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Research Article

WINTER SEASON RAINFALL TREND ANALYSIS BY USING DISTRIBUTION-FREE STATISTICS AND LINEAR REGRESSION TECHNIQUES UNDER SOUTH GUJARAT

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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 pre monsoon rainfall at Valsad and Bharuch shows the increasing trend while, that of Dang, Surat and Navsari districts are in declining. The Mann-Kendall trend, Sen's slope and regression slope revealed that winter season rainfall at Bharuch divulges the increasing trend while, that of Dang, Valsad, Surat and Navsari districts are in declining. Kendall's tau values are conceding negative trend for pre global warming was observed that pre monsoon at Dang, Valsad and Navsari and positive trend was found that Bharuch and Surat districts and present global warming only Navsari district shows decline trend and remain districts are in increasing trend.

Keywords: *Mann-Kendall trend, Sen's slope, Winter season, Excess and Deficit rainfall, south Gujarat*

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Introduction

Studies indicate an increase in the temperature to the tune of 0.57 degree centigrade per 100 years [1]. The available literature suggests a wide range of impacts of climate change in Asia in general and in India in specific. However, the analysis of past rainfall events suggests no clear trend. For three consecutive decades, the decadal departures found are below the long-time averages alternatively [2]. During the recent decades, extreme summer rainfall events were observed in northwest India. Moreover, number of rainy days during monsoons along with the east coast has gone down during the last decade indicating more intense rainfall events in India. Rainfall is one of the most important natural resources input to crop production in the tropical region. Study showed, out of 189.54 million ha (1996-97) gross cropped area (Including are sown more than one) of the country, 61.3% (116.26 million ha) falls under rainfed farming. The gross irrigated area has increased rapidly from 28 mha in 1960-61 to 72.8 mha in 1997-98 in India. In spite of, marginal and small farmers constituting 80% of agricultural income group and majority of are depends on rainfed farming. To take advantages of available rainfall efficiently, crop planning and management must be followed based on the rainfall amount and distribution at a particular place.

The south west (SW) monsoon, which brings about total 80% of the total precipitation over the, is critical for the availability of freshwater for drinking and irrigation. In Indian region, Changes in climate particularly in the south-west monsoon, would have a considerable impact on agricultural production, water resources and overall economy of the country. The heavy concentration of rainfall in the monsoon months (June- September) results in scarcity of water in many parts of the country during the monsoon periods. According to study of Goswami, *et al*., (2006) [3], the frequency of more intense rainfall events in many parts of Asia has increased whereas the number of rainy days and total annual precipitation has decreased. Rajeevan, *et al*., (2008) [4] determined the variability and long-term trends of extreme rainfall events over central India using 104 years (1901-2004) of high resolution daily gridded rainfall data in study. They found statistically significant long-term trend of 6% per decade in the frequency of extreme rainfall events. According to them, the increasing trend of sea surface temperatures and surface latent heat flux over the tropical Indian Ocean. Rainfall is the primary driver of meteorological drought [5-7]. Analysis of daily gridded observed rainfall data for the period 1951-2003, indicated that there are decreasing trend in both early and late monsoon rainfall and number of rainy days, implying a shorter monsoon over India. Similarly, there is a sharp decrease in the area that receives a certain amount of rainfall and number of rainy days during the season [8]. However, very little work has been done on Gujarat state. Ray, *et al*., (2009) [9] studies climate variability and extreme weather events like cold wave and heat wave condition and heavy rainfall events in Gujarat and they recorded a significant steady increase in these events. Lunagaria, *et al*., (2015) [10] studied the rainfall patterns of Gujarat, and rainfall indices also indicate no uniformity for any negative or positive trend over Gujarat. Total annual rainfall and extremely wet days were found to increase at more numbers of stations. Rainfall is the parameter having very high variability, in which very few stations showed statistically significant trends. Thus, still there is ambiguity in the rainfall pattern for Gujarat state. The Indian 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 of 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 percent. Considering Bharuch-Deesa line, the rainfall in the state decreases towards west of the line [11].

Materials and Methods

In south Gujarat five locations were chosen for assessment of scare and excess rainfall intensity and frequency (1) Navsari (2) Bharuch (3) Surat (4) Valsad and (5) Dang.

