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Temporal variations of rainfall over Konkan & Goa during 1901-2020

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सार – **यह अध्ययन** 1901-2020 **के दौरान भारत के कोंकण और गोवा में मासिक, ऋतुनिष्ठ, वार्षिक और दशकीय पैमाने पर वर्षा की कालिक भिन्नता की जाँच करता है। मैन-केंडल टेस्ट और टी-टेस्ट का उपयोग करके वर्षा डेटा का प्रवृत्ति विश्लेषण किया जाता है। पिछले** 120 **वर्षों में वार्षिक वर्षा के साथ-साथ दक्षिण-पश्चिम मॉनसून अवधि के दौरान** 3.2 **मिमी/वर्ष की महत्वपूर्ण वृद्धि की प्रवृत्ति देखी गई है। मासिक पैमाने पर, जून, अगस्त, सितंबर और अक्टूबर के महीनों के दौरान वर्षा में उल्लेखनीय वृद्धि की प्रवृत्ति का संकेत मिलता है, जबकि जनवरी और फरवरी के दौरान महत्वपूर्ण गिरावट की प्रवृत्ति देखी गई है। इस अध्ययन के दौरान,** 1931-1960 **की अवधि के दौरान अधिकतम वर्षा देखी गई। दशकीय वर्षा विश्लेषण से पता चलता है कि अध्ययन की अवधि में कुल** 18 **वर्ष अधिकतम और** 15 **वर्ष न्यूनतम वर्षा के थे।**

ABSTRACT. This study examines the temporal variation of rainfall on a monthly, seasonal, annual, and decadal scale over Konkan & Goa, India during 1901-2020. Trend analysis of rainfall data is carried out by using the Man-Kendall Test and *t*-test. A significant increasing trend of 3.2mm/year has been observed for annual rainfall as well as during the Southwest monsoon period over the last 120 years. On the monthly scale, rainfall indicates a significant increasing trend during June, August, September, and October, while a significant decreasing trend has been observed during January and February. During the period of the study, maximum rainfall was observed during the period from 1931-1960. Decadal rainfall analysis shows a total of 18 excess years and 15 deficit years over the period of study.

Key words – Rainfall trend, Konkan and Goa, Coefficient variation, Meteorological sub-division, Mann-Kendall Test.

1. Introduction

Rainfall analysis has played a vital role in the study of climate change. The southwest monsoon starting from June to September makes a major contribution to the rainfall of India. The monsoon generally reaches Kerala by the end of May or the 1st week of June and progresses to Konkan & Goa, then the northern part of India. Rainfall during monsoon is very important for the Indian economy. System formation and weather change on the west coast that occurred with the presence of an intense low-pressure system in the Bay of Bengal and the formation of an a mid-troposphere cyclone had an impact on Konkan & Goa rainfall (Singh *et al*., 2001). Metri and Singh, 2010 stated that most of the heavy rainfall events in Goa are due to active off-shore troughs and low-pressure systems formed over the southeast Arabian Sea.

Mooley and Parthasarathy (1984) and Thapliyal and Kulshrestha (1991) observed annual rainfall over the country; the rainfall trend does not give any clear indication. Rajeevan *et al*., (2008) depicted rainfall trend patterns over India from 1901 to 2003 and showed the annual and decadal variation of frequency for rainfall events. Sontakke (2008) concluded that monsoon rainfall has a decreasing trend and post-monsoon rainfall has an increasing trend over India. Rajeevan (2000) mentioned that variations in the sea surface temperature and decadal storms during monsoons over the Bay of Bengal may be there for the change in climate conditions.

Bhandari *et al*. (2016) studied the southwest monsoon over western India and concluded its increasing gradually. Joseph *et al*. (2005) discussed the southwest monsoon weakening trend through peninsular India, alarming for food production and the economy. Arya *et al*., (2018) discussed the trend detection of rainfall in the Alluvial Gangetic Plain of Uttarakhand and found an insignificant increasing trend of 2.638 mm/ year is present

