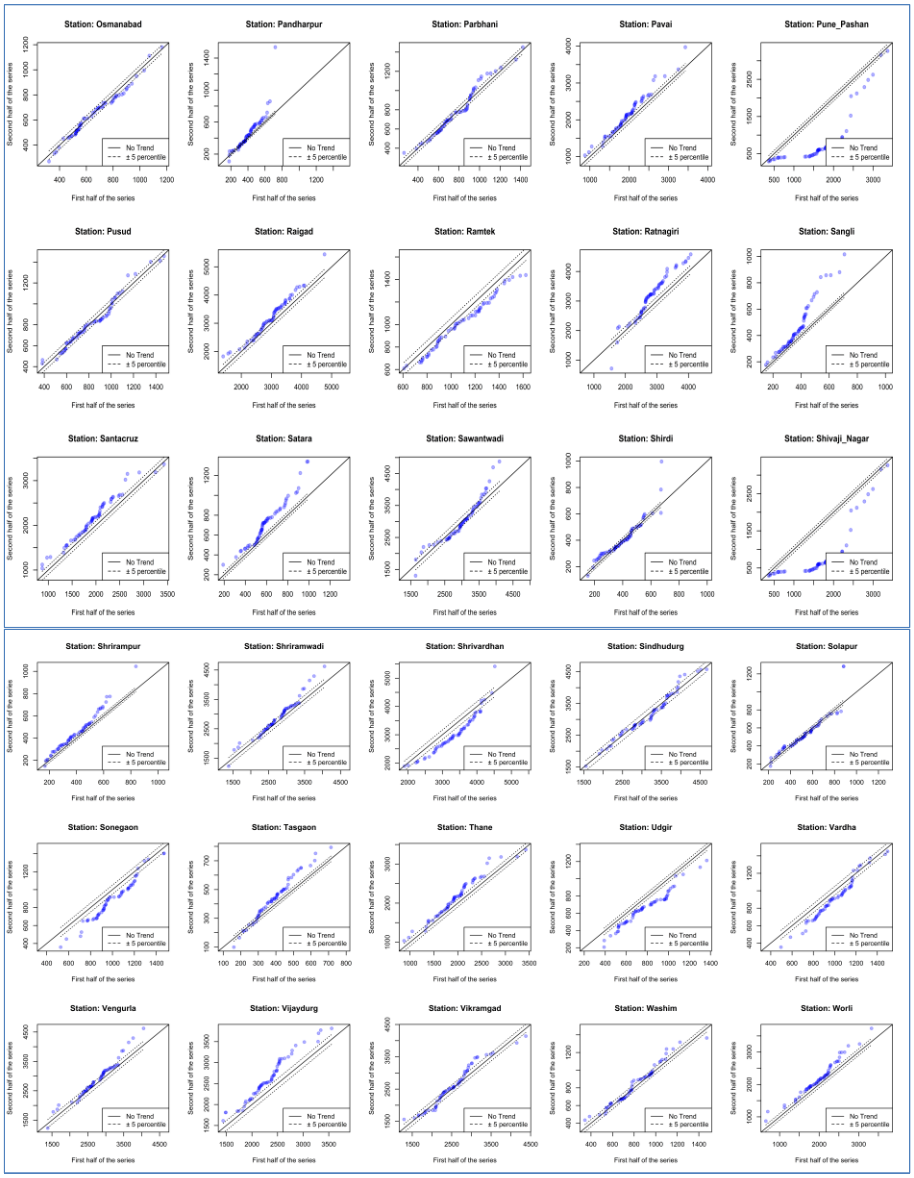
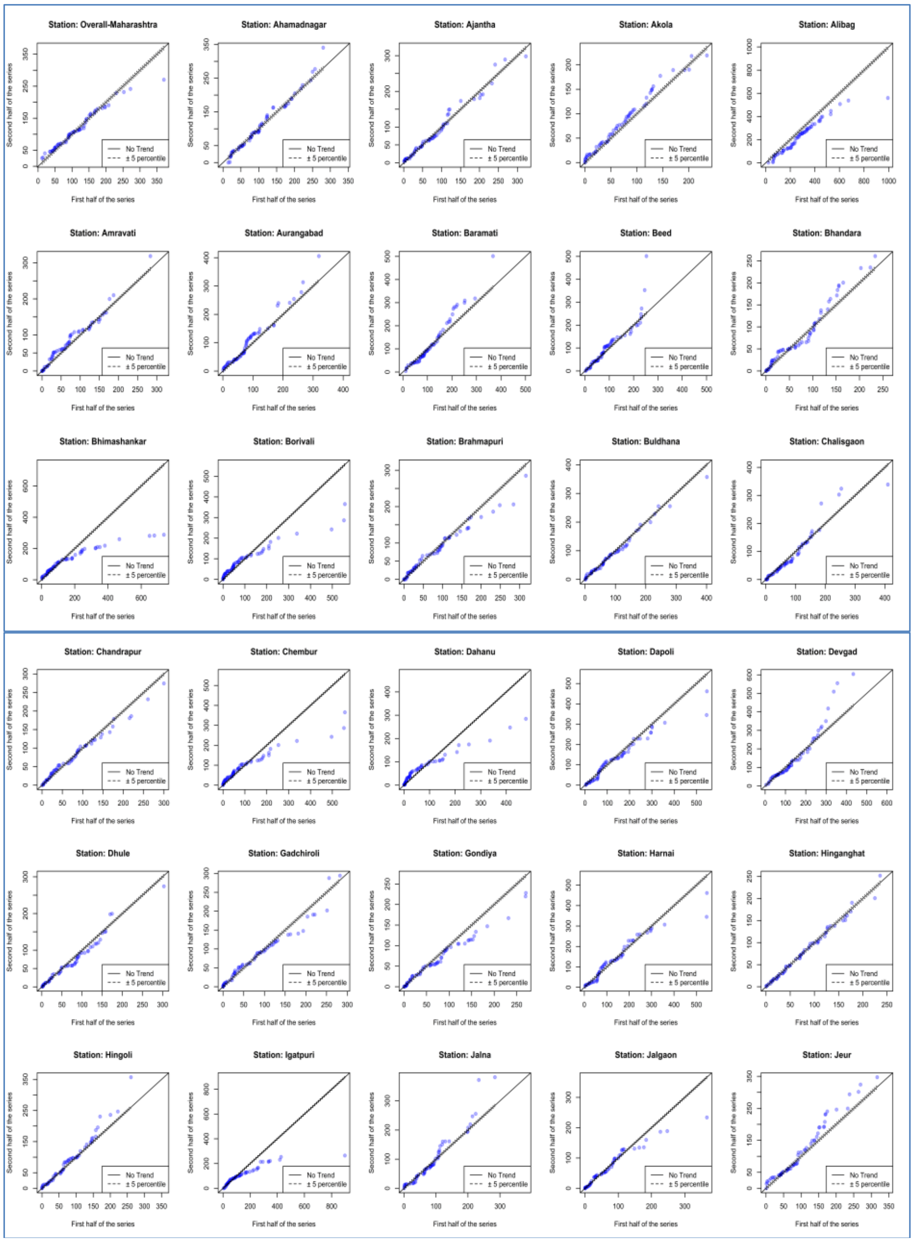


