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Temporal Trend Analysis and Probabilistic Rainfall Estimation for Bhopal District of Madhya Pradesh

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A B S T R A C T

The rainfall analysis including temporal trend is essential for assessing the water scarcity situation of particular region. In this study, the trend analysis of rainfall was carried out using non parametric Mann Kendall and Sen's slope estimator test. The monthly rainfall of 31 years (1985-2015) of Bhopal district was analyzed for detection of trend and estimation of probabilistic rainfall. The probabilistic rainfall was estimated using frequency factor method at 20%, 50% and 80% probability level. Analysis of 31 years rainfall data showed an average annual rainfall of 1044.7 mm. The 25% deficit criteria for drought indicate that year 1992, 2000 and 2002 were dry years. The results showed the presence of statistically non significant decreasing trend in annual and seasonal (pre-monsoon, post-monsoon and monsoon) rainfall series. The annual probabilistic rainfall was found to be 1573.1 mm, 916.5 mm and 411.5 mm at 20%, 50% and 80% probability level, respectively. The results have an important significance in planning and management of water resources and decision making process.

Introduction

Climate change generally refers to statistically significant change in mean climatic or meteorological parameters viz. rainfall, temperature, solar radiation, etc. over the time caused by naturally or anthropogenic sources. Climate change will result in significant impact on agriculture in terms of change in crop yield, crop duration and sequence and irrigation water requirement (Challinor *et al.*, 2014; Rajwade *et al.*, 2015). Rainfall is the most important weather variable for production of agricultural commodity. The magnitude and distribution of rainfall during crop period has effect on rainfed crops. Specifically over India, lower number of monsoon depressions and the increase in the number of dry spells resulted in overall decrease in seasonal mean rainfall. Therefore, rainfall analysis and its temporal trend determination can derive useful information for water resource management of the region.

The several researchers worked on the variability analysis of rainfall in several parts of world. Various parametric and non-parametric tests are used for trend analysis of hydro-meteorological time series variables such as rainfall (Kisi and Ay, 2014). The nonparametric Mann-Kendall test and Sen's slope estimator was utilized in different research studies for trend detection in rainfall time series. The significant and positive trends in rainfall have been observed in the USA (Kunkel *et al.,* 1999), South Africa (Mason *et al.,* 1999) and the United Kingdom (Osborn *et al.,* 2000). In India, Pandey *et al.,* (2017) found both positive and negative trends in rainfall over different regions of India by Mann-Kendall test and discrete wavelet transformation. Waghaye *et al.,* (2018) investigated the rainfall trend using Mann-Kendall test and Sen's slope estimator for districts of Andhra Pradesh and Telangana and found increasing trend in annual rainfall series.

The rainfall time series analysis is needed to estimate probabilistic rainfall at different return period due to the uneven and erratic nature of rainfall. The estimated rainfall may have important role in design of various water harvesting, irrigation and hydraulic structures.

The probabilistic rainfall estimation can be done based on best fit probability distribution. While estimating the probabilistic rainfall, 50% and 80% probability should be considered as 80% probability indicates assured rainfall, while 50 per cent is maximum limit for taking any risk (Bhakar *et al.,* 2006).

In India, the contribution (production) of rainfed agriculture is about 44% of the total food grain, supporting 40% population from 67% of sown area. Among the total cultivated area (14.9 Mha) in Madhya Pradesh, 62% is rainfed, where climate is vital factor. Long term weather analysis is important for deciding future directions and/or alterations required in existing system for sustainable crop production. Hence, it is imperative to analyze rainfall data for trend analysis to determine the rainfall pattern of the region In addition, the probabilistic rainfall estimation provides information on expected rainfall for better planning and management of water resources. In view of above, the aim of present study is to determine the trend in rainfall series along with probabilistic rainfall estimation for Bhopal district of Madhya Pradesh.

Materials and Methods

Study area

Bhopal district of Madhya Pradesh state, situated between the latitudes 23^{o}05'-23^{o}54'N and longitudes 77^{o}10'- 77^{o}40'E with an average altitude of 500 m above mean sea level. The climate of Bhopal district is a humid sub-tropical with cool and dry winters and hot summers falling in the agro-climatic zone of 'Vindhya Plateau'. May is hottest month with maximum mean temperature of 40.7^{o}C and mean minimum temperature of 11.3^{o}Cwas observed during January. The mean relative humidity varies between the minimum of 26% during the summer months and maximum of 88% during the monsoon season (MoWR, 2013). The location of study area is shown in Fig. 1.

