*Vol. 45, No. 2, pp 168-175, 2017*
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

# Long term trend analysis of rainfall at heavy rainfall zone of South Gujarat, India

**R.R. Pisal[1], Neeraj Kumar and S.P. Shukla**

*Navsari Agricultural University, Navsari- 396 450, Gujarat.*

*[1]E-mail: rrpagri@gmail.com*

**ARTICLE INFO**

***Article history :***

Received : February, 2016
Revised : December, 2017
Accepted : January, 2017

***Key words:***
Drought,
Mann-Kendall test,
Sen's slope,
Trend analysis

**ABSTRACT**

The study of precipitation trends is critically important for a country like India whose food security and economy are dependent on the felicitous availability of water. Present study was carried out using monthly, seasonal and annual rainfall data of 112 years (1901-2012) for Navsari and Bharuch districts of heavy rainfall zone of south Gujarat. The long term changes in rainfall were determined by Mann-Kendall rank statistics and linear trend analysis. The annual rainfall at Navsari illustrated significantly increasing trend (+ 2.72 mm $yr^{-1}$), while decreasing trend in rainfall was observed at Bharuch location (- 0.36 mm $yr^{-1}$). This, also reflected into their decadal analysis *i.e.* + 29.22 mm $decade^{-1}$ at Navsari, while -7.61 mm $decade^{-1}$ at Bharuch. During pre-monsoon, post-monsoon and winter season, rainfall showed decreasing trend over both locations. The increasing trend of monsoonal rainfall was observed at Navsari and decreasing trend was found at Bharuch. The long term data analysis divulged that at Bharuch station wider variability rainfall was observed as compared to Navsari.

## 1. INTRODUCTION

Rainfall pattern governs the overall cropping pattern, productivity and sustainability of agriculture enterprise. The standard of living and well being of human is largely dependent 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 Parthasarathy (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; Goswami *et al*., 2006; 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. Antonia and Paolo (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). Nnyaladzi and Brent (2010) identified a trend towards decreased rainfall throughout the Botswana, which is associated with decrease in the number of rainy days. Pali *et al.* (2016) found that about 55 to 66% years experienced rainfall deficit years at all the three study blocks *viz.,* Durg, Dhamdha and Patan Blocks of Durg district of Chhattisgarh.

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, Rupa *et al.* (1992) identified the areas having decreasing and increasing trends of monsoon rainfall. Sinha Ray and De (2003) concluded that all-India rainfall and surface pressure shows no significant trend, except for some periodic behaviour. 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 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. Vinay *et al.* (2010) studied monthly, seasonal and annual trends of rainfall 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 (Chattisgarh) 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 not 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. During the south-west monsoon season, three subdivisions *viz.,* Jharkhand, Chattisgarh, Kerala showed significant decreasing trend and eight subdivisions *viz.,* Gangetic WB, West UP, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra sub-division, Rayalseema, Coastal AP and North Interior Karnataka showed significant increasing trends (Guhathakurta and Rajeevan, 2007). Krishnakumar *et al.* (2009) revealed that there was a major shift in rainfall pattern temporarily during recent years as seasonal rainfall during the southwest monsoon was declining while increasing in post-monsoon season in Kerala.

Rainfall is one of the most important natural resource inputs to crop production in the tropical region. Out of 189.54 m ha (1996-97), gross cropped area (including area sown more than once) of the country, 61.3% (116.26 m ha) falls under rainfed farming. To exploit the available rainfall effectively, crop planning and management practices must be followed based on the rainfall amount and its distribution at a given place. Mandal *et al.* (2015) indicated that total economic loss in semi-arid tropics (SAT) of Maharashtra is to the tune of 15791.67 million for high rainfall year, 1.81 and 3.81 times higher than the normal and drought years, respectively. The concept of estimating probabilities with respect to a given amount of rainfall is extremely helpful for crop and water resources planning. The present analysis, therefore, was taken up to assess the expected rainfall amounts at different locations in future.

## 2. MATERIALS AND METHODS

In south Gujarat, two locations were chosen for assessment of scarce and excess rainfall intensity and frequency (1) Navsari (20°57' N and 72°54' E, Altitude 11.0 m above msl) and (2) Bharuch (22°98' and 70°21', Altitude 3.0 m above msl). The meteorological data set of past 112 years (1901-2012) was utilized for this study. 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) that are depicted in Table 1. The data were subjected to find out long term trends. A linear trend line was added to the series to simplify the trends. To support the trends in annual and seasonal rainfall, decade-wise shifts in rainfall were also analyzed. Temporal changes in the seasonal and annual rainfall were also analyzed by using Mann-Kendall test (MK) (Kendall, 1975; Mann, 1945; Turkeş *et al.,* 2002) and it is used to determine annual and monthly rainfall trends.

$$S = \sum \left[ \sum_{i-1}^{n-1} \overset{n}{\underset{j=i+1}{\mathrm{sgn}}} (Rj - Ri) \right] \qquad \text{...(1)}$$

Where, sgn(x) = 1 for x > 0; sgn(x) = 0 for x = 0; sgn(x) = -1 for x < 0 and R = rainfall.

