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Assessment of rainfall trend and variability of semi-arid regions of Upper and Middle Godavari basin, India

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ABSTRACT

Study of rainfall pattern and trend in the long term is essential from climatic change and socioeconomic perspectives. In the present study, monthly, seasonal and annual rainfall of semi-arid regions (Madhya Maharashtra, Marahwada and Vidarbha) of the Godavari basin is evaluated for the period of 1871–2016. The innovative trend analysis (ITA), Mann–Kendall test (MK) and Sen's slope estimator methods are used to check gradual change. A significant increasing or decreasing trend is not detected in the seasonal and annual rainfall series for any of the regions. The rainfall variability index indicates Madhya Maharashtra has received normal rainfall for 40% of the time, Marathwada for 36% of the time and Vidarbha region for 41% of the time. Very dry and very wet conditions are experienced by all three regions for 15% of the time. The spatial and temporal variation in the seasonal and annual rainfall is not significant in these regions. The results obtained from the study will be useful for water resource management of the Godavari basin.

Key words: Godavari basin, innovative trend method, Mann–Kendall test, rainfall, Sen's slope estimator, trend

HIGHLIGHTS

- Increasing trend in rainfall of August and decreasing trend in September is observed for all the regions.
- Significant upward or downward trend is not found for any season and for annual rainfall.
- All the regions receives the normal rainfall for 39% of the time.
- All the regions experiences very dry and very wet situation for 15% of time.
- The results are matching with the rainfall trend for all India.

1. INTRODUCTION

Precipitation is an important component of the hydrological cycle and variation in magnitude of the precipitation (rainfall) in the long term has the potential to affect sectors such as agriculture. Noticeable changes are observed in the magnitude as well as frequency of rainfall in recent decades. The amount of precipitation and number of rainy days also determines the amount of streamflow and sediment transport of river basins. India is a developing country and agriculture is an important sector which contributes 17–18% of the total GDP. Also, agriculture is the main occupation of people and creates employment to 60% of the population. In regions like India, agro-economy is mainly dependent on the monsoon rainfall as well as on the irrigation facilities provided by government. Due to a rapid increase in population the demand of fresh water for industries as well for agriculture is increasing day by day (Amara Singh *et al.* 2005; Sharma & Goyal 2020). According to the Intergovernmental Panel report on Climate Change (IPCC 2007), upcoming climate change is expected to have an adverse effect on the agriculture sector. The impact of climate change in terms of precipitation are evident in the expression of frequent floods, draughts, design of hydraulic structures, and overall strategic planning and management of water resources (Goyal & Rao 2018). Also, topography in terms of elevated surfaces also has an impact on the distribution of summer monsoon precipitation (Ashfaq 2020). One of the concerns of climate change is that shifting of the total, spatial as well as temporal, deviation in precipitation, will become further severe in several parts of the globe (Zamani *et al.* 2018). Due to the lack of adequate irrigation facilities in some regions, the outcome of agriculture is greatly dependent on the performance of summer rainfall, which occurs in between the months of June to September. Therefore, research on the varying pattern of rainfall, both spatially and

temporally, is an obligatory topic in the planning and handling of water resources and also to design appropriate strategies to handle flood and drought situations.

Many states of India are affected owing to a shortfall of monsoon precipitation so it is necessary to spend huge amounts of money on providing relief in affected areas (Mondal *et al.* 2015; Gupta *et al.* 2021). The contribution of summer rainfall is about 75% of total rainfall. From the eastern to the western part of the country the variation in the annual rainfall pattern ranges from 12,000 mm to less than 100 mm (Godavari basin report Central Water Commission of India 2014). The variation in summer rainfall creates uncertain conditions regarding the availability of water to satisfy irrigation needs every year. The impact of climate change may reduce the availability of freshwater in several river basins of India (Gosian *et al.* 2006). Many researchers across the world have studied precipitation to analyse variability and trend (Partal & Kahya 2006; Xu *et al.* 2007; Krishna Kumar *et al.* 2009, 2010). Precipitation over the central part of India shows significant positive trends in frequency as well as in the magnitude of extreme rainfall events during the monsoon seasons from 1951 to 2000, and a significant negative trend in the frequency of moderate rainfall events (Goswami *et al.* 2006). For the whole of India, the average monsoon rainfall value is 852.4 mm, standard deviation (SD) is 84.7 mm and coefficient of variation (CV) is 9.9% (Parthasarathy *et al.* 1994). However, from one region to another, statistical parameters such as average rainfall, SD and CV values are different from the values of the whole of India and this indicates the existence of spatial variation in monsoon rainfall (Dash *et al.* 2009).

Spatial and temporal variation in the summer monsoon rainfall is also important from the water resource management point of view. In the recent past, the southwest monsoon of 2002 created drought condition (occurrence of less rainfall) all over India, whereas the monsoon of 2003 was evident of normal rainfall over the entire country (Dash *et al.* 2009). According to a study by Deshpande & Singh (2010), temporal changes are more influenced due to an extreme weather event. Guhathakurta & Rajeevan (2008) recognized the positive trend in extreme rainfall events over central India to the positive trend of surface latent heat flux and sea surface temperatures over the tropical Indian Ocean. A study of summer rainfall variability over Narmada basin in central India concluded there was a significant increasing trend at 5% significance level with Z value of 3.66 over the entire basin for 1-day maximum rainfall (Thomas *et al.* 2015). The trend analysis of annual rainfall across the main river basins of India indicates that among 22 main basins, 6 basins exhibited positive trends and 15 basins show negative trends (Kumar & Jain 2011). The spatiotemporal variability in precipitation for Chhattisgarh state in India was analysed using parametric and non-parametric tests. The monthly precipitation data for 102 years (1901–2002) of 16 stations was used. The results exhibited decreasing trends in the annual rainfall for 14 stations, with the exception of Bilaspur and Dantewada stations (Meshram *et al.* 2016).

According to Indian Network for Climate Change Assessment report II, the regional climate projection indicates increase in the summer monsoon precipitation by 3 to 7% in 2030s (INCCA 2010). A similar type of trend will be observed for western coastal regions, whereas a declining trend for summer and winter rainfall will be observed for the same period. With respect to temperature, India shows a significant increase in temperature with 0.51 °C during the period of 1901–2007. For the winter and post-monsoon season a significant increase in temperature is also observed for the same period.

