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Research Paper

Long-term Trends in Rainfall Pattern over Haryana, India

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Abstract- *In this study, seasonal and annual trends of changes in rainfall have been studied over the 110 years (1901-2010) for nineteen districts of Haryana. Mann-Kendall test and Sen's slope estimator was used to detect monotonic trend direction and magnitude of change over time. The annual rainfall varies from 311 mm in the western part (Sirsa district) to 706 mm in the northeast part of Haryana (Yamunanagar district). All the stations except Kurukshetra and Panchkula showed a significant increasing trend in annual rainfall at a significance level of 1%, 5% and 10%. The increase in annual rainfall magnitude varied between 0.53 to 1.5 mm per annum at Sirsa station and Sonipat stations respectively. Seasonally, pre-monsoon rainfall showed significant increasing trends at all the stations and its magnitude varied from 0.07 to 0.20 mm annum^{-1}. Among nineteen stations, only seven stations indicated significant upward trend in monsoon rainfall. Further, significant increase was found in annual, pre monsoon and monsoon rainfall over entire Haryana during the period of analysis. Further, rainfall correlation with cloud cover and temperature variables (maximum temperature, minimum temperature and diurnal temperature range) demonstrates that rainfall of the Haryana state is more responsive to the variation of temperature on annual, winter and pre-monsoon season. However in monsoon and post-monsoon season cloud cover plays the important role in rainfall variation. The results comparing the monsoon rainfall and SST anomaly leads to the idea that all ENSO events are not associated with drought in study area.*

Keywords: Rainfall, cloud cover, Mann Kendall test, Haryana, India.

Introduction

The success or failure of the crops and water scarcity in any year plays an important role to economy of the agricultural country like India [1]. [2]IPCC (2001) have suggested that climate change is causing the increase of extreme events like floods and droughts. It is mostly due to temporal and spatial distribution of precipitation, rather than the total amount which causes the water scarcity problem to Indian subcontinent. The changes in precipitation pattern have occurred all over the world during most of this century and are predicted to change further. Such climatic changes may entail the occurrence of specific effects in the hydrological cycle.

In recent decade, a great emphasis has been given on the studies of local / regional climatic fluctuations. Fluctuating tendency in rainfall has been experienced by many researchers over India. [3]Lal (2001) reported the large fluctuations in Indian rainfall with no systematic change on either an annual or a seasonal scale. However, areas of increasing trend in the seasonal rainfall have been found along the west coast, north Andhra Pradesh and northwest India and decreasing trend over east Madhya Pradesh, Orissa and northeast India during recent years. [4]Guhathakurta and Rajeevan (2007) found the significant decreasing trend in the three subdivisions (Jharkhand, Chhattisgarh and Kerala) and significant increasing trend in eight subdivisions (Gangetic West Bengal, West Utter Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Coastal AP and North Interior Karnataka) in monsoon rainfall during the period of 1901–2003. [5]Kumar el al. (2010) examined the monthly, seasonal and annual trends in rainfall for 30 subdivisions in India during the period of 1871-2005.They reported that half of the sub division showed increasing trends and half showed decreasing trend in annual rainfall. The fluctuations of rainfall amount for the Indo-Gangetic Region have been studied by [6]Singh and Sontakke (2002) using the data of 1829-1999. Their study indicated a significant increasing trend from 1939 over the Central part, and a significant decreasing trend over eastern parts of the country. [7]Sen Roy and Balling (2004) analyzed the trends in the patterns of extreme precipitation events from 1910 to 2000 and showed an increasing trend over most of western India including Deccan Plateau and a decreasing to a neutral trend over the eastern half of the country except the north-eastern corner. [8]Singh et al. (2008) indicated the increasing trends in annual rainfall and relative humidity during the period of 1901-2000 in north Indian River basins. The temporal variation in monthly, seasonal and annual rainfall during the period of 1871 to 2005 was examined by [9] Krishnakumar et al. (2009) in Kerala. They found the decreasing trend in southwest monsoon while increasing trend in post-monsoon season. The study conducted by [10] Kumar and Jain (2010) indicated the decrease in rainfall at four stations and increase at one station in the Kashmir Valley. Recently [11]Joshi and Pandey (2011) also analyzed rainfall trends over the whole Indian Territory, Southwest, Southeast, Central and Northeast India. They found no trend in annual series for the period of 1901-2002.

No detailed study on rainfall characteristics and trends for Haryana has been reported in the literature, which is part of the Indo-Gangetic Plains. The study area is a part of Indo-Gangetic Plain, where agriculture is largely depends on monsoon rainfall. Therefore, any kind of abnormal behaviour of monsoon rainfall and day to day variations in weather causes the drastic decrease in farm produce and ground water table. A comprehensive knowledge of characteristics of rainfall of a region including its variation both in time and space is very essential for proper planning and overall development of an area. Therefore, the present study has been undertaken with the following specific objectives: (1) to detect the monotonic linear trends and magnitude of trends in annual and seasonal rainfall series using the non-parametric Mann Kendall test and Theil–Sen's estimator method, (2) to analysis the correlation of annual rainfall with cloud cover, maximum temperature (Tmax), minimum temperature (Tmin), and diurnal temperature range (DTR) and (3) to carried out the association of monsoon rainfall and El Nino/Southern Oscillation (ENSO) event.

Material and Methods

Study Area

The State of Haryana is located in north-west India. It lies between 27°37' to 30°35' N latitude and 74°28' to 77°36' E longitude. The altitude of Haryana varies between 200 to 1200 metres above mean sea level. The total geographical area of the state is 4.42 m ha, which is 1.4 % of the geographical area of the country. The gross cropped area of the state is 6.32 m ha and net cropped area is 3.62 m ha with a cropping intensity of 177%. The cultivable area is 3.8 m ha, which is 86 % of the geographical area of the state, out of which 3.62 m ha (96.2 %) is under cultivation. The average rainfall of the Haryana is 515 mm (average of 1901-2010) around 80 % rainfall is received during the month from July to September and the remaining rainfall is received during December to February. This 80% of the rainfall occurs in the monsoon season (July–September) sometimes causes local flooding. An area of 1,553 km^2 is covered by forest. A large part of the plains experience a semi-arid climate, except for the northern parts where conditions are sub-humid, and in the western part where it is further deteriorating to arid. The major part of State comes under the fertile Indo-Gangetic belt. It is very hot in summer (up to a high of 50^0C) and cold in winters (down to a low of 1 ^{0}C). The hottest months are May and June and the coldest being December and January.

