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RAINFALL TREND ANALYSIS AND FUTURE SCENARIO ASSESSMENT BY USING MATHEMATICAL AND STATISTICAL TECHNIQUES FOR SOUTH GUJARAT

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ABSTRACT

In the present study, attempts have been made to study temporal variation in seasonal and annual rainfall over the two districts of South Gujarat during the period 1901 to 2012. The statistical and mathematical analysis of annual rainfall indicates good range of variation of Navsari and Bharuch region for 112 years (1901 to 2012) period. The mean, median, mode, standard deviation, coefficient of dispersion, coefficient of variation and coefficient of skewness of Navsari was found 1515.5 mm, 1430.0 mm, 1444.2 mm, 481.4 mm, 0.318 mm, 31.8 %, 0.148 mm and for Bharuch the values were found 972.0 mm, 959.5 mm, 913.7 mm, 293.3 mm, 0.302 mm, 30.2% and 0.199 mm respectively. The annual rainfall over Navsari showed a long term increasing trend, an increase of 304.64 mm only was noticed during the study period of 112 years as against the normal rainfall of 1517.90 mm. Similarly, for Bharuch a decrease of 39.98 mm only was noticed during the study period of 112 years as against the normal rainfall of 972.10 mm. Mode analysis shows class interval 1400 to 1599 has highest number of frequencies of rainfall (21) in Navsari region and for Bharuch highest number of frequencies (32) was found under interval 800 to 999.

Key words: Mathematical analysis, Rainfall, Statistical analysis, Time series analysis.

Precipitation is an important climatic variable that affects both the spatial and temporal patterns of water availability. The distribution of annual, seasonal and seasonal rainfall in space and time plays crucial role in determining the management of water resources (Samui *et al.,* 2013). Rainfall being most important parameter, particularly during monsoon season, has got large scope to analyze for country as a whole or even for a particular location (Chand *et al.,* 2011). Global climate changes may influence long-term rainfall patterns impacting the availability of water, along with the danger of increasing occurrences of droughts and floods. Southwest (SW) monsoon rainfall has been associated with large fluctuations over different time scales (Hamza *et al.,* 2013). Three main characteristics of rainfall are its amount, frequency and intensity, the values of which vary from place to place, day to day, month to month and also year to year. According to Todd (1980), groundwater levels may show seasonal variation due to rainfall. The SW monsoon, which brings about 80% of the total precipitation over the country, is critical for the availability of freshwater for drinking and irrigation. In view of the above, a number of studies have attempted to investigate the trend of climatic variables for the country. These studies have looked at the trends on the country scale, regional scale and at the individual stations. Krishnakumar *et al.* (2009) studied temporal variation in monthly, seasonal and annual rainfall over Kerala and revealed significant decrease in SW monsoon rainfall and an increase in post-monsoon season. Waylen *et al.* (1996), in a study of spatial variability of annual rainfall in Costa Rica for 100 stations, found that rainfall frequency can be rep- resented by a normal distribution. Frequency analysis of rainfall data has been attempted for different places in India (Jeevrathnam and Jaykumar, 1979; Sharda and Bhushan, 1985; Prakash and Rao, 1986; Aggarwal *et al*., 1988; Bhatt *et al.,* 1996; Mohanty *et al.,* 1999; Rizvi *et al.,* 2001; Singh, 2001). The annual and seasonal climatic variability in south Saurashtra region of Gujarat was studied by Sahu (2008) and for north Gujarat by Neeraj and Patel (2012) by using historical weather data. A few attempts have been made earlier (Pandey *et al.* ,1999) to analyze the rainfall data for selected stations of Gujarat state.

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MATERIALS AND METHODS

The past 112 years (1901-2012) rainfall data have been collected for Navsari (20°57' N latitude, 72°54' E longitude and 10 AMSL) and Bharuch (22° N latitude, 73°5' E longitude and 16.5 AMSL) districts from India Meteorological Department, Pune and analyzed by using the mathematical and statistical techniques (Fig. 1-2). The mathematical and statistical procedures involved the determination of monthly and seasonal average rainfall, frequency, mean, median, mode, standard deviation, coefficient of dispersion, coefficient of variation and coefficient of skewness. Based on time series analysis (Croxten *et al.,* 1988), the prediction of future rainfall trend has also been visualized for both stations.

