

# Impact Analysis of Climate Change on Rainfall and Rainy Days in Konkan Region of Maharashtra

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## Abstract

Present study performs the spatial and temporal trend analysis of annual, seasonal and monthly rainfall and rainy days in the Konkan region of Maharashtra State. Trend analysis was undertaken for rainfall and rainy days of twelve different locations spread over the region. Mann Kendall and Sen's slope test were used to know nature of trend and its magnitude, respectively and results were tested at 90, 95 and 99 per cent confidence levels. Results showed significant increase in rainfall ranges from 26.23 to 38.27 mm year<sup>-1</sup>, however, rainy days were significantly increasing with a meagre value of 0.25 day per year at Wakawali. Results also illustrated that monthly rainfall evidenced significant trends during August, September, November and December. Monthly rainy days also exhibited significant change during May, July, August, September, October and November. Overall, the changes in annual rainfall amount and rainy days were observed in the region. These changes may further influence the water resource availability for agriculture in the region. Mango and cashew crop was also affected by climate change in the region and climatic suitability of these crops was also severely changing in the south part of the Konkan region.

**Keywords:** Mann Kendall, Sen's Slope test, rainfall, rainy days, trend.

## Introduction

Konkan is a coastal strip parallel to Sahyadri hill ranges, which rises from mean sea level to 300 meter height. Konkan region ranges from 27 to 48 km in breadth and about 800 km in length, from Goa to Tapi river basin. Konkan belt is categorized under heavy rainfall and hilly region with annual rainfall ranging from 2300 mm

to 4100 mm. The region receives 46 per cent of total precipitation of the State on just 10 per cent of total area of the State (Anonymous 2013). Rainfall is one of the crucial weather parameters for the climate change detection (Sahu and Khare 2015). Climate change is acting as a trigger for changing rainfall pattern which have significant impacts on hydrological cycle and crop calendar of the region (Mirza and Hussain 2003; Abrol *et al.* 2004). Monocropping with rice cultivation during *kharif* season is generally observed, while the horticulture crops like mango, cashew and coconut are major crops of the region. In last few years, production, productivity and quality of mango especially *Alphonso* variety is adversely affected due to change in different meteorological parameters in the region. Most of the crops in the region are rainfed cultivated. An accurate information of rainfall and its trend is of great importance because of economic implications of rainfall dominated operation (Galkate and Thomas *et al.* 1999). Thus, it becomes very essential to analyse rainfall for its spatial and temporal variation to manage the crops accordingly. Detection of rainfall trend in the region is also necessary to establish link between rainfall and other hydrological components which can provide useful insights into the possible changes in the hydrology of the region and can



Fig. 1. Map showing study area and weather stations.

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**Table 1.** Details of station location, period of data for analysis and source of data acquisition

Sr. No.	Name of location	Latitude	Longitude	Period	Source
1	Suksale	19°55'	73°57'	1982 – 2014	WRDHP <sup>#</sup> , Nasik
2	Bhatsanagar	19°26'	73°48'	1996 – 2014	WRDHP <sup>§</sup> , Nasik
3	Karjat	18°91'	73°33'	1989 – 2014	DBSKKV, Dapoli
4	Pali	18°32'	73°16'	1981 – 2014	WRDHP, Nasik
5	Sudkoli	18°30'	72°59'	1981 – 2011	WRDHP, Nasik
6	Harnai	17°48'	73°50'	1975 – 2008	DBSKKV, Dapoli
7	Dapoli	17°54'	73°18'	1981 – 2014	DBSKKV, Dapoli
8	Wakawali	17°45'	73°17'	1980 – 2015	DBSKKV, Dapoli
9	Karak	16°65'	73°52'	1984 – 2014	WRDHP, Nasik
10	Mulde	16°38'	73°70'	1991 – 2014	DBSKKV, Dapoli
11	Awalegaon	16°26'	73°82'	1982 – 2014	WRDHP, Nasik
12	Vengurla	15°43'	73°42'	1981 – 2011	DBSKKV, Dapoli

# WRDHP- Water Resource Department, Hydrological Project; § DBSKKV- Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth

be helpful for the decision making in the water resource management. Rainfall trends at the smaller spatial scale are more useful for the precision water resource and crop planning. By keeping this in view, present study was undertaken for trend analysis of the annual, seasonal and monthly rainfall and rainy days in Konkan region.

## Material and Methods

### Study area and Data Collection

Present study was undertaken to know trends of rainfall and rainy days for which the daily rainfall data of study locations was collected from department of Agronomy, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli and Water Resource Department, Hydrological Project, Government of Maharashtra, Nasik. Location details, period range of rainfall data and source of data acquisition are tabulated in Table 1 and stations are located on map in Fig. 1. The daily data were converted into seasonal (*kharif* from 23<sup>rd</sup> to 41<sup>st</sup> SMW, *rabi* from 42<sup>nd</sup> to 8<sup>th</sup> SMW and summer from 9<sup>th</sup> to 22<sup>nd</sup> SMW).