A positive value of S indicates an increasing trend and *vice-versa*. In addition, the standardized statistical test (t) is used, where positive t values indicate increasing trends and negative t values indicate decreasing trends. The values of t were used as the basis of a significant test by comparing it with:

$$= 0 \pm t_g \sqrt{4N + 10/9N(N - 1)} \qquad \text{...(2)}$$

Where $t_g$ is the desired probability point of the Gaussian normal distribution. In the present study, at 0.05 and 0.01 points were considered for comparison.

**Table: 1**
**Criterion for drought intensity**

| Rainfall deficiency (%) | Drought intensity |
|---|---|
| -0-25% | Mild |
| -26-50% | Moderate |
| ->50% | Severe |
| +0-25% | Mild excess |
| +26-50% | Moderate excess |
| +>50% | Severe excess |

Drought intensity has also been analyzed based on the India Meteorological Department classification (annual rainfall deficit from normal) as given in the Table 1. When deficiency of rainfall exceeds 50% of the normal, it is characterized as severe drought. Moderate droughts are associated with rainfall deficiency of 26-50% and mild drought linked with rainfall deficiency of 0-25% of the normal rainfall. Similarly, excess rainfall was also analyzed (Singh and Rao, 1988).

## 3. RESULTS AND DISCUSSION

### Rainfall Features

Rainfall characteristics of Navsari and Bharuch are presented in Table 2. Long term average rainfall of Navsari and Bharuch is 1515 and 972 mm with SD of 481 and 293 mm, respectively. The range of CV was quite high at both the locations of study. The mean values of CV for annual rainfall at Navsari and Bharuch districts are 31.76 and 30.15%, respectively. There were wider variations occurred in rainfall during all other seasons excluding monsoon. Rainfall during July month is highest (586.9 and 330.3 mm) and contributes about 38.7 and 34.0% of annual rainfall at Navsari and Bharuch, respectively. Rainfall contribution during June, August, September and October at Navsari is 18.3, 22.9, 15.9 and 2.7% and that of Bharuch is 17.0, 23.1, 21.2 and 2.5%, respectively. Rainfall contribution during remaining months was less than 1%. The CV is also highest during non-monsoonal period. The percent contribution of pre-monsoon, post-monsoon and winter rainfall to the annual is 0.5, 3.5, 0.4 at Navsari and 0.8, 3.4 and 0.5 at Bharuch, respectively.

### Annual Rainfall Trends

The mean annual rainfall over longer run for Navsari showed significant increase in rainfall trend with an annual rate of 2.72 mm $yr^{-1}$, while insignificantly decreasing rainfall trend was noticed for Bharuch at an annual rate of 0.36 mm $yr^{-1}$ (Table 5 and Fig. 1). Their decadal analysis also