Data collection and analysis

The daily rainfall data of31 years (1985-2015) for Bhopal district was collected from the meteorological observatory of ICAR- Central Institute of Agricultural Engineering, Bhopal. The rainfall parameters mean, standard deviation, coefficient of variation, skewness and kurtosis were determined.

Trend analysis

The non-parametric tests Mann Kendall test (MK) and Sen's slope estimator were applied to 31 years rainfall series to determine rainfall trend and its magnitude.

Mann Kendall test

The Mann-Kendall test (Mann, 1945; Kendall, 1975) is most commonly used non parametric test for detection of trend in time series data of hydrologic variables. The test statistic is given by equation (2);

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(X_j - X_k) \quad \ldots (2)$$

Where X_1, X_2, X_3, …, X_n represents data points and X_j represents at j^{th} time. Positive test statistic indicates the increasing trend and vice versa.

So,

$$sgn(x) = \begin{cases} 1 \ if \ x > 0 \\ 0 \ if \ x = 0 \\ -1 \ if \ x < 0 \end{cases}$$

The E [S] = 0 and variance is given by,

$$\text{variance } V[S] = \frac{n\,(n-1)(2n+5) - \sum_{i=1}^{m} t_i\,(t_i - 1)(2t_i + 5)}{18}$$

Where n is number of data points, m is the number of tied groups in data set and t_j is number of data points in j^{th} tied group. The standardized z-statistic is given by equation (3);

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \ if \ S < 0 \end{cases} \quad \ldots(3)$$

Sen's slope estimator test

This test is used estimate rate of change (slope) of variable over the period (Sen, 1968). The value of d_k is given by equation (4);

$$d_k = \frac{X_j - X_i}{j - i} \quad \ldots(4)$$

For all $1 \leq i \leq j \leq n$

Sens slope is given by median of all slopes. b = median (d_k). The intercepts at each time 't' are computed by,

$a_t = X_t - b \times t$

Probabilistic rainfall estimation

The monthly rainfall series of 31 years (1985-2015) for monsoon season (June-September) was analyzed to estimate probabilistic rainfall at different probability level (20%, 50% and 80%). The probability distributions such as lognormal, gumbel max, weibull, gamma, generalized extreme value were fitted to monthly rainfall series. The goodness of fit was tested using Chi-square test (eq.1) and based on test statistic value, the rankings were applied to the different probability distributions. Based on best fit distribution, a frequency factor method (eq. 1) was applied for rainfall estimation at different probability level (Waghaye *et al.*, 2015).

$$X_T = \bar{X} + K_T\sigma \quad (1)$$

Where, X_T is the variate value of X of return period T,

$\bar{X}$ is the Mean,
K_T is the frequency factor,
σ is the Standard deviation

Results and Discussion

Rainfall analysis

The statistical parameters have been calculated on monthly and annual basis as shown in Table 2. On the basis of 31 years annual rainfall series, mean annual rainfall was found to be 1044.7 mm. The maximum and minimum rainfall of 1931.5 mm and 579.4 mm was observed during2006 and

2000, respectively (Fig. 2). Based on meteorological drought year criteria, years 1992, 2000 and 2002 were found to be dry years. Monsoon (Jun-Sept), post monsoon (Oct.-Feb.) and pre monsoon (Mar-May) seasonal analysis showed that maximum 88.7% of the annual rainfall was received during the monsoon season. In post monsoon and pre monsoon season, only 6.9% and 4% of total annual rainfall was observed, respectively.

The standard deviation varied from 9 to 175.3 mm over the different month. The skewness varied from -0.3 and 4.5 which indicates the asymmetric nature of monthly rainfall during the period. The peakedness of a symmetrical frequency distribution was explained by the kurtosis (Goyal, 2014), which varied from 0 to 22.7. The coefficient of variation gives the inter-annual variability of annual rainfall in each of the stations and found to be varied from 0.4 to 3.4 over different months.