The rainy days were calculated by using daily rainfall data. The day receiving  $\geq 2.5$  mm rainfall is considered as rainy day. Rainfall and rainy days were arranged in annual, seasonal and monthly time scales and their statistical parameters such as mean, standard deviation and coefficient of variation were determined. Trend analysis was statistically examined in two phases i.e., initially the presence of a monotonic increasing or decreasing trend was tested using the non-parametric Mann-Kendall test (Mann 1945, Kendall 1995). Then the rate of change was estimated with the help of Sen's slope test (Sen 1968). The slope of the trend line indicates the rate and direction of change (Helsel and Hirsch 2002, Drapela and Drapelova 2011, Choudhury

*et al.* 2012). The results of the trends were tested at 90, 95 and 99 per cent confidence levels.

### Mann-Kendall test (M-K)

Let  $x_1, x_2, \dots, x_n$  represent  $n$  data points where  $x_j$  represents the data point at time  $j$  and  $x_k$  represent the data point at time  $k$ . Then the Mann-Kendall statistic ( $S$ ) is given by the following formula -

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \quad \dots(1)$$

$$\text{sign}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad \dots(2)$$

Statistic  $S$  was approximately normally distributed with the mean (Drapela and Drapelova, 2011) and variance as follows.

$$\text{VAR}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5)] \quad \dots(3)$$

Where,

$q$  = Number of tied groups,

$t_p$  = Number of data values in the  $p^{\text{th}}$  group.

The standard test statistic  $Z$  will be computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad \dots(5)$$

follows

The presence of a statistically significant trend was tested using value of  $Z$ . A positive/negative value of  $Z$  indicates an increasing/decreasing trend. At 90 per

**Table 2.** Trend statistics of annual rainfall and rainy days in Konkan region

Location	Annual Rainfall (mm)					Rainy days				
	Mean	CV	SD	Z	Q	Mean	CV	SD	Z	Q
Suksale	2531.3	20.4	516.2	2.31**	26.23	80.6	11.8	9.5	0.10	0.00
Bhatsanagar	2612.3	21.1	552.5	1.88 *	38.27	87.1	3.0	11.2	0.35	0.18
Karjat	3429.2	21.3	730.1	-0.48	-21.10	90.1	26.5	23.8	-0.60	-0.30
Pali	3464.3	19.7	683.3	0.95	15.61	94.5	10.0	9.4	-0.05	0.00
Sudkoli	3113.6	23.5	732.7	0.53	8.06	89.5	11.8	10.5	0.13	0.03
Harnai	2324.8	25.1	591.1	1.12	9.72	82.4	13.8	11.4	0.64	0.17
Dapoli	3657.9	22.5	824.7	0.11	2.36	98.7	11.3	11.1	1.08	0.27
Wakawali	3732.2	15.8	590.1	1.26	12.63	101.6	9.0	9.1	1.68*	0.25
Karak	4098.0	14.6	599.0	1.37	21.08	110.8	10.1	11.1	1.55	0.29
Mulde	3313.9	15.7	521.6	2.01**	31.86	106.2	9.3	9.9	1.00	0.45
Awalegaon	3706.9	16.2	599.9	-0.03	-1.21	106.8	9.4	10.0	0.03	0.00
Vengurla	2936.9	22.3	654.9	1.1	17.37	95.6	9.7	9.3	1.60	0.31

\*Significance at 90 per cent confidence level; \*\*Significance at 95 per cent confidence level

cent confidence level, the null hypothesis of no trend is rejected if  $|Z| \geq 1.64$ ; at 95 per cent confidence level, the null hypothesis of no trend is rejected if  $|Z| \geq 1.96$ ; and at 99 per cent confidence level, the null hypothesis of no trend is rejected if  $|Z| \geq 2.57$ . The significance in trends were denoted as \*\*\* for 99 per cent confidence level, \*\* for 95 per cent confidence level and \* for 90 per cent confidence level, respectively.

**Sen’s slope estimator**

Magnitude of linear trend (change per unit time) was estimated by using a procedure developed by Sen (1968). The slope of trend gave the rate and direction of change for the considered data (Helsel and Hirsch 2002, Salmi *et al.*, 2002). This means that linear model  $f(t)$  can be described as

$$f(t) = Q_t + B \quad \dots (5)$$

Where,

$Q_t$  = Slope

B = Constant.

To derive an estimate of the slope  $Q_t$  the slopes of all data pairs was calculated

$$Q_t = \frac{x_j - x_k}{j - k}, i = 1,2,3 \dots N, j > k \quad \dots (6)$$

Where,

$x_j$  = Magnitude of sample at  $j^{\text{th}}$  time;

$x_k$  = Magnitude of sample at  $k^{\text{th}}$  time;

$j$  = Succeeding year of data; and

$k$  = Preceding year of data.