in annual rainfall. Hatwar *et al*., (2005) presented an intense observation period when some pockets of the west coast of India experienced heavy rainfall. Parthasarathy *et al*. (1993) studied homogeneous Indian monsoon rainfall that covers north western and central parts of India, they found out there were 21 dry and 19 wet years from1871 to 1990 years. Ahmed *et al*. (2019) has shown a declining trend has been observed for light to moderate rainfall classes in most places of Bundelkhand. Bera (2017) concluded that the large spatial and temporal variability in the annual and seasonal rainfall trends over the Ganga basin and its sub-basin areas. Western Orissa rainfall is a result of low-pressure systems cyclonic circulation over Orissa to the northwest and the adjacent west central Bay low pressure systems cyclonic circulation.They observe that there was a greater yearly fluctuation in seasonal rainfall between 1980 and 1999 than 1901 and 1990. Based on departures from the mean, Patra *et al*. (2012) observed that since 1950 in Orissa State, there were more dry years than wet years. Jenamani *et al*. (2006) studied the highest rainfall in Mumbai the event was purely a mesoscale system attributed to thunderstorms having a life period of a few hours more ever a synoptic scale event with an intense atmospheric vortex / offshore trough.

The formation and intensification associated with extremely heavy rainfall events over India were studied using different models. Sheriza *et al*. (2011) proposed Thiessen polygon techniques are best for the estimation of annual rainfall. Rajeevan *et al*. (2008) studied empirical orthogonal function analysis of rainfall to explain the spatial distribution of rainfall events over India. Alahacoon *et al*. (2021) explained trends in annual and seasonal rainfall demonstrating Mann-Kendall (M-K) test and finding out trends. Praveen *et al*. (2020) used the Artificial Neural Network-Multi layer Perceptron (ANN-MLP) was employed to forecast the upcoming 15 years of rainfall across India and found out the increasing rainfall trend was observed during the period 1901-1950, while a significant decline in rainfall was detected after 1951. On the annual scale, a significant increasing trend is observed over Konkan & Goa also reported by Rajeevan *et al*. (2008). The decreasing trend in southwest monsoon rainfall over Kerala has also been reported by Francis and Gadgil (2006). The increasing temperature of the earth has a direct impact on cyclones and rainfall activity. Intra-seasonal oscillation (ISO) and Madden and Julian (1994) have concluded that South Kerala rainfall during summer monsoon has large inter-annual variability in the range of 23-64 days. Lawrence and Webster (2001) have stated that ISO Activity is independent of ENSO or Indian monsoon strength. Potdar *et al*., (2019) studied Konkan Goa rainfall from 1951 to 2018 and found 2936.6 mm further it decreased to 2901.73 mm in 1981-2018.

TABLE 1

Monthly and seasonal means of rainfall (mm) over Konkan & Goa from 1901-2020

	Konkan & Goa	1901-2020		
	SD	Normal	CV (%)	Rainfall (%) to annual
Jan	3.81	1.21	314.89	0.04
Feb	2.01	0.53	382.35	0.02
Mar	4.65	1.34	346.88	0.04
Apr	8.94	4.17	214.14	0.15
May	57.38	32.59	176.06	1.08
Jun	195.87	693.08	28.26	23.02
Jul	275.08	1081.23	25.44	35.92
Aug	256.61	692.51	37.06	23.01
Sep	174.50	358.29	48.70	11.90
Oct	89.02	115.43	77.12	3.83
Nov	33.21	24.01	138.33	0.80
Dec	14.04	4.64	302.36	0.15
Annual	513.35	3010.21	17.05	100
Pre-monsoon	57.62	38.27	150.56	1.27
Southwest monsoon	482.09	2825.10	17.06	93.85
Post-monsoon	95.63	144.16	66.34	4.79
Winter	4.31	1.74	247.68	0.06

2. Data used & methodology

For meteorological analysis purposes, the India Meteorological Department (IMD) has divided India into 36 Meteorological sub-divisions. Konkan & Goa is one of the sub-divisions that cover most parts of the West Ghats shown in Fig. 1. The monthly, seasonal & annual rainfall data (in mm) over Konkan & Goa for the period 1901-2020 are archived from the National Data Centre of India, Climate Research & Services, and Pune Meteorological Department. Konkan Goa subdivision consists of Bombay, Kolaba, Ratnagiri, Thana, Sindhudurg, Mumbai, Palghar, North Goa, and South Goa. Konkan extends throughout the western coasts of Maharashtra, Karnataka, and Goa. Konkan & Goa's climate depends on various geographical conditions like surface winds, offshore troughs, and orography. Konkan & Goa lies in the tropical Zone and it is also bordered by the Arabian Sea in the west. Konkan & Goa's climate is moderate and due to that, the Konkan coast has orographic rainfall. Further, it has a moderate monsoon which is one of the main reasons for the state, with July receiving the highest rainfall.

