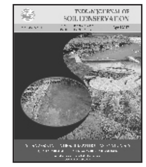
Vol. 45, No. 3, pp 338-347, 2017
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Long term rainfall data analysis over Eastern Ganga canal command area

Radha Krishan[1,4], Ayush Chandrakar[1], Bhaskar R. Nikam[2], Santosh M. Pingale[3] and Deepak Khare[1]

[1]Indian Institute of Technology, Roorkee-247667, Uttarakhand; [2]Indian Institute of Remote Sensing, Dehradun-248001, Uttarakhand; [3]Arba Minch University, Arba Minch - 21, Ethiopia.

[4]E-mail: radheyindia@hotmail.com

ARTICLE INFO

Article history :

Received : September, 2016
Revised : August, 2017
Accepted : September, 2017

ABSTRACT

An attempt has been made in the present study to analyse the variability and trends in annual and seasonal rainfall over Eastern Ganga Canal (EGC) command area, India. The daily gridded (0.25^0x0.25^0) rainfall dataset prepared by the India Meteorological Department (IMD), Pune is used in the present study for the time period 1901-2012. Total 12 grids of IMD rainfall data covering entire command and surrounding area were selected for analysing the trend. To determine the trend in annual rainfall, seasonal rainfall, annual number of rainy days and seasonal number of rainy days, the non-parametric Mann-Kendall (MK) and Sen's methods were used. It has been observed that annual and monsoon rainfall has decreasing trend in grids 6, 7, 12 whereas, no significant trend has been observed in other grids (1, 2, 3, 4, 5, 8, 9, 10, 11). Similarly increasing trend was observed in grids 5, 9, 10 in case of annual rainy days, whereas, grids 6, 7, 8, 12 exhibits decreasing trend. In case of number of rainy days in monsoon season, decreasing trend has been observed in grids 6, 7, 12 with increasing trend only in grid 5 and no significant trend in remaining grids (1, 2, 3, 4, 8, 9, 10, 11). In general, the results of trend analysis revealed a decreasing trend in annual and monsoon rainfall in the range of 18.5 to 61.7 mm decade^{-1} and 19.4 to 56.7 mm decade^{-1}, respectively. Decreasing trend of 1.8 to 2.9 days decade^{-1} was observed in some parts of the command area in annual rainy days, whereas some part showed increasing trend in the range of 0.2 to 1.4 days decade^{-1}. In case of number of rainy days in monsoon season, the decreasing trend varies from 1.4 to 2.2 days decade^{-1} whereas the increasing trend in grid 5 is 1.0 days decade^{-1}. The variability analysis has also been performed to highlight the frequency of dry and wet years. The coefficient of variability of annual rainfall, seasonal rainfall, annual number of rainy days and number of rainy days in monsoon ranges from 0.24 to 0.31, 0.29 to 0.38, 0.14 to 0.21 and 0.20 to 0.27, respectively. Analysis for dry year and wet year on annual scale were carried out for command area, which showed that there are 18 dry years and 21 wet years within 1901 to 2012. The driest year and wettest year were 1987 and 1942, respectively.

Key words:
Eastern Ganga canal command,
Man-Kendall test,
Rainfall trend,
Rainfall variability,
Sen's slope estimator

1. INTRODUCTION

Correct analysis of water resource potential is of prime importance for effective planning, flood protection and control and efficient water management, for which assessment of rainfall is the starting point. Information about the temporal and spatial variability of rainfall is important from both the scientific and practical points of view. Studies have demonstrated that global surface warming has been taking place at the rate of 0.74±0.18^{0}C, over 1906-2005 (IPCC, 2007). The increased atmospheric moisture content associated with warming might be expected to lead to increased global mean precipitation. Global annual land mean precipitation showed a small, but uncertain upward trend of approximately 1.1 mm decade^{-1} (uncertainty ± 1.5 mm) over 1901-2005 (Basistha *et al.*, 2009).

One of the most important requirements of research about climate change is to analyse and discover historical changes in the climatic system (IPCC, 1996). In the last years, several researchers studied variability and trends in precipitation throughout the world (de Luis *et al.*, 2000, 2010; Ventura *et al.*, 2002; del Rio *et al.*, 2005; Partal and Kahya, 2006; Liu *et al.*, 2008; Bocheva *et al.*, 2009; Huang *et al.*, 2009; Krishnakumar *et al.*, 2009; Zhang *et al.*, 2009; de la Casa and Nasello, 2010; Qin *et al.*, 2010; Xu *et al.*, 2010, 2011; Caloiero *et al.*, 2011; Li *et al.*, 2011 and Subash *et al.*, 2011). Gong and Wang (2000); Qian and Zhu (2001) and Kumar *et al.,* 2007 recognized significant negative precipitation trends for different regions of eastern China from 1954 to 1976 and then positive trends from 1977 to 1998. Yue and Hashino (2003) assessed long-term trends in Japan's annual and monthly precipitation using the Mann-Kendall (MK) test. Becker *et al.* (2003) detected the significant positive and negative trends on a monthly precipitation for the second half of the last century for different regions of China. de Lima *et al.* (2010) investigated the trends of annual and monthly precipitation at 10 stations in mainland Portugal by using the MK and Sen's non-parametric methods for long time series. They found a significant sequence of alternating negative and positive trends in annual and monthly precipitation, which were sometimes statistically significant. Liang *et al.* (2011) studied the temporal variation and spatial distribution of precipitation in Northeast China from 1961 to 2008. The results revealed different patterns of trends on both monthly and annual scales, moreover, the mean annual and summer precipitation rates decreased in a south-eastern to north-western trajectory throughout the 48-year period due both to the influence of the East Asian monsoon and to topography. According to Intergovernmental Panel for Climate Change (2007), during the 20th century, precipitation generally increased from 30^0 to 85^{0}N over land; but notable decreases have occurred between 10^{0}S and 30^{0}N in the last 30-40 years. In western Africa and southern Asia, the linear trends in rainfall decrease for 1900-2005 were 7.5% 100 yr^{-1} (significant statistically at <1% level), whereas over much of northwest India the period 1901-2005 shows increase of more than 20% century^{-1} (IPCC, 2007).