Fig. 10. Meteorological substation-wise innovative trend analysis of monsoon rainfall Data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Station: Harnai
Station: Hinganghat
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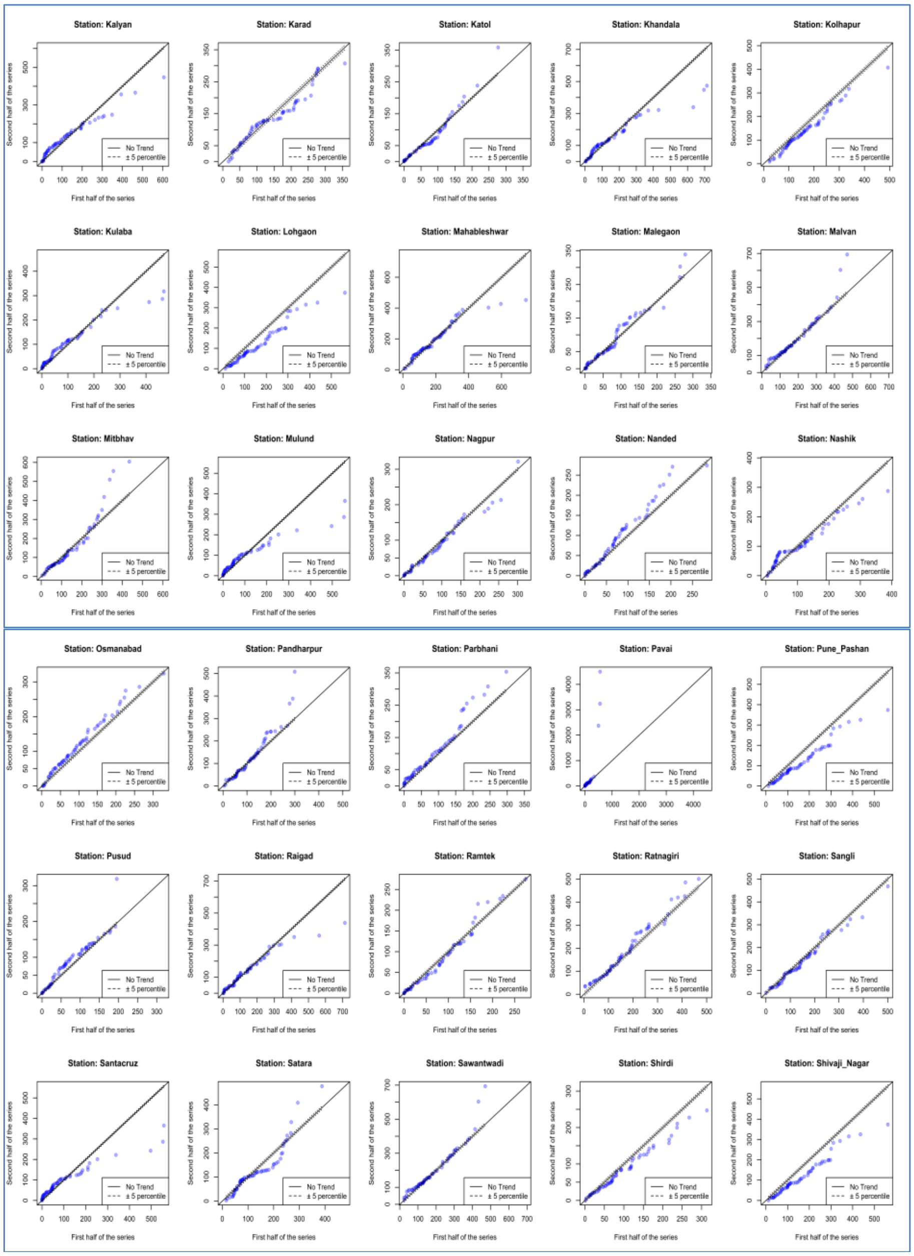
Station: Jeur
Second half of the series
First half of the series
No Trend
± 5 percentile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Station: Ramtek
Station: Ratnagiri
Station: Sangli
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Second half of the series
First half of the series
No Trend
± 5 percentile

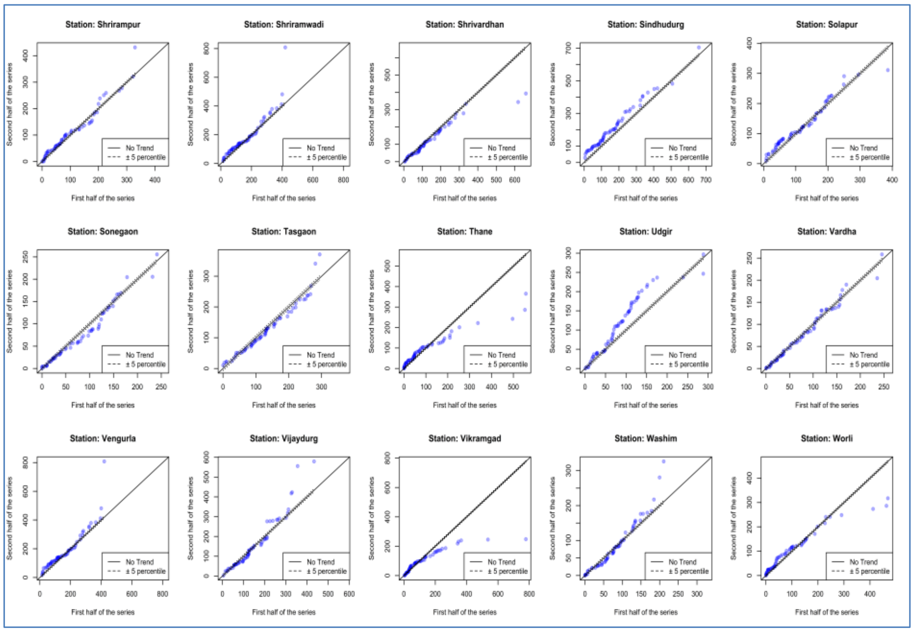

Fig. 11. Meteorological substation-wise innovative trend analysis of post-monsoon rainfall Data