TABLE 2

Linear equations and their significance tested

Rainfall	Linear Equation	Calculated R^2	T-Test	Trend
Annual	y=3.274x+2790.7	R^2=0.219	5.77***	Increasing (significant)
Pre-monsoon	y=-0.072x+42.66	R^2=0.002	0.48	No trend
Southwest monsoon	y=4.247x+2568	R^2=0.093	3.49***	Increasing (significant)
Post-monsoon	y=0.217x+131	R^2=0.006	0.84	Not rend
Winter	y=-0.023x+3.145	R^2=0.035	3.40**	Decreasing (significant)

'**'Indicate significance at95% '***'Indicate significance at 99%

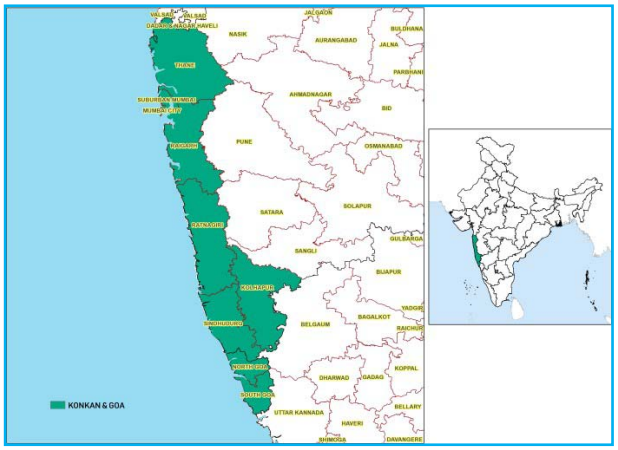

Fig. 1. Location map of Konkan & Goa

Two tests are performed for analysis in this paper - the Mann-Kendall Test and the *T*-test. The Mann-Kendall Test is a non-parametric test used to analyze data collected over time for identifying increasing and/or decreasing trends. *T*-test includes the number of data values of each group, mean values from each dataset, and standard deviation from each group. The output of the *T*-test produces the *t*-values which are compared against the T-distribution table.

3. Rainfall features

Rainfall characteristics of Konkan & Goa are reported in Table 1. The annual normal rainfall over Konkan & Goa from 1901 to 2020 is 3010.21 mm. The coefficient of variation of annual rainfall is 17.05% indicating that is highly stable. Rainfall during the month of July is highest (1081.23 mm) contributing to 35.92%, followed by June (693.08 mm) contributing to 23.02% of annual rainfall. Rainfall in February is at least 0.53 mm and contributes only 0.02% to the annual rainfall. The temporal rainfall pattern on an annual & seasonal scale

TABLE 3

Man-Kend all rank statistics of monthly and seasonal rainfall over Konkan & Goa

Month	M.Ktest VALUE	
JAN	-1.75**	Decreasing (significant)
FEB	-2.37***	Decreasing (significant)
MAR	-1.07	Decreasing
APR	-1.2	Decreasing
MAY	0.39	Increasing
JUN	1.33	Increasing (significant)
JUL	0.86	Increasing
AUG	0.64***	Increasing (significant)
SEP	1.9**	Increasing (significant)
OCT	1.99**	Increasing (significant)
NOV	-1.56	Decreasing
DEC	-0.07	Decreasing
ANNUAL	2.99***	Increasing (significant)
Pre-monsoon	-0.11	Decreasing
Southwest monsoon	3.03***	Increasing (significant)
Post-monsoon	1.47	Increasing
Winter	-2.76***	Decreasing (significant)

'Bold Indicate'-significant trend at 95% '**'Indicate significance at 95% '***'Indicate significant at 99%

over Konkan & Goa is similar to all Indian rainfall (Guhathakurta and Rajeevan, 2008) also supported. The coefficient of variation is also the highest during February at 382.35% followed by March 346.88% and January at 314.89% and the least during July at 25.44% and June at 28.26%. The increasing trend over Konkan and Goa is due to an increase in rainfall in the Southwest monsoon season particularly in July month as shown in Table 3.