Agriculture and related industries have been the backbone of the local economy. Haryana is primarily an agricultural state. About 70% of residents are engaged in agriculture. Wheat and rice are the major crops. Haryana is self-sufficient in food production and the second largest contributor to India's central pool of food grains.

The main crops of Haryana are wheat, rice, sugarcane, cotton, oilseeds, pulses, barley, maize, mille t etc. There are two main types of crops in Haryana: Rabi (sown between Octobers to February and harvested by June) and Kharif (sown during April-July, and harvested by October). The major Kharif crops of Haryana are rice, jowar, bajra, maize, cotton, jute, wheat, tobacco, pulses, linseed, rapeseed and mustard. The major Rabi crops are wheat, tobacco, pulses, linseed, sugarcane, sesame and groundnut. There are two agro climatic zones in the state. The north western part is suitable for Rice, Wheat, Vegetable and temperate fruits and the south western part are suitable for high quality agricultural produce, tropical fruits, exotic vegetables and herbal and medicinal plants.

Description of Data

The monthly rainfall series from 19 stations covering period of 110 years (1901–2010) were provided by the Indian Metrological Department (IMD) Pune.

The temperature variables (maximum, minimum and diurnal temperature) data of 1901-2002 were downloaded from India water portal site (http://www.indiawaterportal.org/metdata). Figure 1 shows the locations of metrological stations. The data quality control is a necessary step before analysis of rainfall series because erroneous outliers can seriously impact their trends. In the present study the data series were plotted to detect the outliers. After visual detection of outliers, the suspected values were calculated using normal ratio method. As all series were complete, no gap filling method was needed. In order to assess the homogeneity of the rainfall series, the standard normal homogeneity test (SNHT) was applied. The homogeneity of the series was guaranteed by applying SNHT test. Based on climatic features, IMD, which is India's nodal agency of WMO, defined four seasons, viz. winter (January–February),pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October–December). For each station, monthly values were summed to obtain annual and seasonal values of rainfall. The temperature variables and cloud cover data were averaged to obtain the annual and seasonal values.

Trend Analysis

First of all statistical characteristics of annual rainfall (mean, standard deviation (SD), Kurtosis, Skewness and coefficient of variation (CV) (CV = (Standard deviation/Mean)*100)) were calculated in order to find out the variability during the study period. The moving average or running mean is a conventional procedure used to reduce the inter-annual variability of the rainfall series [12]. A Ten year running average was used in the present study. Linear trends represented by the slope of the simple least-square regression line provided the rate of rise/fall in the variable. The 10 year moving t-test known as Cramer's test[13] was applied to the annual rainfall data to measure the difference, in terms of moving t statistic, t_k, between the mean of each successive 10 year period and the mean of the entire 100 year period. For significance of Cramer's t value at 5% level, the required t value is ±1.96 or more [14]. Further, Mann–Kendall [15][16] test was used to detect the trend. The two-sided hypothesis was chosen [17][18][19] at 1%, 5% and 10% significant level. In addition to this, the magnitude of a trend was estimated using the procedure proposed by [20] Sen (1968).

Results and Discussion

Rainfall distribution and its variability in different parts of the Haryana.

Detail statistical characteristics (mean, standard deviation, skewness, kurtosis and coefficient of variance) of annual rainfall time series of various stations are carried out for the period 1901 to 2010. Annual rainfall in the state during the 110 years period varied between 311 mm in the western part (Sirsa district) to 706 mm in the northeast part (Yamunanagar district) of Haryana. The standard deviation ranged between 163 mm to 169 mm. Further, coefficient of variation (CV), a statistical measure of the dispersion of data points in a data series around the mean ranged between 22 and 30%. The skewness, which is measure of asymmetric in a frequency distribution around the mean, varied between -0.06 to 1.1 indicating that annual rainfall during the period is asymmetric and it lies to the right of the mean over all the stations. Kurtosis, is a statistic describing the peakedness of a symmetrical frequency distribution, varied from -0.37 to 3.9.

Moving average in mean annual and seasonal rainfall

The 10 years moving average curve and Cramer's t-values of 10 years moving curve (Figure 2-6) of mean annual and seasonal rainfall were analyzed during the period of 1901 to 2010 over Haryana. Ten years moving average was plotted to identify decadal variations in the series. The 10 year moving average curve of annual rainfall (Figure 2a) shows a gradual rise upto the year 1917 and afterward there was decrease upto year 1949 and attained the lowest value in the year 1947. From 1949 onwards it rise upto year 1968 and again there was slight decrease upto year 1971. From 1971 onwards, it shows increasing trend upto year 2004 and the highest value was observed in the year 1984. However, again it starts decreasing from year 2004 to 2010. The t_k 10 years moving average value was significant from 1941-1981 (above long term mean).

For winter rainfall, 10 year moving average curve (Figure 3a) shows a gradual rise upto the year 1916 and afterward it decreases upto year 1922. From 1922 onwards it again rises upto year 1931 and again slightly decreases upto year 1934. From 1934 onwards it shows increasing trend upto 1944 and the highest value was observed in the year 1944. Further, it shows a decrease in the rainfall upto 1981 that reaches its lowest value in 1980. From 1981 onward it shows an increasing trend in the rest of the decades. The t_k value for the winter rainfall (Figure 3b) over Haryana lies between ±1.96 (threshold value for the significance of Cramer's t-value at 5% level) throughout the analysis period.