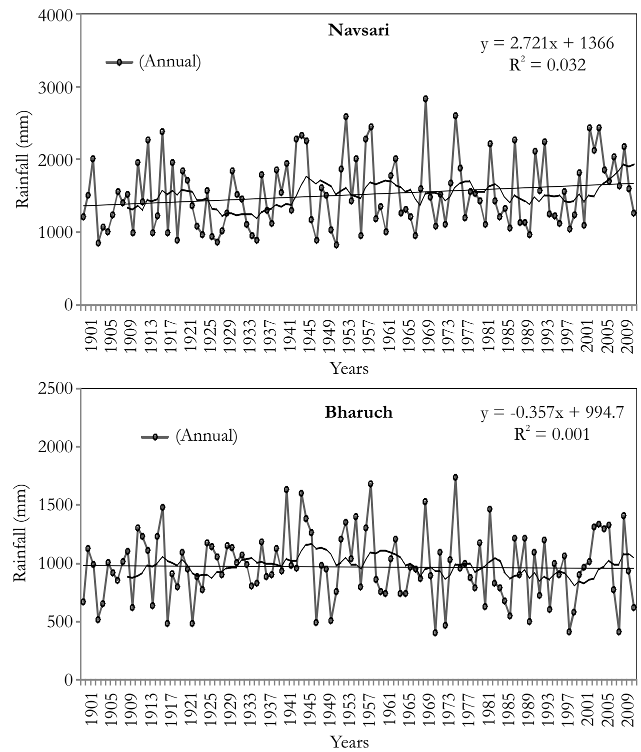


**Fig. 1. Annual rainfall trends over Navsari and Bharuch from 1901-2012**

**Table: 2**
**Monthly and seasonal means of rainfall (mm) over Navsari and Bharuch for 1901 to 2012**

| Months/Season | Rainfall | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Navsari | | | | Bharuch | | | |
| | Mean (mm) | Standard deviation (mm) | CV (%) | Percent contribution to annual rainfall | Mean (mm) | Standard deviation (mm) | CV (%) | Percent contribution to annual rainfall |
| January | 2.28 | 10.88 | 476.27 | 0.2 | 2.18 | 10.11 | 463.22 | 0.2 |
| February | 1.25 | 3.86 | 307.99 | 0.1 | 1.32 | 4.09 | 310.28 | 0.1 |
| March | 0.80 | 3.26 | 408.69 | 0.1 | 0.86 | 3.47 | 401.00 | 0.1 |
| April | 1.09 | 8.08 | 741.63 | 0.1 | 1.64 | 12.43 | 758.85 | 0.2 |
| May | 5.57 | 14.66 | 263.19 | 0.4 | 5.49 | 15.96 | 290.68 | 0.6 |
| June | 277.47 | 208.67 | 75.20 | 18.3 | 165.71 | 125.88 | 75.97 | 17.0 |
| July | 586.97 | 297.85 | 50.74 | 38.7 | 330.36 | 151.53 | 45.87 | 34.0 |
| August | 346.83 | 224.67 | 64.78 | 22.9 | 224.59 | 129.12 | 57.49 | 23.1 |
| September | 241.25 | 187.92 | 77.89 | 15.9 | 206.25 | 128.00 | 62.06 | 21.2 |
| October | 41.46 | 75.47 | 182.02 | 2.7 | 24.27 | 49.75 | 204.97 | 2.5 |
| November | 10.94 | 23.83 | 217.93 | 0.7 | 8.31 | 19.81 | 238.50 | 0.9 |
| December | 1.81 | 5.19 | 286.15 | 0.1 | 1.10 | 3.54 | 321.39 | 0.1 |
| Annual (mm) | 1515.54 | 481.38 | 31.76 | 100 | 972.03 | 293.25 | 30.17 | 100 |
| Pre-monsoon | 7.46 | 16.53 | 221.70 | 0.5 | 7.99 | 20.00 | 250.25 | 0.8 |
| Monsoon | 1450.37 | 474.13 | 32.69 | 95.7 | 926.90 | 281.11 | 30.33 | 95.4 |
| Post-monsoon | 52.30 | 78.95 | 150.96 | 3.5 | 32.58 | 52.08 | 159.85 | 3.4 |
| Winter | 5.35 | 12.74 | 238.03 | 0.4 | 4.60 | 11.29 | 245.25 | 0.5 |

**Table: 3**
**Decadal mean (% departure from normal) of excess, deficit rainfall, Man-Kendall rank statistics, linear equation and their significant tested by t-stat over Navsari and Bharuch from 1901 to 2012**

| Decades | Pre-monsoon | Monsoon | | | Post-monsoon | Winter | Annual | | |
|---|---|---|---|---|---|---|---|---|---|
| | Decadal mean (%) departure from normal | Decadal mean (%) departure from normal | Excess | Deficit | Decadal mean (%) departure from normal | Decadal mean (%) departure from normal | Decadal mean (%) departure from normal | Excess | Deficit |
| Navsari | | | | | | | | | |
| 1901-10 | -30.14 | -10.11 | 1 | 2 | -59.17 | 20.99 | -12.05 | 1 | 2 |
| 1911-20 | 35.29 | -4.95 | 1 | 4 | 89.31 | 229.37 | -0.77 | 2 | 4 |
| 1921-30 | -17.18 | -15.59 | 0 | 4 | -49.71 | -7.25 | -16.96 | 0 | 4 |
| 1931-40 | -65.84 | -11.86 | 0 | 2 | 89.48 | -11.18 | -8.88 | 0 | 2 |
| 1941-50 | 25.31 | 12.13 | 3 | 1 | -20.10 | -21.01 | 10.70 | 3 | 1 |
| 1951-60 | 29.42 | 8.45 | 3 | 3 | 46.57 | -44.78 | 9.46 | 4 | 3 |
| 1961-70 | -43.93 | 3.96 | 2 | 1 | -65.35 | -52.46 | 0.78 | 2 | 2 |
| 1971-80 | 3.29 | 4.32 | 1 | 1 | -19.00 | -45.31 | 3.06 | 1 | 0 |
| 1981-90 | -41.15 | -6.62 | 2 | 0 | 36.34 | -86.42 | -5.28 | 2 | 0 |
| 1991-2000 | -62.55 | -5.85 | 2 | 2 | 12.74 | 37.61 | -5.64 | 2 | 1 |
| 2001-12 | 167.49 | 26.12 | 5 | 0 | -61.10 | -19.58 | 27.29 | 5 | 0 |
| Rainfall (mm) | -0.067 | | 0.244 | | -0.244 | -0.422 | | 0.200 | |
| Linear equation | Y= 0.504x + 7.238 | | Y= 30.28x+1291 | | Y= -4.136x+ 78.75 | Y= -0.808x+ 9.923 | | Y= 29.22x+1375 | |
| t-stat | 0.842 | | 2.020 | | -0.501 | -1.606 | | 1.983 | |
| Bharuch | | | | | | | | | |
| 1901-10 | -40.95 | -6.41 | 0 | 3 | -82.15 | 51.79 | -9.08 | 0 | 3 |
| 1911-20 | 111.93 | -4.41 | 2 | 3 | 97.51 | 180.17 | 0.79 | 2 | 3 |
| 1921-30 | -67.22 | 0.38 | 0 | 1 | -24.28 | 3.91 | -1.10 | 0 | 1 |
| 1931-40 | -59.59 | 0.05 | 0 | 0 | 86.43 | -32.16 | 2.23 | 0 | 0 |
| 1941-50 | 122.69 | 14.55 | 3 | 1 | 8.21 | 2.19 | 15.04 | 3 | 1 |
| 1951-60 | 31.98 | 10.59 | 3 | 1 | 66.66 | -78.75 | 12.13 | 4 | 1 |
| 1961-70 | -52.09 | 1.00 | 1 | 0 | -62.11 | -50.84 | -1.92 | 1 | 0 |
| 1971-80 | -39.95 | -4.11 | 1 | 2 | -8.94 | -49.98 | -4.89 | 1 | 2 |
| 1981-90 | 21.85 | -3.63 | 2 | 2 | 19.78 | -57.71 | -4.46 | 1 | 2 |
| 1991-2000 | -27.69 | -16.45 | 0 | 4 | -40.82 | 97.73 | -16.90 | 0 | 4 |
| 2001-12 | -0.96 | 8.43 | 5 | 2 | -60.30 | -66.37 | 10.66 | 5 | 2 |
| Rainfall (mm) | 0.067 | -0.067 | | | -0.467 | -0.422 | -0.289 | | |
| Linear equation | Y = -0.437x + 10.72 | | Y = -4.833x + 958.0 | | Y = -4.091x + 58.14 | Y = -0.513x + 7.24 | | Y = -7.606x + 1025 | |
| t-stat | -0.311 | | -0.081 | | -0.870 | -1.501 | | -0.127 | |