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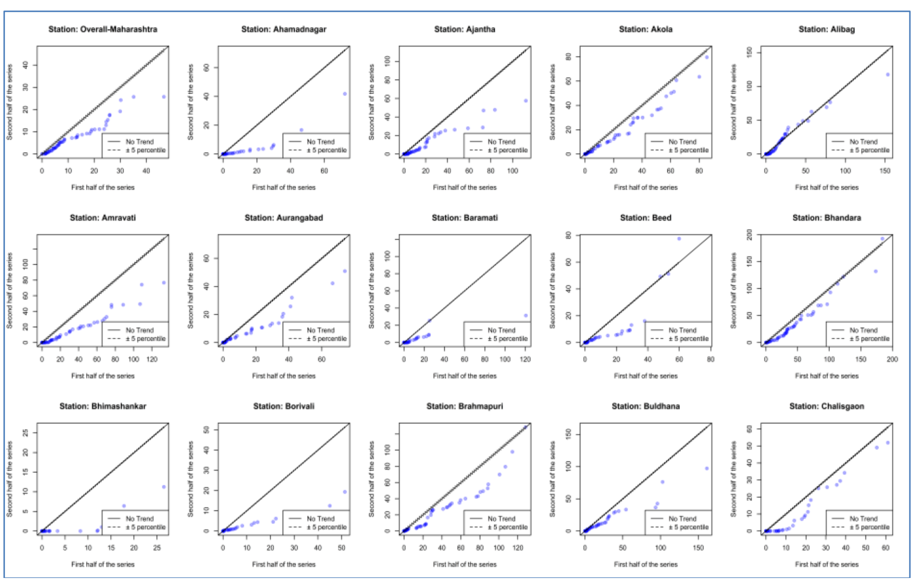

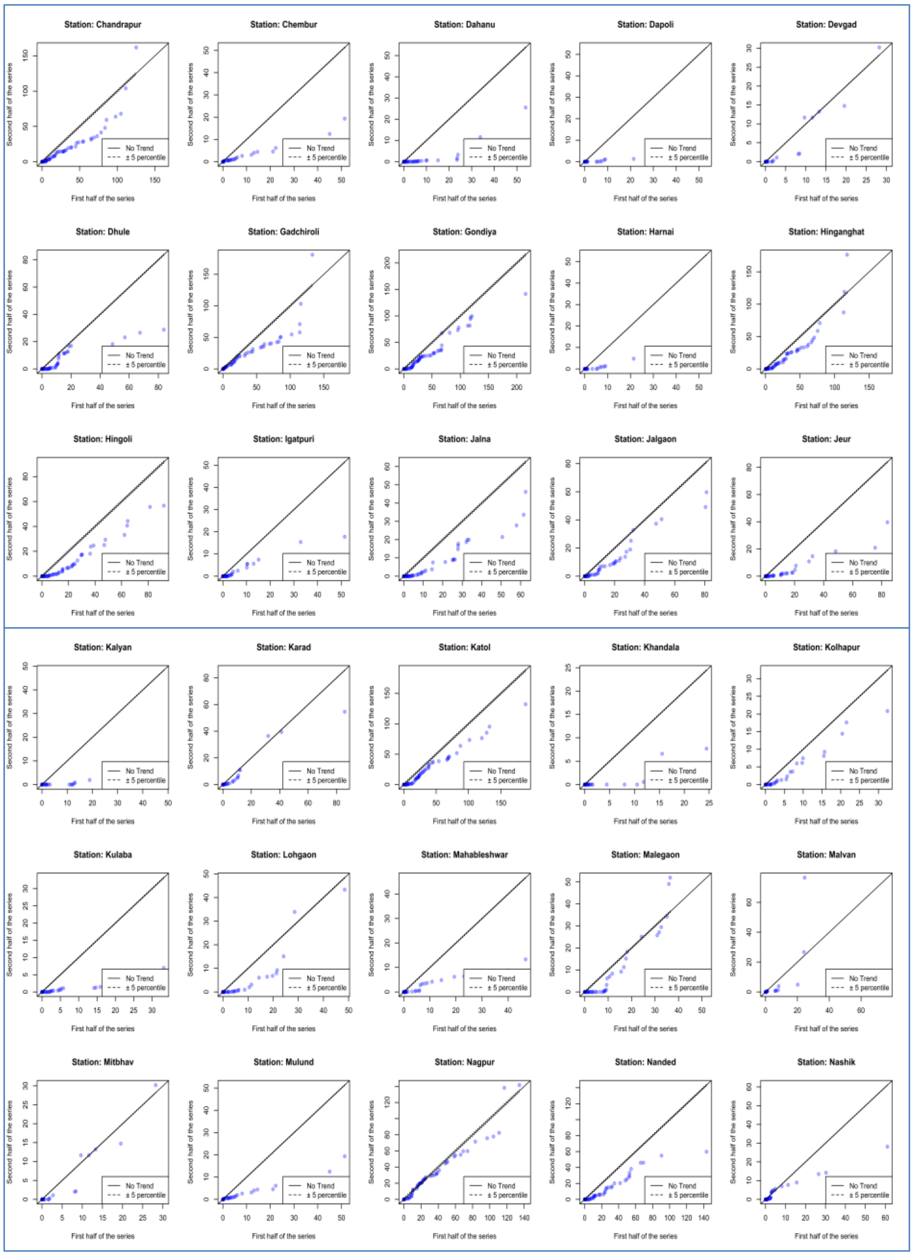
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Station: Hinganghat
Station: Hingoli
Station: Igatpuri
Station: Jalna
Station: Jalgaon
Station: Jeur
Station: Kalyan
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Station: Katol
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Station: Kolhapur
Station: Kulaba
Station: Lohgaon
Station: Mahableshwar
Station: Malegaon
Station: Malvan
Station: Mitbhav
Station: Mulund
Station: Nagpur
Station: Nanded
Station: Nashik
No Trend
± 5 percentile
First half of the series
Second half of the series