For pre-monsoon rainfall, 10 years moving average curve (Figure 4a) shows a gradual rise upto the year 1920 and decrease afterward upto year 1962 and it attained lowest value in 1943. From year 1962 onward it shows an increase in rest of the decades and highest value was observed in the year 2006. The t_k value of pre-monsoon rainfall (Figure 4 b) was significant at 5% significant level during 1947-2007 (above long term mean).

The 10 year moving average curve of monsoon rainfall (Figure 5 a) initially shows an increasing trend upto 1917. Afterward it decrease upto 1949 and attained its lowest value in year 1947. From 1949 onward it again starts increasing upto 1998 and reaches its highest value in year 1984 and there was decrease afterward in rest of the decades. Figure 5(b) shows the 10 year moving average of monsoon t_k value. The t_k values were significant at 5% level during the periods of 1944-1966.

Further, Figure 6 (a) shows the 10 years moving average curve of post-monsoon rainfall which initially shows an increase upto 1918 and shows a slightly decrease upto 1925. Afterward, it increase upto 1932 and it shows the decrease upto 1950 and reaches its lowest value in 1943. From 1950 onwards it shows increasing trend upto 1964 and attained the highest value in the year 1963. Furthermore, it decreases upto year 1978 and increase in rest of the decades. The t_k value for post-monsoon (Figure 6 b) is not significant at 5% level over Haryana throughout the analysis period.

The variability analyzed thus shows the presence of some increasing/decreasing trends during the certain period of time in annual and seasonal rainfall over Haryana. To see whether there is any trend in annual and seasonal rainfall during the epoch of 110 years (1901-2010), linear trends were computed using the linear least squares fitting method, as shown in Figures 2a, 3a, 4a, 5a and 6a. Annual, pre-monsoon, monsoon and post monsoon rainfall showed an increasing trend, whereas a decreasing trend was observed in winter rainfall.

Trend analysis using Mann Kendall and Sen Slope estimator

In addition to this**,** Mann-Kendall test was applied to the annual and seasonal rainfall data to verify the increasing/decreasing trends obtained earlier by using the linear least squares fitting method. The Mann-Kendall Z statistics was worked out on long-term (1901-2010) time series of annual and seasonal rainfall and is presented in Table 1. The results indicated that there is increasing trend in annual rainfall at all the station except the Kurukshetra and Panchkula stations. The highest increase in magnitude was observed at the Sonipat station (1.5 mm per year) and lowest at Sirsa station (0.53 mm per year). Similarly, pre-monsoon rainfall showed significant increasing trends at all stations and their magnitude varied between 0.07 to 0.20 mm annum^{-1}. Among nineteen stations, only seven stations indicated significant upward trend in monsoon rainfall and it ranged between 0.58 (at Fatiyabad station) and 1.11 (at Sonipat station) mm annum^{-1}. Further, in post-monsoon season the increase in magnitude varied between 0.0205 to 0.0233 mm per annum for four stations which shows the significant increasing trend. Mann-Kendall Z statistics worked out on long-term (1901-2010) time series of annual rainfall indicated that there is apparent increasing trend in rainfall at a rate about 1.4 mm/year with respect to entire Haryana. Rainfall during different season particularly in pre-monsoon and monsoon seasons have shown significant increasing trend. The increase in magnitude was 0.73 mm year^{-1} during monsoon season followed by pre-monsoon (0.1385 mm year^{-1}) during the period (1901-2010). The increase in pre-monsoon (April-May) rainfall may be beneficial to vegetables and other crops, but it will lead to the delayed harvesting of wheat crop. The increasing trend of rainfall during monsoon (June-September) will be highly beneficial to rice crop, if the rice planting had been completed with the onset of monsoon. Further, if this widespread increasing trend in rainfall is sustained, it will adversely affect the rice crop and there is a need to increase/improve drainage facilities/structures to remove/store excess water, so that this can be recycled during the critical period of the crop.

Links of rainfall with clouds cover and temperature variables

Table 2 shows the correlation coefficient of annual rainfall with cloud cover, maximum temperature (Tmax), minimum temperature (Tmin), and diurnal temperature range (DTR). The significant of correlation was test at a 5% significant level using Kendall-tau method. The correlation coefficient between annual rainfall, cloud cover and temperature variables indicates a statistically significant trend. The Tmax shows the maximum negative correlation followed by Tmax. However, the correlation between annual rainfall and cloud cover shows the significant positive correlation (0.23). In winter season only Tmax (-0.32) and Tmin (-0.31) shows the significant negative correlation with rainfall. The strong negative correlation was found between rainfall and Tmin (-0.41) followed by Tmax (-0.38) and cloud cover (0.32) in pre-monsoon season. Similarly, in monsoon season the maximum positive correlation of rainfall with cloud cover (0.43) and negative correlation with Tmin (-0.31) and Tmax (-0.30). Further in post-monsoon season only cloud cover (0.37) shows the significant positive correlation. The results demonstrate that rainfall of the region is more and more responsive to temperature variation in Haryana in the past ten decades on annual, winter and pre-monsoon season. However in monsoon and post-monsoon season cloud cover plays the important role in rainfall variation.

Relationship among monsoon rainfall, drought and El Nino/Southern Oscillation (ENSO)

The monthly Nino 3.4 Index (from 1950-2010) downloaded from http://www.cpc.noaa.gov/data/indices/ was used to classify the ENSO events. These data was rearranged to obtain yearly anomaly by taking mean of 12 months of each year. Further, this index was grouped into four major categories as Very Strong, Strong, Moderate and Weak El-Nino years (Table 3). There had been 30 El-Nino events (2 Very Strong, 7 Strong, 11 Moderate and 10 Weak) during the study period (Table 3). From all 30 ENSO events 18 events were related to poor monsoon (negative correlation) and remaining 12 ENSO episodes have shown no significant impact on summer monsoon (positive correlation) in study area.