showed an increase at Navsari (29.22 mm decade$^{-1}$) and decrease at Bharuch (-7.61 mm decade$^{-1}$) districts (Table 3).

## Seasonal Rainfall Features

### Pre-monsoon (March-May)

The normal pre-monsoon rainfall was lies within the range of 7.46 and 7.99 mm at Navsari and Bharuch, respectively, while contribution of pre-monsoon rainfall was quite low *i.e.* 0.5 and 0.8% to that of annual rainfall at both the locations. In contrast to annual rainfall at Navsari, the pre-monsoon rainfall showed the decreasing trend (-0.05 mm yr$^{-1}$) over longer run of 1901-2012, similarly Bharuch district also showed the decreasing trend (-0.01 mm yr$^{-1}$) during pre-monsoon season (Table 5 and Fig. 2). While their decadal trend analysis showed the positive trend at Navsari and negative trend at Bharuch (Table 3) which clearly follows the annual trend and supports the increase in rainfall at Navsari and decrease at Bharuch. The contribution of pre-monsoon rainfall was quite low *i.e.* 0.5 and 0.8% to that of annual rainfall at both the locations. The respective Man-Kendall and 't' stat values for Navsari and Bharuch districts were -0.099, -0.145 and -1.164, -0.176. The test was found significant at 0.05 probability level at Bharuch district.

### Southwest monsoon (June-September)

The southwest monsoon rainfall contributes about 95.70 and 95.36% rainfall to that of annual at Navsari and Bharuch. The normal monsoonal rainfall at these two locations was 1450.37 and 926.90 mm at Navsari and Bharuch, respectively. The Man-Kendall test statistics (0.127 and -0.023) and 't' stat (2.285 and 0.020) for Navsari and Bharuch indicates significant increase in rainfall at Navsari with. The annualized rainfall analysis over the longer run *i.e.* 1901-2012 showed significant increase in rainfall with an annual rate of 3.02 mm yr$^{-1}$ and insignificant decrease in rainfall at Bharuch with the rate of 0.13 mm yr$^{-1}$. The magnitude of rainfall increase in 112

