

TREND ANALYSIS OF RAINFALL USING MANN-KENDALL TEST IN KARMAL WATERSHED OF BHADAR BASIN

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ABSTRACT

Rainfall is very important for the economic growth and development of any nation and one of the vital climatic factors that can indicate climate change. Spatial and temporal changes of rainfall would influence runoff, soil moisture and groundwater reserves. Analysis of precipitation trends is important in studying the impacts of climate change for water resources planning and management. This paper critically examines trends in the monthly and seasonal total rainfall over Karmal watershed of Bhadar basin using 30 years (1982-2011) monthly rainfall data at five rain-gauge stations. The trend analysis was done by using Mann-Kendall test and Sen's slope estimator. The results indicated that seasonal increasing trends varied between 10.72 mm/year to 16.56 mm/year at three rain-gauge stations. The monthly trend analysis of rainfall found non-significant increasing (positive) trend for all stations at 1 per cent significance level.

KEY WORDS: Bhadar basin, Mann-Kendall test, rainfall, Sen's slope estimator, watershed

INTRODUCTION

Water resource has become a prime concern for any development and planning including food production, flood control and effective water resource management. Studies have demonstrated that global surface warming is occurring at a rate of 0.74 ± 0.18 °C over 1906–2005 (IPCC, 2007). Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of 21st century, decrease in annual average runoff and availability of water will project up to 10-30 per cent (IPCC, 2007). Central Water Commission (CWC, 2005) reported that annual average precipitation received by India is about 4000

billion cubic meters (BCM). Out of that, utilized surface water and groundwater resources are approximated to be only 690 and 432 BCM, respectively. Again, in the report of (CWC, 2008-09), the annual average precipitation has been approximated to be 3882.07 BCM and utilizable total surface water and total replenishable groundwater is estimated to be about 690 BCM and 433 BCM correspondingly. Therefore, it is apparent from the report that there is a reduction in the annual average rainfall over the country. With the growing recognition of the possibility of adverse impact of global climate change, the long term rainfall series data is used for analyzing the influence of climate changes. Some researchers have also studied the availability of quality freshwater which is of biggest

concern for the last half-century, because of higher demographic pressure leading to climatic variability (Shiklomanov and Rodda, 2003). The problem is more flimsy in India and China where population is very high and posing continuous threat to the fresh water, because these two countries use about 40 per cent of global freshwater for the purpose of irrigation (Gleick, 2000).

Detecting trends in rainfall, as well as climatic, water quality and other natural time series, has been an active subject for more than three decades now. With the recent extensive work in the field of climatic change and variability, the subject of trend detection has received even greater attention. Trend analysis has been extensively used to assess the potential impacts of climatic change and variability on hydrologic time series in various parts of the world. A precipitation trend analysis, on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change from the scientific community; indicate a small positive global trend, even though large areas are instead characterized by negative trends (IPCC, 1996). Mann-Kendall Test has been used to find any trend of rainfall, temperature and evapotranspiration (both monthly and annual) which has shown some significance in case of rainfall and temperature. MK Test has been used to analyze the long term rainfall trend in Zambia by Kampata *et al.*, (2008). The trend of precipitation and runoff is also studied by Xu *et al.* (2010) in major Chinese rivers in order to find out any human intervention in the trend from 1951 to 2000. Hence, based on the background of previous researches, changes in rainfall have been studied to assess the spatial pattern of rainfall trends on seasonal and monthly scales over Karmal watershed of Bhadar basin.

MATERIALS AND METHODS

Study area

The Karmal watershed of Bhadar river in Saurashtra region of Gujarat is selected. It is located between 21°50' to 22°10' North latitude and 70°55' to 71°20' East longitudes. The total area of the Karmal watershed is 1196.46 km². The study area has maximum elevation of 305 m and a minimum of 80 m above mean sea level. The average annual rainfall in the study area (Karmal watershed) is 660 mm. As the watershed being situated in tropical and sub-tropical region and dominated with agriculture land, water availability in the region is an important and critical issue. The Karmal watershed originates from Vaddi about 26 km North–West of Jasdan in Rajkot district and flows towards South up to Jasdan village and outlet located at Kamdhiya village.

