

Analysis of rainfall by using Mann-Kendall trend, Sen's slope and variability at five districts of south Gujarat, India

NEERAJ KUMAR, C. C. PANCHAL, S. K. CHANDRAWANSHI and J. D. THANKI

Agricultural Meteorological Cell, Department of Agricultural Engineering,

N. M College of Agriculture, Navsari Agricultural University, Navsari- 396 450 (Gujarat), India

(Received 4 August 2016, Accepted 21 November 2016)

e mail : neeraj34012@gmail.com

सार – दक्षिण गुजरात के पाँच जिलों के पिछले 115 वर्षों (1901-2015) के वर्षा के आँकड़ों के आधार पर मेन केण्डल ट्रेण्ड, सेन का स्लोप और समाश्रयण स्लोप (रिग्रेशन स्लोप) से पता चला है कि वलसाड, डांग तथा सूरत में वार्षिक एवं मॉनसून ऋतु की वर्षा में वृद्धि का ट्रेण्ड है जबकि नवसारी एवं भरूच जिलों में कमी की प्रवृत्ति रही। वलसाड, डांग, सूरत, नवसारी तथा भरूच जिलों में मॉनसून ऋतु (ग्रीष्मऋतु) में वर्षा की अस्थिरता / परिवर्तिता क्रमशः 30.1%, 30.9%, 35.9%, 33.3% और 38.6% अभिलेखित की गई है। उच्च भिन्नता-गुणांक (CV) से पता चला है कि वर्षा की भिन्नता समान रूप से नहीं रही है और वर्षा की मात्रा काफी कम रही है। भरूच जिले की वार्षिक और मॉनसून ऋतु के वर्षा के भिन्नता गुणांक (CV) प्रतिशत से पता चला है कि दोनों ऋतुओं में हुई वर्षा की परिवर्तिता काफी अधिक रही है। वलसाड में अधिकतम वर्षा के साथ न्यूनतम भिन्नता गुणांक (CV) अभिलेखित किया गया जबकि वर्षा भिन्नता के आँकड़े बताते हैं कि दक्षिण गुजरात के भरूच से डांग तक के भिन्न-भिन्न जिलों में यह भिन्न-भिन्न रही है। आँकड़े बताते हैं कि दक्षिण गुजरात के डांग जिला में अधिक वर्षा होती है और भरूच जिला में कम वर्षा होती है। अल्प मानक विचलन दर्शाते हैं कि डेटा प्वाइंट्स निर्धारित औसत के काफी नजदीक होते हैं जबकि उच्च मानक विचलन दर्शाते हैं कि डेटा प्वाइंट्स विस्तृत मानों में फैले हुए हैं। इसी प्रकार से डांग जिला में अधिक वर्षा होने के कारण उच्च मानक विचलन (SD) रिपोर्ट किया गया है और भरूच जिला में वर्षा अल्प परिवर्तिता के कारण अल्प मानक विचलन (SD) देखा गया है। दक्षिण गुजरात के सभी पाँच जिलों की भिन्न-भिन्न ऋतुओं जैसे- मॉनसून पूर्व, मॉनसून, मॉनसूनोत्तर तथा शरद ऋतु; में सबसे अधिक वर्षा मॉनसून ऋतु में तथा उसके बाद मॉनसूनोत्तर में देखा गया है। बाकी महीनों में एक प्रतिशत से भी कम वर्षा होती है। वर्षा का माहवार विश्लेषण करने पर पता चला है कि दक्षिण गुजरात के सभी पाँच जिलों में वार्षिक कुल वर्षा में मॉनसून ऋतु के जुलाई माह में सबसे अधिक वर्षा होती है उसके बाद अगस्त तथा जून के महीनों में वर्षा होती है।

ABSTRACT. On the basis of past 115 years (1901-2015) rainfall data of five districts of south Gujarat, the Mann-Kendall trend, Sen's slope and regression slope showed that annual and monsoon rainfall at Valsad, Dang and Surat shows the increasing trend while, that of Navsari and Bharuch districts are declining. The monsoon season (summer monsoon) rainfall variability of Valsad, Dang, Surat, Navsari and Bharuch districts was recorded is 30.1%, 30.9%, 35.9%, 33.3% and 38.6%. The high coefficient of variation (CV) denoted that the variability of rainfall is not equally distributed and the amount of rainfall is lowest. The Bharuch district the annual and monsoon CV per cent denoted that the variability of rainfall in both seasons are very high. Valsad was recorded lowest CV with highest rainfall while the data are represent that variability of rainfall which can varies Bharuch to Dang in different districts of south Gujarat. The data shows that Dang district comes under high rainfall and Bharuch under low rainfall on south Gujarat. A low standard deviation indicates that the data points tend to be close to the mean of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values. Similarly high SD is reported at Dang district because of high range of rainfall and lowest SD is found at Bharuch district because of low rainfall variability. The rainfall distribution different season viz., pre monsoon, monsoon post monsoon and winter season, the highest present contribution of rainfall is observed during monsoon season followed by post monsoon in all the five districts of south Gujarat. Rainfall contribution during remaining months was less than one per cent. While month wise analysis shows during monsoon season highest rainfall per cent contribution to annual rainfall is in July followed by August and June months at all the five districts of south Gujarat.

Key words – Mann-Kendall trend, Sen's slope and rainfall variability.

1. Introduction

Precipitation trend analysis on different spatial and temporal scales has been of great concern during the past

century because of the attention given to global climate change from the scientific community; they indicate a small positive global trend, even though large areas are instead characterized by negative trends (IPCC, 1996).

TABLE 1
Monthly and seasonal means of rainfall (mm) over Valsad, Surat and Dangs for 1901 to 2015

Months/season	Rainfall											
	Valsad				Surat				Dangs			
	Mean (mm)	Standard deviation	CV (%)	Per cent contribution to annual rainfall	Mean (mm)	Standard deviation	CV (%)	Per cent contribution to annual rainfall	Mean (mm)	Standard deviation	CV (%)	Per cent contribution to annual rainfall
January	1.8	3.5	193.8	0.1	0.8	2.3	276.0	0.1	1.3	3.7	288.5	0.1
February	1.0	2.7	278.0	0.1	0.8	2.7	328.1	0.1	0.8	2.6	316.3	0.0
March	1.0	4.5	428.6	0.1	0.8	3.6	484.7	0.1	1.2	3.5	302.6	0.1
April	0.5	1.8	381.3	0.0	0.3	1.2	354.0	0.0	2.2	6.1	273.0	0.1
May	3.0	9.0	300.9	0.2	1.5	3.4	224.4	0.1	3.4	7.0	207.9	0.2
June	327.6	239.6	73.1	17.2	201.0	159.3	79.3	16.3	260.2	200.4	77.0	13.4
July	758.1	308.4	40.7	39.8	488.3	222.6	45.6	39.6	711.7	333.9	46.9	36.7
August	475.2	241.2	50.7	25.0	297.6	183.6	61.7	24.1	567.6	260.6	45.9	29.2
September	278.6	198.8	71.3	14.6	200.0	160.7	80.3	16.2	317.6	222.7	70.1	16.4
October	42.9	76.5	178.3	2.3	30.6	56.1	183.4	2.5	59.2	74.6	126.0	3.1
November	11.7	26.0	223.4	0.6	9.9	24.8	249.4	0.8	14.2	28.0	197.5	0.7
December	1.8	6.4	348.8	0.1	1.5	4.8	331.3	0.1	2.1	6.4	300.1	0.1
Annual (mm)	1903.2	553.9	29.1	100.0	1233.2	434.3	35.2	100.0	1941.4	588.4	30.3	100.0
Pre-monsoon	4.5	9.8	217.2	0.2	2.6	5.0	192.3	0.2	6.8	10.4	153.8	0.3
Monsoon	1833.2	551.2	30.1	96.3	1186.9	425.7	35.9	96.2	1857.0	574.5	30.9	95.7
Post-monsoon	60.4	116.7	193.1	3.2	40.5	60.3	148.8	3.3	73.4	80.8	110.1	3.8
Winter	4.7	7.6	161.9	0.2	3.1	6.2	198.1	0.3	4.2	7.6	181.5	0.2

Extreme events seem to be occurring with increasing frequency over the recent years. The focus on hydro-meteorological conditions is increasing for it holds the key for efficient management of water resources, flood management (Mondal *et al.*, 2012). Rainfall pattern governs the overall cropping pattern, productivity and sustainability of agriculture enterprise. The standard of living and well being of human is largely depends on rainfall intensity and frequency. The knowledge about its probability enables us to deal with the adverse condition faced during the season. Although the subject area of climate change is vast, the changing pattern of rainfall is a topic within this field that deserves urgent and systematic attention, since it affects both the availability of freshwater and food production (Dore, 2005). Indian agriculture continues to be a gamble of the vagaries of monsoon, rainfall being most critical because nearly 70% of the net sown area is still rain dependent Narain *et al.* (2006). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), future climate change is likely to affect agriculture, increase the risk of hunger and

water scarcity, and lead to more rapid melting of glaciers. Bhalme and Mooley (1980), Gregory and Patrthasstry (1986) studied large-scale droughts over India. The rainfall distribution is extremely uneven and irregular as the state located at the peripheral boundary of the main current of South-west monsoon. Recent studies (Khan *et al.*, 2000; Shrestha *et al.*, 2000; Mirza, 2002; Lal, 2003; Min *et al.*, 2003; Dash *et al.*, 2007) show that, in general, the frequency of more intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual amount of precipitation has decreased. Wing Cheung *et al.* (2008) found a significant decline in June to September rainfall (*i.e.*, Kiremt) for the Baro-Akobo, Omo-Ghibe, Rift Valley, and Southern Blue Nile watersheds located in the southwestern and central parts of Ethiopia. Longobardi and Villani (2009) reported the trend appears predominantly negative, both at the annual and seasonal scale, except for the summer period when it appears to be positive in Italy. In recent years, annual rainfall has decreased over the African continent (Morishima and Akasaka, 2010). Batisani and Yarnal

(2010) identified a trend towards decreased rainfall throughout the Botswana, which is associated with decreases in the number of rainy days.