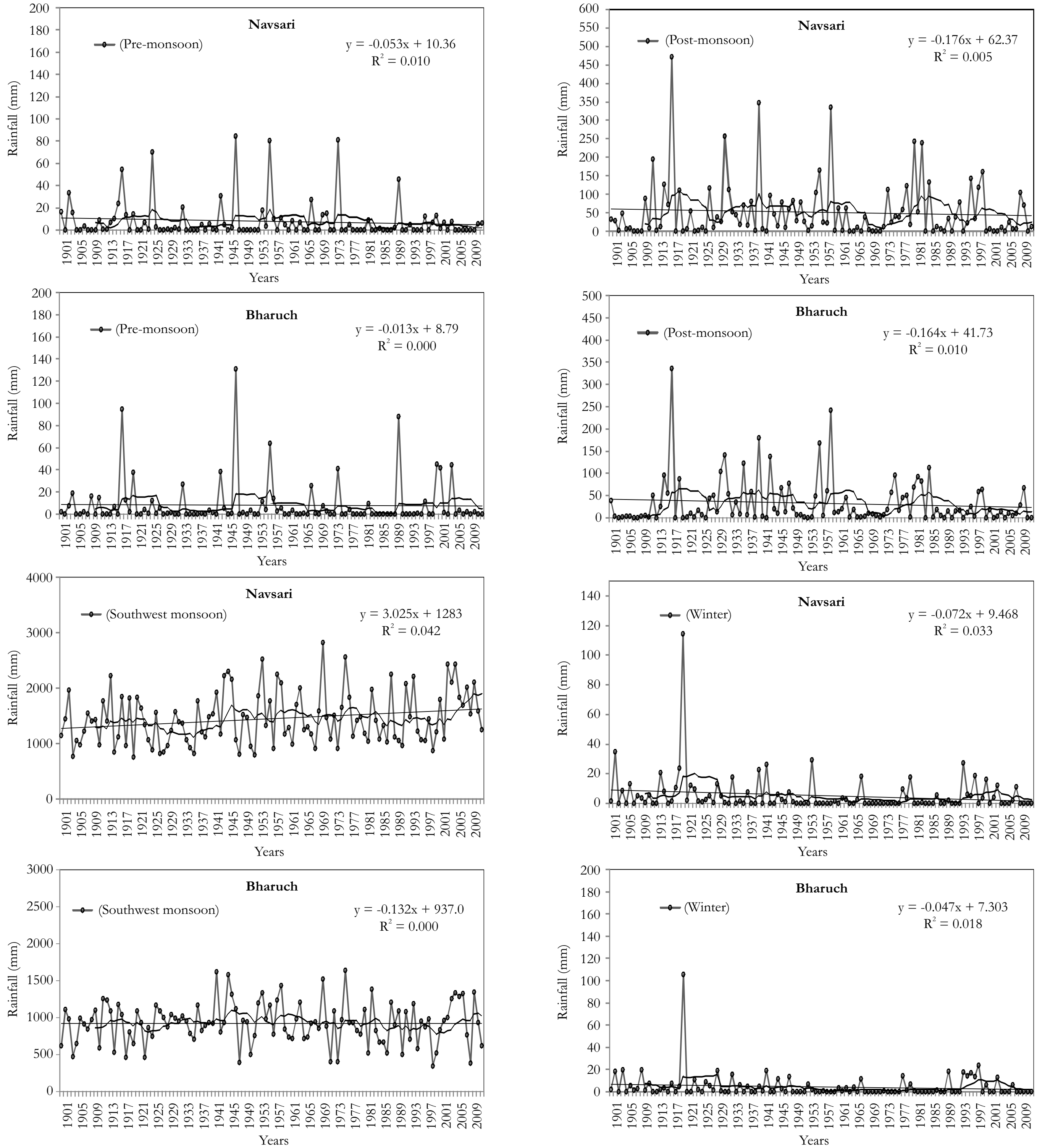


**Fig. 2. Seasonal rainfall trends over Navsari and Bharuch from 1901-2012**

years of about 338.2 and decrease of about 14.56 mm was observed over 1283 and 937 mm rainfall at Navsari and Bharuch, respectively. In recent years, the rainfall was significantly increased at Navsari and decreased at Bharuch during monsoon season.

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

The normal post-monsoon rainfall lies within the range of 52.30 and 32.58 mm at Navsari and Bharuch, respectively, while contributes only about 3.45 and 3.35% in annual precipitation at Navsari and Bharuch, respectively. The Man-Kendall and 't' stat indicated insignificant decrease in post-monsoon rainfall at both locations. There annual and decadal trend also showed the insignificant decrease in rainfall at both the stations. Overall, decline of rainfall was noticed about 19.71 and 18.37 mm at Navsari and Bharuch districts during the period of 112 years (Table 5 and Fig. 2).

### Winter (December-February)

Winter rainfall contributes less than 0.5% to that of annual precipitation at both the stations. The normal rainfall during winter season was 5.35 and 4.60 mm at Navsari and Bharuch, respectively. The Man-Kendall test (-0.184 and -0.199) indicated that seasonal rainfall during winter is significant at 0.01 levels and decreasing trend was noticed with annual rate of 0.07 and 0.05 mm $yr^{-1}$ at Navsari and Bharuch. Their corresponding 't stat' values are -1.88 and -1.07 for Navsari and Bharuch, respectively. Similarly, their decadal analysis also showed the supporting trend with an decreasing rate of 0.81 and 0.51 mm decadly. However, high variability of rainfall was observed during similar period.

**Table: 4**
**Rainfall intensity and frequency at Navsari and Bharuch for 1901 to 2012**

| Intensity | Years | Total years | Frequency |
|---|---|---|---|
| | Navsari | | |
| Mild | 1901, 1902, 1907, 1909, 1913, 1916, 1923, 1930, 1932, 1933, 1938, 1943, 1947, 1950, 1955, 1960, 1961, 1965, 1966, 1967, 1971, 1978, 1981, 1984, 1985, 1986, 1995, 1996, 1998, 2000, 2012 | 31 | 3.61 |
| Moderate | 1904, 1905, 1906, 1911, 1915, 1918, 1920, 1924, 1925, 1927, 1928, 1929, 1934, 1935, 1936, 1939, 1948, 1951, 1952, 1957, 1962, 1968, 1974, 1982, 1987, 1989, 1990, 1991, 1997, 1999, 2002 | 31 | 3.61 |
| Severe | Nil | 0 | - |
| Mild excess | 1908, 1910, 1921, 1922, 1926, 1931, 1937, 1940, 1941, 1949, 1953, 1963, 1969, 1973, 1975, 1977, 1979, 1980, 1993, 2001, 2006, 2007, 2009, 2011 | 24 | 4.67 |
| Moderate excess | 1903, 1912, 1914, 1919, 1942, 1944, 1946, 1956, 1964, 1972, 1983, 1988, 1992, 1994, 2008, 2010 | 16 | 7.00 |
| Severe excess | 1917, 1945, 1954, 1958, 1959, 1970, 1976, 2003, 2004, 2005 | 10 | 11.20 |
| | Bharuch | | |
| Mild | 1907, 1908, 1919, 1920, 1922, 1924, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1941, 1944, 1950, 1952, 1957, 1960, 1961, 1962, 1965, 1966, 1967, 1968, 1969, 1971, 1977, 1979, 1980, 1984, 1985, 1989, 1997, 2001, 2002, 2008, 2011 | 38 | 2.95 |
| Moderate | 1901, 1904, 1905, 1911, 1915, 1948, 1951, 1982, 1986, 1987, 1991, 1993, 1995, 2000, 2012 | 15 | 7.47 |
| Severe | 1918, 1923, 1972, 1974, 1999, 2009 | 6 | 18.67 |
| Mild excess | 1902, 1903, 1906, 1909, 1910, 1914, 1921, 1926, 1927, 1928, 1930, 1931, 1932, 1933, 1934, 1937, 1943, 1949, 1953, 1955,1963, 1964, 1973, 1975, 1978, 1981, 1992, 1994, 1996, 1998, 2003 | 31 | 3.61 |
| Moderate excess | 1912, 1913, 1916, 1946, 1947, 1954, 1956, 1958, 1988, 1990, 2004, 2005, 2006, 2007, 2010 | 15 | 7.47 |
| Severe excess | 1917, 1942, 1945, 1959, 1970, 1976, 1983 | 7 | 16.00 |

