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District Wise Comparative Analysis of Rainfall Trends in Konkan-Goa and Marathwada Meteorological Subdivision of India

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Abstract District-wise monsoon (June - September) rainfall trends over Konkan-Goa and Marathwada meteorological subdivisions of India were analyzed in this study using rainfall data for the period 1951-2018. Mean monsoon rainfall is the highest over Konkan-Goa and the lowest over the Marathwada subdivision in the state of Maharashtra, India. Linear regression, Mann-Kendall test, and Sequential Mann-Kendall were used to identify trends in rainfall. Higher variability in the rainfall trends was noticed over the districts of Marathwada (-25% to +25%). The total number of below and above normal rainfall years (20 to 25) were comparatively equal for both the subdivisions; however, the number of deficient and excess rainfall years was more for the districts of Marathwada. Most of the districts in Marathwada showed declining trends in the summer monsoon rainfall. Significant decreasing trends were noticed in June month over Latur (-11 mm/decade) and Osmanabad (-7mm/decade) districts of Marathwada. The decadal rate of change in the overall monsoon rainfall for the Konkan-Goa subdivision varies between -15mm (Mumbai City) to -59mm (Raigad) and +2mm (Beed) to -30mm (Nanded) over the districts of Marathwada. The study has been carried out to understand the behavior of rainfall patterns post 1980, but the results were similar to the overall 68 years' rainfall trends. In general, insignificant mixed seasonal trends and insignificant negative trends were observed over most of the districts of both the subdivisions, which decline the consideration of monsoon vagaries and droughts due to rainfall change as a manifestation of climate change.

Keywords: *Konkan-Goa, Marathwada, meteorological subdivision, summer monsoon, trend analysis*

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1. Introduction

Indian summer monsoon (June- September) rainfall is the most crucial feature in the meteorology of the Indian sub-continent. India as a whole, more than 70 percent of yearly rainfall occurs in the monsoon period, making people critically reliant on it [1]. The economic intelligence of India [2] reported that a 15% to 20% deficiency in rainfall reduces the gross domestic production by 1% to 2% in the extreme drought years. Hydrological and agricultural planning, disaster management are the other fields that are also highly dependent on the performance of the monsoon. Intergovernmental Panel on climate change (IPCC) reported the adverse effect of changing climate on the Indian subcontinent, resulting in water stress in the 2020s due to reducing summer rainfall over some parts of the country [3]. Therefore, rainfall studies and their variability on different spatio-temporal scales (annual, seasonal) have become an essential research topic in the changing climatic era.

In India, considerable work has been done to understand the changing precipitation patterns at a country level. Parthasarathy and Dhar [4], Mooley and Parthasarathy [5] noticed a rise in the mean summer monsoon precipitation from 1899 to 1953. Jagannathan and Parthasarathy [6], Subbaramayya and Naidu [7] reported significant increasing rainfall trends over the six decades (1940-1990). In the 1990s, significant positive rainfall trends were observed over Southwest and northwest India [8,9,10], whereas Southern Peninsula noticed significant negative trends in rainfall [9,11]. In the early 2000s, a non-significant increase in precipitation was detected over central India [12]. In a recent study, Kothawale and Rajeevan [13] reported weak decreasing rainfall trends of - 0.18mm/year for 1871 - 2018 and -0.17mm for the recent period 1981 - 2018 over India. Global and regional climate models indicated a 5 to 10% increase in monsoon rainfall [14].

In India, the regional variations in the rainfall pattern result from a combination and interlinking factors at local and global scales [15]. Various studies have been carried out to understand the long-term rainfall trends at more minor spatial scales. Chowdhury and Abhyankar [16] observed no trends in rainfalls over most of the subdivisions of India. On the other hand, four subdivisions viz. Konkan-Goa, Punjab, Telangana, and West Madhya Pradesh of India were marked with significant increasing trends in monsoon rainfalls [17,18,19].

A significant decrease in rainfall trends was detected over Sub-Himalayan West Bengal [20], the plains of Bihar, and East Uttar Pradesh [13]. Most of the studies [21,22] over Maharashtra observed mixed rainfall trends, whereas Raghavendra [23] noticed a decreasing tendency of rainfall in the twentieth century. The study by Kothawale and Rajeevan [13] showed the significant increasing trends in monsoon rainfalls over the subdivisions of East Rajasthan, Kutch, and Diu from 1981 to 2018. On the monthly scale, Guhathakurta and Rajeevan [24] observed decreasing contributions of June, July, and September rainfalls to annual rainfalls, whereas August rainfall has shown increased contributions for some subdivisions.

These studies on a country as a whole attracted the attention of researchers, planners, and the common public. However, these are confined to the subdivision or state level. Therefore, it is difficult to understand the comprehensive picture of the nature of rainfall at a smaller spatial scale-like district. Unavailability of knowledge of rainfall variability on more minor scales becomes the major drawback in policymaking and planning activities at a regional scale. Therefore, the present paper addresses this problem. The primary purpose of this study is to understand the district-wise rainfall variation in the second half of the twentieth century over Konkan-Goa, and Marathwada meteorological sub-divisions.

Both these sub-divisions are diverse from each other concerning the rainfall characteristics. These subdivisions fall under the states of Maharashtra and Goa (Figure 1). These subdivisions are on either side of the Western Ghats (WG). Konkan-Goa lies on the windward side, and Marathwada is on the leeward side of WG. This geographical topography results in drastic differences in meteorological characteristics over both subdivisions.