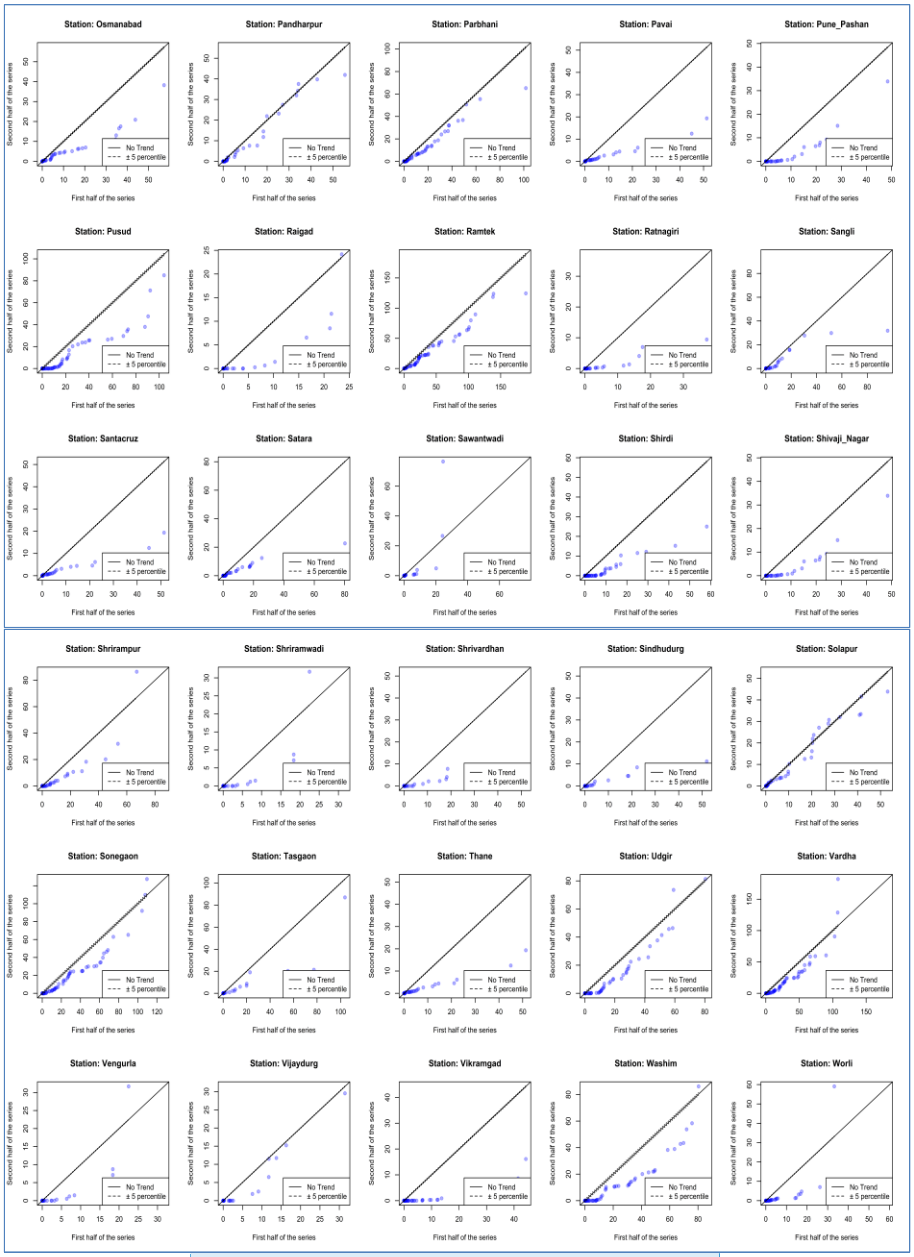

Fig. 12. Meteorological substation-wise innovative trend analysis of winter rainfall

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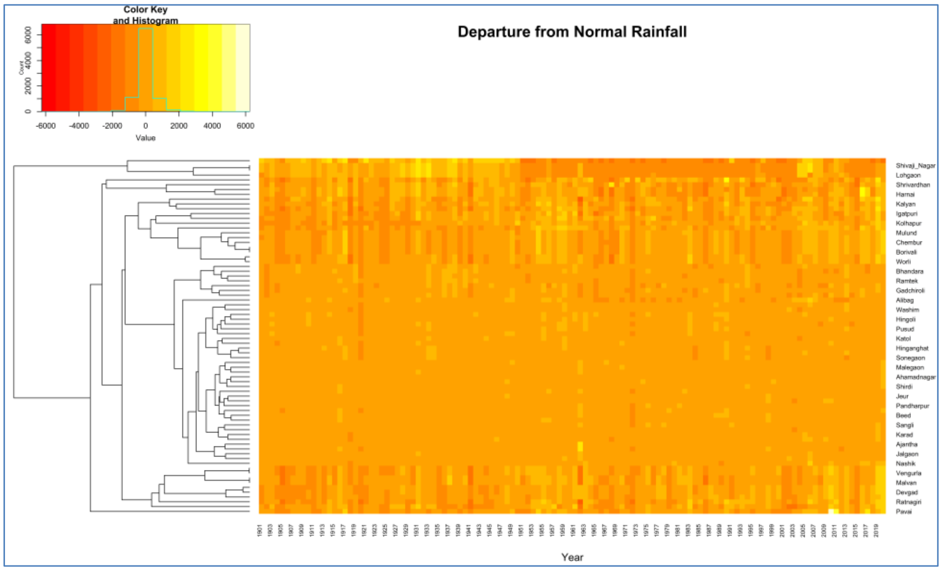

Fig. 13. Heatmap represents the departure of rainfall from normal rainfall for all meteorological substations.

Using the R programme, this heat map was generated (version 5.3). Shades of red and yellow were used to indicate the intensity of the change rate, with shades of red and yellow indicating a highly negative change rate and vice versa. The findings indicate that from 1970, every meteorological subdivision saw a negative deviation in nearly every year from the long-term average rainfall by 50 mm to 2000 mm (Fig. 13).