RESULTS AND DISCUSSION

The mathematical method involved calculation of

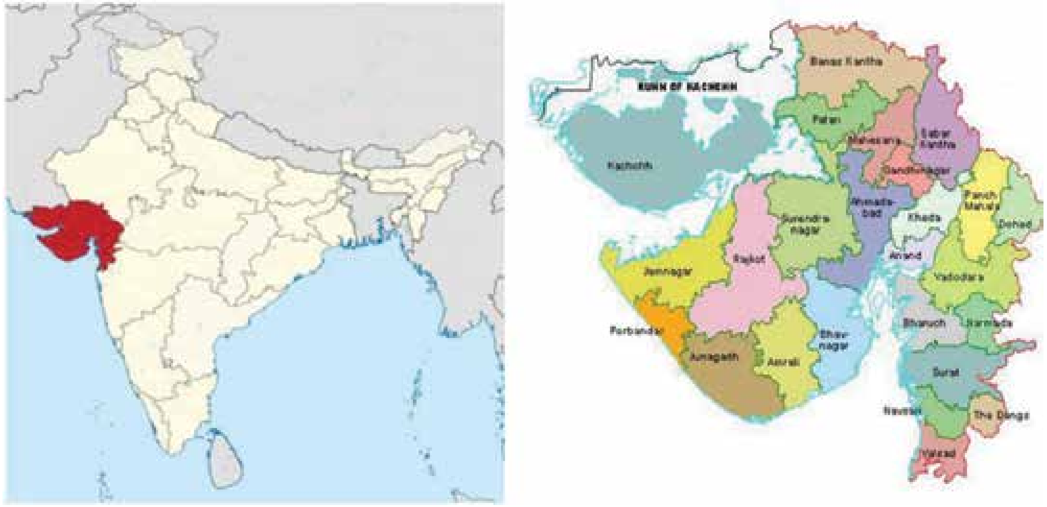

Fig. 1. Location map of Navsari and Bharuch areas.

the average rainfall of years and months as shown by the arithmetic mean of the period of 112 years. A record of 112 years of Navsari and Bharuch districts (1901-2012) was used for rainfall data analysis and to find out the total seasonal and annual rainfall values. Mean monthly and seasonal rainfall shows that in Navsari region around 95% of rainfall is received during the period of southwest monsoon. The normal rainfall of southwest monsoon season is 1452.60 mm (Table 1 and Fig. 2). The normal rainfall during winter and summer seasons was 56.5 and 8.8 mm, respectively. The annual rainfall of Navsari during the past 112 years ranged between 819.3 mm (1952) to 2827.6 mm (1970) with a mean of 1517.9 mm and median of 1430.0 mm. The mean was determined by adding all the data points in a population and then dividing the total by the number of points. The mean is exceedingly sensitive for the extreme values. Similarly, the median represents the numerical value separating the higher half of a data sample of population from the lower half. The median is the middle of a distribution that is less sensitive to extreme values than the mean. Mode refers to the most frequently occurring number found in a set of members. The mode is found by collecting and organizing the data in order to count the frequency of each result. The computed value of mode was 1444.2 mm which indicates ideal rainfall of the area. Mode analysis (Table 3) shows that class interval 1400 to 1599 mm has highest number of frequencies of rainfall (21) followed by interval 1000 to 1119 mm (19), 1200 to 1399 mm (17) and 800 to 999 mm (16) for Navsari region. To obtain an idea of the distribution, the data are broken down into convenient classes, which must be mutually exclusive and are usually equal in width to enable histograms to be drawn. The class boundaries should clearly define the range of each class. Data analysis revealed that Navsari region received good rainfall over the years. The calculated value of