Maharashtra state accounts for 9.4% of the overall geographical area of the country. It is the second largest and second most populated state with a population of 112 million (2011 Census). Out of the total population, nearly 57% of the population belongs to the rural category and agriculture is a primary occupation for 60% of the population. Around 84% of the agricultural area directly depends on the south-west monsoon rainfall. Godavari River is the primary river and covers the catchment area of Maharashtra state. To meet the various demands from domestic, industrial and agricultural sectors numerous dams have been constructed all along the Godavari River. Yet, the percentage of irrigated area in the state is very low, i.e., almost about 16%, as contrasting to the national average of 38%. The Upper and Middle Godavari sub-basin covers the maximum region of Maharashtra state. The runoff from both the catchments are predominantly dependent on the monsoon rainfall. Owing to the tropical climate, both sub-basins experience a considerable amount of discharge in the monsoon months. Extreme weather events quite often occur in the catchment area of the Godavari basin. Around 40% area of Maharashtra state is drought prone and 7% of the area is flood prone. Also, numerous parts of the state have faced frequent droughts for successive years (1970–1974 and 2000–2004; World Bank 2008) that have damaged agriculture and triggered water scarcity in more than 20,000 villages. In contrast to this, due to heavy rainfall (about 37 inches) in July 2005, about 900 people died in the Konkan region. According to the Central Water Commission statistics, out of 100 talukas in the state, 45 have been recognized as being drought prone.

Due to frequent drought conditions in the Marathwada and Vidarabha regions, every year many farmers commit suicide. Of these, most farmers either have less agricultural land and/or, at the same time, there is an inability of government to provide appropriate help to the farmers in terms of better irrigation facilities. This impact of drought is more visible in the

Marathwada region as around 1,000 farmers have committed suicide (Kulkarni *et al.* 2016). Thus, due to the continuous drought incidence, poor irrigation coverage, poor knowledge about farming and less managing and adaptive ability, this region is extremely susceptible to the effects of climate change. The effects of climate change are not only limited to the occurrence of drought and flood, but also adversely affect the streamflow and the suspended sediment discharge of the river. Many river basins (Nile River in Egypt, Yellow River in China and Narmada River in India) across the world show evidence of the reduction in streamflow and suspended sediment discharge in the past 50 years. The reason behind this trend is due to the combined effects of climate change and human influences in the catchment areas. These effects are quite prominent in tropical rivers like Narmada river basin in India.

Many researchers have studied the rainfall trend and pattern in the different parts of the country as well as India as whole (Deshpande & Singh 2010; Amara Singhe *et al.* 2005; Goyal 2014; Meshram *et al.* 2016). The rainfall data for the period of 135 years from 306 rain gauge stations across India indicate non-significant trend in the annual rainfall. A small increasing trend is detected in northwest and tropical India (Kumar *et al.* 2010; Mondal *et al.* 2015). The northeast region of India, which receives the highest rainfall, also indicates no significant positive and/or negative trend for the period of 1871–2008 (Jain *et al.* 2013). The spatiotemporal trends in different climatic variables for Jharkhand state, India indicate decreasing trend in monsoon and annual precipitation time series (Gupta *et al.* 2021). The significant decreasing trend is observed in mean rainfall of July as well as August for central India (Singh *et al.* 2014). Also, several river basins show evidence of a decrease in number of rainy days and an increase in extreme events (Jain *et al.* 2007). Hence, it is essential to understand the characteristics of rainfall, such as the frequency of extreme weather events, nature of the trend, magnitude of change and variability in monthly, seasonal and annual rainfall, so that the required measures can be implemented to avoid drought- and flood-like situations in the future. Also, it is important from the socioeconomic point of view. The increase in droughts and floods due to extreme events also elaborate the indication of regional climate variability and climate change, which will help to implement policies to mitigate climate change. In today's changing atmosphere, it is essential to analyse the long-term trend in rainfall. These studies have significance in both the agriculture and health sectors. The studies reported so far have been focused on flood and drought events in the Godavari basin. Also, very few studies have concentrated on the annual rainfall trend across the Godavari river basin. To the best of our knowledge, no study in the past has been carried out at the micro-level, by using different time series, i.e., seasonal and monthly basis.

The present study aims to fulfil the following objectives: (i) identify the nature of the trend in total monthly, seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual rainfall, using a graphical method, i.e., innovative trend analysis (ITA); (ii) detect the long-term trend in total monthly, seasonal and annual rainfall series using statistical Mann–Kendall (MK) and Sen's slope estimator test; (iii) estimate percentage change in the magnitude in seasonal and annual rainfall; (iv) compute variation in the occurrence of precipitation across Madhya Maharashtra, Marahwada and Vidarbha regions.

2. MATERIALS AND METHODS

2.1. Study area

The Godavari basin is the second major basin after Ganga basin and covers about 9.5% of the entire geographical area of the country (Figure 1). It spreads over different states such as Maharashtra, Madhya Pradesh, Andhra Pradesh, Chhattisgarh, Odisha, Karnataka and Union territory of Pondicherry. The basin extends to 48.7% in the Maharashtra states (Madhya Maharashtra, Marathwada and Vidarabha). It covers an area of 302,065.10 sq. km, having a width of 583 km and length of 995 km. The Central Water Commission of India stated the area of the Godavari basin is 312,812.0 sq. km. The basin lies in the Deccan Plateau in between 73°24′ to 83°4′ E longitude and 16°19′ to 22°34′ N latitude. The entire Godavari basin is divided into eight different sub-basins. Madhya Maharashtra, Marathwada and Vidarbha regions are in Upper and Middle Godavari sub-basins. The Upper and Middle Godavari basins contribute to coverage of 7.1% (21,443.23 sq. km) and 12.1% (36,290.47 sq. km) of the total area of the basin, respectively. The significant soil forms observed in different parts of the basins are lateritic soils, red soils, black soils, alluvium, mixed soils and saline and alkaline soils. Major tributaries of the Godavari River in Upper and Middle sub-basins are Purna, Pravara, Manjara, Wainganga and Penganga. Monthly, seasonal and annual rainfall time series have been prepared for all of India (India taken as one unit) (Kothawale & Rajeevan 2017).