From the Table 4 it can be seen that there is 32 dry seasons during the period and out of 32 dry seasons 18 were inversely correlated with the ENSO events. The warmest ENSO events like 1987, 1997, 1957, 1969, 1982, 1991, 1992, and 2002 were related with poor monsoon rainfalls in the study region. The variation in Sea Surface Temperature (SST) and its correlation with monsoon rain fall (Figure 7, a-d) shows that most of the dry seasons were negative related with the warm ENSO episodes but the years 1958, 1977, 1980, 1983, 1990, 1995, 1998, 2005 (Figure 7-a, b, c, d) shown positive correlation with the ENSO episodes when monsoon rainfall recorded below normal and positive correlated with the ENSO events during that period. Also it is interesting to not that during the wettest monsoon season of 1964 there was no ENSO event. From the result it can be concluded that not all the ENSO event are associated with drought and many droughts were not accompanied by ENSO.

Conclusion

The present study deals with an examination of variability and trends in annual and seasonal rainfall for the nineteen stations of Haryana, India. Considerable variability was observed between the different stations, with a standard deviation of 121 mm, while average annual rainfall was 515 mm. The significant increasing trends were found in annual rainfall at all the stations except the Kurukshetra and Panchkula station. The increase in annual rainfall magnitude varied between 0.53 mm per annum (at Sirsa station) to 1.5 (at Sonipat station) mm per annum. Seasonally, pre-monsoon rainfall shows the significant increasing trends at all the stations and its magnitude varied from 0.07 to 0.20 mm annum^{-1}. Among nineteen stations, only seven stations indicated significant upward trend in monsoon rainfall ranged between 0.58 (at Fatiyabad station) and 1.11 (at Sonipat station) mm annum^{-1}. Further, in post-monsoon season the increase in magnitude varied between 0.0205 to 0.0233 mm per annum for four stations which shows the significant increasing trend. Further, significant increasing trend was detected in annual rainfall over the entire Haryana during the year 1901-2010. The increase in magnitude was 1.4 mm/year over entire Haryana. Rainfall during different season particularly in pre-monsoon and monsoon seasons have shown significant increasing trend. The increase in magnitude was 0.73 mm year^{-1} during monsoon season followed by pre-monsoon (0.1385 mm year^{-1}) during the period (1901-2010). The analysis of correlation of rainfall with cloud cover and temperature variables demonstrates that rainfall of the Haryana state is more responsive to the variation of temperature on annual, winter and pre-monsoon season. However in monsoon and post-monsoon season cloud cover plays the important role in rainfall variation. Further, the results comparing the rainfall and SST anomaly during the 1950-2010 leads to the idea that all ENSO events are not essentially correlated with the poor monsoon in study area. The research results show that the relationship among ENSO, summer monsoon and drought is uncertainty.

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Table 1: Result of Mann Kendall and Sen Slope estimator during 1901-2010.

Weather Stations	Rainfall									
			Seasonal							
	Annual		Winter		Pre-monsoon		Monsoon		Post-Monsoon	
	Z	β	Z	β	Z	β	Z	β	Z	β
Ambla	2.8362*	1.2070	-0.7751	-0.0727	3.0893*	0.2018	2.2369**	1.0907	0.4598	0.0124
Bhiwani	2.0458**	0.7496	0.2409	0.0120	2.7561*	0.1308	1.0177	0.3939	1.6919***	0.0211
Faridabad	1.9011***	1.0010	-0.5159	-0.0268	2.1724**	0.1073	0.9377	0.5068	0.7491	0.0076
Fatiyabad	2.1620**	0.7509	-0.4818	-0.0316	1.9037***	0.0948	1.8495***	0.5820	1.2554	0.0128
Gurgao	2.5107**	1.2697	-0.1702	-0.0076	2.4203**	0.1007	1.4646	0.7960	1.5137	0.0295
Hissar	2.5779*	0.8375	0.1047	0.0040	2.9318*	0.1370	1.5163	0.4837	1.803**	0.0205
Jhajar	2.2808**	0.9938	-0.4163	-0.0205	2.1930**	0.0878	1.4878	0.7522	0.7078	0.0089
Jind	4.0554*	1.4353	0.1074	0.0066	2.3532**	0.1224	3.1953*	1.1773	1.7126***	0.0233
Karnal	2.3454**	0.8950	-1.1652	-0.0711	1.8133***	0.1108	1.6506***	0.7017	-0.0827	0
Kathal	4.2414*	1.4625	0.0838	0.0049	3.0015*	0.1726	3.0945*	1.0939	1.4000	0.0252
Kurukshetra	0.7698	0.3280	-0.6861	-0.0636	2.1543**	0.1317	0.3694	0.1430	-0.1214	-0.0017
Mahendarghat	1.7307***	0.7753	-0.3090	-0.0150	1.759***	0.0804	0.8240	0.3946	1.5395	0.0276
Panchkula	0.9867	0.4769	-1.3485	-0.1480	1.7100***	0.1196	0.9919	0.5147	-0.2247	-0.0051
Panipat	2.4229**	0.9865	-0.3483	-0.0254	1.6842***	0.0856	1.6790***	0.7222	0.3539	0.0047
Rewari	2.0251**	0.9852	-0.4844	-0.0262	1.6505***	0.0721	1.4129	0.6692	1.0875	0.0171
Rohtak	2.4229**	0.9770	0.2933	0.0133	3.3425*	0.1409	1.3716	0.6134	0.0113	0.0226
Sirsa	1.9450***	0.5336	0.4347	0.0218	2.2498**	0.1077	1.3484	0.4212	2.555**	**0.0219**
Sonipat	3.5905*	1.5004	-0.1205	-0.0062	2.8982*	0.1432	2.3403**	1.1100	0.2775	0.0223
Yamunanagar	1.9838**	0.7974	-0.7568	-0.0792	1.9760**	0.1400	1.5111	0.7445	-0.4365	-0.0100
Haryana	2.6967*	1.0389	-0.3902	-0.0223	2.9499*	0.1385	1.7462***	0.7337	1.2631	0.0224

Where*, **and *** values show significant at 1%, 5% & 10 % significant level. Negative (-) & positive (+) values indicate the decreasing & increasing trends.

Table 2: Correlation coefficient of annual rainfall with cloud cover, maximum temperature (Tmax), minimum temperature (Tmin), and diurnal temperature range (DTR). Asterisks denote correlation that is significant at 95% level using the Kendall-tau method.