Table.1 Statistical parameters of rainfall series of Bhopal

Month/ Annual	Mean	SD	CV	Minimum	Maximum	Skewness	Kurtosis
January	12	20.8	1.7	0	64.7	1.7	1.4
February	10.3	14.9	1.4	0	54.8	1.4	1.4
March	13.6	26.2	1.9	0	116.9	2.6	7.7
April	6.1	9	1.5	0	40.7	2.2	5.8
May	15.4	21.8	1.4	0	79.9	1.7	2.3
June	134.8	100.2	0.7	14.6	453	1.4	2.4
July	314.3	125.4	0.4	19.2	535.7	-0.3	0.3
August	321.1	175.3	0.5	131.3	937.2	1.6	3.6
September	156.2	117.7	0.8	1.8	450.2	0.8	0
October	30.3	39.3	1.3	0	149.3	1.6	2.1
November	11.2	37.9	3.4	0	197.5	4.5	21.1
December	8.1	23.7	2.9	0	127.2	4.5	22.7
Annual	1044.7	283	27.1	579.4	1931.5	0.9	1.8

Table.2 Homogeneity analysis of rainfall

Station &Data	SNHT	Buishand's test	von Neumann's test
Bhopal, 31 years (1985-2015)	Homogenous (p value = 0.96)	Homogenous (p value =0.95)	Homogenous (p value =0.89)

Table.3 Mann Kendall test statistic (Z), Sen Slope estimator (β) test and percentage change for annual and seasonal rainfall

Station	Z	β	% change	Z	β	% change	Z	β	% change	Z	β	% change
	Annual			Monsoon			Post-monsoon			Pre-monsoon		
Bhopal	-0.61	-2.7	-7.98	-0.85	-0.9	-12.5	-0.87	-0.13	-25.2	-0.1	-0.04	-7.8

Table.4 Monthly estimated rainfall for monsoon season

Month	Average rainfall (mm)	Standard deviation (mm)	Probability (%)	Frequency factor	Estimated rainfall (mm)
June	134.8	100.2	20	0.758	210.73
			50	-0.164	118.4
			80	-0.993	35.32
July	314.3	125.4	20	0.758	409.3
			50	-0.164	293.7
			80	-0.993	189.8
August	321.1	175.3	20	0.758	454
			50	-0.164	292.4
			80	-0.993	147
September	156.2	117.7	20	0.758	245.4
			50	-0.164	136.9
			80	-0.993	39.4