2.2. Methodology

The sequencing of the steps involved in the data analysis in the present study is included in the form of a flowchart as shown in Figure 2. In the present analysis, monthly, seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual
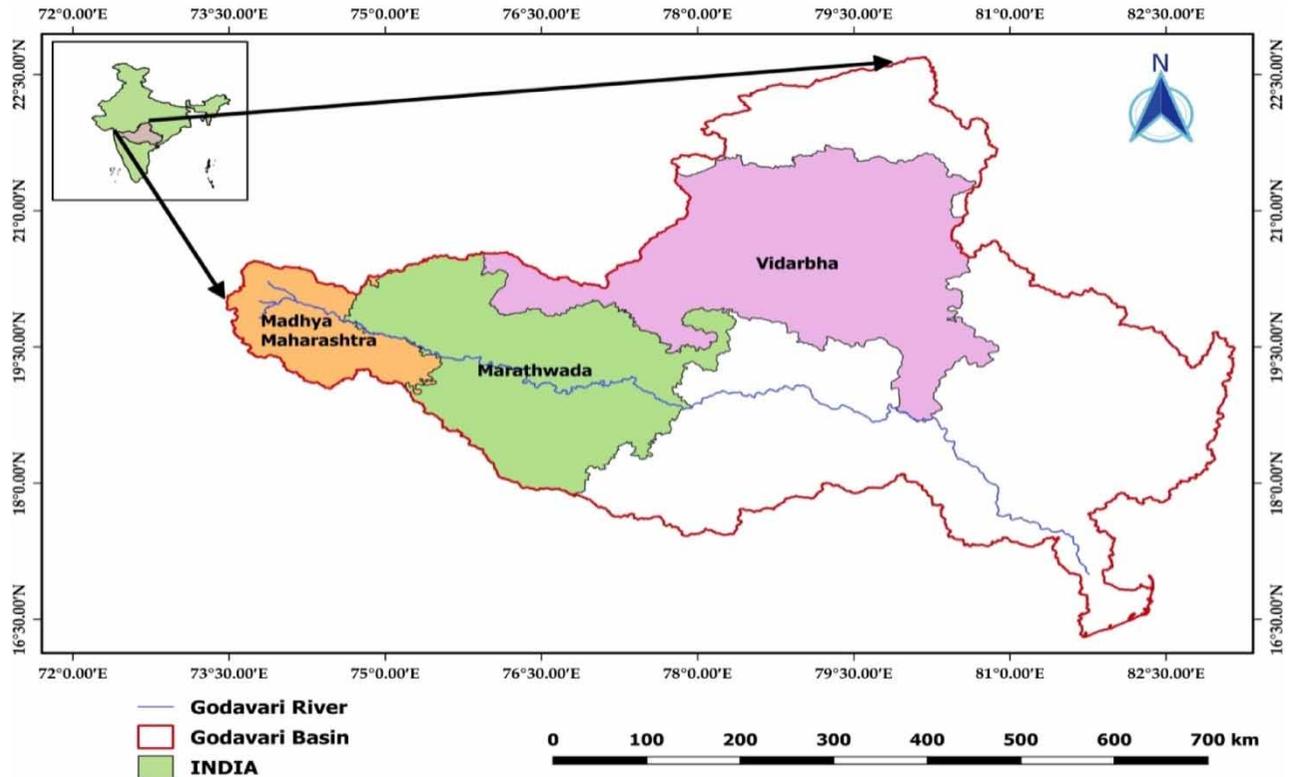
Figure 1 | Location map of Madhya Maharashtra, Marathwada and Vidarabha regions of Godavari basin.

rainfall data for three different regions of the Upper and Middle Godavari river basin are used. The data are collected from the Indian Institute of Tropical Management and IITM research report RR-138. Five homogeneous regions and 30 meteorological sub-divisions are scrutinized for 306 rain gauge stations located all over, for the period 1871–2016 and data series is prepared for the monthly, seasonal and annual time period which is published in IITM research report RR-138. The quality and homogeneity of the obtained data were examined critically before being published in the report. The rainfall time series is analysed for the presence of gradual change using statistical non-parametric, i.e., MK test and the graphical method, i.e., ITA technique. The magnitude of the trend is checked with Sen's slope estimator. The percentage change in magnitude of the trend is checked for seasonal and annual rainfall of Madhya Maharashtra and Vidarbha regions. The rainfall variability index analysis is used to segregate 146 years' rainfall time series into different climatic regimes. The details about the used statistical methods are included in the subsequent sections below.

2.2.1. Mann–Kendall test

The non-parametric trend test MK was used to check the gradual trend in the monthly, seasonal and annual rainfall series. Mann first used this test and statistical distribution was derived by Kendall (Mann 1945; Kendall 1975). The MK test has been recommended by the World Meteorological Organization (WMO) to measure trends in time series. This is a simple method, can handle missing data, does not need to assume normality and is strong against outliers (Hess *et al.* 2001). In hydrological time series non-normally distributed data are very common; this test, when compared to a parametric test like t-test, has a higher power (Yue & Pilon 2004). For a given time series X ($x_1, x_2..., x_n$) the null hypothesis (H_0) shows no trend and alternative hypothesis (H_a) represents the presence of either gradual increasing or decreasing trend in the time series.

The MK trend analysis method is given below.

The standardized test statistics, i.e., Z is calculated as

$$Z = \begin{cases} S - 1/\sqrt{VarS} & S > 0 \\ 0 & S = 0 \\ S + 1/\sqrt{VarS} & S < 0 \end{cases} \tag{1}$$
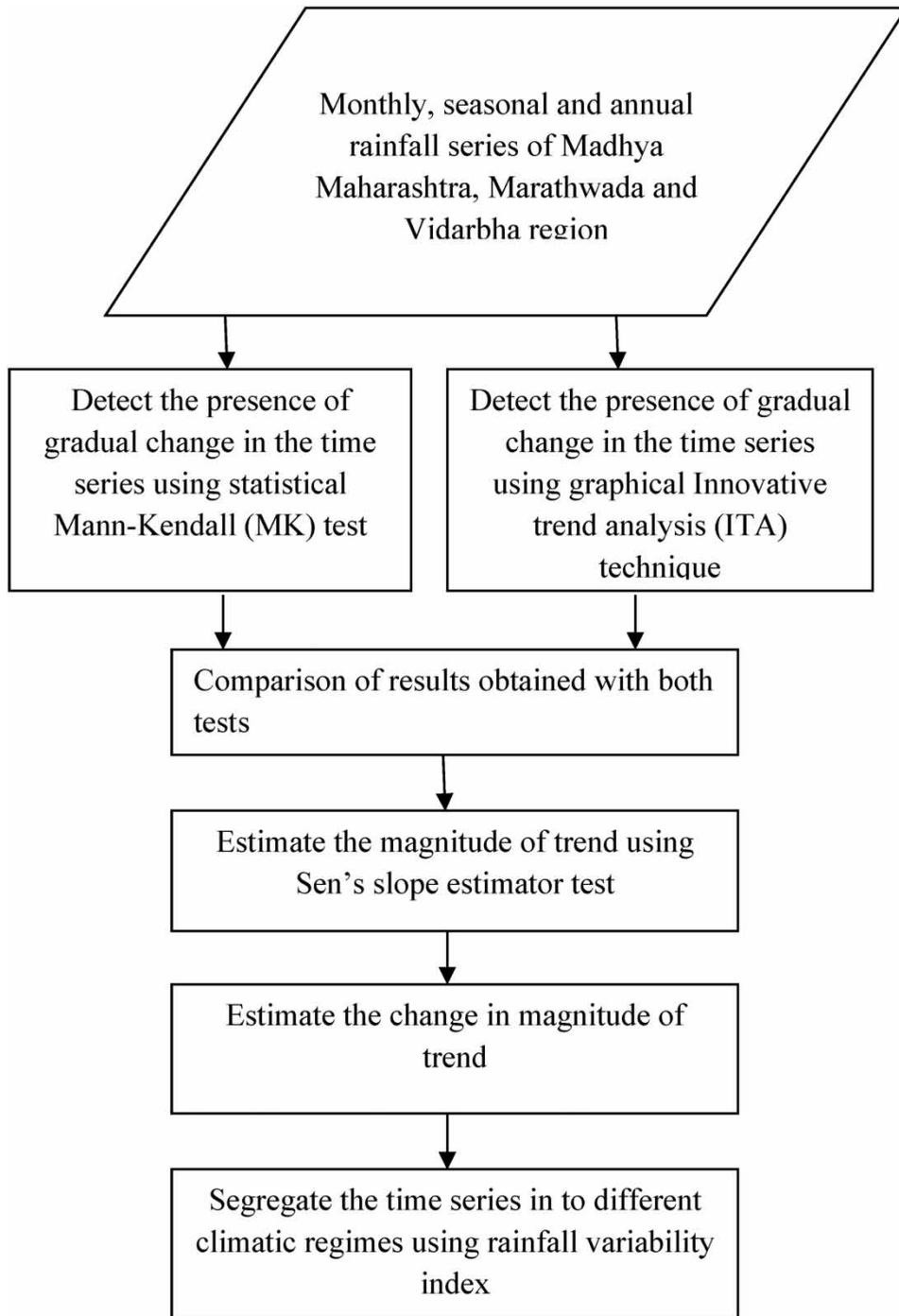
Figure 2 | Flowchart showing methodology adopted in the present study.