Table 1. Computed average monthly and seasonal rainfall of Navsari region

Season	Month	Mean monthly rainfall(mm)	Average seasonal rainfall(mm)
Monsoon	June	277.5	1452.6
	July	587.0	
	August	346.8	
	September	241.3	
Winter	October	41.5	56.5
	November	10.9	
	December	1.8	
	January	2.3	
Summer	February	1.3	8.8
	March	0.8	
	April	1.1	
	May	5.6	
Total		1517.9 mm	

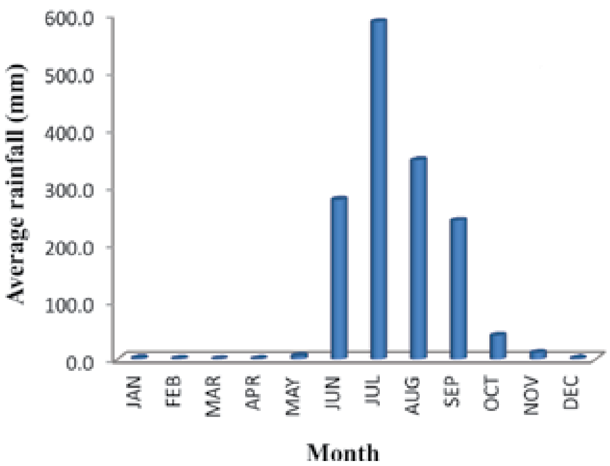

Fig. 2. Average monthly rainfall of Navsari region during 1901 to 2012

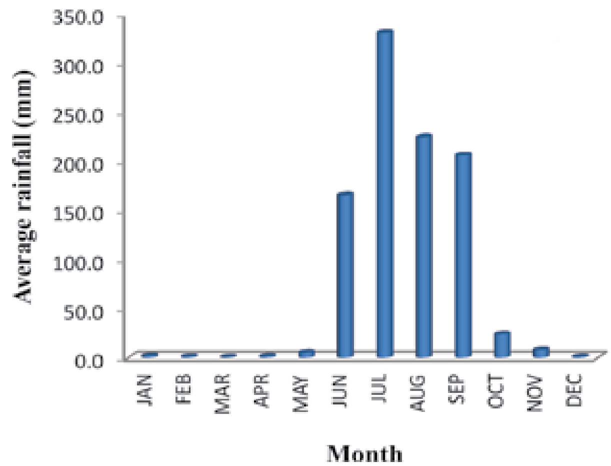

Fig. 3. Average monthly rainfall of Bharuch region during 1901 to 2012

standard deviation reveals how much dispersion exists from the mean. A low standard deviation indicates that the data points tend to be very close to the mean and high standard deviation represents the data points are spread out over a large range of values. The standard deviation of rainfall is 481.1 mm over a period of 112 years for Navsari region. The coefficient of variation of Navsari was found 31.8%. It is useful in comparing the degree of variation from data series. The coefficient of skewness indicates the degree of asymmetry or departure from symmetry of distribution. It was computed as 0.148 mm. The coefficient of skewness of Navsari region indicates positive trend. The coefficient of dispersion for Navsari region came out to be 0.318 mm, which shows a statistical measure of the dispersion of data points in data series around mean (Table 5). The annual rainfall over Navsari showed a long term increasing trend. An increase of 304.64 mm (Y=2.721X+1366, R^2=0.032) in rainfall has been noticed during the study period of 112 years as against the normal rainfall of 1517.90 mm (Fig. 4).

Bharuch district's maximum annual rainfall in past 112 years (1901-2012) was recorded as 1736.0 mm during the year 1976 and minimum of 402.5 mm was noted in the year of 1972 (Table 2 and Fig. 3). Mean monthly and seasonal rainfall shows that at Bharuch region around 95% of rainfall is received during the period of southwest monsoon. The normal rainfall of southwest monsoon season is 926.90 mm. The normal rainfall of Bharuch region during winter and summer seasons was 35.9 and 9.3 mm, respectively. The coefficient of skewness shows positive trend of rainfall for Bharuch. The mean, median, mode, standard deviation, coefficient of dispersion, coefficient of variation and coefficient of skewness were 972.1 mm, 959.5 mm, 913.7 mm, 293.3 mm, 0.302 mm, 30.2 % and 0.199 mm, respectively (Table 6 and 4). Rainfall class interval analysis revealed that the highest