2. Methodology

2.1. Study Area

Two meteorological subdivisions of India, Konkan-Goa, and Marathwada were selected for the study. These subdivisions comprise eight districts each (Figure 1). The eight districts of Marathwada are Aurangabad, Parbhani, Nanded, Jalna, Latur, Osmanabad, Hingoli, and Beed. Marathwada region lies in the upper Godavari basin, which extends from 17° 35' N to 20°41' N latitudes and from 74° 40' E to 78° 16' E longitudes. The Konkan-Goa subdivision covers Mumbai Urban, Mumbai Sub-Urban, Thane, Raigad, Ratnagiri, Sindhudurg, North Goa, and South Goa districts. Konkan- Goa subdivision ranges between 15° 02' N to 19°17' N latitudes and from 72°50'E to 74° 50' E longitudes (Table 1). Konkan-Goa is the second highest rainfall receiving subdivision of India; whereas, Marathwada is the second main drought-prone region of the country [25]. The mean annual rainfall over Marathwada is 700 mm, whereas Konkan-Goa receives 2900 mm average rainfall. The Konkan- Goa has typical climatic characteristics of the Indian west coast. Oppressive weather in the warm summer months, regular and plentiful seasonal rainfall, and high humidity throughout the year results in vibrant biodiversity and agricultural activities.

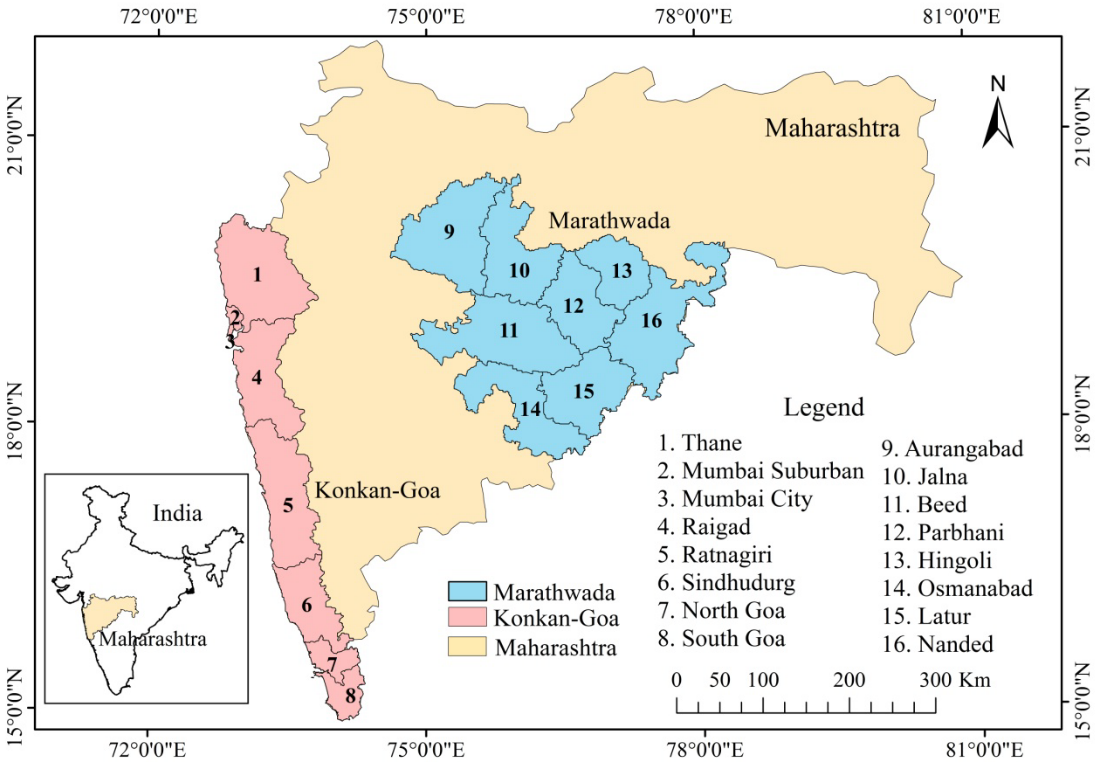

Figure 1. Location map of the subdivisions and districts selected for the study

Table 1. Geographical Details of the District Wise Locations Used in the Study and Information about the Rainfall Data

Name of district	Latitude	Longitude	Length of recorded period	Highest Rainfall	Year of the highest rainfall	Lowest rainfall	Year of lowest rainfall
Mumbai city	18.96⁰N	72.82⁰E	68 years	3433.9	1954	1182.0	1968
Mumbai sub	19.03⁰N	72.5⁰E	35 years	4460.0	1970	1147.7	1986
Thane	19.17⁰N	72.82⁰E	64 years	3758.7	1958	1522.7	1972
Raigad	18.39⁰N	72.52⁰E	64 years	4246.7	1954	1999.4	1972
Ratnagiri	17.00⁰N	73.19⁰E	68 years	4511.9	1955	1926.7	1966
Sindhudurg	19.08⁰N	72.83⁰E	68 years	4282.6	2010	1876.0	1986
North goa	15.5⁰N	74.5⁰E	68 years	4035.8	1961	1788.3	1972
South goa	15.2⁰N	74.2⁰E	51 years	4213.4	1970	1535.0	1972
Aurangabad	19.88⁰N	75.22⁰E	68 years	931.1	2006	302.1	1972
Beed	18.99⁰N	75.76⁰E	68 years	1041.0	1983	217.4	1972
Hingoli	19.17⁰N	77.15⁰E	68 years	1329.2	1983	380.3	1941
Jalna	19.83⁰N	75.88⁰E	68 years	1044.1	1988	275.4	1972/2012
Latur	18.4⁰N	76.56⁰E	68 years	1317.3	1955	219.6	1986
Nanded	19.15⁰N	77.3⁰E	68 years	1651.0	1988	378.4	1972
Parbhani	15.5⁰N	76.75⁰E	68 years	1272.3	1989	347.7	2015
Osmanabad	18.17⁰N	76.05⁰E	68 years	966.0	1988	262.1	1972

Station wise monthly, seasonal, and annual rainfall data from 1951 to 2018 (or of the available period) were collected from India Meteorological Department (IMD). 'Double Mass Curve' [26] analysis has been used to analyze the spatial homogeneity over the time series data. The method involves plotting the accumulating total of the one-time series variable against that of another. The plots of the series were observed reasonably straight, which indicated the homogeneous nature of the data.