If there are  $n$  number of sample values, we get  $x_j$  in time

series as many as slope estimates of  $Q_t$ . The  $N$  number slope values of  $Q_t$  were ranked from the smallest to the largest and the Sen’s estimator is the median of these  $N$  values of  $Q_t$ .

$$Q_t = \begin{cases} Q_{\frac{N+1}{2}} & \text{if } N \text{ is odd} \\ \frac{1}{2}(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}) & \text{if } N \text{ is even} \end{cases} \quad \dots(7)$$

**Results and Discussion**

**Annual variation and trends of rainfall and rainy days**

Annual variation of rainfall and its trend in the Konkan region is presented in Table 2 which varied from  $2324.8 \pm 591.1$  mm  $\text{yr}^{-1}$  at Harnai to  $4098.0 \pm 599.0$  mm  $\text{yr}^{-1}$  at Karak. Amount of annual rainfall received in Northwest and Southeast part of the region was more as compared to Northeast and Southwest part of the region. Karak received annual rainfall more consistently during last 30 years with least 14.6 per cent variation while Harnai showed highest 25.1 per cent variation among the study stations. Similar results were obtained by Naidu *et al.* (1999), Jain and Kumar (2012); Pulak and Saji (2013) and Golekar *et al.* (2016). Decreasing, however, non-significant trend was observed at Karjat and Awalegaon while increasing trend was observed at remaining locations.

Annual average rainy days in the region varied from  $80.6 \pm 9.5$  days  $\text{yr}^{-1}$  at Suksale to  $110.8 \pm 11$  days  $\text{yr}^{-1}$  at Karak (Table 2). The results in Table 2 also revealed that number of annual rainy days were more in South Konkan as compared to the North part of the region. Coefficient of variation showed the most erratic nature of number of rainy days at Karjat, however, this variation was within 15 per cent at other locations. Significant increasing trend of 0.25 day  $\text{yr}^{-1}$  was observed at Wakawali with

90 per cent confidence level. The decreasing, however, non-significant trend was observed at Karjat and Pali stations of North part of the region. Increasing but non-significant trend was exhibited in remaining stations. Number of annual rainy days increased from North to South part of the region. Similar result was reported by Golekar *et al.* (2016). Mandal *et al.* (2013) reported that rainfall amount showed increasing trend and has positive correlation with rainy days in Konkan region.

**Seasonal variation and trends of rainfall and rainy days**

Spatial variation and trend statistics of seasonal rainfall during different season is presented in Table 3. Results revealed that amount of precipitation received in the *kharif* season at all stations was more than 90 per cent of precipitation and remaining precipitation was received during *rabi* and summer seasons. Average rainfall during *kharif* season was in the range of 2247.7 to 3893.5 mm. Rainfall during *kharif* season evinced significant increasing trend at Suksale, Bhatsanagar, Karak and Mulde ranging between 23.36 mm yr<sup>-1</sup> and 35.85 mm year<sup>-1</sup> whereas rainfall during *kharif* season at Karjat and Dapoli showed non-significant decreasing trend. Intensive water conservation practices is needed to implement at Karjat and Dapoli during rainy season which mitigate water scarcity during summer season. Non-significant increasing trend was observed at remaining locations.

Mean rainfall in the region during *rabi* season varied between 12.3 mm and 98.3 mm. Amount of rainfall during *rabi* season increased towards South part of the Konkan region, but this rainfall was very erratic in nature as indicated by the coefficient of variation. Significant increasing rainfall trend at 1.16 mm yr<sup>-1</sup> was observed at Vengurla with 95 per cent confidence level whereas significant decreasing trend of 1.51 mm yr<sup>-1</sup> was observed at Harnai at same confidence level. Out of ten remaining stations, five showed non-significant increasing and five showed non-significant decreasing trend of rainfall during *rabi* season. Rainfall during *kharif* season was reducing at Karjat, Harnai, Dapoli, Wakawali, Karak and Awalegaon which leads to moisture stress and need more supplemental irrigation water. Rainfall during *rabi* season increased at Pali, Mulde and Vengurla which contribute more effectively to crop water requirement.