In the study, historical monthly and annual rainfall data were used of 115 years (1901-2015). By using monthly rainfall data, monthly mean, seasonal averages, were computed monthly and season-wise *viz*, winter (December-February). The data were subjected to find out long term trends. To support the trends in annual and seasonal rainfall, decade-wise, 30 years (3-Decades) and 60 years (2-Decades) shifts in rainfall were also analyzed.

Trend Analysis

Mann-Kendall Test

The trend analysis and estimation of Sen's slope are studied using Kendall (1975) [12] and Sen (1968) method [13], respectively for the given data sets. Man-Kendall test is a non-parametric test used for finding trends in time series. This test compares the relative magnitudes of data rather than data values themselves [14]. 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. Initial study, 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:

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

Where, sign $(x_j-x_k) = 1$, if $(x_j-x_k) > 0$; 0, if $(x_j-x_k)=0$; -1 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 McBean and Motiee (2008) [15]. This test assumes that there are not many tied values within the dataset. The variance (S) is calculated by the following equation:

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

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

The normal Z-statistics is computed as:

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

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.

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. Viessman, *et al*., (1989) [16] 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 [17,18]. Each individual slope (mij) is estimated using the following equation:

$$m_{ij} = \frac{(Y_j - Y_i)}{(j-1)} \quad (2)$$

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:

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

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

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

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:

$$Y = m.\ X + C \quad (3)$$

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.

Results and Discussion

Shift in decade-wise winter season rainfall

The decadal trend analyses of seasonal rainfall for Dang, Valsad, Surat, Navsari and Bharuch in addition to frequencies of excess and deficient years during winter period are depicted in [Table-1-3].

Dang District

The investigation of winter rainfall discloses that at Dang district during past 113 years, the 31 excess and 82 deficit years were realized. During decade 1961-70, 1931-40 and 1921-30 dignified rainfall were recorded with percent hike 107.81, 104.72 and 70.28 correspondingly. Likewise, during decades 2001-15, 1951-60 and 1991-2000 least rainfall was recorded with percent decline -100.00, -65.56 and -47.75 respectively, [Table-1] and [Fig-1].

Table-1 Decadal mean (% departure from normal) of excess, deficit rainfall and linear equation and over Dang and Valsad from 1901 to 2015

Decades	Winter		
	Dang		
	Decadal mean (% departure from normal)	Excess	Deficit
1903-10	30.03	3	5
1911-20	25.63	4	6
1921-30	70.28	6	4
1931-40	104.72	5	5
1941-50	15.18	4	6
1951-60	-65.56	2	8
1961-70	107.81	3	7
1971-80	-38.01	2	8
1981-90	-46.33	1	9
1991-2000	-47.75	1	9
2001-15	-100	0	15
Rainfall (mm)	4.21		
Linear equation	-0.061x + 7.834		
Valsad			
1901-10	32.69	6	4
1911-20	21.59	4	6
1921-30	21.38	5	5
1931-40	13.91	3	7
1941-50	-1.02	4	6
1951-60	-49.66	2	8
1961-70	-82.29	1	9
1971-80	7.94	1	9
1981-90	97.96	8	2
1991-2000	85.57	9	1
2001-15	-98.72	0	15
Rainfall (mm)	4.69		
Linear equation	y = -0.016x + 5.670		

Winter rainfall acknowledges that at Dang district, during decade 1921-30, 1931-40 and 1941-50 elevated surplus events of rainfall were pragmatic with no. 6, 5 and 4 in that order. Alike, during decades 2001-15, 1991-2000 and 1981-90 deficit rainfall events were recorded with no. 15, 9 and 9 respectively.

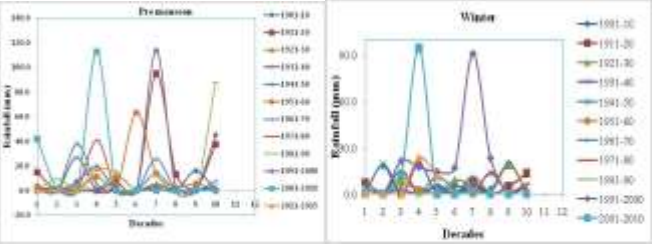

Fig 1a-b re monsoon and winter season rainfall patterns over Dang District from 1903-2015

Valsad district

The scrutiny winter rainfall concedes that at Valsad district during past 115 years, the 43 excess and 72 deficit years were inspected. During decade 1981-90, 1991-2000 and 1901-10 highest rainfall were recorded with percent increase 97.96, 85.57 and 32.69 respectively. Furthermore, during decades 2001-15, 1961-70 and 1951-60 lowest rainfall were recorded with percent decrease -98.72, -82.29 and -49.66 correspondingly. Study of winter rainfall divulges that at Valsad district, during decade 1991-2000, 1981-90 and 1901-10 highest superfluous events of rainfall were detected with no. 9, 8 and 6 respectively. In addition, during decades 2001-15, 1971-80 and 1961-70 least rainfall events were recorded with no. 15, 9 and 9 respectively, [Table-1] and [Fig-2].