Parthasarathy (1984) found that the monsoon rainfall for the two subdivisions *viz.*, sub-Himalayan West Bengal and Sikkim and the Bihar Plains are having decreasing trends while for the four subdivisions *viz.*, Punjab, Konkan and Goa, West Madhya Pradesh and Telangana are having increasing trends. Using the network of 306 stations and for the period 1871-1984, Kumar *et al.* (1992) identified the areas having decreasing and increasing trends of monsoon rainfall. Analysis of rainfall data for the period 1871-2002 indicated a decreasing trend in monsoon rainfall and an increasing trend in the pre-monsoon and post-monsoon seasons (Dash *et al.*, 2007). According to Sinha Ray and Srivastava (1999), the frequency of heavy rainfall events during the southwest monsoon has shown an increasing trend over certain parts of the country, whereas a decreasing trend has been found during winter, pre-monsoon and post-monsoon seasons. Kumar *et al.* (2010) studied monthly, seasonal and annual trends of rainfall have been studied using monthly data series of 135 years (1871-2005) for 30 sub-divisions (sub-regions) in India. Half of the sub-divisions showed an increasing trend in annual rainfall, but for only three (Haryana, Punjab and Coastal Karnataka), this trend was statistically significant. Similarly, only one sub-division (Chhattisgarh) indicated a significant decreasing trend out of the 15 sub-divisions showing decreasing trend in annual rainfall. Jain *et al.* (2012) reported that rainfall has no any clear trend for the region as a whole, although there are seasonal trends for some seasons and for some hydro-meteorological subdivisions of Northeast India. Guhathakurta and Rajeevan (2007) observed significant decrease in pre-monsoon rainfall for the six subdivisions *viz.*, Gujarat Region, West M. P., East M. P., Vidarbha, Chhattisgarh and Jharkhand. However during the post-monsoon season, rainfall is increasing for almost all the sub-divisions except for the nine sub-divisions. Kumar *et al.* (2009) revealed that there are significant differences in rainfall trends at the regional level.

2. Materials and method

In south Gujarat five locations were chosen for assessment of scarce and excess rainfall intensity and frequency (1) Navsari (23.15° N and 69.49° E, Altitude 11.0m) (2) Bharuch (22.98° N and 70.21° E, Altitude 3.0 m) (3) Surat (22.98° E and 70.21° E, Altitude 3.0 m) (4) Valsad (22.35° N and 72.35°E, Altitude 6.10 m) and (5) Dang (20.51° N and 70.21° E, Altitude 440 m). The historical monthly and annual rainfall data were used of 115 years (1901-2015). By using monthly rainfall data, monthly mean, seasonal averages, Standard Deviation

(SD) and Coefficient of Variation (CV) were computed monthly and season-wise *viz.*, Pre-monsoon (March-May), South-west monsoon (June-September), Post-monsoon (October-November) and Winter (December-February). The data were subjected to find out long term trends. A linear trend line was added to the series for simplify the trends. To support the trends in annual and seasonal rainfall, decade-wise and at 30 years (3-Decades) shifts in rainfall were also analyzed.

2.1. Trend analysis

2.1.1. Mann-Kendall test

The trend analysis and estimation of Sen's slope are done using Kendall (1975) and Sen (1968) method, respectively for the given data sets. Mann-Kendall test is a non-parametric test for finding trends in time series. This test compares the relative magnitudes of data rather than data values themselves (Gilbert, 1987). The benefit of this test is that data need not to confirm any particular distribution. In this test, each data value in the time series is compared with all subsequent values. Initially the Mann-Kendall statistics (S) is assumed to be zero, and if a data value in subsequent time periods is higher than a data value in previous time period, S is incremented by 1, and *vice-versa*. The net result of all such increments and decrements gives the final value of S . The Mann-Kendall statistics (S) is given as:

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

where,

$$\text{sign}(x_j - x_k) = 1,$$

$$\text{if } (x_j - x_k) > 0; 0, \text{ if } (x_j - x_k) = 0; -1 \text{ if } (x_j - x_k) < 0.$$

A positive value of S indicates an increasing trend, and a negative value indicates a decreasing trend. However, it is necessary to perform the statistical analysis for the significance of the trend. The test procedure using the normal approximation test is described by Kendall (1975). This test assumes that there are not many tied values within the dataset. The variance (S) is calculated by the following equation:

$$\text{Var}(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^g t_p(t_p-1)(2t_p+5) \right]$$

where, n is the number of data points, g is the number of tied groups and t_p is the number of data points in the p^{th} group.

The normal Z-statistics is computed as:

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

The trend is said to be decreasing if Z is negative and the computed Z-statistics is greater than the z-value corresponding to the 5% level of significance. The trend is said to be increasing if the Z is positive and the computed Z - statistics is greater than the z-value corresponding to the 5% level of significance. If the computed Z-statistics is less than the z-value corresponding to the 5% level of significance, there is no trend.

2.1.2. Sen's Slope estimator

Simple linear regression is one of the most widely used model to detect the linear trend. However, this method requires the assumption of normality of residuals (McBean and Motiee, 2008). Viessman *et al.* (1989) reported that many hydrological variables exhibit a marked right skewness partly due to the influence of natural phenomena and do not follow a normal distribution. Thus the Sen (1968) slope estimator is found to be a powerful tool to develop the linear relationships. Sen's slope has the advantage over the regression slope in the sense that it is not much affected by gross data errors and outliers. The Sen's slope is estimated as the median of all pair-wise slopes between each pair of points in the dataset (Thiel, 1950; Sen, 1968; Helsel and Hirsch, 2002). Each individual slope (m_{ij}) is estimated using the following equation:

$$m_{ij} = \frac{(Y_j - Y_i)}{(j - i)} \quad (2)$$

where, $i = 1$ to $n-1$, $j = 2$ to n , Y_j and Y_i are data values at time j and i ($j > i$), respectively. If there are n values of Y_j in the time series, there will be $N = n(n-1)/2$ slope estimates. The Sen's slope is the median slope of these N values of slopes. The Sen's slope is:

$$m = m_{\left[\frac{N+1}{2} \right]}, \text{ if } n \text{ is odd}$$

$$m = \frac{1}{2} \left(m_{\left[\frac{N}{2} \right]} + m_{\left[\frac{N+2}{2} \right]} \right), \text{ if } n \text{ is even}$$

Positive Sen's slope indicates rising trend while negative Sen's slope indicates falling trend.

2.1.3. Linear regression analysis

Linear regression analysis is a parametric model and one of the most commonly used methods to detect a trend in a data series. This model develops a relationship between two variables (dependent and independent) by fitting a linear equation to the observed data. The data is first checked whether or not there is a relationship between the variables of interest. This can be done by using the scatter plot. If there appears no association between the two variables, linear regression model will not prove a useful model. A numerical measure of this association between the variables is the correlation coefficient, which range between -1 to +1. A correlation coefficient value of ± 1 indicates a perfect fit. A value near zero means that there is a random, nonlinear relationship between the two variables. The linear regression model is generally described by the following equation:

$$Y = mX + C \quad (3)$$

where, Y is the dependent variable, X is the independent variable, m is the slope of the line and C is the intercept constant. The coefficients (m and C) of the modal are determined using the Least-Squares method, which the most commonly used method. t -test is used to determine whether the linear trends are significantly different from zero at the 5% significance level.