3.9 *Discussions*

According to Marumbwa F. *et al*. (Marumbwa F. *et al*. 2019), across a number of domains, including water resource management, sustainable agricultural planning, ecosystem management, and the health sector, it is imperative to analyze historical rainfall trends. Rainfall data from the previous 120 years were utilized to explore the variability of annual and seasonal rainfall in detail, and the trend was analyzed in several ways for seventy-four meteorological sub-stations in Maharashtra. According to the findings of a 120-year annual and monsoon rainfall variation analysis, the meteorological substations in Pune Pashan, Shivaji Nagar, Lohgaon, Bhimashankar, Pandharpur, Baramati, Ajantha, and Jalna experienced the greatest rainfall variance. At the same time, the lowest variation was found in Mahableshwar, Malvan, Nagpur, Sawantwadi, Shriramwadi, Shrivardhan, Vengurla, and Vijaydurg substations in Maharashtra. According to the results of the MK test on annual rainfall, thirty meteorological substations showed a negative trend, while twenty-eight meteorological substations showed a negative trend during the monsoon season. While the rest of the substations showed a positive trend. There was no noticeable trend at the Solapur substation throughout the research period. In the post-monsoon season, meteorological substations in Alibag, Gondiya, Kolhapur, Pune Pashan, Shivaji Nagar, and Sonegaon showed a negative trend, while substations in Borivali, Kulaba, Mulund, Pavai, Santacruz, Sindhudurg, Thane, and Warli showed positive trends (Table 1). In this study, we used Pettit, SNHT, and Buishand's tests to detect change points in the annual, pre-monsoon, monsoon, post-monsoon, and winter seasons for all meteorological substations between 1901 and 2020. In monsoon season, according to Pettit and SNHT tests, 1961 was a change point year for eight meteorological sub-stations, whereas Buishand's test identified 1961 as a change point year for ten sub-stations (Table 2). These three tests show that 1950 was the change-point year for four meteorological substations in Maharashtra. Furthermore, the MK test was applied to monsoon season rainfall data from both the pre- and post-change point phases in order to discover the exact and accurate trend, as various scientists advised using the MK test based on change point analysis to accomplish the accurate trend (Li D. *et al*. 2014, Villarini G. *at el*. 2009, Wang S. & Zhang X. 2012). If the MK test is applied first,

TABLE 4

Meteorological sub-stations wise monsoon season trend for pre and post-change point

Meteorological Sub-Stations	Z value for pre change point	Z value for post change point
1_Overall	-0.02	0.00
Ahamadnagar	0.01	0.00
Ajantha	0.71	1.87
Akola	-0.69	-1.18
Alibag	0.17	3.97
Amravati	-1.01	-1.09
Aurangabad	-0.69	-1.20
Baramati	0.60	0.24
Beed	-0.17	-1.70
Bhandara	-0.22	-0.81
Bhimashankar	2.43	1.86
Borivali	-0.08	1.40
Brahmapuri	1.57	1.43
Buldhana	-0.39	-0.67
Chalisgaon	2.15	1.86
Chandrapur	1.29	1.09
Chembur	0.09	1.55
Dahanu	0.43	0.13
Dapoli	0.55	2.20
Devgad	0.85	1.23
Dhule	0.43	0.00
Gadchiroli	2.80	1.48
Gondiya	1.56	0.31
Harnai	0.28	2.17
Hinganghat	1.01	0.84
Hingoli	1.36	-0.43
Igatpuri	0.83	-0.58
Jalna	-0.14	0.17
Jalgaon	-1.33	-1.94
Jeur	-0.27	-0.80
Kalyan	0.94	-1.46
Karad	0.80	-0.87
Katol	0.80	1.61
Khandala	1.17	-0.82
Kolhapur	1.26	0.59
Kulaba	0.08	0.98
Lohgaon	1.84	2.74
Mahableshwar	0.00	0.73
Malegaon	0.90	0.07
Malvan	0.57	0.00
Mitbhav	0.95	1.23
Mulund	0.05	0.99
Nagpur	0.07	0.90
Nanded	1.44	-0.18
Nashik	0.56	1.67
Osmanabad	-0.76	-2.66
Pandharpur	0.41	-1.27
Parbhani	-1.36	-1.30
Pavai	-0.08	1.10
Pune Pashan	1.96	2.47
Pusud	-0.49	-1.38
Raigad	1.44	0.32
Ramtek	0.21	0.02
Ratnagiri	2.34	-0.15
Sangli	0.81	0.24
Santacruz	0.02	1.40
Satara	0.32	0.02
Sawantwadi	0.57	0.00
Shirdi	-0.56	0.39
Shivaji Nagar	1.96	2.47
Shrirampur	0.90	0.25
Shriramwadi	0.69	-0.82
Shrivardhan	1.41	1.03
Sindhudurg	-1.26	-0.31
Solapur	-0.60	-2.25
Sonegaon	0.39	-0.07
Tasgaon	0.40	-1.24
Thane	-0.08	1.40
Udgir	2.29	-0.08
Vardha	0.34	0.51
Vengurla	0.69	-0.85
Vijaydurg	1.12	1.48
Vikramgad	0.75	-1.41
Washim	0.40	-2.08
Worli	0.08	0.87

false findings may be discovered (Villarini G. *at el*. 2009). Table 4 represents the monsoon rainfall trend for pre- and post-change points in all meteorological sub-stations. However, the results of the MK test on monsoon season rainfall for the pre-change point phase revealed that 18 of the 74 meteorological substations identified a significant negative trend, while 56 found a positive trend. The MK test results for the post-change point phase revealed a significant negative trend in 27 meteorological sub-stations, while 47 meteorological sub-stations exhibited a positive trend.