2.2. Techniques Used

The significant components of trend analysis are the magnitude and statistical significance. Several parametric and non-parametric methods have been used for the trend analysis in this study; Linear regression, Mann-Kendall test, and Sequential Mann-Kendall were used for research and to identify the trends. Linear trend analysis has been used extensively by various researchers, whereas the Sequential Mann-Kendall test is used less frequently over the Indian region. Brief details of Mann-Kendall, and Sequential Mann-Kendall, are given in the following sections.

2.2.1. Mann-Kendall Test

The Mann-Kendall test [27,28] is the most widely used statistical method for various scientific studies. In climatology, this technique analyzes the trends in temperature, temperature range, and rainfall. This test applies to different climatic data for a given precise month or season. The primary input for this test includes the relative values of all terms in the series. Computation of P statistics is done by evaluating the first observation with the later one. Here, the null hypothesis (H_0) shows no trend in rainfall over time, and the alternative hypothesis (H_1) represents an increasing or decreasing trend in precipitation over time. The test statistics are as follows,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sig(Xj - Xi) \quad (1)$$

Here, n is the length of time series, Xi and Xj are the time-series observations.

$$\operatorname{sgn}(Xj - Xi) = \begin{cases} +1 \ \ if\,(Xj - Xi) > 0 \\ 0 \ \ if \ \ (Xj - Xi) = 0 \\ -1 \ if \ \ (Xj - Xi) < 0 \end{cases} \quad (2)$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2tp+5) \right] \quad (3)$$

Where q is the number of tied values, t_p is the number of data points in the p^{th} group.

2.2.2. Sequential Mann-Kendall Test

The sequential Mann-Kendall test [29] is a non-parametric test used to decide the approximate year of the start of the significant trend. Two series viz. progressive *u (t)* and a backward *u(t')* are generated from the data for this test. When both the series cross each other, deviate, and go beyond the threshold value of ±1.96 (p=0.05), then the trend is considered statistically significant. The mutation point (crossing point) of the two series indicates the approximate beginning year of the trend [30]. This method includes the following steps,

$$\begin{aligned} &Counting\ and\ indication\ of \\ &n_i : -\ the\ number\ of\ cases\ x_i > x_j \\ &Where,\ X_i\ (i = 1,\ 2\ldots,\ n)\ and\ X_j\ (j = 1,\ 2\ldots,\ i-1) \\ &(sequential\ values\ in\ series) \end{aligned} \quad (4)$$

Test statistics t_i: -

$$ti = \sum_{j=1}^{i} nj \quad (5)$$

Mean E(t) and Variance var (t_i): -

$$E(t) = \frac{n(n-1)}{4} \quad (6)$$

$$\mathrm{var}(ti) = \frac{i(i-1)(2i+5)}{72} \tag{7}$$

Sequential progressive value (*u(t)*): -

$$u(t) = \frac{ti - E(t)}{\sqrt{\mathrm{var}(ti)}} \tag{8}$$

To analyze the sequential backward series (*u(t')*) same procedure has to be followed and begin with the end of the dataset.

3. Results and Discussions

3.1. Analysis of Monsoon Precipitation - Study Area as a Whole

The study helped to understand the changes in rainfall trends over the meteorological subdivisions of Konkan-Goa and Marathwada (Figure 2). The monthly and seasonal rainfall series were plotted for all the 16 districts of these two subdivisions from 1951 to 2018. The mean monsoon rainfalls over the Marathwada and Konkan-Goa were 700 mm and 2900 mm, respectively. Over both the subdivisions, July contributed the maximum to the total seasonal rainfall. July rainfall gave 37.42% and 28.29% to the seasonal rains in the Konkan-Goa and the Marathwada subdivisions, respectively. The lowest precipitation over the Konkan-Goa subdivision occurred in September and in June over the Marathwada subdivision.

The average rainfall during August was lesser than July and contributed 27.58% to total seasonal rainfall over the Marathwada subdivision. September and June contributed 24.05% and 20.48%, and June rainfall gave 20.48% to the seasonal rains. In the Konkan-Goa subdivision, June contributed 25.77%, 24.78% by August, and 11.92% by September. Most of the variations in the rainfalls have been noticed in September, in which values of coefficient of variation varied between 35 to 40% over Marathwada and 20 to 25% over the Konkan-Goa subdivision. Monsoon season is identified as excess/deficient if the seasonal rainfall is above/below the long-term normal by 10%. In many years, the extreme values in coefficient of variations were associated with above or below normal rainfall years, making that year critical for agricultural and other planning activities. During the period 1951 to 2018, Marathwada and Konkan-Goa recorded 25 and 16 years as below normal years, respectively (Table 2), with some years having high rainfall deficiency.

During the same period, Marathwada and Konkan-Goa recorded 22 and 13 above normal rainfall years (Table 2). Mixed trends of rainfalls were noticed over all the districts of Konkan-Goa and Marathwada subdivisions. In the last seven decades (1951 to 2018), the study area as a whole, decreasing rainfall tendency was observed in the overall monsoon rainfall, but it was not statistically significant (Figure 2).