3. Results and discussion

3.1. Annual rainfall features

Rainfall characteristics of south Gujarat are presented Table 1 and 2. Normal highest annual rainfall recorded at Dang district is 1941.4 mm with SD (588.4 mm) and the CV (30.3%), followed by Valsad (1903.2 mm) with SD (553.9 mm) and the CV (29.1%). At Navsari district the normal annual rainfall is 1692.3 mm with standard deviation (548.8 mm) and coefficient of variation (32.4%). The normal lowest annual rainfall observed at Bharuch district is 822.5 mm with SD (303.2 mm) and the CV (36.9%) followed by Surat (1233.2 mm) with SD (434.3mm) and the CV (35.2%). The high CV is denote that the variability of rainfall those area is not equally distributed and the amount of rainfall is lowest. At Bharuch district highest CV (36.9%) with lowest rainfall 822.5 mm and at Valsad district lowest CV (29.1%) is discerned. The data shows that Dang district comes under high rainfall and Bharuch under low rainfall district on south Gujarat. Therainfall distribution

TABLE 2
Monthly and seasonal means of rainfall (mm) over Navsari and Bharuch for 1901 to 2015

Months/season	Navsari				Bharuch			
	Mean (mm)	Standard deviation	CV (%)	Per cent contribution to annual rainfall	CV (mm)	Standard deviation	CV (%)	Per cent contribution to annual rainfall
January	1.5	4.1	275.3	0.1	2.1	5.5	263.8	0.3
February	1.2	3.8	312.5	0.1	1.7	5.6	331.1	0.2
March	0.9	3.3	385.7	0.1	1.7	6.2	356.5	0.2
April	1.1	8.0	750.8	0.1	1.1	5.2	459.4	0.1
May	5.4	14.5	270.2	0.3	5.6	16.0	285.1	0.7
June	285.6	209.3	73.3	16.9	132.0	124.9	94.7	16.0
July	654.6	335.9	51.3	38.7	303.8	156.1	51.4	36.9
August	424.8	235.8	55.5	25.1	189.9	121.0	63.7	23.1
September	265.9	192.9	72.5	15.7	150.6	136.0	90.3	18.3
October	40.8	74.7	183.0	2.4	23.7	49.4	208.4	2.9
November	11.2	24.1	214.9	0.7	8.6	19.9	229.8	1.1
December	1.8	5.1	290.4	0.1	1.7	5.5	326.9	0.2
Annual (mm)	1692.3	548.8	32.4	100.0	822.5	303.2	36.9	100.0
Pre-monsoon	7.3	16.4	224.3	0.4	8.5	21.1	248.6	1.0
Monsoon	1628.6	541.7	33.3	96.2	776.3	300.0	38.6	94.4
Post-monsoon	51.9	78.1	150.3	3.1	35.6	64.2	180.1	4.3
Winter	4.5	7.4	166.6	0.3	5.4	13.3	244.7	0.7

different season *viz.*, pre monsoon, monsoon post monsoon and winter season, the highest present contribution of rainfall is in monsoon season followed by post monsoon and pre monsoon.

3.2. Pre monsoon

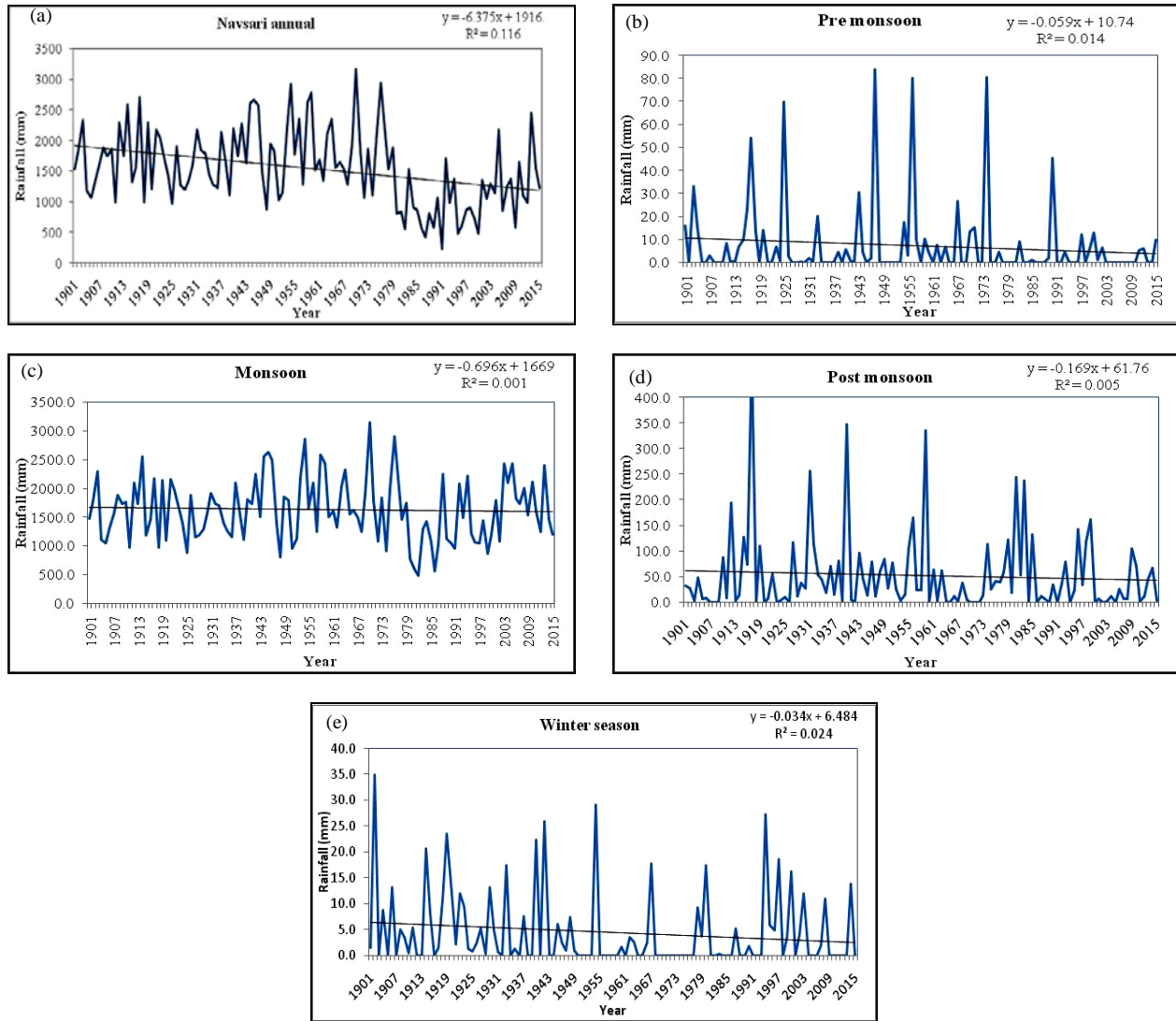
Rainfall characteristics of pre monsoon season at south Gujarat are presented Tables 1 and 2. The highest normal rainfall observed during pre monsoon season of south Gujarat at Bharuch district is 8.5 mm with per cent contribution of annual rainfall (1.0%) and CV (248.6%), followed by Navsari (7.3 mm) with per cent notable inclusion of annual rainfall is (0.4%) and CV (224.3%). At Dang district the pre monsoon rainfall is 6.8 mm with per cent contribution to annual rainfall (0.3%) and CV (153.8%). The pre monsoon season lowest rainfall registered at Surat district is 2.6 mm with per cent addition of annual rainfall only (0.2%) and CV (192.3%), followed by Valsad (4.5 mm) with per cent contribution of annual rainfall (0.2 %) and CV (217.2%).

3.2.1. Dang district

The data analysis of Dang district showed that during pre monsoon season of south Gujarat maximal rainfall in the months of May is 3.4 mm with per cent addition of annual rainfall (0.2%) and CV (207.9%) be subsequent to months of April (2.2 mm) with per cent contribution of annual rainfall (0.1%) & CV (273.0%). The lowest rainfall discerned in the month of March is 1.2 mm with per cent inclusion of annual rainfall (0.1%) and CV (302.6%).

3.2.2. Valsad district

The rainfall in pre monsoon season at Valsad district observed in the months of May is 3.0 mm with per cent addition of annual rainfall (0.2%) and CV (300.9%), followed by months of March (1.0 mm) with per cent contribution of annual rainfall (0.1%) and CV (428.6%). The minimum rainfall perceived in the month of April is 0.5 mm with per cent incorporation of annual rainfall (0.0%) and CV (381.3%).



Figs. 1 (a-e). Annual and seasonal rainfall trends over Navsari from 1901-2015

3.2.3. Navsari district

The pre-monsoon season at Navsari district, the highest rainfall recorded in the months of May is 5.4 mm with per cent incorporation of annual rainfall (0.3%) and CV (270.2%), be subsequent to months of April (1.1 mm) with per cent contribution of annual rainfall (0.1%) and CV (750.8%). The least rainfall is noted in the month of March 0.9 mm with addition of annual rainfall (0.1%) and CV (385.7%).