The variable rainfall pattern associated with the climate change deserves systematic and instant attention as it affects the food production and available fresh water (Dore, 2005). Intergovernmental Panel for Climate Change (IPCC, 2007) has reported spatial, inter-seasonal and inter-annual variability in rainfall trend in Asia in the last few decades. It was found that changing rainfall pattern has a considerable impact on the agricultural and water sector of the Asia-Pacific region (Cruz *et al.,* 2007). Dore (2005) provides a comprehensive review of precipitation changes at the global and regional level. It brings out decreasing rainfall trends in Russia, Kazakhstan, China, and Thailand, as well as a global increase in the variance of precipitation. Broadly, there is consensus regarding evidence of no significant trend in annual rainfall series over India (Parthasarathy and Mooley, 1978; Fleer *et al.*, 1984; Mooley and Parthasarathy, 1984; Lakshmanaswamy and Jindal, 1990; Srivastava *et al.*, 1992; Stephenson *et al.*, 2001; Kripalani and Kulkarni, 1997 and 2001 and Kripalani *et al.*, 2003), however, divergences do exist depicting an increase (Parthasarathy and Dhar, 1976) or decrease (Singh *et al.*, 2005).

The Indian climate is mainly characterized by monsoon rainfall and feeds most of the agricultural sectors. Therefore, variation in the rainfall pattern may significantly influence the economy of the country. With the growing stress on water due to climatic changes, analysis on a broad as well as a regional scale is required, as India has vast climatic zones and variations (Panigrahi and Panda, 2001). Major parts of India are facing the decrease in precipitation during the monsoon period. A decreasing trend has been observed in north-east India, central north-east India and west-central India (Kumar *et al.*, 2010). Since agriculture is the backbone of Indian economy, hence it is extremely significant to study the distribution of rainfall that governs the output from the agriculture sector. So, in the present study, trend and variability of rainfall and rainy days during past century (1901-2012) has been analysed using the MK test and Sen's slope estimator for the EGC command area, part of Asia's largest canal system. The variability analysis of annual and seasonal rain has also been done to identify the wet and dry years and their occurrence frequency in the area.

2. MATERIALS AND METHODS

Study Area

The EGC command area which covers major part of two districts, *i.e.* Haridwar (in Uttarakhand) and Bijnor (in Uttar Pradesh) extends from 29^0 to 30^{0}N and from 78^0 to 78^{0}45'E. EGC project utilizes the surplus water of Ganga River during monsoon period for the development of *kharif* cultivation in the districts of Bijnor, Haridwar and a very small part of Moradabad. The project has a gross command area of 3.01 lakh ha, out of which 2.33 lakh ha is culturable command area (CCA) and ultimate irrigation potential (IP) of the project is around 1.05 lakh ha. In the period other than *kharif* season the command area is mainly depended on precipitation occurred in that region, as the EGC project is designed to supply water only in *kharif* season. The location map of the project is shown in Fig. 1.

Data Collection

Daily gridded (0.25^0 x 0.25^0 spatial resolution) rainfall data, of the period 1901 to 2012, was procured from IMD, Pune. The daily precipitation data was extracted for the EGC command and surrounding area, which covers 12 grids of IMD data, as shown in Fig. 1. Further, the daily precipitation data was converted into monthly seasonal and annual scale. To analyse the long term trend in the rainy days in the study area, the IMD criteria of rainy day (rainfall equal to or greater than 2.5 mm day^{-1}) has been used in the present study to estimate rainy days of each year and each monsoon season (July to October). The number of rainy days of each grid in each year and monsoon season were also used in trend and variability analysis.

Description of Trend and Variability

In this study, two non-parametric methods *e.g.* MK test (Mann, 1945 and Kendall, 1975) and Sen's slope estimator technique (Sen, 1968), were used to detect and quantify the trends in the rainfall and rainy days. Before applying the MK test, all the data series were tested for serial correlation using Lag-1 autocorrelation (Anderson, 1941) at 1, 5, and 10% significance level to eliminate the effect of serial correlation. All the series were found to be serially independent, hence, MK test was directly applied to original data series to detect the trend using the two-sided hypothesis (Fu *et al*., 2009 and Xu *et al*., 2007) at 5% significant level. The value of statistically significant trend was calculated using Sen's estimator. The detailed description of all the statistical tests used in the present study is beyond the scope of this paper, however, detailed information for the same is available in the literature (Mann, 1945; Kendall, 1975; Sen, 1968; Xu *et al*., 2007 and Fu *et al*., 2009).

The coefficient of variation (CV), a statistical measure of the dispersion of data points in a data series around the mean, was used in the present study for quantifying the variability of input data.

The mean annual and seasonal rainfall of each grid and the weighted mean annual and seasonal rainfall of entire command area have been calculated for the EGC command area. The variability of annual and seasonal rainfall along with number of rainy days was evaluated using values of CV. Meteorologically negative deviation from mean annual rainfall will create meteorological stress year (dry year) and positive deviation from mean annual rainfall will generate the wet year. The numerical criteria proposed by IMD to define dry year and wet year (*e.g.* negative deviation equal to or greater than 25% of mean annual will be termed as dry year and positive deviation of same value range will be indicated as wet year) have been utilized in the present study to identify and analyses occurrence pattern of the wet and dry years during past century in the study area.