Compared to Marathwada, the decrease in rainfall per decade was more over the Konkan-Goa subdivision. In the Marathwada subdivision highest rate of decrease was detected over Hingoli (-35.94mm/decade) followed by Nanded (-30.16mm/decade) and Latur (-20.16mm/decade).

In the Konkan-Goa subdivision, Mumbai-Suburban showed a statistically significant decreasing trend (-0.446/decade) at a 95% confidence level. The rate of rainfall decrease at Mumbai Suburban was 43.00 mm (calculated for available 35years dataset), and it was the maximum rate of decrease observed all over the study area. Following Mumbai- Suburban, the decreasing rainfall tendency was observed over the Raigad (-59.49 mm/decade) and North Goa (-33.19 mm/decade) districts of Konkan-Goa.

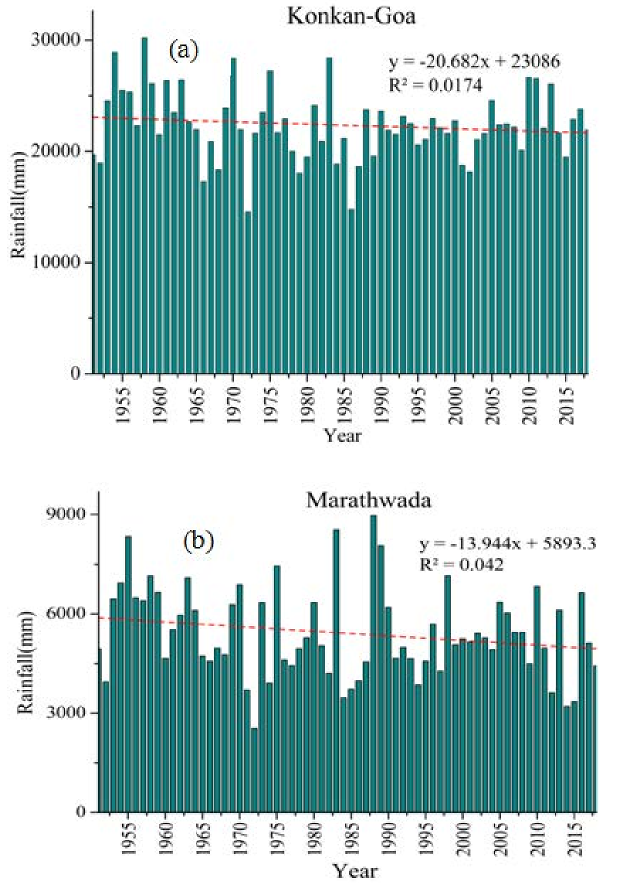

Figure 2. Temporal Variation in annual monsoon Rainfall over Konkan-Goa (a) and Marathwada (b) subdivision for the duration 1951-2018

Table 2. Number of Below and Above Normal Rainfall Years during the Period 1951-2018

Subdivision	Month	Below normal years	Above normal years	Normal years
Marathwada	June	29	25	14
	July	28	31	09
	August	34	22	12
	September	33	22	13
	Monson	25	22	21
Konkan-Goa	June	23	19	26
	July	20	21	27
	August	25	22	21
	September	24	24	20
	Monsoon	16	13	39

This study brought out that the highest decadal rate of change occurred over Konkan-Goa, however in terms of percentages, decadal changes were lower over the Konkan-Goa compared to trends over Marathwada.

The changes varied from -13% to +14% for Marathwada and -6% to +2% for Konkan-Goa. In the last six decades, four decades reported negative percent changes. 1971 to 1980 was the decade for both the subdivisions where maximum decreases (Marathwada -14% and Konkan-goa -6%) were noticed. The decade 1981 to 1990 noticed a +14% increase in monsoon rainfall over Marathwada, the highest increase of +3% for Konkan-Goa was observed from 1991 to 2000. In general, analyses by various methods indicated the decrease in rainfall over these subdivisions. Therefore, it can be concluded that a homogeneous picture of the decrease in rainfall was observed for the study area as a whole.

3.1.1. Analysis of Monsoon Rainfall over Marathwada

The districts included in this subdivision portray a decrease in the overall summer monsoon rainfall (Table 3). None of the districts has shown an increase in summer monsoon and June rainfall for the last 68 years. However, no significant decrease was observed in the monsoon rainfall. The decadal variation in the June rainfall ranged from -14% to +9%. 1961 to 1970 was the decade with maximum negative change, and the decade 1981 to 1990 was the decade with the highest positive variations. In July 1971to 1980 was the decade with maximum negative change (-29%) whereas, like June month, the decade 1981 to 1990 showed the maximum positive change in July (+21%) and in September (+38%). August 2001 to 2010 was the decade with the highest positive change (+22%), which contradicted June, July, and September changes. 1981 to 1990 was the decade for August with maximum negative change (-4%).

The highest decrease in rainfall was noticed over the districts of Hingoli (-0.265), Nanded (-0.235), and Osmanabad (-0.201), respectively. Remaining districts except Beed showed the declining tendency with the rate of change of -7mm/decade to -20mm/decade (Jalna-7.85mm/decade), (Aurangabad -12.22mm/decade), (Latur -20.30mm/decade) (Table 3). A positive rate of change was observed over the Beed district (2.22mm/decade). 3rd and 5th moving averages also showed the decreasing tendency in the rainfall on the smoothen scale.

The sequential Mann-Kendall test showed the year of changes (mutation point) for each district. For the Aurangabad district, mutation point was observed over the year 1974. From the year 1974 onwards, a non-significant negative trend was noticed up to the year 2004. Similar to Aurangabad, most of the districts continued with the non-significant negative trend after the mutation point, e.g., Hingoli (1964), Jalna (1960), Osmanabad (1961) (Figure 3. a), Latur (1958) (Figure 3. b). In contrast, other districts like Beed (1970), Nanded (1965) followed the mixed trend of monsoon rainfall.