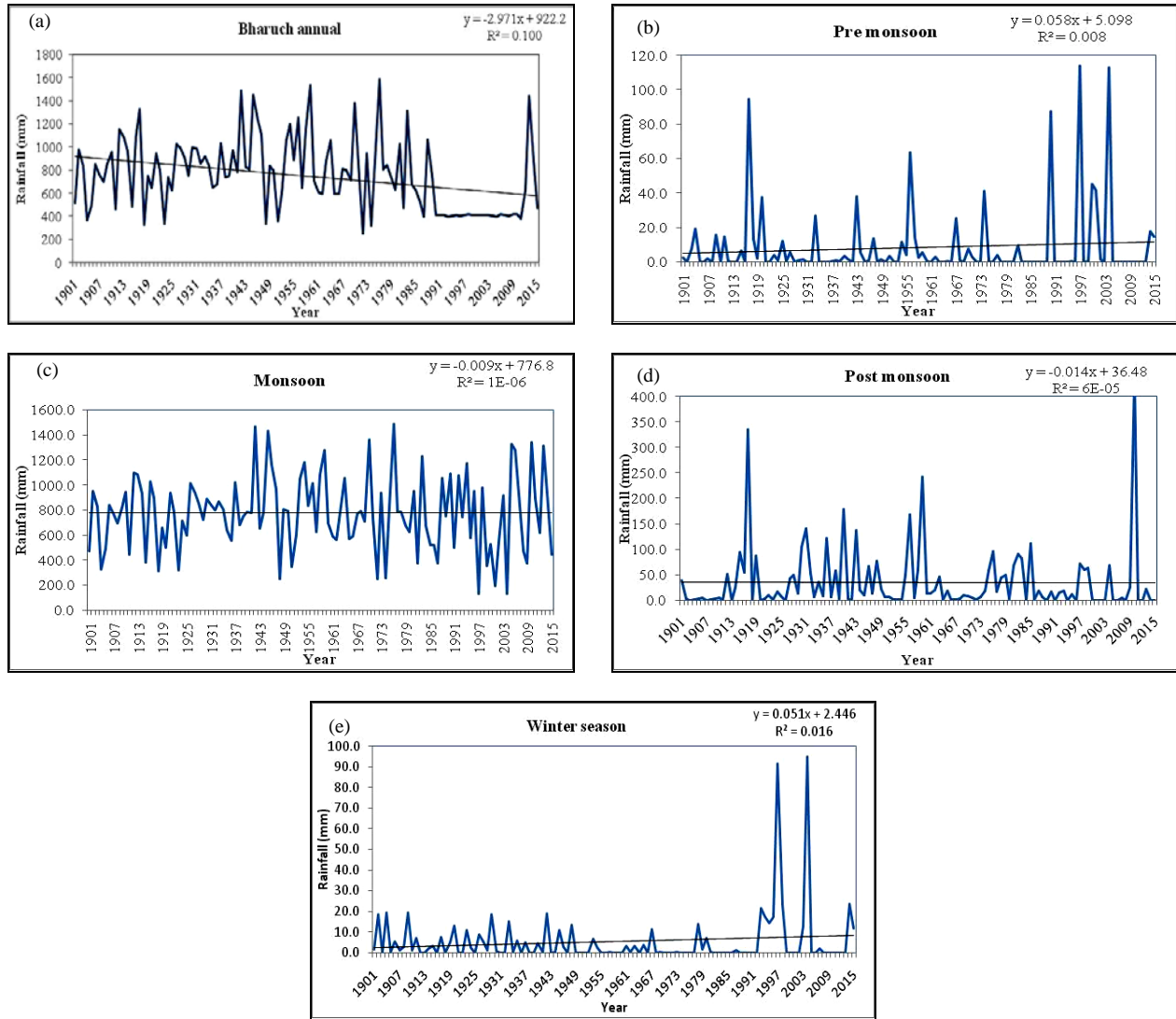
3.2.4. Surat district

At Surat district during pre monsoon season uttermost rainfall noted in the months of May is 1.5 mm with per cent inclusion of annual rainfall (0.1%) and

CV (224.4%) followed by months of March (0.8 mm) with per cent remarkable inclusion of annual rainfall (0.0%) and CV (354.0%). The lowest rainfall discerned in the month of April is 0.3 mm with per cent contribution of annual rainfall (0.0%) and CV (354.0%).

3.2.5. Bharuch district

The pre-monsoon season Dang district, the highest rainfall detected in the months of May is 5.6 mm with per cent contribution of annual rainfall (0.7%) and CV (285.1%), be subsequent to months of March (1.7 mm) with per cent remarkable inclusion of annual rainfall (0.2%) and CV (356.5%). The nethermost rainfall is perceived in the month of April is 1.1 mm with per cent addition of annual rainfall (0.1%) and CV (459.4%).



Figs. 2 (a-e). Annual and seasonal rainfall trends over Bharuch from 1901-2015

3.3. *Monsoon season*

Rainfall characteristics of monsoon season at south Gujarat are presented Tables 1 and 2. The state receives rain under the influence of southwest monsoon only during the four month from June to September. However, the onset, withdrawal and duration of monsoon are not uniform throughout the state. In south Gujarat, the monsoon commences from the middle of June and lasts up to end of October, while in north Gujarat in state a little latter and end by about the middle of September. In Saurashtra region, it commences from second week of June and lasts up to second week of September. The India Meteorological department views Gujarat state as two Sub-divisions, Gujarat region and Saurashtra-Kutch region. The state’s annual average rainfall is

about 820 mm received in 30 rainy days. The annual average rainfall Gujarat region 970 mm received in 43 rainy days, while that of Saurashtra- Kutch region is only 580 mm received in an average in only 23 rainy days. The coefficient of variation (CV %) of rainfall for Gujarat region is 23% and that of Saurashtra-Kutch is 35 per cent. Considering Bharuch-Deesa line, the rainfall in the state decreases towards west of the line (Sahu, 2007).

The monsoon season of south Gujarat, highest rainfall recorded at Dang district is 1857.0 mm with per cent remarkable contribution of annual rainfall (95.7%) and CV (30.9 %), followed by Valsad district (1833.2 mm) with astonishing inclusion of annual rainfall (96.3%) and CV (30.1%) and at Navsari district (1628.6 mm) with per cent contribution to annual rainfall

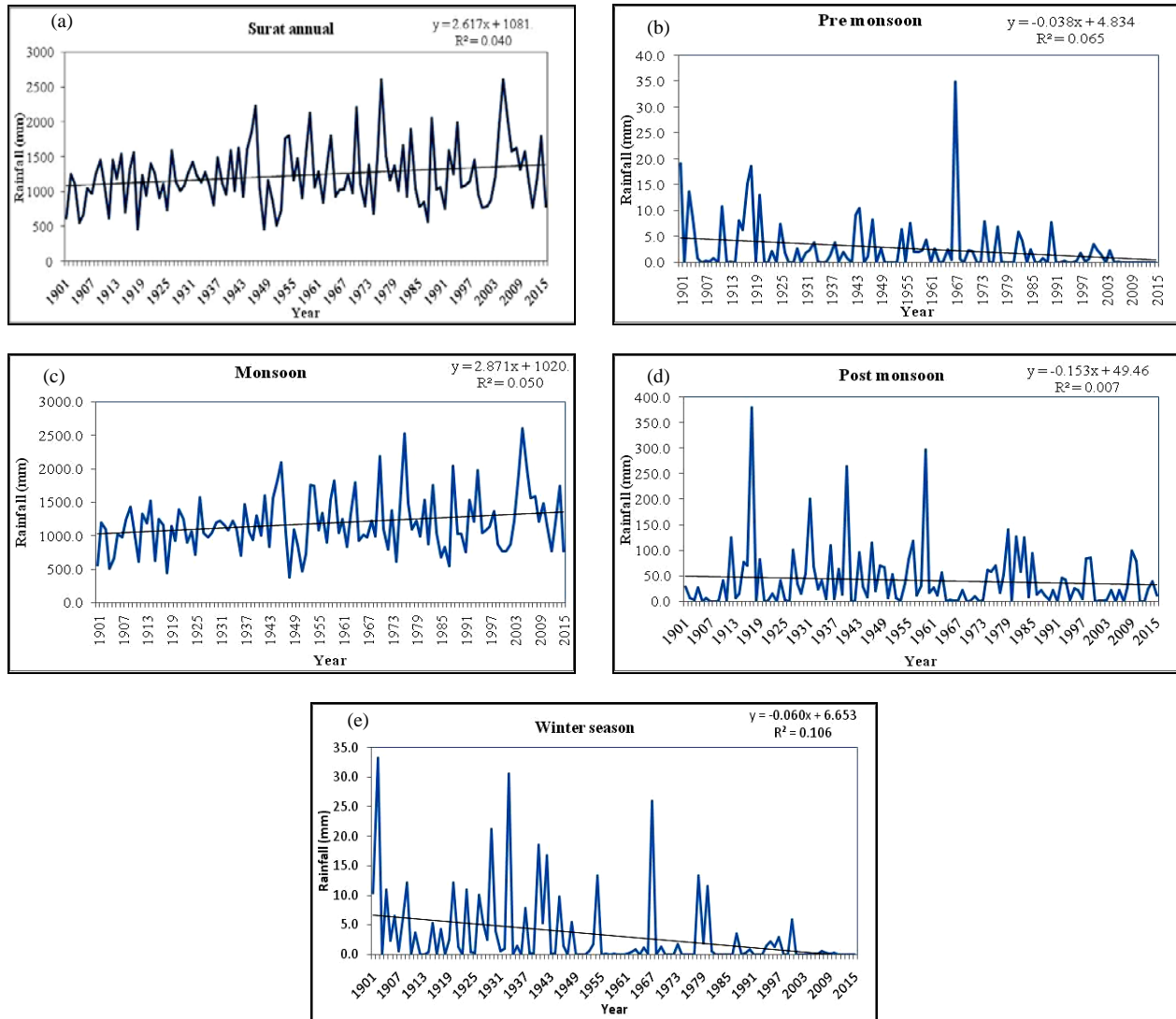


Fig. 3 (a-e). Annual and seasonal rainfall trends over Surat from 1901-2015

(96.2%) and CV (33.3%). As compare to other districts, the monsoon season lowest rainfall observed at Bharuch district is 776.3 mm with per cent notable inclusion of annual rainfall (94.4%) and CV (38.6%), be subsequent to Surat district (1186.9 mm) with per cent significant addition of annual rainfall (96.2 %) and CV (35.9%).