The positive and negative Z value specifies an upward and downward trend, respectively. The test is carried out at 5% significance level, where,

$$S = \sum_{j=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$ (2)

$$\sin(x_j - x_i) = \begin{cases} +1 \; x_j > x_i \\ 0 \; if \; x_j = x_i \\ -1 \; x_j < x_i \end{cases} \tag{3}$$

$$Var(S) = \{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i \, (i-1)(2i+5)\}/18 \tag{4}$$

2.2.2. Sen's slope estimator

This is the non-parametric robust test which is used to detect the monotonic trend in the hydrologic time series and proposed by Hirsch *et al.* (1982).

The equation is given as:

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j - i}\right) \text{for } j > i \tag{5}$$

where, β = slope in between data points x_i and x_j, x_i = data measurement at time i, x_j = data measurement at time j. A positive value of β specifies an 'increasing trend in the time series', and the negative value specifies a 'decreasing trend in the time series' (Xu *et al.* 2007).

2.2.3. Innovative trend analysis

Şen (2011) proposed a new approach for detecting the trend in the time series. This considers 1:1 (45°) as the straight line on the Cartesian coordinate system. In this method, the recorded hydrological time series is divided into two equal sub-series, and then both the sub-series are organized according to ascending order. Thereafter, the first sub-series series is plotted as abscissa against the second sub-series as ordinate based on the Cartesian coordinate system. If the plotted data points are collected on the 1:1 (45°) line, this indicates an absence of trend in the time series. Additionally, if the data points fall in the lower triangular part of the 1:1 line this represents a negative trend, whereas if the data points fall in the upper triangular part of the 1:1 line a positive trend is indicated. This method also enables detection of trends in different hydrologic regimes, namely, low, medium and high.

2.2.4. Change in magnitude of trend

Change in magnitude of the trend is calculated by likening it with a linear trend, which can be evaluated from the median slope (β) multiplied with the data period length and divided by the corresponding average value which is expressed in the percentage (Yue & Hashino 2003):

$$Percentage \; change \, (\%) = \frac{\beta \; \times \; length \, of \, year}{mean} \times 100 \tag{6}$$

2.2.5. Rainfall variability index

The rainfall variability index is generally calculated as the standard departure in the precipitation time series and helps to segregate the existing precipitation time series into different climatic regimes, such as normal, wet, very wet, dry and very dry climatic year (L'hote *et al.* 2002). The rainfall variability index (D_i) was calculated from the equation given as:

$$D_i = \frac{(p_i - \mu)}{\sigma} \tag{7}$$

where, D_i represents the rainfall variability index for year i, and P_i is the annual rainfall of year i. σ and μ are the standard deviation and mean of the annual precipitation series, respectively, for duration under the study at the given station. The value of D_i within ± 0.5, between $+0.5$ and $+1$ and more than $+1$ is categorized as a normal, wet and very wet climatic year, respectively. Correspondingly, when the value of D_i lies in between -0.5 and -1 and less than -1 a dry and very dry, climatic year, respectively, is indicated (L'hote *et al.* 2002).

3. RESULTS AND DISCUSSION

The monthly, seasonal and annual rainfall time series of Madhya Maharashtra, Marathwada and Vidarbha regions are used for the purpose of analysis. These three regions cover the catchment area of Upper and Middle Godavari sub-basins. The Godavari basin receives 80% of its annual rainfall from the southwest monsoon. Thus, ultimately, the streamflow as well as sediment transport of the basin is highly dependent upon the precipitation the basin receives in the months of June, July, August and September (Godavari Basin report, Central Water Commission of India). Hence, it is very important to check the rainfall pattern over the basin as it gives a fair idea about the characteristics of the river basin. Similarly, the population situated in the catchment area of the Godavari basin is highly dependent upon agriculture and so directly depends upon the monsoon rainfall. As mentioned earlier, in the recent past years, the Marathwada and Vidarbha regions have been the victim of frequent drought and flood situations. The extreme weather events caused by climate change are greatly responsible for such situations. Owing to the overall increase in warmer climate across the globe, it is important to check the impact of the increase in temperature on the regional scale also. Such impacts of warmer climate are visible in terms of extreme weather events. Now, to analyse the impact of climate change on rainfall, it is very much important to study the long-term pattern, the trend, variability and change in magnitude of rainfall. The basic statistical parameters of series were then estimated, however, not reported in this paper due to the paucity of space. Further, the trend analysis was carried out using the statistical MK test and graphical method ITA. The results of both the tests are shown in Table 1.

3.1. Statistical trend analysis

The monthly, seasonal and annual rainfall series was checked for the existence of serial correlation (at 5% significance level), prior to the application of the MK test. The trends in the time series for Madhya Maharashtra, Marathwada and the Vidarbha regions were investigated using non-parametric MK and Sen's slope estimator tests and ITA method.

The results of the rainfall trend for the years 1871–2016 (Table 1) exhibit the presence of mixed trend in the total monthly rainfall. A decreasing trend is observed for the months of April, July, September, November and December and these months

Table 1 | Trend analysis of monthly, seasonal and annual rainfall of Madhya Maharashtra

Time series	Mann–Kendall Z statistic	p-value	Sen's slope (β) value	Nature of trend (low medium high)		
January	0.284	0.78	0	○	↓	↓
February	0.535	0.58	0	↓	↓	↓
March	1.314	0.12	0.03	↑	↑	↑
April	− 0.447	0.66	− 0.56	○	○	↓
May	0.031	0.98	0.28	↑	↑	↓
June	0.419	0.67	1.84	○	↑	↓
July	− 0.652	0.51	− 6.13	↑	○	○
August	2.276	**0.023**	6.92	↑	↑	↑
September	− 0.650	0.51	3.56	↑	↓	↑
October	0.141	0.88	0.83	↑	○	↓
November	− 0.161	0.88	− 0.05	↓	↑	↓
December	− 0.829	0.41	0	↓	↓	↓
Pre-monsoon	0.203	0.11	0.84	↑	↑	↓
Monsoon	0.522	2.62	0.60	↑	○	↓
Post-monsoon	0.076	0.34	0.94	○	○	↓
Winter	− 1.168	0.24	− 0.91	↓	↓	↓
Annual	0.125	2.63	0.90	↑	○	↓