	Cloud cover	Tmax	Tmin	DTR
Annual	0.23*	-0.36*	-0.35*	-0.07
Winter	-0.15	-0.32*	-0.31*	-0.09
Pre-monsoon	0.32*	-0.38*	-0.41*	0.04
Monsoon	0.43*	-0.30*	-0.31*	-0.02
Post-monsoon	0.37*	-0.04	-0.02	-0.06

Table 3: El-Nino events during the study period and their temperature anomalies.

	Category	Temp: Anomaly	Year
El-Nino (30 events)	Very Strong	Ta>1	1987,1997
	Strong	Ta=0.7-1	1957,1969,1972, 1982,1991,1992,2002
	Moderate	Ta= 0.3-0.69	1953,1958,1963,1965,1977,1983,1993,1994,2003,2004,2009
	Weak	Ta=0-0.29	1951,1966,1979,1980,1986,1990,1995,1998,2005,2006

Table 4: year of dry monsoon seasons during the study period.

	Category	Rainfall normally	Year
Dry monsoon (32 events)	Cat:1	Ra=-0.5 and below	1987
	Cat:2	Ra=-0.1to -0.5	1951,1952,1954,1957,1960,1962,1963,1965,1968,1969,1970,1974,1979,1981,1986,1989,1991,1992,1999,2000,2001,2002,2003,2004,2006,2007,2009
	Cat:3	Ra= 0 to -0.1	1956,1966,1973,1982

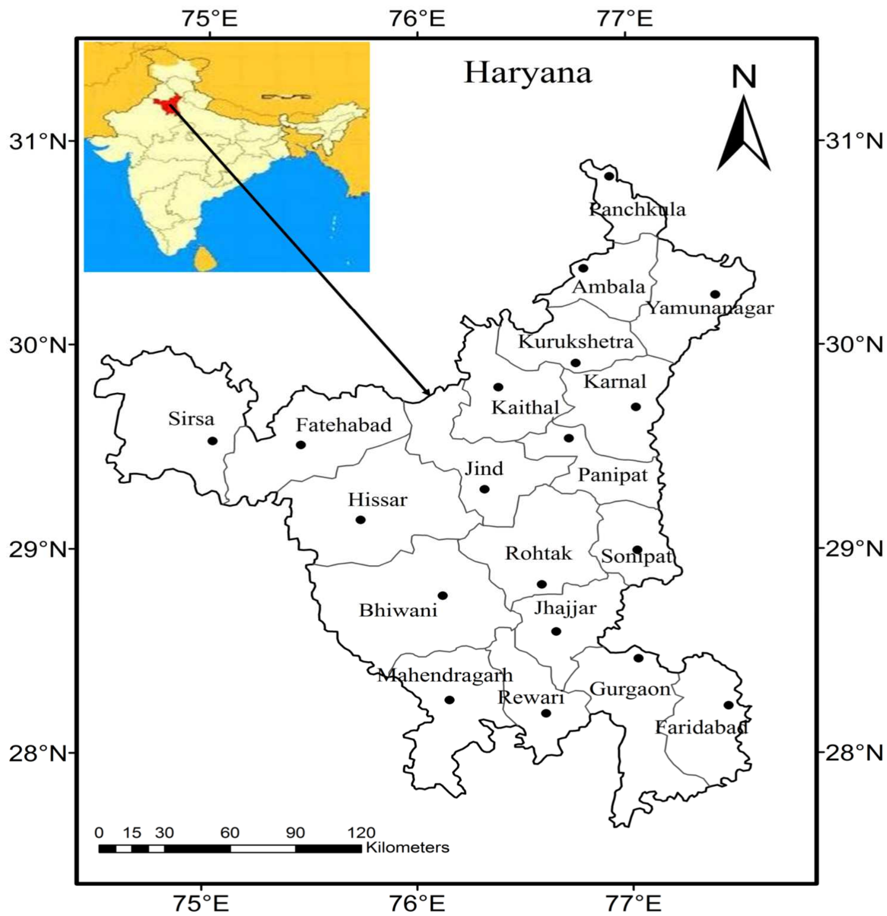

Figure 1: Location of metrological stations in the study area

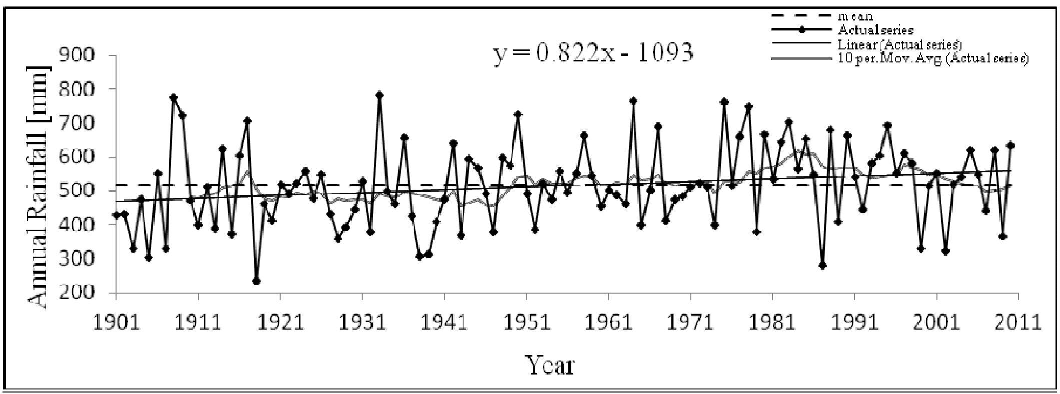

Figure 2 (a): Mean annual rainfall, linear trend line and 10 years moving average at Haryana.