However, the results of the innovative trend analysis on annual rainfall revealed a significant negative trend in Pune Pashan, Shivaji Nagar, Lohgaon, Bhimashankar, Dapoli, and Harnai with 35 meteorological substations, whereas 39 meteorological substations exhibited a positive trend. During the monsoon season, a substantial negative trend was observed in Pune Pashan, Shivaji Nagar, Lohgaon, Bhimashankar, and Dapoli, with 34 meteorological substations, whereas 40 substations showed a positive trend. During the pre-monsoon season, only Aurangabad, Devgad, Gadchiroli, Mitbhav, Sindhudurg, Solapur, and Vijaydurg meteorological substations showed a positive trend, while the rest 67 showed a negative trend. In the post-monsoon season, 42 meteorological substations reported a negative trend, while 32 reported a positive trend. During the winter season, only Malvan and Sawantwadi meteorological substations showed a positive trend, while the other 72 showed a negative trend. In the current study, the change rate was greatest in the meteorological substations of Kolhapur, Nashik, Sawantwadi, and Malvan, while it was lowest in Lohgaon, Shivaji Nagar, Pune Pashan, and Bhimashankar.

This study holds notable interdisciplinary relevance and novelty. By integrating multiple statistical techniques-Mann-Kendall, SNHT, Pettitt, Buishand, and innovative trend analysis-it provides a comprehensive understanding of long-term rainfall variability and change points across Maharashtra. Unlike many earlier works that rely on singular methods or focus on short time frames, this study covers a 120-year period and captures spatial-temporal variations across diverse agro-climatic zones. The findings have direct implications not only in climatology and hydrology but also in agriculture, water resource management, and environmental planning. For instance, identifying long-term rainfall shifts aids in planning climate-resilient cropping patterns, regional irrigation infrastructure, and drought preparedness strategies. Moreover, the study offers useful insights for policymakers and disaster risk reduction agencies in addressing the dual challenges of drought and flood occurrences, especially in southern Maharashtra. Thus, the methodological framework and findings offer transferable value to regions facing similar climate-related vulnerabilities, strengthening their adaptive capacity through science-based planning.

4. Conclusions

The investigation of the spatiotemporal distribution and changing pattern of rainfall in any location is a fundamental necessity for the management and planning of water resources, sustainable agricultural growth, and other industries. Based on the extensive analysis of rainfall trends across multiple meteorological substations in Maharashtra over a 120-year period, several significant findings emerge. Firstly, it is evident that there is considerable variability in annual and seasonal rainfall across the region, with some substations experiencing greater variance than others. This indicates the complex nature of rainfall patterns in Maharashtra. The trend analysis, conducted using various statistical tests such as the Mann-Kendall (MK) test, Pettit, SNHT, and Buishand's tests, revealed interesting insights into the temporal evolution of rainfall patterns. While some substations exhibited consistent negative trends in annual and seasonal rainfall, others displayed positive trends. Notably, certain substations showed change points around the year 1961, indicating shifts in rainfall patterns during the monsoon season. The post-change point analysis further elucidated the trends in rainfall, with a significant number of substations showing negative trends post-1961, particularly during the monsoon season. However, it's important to note that there were variations in trend direction across different seasons and substations. The innovative trend analysis provided additional insights, highlighting specific substations experiencing significant negative trends in annual and seasonal rainfall, such as Pune Pashan, Shivaji Nagar, Lohgaon, Bhimashankar, and Dapoli. This suggests localized changes in precipitation patterns that may have implications for various sectors, including agriculture, water resource management, and ecosystem health. Overall, the study underscores the importance of long-term rainfall trend analysis for effective planning and decision-making in various sectors. The observed trends and change points have implications for climate resilience strategies, agricultural planning, and water resource management in Maharashtra. Further research may be warranted to understand the underlying drivers of these trends and their potential impacts on local communities and ecosystems.

Data Availability

The rainfall dataset used in this study was obtained from the India Meteorological Department (IMD). The data are subject to IMD’s data-sharing policies and can be made available from the corresponding author upon reasonable request, with due permission from IMD.

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All authors have read and approved the final manuscript. The authors declare that this work is original, has not been published elsewhere, and is not under consideration in any other journal.

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Supplementary

Supplementary TABLE 1

Innovative trend analysis for Pre-monsoon season

Sr. No.	Station	Sen Slop	D Value
1	Overall	-0.1307	-1.8682
2	Ahamadnagar	-0.1631	-2.8076
3	Ajantha	-0.1308	-2.9594
4	Akola	-0.0846	-1.7944
5	Alibag	-0.6030	-1.8901
6	Amravati	-0.1122	-2.4145
7	Aurangabad	0.0593	1.3167
8	Baramati	-0.1403	-2.0597
9	Beed	-0.0422	-0.7018
10	Bhandara	-0.1654	-2.0003
11	Bhimashankar	-0.1796	-3.2767
12	Borivali	-0.0110	-0.3440
13	Brahmapuri	-0.1439	-1.9954
14	Buldhana	-0.1818	-3.6476
15	Chalisgaon	-0.0594	-1.6430
16	Chandrapur	-0.1082	-1.4146
17	Chembur	-0.0109	-0.3404
18	Dahanu	-0.0508	-2.1696
19	Dapoli	-0.2648	-4.1444
20	Devgad	0.0085	0.1018
21	Dhule	-0.1098	-3.7002
22	Gadchiroli	0.0468	0.7708
23	Gondiya	-0.2363	-3.4354
24	Harnai	-0.1246	-1.9645
25	Hinganghat	-0.2103	-3.0922
26	Hingoli	-0.1031	-2.0246
27	Igatpuri	-0.1742	-3.3422
28	Jalna	-0.0571	-1.2286
29	Jalgaon	-0.0813	-2.7936
30	Jeur	-0.0622	-1.0830
31	Kalyan	-0.0927	-2.6120
32	Karad	-0.2844	-2.5218
33	Katol	-0.2209	-3.0989
34	Khandala	-0.0020	-0.0512
35	Kolhapur	-0.2937	-2.0691
36	Kulaba	-0.0920	-2.7615
37	Lohgaon	-0.3332	-3.4041
38	Mahableshwar	-0.2174	-2.0562
39	Malegaon	-0.0960	-2.4234
40	Malvan	-0.3411	-2.4613
41	Mitbhav	0.0417	0.5230
42	Mulund	-0.0228	-0.6810
43	Nagpur	-0.1573	-1.9418
44	Nanded	-0.0876	-1.6011
45	Nashik	-0.1101	-2.3253
46	Osmanabad	-0.1301	-1.6439
47	Pandharpur	-0.1102	-1.6190
48	Parbhani	-0.0335	-0.5945
49	Pavai	-0.0523	-1.6385
50	Pune Pashan	-0.2746	-2.7511
51	Pusud	-0.2163	-3.4952
52	Raigad	-0.1011	-2.4185
53	Ramtek	-0.2293	-2.8478
54	Ratnagiri	-0.0197	-0.2920
55	Sangli	-0.1737	-1.2815
56	Santacruz	-0.0704	-1.8590
57	Satara	-0.0933	-0.9036
58	Sawantwadi	-0.3411	-2.4613
59	Shirdi	-0.0848	-2.1393
60	Shivaji Nagar	-0.2746	-2.7511
61	Shrirampur	-0.0413	-1.0655
62	Shriramwadi	-0.2428	-1.9945
63	Shrivardhan	-0.1607	-2.7174
64	Sindhudurg	0.0793	0.9601
65	Solapur	0.0469	0.5895
66	Sonegaon	-0.1969	-2.8245
67	Tasgaon	-0.2013	-1.5048
68	Thane	-0.0110	-0.3440
69	Udgir	-0.0052	-0.0580
70	Vardha	-0.2067	-2.9916
71	Vengurla	-0.2328	-1.9124
72	Vijaydurg	0.0311	0.3996
73	Vikramgad	-0.2415	-5.9814
74	Washim	-0.2009	-3.7775
75	Worli	-0.0771	-2.3152

