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Detection of Changes in the Annual Rainfall over theTapi Basin of Central-Western India

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ABSTRACT

It is widely accepted that various elements of climate, especially rainfall, is extremely sensitive to climate change phenomena and it is reflected through the variability in its amount and intensity. In this paper an attempt has been made been made to evaluate the long-term changes/trends in the annual rainfall over the Tapi Basin from Central-Western India by using the test of Mann-Kendall. The rainfall data were procured from India Meteorological Department (IMD) for fifty six raingaugestations located at the tahsilheadquartersin the basinfor the 20thcentury. It is obvious that the scrutiny of various stations in the basin will underline visible long-term changes/trends in the rainfall at few stations. However, summarizing the rainfall trends obtained at various stations in the basin, it is evident that the low rainfall stations in the basin shows a significant increasing rainfall trend. The stations having rainfall close to the average rainfall of the basin does not present increasing or decreasing rainfall trend. Most importantly, the Tapi Basin, as a whole, does not show any significant rainfall trend over the period of a century. Since, the rainfall over the Tapi Basin not had undergone large variations, which can indicate any specific trend of it, these observations, therefore, provide a weak support to the general view that the rainfall in the basin is progressively decreasing.

Keywords : Tapi Basin, Annual Rainfall, Rainfall Trend

I. INTRODUCTION

A question of prime importance to rainfall studies in India is whether the monsoon rainfall has changed over the last few decades and whether a change is likely to occur in future. Although it is difficult to recognize the likely future trend of rainfall, it is possible to detect the nature of changes that have occurred in the past. Determining the trends or changes in the rainfall are extremely important because studies of hydro-meteorological conditions caused them is useful to detect climatic changes[1]. Even though most of the investigations in the last few decades have revealed secular variations in the Indian monsoon rainfall [2]-[5] However, the studies of rainfall to determine long-term trends/changes on river basin scale are limited. In the present paper an attempt has been made to analyze the annual rainfall data of the Tapi Basin to study the long-term fluctuations in the rainfall. The data analyzed in this paper consists of long-term annual rainfall series available for 56 representative rain gauge stations in the basin. Almost all the stations have long records of rainfall and hence are suitable for identifying long-term trends that might have resulted from long-term changes in the rainfall. The length of data for most of the stations is about over 100 years which is reasonably suitable for long-range studies of rainfall. The objective of this paper is, therefore, to analyze the annual rainfall records and to detect changes/trends in the annual rainfall of the basin.

There are many studies carried out to detect the rainfall trend on all India or regional scales. According to the type and record length of the rainfall data used for analysis there are varied results regarding the trend of rainfall in the country.Rupa Kumar et al. [6] found increasing trend of monsoon rainfall over central peninsula and western coastal area and decreasing trend over northeast peninsula and northwest peninsula. Pattanaik[7] concluded that the monsoon rainfall over the central and northwest India during 1941–2002 presents decreasing trend. The annual rainfall for the first six decades of India has been analyzed by Parthasarthy and Dhar[8] and noticed an increasing trend over central India and decreasing trend over eastern India. However, Kumar et al. [9] found that the analysis of fairly long-term rainfall data of India for the period 1871-2005 does not show any visible trend on country level. Although less in number, a few studies examined the rainfall data of some major river basins of India to determine the trend of rainfall on the basin scale. The study of Mirza et al. [10] revealed that the rainfall over Ganges, Brahmaputra and Meghna Basins does not present any significant trend. The trend analysis of rainfall over the Mahanadi Basin carried out by Rao[11] also does not show any clear trend. However, the analysis of rainfall after 1960 over major river basins in the central India by Singh et al.[12] exhibit varying results. They found an increasing trend of rainfall over Indus, Brahmaputra, Ganga, Cauvery and Krishna Basins and decreasing trend over Narmada, Tapi, Sabarmati, Mahi, Godavari and Mahanadi Basins.

II. THE STUDY AREA

The Tapi Basin is an important interstate river basin of central-western India (Fig.1). The Tapi River is one of the major rivers of peninsular India. The river rises in the eastern Satpura Range at an elevation of 730 m ASL near Multai in the Betul District of Madhya Pradesh. The river flows almost east to west and it is the second longest west flowing river of India after Narmada. With a total length of 724 km, the river drains a catchment of 65145 km^2 which is nearly 2% of the total geographical area of India. Flowing through Madhya Pradesh (9804 km^2), Maharashtra (51504 km^2) and Gujarat (3837 km^2), the river discharges into the GulfofKhambhat of the Arabian Sea near Surat city in Gujarat State. The average annual rainfall of the basin is 814 mm received in average 44 rainy days. The basin is located within the zone of severe rainstorms. Thus, the occasional heavy rains results from incursion of cyclonic storms and depressions originating over the Bay of Bengal or adjoining land.