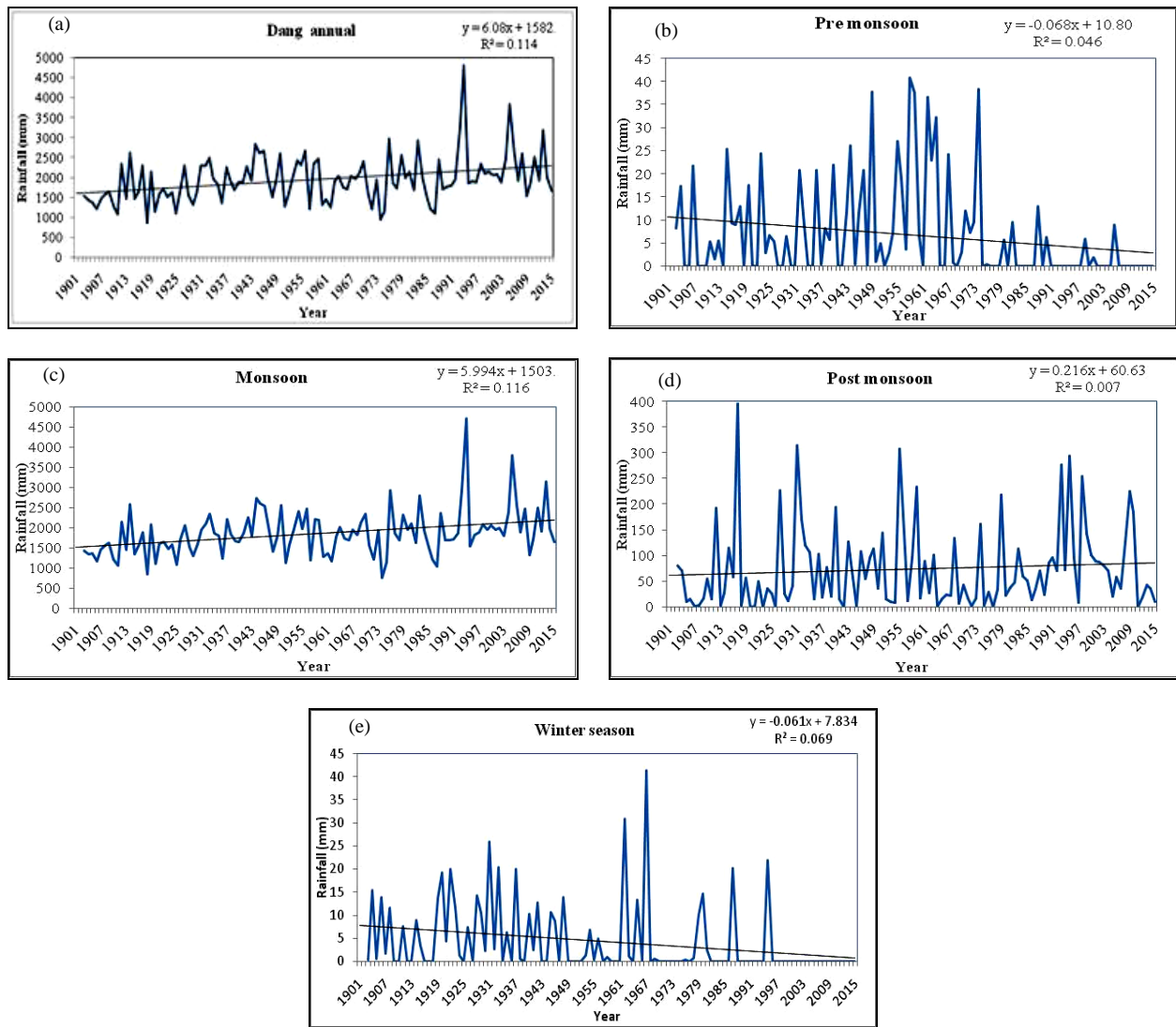
3.3.1. Dang district

During monsoon season at Dang district utmost rainfall recorded in the months of July is 711.7 mm with per cent contribution of annual rainfall (36.7%) and CV (46.9%), followed by months of August (567.6 mm) with per cent notable inclusion of annual rainfall (29.2%) and CV (45.9%) and during September month (317.6 mm) with per cent contribution of annual rainfall is 16.4% along with CV (70.1%). The minimal rainfall

registered in the month of June is 260.2 mm with per cent notable addition of annual rainfall (13.4%) and CV (77.0%).

3.3.2. Valsad district

The monsoon season Valsad district, maximal rainfall recorded in the months of July is 758.1 mm with per cent contribution of annual rainfall (39.8%) and CV (40.7%), be subsequent to months of August (475.2 mm) with per cent significant addition of annual rainfall (25.0%), CV (50.7%) and in June month (327.6 mm) with per cent remarkable incorporation of annual rainfall is 17.2% in addition to CV (73.1%). The least rainfall showed in the month of September is 278.6 mm with per cent incorporation of annual rainfall (14.6 %) and CV (71.3%).



Figs. 4 (a-e). Annual and seasonal rainfall trends over Dang from 1901-2015

3.3.3. *Navsari district*

At Navsari district paramount rainfall observed in the months of July is 654.6 mm with per cent contribution of annual rainfall (38.7%) and CV (51.3%), followed by months of August (424.8 mm) with per cent weighty inclusion of annual rainfall (25.1%) and CV (55.5%) and in June (285.6 mm) with per cent contribution of annual rainfall is 16.9% along with CV (73.3%). The lowest rainfall discerned in the month of September is 265.9 mm with per cent remarkable inclusion of annual rainfall (15.7 %) and CV (72.5%).

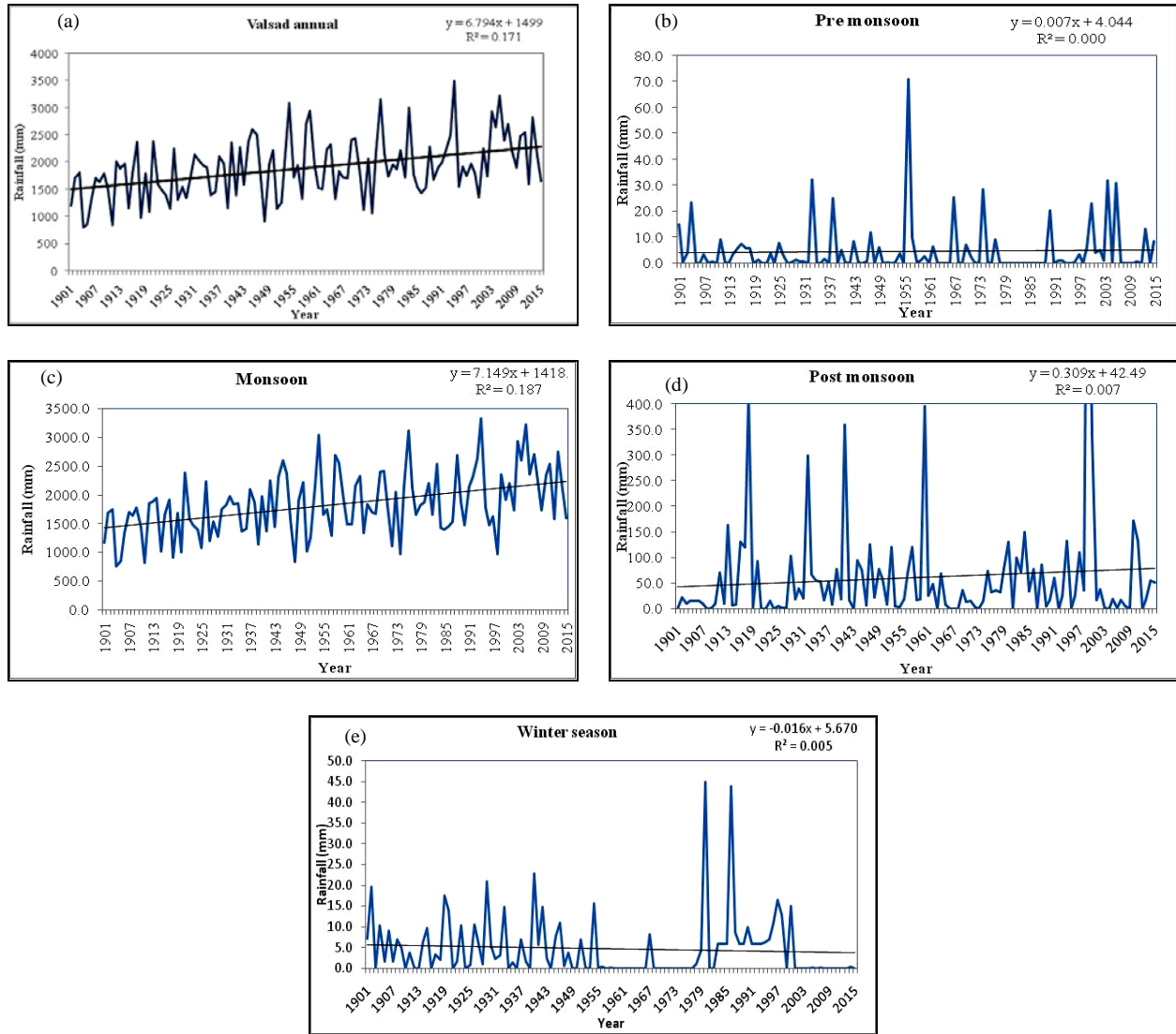
3.3.4. *Surat district*

The uttermost rainfall during monsoon season at Surat district noted in the months of July is 488.3 mm

with per cent noteworthy incorporation of monsoonal rainfall (39.6%) and CV (45.6%), be subsequent to months of August (297.6 mm) with per cent remarkable inclusion of monsoonal rainfall (24.1%) and CV (61.7%) and in June month (201.0 mm) with per cent contribution of monsoonal rainfall is 16.3% including CV (79.3%). The merest rainfall recorded in the month of September is 200.0 mm with per cent contribution of monsoonal rainfall (16.2%) and CV (80.3%).

