Rainfall Trend Analysis of Various Districts of Haryana, India

Deeksha Malik and K. K. Singh

Abstract The study attempts to explore rainfall pattern characteristics in the Haryana region during (1997–2014) Kharif season. In this work, daily and seasonal variations of rainfall along with the determination of dry spells (interval between two wet spells of 7 days magnitude with at least 25 mm of rain) and wet spells (a period of number of consecutive days on each of which precipitation exceeding a specific minimum amount has occurred) during the specified time period have been studied. Mann–Kendall test is applied to detect trend and Sen's slope estimator is for the determination of slope. Results demonstrate that monthly maximum and total rainfall have positive trend and there is a strong spatial relationship in their variability. The increase of monthly precipitation is mainly associated with the increase of frequency and intensity of heavy precipitation during Kharif season. The variation of precipitation is likely to increase flood and drought risk.

Keywords Rainfall · Trends · Dry spells · Wet spells · MK test · Sen's slope estimator

1 Introduction

Variability of rainfall is an important feature of every climate. Change in climate is very likely to increase the magnitude, frequency, and variability of extreme weather events such as droughts, floods and storms. The economic condition of Haryana mostly depends on agriculture. In spite of increased grain yield through various methods, the agricultural scenario of the state is still heavily dependent on annual rainfall and rainfall distribution patterns. Rainfall occurrence and distribution are erratic, temporal and spatial variations in nature. The spatial difference in trends occurs as a result of spatial difference in the changes in the temperature, rainfall and catchment characteristics. For sound crop planning, knowledge of rainfall in any particular region is very helpful. Many researchers have studied the rainfall analysis

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for crop planning at different temporals as well as spatial scales. Variations in the hydro-metrological series can take place in many different ways. A change can occur suddenly (steep changes) or gradually (trend) or in more complex forms.

Impact of changing climate is quite severe as given by International Protocol for Climate Change (IPCC) reports that there will be reduction in the freshwater availability because of climate change. By the middle of twenty-first century, decrease in annual average run-off and availability of water will project up to 10–30% (IPCC 2007). By the study of different time series data, it has been proved that trend is either increasing or decreasing, both in case of temperature and in case of rainfall. It has been reported that annual average precipitation received by India changed from 4000 (CWC 2005) to 3882.07 (CWC 2008) billion cubic metre (BCM), out of that utilised surface water and groundwater resources are approximated to be only 690 BCM and 433 BCM, respectively, (CWC 2008). Mondal et al. (2012) examined that there are rising rates of precipitation in some months and decreasing trend in some other months in the north-eastern part of Cuttack district, Orissa obtained by the statistical tests suggesting overall insignificant changes in the area. Dubey et al. (2016) examined the significant decreasing trend in annual monsoon and winter rainfall.

The study of trend analysis in rainfall finds use in many applications like irrigation engineering, water harvesting, public health engineering, etc. Also, rainfall trend analysis is very useful in rainfall forecasting. Researchers have utilised various methods and techniques to identify trends and shifts in hydrological series at different scales and places. The present study analyses the trend in rainfall pattern for Kharif season in three districts of Haryana viz. Yamunanagar, Kurukshetra and Panchkula from the year 1997 to 2014 along with wet spells and dry spells analyses.

1.1 Study Area and Data

Haryana is located in the northern part of India. It has a very fertile land and is called the green land of India. Geographically, it is situated at 29.0588°N latitude and 76.0856°E longitude. The area falls under monsoon climate region and annual temperature differs from 7.7 to 40.5 °C. Maximum amount of rainfall occurs during monsoon period, i.e. June to October. Pre-monsoon as the month of April, May and winter constituted the month of November, December and January. The economy of study area is comprised of agriculture and more than 80% population is practicing agriculture here. The climate of the region is characterised by arid to semi-arid. The annual precipitation of the region is about 589 mm. Rainfall of three districts viz. Yamunanagar, Kurukshetra and Panchkula shown in Fig. 1 is chosen for analysis. The daily rainfall data for the period (1997–2014) of these districts were taken from 'https://power.larc.nasa.gov'.