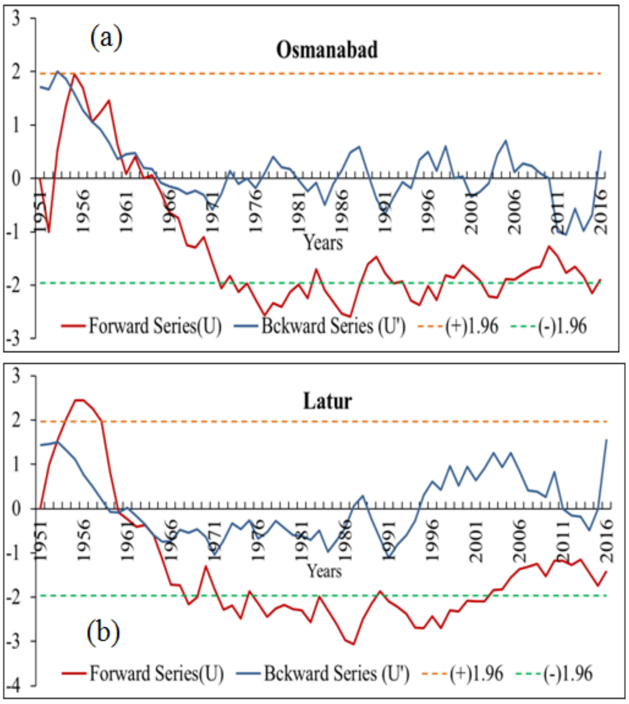

Figure 3. Sequential Mann-Kendall analysis of (a) Osmanabad and (b) Latur districts of Marathwada during June (1951-2018) (+1.96 and -1.96 are the thresholds at 95% confidence level)

Table 3. Monthly and Seasonal Linear Trends in Rainfall over the Districts of Marathwada and Konkan-Goa During the Period 1951-2018 (* Significant at 0.05 level, ** Significant at 0.01 level)

Subdivision	District	June	July	August	September	Monsoon
Marathwada	Aurangabad	-0.119	-0.15	-0.08	-0.004	-0.164
	Jalna	-0.17	-0.044	0.001	-0.27	-0.095
	Beed	-0.023	-0.056	0.33	0.006	-0.014
	Latur	-0.363**	-0.099	-0.011	-0.061	-0.175
	Nanded	-0.121	-0.135	-0.142	-0.17	-0.235
	Parbhani	0.034	0.004	-0.029	-0.09	-0.047
	Osmanabad	-0.277**	-0.18	-0.011	-0.052	-0.201
	Hingoli	-0.067	-0.222	-0.122	-0.167	-0.265
Konkan-goa	Mumbai sub	-0.123	-0.333	-0.361*	-0.413*	-0.446*
	Mumbai city	-0.163	-0.014	0.025	0.11	-0.066
	North goa	-0.124	-0.194	0.064	0.073	-0.113
	Ratnagiri	0.065	-0.092	-0.182	0.139	-0.075
	Sindhudurg	-0.063	-0.064	-0.042	0.119	-0.051
	South goa	0.09	-0.144	0.026	-0.131	-0.067
	Thane	-0.142	-0.093	-0.012	-0.02	-0.113
	Raigad	-0.125	-0.161	-0.128	0.033	-0.202

All the districts belonging to Konkan-Goa were characterized by a negative trend in the monsoon rainfall (Figure 4). None of the districts showed an increase in rain per decade. Mumbai suburban (35years data) was the only district with a significant negative trend in the overall summer monsoon rainfall. The month of June 1961 to 1970 was the decade with maximum negative change (-15%), whereas the decade 1971 to 1980 was the decade with the highest positive change (+14%) in the overall summer monsoon rainfall (Figure 5).

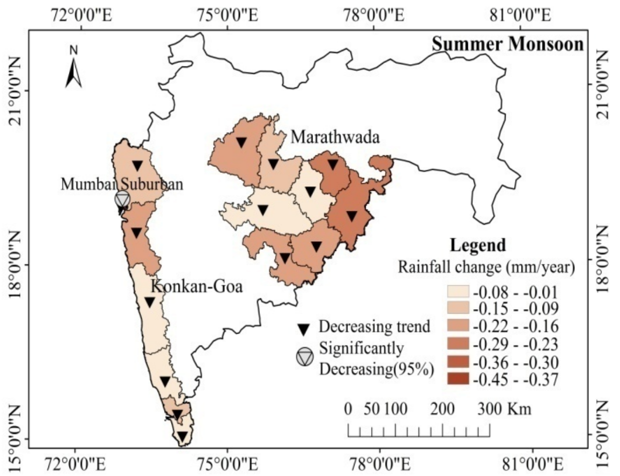

Figure 4. Spatial distribution of changes in rainfall and trends in seasonal monsoon precipitation by Mann Kendall test

For July (-20%) and September (-15%), the decade 1971-1980, and for August (-13%), the decade 1991-2000 showed a maximum declining tendency of rain (Figure 5). The decadal decreases in the rainfalls over South Goa, Thane, and Ratnagiri were ranged between 20 to 23mm, while districts of Sindhudurg and Mumbai city showed a 15mm decrease in decadal rains. Like Marathwada, in Konkan-Goa, 3rd and 5th moving averages show decreasing trends in the rainfall on the smoothen scale. The results of sequential Mann-Kendall showed that 1968 was the changing year (mutation point) for Mumbai city. In contrast, for Raigad, Ratnagiri, and Sindhudurg, the year 1967 was the year from onwards where significant changes have occurred.