3.3.5. *Bharuch district*

At Bharuch district in during monsoon season acute rainfall perceived in the months of July is 303.8 mm with per cent contribution of monsoonal rainfall (36.9%) and CV (51.4%), followed by months of August (189.9 mm) with per cent notable addition of monsoonal



Figs. 5 (a-e). Annual and seasonal rainfall trends over Valsad from 1901-2015

rainfall (23.1%) and CV (63.7%) and September (150.6 mm) with per cent contribution of monsoonal rainfall is 18.3% in addition to CV (90.3%). The minimum rainfall recorded in the month of June is 132.0 mm with per cent noteworthy incorporation of monsoonal rainfall (16.0%) and CV (94.7%).

3.4. *Post monsoon*

Rainfall characteristics of post monsoon season at south Gujarat are presented Table 1 and 2. The post monsoon season of south Gujarat, highest rainfall recorded at Dang district is 73.4 mm with per cent contribution of annual rainfall (3.8%) and CV (110.1%), followed by Valsad (60.4 mm) with per cent inclusion of annual rainfall (3.2%) as well as CV (193.1%) and at

Navsari (51.9 mm) with per cent addition of annual rainfall is 3.1% along with CV (150.3%). The post monsoon season lowest rainfall unveiled at Bharuch (35.6 mm) with per cent incorporation of annual rainfall is 4.3% and CV (180.1%), followed by Surat (40.5 mm) with per cent contribution of annual rainfall (3.3%) in addition to CV (148.8%).

3.4.1. *Dang district*

The post monsoon season dang district, highest rainfall noticed in the months of October is 59.2 mm with per cent contribution of monsoonal rainfall (3.1%) and CV (126.0%) and the lowest rainfall recorded in the month of November (14.2 mm) with per cent contribution of monsoonal rainfall is 0.7% along with CV (300.1%).

TABLE 3

Mann-Kendall trend analysis of rainfall at Dang, Valsad, Navsari, Surat and Bharuch from 1901 to 2015

Districts	Season	S - Statistics	Kendall's tau	P Value	Trend	Trend at 5% Significant level
Dang	Pre-monsoon	-1222.00	-0.2221	0.0012	Falling	No
	Monsoon	1519.00	0.2400	0.0001	Rising	No
	Post-monsoon	704.00	0.1114	0.0810	Rising	No
	Winter	-1740.00	-0.336	<0.0001	Falling	No
	Annual	1417.00	0.2323	0.0002	Rising	No
Valsad	Pre-monsoon	-353.00	-0.0605	0.3697	Falling	No
	Monsoon	1769.00	0.2746	<0.0001	Rising	No
	Post-monsoon	276.00	0.0431	0.5002	Rising	No
	Winter	-880.00	-0.1511	0.0250	Falling	No
	Annual	1831.00	0.2842	<0.0001	Rising	No
Navsari	Pre-monsoon	-574.00	-0.1047	0.1285	Falling	No
	Monsoon	-249.00	-0.0386	0.5436	Falling	No
	Post-monsoon	-161.00	-0.0253	0.6945	Falling	No
	Winter	-1000.00	-0.1781	0.0091	Falling	No
	Annual	-247.00	-0.0383	0.5468	Falling	No
Surat	Pre-monsoon	-1090.00	-0.1870	0.0055	Falling	No
	Monsoon	587.00	0.0911	0.1512	Rising	No
	Post-monsoon	-38.00	-0.0059	0.9277	Falling	No
	Winter	-1630.00	-0.2810	<0.0001	Falling	No
	Annual	543.00	0.0843	0.1844	Rising	No
Bharuch	Pre-monsoon	-936.00	-0.1634	0.0160	Falling	No
	Monsoon	-235.00	-0.0364	0.5666	Falling	No
	Post-monsoon	-441.00	-0.0696	0.2796	Falling	No
	Winter	-891.00	-0.1534	0.0229	Falling	No
	Annual	-265.00	-0.0411	0.5179	Falling	No

3.4.2. Valsad district

At Valsad district during post monsoon season highest rainfall recorded in the months of October is 42.9 mm with per cent contribution of monsoonal rainfall (2.3%) and CV (178.3) and the lowest rainfall perceived in the month of November (11.7 mm) with per cent contribution of monsoonal rainfall is 0.6% and CV (223.4%).

3.4.3. Navsari district

Highest rainfall at Navsari district discerned in the months of October is 40.8 mm with per cent contribution of monsoonal rainfall (2.4%) and CV (183.0) and the lowest rainfall recorded in the month of November (11.2 mm) with per cent contribution of monsoonal rainfall is 0.7% and CV (214.9%).

3.4.4. Surat district

The post monsoon season at Surat district, highest rainfall registered in the months of October is 30.6 mm with per cent contribution of monsoonal rainfall (2.5%) and CV (183.4%) and the lowest rainfall showed in the month of November (9.9 mm) with per cent contribution of monsoonal rainfall is 0.8 % and CV (249.4%).

3.4.5. Bharuch district

The post monsoon season Bharuch district, highest rainfall documented in the months of October is 23.7 mm with per cent contribution of monsoonal rainfall (2.9%) and CV (208.4) and the lowest rainfall was revealed in the month of November (8.6 mm) with per cent contribution of monsoonal rainfall is 1.1% and CV (229.8%).

TABLE 4
Sen's slope estimator of rainfall at Dang, Valsad, Navsari, Surat and Bharuch from 1901 to 2015

Districts	Season	Sen's Slope	Trend	Confidence limits for slope at 5% Significance Level	Regression Slope
Dang	Pre-monsoon	0.000	No Trend	Lower Limit = 0.000;Upper Limit = 0.000	-0.068
	Monsoon	5.068	Rising	Lower Limit = 4.060;Upper Limit = 6.074	5.994
	Post-monsoon	0.226	Rising	Lower Limit = 0.121;Upper Limit = 0.334	0.216
	Winter	0.000	No Trend	Lower Limit = 0.000;Upper Limit = 0.000	-0.061
	Annual	5.122	Rising	Lower Limit = 4.188;Upper Limit=6.304	6.08
Valsad	Pre-monsoon	0.000	No Trend	Lower Limit = 0.000;Upper Limit = 0.000	0.007
	Monsoon	6.817	Rising	Lower Limit = 5.731;Upper Limit = 8.047	7.149
	Post-monsoon	0.027	Rising	Lower Limit = 0.000;Upper Limit = 0.094	0.007
	Winter	0.000	No Trend	Lower Limit = -0.001;Upper Limit = 0.000	-0.016
	Annual	7.217	Rising	Lower Limit = 6.056;Upper Limit = 8.287	6.794
Navsari	Pre-monsoon	0.000	No Trend	Lower Limit = 0.000;Upper Limit = 0.000	-0.059
	Monsoon	-0.902	Falling	Lower Limit = -1.967;Upper Limit = 0.329	-0.696
	Post-monsoon	-0.002	Falling	Lower Limit = -0.049;Upper Limit = 0.001	-0.169
	Winter	0.000	No Trend	Lower Limit = 0.000;Upper Limit = 0.000	-0.034
	Annual	-0.985	Falling	Lower Limit = -2.196;Upper Limit = 0.225	-6.375
Surat	Pre-monsoon	0.000	No Trend	Lower Limit = -0.002;Upper Limit = 0.000	-0.038
	Monsoon	1.666	Rising	Lower Limit = 0.756;Upper Limit = 2.650	2.871
	Post-monsoon	0.000	No trend	Lower Limit = -0.027;Upper Limit = 0.020	-0.153
	Winter	-0.005	Falling	Lower Limit = -0.008;Upper Limit = -0.002	-0.060
	Annual	1.579	Rising	Lower Limit = 0.632;Upper Limit = 2.515	2.617
Bharuch	Pre-monsoon	0.000	No Trend	Lower Limit = 0.000;Upper Limit = 0.000	0.058
	Monsoon	-0.544	Falling	Lower Limit = -1.284;Upper Limit = 0.240	-0.009
	Post-monsoon	-0.016	Falling	Lower Limit = -0.031;Upper Limit = 0.000	-0.014
	Winter	0.000	No Trend	Lower Limit = -0.001;Upper Limit = 0.000	0.051
	Annual	-0.657	Falling	Lower Limit = -1.334;Upper Limit = 0.178	-2.971

The per cent contribution of winter rainfall to the annual at Bharuch, Navsari, Surat, Dang and Valsad districts are 0.7, 4.5, 0.3, 0.3 and 0.2, respectively. Rainfall contributions during remaining months were less than one per cent. The coefficient of variation is also very high during non-monsoonal period.