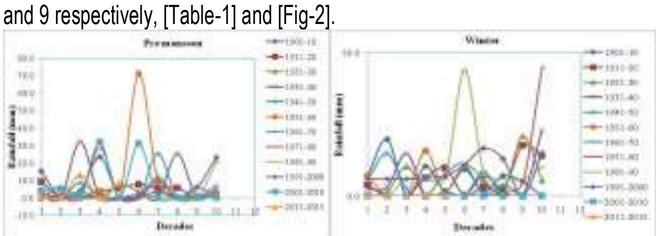

Fig 2a-b Pre monsoon and winter season rainfall patterns over Valsad district from 1901-2015

Table-2 Decadal mean (% departure from normal) of excess, deficit rainfall and linear equation and over Surat and Navsari from 1901 to 2015

Decades	Winter		
	Surat		
	Decadal mean (% departure from normal)	Excess	Deficit
1901-10	162.05	6	4
1911-20	-9.67	4	6
1921-30	78.74	5	5
1931-40	93.1	3	7
1941-50	24.16	4	6
1951-60	-49.25	1	9
1961-70	-4.57	1	9
1971-80	-8.71	2	8
1981-90	-83.72	1	9
1991-2000	-55.95	1	9
2001-15	-97.45	0	15
Rainfall (mm)	3.13		
Linear equation	y = -0.060x + 6.653		
Navsari			
1901-10	51.62	3	7
1911-20	88.79	6	4
1921-30	16.23	5	5
1931-40	11.3	3	7
1941-50	-10.13	2	8
1951-60	-30.8	1	9
1961-70	-40.43	1	9
1971-80	-31.47	2	8
1981-90	-82.98	1	9
1991-2000	72.44	5	5
2001-15	-35.8	3	12
Rainfall (mm)	4.47		
Linear equation	y = -0.034x + 6.484		

Surat District

Winter rainfall enquiry exposes that at Surat district during past 115 years, the 28 excess and 87 deficit years were seen. During decade 1901-10, 1931-40 and 1921-30 highest rainfall were recorded with percent increase 162.05, 93.10 and 78.74 respectively. Then as well, during decades 2001-15, 1981-90 and 1991-2000 lowest rainfall were recorded with percent diminution -97.45, -83.72 and -55.95 respectively. The study of winter rainfall notifies that at Surat district, during decade 1901-10, 1921-30 and 1911-20 highest surplus events of rainfall were scrutinized with no. 6, 5 and 4 in that order. Thus, during decades 2001-15, 1991-2000 and 1981-90 minimal rainfall events were recorded with no. 15, 9 and 9 respectively, [Table-2] and [Fig-3].

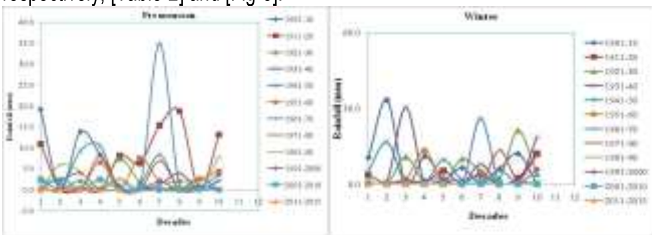

Fig 3a-b Pre monsoon and winter season rainfall patterns over Surat district from 1901-2015

Table-3 Decadal mean (% departure from normal) of excess, deficit rainfall and linear equation and over Bharuch from 1901 to 2015

Decades	Winter		
	Bharuch		
	Decadal mean (% departure from normal)	Excess	Deficit
1901-10	30.11	4	6
1911-20	-28.78	3	7
1921-30	-10.93	3	7
1931-40	-41.85	2	8
1941-50	-12.4	2	8
1951-60	-81.78	1	9
1961-70	-57.86	1	9
1971-80	-57.12	2	8
1981-90	-96.87	0	10
1991-2000	240.64	6	4
2001-15	77.9	4	11
Rainfall (mm)	5.43		
Linear equation	y = 0.051x + 2.446		