Rainfall during summer season varied from 3.2 mm at Bhatsanagar to 156.9 mm at Mulde. Rainfall exhibited significant decreasing trend at Wakawali station only. Rainfall during summer season at other stations was non-significant with increasing or decreasing trends. Annual and seasonal variations of rainfall and rainy days are discussed in the previous parts of this paper, in which it was seen that very less amount of rainfall along with the rainy days occur in *rabi* and summer seasons, however, it is very important to assess

**Table 3.** Statistical parameters and trend statistics of seasonal rainfall in Konkan region

Location	Kharif season				Rabi season				Summer season						
	Mean	CV	SD	Z	Q	Mean	CV	SD	Z	Q	Mean	CV	SD	Z	Q
Suksale	2505.3	20.4	511.8	2.4**	26.26	12.3	175.6	21.6	0.00	0.00	13.6	281.6	38.4	-0.50	0.00
Bhatsanagar	2558.5	20.9	534.1	2.16**	35.85	20.3	193.3	39.2	0.00	0.00	3.2	183.9	5.8	0.00	0.00
Karjat	3353.6	22.0	736.5	-0.74	-20.92	46.2	124.0	57.2	-1.14	-1.70	29.4	115.4	33.9	0.68	0.29
Pali	3403.8	19.3	655.7	0.78	12.86	22.7	159.0	36.0	0.63	0.01	37.7	195.8	73.7	0.98	0.00
Sudkoli	3086.5	23.7	729.2	0.25	7.20	10.8	193.0	20.9	0.00	0.00	15.9	319.2	50.8	0.00	0.00
Harnai	2247.7	25.1	563.3	1.09	11.88	46.1	107.5	49.6	-2.10**	-1.51	58.5	189.3	110.8	1.44	0.34
Dapoli	3684.0	20.5	755.4	-0.85	-9.62	55.5	121.3	67.4	-0.51	-0.21	58.2	173.9	101.2	0.35	0.01
Wakawali	3630.1	16.5	600.6	1.34	12.33	56.1	112.1	62.9	-0.27	-0.23	45.7	191.6	87.5	1.75*	0.33
Karak	3893.5	14.1	550.1	1.76*	23.36	83.4	78.6	65.5	-0.47	-0.54	119.1	131.3	156.4	0.35	0.20
Mulde	3081.9	16.4	504.1	1.71*	29.93	75.0	87.4	65.6	0.66	0.67	156.9	92.9	145.7	1.16	3.32
Awalegaon	3546.1	17.2	610.2	0.30	5.08	98.3	109.3	107.4	-1.11	-1.35	90.1	143.2	129.0	0.63	0.44
Vengurla	2872.9	21.9	629.6	0.90	14.38	34.3	165.7	56.8	2.07**	1.16	29.5	102.9	30.3	-0.23	-0.15

\*Significance at 90 per cent confidence level; \*\*Significance at 95 per cent confidence level

the trend of rainfall during these seasons immediately after or before *kharif* season because this rainfall is very important as far as the strategies to cope up with the scarcity of water after monsoon season is concerned (Table 4). Increasing rainfall during summer season reduce moisture stress of mango and cashew crop, it leads to increase the incidence of pest and disease and affect the quality and yield of crop (Datta 2013).

Variation of rainy days during different seasons with their statistical parameters and trends is presented in the Table 4. The data revealed that the rainfall occurs in more than 80 rainy days during *kharif* season, which is more than 90% of the annual rainy days. Remaining rainy days occur during *rabi* and summer seasons. Number of rainy days during *kharif* season varied between 79.5 days at Suksale to 100.7 days at Karak. Rainy days during all seasons didn't show any significant trend of variation in the region.

**Monthly variation and trends of rainfall and rainy days**

Monthly assessment of rainfall variation and its trend was also done for all locations under study are presented in Table 5 and Table 6, respectively. Average monthly rainfall during January, February, March and April was very meagre which was less than 2 mm at most of the stations. South part of the Konkan region receive more rainfall as compared to middle and north part of the region. Suksale and Bhatsanagar stations did not received rainfall during January to April. Rainfall in the month of November was less than 10 mm in the North Konkan whereas it was more than 20 mm in the south part of the region. December month rainfall was less than 5 mm at most of the stations in the region. Rainfall during December to April was very scanty at all the study stations. This situation was good for the mango and cashew cultivation because the plants are on the inflorescence and fruiting stage during these months and no damage is expected due to rainfall during this period. Major rainfall i.e more than 85 per cent amount is concentrated during June to October in the region. Rainfall in the month of June was less than 700 mm in the north part of the region while it was more than 800 mm in the south part of the region at most of the stations. July month received highest rainfall in the Konkan region which was more than 1000 mm at eight stations out of twelve study stations. At most of the station, highest rainfall was observed in the month of July followed by August, June, September and October. The pre-monsoon rainfall is expected in many parts of the region during the month of May. The post-monsoon rainfall i.e. during October and November months did not indicate any significant trend, however, very little but non-significant variation could be seen in both increased and decreased trends. Trend statistic revealed that rainfall during January to July did not evince any significant trend at any of the study station. Significant decreasing rainfall trend was