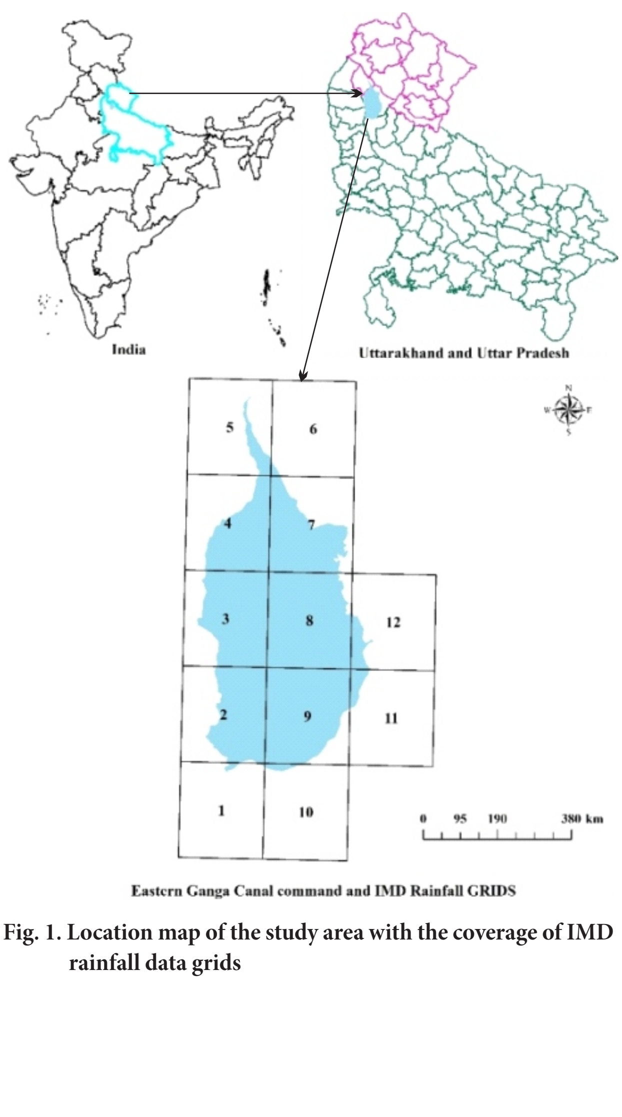


Fig. 1. Location map of the study area with the coverage of IMD rainfall data grids

3. RESULTS AND DISCUSSION

The annual and seasonal rainfall trends in precipitation were first estimated using MK test and Sen's slope estimator for the time-series of 112 years (1901-2012) over EGC command and surrounding area. Trend and variability analysis have been opted to analyse the trends and variability in annual rainfall, seasonal rainfall, annual number of rainy days and seasonal number of rainy days in twelve grids of EGC command. Trends plots for all the parameters of grid 7 are shown in Fig. 2.

Annual average rainfall in the region varies from 919.57 mm yr^{-1} to 1558.08 mm yr^{-1}, with the weighted average rainfall of 1165.93 mm yr^{-1} for entire command area (Table 1). A total of 77.36% of annual rainfall occurs in monsoon season. Monsoon rainfall varies from 722.39 mm yr^{-1} to 1198.32 mm yr^{-1} within 12 grids, with the weighted average monsoon rainfall of 901.95 mm yr^{-1} for all grids. Annual number of rainy days in EGC command varies from 53 days to 93 days