↑ Indicates increasing trend, ↓ indicates decreasing trend and ○ indicates no trend.
Bold values indicate that trends are statistically significant at 5% significance level.

are negative with Z_{mk} values of −0.447, −0.652, −0.650, −0.161, −0.829, respectively. Increasing trend is observed for January (0.284), February (0.535), March (1.314), May (0.031), June (0.419) August (2.276) and October (0.141). A significant downward trend is not reported for any of the months at 5% significance level, but a significant increasing trend is observed in August (Figure 3) as the estimated p value ($p = 0.023$) is less than 0.05. The Sen's slope results are also in agreement with the MK test results. The pre-monsoon, monsoon and post-monsoon seasons are reported with a positive trend with Z_{mk} values being 0.203, 0.522 and 0.076, respectively. The magnitude of trend slope for post-monsoon rainfall is 0.94 which is highest among the pre-monsoon and post-monsoon. The rainfall trend in the winter season is decreasing with Z_{mk} value of 1.168. For the winter season, the ITA results also show decreasing trend in low, medium and high regimes. The annual rainfall trend of Madhya Maharashtra is increasing ($Z_{mk} = 0.12$) for the period of 146 years. The monthly, seasonal and annual rainfall trend analysis indicates that no significant reduction in rainfall is observed in the Madhya Maharashtra region. This also indicates that Godavari River flowing through the Madhya Maharashtra region has received a considerable amount of rainfall in the last 146 years.

The result of ITA methods are also tabulated in Table 1 and compared with the MK test results. The ITA plots are divided into low, medium and high regions. Each region indicates the nature of trend. The sample of ITA for August is plotted (Figure 4). The ITA plot for August shows an increasing trend in low, medium and high regimes. The ITA also specifies that in the low regime the nature of trend is increasing for March, May, July, August, September and October (Table 1), while for January, February and June, no particular increasing or decreasing trend is observed. The pre-monsoon, monsoon and annual rainfall trend is positive and winter rainfall trend shows a negative trend in the low regime. As compared with the low and medium regime, the high region reported with the maximum negative trend.

The monthly, seasonal and annual trend analysis results of the Marathwada region is tabulated in Table 2. Out of 12 months, four months, i.e., April, June, September and December are observed with a negative trend in monthly rainfall
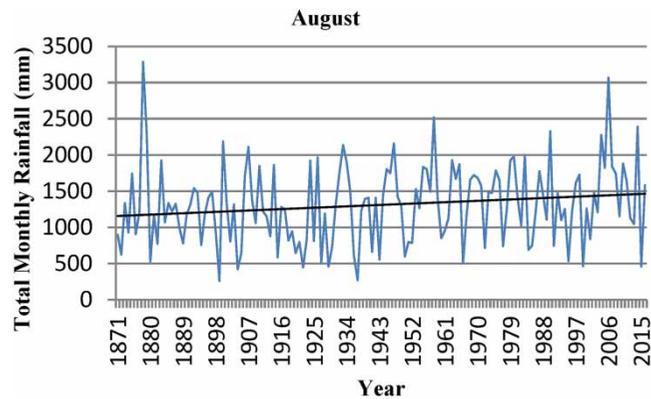

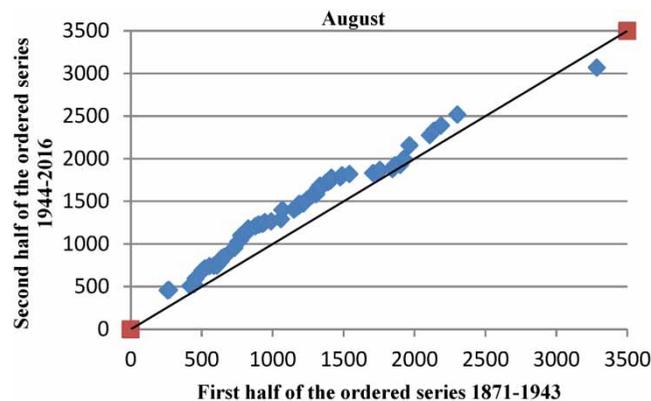**Figure 3** | Long-term temporal trend in the month of August for Madhya Maharashtra region.

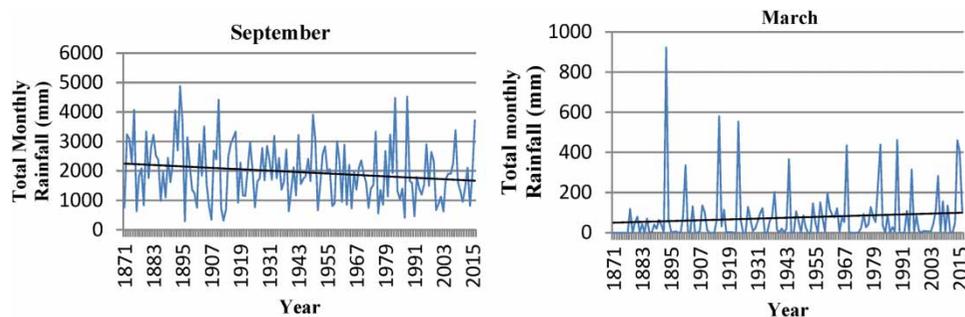**Figure 4** | Innovative trend analysis plot of August for Madhya Maharashtra region.

Table 2 | Trend analysis of monthly, seasonal and annual rainfall of Marathwada region

Time series	Mann–Kendall Z statistic	p-value	Sen's slope (β) value	Nature of trend (low medium high)		
January	0.67	0.51	0.00	↑	↓	↓
February	0.89	0.37	0.00	↑	↓	↓
March	2.50	**0.01**	0.00	↑	↑	↓
April	− 0.33	0.74	− 0.03	○	↓	↓
May	1.23	0.20	0.58	↑	○	↑
June	− 0.56	0.58	− 6.81	○	↓	↓
July	0.49	0.63	0.03	↑	↑	↑
August	1.66	0.10	8.65	↑	↑	↑
September	− 2.44	**0.01**	− 11.88	○	↓	↓
October	1.19	0.24	6.06	↑	↑	↑
November	0.78	0.44	0.00	○	↑	↑
December	− 0.34	0.73	0.00	↓	↓	↓
Pre-monsoon	0.95	0.34	2.00	○	↑	↓
Monsoon	− 0.45	0.65	− 1.36	↑	○	↓
Post-monsoon	1.20	0.23	8.81	↑	↑	↑
Winter	− 0.38	0.70	− 0.17	○	↓	↓
Annual	− 0.04	0.96	− 8.16	↑	○	↓

↑ Indicates increasing trend, ↓ indicates decreasing trend and ○ indicates no trend.
Bold values indicate that trends are statistically significant at 5% significance level.

with Z_{mk} values of −0.33, −0.56, −2.44, −0.34, respectively. The remaining eight months, namely, January, February, March, May, July, August, October and November exhibit a positive trend with Z_{mk} values of 0.67, 0.89, 2.50, 1.23, 0.49, 1.66, 1.19 and 0.78, respectively. The pre-monsoon ($Z_{mk} = 0.95$) and post-monsoon ($Z_{mk} = 1.20$) rainfall exhibits a positive trend, while monsoon ($Z_{mk} = −0.45$) and winter ($Z_{mk} = −0.38$) rainfall exhibits a negative trend. Total annual rainfall also shows the decreasing trend with p value 0.96 and Z_{mk} value −0.04. The significant increasing or decreasing trend is absent in the seasonal and annual rainfall time series.