Table 2. Computed average monthly and seasonal rainfall of Bharuch region

Season	Months	Mean monthly rainfall (mm)	Average seasonal rainfall (mm)
Monsoon	June	165.7	926.9
	July	330.3	
	August	224.6	
	September	206.3	
Winter	October	24.3	35.9
	November	8.3	
	December	1.1	
	January	2.2	
Summer	February	1.3	9.3
	March	0.9	
	April	1.6	
	May	5.5	
Total		972.1 mm	

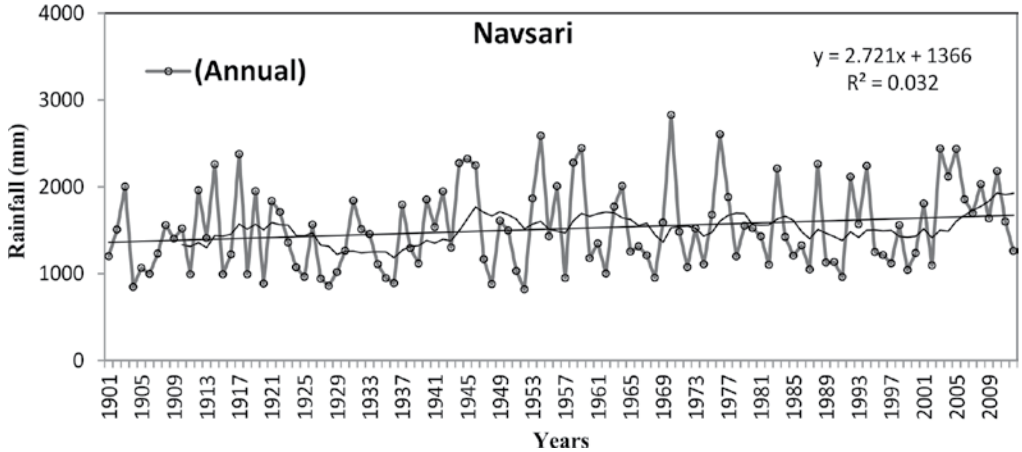

Fig. 4. Annual rainfall trends in Navsari (1901-2012)

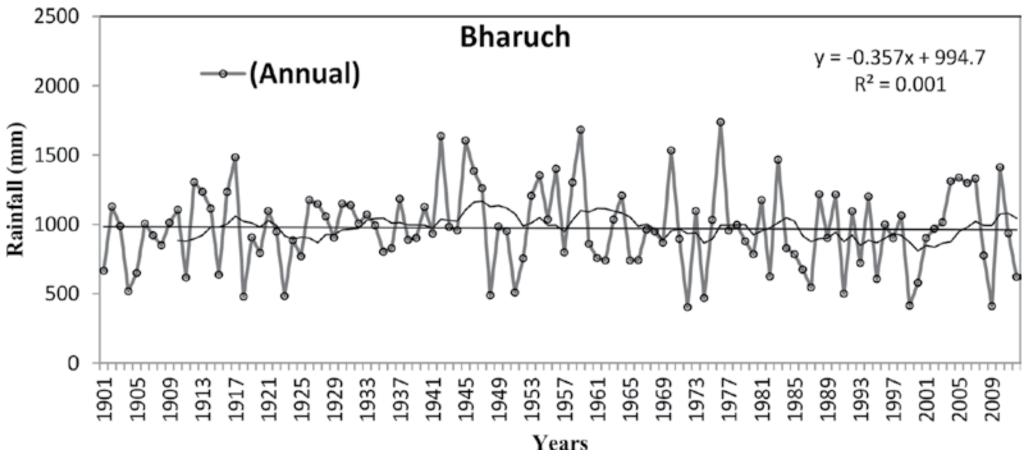

Fig. 5. Annual rainfall trends in Bharuch (1901-2012)