Navsari

Winter rainfall analysis reveals that at Navsari district during past 115 years, the 32 excess and 83 deficit years were viewed. During decade 1911-20, 1991-2000 and 1901-10 highest rainfall were recorded with percent increase 88.79, 72.44 and 51.62 respectively. Correspondingly, during decades 1981-90, 1961-70 and 2001-15 lowest rainfall were recorded with percent decrease -82.98, -40.43 and -35.80 respectively, [Table-2] and [Fig-4]. The investigation of winter rainfall reveals that at Navsari district, during decade 1911-20, 1921-30 and 1991-2000 highest excessive events of rainfall were noticed with no. 6, 5 and 5 respectively. Correspondingly, during decades 2001-15, 1981-90 and 1961-70 scarcity rainfall events were recognized with no. 12, 9 and 9 respectively, [Table-2].

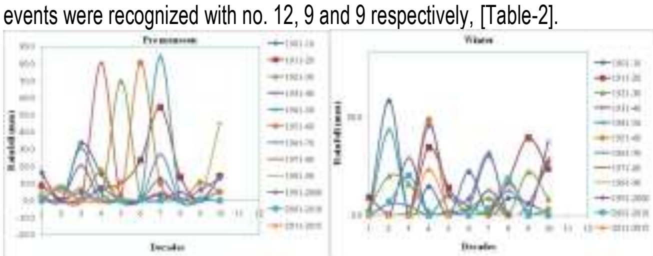

Fig 4a-b Pre monsoon and winter season rainfall patterns over Navsari district from 1901-2015

Bharuch district

Analysis of winter rainfall concedes that at Bharuch district during past 115 years, the 28 excess and 87 deficit years were observed. During decade 1991-2000, 2001-15 and 1901-10 highest rainfall were recorded with percent increase 240.64, 77.90 and 30.11 respectively.

Table-4 *Decadal Mann-Kendall trend analysis of rainfall at Dang, from 1901 to 2015*

Decades	Season	Kendall's tau	S- Statistics	P Value	Trend	Trend at 5% Significant level
1903-10	Winter	-0.327	-9.000	0.319	Falling	No
1911-20	Winter	0.227	9.000	0.442	Rising	No
1921-30	Winter	-0.135	-6.000	0.653	Falling	No
1931-40	Winter	-0.276	-12.000	0.318	Falling	No
1941-50	Winter	-0.176	-7.000	0.564	Falling	No
1951-60	Winter	-0.126	-5.000	0.701	Falling	No
1961-70	Winter	-0.126	-5.000	0.701	Falling	No
1971-80	Winter	0.762	28.000	0.006	Rising	No
1981-90	Winter	-0.181	-5.000	0.605	Falling	No
1991-2000	Winter	-0.050	-1.000	1.000	Falling	No
2001-2015	Winter					

Table-5 *Decadal Sen's slope estimator of rainfall at Dang, from 1901 to 2015*

Decades	Season	Sen's Slope	Trend	Confidence limits for slope at 5% Significance Level		Regression slope
				Lower Limit	Upper Limit	
1903-10	Winter	-0.363	Falling	-0.626	-0.121	-0.692
1911-20	Winter	0.000	Rising	0.000	0.466	1.030
1921-30	Winter	-0.433	Falling	-0.738	-0.22	-0.410
1931-40	Winter	-0.675	Falling	-1.020	-0.579	-0.205
1941-50	Winter	0.000	Rising	-0.028	0.000	-0.264
1951-60	Winter	0.000	Rising	0.000	0.000	-0.107
1961-70	Winter	0.000	Rising	0.000	0.000	-0.650
1971-80	Winter	0.200	Rising	0.157	0.200	1.261
1981-90	Winter	0.000	Rising	0.000	0.000	0.236
1991-2000	Winter	0.000	Rising	0.000	0.000	-0.133
2001-2015	Winter	0.000	Rising	0.000	0.000	0.000

Table-6 *Decadal Mann-Kendall trend analysis of rainfall at Valsad, from 1901 to 2015*