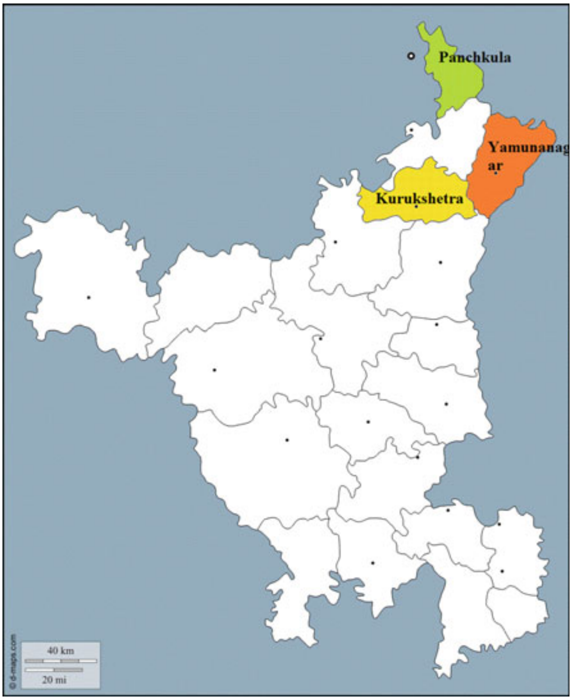

Fig. 1 Study area of Haryana

2 Methodology

Both parametric (regression analysis) and non-parametric can be used to test the trends in the metrological data (rainfall and rainy days) but non-parametric tests are more suitable for non-normally distributed data as compared to statistical tests Lanzante (1996), Jana et al. (2015). Also non-parametric tests can eliminate the problem aroused by data skew (Smith 2000).

In the present study trend, determination in rainfall has been done by Mann–Kendall non-parametric test and determination of slope magnitude by non-parametric Sen's slope estimator in MAKESENS software. Mann–Kendall test is the most frequently used non-parametric statistical tool for identifying the trends in hydro-metrological time series variables such as water quality, stream flow, temperature and precipitation. This is a test which is generally used for studying the temporal trends and spatial variations of hydro-metrological climate series. Also, Mann–Kendall test is preferred when various stations are being tested in a single study (Hirsch et al. 1991). Mann (1945) originally formulated this test as non-parametric test for detection of trend and then test statistic distribution had been given by Kendall (1975). Mostly, previous trend detection has been performed using this technique (Hirsch and Slack 1984; Gan 1988).

2.1 Mann–Kendall Test

Mann–Kendall test is applicable when the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \tag{1}$$

where $f(t)$ is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. To test the null hypothesis of no trend, H_o (the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is increasing or decreasing monotonic trends.

The test statistic is defined as follows:

$$S = \sum_{i=0}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \tag{2}$$

where x_j and x_i are the annual values in years, j and i, j > i, respectively, and each of the data points x_i is taken as reference point which is compared with the rest of the data points x_j as

$$\text{Sgn}(x_j - x_i) = \begin{cases} 0, & = (x_j - x_i) \\ +1, & > (x_j - x_i) \\ -1, & < (x_j - x_i) \end{cases} \tag{3}$$

If $n < 10$, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall and for $n \geq 10$, the normal approximation test is used (Gilbert 1987). The two-tailed test is used in MAKESENS for four significance levels α: 0.1, 0.05, 0.01 and 0.001. At certain probability level, H_o is rejected in favour of H_1 if the value of S equals or exceeds a specified value $S_{\alpha/2,}$ where $S_{\alpha/2}$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive value of S indicates an upward trend and a negative value indicates downward trend.

Minimum values of n with which these four significance levels can be reached are derived from the probability table for S as follows:

Significance level (α)	0.1	0.05	0.01	0.001
n required	≥4	≥5	≥6	≥7

The significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting H_o of no trend. Thus, the significance level 0.001 means that the existence of a monotonic trend is very probable.

If n ≥ 10, the normal approximation test is used. First, the variance of S is calculated by the following equation which takes into account that ties (equal values) may be present, otherwise, it may reduce the validity of the normal approximation when the number of data values is close to 10.

$$Var(\mathrm{S}) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t(i)(i-1)(2i+5)}{18} \tag{4}$$

Here, m is the number of tied groups and t_i is the number of data values in the ith group.

The test statistic *Z* is as follows:

$$Z_{\mathrm{c}} = \begin{cases} \frac{S-1}{\sqrt{r(Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S=1}{\sqrt{Var(S)}}, & S < 0 \end{cases} \tag{5}$$

A positive value of *Z* indicates an upward trend and negative value indicates downward trend. The static *Z* has a normal distribution. For testing an upward or downward monotonic trend (a two-tailed test) at α level of significance, H_0 is rejected if the value of $Z > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In MAKESENS, the tested significance levels are 0.001, 0.01, 0.05 and 0.1.

2.2 Sen's Method

To estimate the magnitude of existing trend the Sen's non-parametric method is used. This method can be used where the trend assumed to be linear as

$$f(t) = Qt + B \tag{6}$$

Here, the slope of all the data pairs is computed as (Sen 1968)

$$\mathrm{T_i} = \frac{(x_j - x_k)}{j - k} \qquad \text{for i} = 1, 2, \ldots, \mathrm{n} \tag{7}$$

where j > k and x_j and x_k are considered as data values at time j and k, respectively. The median of these N values of T_i is represented as Sen's estimator of slope as

$$\mathrm{Q_i} = \begin{cases} T_{(N+1/2)} & N\ is\ odd \\ 1/2(T_{(N/2)} + T_{(N+\frac{2}{2})}) & N\ is\ even \end{cases} \tag{8}$$

At the end, a 100(1 − α)% two-sided confidence interval about the slope estimate is obtained by the non-parametric techniques based on the normal distribution. This method is valid for n as small as 10 unless there are many ties. MAKESENS software has been used for analyses.