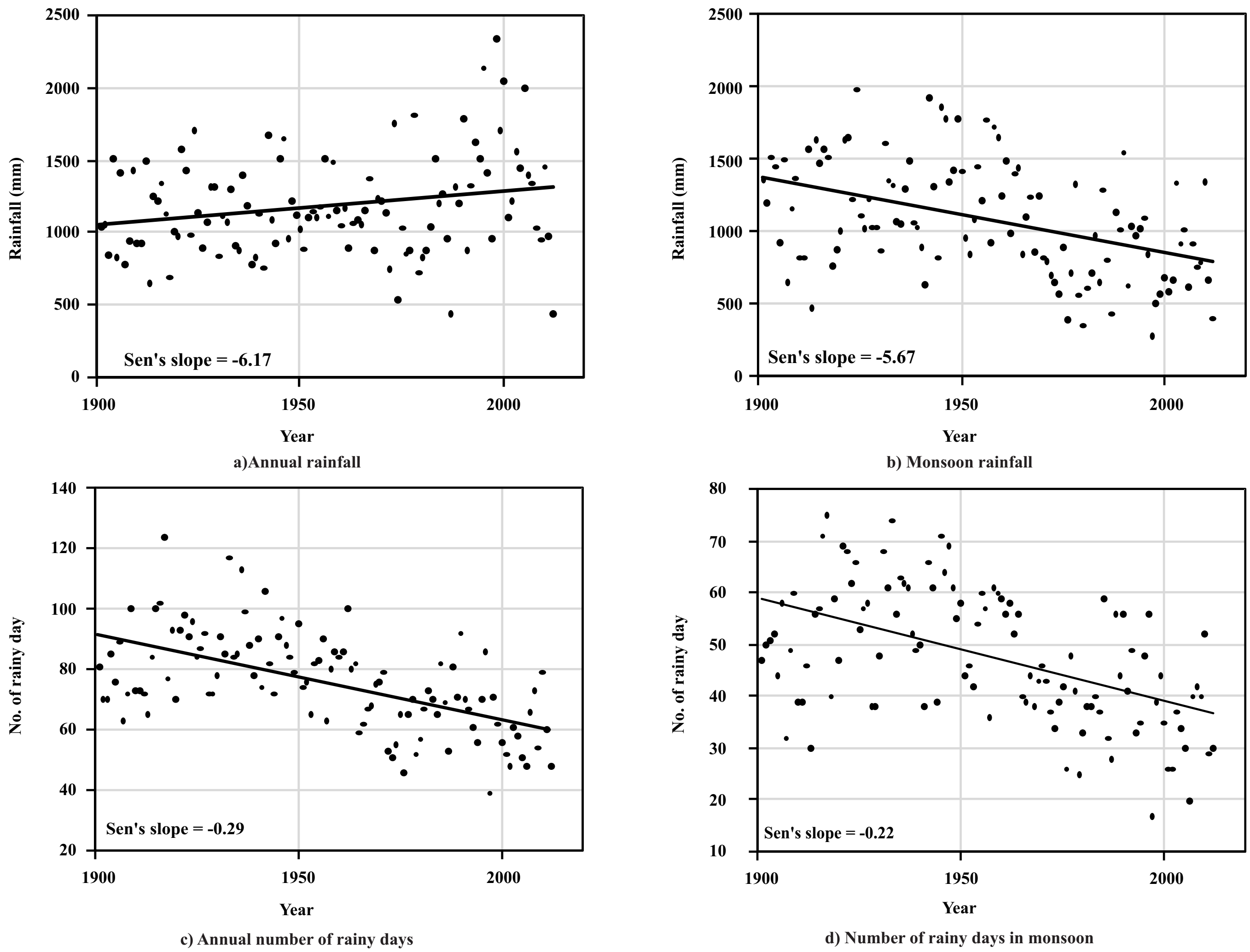


Fig. 2. Observed trends of different parameters in Grid 7

Table: 1
Preliminary statistics of mean annual/seasonal rainfall/rainy days of each grid and their coefficient of variation values

Grid	Annual rainfall		Monsoon rainfall		For Annual rainy days		Monsoon rainy days	
	Mean (mm)	CV	Mean (mm)	CV	Mean (day)	CV	Mean (day)	CV
1	919.6	0.28	722.4	0.35	52.0	0.20	35.9	0.25
2	986.6	0.26	759.0	0.32	53.2	0.17	35.4	0.23
3	1049.5	0.25	808.5	0.31	57.1	0.16	37.0	0.23
4	1188.1	0.24	912.4	0.29	67.9	0.15	43.9	0.20
5	1320.9	0.26	1014.5	0.32	65.3	0.19	41.7	0.26
6	1558.1	0.25	1198.3	0.30	92.7	0.16	59.2	0.21
7	1379.9	0.31	1075.6	0.36	75.8	0.21	47.6	0.27
8	1182.8	0.29	917.5	0.32	57.9	0.15	34.1	0.22
9	1079.6	0.25	832.5	0.31	60.2	0.15	35.5	0.22
10	992.8	0.31	780.7	0.38	57.9	0.18	33.8	0.26
11	1091.9	0.25	843.2	0.30	65.2	0.14	37.9	0.21
12	1241.6	0.24	958.7	0.29	78.3	0.17	46.5	0.25

with the mean of 66 days, out of which 34 days to 60 days were spread in monsoon season, with a weighted average of 41 rainy days in monsoon.

The results of trend analysis showed that annual and seasonal rainfall is shown decreasing trend in grids 6, 7, 12, whereas no significant trend is observed in other grids (1, 2, 3, 4, 5, 8, 9, 10 and 11) at 5% significance level, as tabulated in Table 2. In grids 6, 7, 12; both the decreasing trend in annual and monsoonal rainfall ranges from 18.5 to 61.7 mm decade^{-1} and 19.4 to 56.7 mm decade^{-1}, respectively. In case of annual rainy days, trend is increasing for grids 5, 9, 10 and decreasing for 6, 7, 8, and 12, with no significant trend in remaining grids (1, 2, 3, 4, and 11). Whereas, in case of seasonal (monsoon) rainy days, the trend is decreasing in grids 6, 7, 12 and increasing only in grid 5. However, no significant trend is observed in the remaining grids (1, 2, 3, 4, 8, 9, 10, and 11). A common decreasing trend is observed for grid 6, 7, and 12 for all four variables (annual rainfall, monsoon/seasonal rainfall, annual no. of rainy days and seasonal no. of rainy days). In case of seasonal rainy days these three grids demonstrate a decreasing trend, which ranges from 1.4 to 2.2 days decade^{-1} and only grid 5 shows increasing of 1 day decade^{-1}. Whereas, annual rainy days, these three grids and grid 8 have the decreasing trend, in the range of 1.8 to 2.9 days decade^{-1} and other three grids (5, 9 and 10) shows increasing trend ranging from 0.2 to 1.4 days decade^{-1}.

From Table 2, it is clear that there is a decrease in both annual and seasonal rainfall in grid 6, 7, 12; which may reduce the water availability with time. However, the trend in annual and seasonal number of rainy days are also indicating decreasing trend in these grids which may lead to no effective change in average rainfall per rainy day. In grid 5, the increasing trend for annual rainy days may decrease the rainfall per rainy day due to which there would be a decrease in runoff from the area. There is no trend for grid 8 within annual rainfall, seasonal rainfall and seasonal rainy days, however, there is a decreasing trend in annual number of rainy days, which indicates that the rainfall per rainy day during non-monsoon season might increase. In grid 9 and 10, there is increasing trends for annual rainy days only, which signifies that increase in rainy days would lead to decrease in rainfall per rainy day in non-monsoon period. This will cause a decrease in both the rainfall intensity and runoff, which may increase the initial losses in the area. The trend analysis on weighted mean annual rainfall over entire command area indicates decreasing trend of -1.02 mm yr^{-1} or 10.2 mm decade^{-1} (Sen's slope) as shown in Fig. 3. This information is of vital importance for future water resource planning in the command area.

It appears from trend plot of annual and seasonal rainfall of grid 5 (Fig. 4) that there is a dominating increasing trend in these variable, however, the statistical test of trend shows

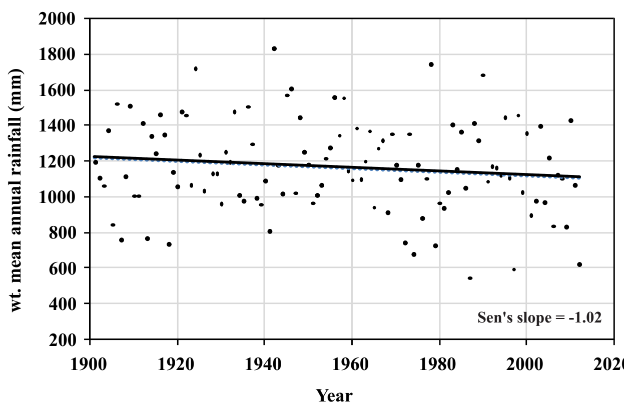


Fig. 3. Trend in weighted mean annual rainfall of EGC command and surrounding area