Decades	Season	Kendall's tau	S- Statistics	P Value	Trend	Trend at 5% Significant level
1901-10	Winter	-0.333	-15.000	0.216	Falling	No
1911-20	Winter	0.368	16.000	0.173	Rising	No
1921-30	Winter	0.360	16.000	0.178	Rising	No
1931-40	Winter	0.000	0.000	1.000	Rising	No
1941-50	Winter	-0.414	-18.000	0.123	Falling	No
1951-60	Winter	-0.307	-12.000	0.288	Falling	No
1961-70	Winter	0.149	3.000	0.728	Rising	No
1971-80	Winter	0.730	24.000	0.010	Rising	No
1981-90	Winter	0.562	22.000	0.043	Rising	No
1991-2000	Winter	0.506	22.000	0.057	Rising	No
2001-2015	Winter	0.095	6.000	0.720	Rising	No

Table-7 *Decadal Sen's slope estimator of rainfall at Valsad, from 1901 to 2015*

Decades	Season	Sen's Slope	Trend	Confidence limits for slope at 5% Significance Level		Regression slope
				Lower Limit	Upper Limit	
1901-10	Winter	-0.850	Falling	-0.946	-0.77	-0.913
1911-20	Winter	1.050	Rising	0.839	1.148	1.257
1921-30	Winter	0.800	Rising	0.599	0.884	1.006
1931-40	Winter	0.000	Rising	-0.009	0.007	0.710
1941-50	Winter	-0.725	Falling	-0.875	-0.628	-0.871
1951-60	Winter	-0.040	Falling	-0.055	0.000	-0.659
1961-70	Winter	0.000	Rising	0.000	0.000	0.150
1971-80	Winter	0.183	Rising	0.141	0.226	2.678
1981-90	Winter	0.800	Rising	0.745	0.857	1.081
1991-2000	Winter	1.000	Rising	1.000	1.000	0.659
2001-2015	Winter	0.000	Rising	0.000	0.000	0.007

Table-8 *Decadal Mann-Kendall trend analysis of rainfall at Surat, from 1901 to 2015*

Decades	Season	Kendall's tau	S- Statistics	P Value	Trend	Trend at 5% Significant level
1901-10	Winter	-0.225	-10.000	0.419	Falling	No
1911-20	Winter	0.263	11.000	0.354	Rising	No
1921-30	Winter	0.289	13.000	0.291	Rising	No
1931-40	Winter	0.045	2.000	0.928	Rising	No
1941-50	Winter	-0.358	-15.000	0.194	Falling	No
1951-60	Winter	-0.307	-12.000	0.288	Falling	No
1961-70	Winter	0.023	1.000	1.000	Rising	No
1971-80	Winter	0.490	18.000	0.084	Rising	No
1981-90	Winter	0.272	10.000	0.36	Rising	No
1991-2000	Winter	0.378	15.000	0.179	Rising	No
2001-2015	Winter	0.000	0.000	1.000	Rising	No

Table-9 *Decadal Sen's slope estimator of rainfall at Surat, from 1901 to 2015*

Decades	Season	Sen's Slope	Trend	Confidence limits for slope at 5% Significance Level		Regression slope
				Lower Limit	Upper Limit	
1901-10	Winter	-0.780	Falling	-0.926	-0.599	-1.433
1911-20	Winter	0.357	Rising	0.190	0.400	0.603
1921-30	Winter	0.525	Rising	0.492	0.607	0.940
1931-40	Winter	0.020	Rising	-0.004	0.038	0.163
1941-50	Winter	-0.50	Falling	-0.596	-0.348	-0.899
1951-60	Winter	-0.025	Falling	-0.035	0.000	-0.318
1961-70	Winter	0.000	Rising	0.000	0.003	0.474
1971-80	Winter	0.238	Rising	0.030	0.282	1.067
1981-90	Winter	0.000	Rising	0.000	0.000	0.083
1991-2000	Winter	0.400	Rising	0.319	0.437	0.345
2001-2015	Winter	0.000	Rising	0.000	0.000	0.000

Table-10 *Decadal Mann-Kendall trend analysis of rainfall at Navsari, from 1901 to 2015*