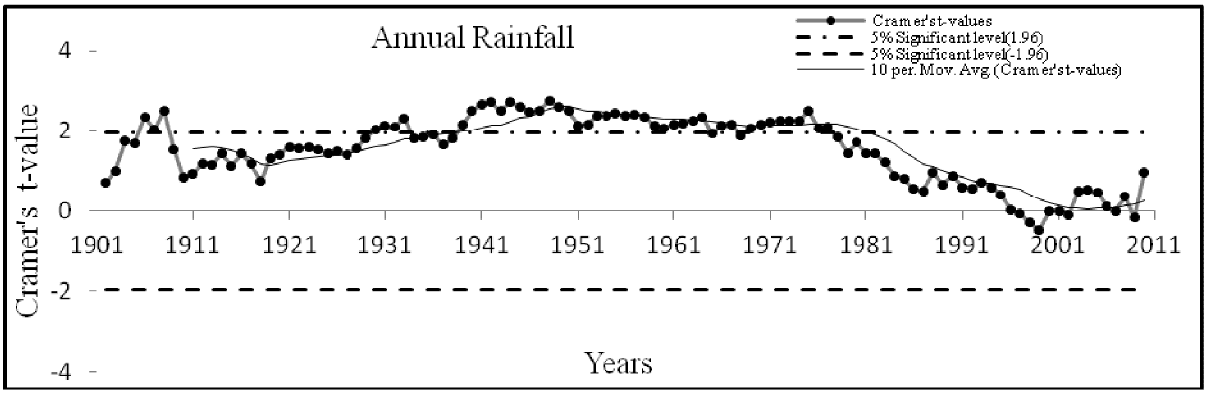

Figure 2 (b): The 10 years annual rainfall moving Cramer's t-value for Haryana

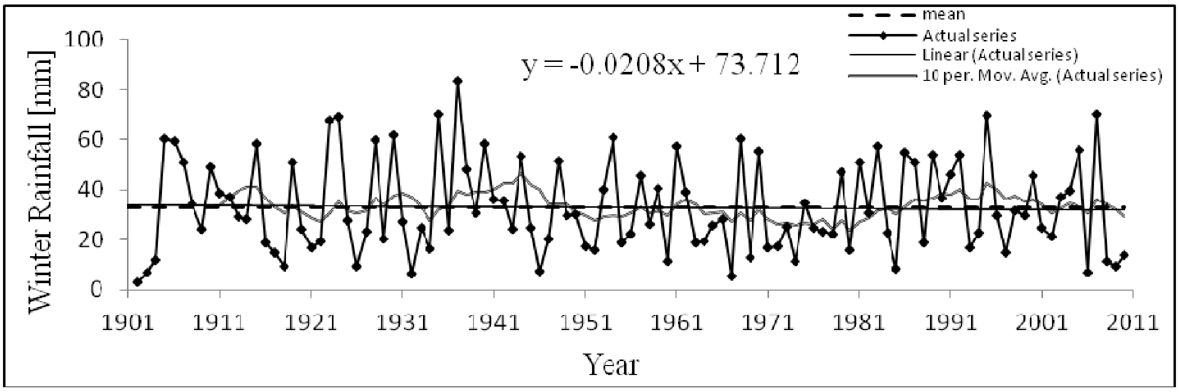

Figure 3 (a): Mean winter rainfall, linear trend line and 10 years moving average at Haryana

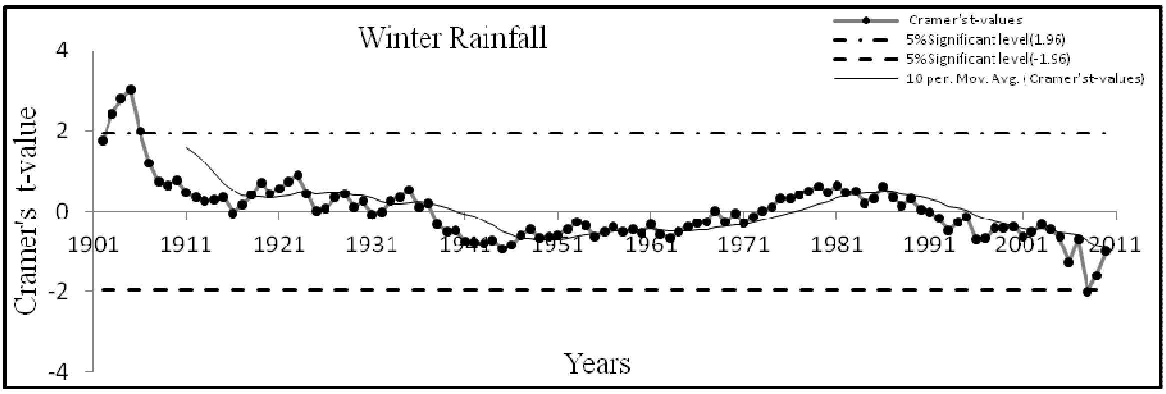

Figure 3 (b): The 10 years winter rainfall moving Cramer's t-value for Haryana

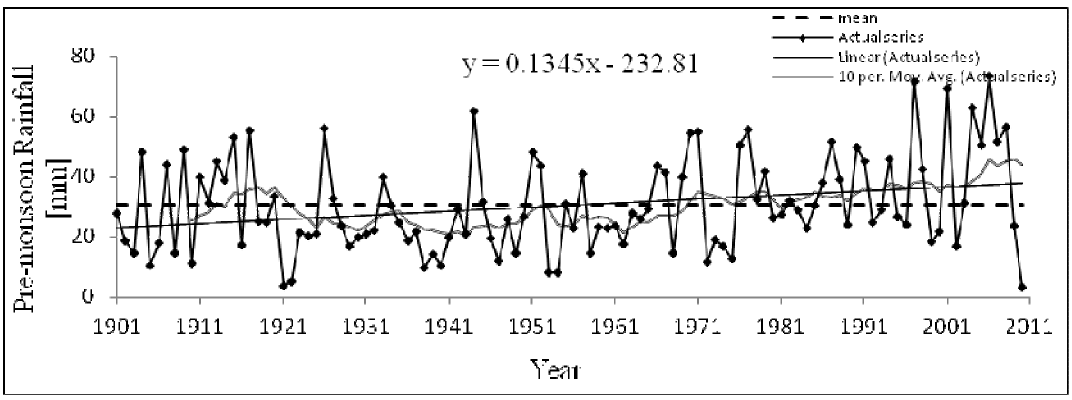

Figure 4 (a): Mean pre-monsoon rainfall, linear trend line and 10 years moving average at Haryana.