Table: 2
Results of Mann-Kendall test and Sen's slope at 5% significance level

Grid	Annual Rainfall	Rainfall in Monsoon	Annual no. of rainy days	Seasonal no. of rainy days
1	NT	NT	NT	NT
2	NT	NT	NT	NT
3	NT	NT	NT	NT
4	NT	NT	NT	NT
5	NT	NT	Increasing (0.14)	Increasing (0.10)
6	Decreasing (-5.34)	Decreasing (-4.35)	Decreasing (-0.18)	Decreasing (-0.14)
7	Decreasing (-6.17)	Decreasing (-5.67)	Decreasing (-0.29)	Decreasing (-0.22)
8	NT	NT	Decreasing (-0.02)	NT
9	NT	NT	Increasing (0.02)	NT
10	NT	NT	Increasing (0.03)	NT
11	NT	NT	NT	NT
12	Decreasing (-1.85)	Decreasing (-1.94)	Decreasing (-0.19)	Decreasing (-0.16)

*NT- No significant trend

no significant value in these variables. The visual analysis is also a well-practiced technique of trend analysis. In general, the conclusions drawn from the visual analysis are only refined using statistical tests. However, in above cases, the results of visual analysis and statistical analysis are contradictory to each other. The main reason for this contradictory results may the significance level of the test and the variability of the data itself. In case of grid 5, the values of annual rainfall ranges from 201.16 to 2080.06 mm and the seasonal rainfall ranges from 111.9 to 1786.73 mm. The variability of annual and seasonal rainfall and rainy days have been evaluated using the CV and given in Table 1. A data series with smaller variation

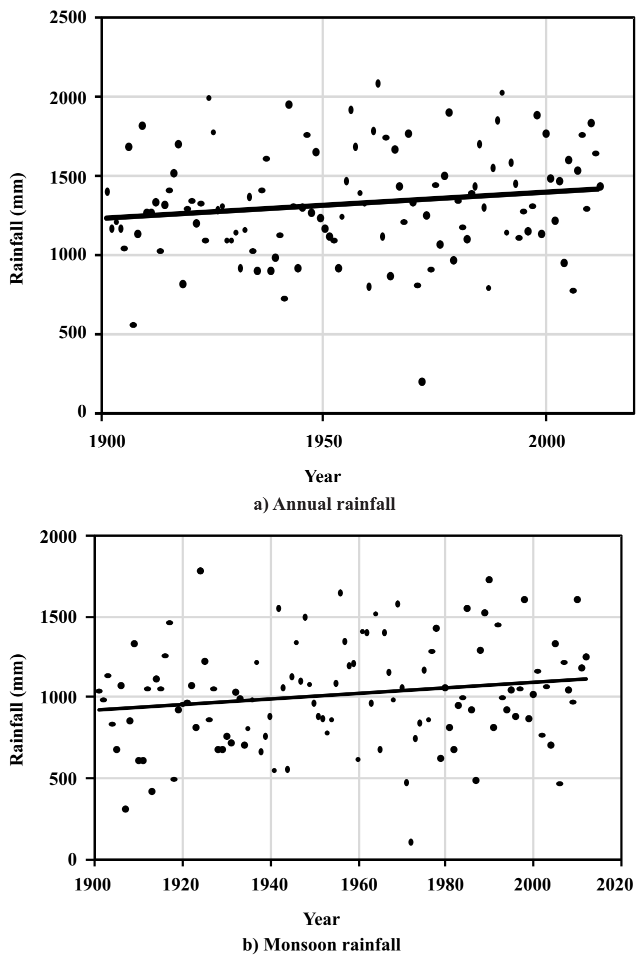


Fig. 4. Observed trends in annual and seasonal rainfall in Grid 5

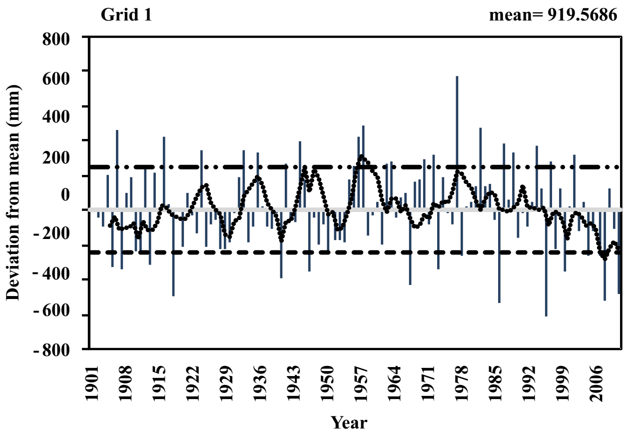
will have lower CV, and the numerical value of CV depends on the value range of the data series. It is evident from Table 1 that annual and seasonal rainfall of grid 5 exhibits higher variability compared to other grids showing a significant trend in these parameters. This might be the reason due to which statistical trend test has not given any significant trend value at 5% significance level for grid 5. The trend analysis of same data (of grid 5) with 10% significant level yields statistically significant trend of 1.8 mm yr^{-1} and 1.9 mm yr^{-1} for annual and seasonal rainfall of grid 5. This proves that variability of data affects the results of trend analysis. Hence, the variability within the data series should also be analysed along with trend analysis, so that appropriate significance level can be selected for the data having high variability.