Decades	Season	Kendall's tau	S- Statistics	P Value	Trend	Trend at 5% Significant level
1901-10	Winter	-0.138	-6.000	0.65	Falling	No
1911-20	Winter	0.414	18.000	0.123	Rising	No
1921-30	Winter	-0.022	-1.000	1.000	Falling	No
1931-40	Winter	-0.024	-1.000	1.000	Falling	No
1941-50	Winter	0.024	1.000	1.000	Rising	No
1951-60	Winter	0.181	5.000	0.605	Rising	No
1961-70	Winter	-0.218	-8.000	0.476	Falling	No
1971-80	Winter	0.669	22.000	0.019	Rising	No
1981-90	Winter	0.243	8.000	0.436	Rising	No
1991-2000	Winter	0.263	11.000	0.354	Rising	No
2001-2015	Winter	-0.101	-8.000	0.678	Falling	No

Table-11 *Decadal Sen's slope estimator of rainfall at Navsari, from 1901 to 2015*

Decades	Season	Sen's Slope	Trend	Confidence limits for slope at 5% Significance Level		Regression slope
				Lower Limit	Upper Limit	
1901-10	Winter	-0.267	Falling	-0.44	-0.110	-1.321
1911-20	Winter	1.180	Rising	0.957	1.515	1.404
1921-30	Winter	-0.067	Rising	-0.143	0.035	0.007
1931-40	Winter	0.000	Rising	0.000	0.000	0.786
1941-50	Winter	0.000	Rising	0.000	0.000	-0.832
1951-60	Winter	0.000	Rising	0.000	0.000	-0.438
1961-70	Winter	0.000	Rising	0.000	0.000	-0.110
1971-80	Winter	0.463	Rising	0.000	0.537	1.396
1981-90	Winter	0.000	Rising	0.000	0.000	0.187
1991-2000	Winter	0.600	Rising	0.508	1.025	0.877
2001-2015	Winter	0.000	Rising	0.000	0.000	-0.007

Table-12 *Decadal Mann-Kendall trend analysis of rainfall at Bharuch, from 1901 to 2015*

Decades	Season	Kendall's tau	S- Statistics	P Value	Trend	Trend at 5% Significant level
1901-10	Winter	0.068	3.000	0.857	Rising	No
1911-20	Winter	0.310	13.000	0.266	Rising	No
1921-30	Winter	0.180	8.000	0.530	Rising	No
1931-40	Winter	0.023	1.000	1.000	Rising	No
1941-50	Winter	-0.263	-11.000	0.354	Falling	No
1951-60	Winter	-0.163	-6.000	0.611	Falling	No
1961-70	Winter	-0.230	-10.000	0.414	Falling	No
1971-80	Winter	0.479	19.000	0.084	Falling	No
1981-90	Winter	-0.181	-5.000	0.605	Falling	No
1991-2000	Winter	0.072	3.000	0.853	Rising	No
2001-2015	Winter	0.050	4.000	0.859	Rising	No

Table-13 *Sen's slope estimator of rainfall at Bharuch, from 1901 to 2015*

Decades	Season	Sen's Slope	Trend	Confidence limits for slope at 5% Significance Level		Regression slope
				Lower Limit	Upper Limit	
1901-10	Winter	0.129	Rising	0.000	-0.144	-0.213
1911-20	Winter	0.656	Rising	0.603	0.741	0.620
1921-30	Winter	0.143	Rising	0.135	0.220	0.637
1931-40	Winter	0.000	Rising	0.000	0.001	-0.160
1941-50	Winter	-0.067	Rising	-0.078	-0.059	-0.497
1951-60	Winter	0.000	Rising	0.000	0.000	-0.240
1961-70	Winter	-0.075	Falling	-0.085	-0.061	-0.103
1971-80	Winter	0.213	Rising	0.190	0.244	0.862
1981-90	Winter	0.000	Rising	0.000	0.000	-0.012
1991-2000	Winter	0.000	Rising	0.000	0.040	1.421
2001-2015	Winter	0.000	Rising	0.000	0.000	-0.789

Furthermore, during decades 1981-90, 1951-60 and 1961-70 lowest rainfall were recorded with percent decrease -96.87, -81.78 and -57.86 correspondingly, [Table-3] and [Fig-5]. The analysis of winter rainfall divulges that at Bharuch district, during decade 1991-2000, 1901-10 and 2001-15 highest excess events of rainfall were observed with no. 6, 4 and 4 respectively. In addition, during decades 2001-15, 1981-90 and 1951-60 deficit rainfall events were recorded with no. 11, 10 and 9 in that order.