**Table: 5**
**Man-Kendall rank statistics, linear equation and their significant tested by t-stat of monthly and seasonal rainfall over Navsari and Bharuch from 1901 to 2012**

| Months/season | Navsari | | | Bharuch | | |
|---|---|---|---|---|---|---|
| | Rainfall (mm) | Linear equations | t-stat | Rainfall (mm) | Linear equations | t-stat |
| January | -0.143 | Y = -0.044x + 4.782 | -1.357 | -0.188* | Y = -0.030x + 3.902 | -1.006 |
| February | -0.183* | Y = -0.021x + 2.493 | -1.857 | -0.169* | Y = -0.003x + 1.496 | -0.188 |
| March | -0.091 | Y = -0.008x + 1.272 | -0.811 | -0.108 | Y = -0.014x + 1.671 | -1.367 |
| April | -0.158* | Y = -0.012x + 1.687 | -0.778 | -0.182* | Y = -0.018x + 2.683 | -0.470 |
| May | -0.021 | Y = -0.032x + 7.408 | -0.699 | -0.103 | Y = 0.019x + 4.435 | 0.440 |
| June | 0.096 | Y = 1.086x + 216.0 | 1.697 | -0.057 | Y = -0.019x + 167.9 | 0.118 |
| July | 0.061 | Y = 0.676x + 551.0 | 0.874 | -0.072 | Y = -0.456x + 355.5 | -1.046 |
| August | 0.077 | Y = 0.790x + 302.0 | 1.134 | 0.073 | Y = 0.587x + 192.5 | 1.640 |
| September | 0.112 | Y = 1.905x + 180.0 | 1.052 | -0.071 | Y = -0.243x + 221.0 | -0.474 |
| October | -0.028 | Y = -0.137x + 49.25 | -0.589 | -0.040 | Y = -0.187x + 34.65 | -1.307 |
| November | -0.018 | Y = -0.064x + 13.50 | -0.471 | -0.019 | Y = 0.023x + 7.081 | 0.458 |
| December | -0.101 | Y = -0.006x + 2.193 | -0.357 | -0.109 | Y = -0.014x + 1.904 | -1.284 |
| Annual (mm) | 0.129* | Y = 2.721x + 1366 | 2.017* | -0.036 | Y = -0.357x + 994.7 | -0.234 |
| Pre-monsoon | -0.099 | Y = -0.053x + 10.36 | -1.164 | -0.145* | Y = -0.013x + 8.79 | -0.176 |
| Monsoon | 0.127* | Y = 3.025x + 1283 | 2.285* | -0.023 | Y = -0.132x + 937.0 | 0.020 |
| Post-monsoon | -0.032 | Y = -0.176x + 62.37 | -0.705 | 0.000 | Y = -0.164x + 41.73 | -1.070 |
| Winter | -0.184** | Y = -0.072x + 9.468 | -1.879 | -0.199** | Y = -0.047x + 7.303 | -1.376 |

**Table: 6**
**Monthly and seasonal contribution of rainfall (%) to annual over Navsari and Bharuch from 1901 to 2012**

| Month/season | Navsari | | | | Bharuch | | | |
|---|---|---|---|---|---|---|---|---|
| | 1901-30 | 1931-60 | 1961-90 | 1991-2012 | 1901-30 | 1931-60 | 1961-90 | 1991-2012 |
| June | 17.06 | 17.02 | 18.55 | 21.08 | 19.10 | 13.80 | 17.47 | 18.72 |
| July | 39.32 | 39.76 | 37.74 | 37.96 | 35.56 | 34.91 | 30.32 | 35.43 |
| August | 23.67 | 20.92 | 24.41 | 22.64 | 19.68 | 22.14 | 26.55 | 24.60 |
| September | 14.89 | 16.77 | 16.27 | 15.55 | 20.53 | 23.14 | 21.89 | 18.22 |
| October | 2.77 | 3.94 | 2.05 | 1.98 | 2.90 | 3.84 | 1.47 | 1.24 |
| November | 0.85 | 0.72 | 0.93 | 0.33 | 0.49 | 0.90 | 1.43 | 0.48 |
| Pre-monsoon | 0.68 | 0.60 | 0.47 | 0.17 | 0.86 | 0.99 | 0.65 | 0.75 |
| Monsoon | 94.95 | 94.47 | 96.43 | 97.23 | 94.87 | 94.00 | 96.22 | 96.98 |
| Post-monsoon | 3.62 | 4.66 | 2.95 | 2.31 | 3.39 | 4.75 | 2.90 | 1.73 |
| Winter | 0.74 | 0.26 | 0.14 | 0.29 | 0.88 | 0.28 | 0.23 | 0.54 |