2.3 Wet and Dry Spells

In this study, the analysis of wet and dry spells has been carried out using daily rainfall data for selected cities in Haryana. The daily rainfall data were examined according to the criteria of wet and dry spells. Wet spell is defined as the 7-day spell where the total amount of rainfall in 7 days equals to 25 mm or more and the condition that 3 out of these 7 days must be rainy with rainfall of more than 2.5 mm of each day. Dry spell like the drought means from agronomic point of view, a dry spell is not a drought of climatic magnitude but a period of a few days or weeks. A dry spell is interval between two wet spells of 7 days magnitude with at least 25 mm of rain. Dry spell at critical crop growth stages affects the growth and the ultimate production of crop.

3 Results and Discussion

Trend analysis of selected cities of Haryana has been done in the present study with 18 years of daily rainfall data from 1997 to 2014. Mann–Kendall and Sen's slope estimators have been used for the determination of the trend. Figures 2, 3 and 4 represent the trend analysis of monthly maximum rainfall for 18 years of Yamunanagar, Panchkula and Kurukshtera districts of Haryana for the months of July, August and September, respectively.

Trend of Yamunanagar for the months of July and October is decreasing with the values of slope −0.64 and −0.45, respectively, and for the months of August

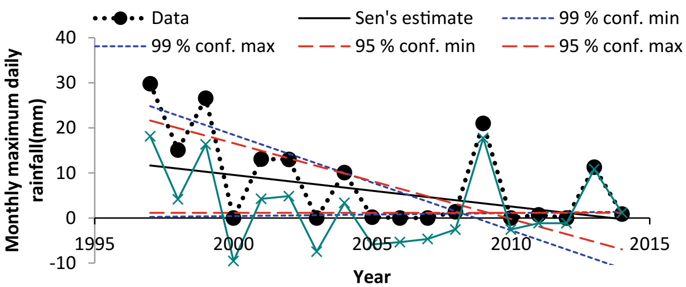

Fig. 2 Variation of monthly maximum daily rainfall for Yamunanagar (July)

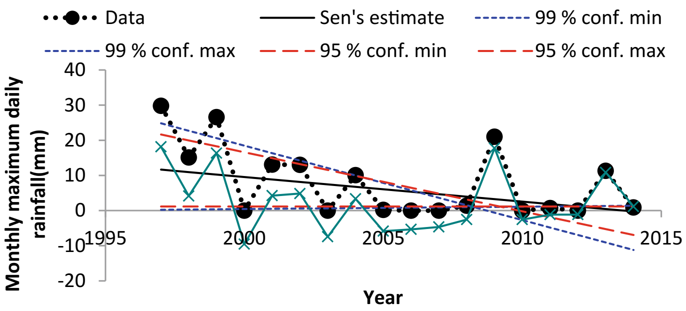

Fig. 3 Variation of monthly maximum daily rainfall for Kurukshetra (August)

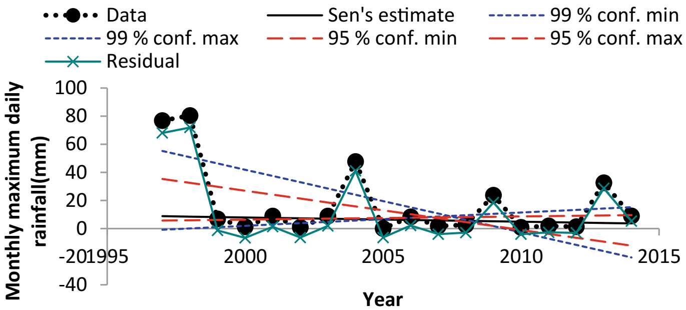

Fig. 4 Variation of monthly maximum daily rainfall for Panchkula (September)

and September is increasing with the slope of 0.15 and 1.67, respectively. Trend of Kurukshetra for the months of July and October is decreasing with the values of slope −1.10 and −1.74, respectively, and for the months of August and September is increasing with the values of 1.82 and 0.38, respectively. Trend of Panchkula for the month of October is decreasing with the value of slope −0.49 and for the months of July, August and September is increasing with the values of 0.61, 1.55 and 1.21, respectively.