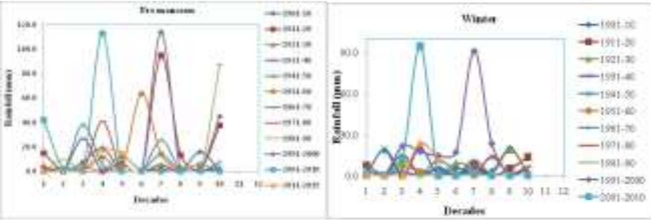

Fig 5a-b Pre monsoon and winter season rainfall patterns over Bharuch district from 1901-2015

Decades wise Mann-Kendall trend analysis and Sen's slope estimate

Mann-Kendall trend and Sen's slope analysis of different intensities at Dang, Valsad, Surat, Navsari and Bharuch districts are demonstrated in [Table-4 to 13]. The decade wise analysis was done for pre monsoon and winter seasons on the basis of past 115 years data.

Dang District

The trend investigation based on Mann-Kendall of winter rainfall acknowledges that at Dang district during past 113 years, the increasing trend was observed during decade 1971-80 and 1911-20 highest Kendall's tau value were recorded with increase 0.762 and 0.227 mm respectively. Alike, during decades diminishing trend 1901-10, 1931-40 and 1981-90 lowest rainfall were recorded with decrease -0.327, -0.276 and -0.181 respectively, [Table-4]. The Sen's slope study of winter rainfall admits that at Dang district during past 113 years, the escalating trend was detected during decade 1971-80, 1991-2000 and 1981-90 highest Sen's slope were recorded with increase 0.200, 0.000 and 0.000 mm respectively. Correspondingly, during decades decreasing Sen's slope 1931-40, 1921-30 and 1901-10 lowest rainfall were recorded with decrease -0.675, -0.433 and -0.363 respectively, [Table-5].

Valsad district

The Mann-Kendall trend exploration of winter rainfall concedes that at Valsad district during past 115 years, the increasing trend was observed during decade 1971-80, 1981-90 and 1991-2000 highest Kendall's tau value were recorded with increase 0.730, 0.562 and 0.506 mm respectively. In addition, during decades lessening trend 1941-50, 1901-10 and 1951-60 lowest rainfall were recorded with decrease -0.414, -0.333 and -0.307 respectively, [Table-6]. The Sen's slope analysis of winter rainfall explains that at Valsad district during past 115 years, the mounting trend was observed during decade 1911-20, 1991-2000 and 1981-90 highest Sen's slope were recorded with increase 1.050, 1.000 and 0.800 mm respectively. So, during decades declining Sen's slope 1901-10, 1941-50 and 1951-60 lowest rainfall were recorded with decrease -0.850, -0.725 and -0.040 respectively, [Table-7].

Surat District

The analysis (Mann-Kendall trend) of winter rainfall found that at Surat district during past 115 years, the increasing trend was observed during decade 1971-80, 1991-2000 and 1921-30 highest Kendall's tau value were recorded with increase 0.490, 0.378 and 0.289 mm respectively. Thus, during decades decreasing trend 1941-50, 1951-60 and 1901-10 lowest rainfall were recorded with decrease -358, -0.307 and -0.225 respectively, [Table-8]. The Sen's slope analysis of winter rainfall notifies that at Surat district during past 115 years, the rising trend was observed during decade 1921-30, 1991-2000 and 1911-20 highest Sen's slope were recorded with increase 0.525, 0.400 and 0.357 mm respectively. Similarly, during decades lessening Sen's slope 1901-10, 1941-50 and 1951-60 lowest rainfall were recorded with decrease -0.780, -0.500 and -0.025 [Table-9].

Navsari district

The Mann-Kendall trend analysis of winter rainfall acknowledges that at Navsari district during past 115 years, the growing trend was observed during decade 1971-80, 1911-20 and 1991-2000 highest Kendall's tau value were recorded with increase 0.669, 0.414 and 0.263 mm respectively. Correspondingly, during decades declining trend 1961-70, 1901-10 and 2001-15 lowest rainfall were recorded with decrease -0.218, -0.138 and -0.101 respectively, [Table-10]. The Sen's slope analysis of winter rainfall admits that at Navsari district during past 115 years, the growing trend was observed during decade 1911-20, 1991-2000 and 1971-80 highest Sen's slope were recorded with increase 1.180, 0.600 and 0.463 mm respectively. Equivalently, during decades diminishing Sen's slope 1901-10 and 1921-30 lowest rainfall were recorded with decrease -0.267 and -0.067 respectively, [Table-11].