3.2. Month-wise Comparison of Monsoon Precipitation Trends over Marathwada and Konkan-Goa

The behavior of monsoon rainfall varies concerning spatial and temporal scales. There may be or may not be any significant change on the county or subdivision level. Still, the chances of high variability at a local/ regional level are not negligible for different small-scale activities. Therefore, the present study thoroughly analyses the monthly nature of summer monsoon rainfalls for the districts of Konkan-Goa and Marathwada.

3.2.1. June

In June (Table 3), except Parbhani (0.034), a negative tendency of rain is observed for all the districts of Marathwada, in which statistically significant decrease trends were noticed over Latur (-0.363) and Osmanabad (-0.277). The trends were significant at a 99.9% confidence level. Over the Konkan-Goa subdivision, a non-significant increasing tendency of rain was observed for Ratnagiri (0.065) and South Goa (0.09) districts. In contrast, the rest of the districts from Konkan-Goa have experienced decreasing rainfall tendency in June month (Table 3). It was observed that, as compared to positive trends, negative rainfall trends were more dominant with a higher rate of change. Over the Marathwada, a maximum rate of change in the June month was noticed in the Latur (-11.33mm/decade) followed by Osmanabad (-7.50mm/decade), Jalna (-5.05mm/decade), and Hingoli (-4.58mm/decade) districts respectively. For the Konkan-Goa subdivision, Mumbai City (-21.20mm/decade), North Goa (-15.60mm/decade), Thane, and Raigad (-14.0mm/decade) were the districts with higher values of negative change. The positive changes were +14.91mm/decade for South Goa and +9.01mm/decade for Ratnagiri.

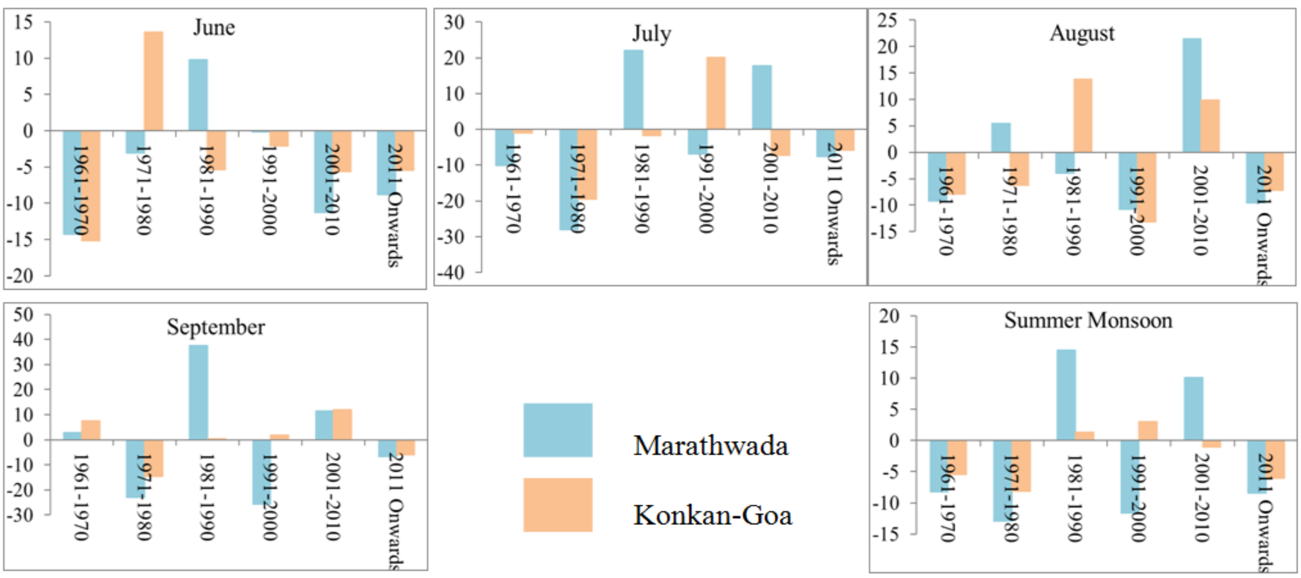

Figure 5. Decadal variability of monthly and seasonal (monsoon) rainfall over the Marathwada and Konkan-Goa (X-axis represents the decades, and Y-axis characterizes the variation in rainfall (mm)

Graphical representation of sequential Mann-Kendall test notified the exact year of changes in the rainfall series in mutation point. The month of June 1959 and 1960 were the changing years for the significantly decreasing rainfalls for the districts of Latur and Osmanabad, respectively (Figure 3).

Ratnagiri (1965) and Aurangabad (1969) were the districts whose mutation points lie between 1960 to 1970. The mutation points for most of the districts were found after 1975 similar to, Thane (1981), Mumbai City (1991), Beed (1979), Parbhani (1988), etc.

Decadal-based percentage departures are shown in Figure 5 and Figure 6, in which a maximum change was seen in the decade 1961 to 1970 for the June month followed by 2001 to 2010 decade. Clustering of dry and wet anomalies and multi-decadal variations were the two major characteristics observed in this month. In the first decade (1961 to 1970), all the districts were under negative change, in which highest values were noticed for the Latur (-24%), Nanded (-21%), Parbhani (-18%) districts of Marathwada and Ratnagiri (-25%), Mumbai city (-23%), Thane (-18%) of Konkan-Goa. After the year 1970, continue two wet decades, viz. 1971 to 1980(+8%) and 1981 to 1990(+12%) experienced positive changes for both the subdivisions. In the decade 1981 to 1990 except two, all districts among 16 were under positive change. The maximum change was over the Nanded (+21%), Hingoli (+11%) of Marathwada and South Goa (13%), Ratnagiri (8%) of Konkan-Goa subdivision (Figure 6).