TABLE 4

Monthly and seasonal Contribution rainfall (%) to annual from 1901-2020 over Konkan & Goa

Konkan & Goa	1901-1930	1931-1960	1961-1990	1991-2020
Jan	0.07	0.06	0.01	0.03
Feb	0.03	0.02	0.01	0.01
Mar	0.04	0.03	0.01	0.10
Apr	0.15	0.27	0.06	0.08
May	1.02	1.25	1.13	0.94
June	21.42	23.85	23.19	23.64
July	32.68	39.18	34.79	37.02
Aug	19.71	23.03	24.46	24.81
Sep	10.35	12.43	11.23	13.60
Oct	2.93	4.80	3.11	4.50
Nov	0.80	1.02	0.83	0.54
Dec	0.09	0.12	0.26	0.14
Annual	89.30	106.07	99.08	105.56
Winter	0.10	0.07	0.01	0.04
Pre-monsoon	1.20	1.55	1.20	1.13
Southwest monsoon	84.17	98.49	93.67	99.07
Post-monsoon	**3.82**	**5.94**	**4.21**	**5.19**

Rainfall during the south west monsoon (June-September) contributes 93.85% of the annual rainfall this study is supported by. The contribution of post-monsoon, pre-monsoon (March-May) and winter rainfall to the annual is 4.79, 1.27 and 0.06 respectively. The seasonal rainfall during monsoon (June-September) is dependable as the coefficient of variation is 17.06%. At the same time, rainfall during winter is not dependable as the coefficient to f variation is very high 247.68% between 302.36% in December and 314.89% in January. Table 1 shows that the standard deviation (SD) values for the annual, southwest monsoon season are 513 & 482 respectively and SD for June to September varies from 174 to 276.

4. Results and discussion

The rainfall trend of the Konkan & Goa region was studied using annual rainfall data from 1901 to 2020. The main objective of this research work is to explore variability and trends in rainfall. Several researchers have studied rain fall trends in different regions which are limited to monsoon season rainfall. In addition to the monsoon season, we have studied trends for annual, seasonal and major rainfall months. During the winter season, the rain fall was found to have a decreasing trend in Konkan & Goa, as is the case with many parts of India; however, the rainfall trend is increasing during post monsoon season and southwest monsoon season.

4.1. *Annual rainfall trends*

As per the Mann - Kendal Test, the mean annual rainfall over Konkan & Goa shows a significant increasing trend (Table 2) during the period 1901-2020. An increase of 392.91 mm was only noticed during the study period of 120 years as the normal rainfall of 3010.21 mm. A relatively wet period (excess rainfall) was seen during1933-1969 (Fig. 2).

4.2. *Seasonal rainfall trends*

4.2.1. *Pre-monsoon (March-May)*

The pre-monsoon annual rainfall over Konkan & Goa shows no trend (Table 2) during the period 1901-2020. A decline in pre-monsoon rainfall was noticed up to