**Table 4. Statistical parameters and trend statistics of seasonal rainy days in Konkan region**

Location	Kharif season					Rabi season					Summer season				
	Mean	CV	SD	Z	Q	Mean	CV	SD	Z	Q	Mean	CV	SD	Z	Q
Suksale	79.5	11.6	9.2	0.00	0.00	0.7	172.8	1.3	0.0	0.00	0.4	204.4	0.9	0.00	0.00
Bhatsanagar	85.1	12.7	10.8	0.18	0.19	0.9	174.3	1.6	-0.90	0.00	1.1	159.3	1.8	0.73	0.00
Karjat	85.6	26.6	22.8	-0.09	-0.05	2.7	118.2	3.2	-1.18	-0.12	1.8	99.0	1.8	-0.10	0.00
Pali	91.7	9.1	8.4	-0.49	-0.11	1.5	125.7	1.9	0.37	0.00	1.3	149.4	1.9	1.15	0.00
Sudkoli	88.1	11.3	9.9	0.11	0.00	0.8	162.3	1.3	0.43	0.00	0.6	211.3	1.3	0.55	0.00
Hamai	77.6	13.6	10.5	0.53	0.13	2.4	89.2	2.2	-2.03	-0.08	2.3	148.1	3.4	1.16	0.00
Dapoli	92.0	11.8	10.9	0.58	0.14	3.1	75.4	2.3	1.11	0.04	3.6	112.8	4.1	0.72	0.00
Wakawali	95.8	8.5	8.2	1.37	0.22	3.3	80.8	2.7	0.00	0.00	2.4	139.5	3.4	1.19	0.00
Karak	100.7	7.1	7.2	1.60	0.22	4.6	75.6	3.5	0.05	0.00	5.5	89.6	4.9	0.36	0.00
Mulde	94.9	9.3	8.8	1.34	0.34	6.2	57.4	3.6	0.38	0.00	5.0	89.6	4.5	-0.07	0.00
Awalegaon	96.9	10.4	10.0	0.96	0.20	5.7	61.0	3.5	-1.98	-0.13	4.2	84.7	3.6	-0.14	0.00
Vengurla	86.2	10.9	9.4	1.19	0.21	5.1	56.4	2.9	0.69	0.00	4.2	107.2	4.5	0.34	0.00

\*Significance at 90 per cent confidence level; \*\*Significance at 95 per cent confidence level



**Table 5.** Statistical parameters of monthly rainfall in Konkan region

Months		SU	BH	KA	PA	SD	HA	DA	WA	KR	MU	AW	VE
January	Mean	0.0	0.0	1.3	0.3	0.0	0.6	0.2	0.2	0.4	2.4	0.3	0.5
	SD	0.0	0.0	4.4	1.6	0.0	2.3	0.8	1.0	1.7	6.4	1.8	2.1
	CV	0.0	0.0	345.0	556.8	0.0	375.3	407.4	600.0	380.6	271.0	574.5	428.9
February	Mean	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.2	0.0	0.7	0.2	1.9
	SD	0.0	0.0	0.0	0.4	0.0	1.7	0.0	1.2	0.0	2.7	1.3	9.5
	CV	0.0	0.0	0.0	556.8	0.0	583.1	0.0	600.0	0.0	390.3	574.5	508.6
March	Mean	0.0	0.0	0.2	0.0	0.0	0.3	1.8	5.1	6.6	2.4	0.0	0.4
	SD	0.0	0.0	0.7	0.0	0.0	0.9	6.1	18.1	27.1	10.3	0.0	1.9
	CV	0.0	0.0	447.2	0.0	0.0	330.1	348.1	351.4	411.8	437.0	0.0	507.4
April	Mean	0.0	0.7	1.8	1.8	0.0	0.5	0.1	0.5	8.0	7.3	7.0	7.1
	SD	0.0	3.2	5.5	7.5	0.0	2.4	0.4	2.0	21.7	12.9	13.1	21.0
	CV	0.0	435.9	299.2	407.3	0.0	477.4	583.1	422.7	269.8	175.7	186.8	295.7
May	Mean	6.3	8.9	14.8	24.2	2.9	28.9	31.8	21.8	74.9	70.3	53.7	68.6
	SD	33.7	35.1	30.3	67.5	15.6	60.8	59.4	45.2	111.8	95.3	104.3	107.4
	CV	534.9	394.5	205.1	279.2	529.2	210.3	186.8	206.7	149.2	135.6	194.2	156.5
June	Mean	408.1	494.3	544.8	683.1	728.3	630.3	857.1	905.4	897.6	849.1	924.0	857.3
	SD	242.0	300.3	306.2	251.0	291.8	259.6	392.6	324.7	264.6	226.4	262.4	281.0
	CV	59.3	60.7	56.2	36.7	40.1	41.2	45.8	35.9	29.5	26.7	28.4	32.8
July	Mean	994.8	877.8	1248.9	1312.5	1127.7	753.7	1377.3	1346.9	1401.5	1096.1	1208.7	960.4
	SD	301.4	249.1	417.1	353.5	350.9	297.6	367.2	354.0	351.9	333.1	304.9	314.9
	CV	30.3	28.4	33.2	26.9	31.1	39.5	26.7	26.3	24.9	30.4	25.2	32.8
August	Mean	734.3	736.5	1045.6	910.6	779.4	161.1	912.3	899.7	1010.7	681.8	872.7	581.4
	SD	308.1	282.1	472.8	361.2	297.3	146.3	303.7	279.5	224.2	190.0	225.2	269.9
	CV	42.0	38.3	45.2	39.7	38.1	90.8	33.3	31.1	22.2	27.9	25.8	46.4
September	Mean	315.3	355.6	442.5	394.5	390.4	286.3	475.8	396.9	486.0	338.0	393.0	255.7
	SD	235.2	224.0	225.0	204.6	234.1	214.7	231.4	213.9	231.7	187.1	207.4	189.8
	CV	74.6	63.0	50.8	51.9	60.0	75.0	48.6	53.9	47.7	55.4	52.8	74.2
October	Mean	66.7	97.9	108.8	143.5	84.9	69.0	129.3	125.2	216.1	201.4	210.6	151.2
	SD	54.5	70.1	96.8	103.6	75.1	92.1	111.1	100.9	123.5	124.4	162.9	150.9
	CV	81.7	71.7	89.0	72.2	88.5	133.5	85.9	80.6	57.1	61.8	77.4	99.8
November	Mean	0.8	1.8	10.0	0.5	0.0	24.0	18.7	25.4	18.3	35.3	34.3	30.2
	SD	3.2	7.7	18.5	1.9	0.0	42.4	35.4	47.7	30.2	56.8	55.1	40.0
	CV	403.7	435.9	184.8	399.8	0.0	176.8	189.1	187.6	164.6	161.0	160.5	132.4
December	Mean	1.3	1.8	5.8	0.1	0.0	4.7	4.3	4.2	0.5	5.2	3.3	4.1
	SD	7.6	8.3	13.9	0.8	0.0	16.4	13.8	13.5	2.8	21.4	13.0	14.9
	CV	574.5	435.9	239.1	556.8	0.0	346.0	316.9	317.5	547.7	414.4	392.1	362.5