3.5. Annual Mann-Kendall and Sen's slope trends of rainfall

The mean annual rainfall over longer run for south Gujarat revealed significant increase in rainfall trend, the highest increasing trend was showed that Valsad district with an annual rate of 6.794 mm per year, with the R^2 (0.171), followed by Dang an annual rate of 6.08 mm

per year, with the R^2 (0.144) and Surat with an annual rate of 2.617 mm per year, with the R^2 (0.040). The mean annual rainfall for south Gujarat also documented significant decreasing in rainfall trend, the decreasing rainfall trend was found at Navsari district with an annual rate of -6.375 mm per year with the R^2 (0.116), followed by Bharuch - (2.971 mm) per year with the R^2 (0.100) [Figs. 1(a) to 5(a)].

The Mann-Kendall analysis shows annual basis increasing trend of rainfall in Valsad with Mann-Kendall tau coefficient shows rising (0.2842) with Sen's slope (7.217), followed Dang (0.2323) with Sen's slope (5.122) and at Surat (0.0843) with Sen's slope (1.579) respectively. The trends shows non significantly

increasing trend at 5% significant level. The decreasing trend was found at Navsari and Bharuch districts with Mann-Kendall tau coefficient (-0.0383) with Sen's slope (-0.985) and (-0.0411) with Sen's slope (-0.657) respectively (Tables 3 and 4).

The *P* value shows the all the districts for all season there is a trend in the series. The Sen's slope and regression slope showed that same result for all the five respective districts of south Gujarat. Similar finding was found that the rainfall trend is falling while in some cases rainfall trend rising. There is no significant rising/falling trend in Sagar Madhya Pradesh (Singh and Kumar, 2016).

3.6. Seasonal rainfall features

3.6.1. Pre-monsoon (March-May)

The significant increasing trend was noticed at Bharuch district with the annual rate of rate of 0.058 mm, with the R^2 (0.008), and at Valsad the rate of 0.007 mm per year with the (R^2 0.00). The decreasing rainfall trends were found at Navsari, Dang and Surat with the rate of -0.059, -0.068 and -0.038 mm per year with the R^2 0.014, 0.046 and 0.065, respectively [Figs. 1(b) to 5(b)].

The analysis of Mann-Kendall test shows decreasing trend with Sen's slope 0.000 at all the five districts.

3.6.2. Southwest monsoon (June-September)

The highest increasing trends was perceived that at Valsad district with the rate of 7.149 mm per year, with the R^2 (0.187), followed by Dang with increasing rate of 5.994 mm per year, with the R^2 (0.116) and Surat with the rate of 2.871 mm per year, with the R^2 0.050 (Kumar *et al.*, 2015; Jaswal and Rao, 2010; Jasawl *et al.*, 2015; Basu *et al.*, 2004) the highest trend of monsoon rainfall anomalies of increasing nature is noticed. The decreasing rainfall trend was found that Navsari with the rate of -0.696 mm per year with the R^2 (0.001), followed by Bharuch -0.009 mm per year with the R^2 (1E - 06) [Figs. 1(c) to 5(c)].

The monsoon season analysis of data as per the Mann-Kendall test revealed increasing trend of rainfall in Valsad district the Mann-Kendall tau coefficient shows rising (0.2746) with Sen's slope (6.817) followed by Dang (0.2400) with Sen's slope (5.068). At Surat district the Mann-Kendall tau coefficient shows rising (0.911) with Sen's slope (1.666). At Valsad, Dang and Surat districts trends were not significant at 5% level. The decreasing trend was found at Navsari and Bharuch districts the Mann-Kendall tau coefficient shows falling in respect to monsoon season (-0.0386) with Sen's slope (-0.902)

and (-0.0364) with Sen's slope -0.544, respectively. The Navsari and Bharuch trends were not significant at 5% level (Tables 3 and 4).

3.6.3. Post-monsoon (October-November)

The significant increasing trend at Valsad district was documented the rate of 0.309 mm per year, with the R^2 (0.007) and Dang the rate of 0.216 mm per year, with the R^2 (0.007). The mean post-monsoon rainfall also showed decreasing in rainfall trend, the decreasing rainfall trends were found at Navsari, Bharuch and Surat with the rate of -0.169, -0.001 and -0.153 mm per year with the R^2 0.005, 6E-05 and 0.007 [Figs. 1(d) to 5(d)].

During post monsoon season at Valsad and Dang districts the Mann-Kendall tau coefficient shows rising trend (0.0431) with Sen's slope (0.027) and 0.2400 with Sen's slope 0.1114 respectively. All through during post monsoon season at Navsari, Surat and Bharuch districts the Mann-Kendall tau and Sen's slope shows falling trend with coefficients -0.0253, -0.0059 and -0.0696 and -0.002, 0.000 and -0.016 respectively. The Mann-Kendall test shows non significant trend at Valsad, Dang, Surat, Navsari and Bharuch districts at 5% level (Tables 3 & 4).

3.6.4. Winter (December-February)

The winter rainfall registered increasing trend at Bharuch district with the rate of 0.051 mm per year, with the R^2 (0.016) respectively. The mean winter rainfall over longer run for south Gujarat showed decreasing in rainfall trend, the decreasing rainfall trend was found that Navsari, Dang, Valsad and Surat with the rate of -0.034, -0.061, -0.016 and -0.060 mm per year with the R^2 0.024, 0.069, 0.005 and 0.106, respectively [Figs. 1(e) to 5(e)].

The analysis of Mann-Kendall test shows decreasing trend with meager Sen's slope at all the five districts (Tables 3 and 4).

3.7. Patterns of rainfall at 3-Decades (3-D_s)

3.7.1. Dang district

At Dang district during monsoon season 30 years or 3-Decades (3-D_s) (1961-90) high rainfall per cent contribution (96.80%) revealed followed by (1901-30) with 95.78% and (1991-15) with 95.64%. While month wise monsoon season shows highest rainfall per cent notable inclusion of annual rainfall is in July month (1901-2015) followed by August and June months. Rainfall variability of June month slightly varies of all, 3-D_s ranges between 12.18% to 15.55, for rainfall per cent notable addition of annual rainfall and it is noticed that

increasing pattern of rainfall in all decades. In month of July rainfall variability of per cent significant addition of annual rainfall in past two, 3-D_s were increased 37.64% and 38.79% in 1901-30 and 1931-60 respectively then after decreasing pattern 36.47% and 32.79% in 1961-90 in 1991-2015 respectively were reported. In case of August month it was found that rainfall variability on per cent remarkable inclusion of annual rainfall in two 3-D_s were decreasing 28.70% and 26.23% in 1901-30 and 1931-60 respectively then after increasing pattern (32.11%) in 1961-90 and slightly decrease (31.07%) in 1991-2015 was noticed. In the month of September rainfall variability on per cent significant addition of annual rainfall registered that 18.02% in, 3-D_s (1931-60) then after it was decreasing in both of two, 3-D_s. The results clearly indicated that at Dang district there is an increase in monsoonal rainfall in all the months viz., June, July, August and September. The, 3-D_s wise rainfall per cent noteworthy incorporation to annual rainfall documented that the pre monsoon and winter season was in decreasing trend in all the, 3-D_s. While, in all previous, 3-D_s post monsoon rainfall per cent contribution of annual rainfall was found on lower side except in (1991-2015) (Table 5).

3.7.2. Valsad district

During monsoon season at Valsad district, in (1961-90) high rainfall per cent contribution was reported in annual rainfall (97.47%) be subsequent to 1901-30 (96.55%) and 1991-15 (95.76%). Month wise monsoon season analysis shows that highest rainfall per cent noteworthy incorporation of annual rainfall in July month (1901-2015) followed by August and June month. Rainfall variability of June month for per cent significant addition of annual rainfall slightly varies of all, 3-D_s ranges between 15.48% to 18.36% with increasing pattern of rainfall in all, 3-D_s. The month of July shows rainfall variability in terms of per cent remarkable inclusion of annual rainfall was 41.99% (1991-30) then after decreasing pattern. In case of August month it was found that rainfall variability on per cent significant addition of annual rainfall 27.27% (1961-90) was higher side then before and after, 3-D_s it was on lower side. Data analysis revealed that the September month rainfall variability on per cent notable addition of annual rainfall was 15.45% (1931-60) in while before and after, 3-D_s it was on lower side. The results clearly indicated that an increase in monsoonal rainfall at Valsad district for all the months viz., June, July, August and September. The, 3-D_s wise rainfall per cent notable inclusion of annual rainfall revealed that in pre monsoon and winter, it was decreasing on all, 3-D_s. The post monsoon rainfall per cent contribution showed that (1931-60) was higher side 3.91% and previous and after all, 3-D_s, it was on lower side Table 5.