From Table 1, probabilities of wet spells of 10 days or more in Yamunanagar in the month of July, August and September are 88%, 100% and 83%, respectively. From Table 2, probabilities of wet spells in Kurukshetra in the month of July, August and September are 77%, 61% and 50%, respectively. From Table 3, probabilities of dry spells in Panchkula in the month of July, August and September are 44%, 50% and 29%, respectively. From these analyses, it is seen that out of three districts Kurukshetra and Panchkula districts require irrigation and are more critical from irrigation point of view so that the crops could be sustained.

From Table 4, probabilities of dry spells of 7 days or more in Yamunanagar in the month of July, August and September are 17%, 39% and 77%, respectively. From Table 5, probabilities of dry spells in Kurukshetra in the month of July, August and September are 77%, 83% and 100%, respectively. From Table 6, probabilities

Table 1 Wet spell numbers and duration in days for Yamunanagar

Year	1997	’98	’99	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14
July	27	31	7, 17	26	28	7, 7	10, 21	11, 12	31	30	13, 18	31	26	31	30	4, 13	31	7, 7
Aug	27	30	7, 12	14	19	7, 14	31	27	9, 12	30	31	28	7, 12	28	31	30	31	19
Sep	18	16	7, 19	8	0	21	7, 10	13	25	9	11, 13	11, 11	11	17	15	7, 12	7, 7	15
Oct	7, 11	7	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0

Table 2 Wet spell numbers and duration in days for Kurukshetra

Year	1997	’98	’99	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14
July	27	28	14	20	7, 11	0	8, 11	8	31	8	8, 9	13	10	9, 16	28	9, 11	23	19
Aug	7, 11	24	8	7	27	18	0	25	7	10	7, 7	16	7, 8	7, 7, 13	26	14, 14	26	11
Sep	23	12	13	0	0	0	9	13	9	0	7	11	8	16	10	12	17	13
Oct	15	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0

Table 3 Wet spell numbers and duration in days for Panchkula

Year	1997	’98	’99	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14
July	7	8	14	8	10	0	8, 10	0	31	7	10, 13	8, 9	15	7, 15	7, 7	8	7, 15	8
Aug	7, 10	6, 12	8	13	8	11	7, 10	7, 15	0	0	7	9	7	9	8, 17	7, 13	12	7, 8
Sep	8	14	9	0	0	7	0	0	7	7	7	8	7	15	9, 30	7, 8	8	11
Oct	11	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	7	0

Table 4 Dry spell numbers and duration in days for Yamunanagar

Year	1997	’98	’99	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14
July	5	0	7	5	3	8, 9	0	8	0	0	0	0	5	0	0	4	0	3
Aug	4	0	3, 9	7	12	10	0	4	10	0	0	3	3, 8	3	0	0	0	12
Sep	3, 9	6, 8	22	22	31	9	6	8, 9	2, 3	21	5	7	4, 15	13	15	2, 8	5, 5	15
Oct	11	11, 13	31	31	31	31	31	31	31	31	31	31	24	31	31	31	31	31

Table 5 Dry spell numbers and duration in days for Kurukshetra

Year	1997	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14
July	0	0	17	11	7	31	7	11, 12	0	22	11	7	7, 15	7	0	10	9	12
Aug	13	7	20	7, 17	31	13	31	7	10, 13	10, 12	16	15	8, 10	0	7	0	4	20
Sep	8	7, 11	16	30	30	30	10, 11	14	17	30	22	8, 12	22	14	20	7, 13	18	16
Oct	16	31	31	31	31	31	31	14	31	31	31	31	31	31	31	31	31	31

Table 6 Dry spell numbers and duration in days for Panchkula

Year	1997	’98	’99	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14
July	7, 17	10, 13	17	11, 12	18	31	7	31	0	8, 15	9	8	8, 8	8	12	23	0	11, 12
Aug	12	8	20	8, 10	21	20	10	7	31	31	24	22	9, 15	8, 15	6	7	8, 11	17
Sep	7, 15	6, 10	17	30	30	23	30	30	7, 16	23	23	9, 13	23	16	8	4	22	18
Oct	9, 11	31	31	31	31	31	31	24	31	31	31	31	31	31	31	31	8, 15	31

of dry spells in Panchkula in the month of July, August and September are 88%, 94% and 94%, respectively. From these analyses, it is seen that out of three districts Kurukshetra and Panchkula districts irrigation requirements are more critical for crops sustenance.

4 Conclusions

The present study analysed the rainfall data for 18 years from 1997 to 2014 of selected cities of Haryana (Yamunanagar, Kurukshetra and Panchkula) for the determination of trend in maximum monthly daily rainfall during Kharif season using Mann–Kendall test along with Sen's slope estimator for the magnitude of trend. It can be concluded that rainfall of July in Yamunanagar and Kurukshetra is decreasing with slope >-0.6. This will have implication on Kharif crop sowing. Yamunanagar is having the maximum number of wet spells. Kurukshetra and Yamunanagar are having long periods of dry spells.

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