The long-term MK test and ITA trend test results of monthly rainfall of March and September for the Marathwada region are represented in Figures 5 and 6. Monthly rainfall of March shows a significant increasing trend ($Z_{mk} = 2.50$) from 1871 to 2016, while for the same period, September shows a significant decreasing trend ($Z_{mk} = −2.44$). ITA trend analysis plots for March show increasing, increasing and decreasing trend in the low, medium and high regime, respectively. It is important to note that rainfall of one of the important monsoon months, i.e., September, is significantly decreasing from 1871 to 1943 for the Marathwada region. The ITA results indicate that the nature of trend is either increasing or no trend in the low regime for

Figure 5 | Long-term temporal trend in months of March and September for Marathwada region.
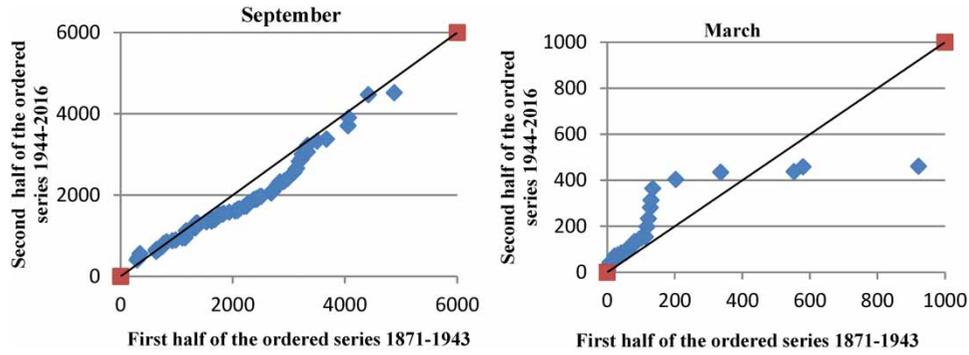
Figure 6 | Innovative trend analysis plot for March and September for Marathwada region.

all the monthly, seasonal and annual time series, except for being negative in December and no specific trend in April, June, September, November, pre-monsoon and winter season.

The result of trend tests for total monthly, seasonal and annual rainfall for the Vidarbha region (Table 3) shows a negative trend for six months, i.e., February ($Z_{mk} = -0.01$), May ($Z_{mk} = -0.56$), June ($Z_{mk} = -1.07$), July ($Z_{mk} = -1.65$), September ($Z_{mk} = -1.99$) and December ($Z_{mk} = -0.60$), while a positive trend is observed in January ($Z_{mk} = 1.14$), March ($Z_{mk} = 1.86$), April ($Z_{mk} = 0.91$), August ($Z_{mk} = 1.85$), October ($Z_{mk} = 1.02$) and November ($Z_{mk} = 1.11$). Due to the significant reduction in rainfall for July and September, overall trend for the monsoon season also shows a decreasing trend.

The results of MK trend test and ITA are shown in Figures 7 and 8. ITA plots for July and September show a decreasing trend in all low, medium and high regimes. Both the methods specify the same results in terms of identification of significant trend. The nature of trend for the monsoon period is decreasing with Z_{mk} value of -0.86, while pre-monsoon ($Z_{mk} = 0.56$), post-monsoon ($Z_{mk} = 0.61$) and winter ($Z_{mk} = 0.42$) season show an increasing trend. Annual rainfall trend for the Vidarbha

Table 3 | Trend analysis of monthly, seasonal and annual rainfall of Vidarabha region

Time series	Mann–Kendall *Z* statistic	*p*-value	Sen's slope (β) value	Nature of trend (low medium high)		
January	1.14	0.26	0.0	↑	↓	↑
February	− 0.01	0.1	0.21	○	↓	↓
March	1.86	0.07	0.82	↑	↑	↑
April	0.91	0.4	0.19	○	↑	↑
May	− 0.56	0.6	− 0.21	↑	↓	↓
June	− 1.07	0.3	0.44	↑	↓	↓
July	− 1.65	**0.01**	− 18.7	↓	↓	↓
August	1.85	0.07	12.28	↑	↑	↑
September	− 1.99	**0.04**	− 14.50	↓	↓	↓
October	1.02	0.32	2.9	↑	↓	↑
November	0.11	0.1	0.0	↓	↓	↑
December	− 0.60	0.6	0.0	○	↓	↓
Pre-monsoon	0.56	0.6	1.2	○	↑	↑
Monsoon	− 0.86	0.4	− 13.0	↓	○	↓
Post-monsoon	0.61	0.6	3.2	↑	↑	↓
Winter	0.424	0.7	0.2	○	↓	↓
Annual	− 0.74	0.5	− 15.7	○	↓	↓

↑ Indicates increasing trend, ↓ indicates decreasing trend and ○ indicates no trend.
Bold values indicate that trends are statistically significant at 5% significance level.
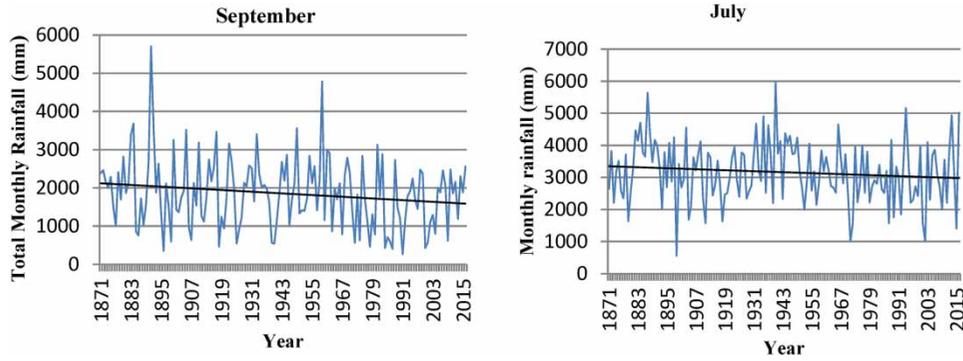
Figure 7 | Long-term temporal trend in months of July and September for Vidarbha region.
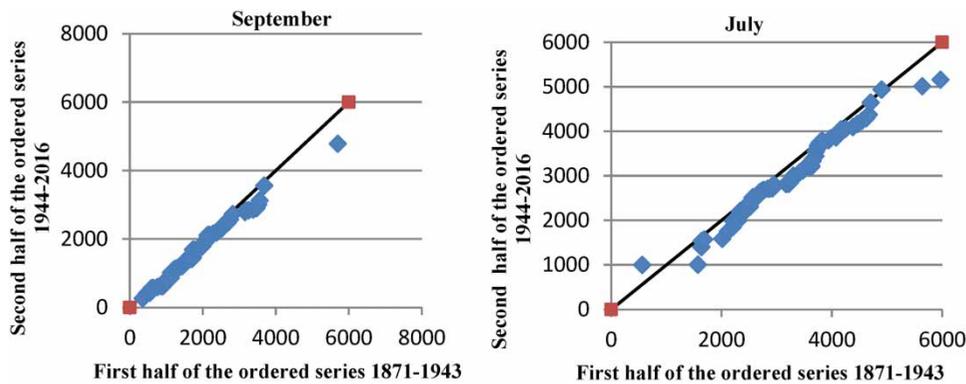