Meteorological data

The daily precipitation data for 30 years (1982-2012) for 5 (five) rain gauge stations of Karmal watershed namely Kamadhiya, Jasdan, Ishwariya, Alangsagar and Rajavadala (Figure 1) have been collected from the office of State Water Data Centre, Gandhinagar, Gujarat. A rainfall analysis was carried out for all the months and for the whole monsoon season (June to September) separately. The average monthly and seasonal rainfall for each station of Karmal watershed of Bhadar basin has been computed by the arithmetic mean method.

Trend analysis

In the present study, trend analysis has been done by using non-parametric Man- Kendall test. This is a statistical method which is being used for studying the spatial variation and temporal trends of hydroclimatic series. The null hypothesis in the Mann-Kendall test is independent and randomly ordered data. The Mann-Kendall test does not require assuming normality,

and only indicates the direction but not the magnitude of significant trends (Mann, 1945; Kendall, 1975).

Mann–Kendall (MK) test

The Mann–Kendall test (Mann, 1945; Kendall, 1975) is based on the correlation between the ranks of a time series and their time order. The MK test searches for a trend in a time series without specifying whether the trend is linear or non-linear. It is based on the test statistic S defined as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sign}(Y_j - Y_i) \quad \text{.. (1)}$$

Where, Y_i and Y_j are the sequential data, N is the total number of data in the time series and

$$\text{sign}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \quad \text{..(2)}$$

A positive value of S indicates an upward trend and *vice-versa*. For $N \geq 8$, Mann (1945) and Kendall (1975) have documented that the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0 \quad \text{..(3)}$$

$$\text{Var}(S) = \left[N(N-1)(2N+5) - \sum_{j=1}^n t_j(t_j-1)(2t_j+5) \right] / 18 \quad \text{..(4)}$$

Where, t_i is the number of ties of extent i (i.e. the number of data in the tied group) and n is the number of tied groups. The standardized test statistic Z , given below, follows the standard normal distribution:

Kendall (1975) also shows that the distribution of S tends to normality as the number of observations becomes large. The significance of trends can be tested by comparing the standardized variable Z in Eq. (5) with the standard normal variate at the desired significance level α , where the subtraction or addition of unity in Eq. (5) is a continuity correction (Kendall, 1975).

$$Z = \begin{cases} (S-1)/\sqrt{\text{Var}(S)} & S > 0 \\ 0 & S = 0 \\ (S+1)/\sqrt{\text{Var}(S)} & S < 0 \end{cases} \quad \text{..(5)}$$

At α_L (where ‘L’ stands for local) significance level, the null hypothesis of no trend is rejected if the absolute value of Z is greater than the theoretical value $Z_{1-\alpha_L/2}$.

Sen’s slope (SS)

Using the method of Sen (1968), the magnitude of the slope can be obtained as follows;

$$Q_i = \frac{(x_j - x_k)}{(j - k)} \quad \text{..(6)}$$

Where, x_j and x_k are data at time points j and k ($j > k$), respectively. If there are n values, x_j in the time series we get as many as $N = n(n-1)/2$ slope estimates Q_i . The Sen’s estimator of the slope is median of these N values of Q_i . The N values of Q_i are ranked from the smallest to the largest and the Sen’s estimator is

$$Q = Q_{(N+1)/2} \quad \text{if } N \text{ is odd} \quad \text{..(7)}$$

$$Q = \frac{1}{2} [Q_{N/2} + Q_{(N/2)+1}] \quad \text{if } N \text{ is even} \quad \text{..(8)}$$

The two-sided test is carried out at 100 (1- α) per cent of the confidence interval to obtain the true slope for the non-parametric test in the series (Kwarteng *et al.*, 2009). Positive and negative sign of test statistics indicate increasing trend and decreasing trends, respectively.

RESULTS AND DISCUSSION

Mean seasonal and monthly rainfall

Rainfall distribution of Karmal watershed has been studied for 30 years (1982-2011) precipitation data. The average monsoon season rainfall of the Karmal watershed estimated from the 30 years (1982-2011) precipitation data of 5 rain gauge stations is 453.7 mm. It is evident from the Figure 2 that the highest monsoon season rainfall was 799.9 mm in 2011 and the lowest one was 134.8 mm in 1987. Among the 5 rain gauge stations, the annual rainfall is the maximum for the station Kamdhiya located at the outlet of Karmal

watershed, which is around 566.3 mm and a minimum annual rainfall of 544.19 mm in Alangsagar station, which is located on the upper Northern side of the Karmal watershed. The central to outlet parts of the Karmal watershed receive rainfall of about 500-566 mm. In the upper Northern part the region around Rajavadala and Alangsagar receives low rainfall i.e. less than 400 mm. Seasonal average is least for the month of June for all these 30 years (74.6 mm), while the maximum rainfall occurs in the month of July (185.5 mm) followed by August (103.7 mm) and September (79.5 mm). Figure 3 shows the rainfall distribution of 30 years of individual months.