SU: Suksale; BH: Bhatsanagar; KA: Karjat; PA: Pali; SD: Sudkoli; HA: Harnai; DA: Dapoli; WA: Wakawali; KR: Karak; MU: Mulde; AW: Awalegaon; VE: Vengurla

observed at Dapoli ( $-10.53 \text{ mm yr}^{-1}$ ) in the month of August with a 90 per cent confidence level. The results also indicated the significant increasing trend of rainfall during September month was exhibited at Suksale, Bhatsanagar, Wakawali, Karak, Mulde, Awalegaon and Vengurla at a rate between 5.87 to 14.54  $\text{mm yr}^{-1}$ . This is positive indication as far as longevity of water availability in the region is concerned. Rainfall in the month of October also did not exhibit significant trend, whereas significant decreasing trend was observed in the month of November at Harnai. December month rainfall showed significant increasing trend at Vengurla at 90 per cent confidence level. This increasing rainfall would affect the flowering period of mango at Vengurla. Rainfall in the region was shift mainly from June and August months to September at many locations. These trends

are useful for the strategies for flood management, soil erosion control and water conservation and management.

Monthly variation and trend statistics of rainy days is presented in Table 7 and Table 8, respectively, which revealed that number of rainy days during December to April were less than 1 day at most of the stations. Rainfall and rainy days having positive correlation in the region. Significant rainy days were observed only during June to October months. Pre-monsoon rainfall in the month of May was received in the south part of the region which increased significantly at Harnai. Number of rainy days in the month of June varied from 6 days at Karjat to 20.5 days at Vengurla which did not show any significant trend in the region. July month has highest monthly rainy days in the region which varied from 23 days at Harnai to 29