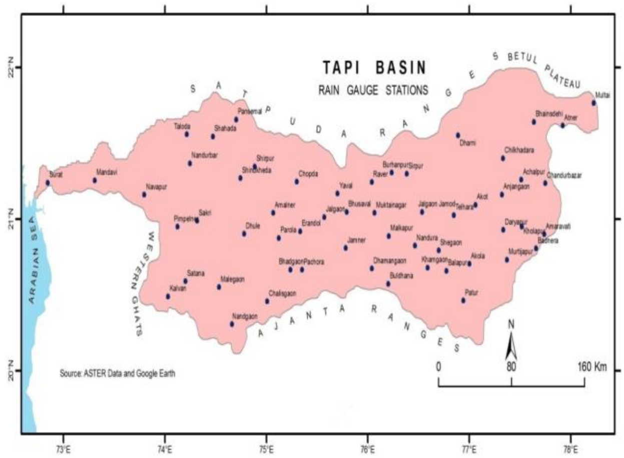

Figure 1. Map of the TapiBasin and location of raingauge stations

III. DATA AND METHODOLOGY

The principal objective of the present study is to analyze the annual rainfall records and to detect changes/trends in the annual rainfall of the Tapi Basin. Therefore, average annual rainfall data were obtained for rain gauge stations located at 56 talukaheadquarters within the basin from India Meteorological Department (IMD), Pune. The data have been obtained for the period of 1901-2004 i.e. mainly for the 20th century. The data analyzed in this paper consists of long-term annual rainfall series available for 56 rain gauge stations in the basin. Almost all the stations have long records of rainfall of about 100 years and hence are suitable for identifying long-term trends that might have resulted from long-term changes in the rainfall. To evaluate the long-term changes/trends in the annual rainfall records of the Tapi Basin, Mann-Kendall test [13] is used. Mann-Kendall test is a powerful statistical technique for randomness against trend [14].

IV. RESULTS AND DISCUSSION

A. *Detection of changes in the annual rainfall*

Use of Mann-Kendall test in trend analysis of meteorological parameters, particularly of rainfall has been reported by several workers.Srivastava et al. [15] utilized Mann-Kendall test for finding the trend in rainfall over India for the period 1901-1992. Krishnakumar et al. [16] determined the long-term changes in seasonal and annual rainfall over Kerala with the help of Mann-Kendall trend test. This non-parametric method has also been used by several workers to quantify the direction and magnitude of trends in the streamflow and rainfall records [17]-[24]. Suresh et al. [25] also applied this test for identification of the nature of changes in the rainfall of the small regions or stations.

The Mann-Kendall's Tau (τ) has been obtained by following equation;

$$\tau = \frac{\text{Actual total of scores}}{\text{Maximum possible total}} \ldots\text{Eq. 1}$$

The actual total of scores (ATS) is achieved by procedure outlined in Table 1, which is just a demonstration. The scores obtained by this procedure are not used in final results of the study. The annual rainfall data of the Tapi Basin for twelve years have been selected as a representative for calculation of actual total of scores, maximum possible total, and for calculation of τ.

The annual rainfall (AR) of the first year i.e. 1901 is compared with the AR of the subsequent years i.e. 1902, 1903, 1904 and so on. If the values (AR) of the subsequent years (1902, 1903, 1904 and so on) are greater than the value (AR) of the first year (1901) then the scores are +1 and if the values subsequent are smaller than the value of the first year then the scores are –1. For instance, AR of the year 1902 (677 mm) is smaller than AR of the year 1901 (721 mm), therefore, the score is -1; and AR of the year 1903 (828 mm) is greater than AR of the year 1901 (721 mm), thus, the score is +1. In this manner, the AR value of the first year is compared with the AR values of all the years and the scores are obtained. Then sum of scores is calculated, which in this illustration is -3. For the next comparison, the first year's (1901) AR value is dropped and the second year's (1902) value is compared with the rainfall values of the subsequent years (i.e. 1903, 1904, 1905 and so on) and the sum(s) scores are calculated for it. The actual total of scores (ATS) is the total of all sum(s), which in this illustration is -2.

Table 1. Scores for calculating Mann-Kendall's τ for the Tapi Basin (An illustration)

YEAR	AR												
1901	721												
1902	677	-1											
1903	828	1	1										
1904	600	-1	-1	-1									
1905	622	-1	-1	-1	1								
1906	863	1	1	1	1	1							
1907	620	-1	-1	-1	1	-1	-1						

1908	710	-1	1	-1	1	1	-1	1					
1909	757	1	1	-1	1	1	-1	1	1				
1910	911	1	1	1	1	1	1	1	1	1			
1911	549	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1		
1912	625	-1	-1	-1	1	1	-1	1	-1	-1	-1	1	**ATS**
	Sum	-3	0	-5	6	3	-4	3	0	-1	-2	1	**-2**

The maximum possible total has been obtained with following equation;

Maximum possible total = $N(N\text{-}1) / 2$ ... Eq. 2

Where; N = Number of observations (for this illustration, N=12).