Mann-Kendall trend analysis

The results of the Mann-Kendall analysis to deduct the trend and the magnitude of the trend using Sen's slope estimator for monthly and monsoon season rainfall for five stations in the study area are given in Table 1 and Table 2. The trend analysis revealed that the seasonal rainfall in the stations Kamadhiya, Rajavadala and Alangsagar showed a significantly increasing trend with Z values 2.49, 3.24 and 4.07, respectively at 1 per cent significance level. The increase in seasonal rainfall of Kamadhiya, Rajavadala and Alangsagar stations are 10.72 mm/year, 12.77 mm/year and 16.56 mm/year, respectively, which are slightly high when compared to other stations. The seasonal rainfall in the stations Kamadhiya, Jasdan, Ishwariya, Alangsagar and Rajavadala showed the significant increasing trend at 5 per cent significance level. The trend analysis of monthly rainfall revealed that non-significant increasing (positive) trend was identified in the month of June at 1 per cent and 5 per cent significance level. In month of July, except rain gauge station Ishwariya, the four stations namely Kamadhiya, Jasdan, Alangsagar and Rajavadala showed significant increased

(positive) trend at 5 per cent significance level, the Sen's slope estimator showed that the rainfall increase by 5.51 mm/year, while at 1 per cent significance level, all stations showed non-significant increasing (positive) trend. In month of August, only Alangsagar rain gauge station showed significant increased (positive) trend at 5 per cent significance level, while at 1 per cent significance level, all stations showed non-significant increasing (positive) trend. The trend analysis of monthly rainfall in September revealed that out of five rain gauge stations, three i.e. Jasdan, Rajavadala and Alangsagar showed a significantly increasing trend with Z values 1.76, 2.30 and 2.02, respectively at 5 per cent significance level. The Sen's slope estimator showed that the rainfall increases by 7.32 mm/year, 4.39 mm/year and 7.57 mm/year for the rain gauge stations Jasdan, Rajavadala and Alangsagar, respectively, while at 1 per cent significance level, all stations showed non-significant increasing (positive) trend.

CONCLUSION

The present study has revealed the temporal variations in monthly and seasonal rainfall amounts over Karmal watershed. The rainfall in Karmal watershed is highly variable, uneven and heterogeneous. The monthly and seasonal trends of precipitation were investigated by the Mann-Kendall test and the Sen's slope estimator in this paper. The results indicated that significant increasing trend in seasonal precipitation found at three rain gauge stations at the 99 per cent confidence levels. The trend analysis results showed wide variations during all the months. The increasing trend of rainfall is found to be dominant during monthly and seasonal rainfall trend identification. Since the monthly and seasonal rainfall seems to be increasing in these regions, water storage structures and artificial recharge structures may be

constructed in these regions in order to increase the surface cum groundwater availability. Furthermore, the knowledge of temporal pattern of rainfall trends analyzed in this study is a basic and important requirement for agricultural planning and management of water resources.

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Table 1: Mann-Kendall and Sen's slope estimator test results for annual rainfall in Karmal watershed (1982-2011)

Sr. No.	Raingauge Station	M-K (Z)					Sen's Slope (Q)				
		Monsoon	June	July	Aug	Sept	Monsoon	June	July	Aug	Sept
1	Kamadhiya	2.50	0.27	1.75	1.45	1.11	16.13	0.26	5.32	3.24	1.35
2	Jasdan	2.27	0.09	1.80	0.96	1.77	13.30	0.00	7.23	1.50	2.77
3	Ishwariya	2.09	0.86	0.23	1.23	1.50	10.52	1.00	0.56	2.28	2.12
4	Rajavadala	3.25	0.87	1.75	1.34	2.30	12.75	0.50	4.00	1.63	2.86
5	Alangsagar	4.07	0.62	2.09	2.24	2.02	16.66	0.00	5.50	3.33	2.33