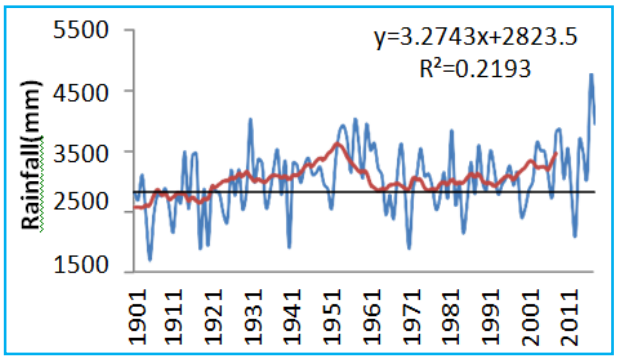

Fig. 2. Annual rainfall trend over Konkan & Goa from 1901 to 2020

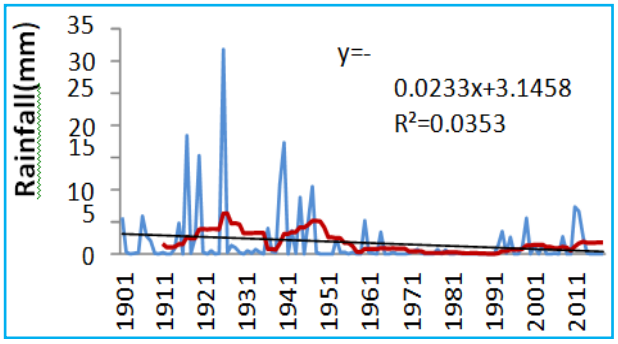

Fig. 3. Rainfall trend during winter over Konkan & Goa from 1901 to 2020

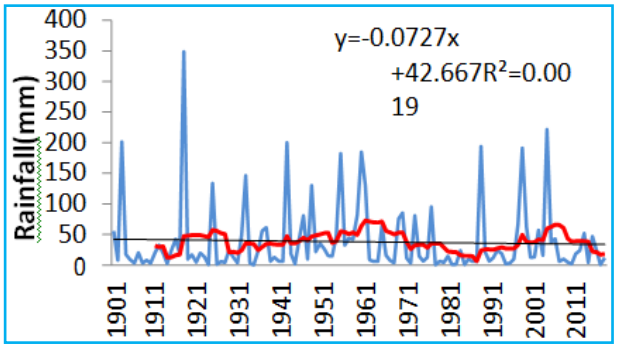

Fig. 4. Same as Fig. 3 for pre-monsoon

mid-1919-1926 then again decreased during the period of 1980-1998. (Fig. 4) A decrease of 8.72 mm has been noticed during the study period of 120 years as against the normal 38.37 mm.

4.2.2. *Southwest monsoon (June-September)*

The southwest rainfall was more during the period of 1935-1971 than against normal while decreasing from 1971-1978. Overall, an increase of 509.64 mm was

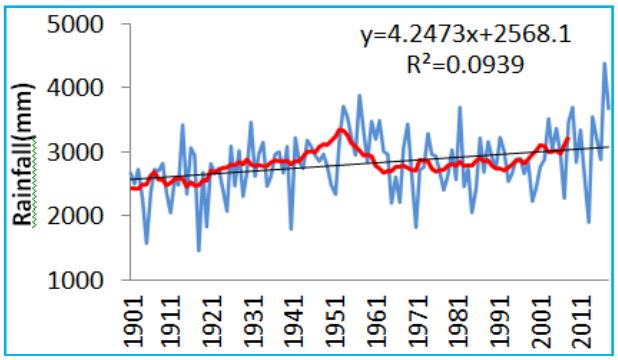

Fig. 5. Same as Fig. 3 for Southwest-monsoon

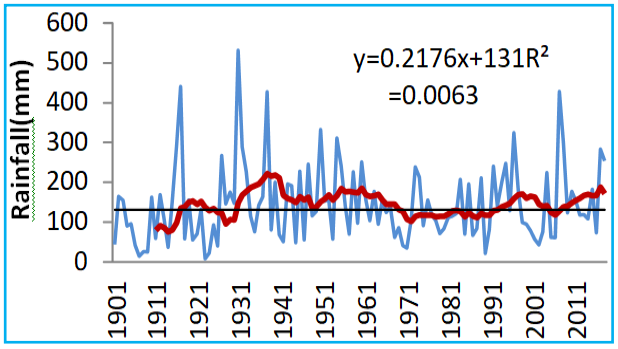

Fig. 6. Same as Fig. 3 for post-monsoon

noticed during the study period of 120 years (Fig. 5). Average heavy rainfall is predominantly high in the Southwest Monsoon season.

4.2.3. *Post-monsoon (October-November)*

Post-monsoon rainfall depicts two epochs of high rainfall around mid-1920 and 1940. The man-Kendal test indicated that the seasonal rainfall during the post-monsoon is 1.47 and *T*-test 0.84. During the study period of 120 years post-monsoon 1955-1964, rainfall increased (Fig. 6).

4.2.4. *Winter (January-February)*

The winter rainfall had a decreasing tendency, which is not statistically significant. The 11- year running mean indicated that winter rainfall increased in 1926 and 1948 (Fig. 3). It also showed the trend line that a decrease of 2.79 mm was noticed during the period of 120 years.