**Table 6.** Trends of monthly rainfall in Konkan region

Months		SU	BH	KA	PA	SD	HA	DA	WA	KR	MU	AW	VE
January	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	-1.1	0.9	0.25
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	Z	0.00	0.00	0.43	0.60	0.00	1.81	0.85	0.06	-0.43	0.92	-0.03	1.73
	Q	0.00	0.00	0.00	0.00	0.00	0.10	0.02	0.00	-0.16	1.5	0.00	1.46
June	Z	0.75	-0.21	-0.55	0.00	-0.77	0.44	0.50	0.15	-0.29	-0.52	-0.54	-0.04
	Q	2.93	-2.86	-9.52	0.2	-6.78	1.49	4.63	0.95	-1.39	-4.86	-3.9	-1.00
July	Z	1.41	1.33	0.00	-0.37	-0.10	-0.09	-1.39	0.91	0.82	0.32	0.45	0.43
	Q	5.77	13.99	0.19	-2.5	-0.82	-0.3	-9.99	6.22	7.98	3.9	1.2	1.95
August	Z	0.82	1.40	-1.00	1.41	0.18	0.36	-1.87*	-1.21	-0.79	0.42	-1.22	-0.24
	Q	4.56	13.21	-23.80	10.5	1.52	0.59	-10.53	-4.46	-4.22	3.02	-5.8	-1.09
September	Z	1.91*	1.67*	0.91	1.56	0.89	0.83	0.18	2.6***	3.03***	2.51**	2.4**	2.72***
	Q	5.87	13.51	3.72	6.97	6.17	2.45	1.08	9.2	14.54	12.78	8.2	11.42
October	Z	0.96	-0.32	-1.31	0.14	0.04	0.48	-0.07	1.26	0.14	0.00	0.14	0.79
	Q	1.12	-1.8	-3.44	0.33	0.07	0.25	-0.14	1.6	0.81	-0.1	0.3	1.27
November	Z	0.00	0.00	-1.61	0.00	0.00	-2.62***	0.00	-0.52	-1.04	1.41	-1.00	0.43
	Q	0.00	0.00	0.00	0.00	0.00	-0.21	0.00	0.00	0.00	0.5	-0.1	0.00
December	Z	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00	0.00	1.89*
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SU: Suksale; BH: Bhatsanagar; KA: Karjat; PA: Pali; SD: Sudkoli; HA: Harnai; DA: Dapoli; WA: Wakawali; KR Karak; MU: Mulde; AW: Awalegaon; VE: Vengurla

\*Significant at 90 per cent confidence level; \*\*significant 95 per cent confidence level; \*\*\*Significant at 99 per cent confidence level

days at Karak. In the north part of the Konkan region rainy days were evinced significant increasing trend in the month of July at Bhatsanagar and Karjat. Rainy days in the month of August was more than twenty days in the region which indicated significant decreasing trend at Karjat, Pali, Wakawali and Awalegaon. Average monthly rainy days in the month of September varied between 10 to 20 days in the region. Significant increasing trend of rainy days were observed in the south part of the Konkan region during September month at Karak, Mulde, Awalegaon and Vengurla. average monthly rainy days was less than 10 in the month of October which showed increasing trend at Vengurla. rainy days during November month was very scanty in the region which exhibited significant decreasing trend at Harnai whereas it was increasing significantly at Mulde. Positive correlation was observed between rainfall and rainy days during most of the months at almost all the stations.

### Conclusions

Dominance of variation in rainfall and rainy days during *kharif* season was observed more prominent on

the annual variation at all study stations in the Konkan region. The assured and uniform distribution was observed in both parameters during *kharif* season at all stations. The annual rainfall and rainy days revealed significant increasing trend at Suksale, Bhatsanagar and Muldhe stations, whereas annual rainy days significantly increased at Wakawali. During *kharif* season rainfall increased significantly at Suksale, Bhatsanagar, Karak and Mulde. Rainfall during *rabi* and summer seasons was very erratic at all study station and significant increasing trend was observed at Vengurla during *rabi* season, while it was decreasing significantly at Harnai. Rainfall and rainy days in the month of September showed more impact of climate change as compared to other months. Significant change in rainy days were observed in the north part of the region during July, whereas it was varied in the south part of the region in the month of September, October and November.

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**Table 7.** Statistical parameters of monthly rainy days in the Konkan region