## Monthly Rainfall Trends

The variability of rainfall was experienced very high excluding monsoonal period. The CV was observed at higher side during the month of April and was closely followed by the month January for both locations (Table 2). In rainy season September month showing higher variability at Navsari and June month at Bharuch over others. Month wise trend analysis was carried out by Mann Kendall test for determining their significance level (Table 5). The results clearly indicated that an increase in monsoonal rainfall at Navsari for all the months *viz.*, June, July, August and September show similar pattern but it is not up to their significance level. Bharuch district shows varigated results *viz.*, June, July and September months shows decreasing trend, while August revealed increasing trend. There was an increase in rainfall contribution of June (17.02-21.08%) and September (14.89-16.77%) to the annual rainfall over period of time and slight differences during the months of August. While steep decline tendency was observed during July (39.76-37.74%), October (3.94-1.98) and November (0.93-0.33) at Navsari (Table 6). At Bharuch, high rate of increase in rainfall was observed during the month of August (19.68-26.55) and decrease during month of October (3.84-1.24), while other moths were quite stable.

## Shift in Decade-wise Annual and Seasonal Rainfall

The decadal analysis trend analysis of annual and seasonal rainfall for Navsari and Bharuch and frequencies of excess and deficient years during monsoon and annual period is depicted in Table 3. The excess and deficient years are defined for those years when rainfall is less or more than the SD. There was decrease in rainfall during pre-monsoon, post-monsoon and winter season, while increase in rainfall during monsoon. The monsoonal increase was at higher level which tends to increase in annual rainfall at Navsari over the decades. While, at Bharuch during all the seasons excluding pre-monsoon shows decrease in rainfall over the decades, which clearly denotes the decreasing trend of rainfall at Bharuch. Frequency analysis showed the variable results in rainfall behavior. However the there is an clear phenomenon of deficient years during early period of time and excess rainfall in later decades which supports the increasing trend of rainfall at Navsari, while Bharuch shows the controversial results of having deficient at initial and later while excess during middle decades. Out of 112 years, the Navsari rainfall shows 22 excess and 19 deficient years, while Bharuch shows 17 excess and 19 deficient years. The rainfall during the last 12 years was at higher side at both the locations and produces 5 excess and 2 deficient years.

## Drought Analysis

Navsari district is categorized as heavy rainfall zone of south Gujarat and the rainfall severity was observed towards higher side. South Gujarat receives 97% rainfall from Southwest monsoon (24 to 32 standard weeks) during the months of June to September. The least attempts had been made for assessing the intensity and frequency of drought as well as excess rainfall for this region. Drought of different intensities at Navsari and Bharuch is demonstrated in Table 4. During past 112 years, Navsari experienced 31 mild and 31 moderate droughts, while 24 mild, 16 moderate and 10 severe excess rainfall years. The frequency of occurrence of drought at Bharuch is much higher as compared to Navsari. Bharuch experienced 38 mild, 15 moderate and 6 severe droughts, while 31 mild, 15 moderate and 7 severe excess rainfall years during the past 112 years. At Navsari, the intensity of occurrence of moderate and mild droughts was about once in 3.6 years, while, severe excess, moderate excess and mild excess rainfall years are once in 11.2, 7.0 and 4.6 years, respectively (Table 4). Twenty six years received more than 20% rainfall than normal during the period of 112 years (1901-2012). Similarly, more than 20% excess rainfall occurred in every 4.3 years at Navsari.

At Bharuch, the severe moderate and mild droughts occurred once in 18.6, 7.4 and 2.9 years, respectively, while severe excess, moderate excess and mild excess rainfall was observed once in 16.0, 7.4 and 3.6 years, respectively (Table 4). Twenty two years received more than 20% rainfall than normal during the period of 112 years (1901-2012). Similarly, more than 20% excess rainfall occurred in every 5.0 years at Bharuch.

## 4. CONCLUSIONS

Past century rainfall behavior showed the variations in their anomaly. Annual rainfall at Navsari shows the increasing trend, while that of Bharuch was declining. Their seasonal analysis shows the increasing trend of rainfall during pre-monsoon, monsoon at Navsari and decreasing during other seasons. Bharuch district year round decrease was observed at more or less significance level. Drought anomaly was found that frequency of mild drought occurrence was quite low and occurred at regular interval at both the locations. Both the locations had higher rainfall deficit years than excess. This increasing trend of annual rainfall affects the cropping pattern, crop growth and yield of the region, while decreasing monsonal phenomenon may adversely affect the water availability in Bharuch region. So, during peak availability in excess rainfall months it is required to go for *ex-situ* soil moisture conservation at Navsari, but there is an urgent need to go for *in-situ* moisture conservation at Bharuch district to fulfill crop needs and ground water recharge.

## REFERENCES

Antonia, L. and Paolo, V. 2010. Trend analysis of annual and seasonal rainfall time series in Mediterranean area. *Int. J. Climatol.,* 30(10): 1538-1546.