4.3. *Monthly rainfall trends*

Monthly rainfall has been studied for Individual months by man-Kendal test and *T*-test. The results are presented in Table 3. It is interesting to note that rainfall

TABLE 5

Decadal mean (% departure from normal) frequency of excess and deficit rainfall years over Konkan & Goa from 1901-2020

Year	Pre-monsoon (MAM)			Southwest monsoon (JJAS)			Post-monsoon (OND)			Winter (JF)			Annual		
	Decadal mean (% Departure from normal)	Excess	Deficit	Decadal mean (% Departure from normal)	Excess	Deficit	Decadal mean (% Departure from normal)	Excess	Deficit	Decadal mean (% Departure from normal)	Excess	Deficit	Decadal mean (% Departure from normal)	Excess	Deficit
1901-1910	-13.49	1	0	-8.47	0	2	-54.35	0	5	-1.98	0	2	-12.97	0	3
1911-1920	41.06	1	0	-8.01	1	3	-15.20	2	1	141.32	2	3	-9.42	0	3
1921-1930	-41.80	1	0	-2.82	0	2	-38.55	1	3	102.91	1	2	-7.19	0	2
1931-1940	-4.78	1	0	7.21	1	0	25.22	3	0	-2.56	1	2	6.18	1	0
1941-1950	36.49	2	0	5.01	0	1	-26.09	1	1	160.23	3	2	1.71	0	1
1951-1960	37.28	1	0	16.2	4	1	-0.68	3	1	-81.66	0	6	13.32	5	0
1961-1970	32.3	2	0	9.6	3	2	-24.8	1	0	-47.3	0	5	5.8	3	2
1971-1980	-17.0	0	0	-0.8	0	1	-34.5	0	2	-88.5	0	4	-4.9	0	1
1981-1990	-31.6	1	0	3.6	1	1	-29.5	0	0	-95.4	0	8	-0.8	2	1
1991-2000	-6.7	1	0	5.0	0	0	-7.3	3	1	-50.1	0	5	2.1	0	0
2001-2010	25.6	1	0	7.0	3	2	-20.9	2	1	-36.9	0	5	3.5	2	1
2011-2020	-50.3	0	1	18.5	5	1	-11.4	2	0	4.3	2	6	14	5	1

in June, August, September and October showed an increasing trend. While January and February show a decreasing trend. As a whole percentage rainfall contribution during the southwest monsoon and post-monsoon trend was noticed.

4.4. *Analysis of decadal rainfall*

Table 5 depicts the decade-wise percentage departure of annual and seasonal rainfall during the last 120 years over Konkan & Goa. All-India, homogeneous regions, and sub-divisional monsoon rainfall of decadal year have been categorized as Excess, Deficit, and Normal. The excess and deficit years are defined as those years when rainfall is more or less than one standard deviation. The first three decades, *i.e.*, 1901 to 1930, observed a dry period with 7 deficit years and only 1 excess year. During the wet decades of 1951-1960 & 1961-1970, there were 7 excess years and 3 deficit years. Another wet decade was observed during 2001-2010 & 2011-2020 when there was a total of 8 excess years and 3 deficit years. The period 2011-2020 is the wettest decade with a maximum number (05) of excess years. On an annual scale, decadal rainfall shows a total of 18 excess years and 15 deficit years.

Analysis has been carried out on the '30 years as well. The monthly, seasonal, and annual rainfall for the whole period (1901-2020), Period I (1901-1930), Period II (1931-1960), Period III (1961-1990), Period IV (1991-1920) has been categorized for 30 years and is shown in Table 4. Average effective rainfall for 30 years was found and tabulated. From Table 4, it is observed that the average effective rain is higher in the period 1931-1960.

5. Conclusion

An attempt was made to study temporal variation, in monthly, seasonal, annual, and decadal scales over Konkan & Goa. The highest mean monthly rainfall (1081.23 mm) is found during the month of July. The lowest mean monthly rainfall (0.53 mm) is in February during the 120-year period. Konkan & Goa as a whole receives a mean annual rainfall of about 2825.10 mm. The study reveals that the Southwest monsoon contributes 93.85% of the annual rainfall.

During 1901-2020, the Man-Kendall Test and *t*-test analysis of rainfall data over Konkan & Goa indicated a significant increasing trend in annual rainfall data. Seasonal analysis of data for the period 1901–2020 reveals a significant increasing trend (Man-Kendall Test and *t*-test) during the southwest monsoon season over Konkan & Goa, whereas the winter season shows a significant increasing trend (Man-Kendall and *t*-test). On the monthly scale, Rainfall during June, August, September, and October showed a significant increasing trend, whereas January & February showed a significant decreasing trend during the 120-year period of study.

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Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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