Table 3. Frequency distribution of rainfall in Navsari region

Class interval (mm)	Mid value (x)	Frequency (f)	fx	d= x-1899.5/ 199	fd	fd²	d²	Cumulative frequency
800-999	899.5	16	14392.0	-5	-80	6400	25	16
1000-1199	1099.5	19	20890.5	-4	-76	5776	16	35
1200-1399	1299.5	17	22091.5	-3	-51	2601	9	52
1400-1599	1499.5	21	31489.5	-2	-42	1764	4	73
1600-1799	1699.5	7	11896.5	-1	-7	49	1	80
1800-1999	1899.5	10	18995	0	0	0	0	90
2000-2199	2099.5	7	14696.5	1	7	49	1	97
2200-2399	2299.5	9	20695.5	2	18	324	4	106
2400-2599	2499.5	4	9998.0	3	12	144	9	110
2600-2799	2699.5	1	2699.5	4	4	16	16	111
2800-2999	2899.5	1	2899.5	5	5	25	25	112
Total		Σf =112	Σfx =170744.0	Σd =0	Σfd =-210	Σfd²=17148	Σd²=110	

Table 4. Frequency distribution of rainfall in Bharuch region

Class interval	Mid value(x)	Frequency (f)	Fx	d= x-1099.5/ 199	fd	fd^2	d^2	Cumulative frequency
400-599	499.5	12	5994.0	-3	-36	1296	9	12
600-799	699.5	20	13990	-2	-40	1600	4	32
800-999	899.5	32	28784	-1	-32	1024	1	64
1000-1199	1099.5	23	25288.5	0	0	0	0	87
1200-1399	1299.5	16	20792	1	16	256	1	103
1400-1599	1499.5	5	7497.5	2	10	100	4	108
1600-1799	1699.5	4	6798	3	12	144	9	112
		Σf =112	Σfx =109144.0	Σd =0	Σfd =-70	Σfd^2=4420	Σd^2=28	

Table 5. Computation of statistical parameters of rainfall data of the Navsari region

Statistical parameter	Computed Value
Mean	1517.9
Median	1430.0
Mode	1444.2
Standard Deviation	481.4
Coefficient of Dispersion	0.318
Coefficient of Variation	31.8
Coefficient of Skewness	0.148

Table 6. Computation of statistical parameters of rainfall data of the Bharuch region

Statistical parameter	Computed Value
Mean	972.1
Median	959.5
Mode	913.7
Standard Deviation	293.3
Coefficient of Dispersion	0.302
Coefficient of Variation	30.2
Coefficient of Skewness	0.199

number of frequencies was under under interval 800 to 999 mm (32), followed by 1000 to 1199 mm (23), 600 to 799 mm (20) and 1200 to 1399 mm (16). The close values of mean, median and mode indicate that the rainfall variation in Bharuch district is less as compared to Navsari. The mean annual rainfall over Bharuch showed a long term declining trend. A decrease of 39.98 mm (Y=-0.357X+994.7, R^2 = 0.001) in rainfall was noticed during the study period of 112 years as against the normal rainfall of 972.10 mm (Fig. 5). The mean annual rainfall over longer run for Navsari showed significant increase in rainfall trend with an annual rate of 2.72 mm per year, while insignificantly decreasing rainfall trend was noticed at Bharuch at an annual rate of 0.36 mm per year.

Time series analysis

The time series analysis is an effective method for studying variations of rainfall data in cyclic nature and generates valuable information regarding the trend of a series of observations. It helps to measure the deviation from the trend and also provides information pertaining to the nature of trend. The method of least square fit of straight line has been used for performing the trend analysis of the behavior of rainfall (Singh and Dev, 2012). The straight line equation can be represented as:

Where $y_{c\,=}$ a + bx

$y_{c\,=}$ Trend value of dependent variable

x = Independent variable

a and b = unknown

To set up a best fit straight line, the values of a and b must be determined from the observed data. Simultaneous solving of two normal equations does this.