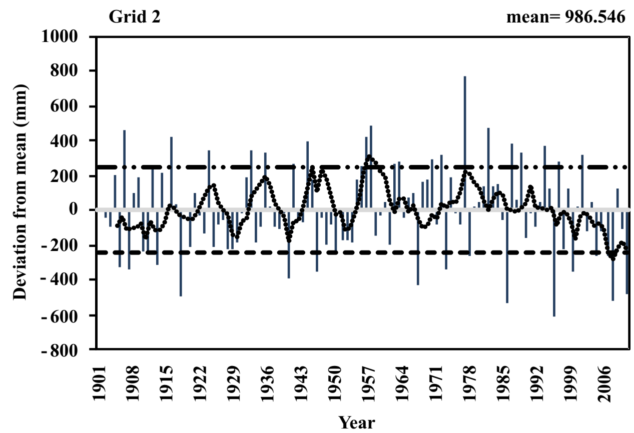
The weighted mean annual rainfall of the EGC command and surrounding area is 1165.93 mm, with a standard deviation of 309.47 and CV of 0.27. Analysis of dry and wet year with 5 year moving average has been carried out on the annual scale for all individual grids of the EGC command and surrounding area. The result tabulated in Table 3 indicates that in the entire century (1901-2012) the average number of years in dry and wet departures are about 18 years and 21 years, respectively. The number of wet years are dominating over the number of dry years for whole command and surrounding area in the ratio of 13:14. On the basis of dry and wet years, it came to light that the chances of wet years are more in comparison to drought years, which is good for the agricultural sector. Whereas, it has also been observed that during last decade, number of dry years are more in most of the grids compared to wet years as shown in Table 3. This decrease in wet years within last twelve years indicates that there may be a huge deficit of rain water in coming future. Moreover, inconsistent nature of rainfall in last twelve years might have severely affected the crop calendar in this region. Year 1913, 1918, 1979 and 1987 are the common dry years and 1924, 1942 and 1990 are the common wet years within all grids. Number of dry years range from 14 to 22 years and wet years from 14 to 27 years within all grids; as shown in Fig. 5 and Fig. 6.

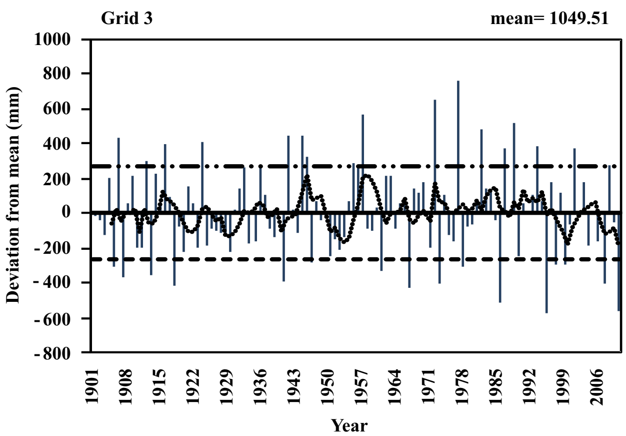
The wet and dry year analysis reveals the fact that, year

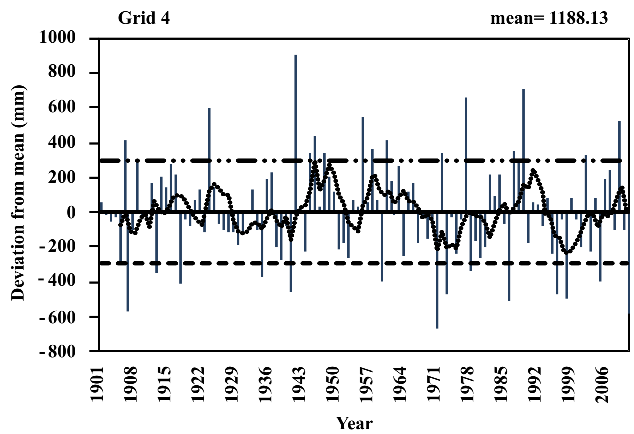
Table: 3
Number of dry and wet years in EGC command area

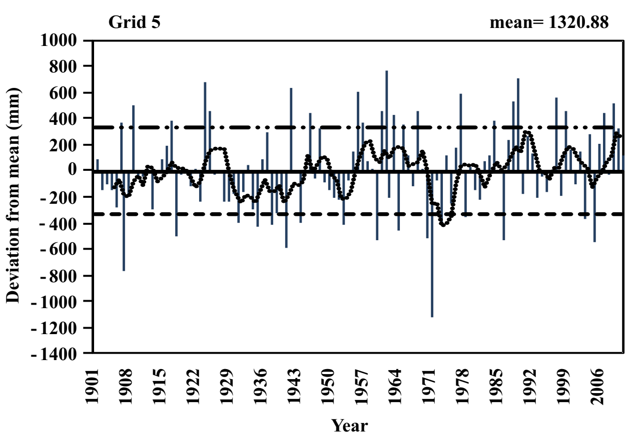
Grid		1	2	3	4	5	6	7	8	9	10	11	12	Weighted average of EGC command
No. of years	Dry	21	16	16	15	18	19	22	21	14	19	14	14	13
(1901-2012)	Wet	22	21	18	16	22	17	27	21	23	23	22	18	14
No. of years	Dry	6	5	3	2	2	6	7	1	2	3	5	2	3
(2000-2012)	Wet	1	1	2	2	3	0	0	3	1	3	1	0	0