3.7.3. Navsari district

Data analysis revealed that during monsoon season at Navsari district in (1991-2015) high rainfall per cent contribution of annual rainfall (97.26%) followed by 1961-90 (96.61%) and during 1901-30 (96.02%) was reported. While month wise monsoon season analysis shows highest rainfall per cent notable inclusion of annual rainfall in July (1901-2015) followed by August and June month. Rainfall variability of per cent notable addition of annual rainfall in June month slightly varies of all, 3-D_s ranges between 14.71% to 20.79 and it was revealed that increasing pattern of rainfall in all, 3-D_s. Similarly, in month of July rainfall variability of per cent significant addition for annual rainfall first two, 3-D_s were increased 40.80% and 41.07% during 1901-30 & 1931-60 respectively then after decreasing patterns 34.57% and 37.65% in 1961-90 & 1991-2015 were reported. In case of August month it was found that rainfall variability on per cent remarkable inclusion of annual rainfall 28.03% (1961-90) was higher side while before & after, 3-D_s it was on lower side. The month of September rainfall variability on per cent significant addition of annual rainfall was showed that a high 17.22% in (1991-2015), 3-D_s then before it was on decreasing trend. The results clearly indicated that an increase in monsoonal rainfall at Navsari for all the months viz., June, July, August and September was reported. The, 3-D_s wise rainfall per cent contribution of annual rainfall shows that in pre monsoon and winter season, it was decreasing on all, 3-D_s. While, in all previous, 3-D_s post monsoon rainfall per cent noteworthy incorporation of annual rainfall was found on lower side except in (1961-90) (Table 5).

3.7.4. Surat district

The analysis of monsoon season data shows at Surat district in (1991-2015), 3-D_s high rainfall per cent notable inclusion of annual rainfall 97.99% be subsequent to 1961-90 (96.91%) and 1901-30 (95.61%) was reported. In month wise monsoon season shows highest rainfall per cent notable addition of annual rainfall in July month (1901-2015) followed by August and June months. Rainfall variability of per cent significant addition of annual rainfall in June month varies of all, 3-D_s ranges 14.32% to 42.47%, respectively and it was shows that decreasing pattern of rainfall in all, 3-D_s. In month of July rainfall variability of per cent remarkable inclusion of annual rainfall was increasing pattern 20.76% and 38.11% in 1901-30 and 1931-60 respectively and 37.63% and 40.73% in 1961-90 and 1991-2015 respectively. In case of August month rainfall variability of per cent significant addition of annual rainfall was increasing pattern 15.11% and 23.96% in 1901-30 and 1931-60 and 26.99% and 24.39% in 1961 - 90 & 1991 - 2015 respectively while in

TABLE 5

Monthly and seasonal contribution of rainfall (%) to annual over Navsari, Bharuch, Surat, Valsad and Dang from 1901 to 2015

Months/season	Navsari				Bharuch			
	1901-30	1931-60	1961-90	1991-2015	1901-30	1931-60	1961-90	1991-2015
June	14.71	14.87	18.06	20.79	18.86	12.72	16.89	16.27
July	40.80	41.07	34.57	37.65	39.20	37.97	32.73	37.85
August	26.65	23.86	28.03	21.60	20.21	23.03	28.26	20.41
September	13.87	15.55	16.50	17.22	15.98	19.67	17.71	19.91
October	2.30	3.32	1.95	1.85	3.47	4.49	1.75	1.30
November	0.70	0.61	0.88	0.45	0.59	1.06	1.69	0.82
Pre-monsoon	0.57	0.50	0.45	0.16	1.03	0.73	0.77	1.77
Monsoon	96.02	95.35	96.61	97.26	94.25	93.40	95.58	94.44
Post-monsoon	3.00	3.93	2.81	2.30	4.06	5.55	3.45	2.12
Winter	0.41	0.22	0.14	0.29	0.67	0.33	0.20	1.67

Months/season	Surat				Valsad			
	1901-30	1931-60	1961-90	1991-2015	1901-30	1931-60	1961-90	1991-2015
June	42.47	14.32	17.04	16.77	16.90	18.02	15.48	18.36
July	20.76	38.11	37.63	40.73	41.99	39.86	40.12	37.79
August	15.11	23.96	26.99	24.39	23.73	22.21	27.27	26.47
September	2.77	18.23	15.25	16.10	13.93	15.45	14.61	14.42
October	0.71	3.84	1.54	1.71	2.30	3.23	1.24	2.24
November	0.18	1.0472	1.17	0.22	0.54	0.69	0.84	0.36
Pre-monsoon	0.40	0.1934	0.22	0.04	0.22	0.31	0.18	0.23
Monsoon	95.61	94.615	96.91	97.99	96.55	95.55	97.47	95.76
Post-monsoon	3.48	4.8885	2.70	1.93	2.80	3.91	2.02	3.88
Winter	0.51	0.3029	0.17	0.04	0.38	0.21	0.27	0.15

Months/season	Dang			
	1901-30	1931-60	1961-90	1991-2015
June	14.64	12.18	12.44	15.55
July	37.64	38.79	36.47	32.79
August	28.70	26.23	32.11	31.07
September	14.81	18.02	15.78	16.23
October	2.75	2.97	2.06	3.72
November	0.68	1.03	0.59	0.57
Pre-monsoon	0.40	0.57	0.35	0.03
Monsoon	95.78	95.22	96.80	95.64
Post-monsoon	3.43	4.00	2.65	4.29
Winter	0.38	0.21	0.20	0.04

last, 3-D_s (1991-2015) it was slightly decreased. During the month of September rainfall variability on per cent

noteworthy incorporation of annual rainfall showed 18.23% in (1931-06) subsequently before and after it was

decreasing. The results obviously indicated that an increase in monsoonal rainfall at Navsari district for all the months *viz.*, June, July, August and September. The 3-D_s wise rainfall per cent contribution of annual rainfall was found that in pre monsoon and winter season it was decreasing on all, 3-D_s. While, in all previous, 3-D_s post monsoon rainfall per cent contribution of annual rainfall was found on lower side except in (1931-60) (Table 5).

3.7.5. Bharuch district

The data analysis revealed that at Bharuch district in 1961-90, 3-D_s high rainfall per cent contribution of annual rainfall 95.58% was noticed followed by 1991-2015 (94.44%) and 1901-30 (94.25%). In month wise monsoon season analysis shows highest rainfall per cent notable inclusion of annual rainfall in July month (1901-2015) followed by August and June month. Rainfall variability of per cent notable addition for annual rainfall in June month slightly varies of all, 3-D_s ranges 12.72% to 18.86% and it was showed decreasing pattern of rainfall in all, 3-D_s. In month of July rainfall variability of per cent contribution of annual rainfall first two, 3-D_s were slightly decreased with 39.20% and 37.97% in 1901-30 in 1931-60 respectively then after decreasing pattern 32.73% and 37.85% in 1961-90 and 1991-2015 respectively observed. In case of August month rainfall variability on per cent significant addition of annual rainfall 28.26% in 1961-90, 3-D_s, it was higher side then before and after decade it was on lower side. The month of September rainfall variability on per cent remarkable inclusion of annual rainfall is shows that high 19.91% in 1991-2015, 3-D_s then before it was decreasing. The results clearly indicated that an increase in monsoonal rainfall at Navsari for all the months *viz.*, June, July, August and September. The 3-D_s wise rainfall per cent significant addition of annual rainfall revealed that in pre monsoon and winter season it was decreasing. While, in all previous, 3-D_s post monsoon rainfall per cent noteworthy incorporation of annual rainfall was found on lower side except in (1961-90) (Table 5). Pant and Rupa Kumar (1997) reported that Indian summer monsoon displays multi-decadal variations in which there is clustering of dry or wet anomalies.

4. Conclusions

Past century rainfall behavior showed the variations in their anomaly. On the basis of Mann-Kendall, Sen's slope and regression slope showed that annual and monsoon rainfall at Valsad, Dang and Surat shows the increasing trend while, while at Navsari and Bharuch districts were declining. The highest CV during annual (36.9%) and monsoon season (38.6%) is recorded at Bharuch district and lowest annual CV (29.1%) and

monsoon season CV (30.1%) is observed at Valsad district as compared to other districts. The coefficient of variation (CV) is high is denote that the variability of rainfall in those areas are not equally distributed and the amount of rainfall is lowest. Similarly at Bharuch district the annual and monsoon CV per cent denoted that the variability of rainfall is very high. At Valsad district lowest CV was recorded with highest rainfall. The highest SD during annual (588.4 mm) and monsoon season (574.5 mm) is recorded at Dang district and lowest annual SD (303.2 mm) and monsoon season SD (300.0 mm) is observed at Bharuch district as compared to other districts. The monsoon season (summer monsoon) rainfall variability of Valsad, Dang, Surat, Navsari and Bharuch districts was recorded is 30.1%, 30.9%, 35.9%, 33.3% and 38.6%, respectively. A low standard deviation indicates that the data points tend to be close to the mean of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values. Similarly high SD is reported at dang district because of high range of rainfall and lowest SD is found at Bharuch district because of low rainfall variability. The rainfall distribution different season *viz.*, pre monsoon, monsoon post monsoon and winter season, the highest present contribution of rainfall is observed during monsoon season followed by post monsoon in all the five districts of south Gujarat. Rainfall contribution during remaining months was less than one per cent. While month wise analysis shows during monsoon season highest rainfall per cent contribution to annual rainfall is in July followed by August and June months at all the five districts of south Gujarat. Monthly rainfall trends, even small, were also identified to be both increasing and decreasing in the region. It is recommended that farmers should overcome the problem of declining rainfall by planting drought resistance crops or early maturity species. Diversifying the economic base of the populace with emphasis on reducing over dependence on rainfed agriculture is another way of coping with this problem. It is also recommended that government policies in this area should be based on recent rainfall trends.

Acknowledgement

The authors are thankful to India Meteorological Department, Pune for facilitating this work. Authors are also grateful to anonymous reviewer for his valuable comments to improve the quality of research paper.

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