$\Sigma y = Na + b\Sigma x$ (1)

$\Sigma xy = a\Sigma x + b\Sigma x^2$ (2)

The values of the various elements in the above equations have been determined by taking into account y as variable (annual rainfall) and x as constant (year). The determinations were completed as per the procedure described below.

N = 112 Σx = 0 Σy = 169736.7 Σx^2 = 468272 Σxy = 655682.0 (Navsari)

N = 112 Σx = 0 Σy = 108867.6 Σx^2 = 468272 Σxy = -47082.5 (Bharuch)

Substituting these values in normal equation (1) and (2), equations (3), (4) and (5) ,(6) in terms of a and b were developed

169736.7 = 112 a + 0 (Navsari) (3)

655682.0 = 0 + b 468272 (Navsari) (4)

108867.6= 112 a + 0 (Bharuch) (5)

-47082.5 = 0 + b 468272 (Bharuch) (6)

Solving equations (3), (4), (5) and (6), the values of a and b were obtained as 1515.5, 1.400, 972.0 and 0.101,

Table 7. Determination of expected future trend of rainfall in Navsari region

Year	Procedure	Expected future trend
2013	1515.5 + 1.400 (113)	1673.7 mm
2014	1515.5 + 1.400 (115)	1676.5 mm
2015	1515.5 + 1.400 (117)	1679.3 mm
2016	1515.5 + 1.400 (119)	1682.1 mm
2017	1515.5 + 1.400 (121)	1684.9 mm
2018	1515.5 + 1.400 (123)	1687.7 mm
2019	1515.5 + 1.400 (125)	1690.5 mm
2020	1515.5 + 1.400 (127)	1693.3 mm
2021	1515.5 + 1.400 (129)	1696.1 mm
2022	1515.5 + 1.400 (131)	1698.9 mm

Table 8. Determination of expected future trend of rainfall in Bharuch region

Year	Procedure of determinates	Expected future trend
2013	972.0+ 0.101 (113)	983.4 mm
2014	972.0+ 0.101 (115)	983.6 mm
2015	972.0+ 0.101 (117)	983.8 mm
2016	972.0+ 0.101 (119)	984.0 mm
2017	972.0+ 0.101 (121)	984.2 mm
2018	972.0+ 0.101 (123)	984.4 mm
2019	972.0+ 0.101 (125)	984.6 mm
2020	972.0+ 0.101 (127)	984.8 mm
2021	972.0+ 0.101 (129)	985.0 mm
2022	972.0+ 0.101 (131)	985.2 mm

respectively. Hence equation of straight line is developed, which can be written as

$$i/c = 1515.5 + 1.400x \quad \text{(Navsari)} \quad (7)$$

$$i/c = 972.0 + 0.101x \quad \text{(Bharuch)} \quad (8)$$

With the help of equations (7) and (8), the trend values of Navsari and Bharuch were calculated. On this basis, the future forecast of rainfall quantity for a period of 10 years from 2013 to 2022 of Navsari and Bharuch has been primed (Table 7 and 8) which shows a projected future trend for the coming years. Model projected an increase of 181 mm of rainfall at Navsari and 13.1 mm for Bharuch district till 2022. The analysis may be used as a tool to forecast the future performance of the rainfall trend.

To sum up, south Gujarat is highly sensitive for southwest monsoon rainfall. Changes in the frequency and magnitude of rainfall events bring in subsequent changes in the soil water content. An increase of 304.64 mm in rainfall was noticed for Navsari district during the study period of 112 years as against the normal rainfall of 1517.90 mm and 39.98 mm decline for Bharuch was noticed during the study period against the normal rainfall of 972.10 mm. Time series model based on Croxten *et al.* (1988) revealed future increase in rainfall for both stations. Mode analysis shows that class interval 1400 to 1599 has highest number of frequencies of rainfall (21) of Navsari region and for Bharuch highest number of frequencies was found under interval 800 to 999 (32).

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Authors' contribution

Conceptualization of research work and designing of experiments (NK, SKC, GGR); Execution of field/lab experiments and data collection (SKC, NK); Analysis of data and interpretation (NK, SKC, GGR); Preparation of manuscript (SKC, NK, GGR).

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