Konkan-Goa and Marathwada, respectively have experienced positive signs of changing rate of rainfalls. For the majority of districts from both the subdivisions, mutation point (change point year) was found between the years 1965 to 1970, making these five years highly critical for August.

Among all the monsoon months, August was the period when maximum numbers of below normal years were identified for Marathwada (34) and Konkan-Goa (25) subdivisions (Table 2).

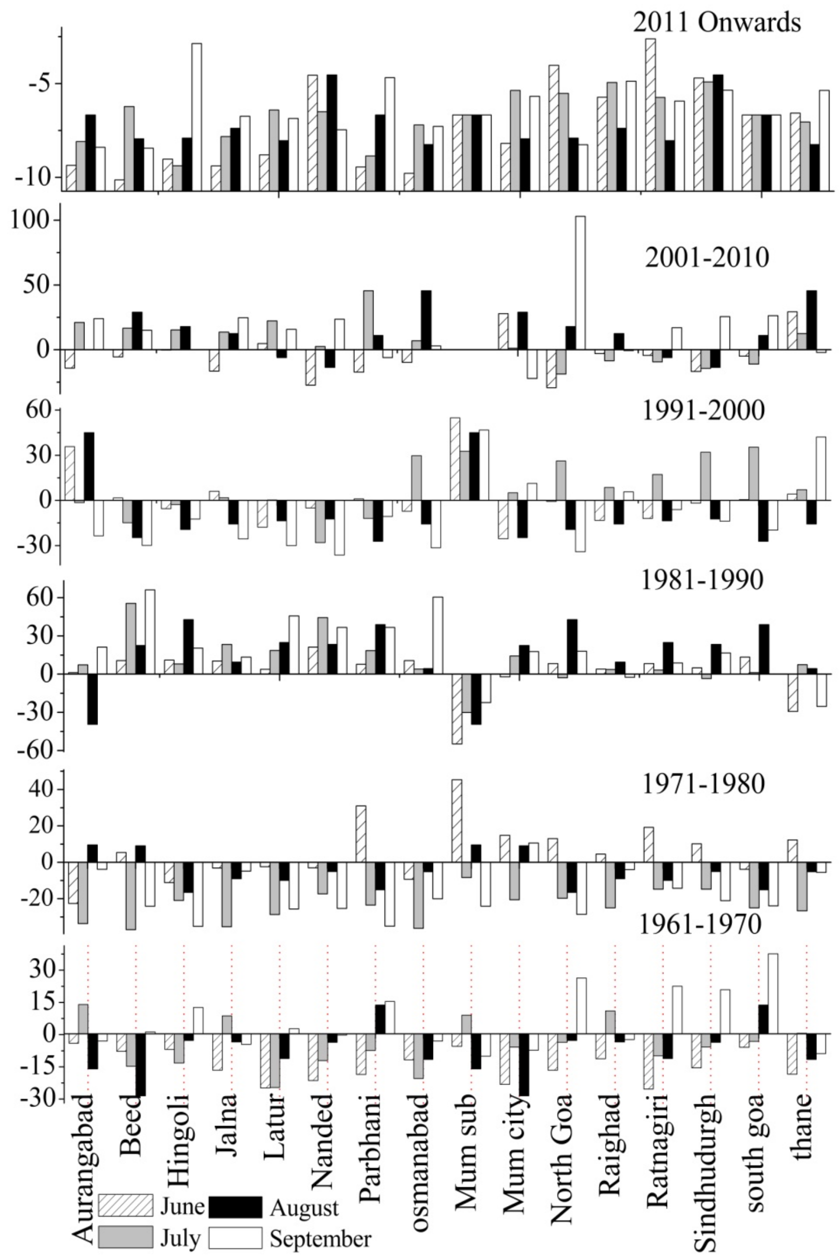

Figure 6. Decadal variability of monthly rainfall over the districts of Marathwada and Konkan-Goa (X axis represents the districts and Y axis characterizes the variation in rainfall (mm)

During the last six decades, alternate negative and positive decades were noticed for this month. Decade 1991 to 2000 was the decade in which the highest (-30%) declining change was detected, Parbhani (-27%), Beed (-24%) from Marathwada and South Goa (-27%), North Goa (-19%) from Konkan-Goa, contributed with the maximum values of negative change (Figure 6). 1981 to 1990 and 2001 to 2010 were the decades when the pick positive anomalies of change were noticed (Figure 6).

Except for Aurangabad from Marathwada other all districts of both the subdivisions had positive percent changes (+4% to +42%) over the decade 1981 to 1990.

3.2.4. September

This month gives the least contribution to monsoon rainfall for the Konkan-Goa subdivision. Except for Beed (0.006), all other districts of Marathwada and two districts of Konkan-Goa (Mumbai Suburban and South Goa (-0.131) showed a negative rainfall tendency this month. A significant decreasing trend was noticed over the Mumbai Suburban (-4.13 for 35years data), followed by a non-significant decrease over Hingoli (-0.167). From the Konkan- Goa subdivision, six districts showed insignificant increasing trends. The maximum was observed over Ratnagiri (+0.139) and Sindhudurg (+0.11) (Table 3).

In September, all the districts of Marathwada followed the negative tendency of rainfall, where the maximum decrease was observed over Nanded (-8 mm/decade) and Hingoli (-7 mm/decade). Diverse nature of rate of change was noticed for the districts of Konkan-Goa in which Mumbai city (+10mm/decade) and North Goa (+7mm/decade) experienced positive values. For most of the district's mutation point was observed after the year 1965.