Months		SU	BH	KA	PA	SD	HA	DA	WA	KA	MU	AW	VE
January	Mean	0.0	0.0	0.2	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1
	SD	0.0	0.0	0.5	0.2	0.0	0.3	0.2	0.2	0.3	0.3	0.3	0.3
	CV	0.0	0.0	287.7	556.8	0.0	326.3	406	600	393.2	270.3	574.5	399.7
February	Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	SD	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0	0.2	0.2	0.9
	CV	0.0	0.0	0.0	0.0	0.0	583.1	0.0	600	0	489.9	574.5	485.8
March	Mean	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.2	0.0	0.0
	SD	0.0	0.0	0.2	0.0	0.0	0.2	0.4	0.4	1.1	0.8	0.0	0.2
	CV	0.0	0.0	491.9	0.0	0.0	406	296.3	268.3	348.6	399.8	0.0	575.7
April	Mean	0.0	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.5	0.5	0.5	0.3
	SD	0.0	0.2	0.4	0.2	0.0	0.4	0.2	0.2	0.9	0.7	0.8	0.7
	CV	0.0	435.9	161.2	387.1	0.0	429.3	406	418.2	190.5	157.3	155.7	227.4
May	Mean	0.2	0.3	0.9	0.7	0.2	1.6	2	1.6	3.5	3.4	2.4	2.8
	SD	0.7	1.0	1.3	1.4	1.1	2.9	3.2	2.5	4.1	3.6	3.7	3.8
	CV	399.8	317.6	144.9	203.2	548	179.5	159.3	162.2	119.7	106.9	152.6	134
June	Mean	13.1	14.3	15.5	16.7	16.7	15.6	19.2	18.8	20	19.2	20.1	20.5
	SD	4.0	4.6	37.2	3.8	4.2	3.8	4.0	4.4	4.1	4.3	3.8	3.1
	CV	30.6	32.1	619.8	22.7	25.5	24.4	20.6	23.2	20.3	22.5	19.1	15.1
July	Mean	25.7	25.5	27.2	27.8	28	23.8	28	28.6	29	28.2	28.2	26.1
	SD	3.2	3.4	10	2.5	2.6	3.5	2.4	2.1	2.0	2.9	2.4	2.4
	CV	12.4	13.3	43.5	9.1	9.2	14.5	8.7	7.2	7.0	10.1	8.6	9.3
August	Mean	24.7	25.4	26.5	26.6	26.4	22.1	27.1	28	28	26.6	27.4	23.5
	SD	3.4	3.1	23.4	2.9	3.6	4.4	3.3	2.6	2.8	3.2	3.0	3.1
	CV	13.7	12.1	292.3	10.9	13.7	19.8	12.1	9.3	9.9	11.9	11.1	13.1
September	Mean	13.1	15.8	16.6	16.2	14.4	13.3	15.4	16.6	18.4	16.3	17.2	13.2
	SD	4.6	5.1	31.3	5.3	5.6	5.8	5.4	5.0	4.8	5.2	5.8	5.5
	CV	34.8	32.3	1041.9	32.6	38.6	43.3	34.9	29.9	26	31.6	34	41.6
October	Mean	3.7	5.6	5.1	6.3	3.8	4.4	5.2	6.2	9.9	9.2	9.0	6.9
	SD	2.4	3.6	69.4	3.5	2.5	3.6	3.4	3.5	4.2	3.8	4.1	3.1
	CV	64	64.7	0.0	55.7	65.1	81.1	66	56.9	42.5	41	46.1	45.6
November	Mean	0.1	0.1	1.0	0.1	0.0	1.1	0.8	1.3	1.0	2.3	2.0	1.8
	SD	0.4	0.2	1.5	0.2	0.0	1.6	1.4	1.7	1.7	2.8	2.6	2.2
	CV	422.8	435.9	150.4	387.1	0.0	150.7	165	124.2	171.2	123.1	131.7	122.8
December	Mean	0.1	0.1	0.3	0.0	0.0	0.3	0.2	0.3	0.2	0.2	0.2	0.3
	SD	0.3	0.5	0.7	0.0	0.0	0.6	0.6	0.6	0.6	0.7	0.6	0.6
	CV	574.5	435.9	210.8	0.0	0.0	233.6	235.3	221.3	401.6	315.8	282.8	203.7

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**Table 8.** Trend statistic monthly rainy days in the Konkan region

Months		SU	BH	KA	PA	SD	HA	DA	WA	KR	MU	AW	VE
January	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
February	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
March	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.2	-1.13	0.3	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
May	Z	0.00	0.00	0.35	0.49	0.00	2.24**	-0.55	0.15	-0.19	0.08	-0.20	0.47
	Q	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.03	0.01	0.04	0.05
June	Z	0.53	0.11	0.05	-0.10	0.00	-0.06	1.02	1.12	-0.29	0.07	-0.02	-1.30
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.1	0.00	0.00	0.00	-0.1
July	Z	0.55	1.77*	2.32**	-0.54	0.53	0.46	1.40	0.62	1.28	0.15	0.89	0.07
	Q	0.01	0.20	0.40	0.00	0.01	0.01	0.1	0.00	0.00	0.00	0.00	0.00
August	Z	-1.41	0.29	-1.81*	-1.65*	-1.46	-0.04	-1.44	-1.88*	-1.46	-0.40	-2.37**	-1.34
	Q	-0.1	0.0	-0.6	-0.1	-0.1	0.0	-0.1	-0.1	-0.1	0.0	-0.1	-0.1
September	Z	0.42	0.32	0.73	0.50	0.96	1.40	1.23	1.44	2.57***	2.57***	2.25**	2.09**
	Q	0.00	0.1	0.3	0.0	0.1	0.2	0.1	0.1	0.2	0.4	0.2	0.2
October	Z	0.72	0.46	-0.82	0.72	0.82	0.06	0.37	1.54	1.25	-0.45	0.30	2.17**
	Q	0.00	0.10	-0.2	0.02	0.03	0.00	0.00	0.1	0.1	0.00	0.00	0.1
November	Z	0.00	0.00	-1.5	0.00	0.00	-2.8***	0.4	0.1	-0.5	2.0**	-0.9	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.1	0.00	0.00
December	Z	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.8	0.00	0.00
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

\*Significant at 90 per cent confidence level, \*\*significant 95 per cent confidence level, \*\*\*Significant at 99 per cent confidence level

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