Fig.1 Location of study area

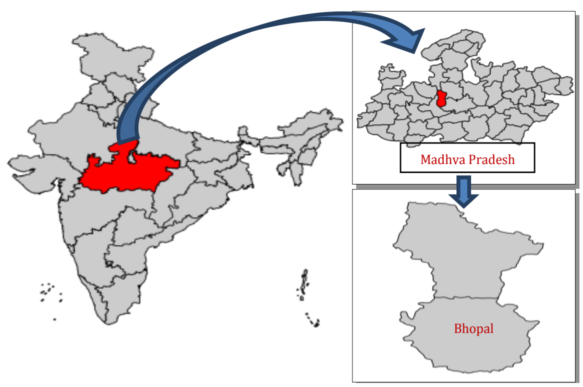


Fig.2 Total annual rainfall recorded for the period 1985-2015

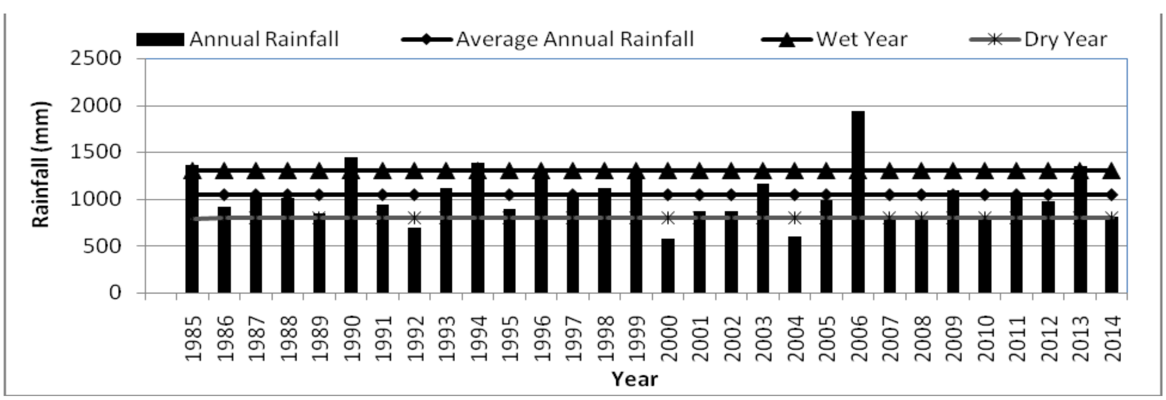
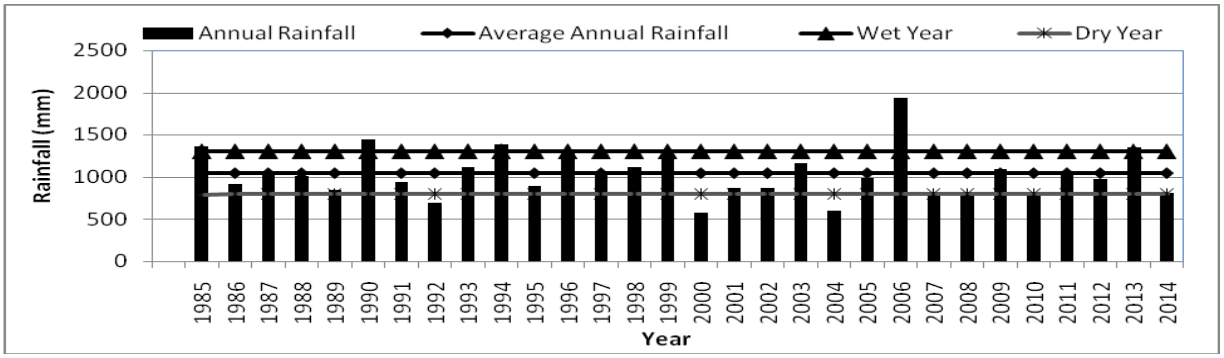


Fig.3 Estimated seasonal rainfall at 20, 50 and 80% probability level



Homogeneity test

The three different tests (SNHT test, Buishand's test and von Neumann's test) were applied to the rainfall series of Bhopal to check the homogeneity of rainfall series at 5% significance level. The results of the homogeneity tests revealed that the rainfall series was homogenous for Bhopal stations (Table 3).

Trend analysis

The rainfall trend has been determined using non-parametric MK test and Sen's slope estimator test for annual and seasonal (pre-monsoon, monsoon and post-monsoon) rainfall series. The MK test showed statistically nonsignificant decreasing trend in rainfall series (Table 4). The magnitude of the trends in annual rainfall was -2.7 mm per year. The decrease of 7.98% in percentage change in annual rainfall was observed at Bhopal station. The MK test applied to the seasonal rainfall series showed decreasing trend with magnitude of the trends, -0.04,-0.9 and 0.13mm/year for pre-monsoon, monsoon and post-monsoon season respectively. The percentage decrease of 7.8%, 12.5% and 25.2% was observed in pre-monsoon, monsoon and post-monsoon season, respectively.

Design rainfall estimation

On the basis of Chi-Square test, Gamma distribution was best fitted to monthly rainfall series. Using frequency factor method, rainfall was estimated at 20%, 50% and 80% probability level (Table 5).For monsoon season, the seasonal estimated rainfall at 20%, 50% and 80% probability level was found to be 1319.4, 841.4, and 411.5 mm respectively (Fig. 3). The annual design rainfall was found to be 1573.1 mm, 916.5 mm and 411.5 mm at 20%, 50% and 80% probability level respectively.

In conclusion the rainfall is important for rainfed dependent small holder farmers The rainfall variability analysis has significant role for planning and management of agricultural activities to overcome challenge of poverty in developing nations. The analysis of 31 years rainfall data using MK test and Sen's slope estimator test revealed the presence non-significant decreasing trend in annual rainfall series. The monsoon rainfall series showed a presence of non-significant decreasing trend in rainfall series. The estimated seasonal rainfall in monsoon season at 20%, 50%, 80% probability level was found to be 1319.4 mm, 841.4 mm and 411.5 mm respectively. Results help in analyzing the changing climate, its effect on water resources and to take better agricultural decisions.

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