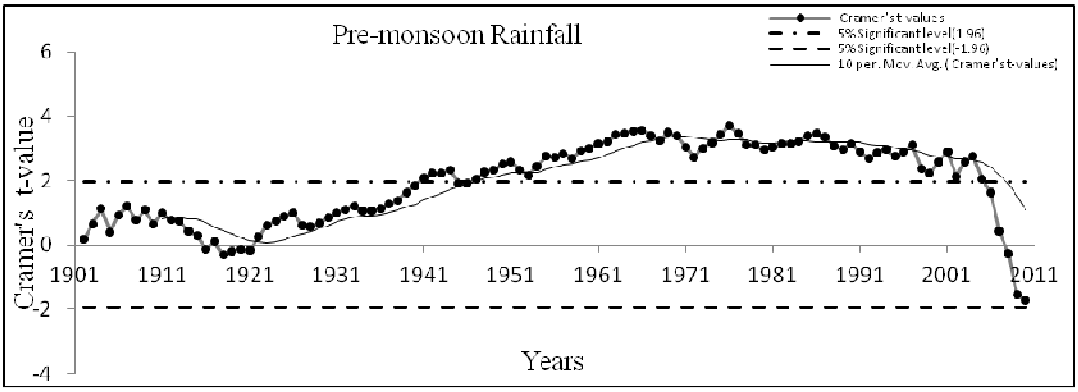

Figure 4 (b): The 10 years pre-monsoon rainfall moving Cramer's t-value for Haryana.

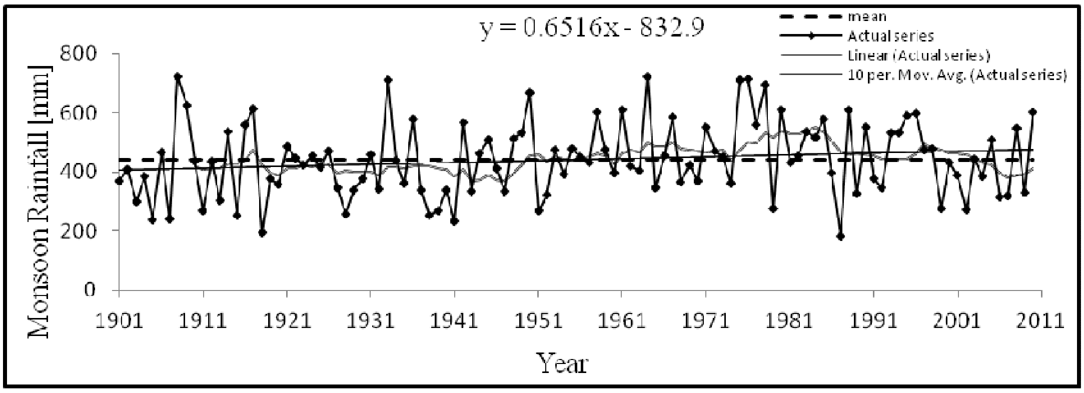

Figure 5 (a): Mean monsoon rainfall, linear trend line and 10 years moving average at Haryana.

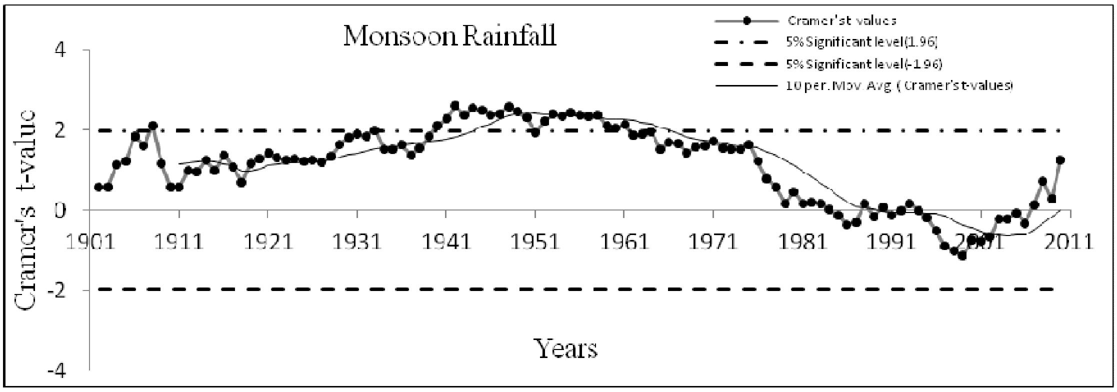

Figure 5 (b): The 10 years monsoon rainfall moving Cramer's t-value for Haryana.

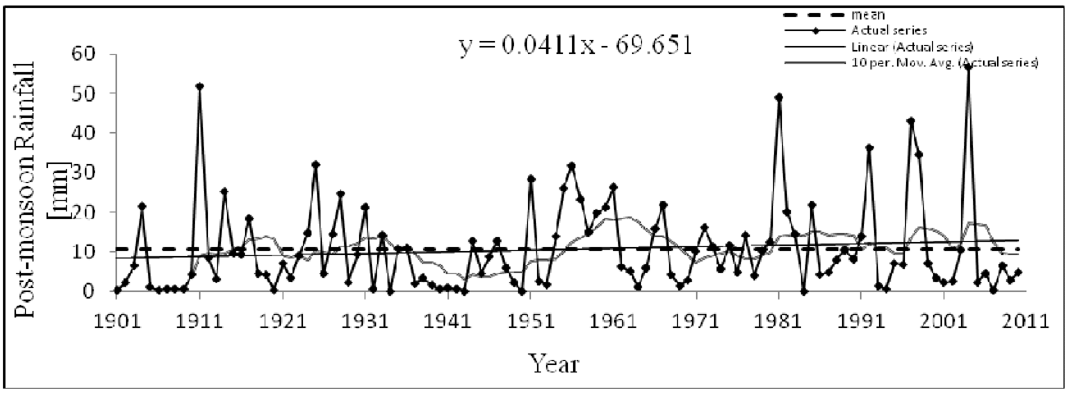

Figure 6 (a): Mean post-monsoon rainfall, linear trend line and 10 years moving average at Haryana.