Table 2: Mann-Kendall test results for annual rainfall in Karmal watershed (1982-2011)

Sr. No.	Raingauge Station	1% Significance Level					5% Significance Level				
		Monsoon	June	July	Aug	Sept	Monsoon	June	July	Aug	Sept
1	Kamadhiya	S	NS	NS	NS	NS	S	NS	S	NS	NS
2	Jasdan	NS	NS	NS	NS	NS	S	NS	S	NS	S
3	Ishwariya	NS	NS	NS	NS	NS	S	NS	NS	NS	NS
4	Rajavadala	S	NS	NS	NS	NS	S	NS	S	NS	S
5	Alangsagar	S	NS	NS	NS	NS	S	NS	S	S	S

S – significant, NS – non-significant

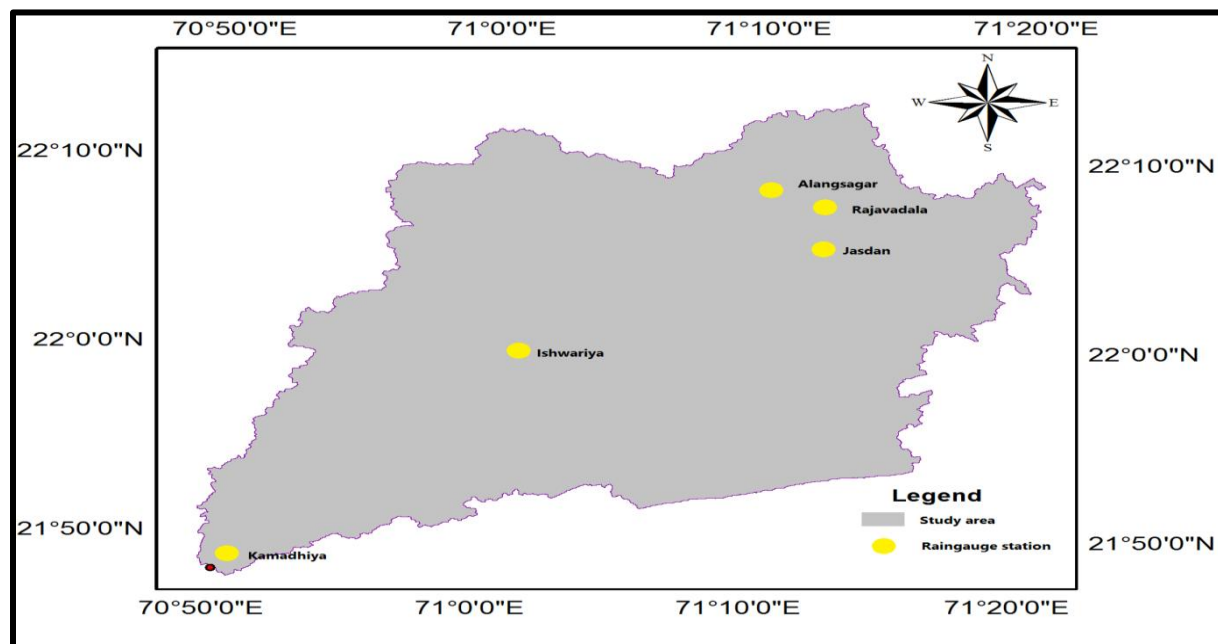


Figure 1: Location map of rain gauge station of Karmal watershed

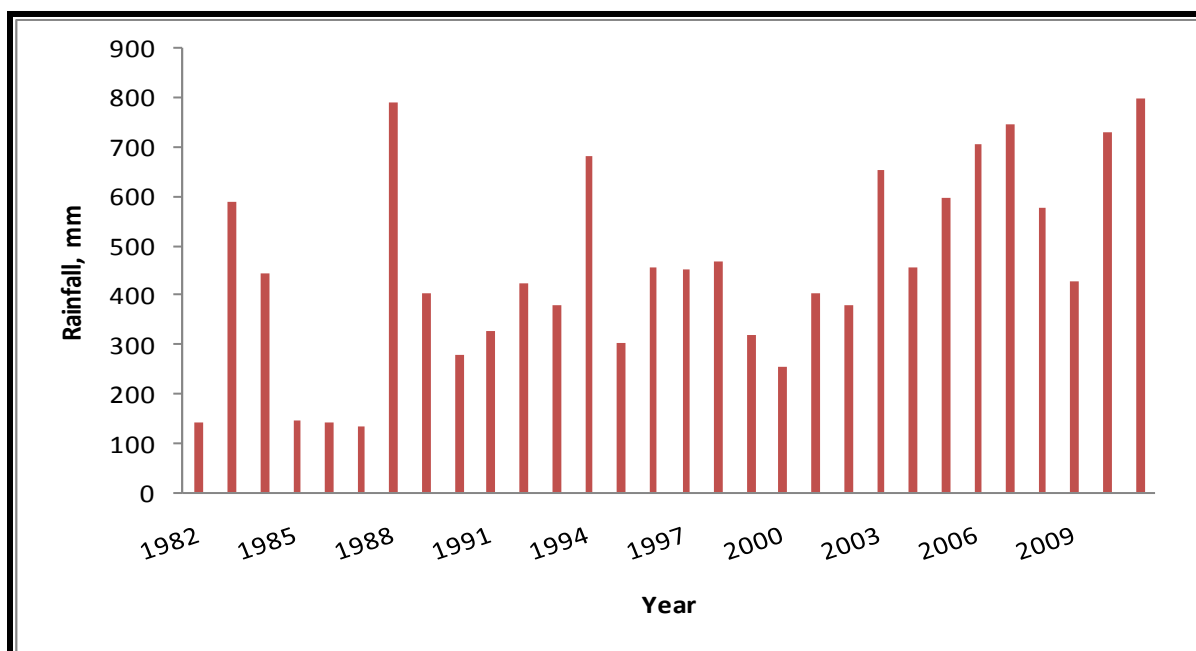


Figure 2: Mean annual rainfall of the study area (1982-2011)

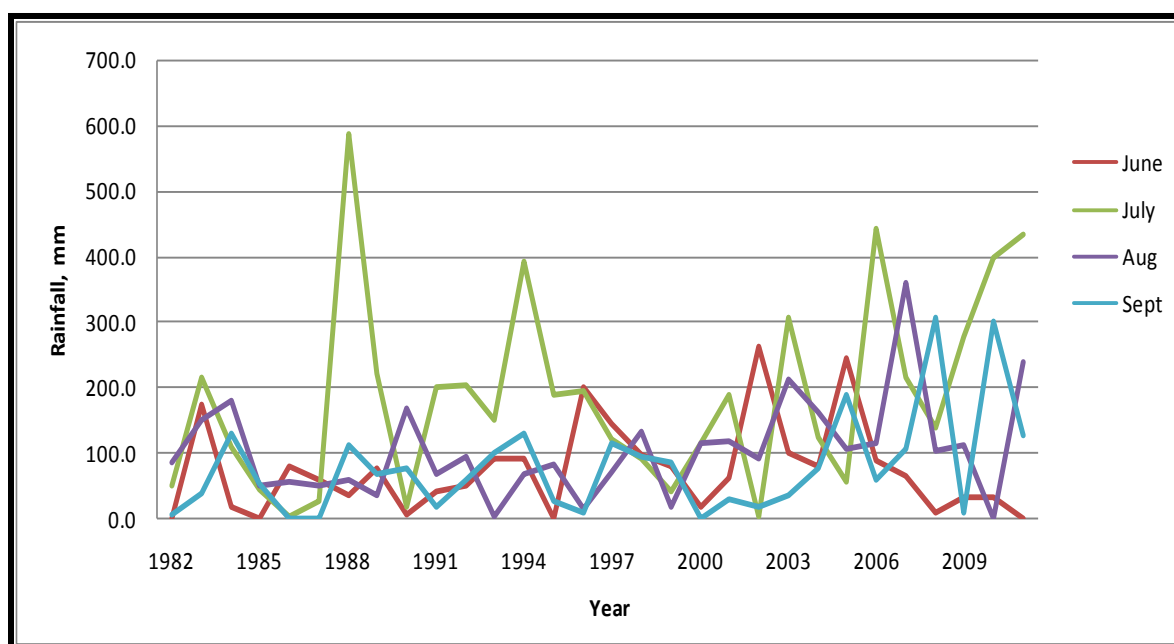


Figure 3: Mean monthly rainfall of June, July, August and September for 30 years

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