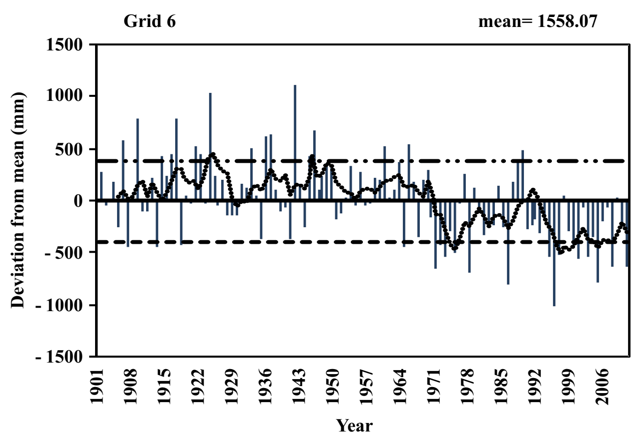

Grid 1
mean= 919.5686
Deviation from mean (mm)
Year

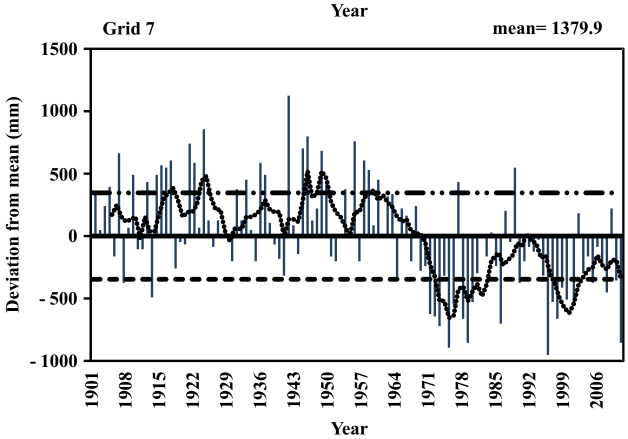

Grid 2
mean= 986.546
Deviation from mean (mm)
Year

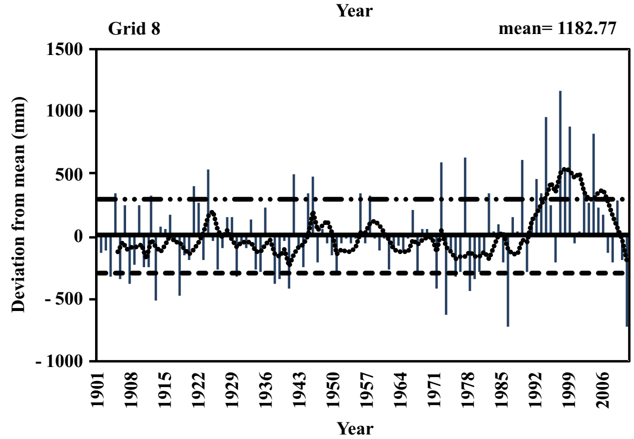

Grid 3
mean= 1049.51
Deviation from mean (mm)
Year


Grid 4
mean= 1188.13
Deviation from mean (mm)
Year


Grid 5
mean= 1320.88
Deviation from mean (mm)
Year


Grid 6
mean= 1558.07
Deviation from mean (mm)
Year


Grid 7
mean= 1379.9
Deviation from mean (mm)
Year


Grid 8
mean= 1182.77
Deviation from mean (mm)
Year

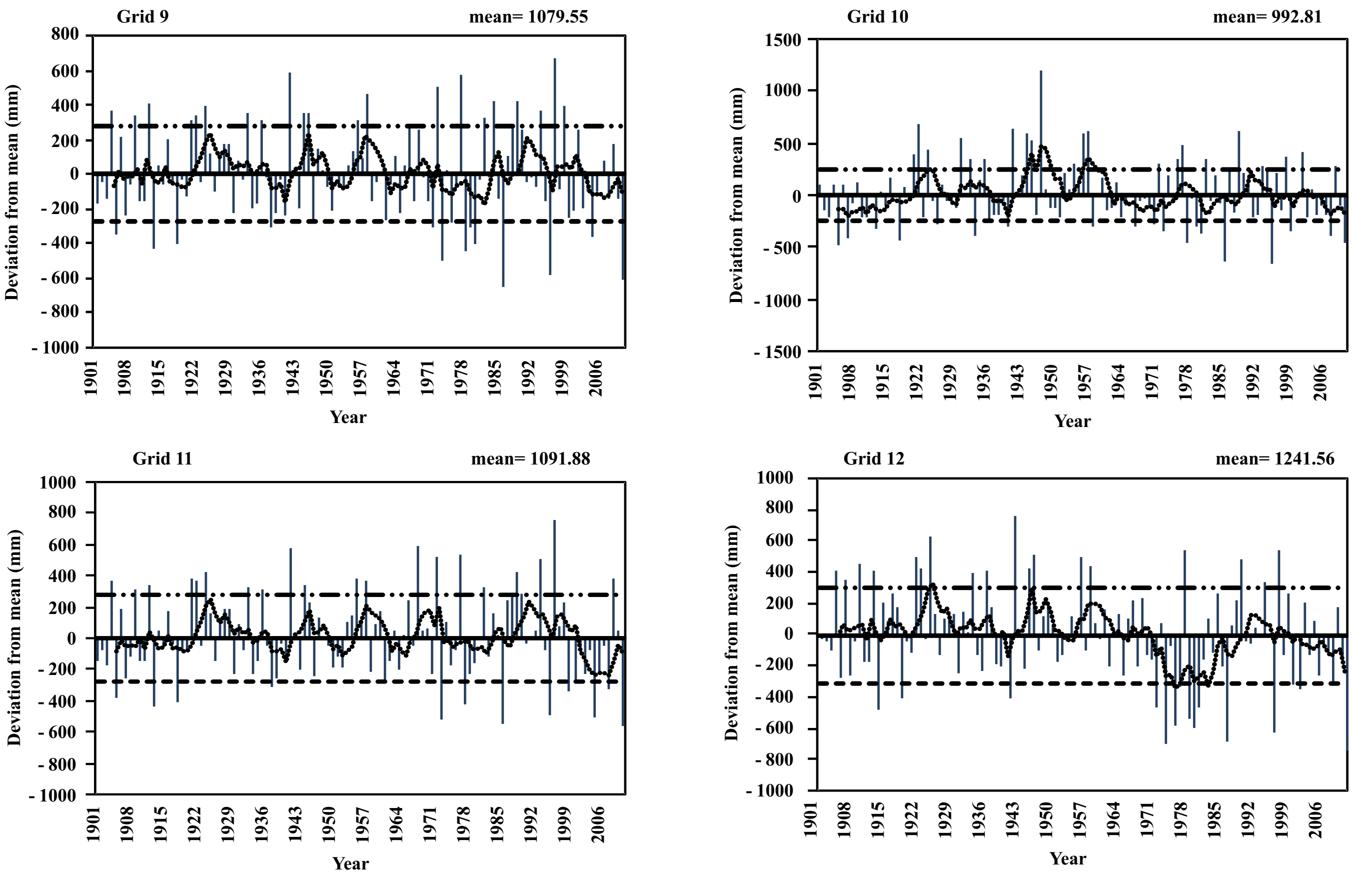


Fig. 5. Annual rainfall departures for grid 1 to 12 with five year moving average