Bhalme, H.N. and Mooley, D.A. 1980. Large scale droughts/floods and monsoon circulation. *Mon. Wealth Rev.*, 108(8): 1197-1211.

Dash, S.K., Jenamani, R.K., Kalsi, S.R. and Panda, S.K. 2007. Some evidence of climate change in twentieth-century India. *Climatic Change,* 85: 299-321.

Dore, M.H.I. 2005. Climate change and changes in global precipitation patterns: What do we know? *Environment Int.,* 31:1167-1181.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanam, M.S. and Xavier, P.K. 2006. Increasing trends of extreme rain events over India in a warming environment. *Science,* 314: 1442-1445.

Gregory, S. and Parthasrathy, B. 1986. Extreme monsoon rainfall deficits in India. *Theo. Appl. Climatol.,* 37:194-204.

Guhathakurta, P. and Rajeevan, M. 2007. Trends in the rainfall pattern over India. *Int. J. Climatol.*, 28(11):1453-1469.

IPCC (Intergovernmental Panel on Climate Change), 2007. *Summary for policymakers. In: Climate Change 2007: The Physical Science Basis* (ed. by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller). Cambridge University Press, UK.

Jain, S.K., Vijay, K. and Sahraia, M. 2012. Analysis of rainfall and temperature trendsin northeast India. *Int. J. Climatol.,* doi: 10.1002/joc.3483.

Kendall, M.G. 1975. Rank correlation methods. London: Charles Griffin.

Khan, T.M.A., Singh, O.P. and Sazedur Rahman, M.D. 2000. Recent sea level and sea surface temperature trends along the Bangladesh coast in relation to the frequency of intense cyclones. *Marine Geodesy,* 23: 103-116.

Krishnakumar, K.N., Prasada Rao, G.S.L.H.V. and Gopakumar, C.S. 2009. Rainfall trends in twentieth century over Kerala. *India. Atmos. Environ.*, 43:1940-1944.

Lal, M. 2003. Global climate change: India's monsoon and its variability. *J. Environ. Studies Policy,* 6:1-34.

Mandal, D.K., Goswami, S.N., Mandal, C., Prasad, J. and Nirmal K., 2015. Economic loss estimation under rainfall aberration in semi-arid tropics of India. *Ind. J. Soil Cons.,* 43(2): 182-186.

Mann, H.B. 1945. Non-parametric tests against trend. *Econometrica*, 13:245-259.

Min, S.K., Kwon, W.T., Park, E.H. and Choi, Y. 2003. Spatial and temporal comparisons of droughts over Korea with East Asia. *Int. J. Climatol.*, 23:223-233.

Mirza, M.Q. 2002. GlobalWarming and changes in the probability of occurence of floods in Bangladesh and implications. *Global Environ. Chang.*, 12:127-138.

Morishima, W. and Akasaka, I. 2010. Seasonal trends of rainfall and surface temperature over Southern Africa. *African Study Monographs*, 40: 67-76.

Narain, P., Rathore, L.S., Singh, R.S. and Rao, A.S. 2006. Drought assessment and management in arid Rajasthan by CAZRI Jodhpur and NCMRWF Noida, 1-29.

Nnyaladzi, B. and Brent, Y. 2010. Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. *Applied Geography,* 30: 483-489.

Pali, A.K., Thakur, H. and Khalkho, D. 2016. Rainfall analysis based rice crop planning in Durg district of Chhattisgarh. *Ind. J. Soil Cons.,* 44(1): 30-36.

Parthasarathy, B. 1984. Inter-annual and long term variability of Indian summer monsoon rainfall', *Proc. Indian Acad. Sci. Earth Planet. Sci.,* 93: 371-385.

Rupa, K., Pant G.B., Parthasarathy, B. and Sontakke, N.A. 1992. Spatial and sub-seasonal patterns of the long-term trends of Indian summer monsoon rainfall. *Int. J. Climatol.*, 12: 257-268.

Shrestha, A.B., Wake, C.P., Dibb, J.E. and Mayewski, P.A. 2000. Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters. *Int. J. Climatol.*, 20: 317-327.

Singh, R.P. and Rao, B.V.R. 1998. Agricultural drought management in India (Principles and Practice), Central Research Institute for Dry land Agriculture, Hyderabad: 1-45.

Sinha Ray, K.C. and De, U.S. 2003. Climate change in India as evidenced from instrumental records. *Bulletin of the World Meteorological Organization*, 52: 53-59.

Sinha Ray, K.C. and Srivastava, A.K. 1999. Is there any change in extreme events like droughts and heavy rainfall? In: INTROPMET-97 (IIT New Delhi, 2-5 December, 1997).

Turkeş, M., Sumer, U.M. and Demir, I. 2002. Re-evaluation of trend and changes in mean, maximum and minimum temperatures of Turkey for the peiod 1929-1999. *Int. J. Climatol.,* 22: 947-977.

Vinay K., Jain, S.K. and Singh, Y. 2010. Analysis of long-term rainfall trends in India. *Hydrol. Sci. J.,* 55(4): 484-496.

Wing H.C., Gabriel, B.S. and Singh, A. 2008. Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. *Int. J. Climatol.,* doi: 10.1002/joc1623.