Therefore, the Mann-Kendall's τ is obtained by putting values in Eq. 1;

$$\tau = \frac{-2}{66} = -\ 0.030 \qquad \text{...Eq. 3}$$

The positive (negative) sign of τ indicates increasing (decreasing) trend. Therefore, the negative value of τfor the given illustration suggests that the rainfall trend for the given period is decreasing. It to be noted that the scores obtained for this example are not used in the study.

B. ***Testing the significance of Tau (τ)***

For the large N, the method outlined for testing the significance of τ becomes extremely cumbersome. However, Kendall [26] has shown that when N is larger than 8, the theoretical distribution of all possible values of τ approaches the normal distribution. The τ may be transformed into a normal standard deviate as follows;

$$z = \frac{\tau}{\sqrt{2(2N+5)/9N(N-1)}} \qquad \text{...Eq. 4}$$

Substituting the calculated value of τ, the value of the z can be obtained. For large number of observations (N> 30), z value has to be greater than 2.32 at 0.01 level and 1.64 at 0.05 level for the sample to be statistically significant.

It is obvious that different stations in the basin cannot present similar trend of rainfall. Therefore, to check the rainfall trend at a station, three representative stations viz. Chikhaldara, SakriandJamner are selected. The basis to choose these specific stations is that these stations represent different zones of the basin as well as they are having varying annual rainfall amounts. Chikhaldara, situated in the eastern hilly areas, is the highest rainfall receiving station in the basin. Sakri, located to the west, is the lowest rainfall receiving station whereas, Jamner, having almost similar rainfall to that of the average rainfall of the basin, represents to the central area of the basin. This exercise predominantly intended to observe the change/trend over the basin scale, therefore, Mann-Kendall's τ and z scores are obtained for the whole basin besides the above-mentioned three representative stations and the results are given in Table 2.

The application of this non-parametric test to the annual rainfall data of the basin designate varied results for different stations. Significant decreasing trend at 0.05 level is observed for Chikhaldara, a highest rainfall receiving station in the basin. Conversely, Sakri, the lowest rainfall receiving station in the basin present significant increasing trend at 0.05 level(Table 2). The test, however, does not exhibit any clear trend in the annual rainfall for Jamner, a rainfall station with average annual rainfall close to the basin's average rainfall, located in the central part of the basin (Table 2). It is very important to note here that the Tapi Basin does not show any significant trend of the rainfall (Table 2). Therefore, it can be stated that the annual rainfall is decreasing with respect to time at high rainfall stations in the basin. Conversely, low rainfall stations in the basin present an increasing trend of rainfall. However, the stations having similar rainfall amount with the basin does not indicate any considerable trend.

The Tapi Basin is an extensive in area, therefore, before generalizing the results of rainfall trend given in Table 2, and to validate these results, trend analysis has been further carried out for three more stations with same procedure. These stations are Multai (high rainfall station), Jalgaon (a station with annual rainfall close to the average annual rainfall of the basin) and Satana (low rainfall station) representing to east, central and west zones of the basin respectively. It is found that no specific rainfall trend has been noticed at Multai. Similarly, Jalgaon also does not designate any specific rainfall trend. However, Satana, a low rainfall station indicate a statistically significant increasing rainfall trend at 0.01 level (z score = 3.80).

Table 2. Nature of changes/trends in annual rainfall records based on Mann-Kendall test

Station	**Period**	***N***	**Tau (τ)**	***z*score**	**Trend/change**
Chikhaldara	1901 – 2004	104	-0.118	-1.78	Decreasing* trend
Sakri	1901 – 2004	104	0.110	1.66	Increasing* trend
Jamner	1901 – 2004	104	0.022	0.33	No specific trend
Tapi Basin	1901 – 2004	104	0.270	0.27	**No specific trend**

See Figure 1 for location of stations; N = number of observations; * = statistically significant at 0.05 level

V. CONCLUSIONS

Summarizig the rainfall trends obtained at above-mentioned stations in the basin, it is evident that the low rainfall receiving stations in the basin shows a significant increasing rainfall trend. The stations having rainfall close to the average rainfall of the basin does not present increasing or decreasing rainfall trend. Most importantly, the Tapi Basin, as a whole, does not show any significant rainfall trend over the period of a century. It is obvious that the scrutiny of various stations in the basin will underline visible long-term changes/trends in the rainfall at few stations.However, certainly the rainfall over the Tapi Basin not had undergone large variations, which can indicate any specific trend of it. These observations, therefore, provide a weak support to the general view that the rainfall in the basin is progressively decreasing.

Most of the investigations for larger areas (all-India scale) during last few decades have given similar results. These studies clearly specified that the monsoon rainfall, particularly on all-India scale, is trendless and is predominantly random in nature over a long period of time.Mooley and Parthasarathy [2], Gregory[27]observed that there is no significant linear trend in the monsoon rainfall of any of the ten macro-regions that he recognized. However, though not at particular locations, the presence of some pockets of significant long-term rainfall changes are also reported by some workers [6], [28], [29].

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