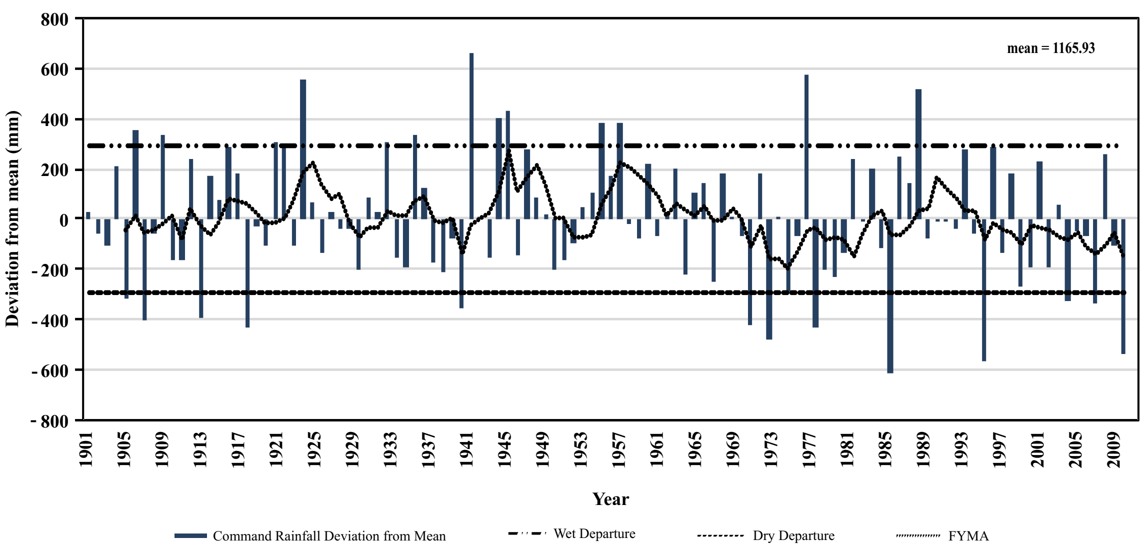


Fig. 6. Departures of weighted annual rainfall of EGC command and surroundings with 5 year moving average

1987 was the driest with around 620.92 mm (53.26%) of negative departure and year 1942 was the wettest with 664.2 mm (56.97%) of positive departure from the weighted mean annual rainfall of the command area (1165.93 mm). During past century (1901-2012) EGC command area has faced total 14 dry years and 13 wet years.

Five year moving average of departure from mean annual rainfall for all the grids and weighted mean annual rainfall has been estimated and plotted along with the annual rainfall departures. Pictorial representation of dry and wet departures with 5 year moving average of departures of all grids and entire command area are given in Fig. 5 and Fig. 6, respectively.

The moving average of departure represents the continuous behaviour of the departure with time, whereas annual departure only represents the discrete behaviour of that variable for the year under consideration. The plots of annual departures from mean annual rainfall indicate that there is a random distribution of dry years and wet years in all the grids and in case of weighted mean annual rainfall of the command area. However, the plots of 5 year moving average departure (Fig. 5 and Fig. 6) highlights the cyclic trend in dry and wet periods (years). In case of all the individual grids, it can be seen from Fig. 5 that the dry period are followed by wet periods of same or higher duration and same to higher departures. In all the grids the wet periods have dominated the early-mid-century to the late mid-century period (1930-1960). However, the end of 20th century and early 21st century period is dominated by frequent dry years. Overall, it can be seen from Fig. 5 and 6 that the frequency of dry years is more in last one to one and half decade in almost all the grids. The number of dry years have increased with frequent intervals while on the other side, the number of wet years have reduced tremendously, which is a warning situation for the command. This information can be used as the basis of preparing alternate water distribution strategies for the command area.

4. CONCLUSIONS

The analysis of annual rainfall, seasonal rainfall, annual rainy days and seasonal rainy days showed significant, however varying trend in the different parts of EGC command area. Present study brings out some of the interesting and also significant changes in the rainfall pattern in parts of EGC command area. The result of MK test showed that annual and monsoon rainfall has decreasing trend in grids 6, 7, 12 of EGC command area. For annual rainy days, the increasing trend was observed in grids 5, 9, 10 and decreasing in grids 6, 7, 8, 12. Visual analysis of long term data pertaining to all the four parameters indicated significant increasing or decreasing trend in many grids covering the EGC command area. However, no statistically significant trend was obtained for those grids at 5% significance level. The analysis of CV revealed the high variability in the values of the parameters under consideration in these grids. To understand the effect of data variability on the selection of significance level of statistical trend test, the trend of one such grid has been re-evaluated with changed significance level to 10% and statistically significant increasing trend in annual and seasonal rainfall was observed at changed significance level. Based on this analysis, it is recommended that the variability of data should also be analysed along with the trend and the appropriate significance level must be selected. Analysis of dry and wet years showed that the number of dry year ranges from 14 to 22 and wet year from 14 to 27 within EGC command area; with 1987 as the driest year and 1942 as wettest for the command. Five year moving average of departure from mean annual rainfall of all the grids and weighted mean annual rainfall of entire command area indicates cyclic nature of wet and dry periods in the command area. The mid-century to the late mid-century period in the command area was dominated by wet periods, however, the frequency of dry years has increased in near past (*e.g.* in the last one to one and half decade). The change in this cycle must be taken in to account for planning the near and mid future activities related to water distribution in the command area. Furthermore, since the variability in the annual and seasonal data was high in case of all the grids of EGC command area. It is suggested to test the trend of rainfall and rainy data with higher order significance level (*e.g.* 10%, 15% *etc.*).

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