Figure 8 | Innovative trend analysis plot for July and September for Vidarbha region.

region is of a decreasing nature ($Z_{mk} = -0.74$) from 1871 to 2016. As compared with the Marathwada region (-8.16), magnitude of the trend is higher (-15.7) in the annual rainfall series for the Vidarabha region.

Now, the impact of significantly decreasing trend, particularly in July and September, is visible in terms of water scarcity throughout the year for the entire Vidarbha region. Most of the districts in the Vidarbha region have faced frequent droughts in the past two decades. Also, due to inadequate water resources management, inadequate irrigation facilities, agricultural production is decreased to a large extent. In the past two decades, nearly 23,000 farmers have committed suicide and this rate is quite high in Marathwada and Vidarbha regions. The impact of reduced monthly, seasonal and annual rainfall is visible in terms of reduced discharge as well as sediment load in the Godavari River (Godavari Basin Report, Central Water Commission). Anthropogenic factors, such as construction of numerous dams (921), deforestation, mining activities, etc., are equally contributing to the reduced streamflow and sediment load.

3.2. Change in magnitude of trend

Seasonal and annual rainfall series for the Madhya Maharashtra, Marathwada and Vidarbha region are checked to determine the magnitude of change in the trend (Table 4). The methodology for detecting the percentage of the magnitude of trend is discussed in section 2.2.4 (Yue & Hashino 2003). The results indicate that, for Madhya Maharashtra region, the change in

Table 4 | Percentage change in magnitude of trend

Regions	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Madhya Maharashtra	4.64	6.51	3.78	−104.38	5.06
Marathwada	78.91	−2.88	154.71	−14.49	14.39
Vidarbha	42.66	−20.10	70.94	9.93	−21.13

magnitude of trend is −104.38% for the winter season. On the other hand, pre-monsoon (4.64%), monsoon (6.51%) and post-monsoon (3.78%) indicate a positive change in the trend.

For Marathwada region, change in magnitude of the trend for monsoon and winter season is −2.88% and −14.49%, respectively, whereas pre-monsoon and post-monsoon exhibit positive change of 78.91% and 154.71%, respectively. For the Vidarbha region, the change in trend for monsoon (−20.10) is observed to be negative, while the remaining three seasons, i.e., pre-monsoon, post-monsoon and winter indicate positive change in trend. The annual rainfall series shows positive change for Madhya Maharashtra (5.06) and Marathwada (14.39) regions, whereas for Vidarbha region, the change in annual trend is found to be negative (−21.13).

3.3. Rainfall variability analysis

The rainfall variability index has been evaluated using methodology described by L'hote *et al.* (2002). On the basis of *Di* value, climatic years are categorized as normal, wet, very wet, dry and very dry years. The rainfall variability index plots for Madhya Maharashtra, Marathwada and Vidarbha stations are shown in Figure 9(a)–9(c). Annual rainfall data for 146 years is used to find the normal rainfall (within ± 0.5) years, wet (+0.5 to +1) years, very wet (> +1) years, dry years (−0.5 to −1) and very dry (< −1) years. From the analysis it is observed that for Madhya Maharashtra, 2006 was the wettest year and 1899 was the driest year with rainfall variability index of 2.73 and −2.72, respectively. For the Marathwada region, 1892 was the wettest year and 1871 was the driest year, the rainfall variability index is 3.15 and −2.54, respectively. For the Vidarbha region, 1883 was the wettest year and 1899 was the driest year, with rainfall variability index 2.29 and −3.10, respectively (see Supplementary Material, Table S1).

The percentage-wise distribution of the 146-year time series, in various climatic regimes such as normal year, wet year, very wet year, dry year and very dry year is represented by Figure 10. It is seen that 40% of the time Madhya Maharashtra region received normal rainfall, while 14% of the time it experienced very wet periods and 17% of the time experienced very dry periods. The rainfall variability pattern for all of Marathwada shows that 36% of the time the region received normal rainfall, while 16% of the time it experienced very wet periods and 15% of the time experienced very dry periods. The rainfall pattern
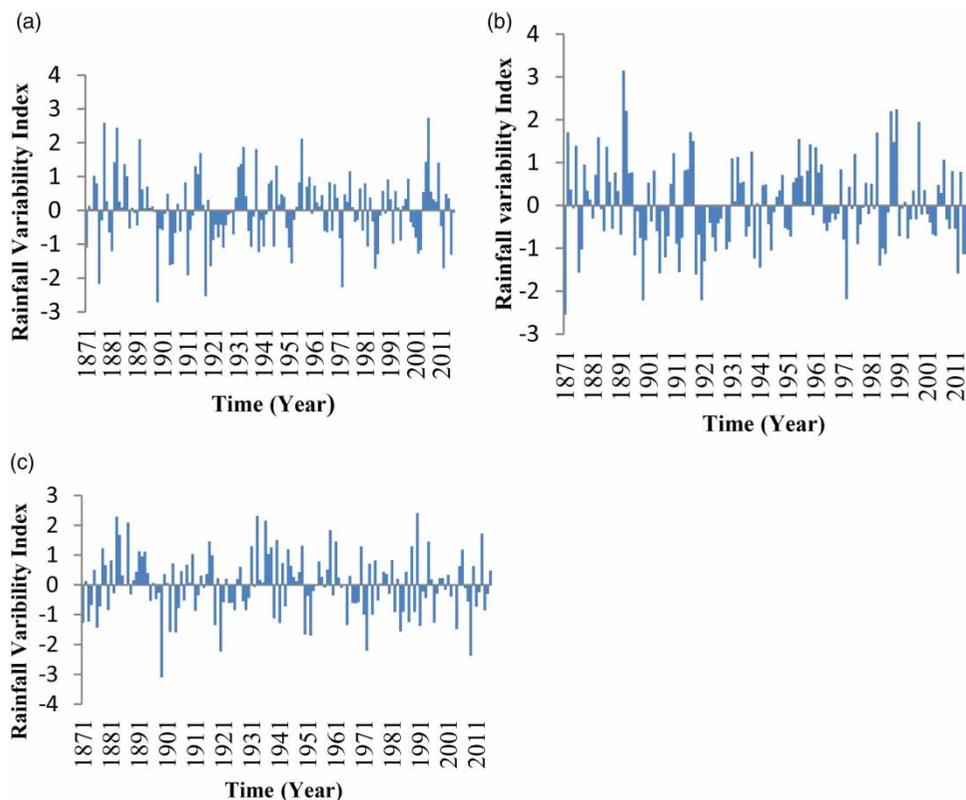