A decadal study showed the inter-changing of dry and wet decades from 1961 onwards (Figure 5). The decade 1981 to 1990 was the decade with a maximum percentage of positive changes in which Beed (68%), Latur (45%) of Marathwada and North Goa (18%), Mumbai city (17%) had a maximum percentage of changes. The percentage-wise highest decrease was in 1971 to 1980 followed by the decade 1991 to 2000. In these decades, the maximum decrease was at Hingoli (35%), Parbhani (35%), and North Goa (28%) compared to earlier decades (Figure 6).

3.3. Scenario after 1981

From the 1980s onwards, the climatic regime shift has been observed [31]. India as a whole, some studies [32,33] also documented the latest period as an increasing warming period. Therefore, the current research focuses on the rainfall trends and changes in monsoon rainfalls after 1981. Based on data availability, this analysis was carried out for five districts of Konkan-Goa and seven districts of Marathwada.

The Konkan-Goa subdivision noticed a decrease in mean summer monsoon rainfall after 1981. The mean rainfall for 1951 to 2018 (68 years) was 2936.6 mm; however, it decreased to 2901.73mm in 1981-2018. Thane district in the Konkan-Goa subdivision showed the maximum variation of +80 mm. The increasing trend over Thane (+0.559) district for the overall monsoon season was statistically significant at a 99.9% confidence level. Other districts noticed 0 to 11mm variation in the monsoon rainfall. The non-significant mixed tendency of rains has been seen over all other districts of Konkan-Goa.

1981 onwards, Marathwada experienced an increase in the mean monsoon rainfall compared to the overall study period (68years). Over Marathwada, the mean summer monsoon rainfall for 68 years was 648.71mm, whereas it increased to 648.71 mm for 1981-2018.

The maximum increase in mean rainfall was detected over Latur (+25mm), followed by Osmanabad (+21mm), Aurangabad (+20mm), and Nanded (+20mm) (Figure 6). Like Konkan-Goa, mixed nature of insignificant tendency of rains was noticed over the Marathwada.

As per monthly variation was considered, all the monsoon months (June, July, August, and September) followed the increasing rainfall trends for Thane and Ratnagiri (except August). A statistically significant decrease was observed over the Ratnagiri in August (-0.387mm). All the Konkan-Goa, viz., Raigad, Sindhudurg, and North Goa noticed negative rainfall tendency for June and August. In contrast, insignificant positive trends were observed in July and September months. The Nanded district of Marathwada experienced a non-significant negative tendency of rain for all four monsoon months. Positive trends in July and August and negative tendencies in June and September were observed over Aurangabad, Beed, Jalna, Latur, and Osmanabad. None of the above increase or decrease in rainfall was statistically significant.

In the overall decadal variations, it was observed that 1981 to 1990 was the decade for all the monsoon months having the maximum positive changes. In the further decades, mixed increasing and decreasing nature of rainfall were noticed. As various researchers noticed, these spatial and temporal variations in the rainfall trends were may be due to the varying sea surface temperatures, teleconnection, and monsoon-ENSO relationship [34,35,36].

4. Summary and Conclusions

This study aimed at investigating district-wise, long-term rainfall trends over the sub-divisions of Konkan - Goa, and Marathwada of Maharashtra state in India for the period 1951 to 2018. Rainfall trends over different parts of India and the country as a whole have always been part of the research, while various studies have found that for a country as a whole, there was no significant long-term trend observed in monsoonal rainfall. The present research also is in line with these findings for all districts of selected meteorological subdivisions. Other statistical tests viz. Breaks for Additive Season and Trends (BFAST) [37], Sen's estimator of slop [38], were in accordance with the results and validated the outcomes of this study. The important conclusions of this study are as follows,

i. In Monsoon rainfall, a negative rainfall tendency was observed for all the districts, among which a declining trend over Mumbai Suburban (for 35years available data) was statistically significant at 95% level.

ii. Hingoli (-0.26), Nanded (-0.24) districts of Marathwada and Mumbai Suburban (-0.446*), Thane (-0.12), North Goa (-0.12) districts of

Konkan-Goa showed the maximum decrease in the summer monsoon rainfall.

iii. In June statistically significant decrease in rainfall was noticed over the Latur (-0.363) and Osmanabad (-0.277) districts which were significant at a 99% confidence level.

iv. On the monthly rainfall scale, pockets of positive rainfall trends were observed, but they were statistically insignificant. e.g., rainfall trends in June over Parbhani (0.065), Ratnagiri (0.065), and South Goa (0.09)

v. For all the districts, the maximum rainfall contribution in monsoon was by July (37.42% for Konkan-Goa and 28.29% for Marathwada).

vi. Compared to Marathwada, the rate of change in precipitation per decade was higher over the districts of Konkan-Goa. The maximum change was observed over the Raigad district (-59.49mm/decade), followed by North Goa (-33.19mm/decade).

vii. Maximum decadal rainfall change in percentage was observed over Marathwada making Marathwada a most vulnerable subdivision for the monsoon rainfall.

viii. 1970-75 was the period for most of the districts in which year of change(mutation point) in rainfall was detected.

ix. In alternative decades, wet and dry spells in monsoon rainfall were noticed in the decadal analysis. In the last six decades, maximum positive change was detected in the decade 1981 to 1990 for most of the districts.

One of the essential findings of this study is related to the changing scenarios after the year 1980's due to accelerated warming. This study found no significant variations in the rainfall trends throughout 1980 to 2018 compared to 68 years of monsoon rainfalls. Therefore, rainfall may not be considered as a reason for changing climatic conditions and vice versa for the selected districts in these two subdivisions.

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