Supplementary TABLE 2

Innovative trend analysis for monsoon season

Sr. No.	stations	Sens Slop	D Value
1	Overall	-0.3123	-0.1256
2	Ahamadnagar	-0.0286	-0.0394
3	Ajantha	-0.8310	-0.7020
4	Akola	-0.1099	-0.0913
5	Alibag	-2.2048	-1.2723
6	Amravati	-0.0423	-0.0342
7	Aurangabad	0.0487	0.0491
8	Baramati	1.2606	2.3716
9	Beed	0.3580	0.3721
10	Bhandara	-2.2009	-1.0614
11	Bhimashankar	-24.2271	-4.4916
12	Borivali	2.9357	0.8991
13	Brahmapuri	-1.6920	-0.7797
14	Buldhana	-0.0470	-0.0380
15	Chalisgaon	-0.1254	-0.1257
16	Chandrapur	-1.2968	-0.6945
17	Chembur	2.5724	0.7837
18	Dahanu	5.7050	1.9569
19	Dapoli	-6.7691	-1.2990
20	Devgad	5.4321	1.4923
21	Dhule	0.6085	0.6547
22	Gadchiroli	-1.2513	-0.5885
23	Gondiya	-2.7528	-1.2284
24	Harnai	-6.1471	-1.1800
25	Hinganghat	-1.2917	-0.7712
26	Hingoli	-0.3405	-0.2551
27	Igatpuri	0.8640	0.2103
28	Jalna	0.0291	0.0267
29	Jalgaon	-0.0958	-0.0840
30	Jeur	0.2316	0.3331
31	Kalyan	-0.2850	-0.0622
32	Karad	0.9827	0.9425
33	Katol	-1.0374	-0.7151
34	Khandala	4.4610	0.7741
35	Kolhapur	6.5885	2.7800
36	Kulaba	3.1389	0.9448
37	Lohgaon	-14.5761	-5.2486
38	Mahableshwar	-0.2506	-0.0398
39	Malegaon	2.0709	2.7341
40	Malvan	0.4311	0.0861
41	Mitbhav	5.2936	1.4487
42	Mulund	3.2539	1.0008
43	Nagpur	-1.6952	-0.9448
44	Nanded	-0.5109	-0.3793
45	Nashik	2.5722	2.2160
46	Osmanabad	-0.2615	-0.2361
47	Pandharpur	0.8350	1.2253
48	Parbhani	0.0892	0.0688
49	Pavai	2.8583	0.8754
50	Pune Pashan	-14.2960	-5.0722
51	Pusud	-0.1084	-0.0786
52	Raigad	3.6831	0.7416
53	Ramtek	-1.2733	-0.7021
54	Ratnagiri	5.4086	1.1420
55	Sangli	1.4276	2.2974
56	Santacruz	3.2870	1.0177
57	Satara	1.9658	1.9612
58	Sawantwadi	0.4311	0.0861
59	Shirdi	0.1873	0.2841
60	Shivaji Nagar	-14.2960	-5.0722
61	Shrirampur	0.8149	1.2174
62	Shriramwadi	2.1906	0.4787
63	Shrivardhan	-4.8745	-0.8744
64	Sindhudurg	-0.1503	-0.0284
65	Solapur	0.1519	0.1760
66	Sonegaon	-1.9104	-1.1437
67	Tasgaon	0.7730	1.1885
68	Thane	2.9357	0.8991
69	Udgir	-2.0249	-1.5637
70	Vardha	-1.4509	-0.8762
71	Vengurla	2.1579	0.4715
72	Vijaydurg	4.8912	1.2601
73	Vikramgad	0.8946	0.2127
74	Washim	0.3358	0.2502
75	Worli	3.1880	0.9596

Supplementary TABLE 3

Innovative trend analysis for post-monsoon season

Sr. No.	Station	Sen Slop	D Value
1	Overall	-0.0080	-0.0429
2	Ahamadnagar	0.0255	0.1476
3	Ajantha	0.0165	0.1229
4	Akola	0.1416	1.2258
5	Alibag	-0.9591	-2.0521
6	Amravati	0.1250	1.0557
7	Aurangabad	0.2164	1.5311
8	Baramati	0.1353	0.6952
9	Beed	0.1687	1.0700
10	Bhandara	0.0890	0.7396
11	Bhimashankar	-0.6511	-2.5758