Figure 9 | Rainfall variability plots for (a) Madhya Maharashtra, (b) Marathwada and (c) Vidarbha Regions
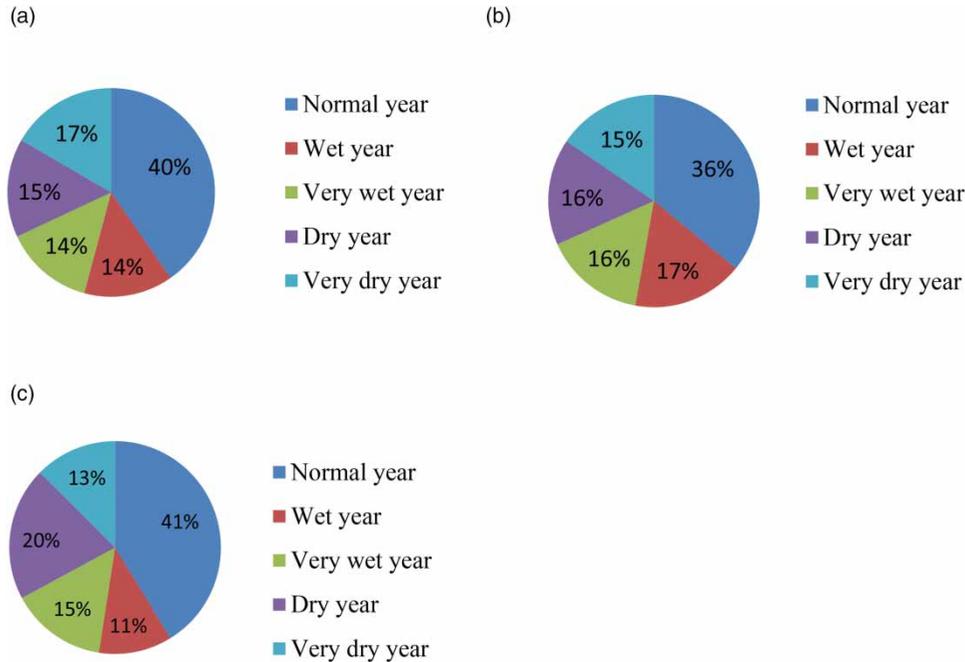
Figure 10 | The rainfall variability index distribution plots for the regions of (a) Madhya Maharashtra, (b) Marathwada and (c) Vidarbha.

for all of Vidarbha indicates that 41% of the time the region received normal rainfall, while 15 and 13% of time it experienced very wet and very dry periods, respectively. The region-wise variation in the normal rainfall period is from 36 to 41%, the very dry period lies within 13–17% and very wet period from 14 to 16%. Across the 146-year time span, most of the time these three regions are experiencing normal rainfall and, as well, the percentage of dry year and wet year is not more than 20%. The rainfall variability index analysis reveals no significant spatial variation is observed in any of the climatic regimes in Madhya Maharashtra, Marathwada and Vidarbha regions. The rainfall variability index analysis reveals no significant spatial variation is observed in any of the climatic regimes in Madhya Maharashtra, Marathwada and Vidarbha regions. Although all three regions are receiving normal rainfall for the maximum period, the impact of climate change can be seen through the occurrence of frequent droughts and flood situations, due to extreme events. Owing to rapid urbanization and industrialization, water demand also increased, which will be creating stress on the existing water resources. To cope with such situations, in the last five decades numerous dams have been constructed in the Godavari river basin. This leads to the Godavari River being the most regulated east flowing river. Due to constant human interference and anthropogenic impacts, the basin is at risk because of reduced discharge and sediment load. According to Subramniya, the Godavari River was the ninth largest river to transport higher loads of sediment to the Bay of Bengal, but which shows a reduction in the sediment load in past decades. Also, in the recent past years, many tropical rivers of India are showing a declining trend in sediment discharge due to the impact of climate change as well as human interference (Resmi *et al.* 2020).

4. CONCLUSION

The present study was carried out to analyse the nature of trends in monthly, seasonal and annual rainfall of Madhya Maharashtra, Marathwada and Vidarbha regions of Upper and Middle Godavari basins for a period of 146 years (1871–2016). The MK test showed an increasing trend in rainfall in the month of August for the Madhya Maharashtra, Marathwada and Vidarbha regions. Subsequently, for the Marathwada region, significant decreasing trend is detected in September and significant increasing trend is observed in March. For the Vidarbha region, significant decreasing trend is observed in the months of July and September. A positive trend is detected in the pre-monsoon, monsoon and post-monsoon season for the Madhya Maharashtra region, and negative trend is detected in monsoon and winter season for the Marathwada region. In the case of Vidarbha region, the pre-monsoon, post-monsoon and winter shows increasing trend but monsoon shows decreasing trend. Overall increasing trend is observed in annual rainfall for Madhya Maharashtra region and negative for the Marathwada and Vidarbha regions.

The statistical trend analysis (MK) results and graphical analysis (ITA) results are in agreement, specifically in the identification of significant trend. The spatial and temporal trend analysis indicates no significant upward and downward trend in the pre-monsoon, monsoon, post-monsoon and in the winter season. All three regions receive normal rainfall for 39% of the time. and very dry and wet situations for 15% of the time. The analysis of extreme weather events will throw more light on the impact of climate change. The spatial as well as temporal distribution does not show any significant increasing or decreasing trend in the rainfall over different parts of India (Jain *et al.* 2013; Mondal *et al.* 2015). The results obtained are in agreement with the results of rainfall pattern across India. The rainfall variability across the Madhya Maharashtra, Marathwada and Vidarbha regions is well poised and not skewed towards either extreme.

The results of the study are useful for the management of water resources in the Godavari basin. The Upper Godavari basin is highly regulated with large numbers of reservoirs and due to upstream damming, some districts of Middle Godavari basin face water scarcity every year. As Godavari is a tropical river, the significant reduction in rainfall, specifically in July and September, will affect the streamflow and suspended load. In these three regions, there is need to concentrate on water conservation activities and micro-level planning of existing water resources. The present study will also help policy makers in the systematic planning of existing water resources.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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