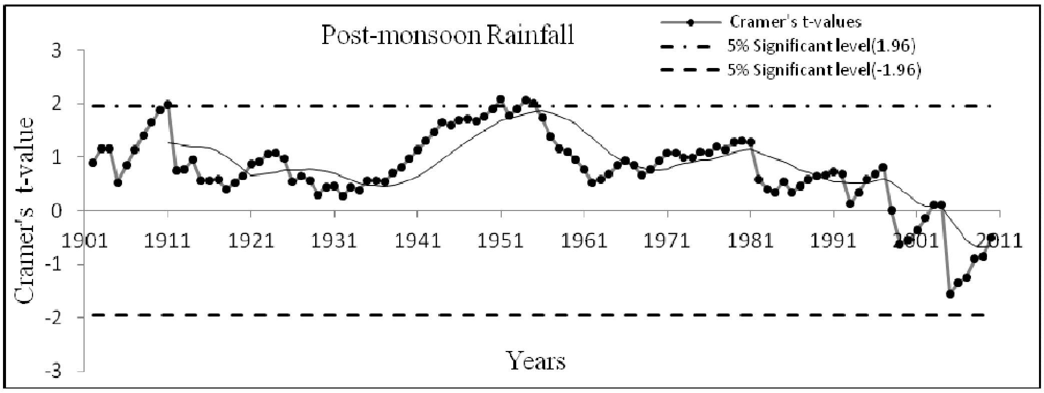

Figure 6 (b): The 10 years post-monsoon rainfall moving Cramer's t-value for Haryana.

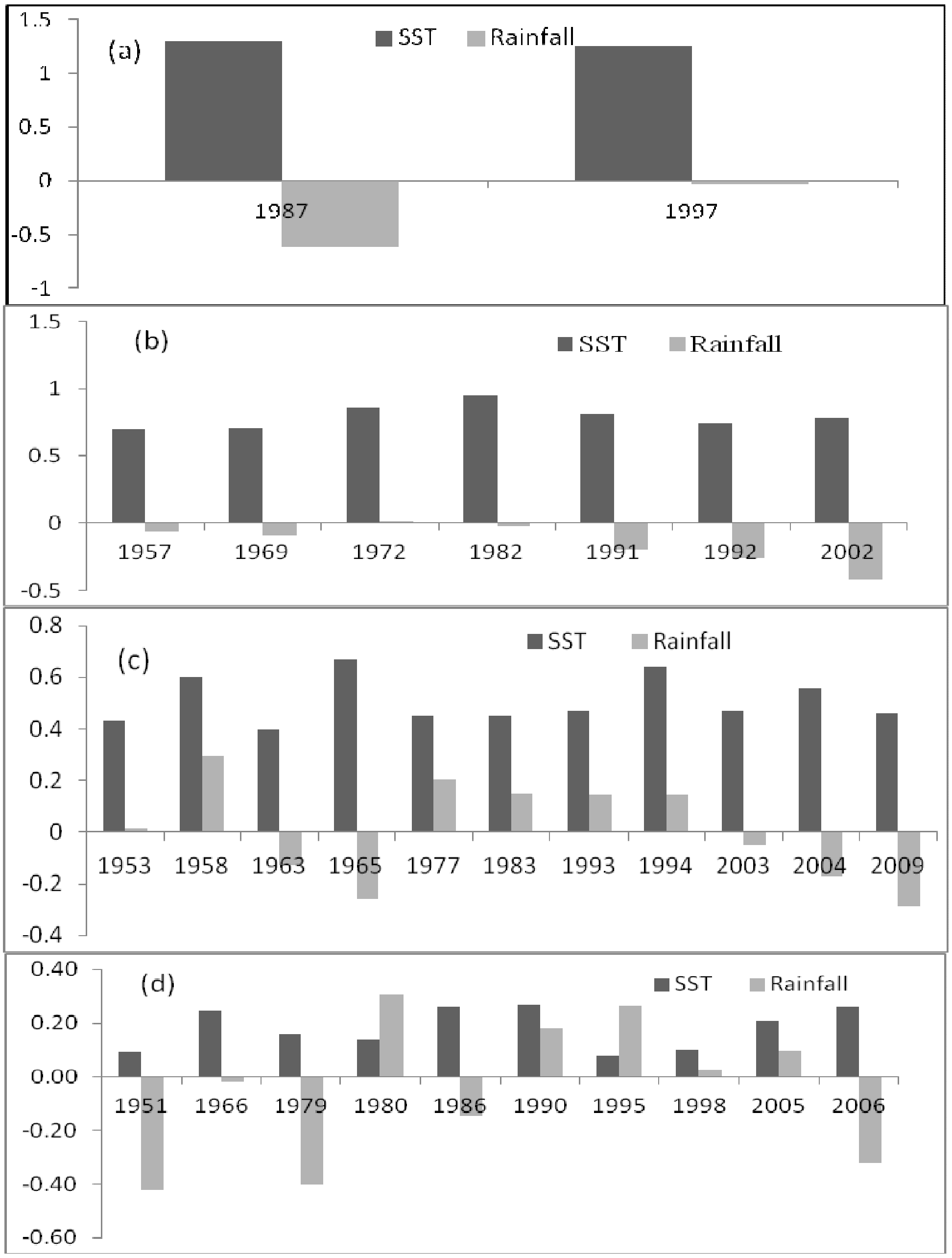

Figure 7: Rainfall and SST Anomaly during the period. (a) Temperature Anomaly T > 1.0. (b) Temperature Anomaly T = 0.7 - 1.0. (c) Temperature Anomaly T = 0.3 - 0.7. (d) Temperature Anomaly T = 0.0 - 0.3