12	Borivali	-0.1820	-1.1378
13	Brahmapuri	-0.0830	-0.6309
14	Buldhana	-0.0547	-0.3884
15	Chalisgaon	-0.0434	-0.3137
16	Chandrapur	-0.0250	-0.2047
17	Chembur	-0.2051	-1.2804
18	Dahanu	-0.1063	-0.9086
19	Dapoli	-0.2096	-0.9396
20	Devgad	0.1540	0.6628
21	Dhule	-0.0923	-0.7945
22	Gadchiroli	-0.0302	-0.2268
23	Gondiya	-0.1692	-1.4306
24	Harnai	-0.0684	-0.3128
25	Hinganghat	-0.0187	-0.1470
26	Hingoli	0.1350	1.0568
27	Igatpuri	-0.6128	-2.7290
28	Jalna	0.0956	0.6704
29	Jalgaon	-0.0749	-0.6789
30	Jeur	0.2275	1.3852
31	Kalyan	0.0256	0.1297
32	Karad	-0.1276	-0.5482
33	Katol	-0.0367	-0.3036
34	Khandala	-0.2407	-0.9532
35	Kolhapur	-0.4078	-1.5385
36	Kulaba	-0.0033	-0.0209
37	Lohgaon	-0.7142	-2.7589
38	Mahableshwar	-0.0673	-0.2157
39	Malegaon	0.0877	0.7033
40	Malvan	0.2191	0.7297
41	Mitbhav	0.1342	0.5727
42	Mulund	-0.1718	-1.0753
43	Nagpur	-0.0769	-0.5669
44	Nanded	0.2346	1.9040
45	Nashik	-0.0256	-0.1515
46	Osmanabad	0.2726	1.7059
47	Pandharpur	0.1832	0.9507
48	Parbhani	0.2766	1.9900
49	Pavai	2.5768	16.0957
50	Pune Pashan	-0.7487	-2.8910
51	Pusud	0.1921	1.6428
52	Raigad	-0.1516	-0.6630
53	Ramtek	-0.0446	-0.3494
54	Ratnagiri	0.2396	0.8612
55	Sangli	-0.1631	-0.6936
56	Santacruz	-0.1794	-1.1233
57	Satara	-0.1225	-0.5584
58	Sawantwadi	0.2191	0.7297
59	Shirdi	-0.2677	-1.6985
60	Shivaji Nagar	-0.7487	-2.8910
61	Shrirampur	0.1076	0.6605
62	Shriramwadi	0.3510	1.3311
63	Shrivardhan	-0.3279	-1.4307
64	Sindhudurg	0.7006	2.5694
65	Solapur	0.1350	0.7192
66	Sonegaon	-0.1052	-0.8002
67	Tasgaon	-0.1075	-0.4861
68	Thane	-0.1820	-1.1378
69	Udgir	0.4428	3.0777
70	Vardha	-0.0263	-0.2046
71	Vengurla	0.3782	1.4345
72	Vijaydurg	0.1113	0.4571
73	Vikramgad	-0.4229	-2.1277
74	Washim	0.0550	0.4182
75	Worli	-0.0056	-0.0360

Supplementary Table 4

Innovative trend analysis for winter season

Sr. No.	Station	Sen Slop	D Value
1	Overall	-0.0725	-3.9942
2	Ahamadnagar	-0.0852	-7.3933
3	Ajantha	-0.1263	-4.8215
4	Akola	-0.0818	-2.4747
5	Alibag	-0.0189	-0.6496
6	Amravati	-0.2332	-5.2891
7	Aurangabad	-0.0744	-4.4768
8	Baramati	-0.0642	-6.5427
9	Beed	-0.0538	-3.9381
10	Bhandara	-0.1615	-2.4977
11	Bhimashankar	-0.0388	-8.4605
12	Borivali	-0.0455	-7.0562
13	Brahmapuri	-0.1778	-3.4783
14	Buldhana	-0.1209	-4.1168
15	Chalisgaon	-0.0565	-3.8480
16	Chandrapur	-0.1887	-3.8618
17	Chembur	-0.0455	-7.0562
18	Dahanu	-0.0693	-8.3474
19	Dapoli	-0.0428	-8.5847
20	Devgad	-0.0061	-2.0215
21	Dhule	-0.0834	-5.5609
22	Gadchiroli	-0.1582	-3.1237
23	Gondiya	-0.2236	-3.3966
24	Harnai	-0.0357	-8.3086
25	Hinganghat	-0.1377	-2.9271
26	Hingoli	-0.1498	-5.1189
27	Igatpuri	-0.0382	-6.3849

28	Jalna	-0.1049	-5.5186
29	Jalgaon	-0.0776	-4.0040
30	Jeur	-0.1016	-7.0948
31	Kalyan	-0.0473	-9.4711
32	Karad	-0.0213	-2.9763
33	Katol	-0.2039	-3.5638
34	Khandala	-0.0325	-8.4280
35	Kolhapur	-0.0220	-4.2824
36	Kulaba	-0.0443	-8.5481
37	Lohgaon	-0.0377	-4.9618
38	Mahableshwar	-0.0510	-7.3631
39	Malegaon	-0.0284	-2.4007
40	Malvan	0.0022	0.7108
41	Mitbhav	-0.0061	-2.0215
42	Mulund	-0.0454	-7.0518
43	Nagpur	-0.0487	-0.9591
44	Nanded	-0.1613	-5.0376
45	Nashik	-0.0233	-4.2282
46	Osmanabad	-0.0770	-5.7074
47	Pandharpur	-0.0160	-1.4975
48	Parbhani	-0.0699	-3.0069
49	Pavai	-0.0455	-7.0497
50	Pune Pashan	-0.0493	-6.5475
51	Pusud	-0.1789	-5.0449
52	Raigad	-0.0256	-6.1864
53	Ramtek	-0.1874	-2.9457
54	Ratnagiri	-0.0284	-8.0663
55	Sangli	-0.0403	-4.8105
56	Santacruz	-0.0419	-6.8800
57	Satara	-0.0472	-6.3251
58	Sawantwadi	0.0022	0.7108
59	Shirdi	-0.0715	-7.0134
60	Shivaji Nagar	-0.0493	-6.5475
61	Shrirampur	-0.0431	-4.0956
62	Shriramwadi	-0.0125	-4.6822
63	Shrivardhan	-0.0360	-8.1808
64	Sindhudurg	-0.0295	-7.5075
65	Solapur	-0.0145	-1.0746
66	Sonegaon	-0.1479	-3.0898
67	Tasgaon	-0.0480	-4.8967
68	Thane	-0.0455	-7.0562
69	Udgir	-0.0897	-3.4851
70	Vardha	-0.1264	-2.6887
71	Vengurla	-0.0125	-4.6822
72	Vijaydurg	-0.0098	-3.0814
73	Vikramgad	-0.0652	-8.7723
74	Washim	-0.1556	-4.6374
75	Worli	-0.0279	-5.3810