Bharuch district

The trend analysis of winter rainfall divulges that at Baruch district during past 115 years, the increasing trend was observed during decade 1971-80, 1911-20 and 1921-30 highest Kendall's tau value were recorded with increase 0.479, 0.310 and 0.180 mm respectively. In addition, during decades lessening trend 1941-50, 1961-70 and 1981-90 lowest rainfall were recorded with decrease -0.263, -0.230 and -0.181 respectively, [Table-12]. The Sen's slope analysis of winter rainfall explains that at Baruch district during past 115 years, the rising trend was observed during decade 1911-20, 1971-80 and 1921-30 highest Sen's slope were recorded with increase 0.656, 0.213 and 0.143 mm respectively. So, during decades decreasing Sen's slope 1961-70 and 1941-50 lowest rainfall were recorded with decrease -0.075 and -0.067 respectively, [Table-13].

Conclusion

The aim of the current study is to portray the analysis rainfall time series, detecting potential trends and assessing their significance. The past 115 years (Year 1901-Year 2015) rainfall data of five respective districts of south Gujarat, the Mann-Kendall trend, Sen's slope and regression slope proved that pre-monsoon rainfall at Valsad and Bharuch district indicates the increasing trend while, that of Dang, Surat and Navsari districts are declining in trends. Similarly, the Mann-Kendall trend, Sen's slope and regression slope showed that winter season rainfall at Bharuch demonstrates the increasing trend while, that of Dang, Valsad, Surat and Navsari districts are declining. On the basis of IMD criteria, the frequency of occurrence of drought in pre monsoon season at Bharuch and Navsari districts is higher as compared to Dangs, Valsad and Surat districts. Similarly, the frequency of occurrence of excess rainfall at Dangs and Valsad districts is higher as compared to Surat, Navsari and Bharuch districts. Drought anomaly was found that frequency of mild drought occurrence was quite high and occurred at regular interval at all the locations. The decadal analysis of pre monsoon rainfall illustrates that at Dang district Kendall's tau values are in increasing trend during decades 1911-20, 1931-40, 1941-50, 1951-60, 1981-90 and 1991-2000, while values are admitting negative trend in decades 1903-10, 1921-30, 1961-70, 1971-80 and 2001-15. Similarly, winter season rainfall illustrates that at Dang district Kendall's tau values are in increasing trend during decades 1911-20 and 1971-80 while values are admitting negative trend in remaining decades. In case of Valsad district, pre monsoon decades 1901-10, 1911-20, 1971-80 and 2001-15 were affirming negative trends and remaining decades stand for positive trends. Similarly, winter season decades 1901-10, 1941-50 and 1951-60 were affirming negative trends and remaining decades stand for positive trends. Surat district study divulges that pre monsoon during decades 1901-10, 1941-50, 1971-80, 1981-90 and 2001-15 decreasing trends were observed, Thus Kendall's tau values for Surat district pre monsoon for six decades exposes a positive trend and for other five decades it imparts negative trend. Similarly, winter season during decades 1901-10, 1941-50 and 1951-60, decreasing trends were observed, and remaining decades stand for positive trends. Decadal analysis of pre monsoon on Navsari district reveals that during decades 1911-20, 1951-60, 1961-70, 1981-90 and 2001-15 increasing trends were observed, while Kendall's tau values are conceding negative trend in remaining six decades. Thus, winter season Kendall's tau values for five decades 1941-50, 1951-60, 1971-80, 1981-90 and 1991-2000 revealed positive trend and for other six decades it shows negative trend for Navsari district. Bharuch district investigation acknowledges that pre monsoon season during decades 1941-50 and 2001-15 decreasing trends were observed. Thus, Kendall's tau values for nine decades notified positive trend and for other two decades it shows negative trend for Bharuch district. Greenhouse gas concentrations in the atmosphere will continue to increase unless the billions of tons of our annual emissions decrease substantially. Global precipitation patterns are being moved in new directions by climate change [19].

Application of research: Winter season rainfall trend analysis and forecasting

Research Category: Agro- meteorology

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Study area / Sample Collection: Navsari, Bharuch, Surat, Valsad and Dang districts of Gujarat state

Cultivar / Variety / Breed name: Nil

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