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Research Article

TREND ANALYSIS OF RAINFALL AND TEMPERATURE USING THE MANN KENDALL TEST IN JARAIKELA CATCHMENT OF BRAHMANI RIVER BASIN

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Abstract: The study of meteorological parameters like rainfall and temperature characteristics changes are critical for agricultural, environmental and water resources projects. Generally, trend analysis is performed to evaluate the direction and magnitude of changes in meteorological variables. In this study, the trends in rainfall and temperature and the possible relation between them have been investigated at four stations of Jaraikela catchment of Brahmani river basin in annual, monthly and seasonal time steps. The annual rainfall and temperature show an increasing trend at all stations. As far as monthly analysis is concerned, no definite pattern has been observed in maximum and minimum temperature and rainfall. This study revealed that there exists no direct relationship between increasing rainfall and increasing maximum temperature when the monthly or seasonal pattern is concerned over meteorological subdivisions of the catchment; however, it is concluded that the relations between the trends of rainfall and temperature have large scale spatial and temporal dependence.

Keywords: Rainfall, temperature, trend analysis, spatial and temporal dependence

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Introduction

Climate change is now a broad area of research. Precipitation and temperature are two very important climatic parameters that regulate the hydrological cycle. The changing pattern of precipitation deserves urgent and systematic attention, as it directly affects the fresh water availability and other related systems like the agricultural production system [4]. Precipitation is a vital part of the hydrologic cycle and changes in its pattern would directly influence the water resources of the concerned region. Changes in rainfall quantity and frequency would alter the spatial and temporal distribution of runoff, soil moisture, and groundwater reserves. This imposes to review of our reservoir operation and water resources management policies. Trend analysis in spatiotemporal scale reveals regional water resources availability, drought and flood distribution with respect to climate change. Air temperature is also considered a good indicator of climate change because of its ability to represent the energy exchange process over the earth's surface with reasonable accuracy [21, 22].

A large number of studies have been conducted in the Indian subcontinent and several investigators have concluded that the trend and magnitude of warming over India/Indian subcontinent over the past century is broadly consistent with the global trend and magnitude ([1, 3, 17]. Several studies relating to changing pattern of rainfall over India observed that there is no clear trend of increase or decrease in average rainfall over the country [11, 13, 16, 21]. Although long-term trends in monsoon rainfall have not been observed on an all-India scale, several studies have found significant trends in rainfall on a regional scale [2, 3, 7, 10-12, 18]. Some studies have shown that, in general, the frequency of intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual precipitation has decreased [3, 9, 5, 15, 20]. This study aims to determine the monthly, seasonal and annual trend in rainfall (sale), and temperature (maximum, minimum and mean temperature) at four stations during 1980-2014.

Materials and methods

Study area and data

The Brahmani river basin lies between 83°52' to 87°03' east longitudes and 20°28' to 23°35' north latitudes. The basin spread is 39,033 km^2 and has a maximum elevation of 600 m above the mean sea level. The study was undertaken at Jaraikela catchment which is situated at the northern end of the Brahmani basin. The total area of the catchment is 8995 km^2 having a major area under rainfed agriculture. The average temperature varies from 30-36°C during summer and 16-17°C during the winter season. Rice, groundnut, sugarcane, millets and vegetables are the important crops cultivated in the region. During the south-west monsoon season, the relative humidity varies from 75-90% and in the summer it varies from 30-40%. The normal rainfall of the catchment is 1429.2 mm. Daily rainfall and temperature (1980-2014) gridded (1°×1°) data were collected from the India Meteorological Department (IMD), Pune.

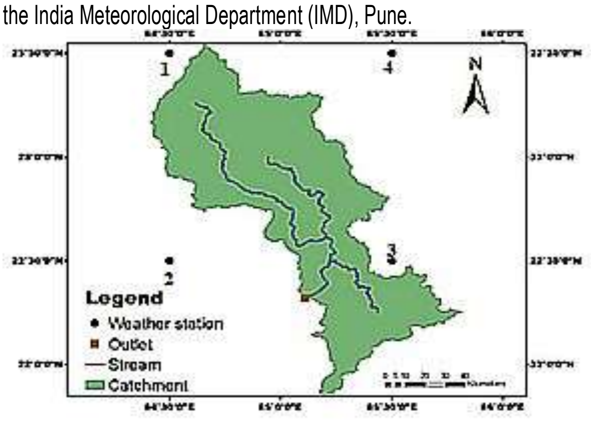

Fig-1 Location of the study area

Trend analysis

Trend analysis is defined as quantification of changes occurred in a system over a long period of time using different empirical methods. The purpose of trend testing is to determine if the values of a random variable generally increase (or decrease) over a period of time in statistical terms. Generally parametric or non-parametric statistical tests are used to decide whether there is a statistically significant trend. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution), and the data observations are independent of one another. Whereas, the nonparametric test is distribution-free because it is assumed that the data don't follow any specific distribution. For seasonal analysis, each year was divided into four climatic seasons, namely winter (January-February), pre-monsoon (March-May), southwest monsoon (June-September), and post-monsoon (October-December), as recommended by IMD. Analysis of the data was carried out the month, season and year-wise for temperature (1980-2014) and rainfall (1980-2014). In this study, the magnitude of a trend in a time series was determined using a nonparametric method known as Sen's estimator [18] and statistical significance of the trend in the time series was analyzed using Mann–Kendall (MK) test [8, 14].

Mann Kendall test

Mann Kendall test is a statistical non-parametric test, widely used for analysis of trend in climatologic and in hydrologic parameters. It has two major advantages; first, it does not require normally distributed data, second, low sensitivity to abrupt heterogeneity in the data series. Any non-detected data are assigned with a smaller value than the smallest measured data. In this method, assumption of no trend is considered as null hypothesis (H0) and increasing or decreasing trend as alternative hypothesis (H1). The mathematical procedure for the Mann Kendall test is presented in equations1-5. Where n is the number of data points and xi and xj are two data subsets, i=1,2,3,..., n-1 and j=i+1, i+2, i+3, ..., n. The data are evaluated in an orderly manner and each data is compared with all subsequent data values. The statistic S is incremented by 1, if a data value is higher than its earlier data value. On the contrary, S is decremented by 1, if the data value is lower than its earlier data value. The summation of all increments and decrements gives the final value of S.

The Mann-Kendall S Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \tag{1}$$

$$Sign(x_j - x_i) = \begin{cases} 1 \; if \; x_j - x_i > 0 \\ 0 \; if \; x_{j\_}x_i = 0 \\ -1 \; if \; x_j - x_i < 0 \end{cases} \tag{2}$$

where, xj and xi are the annual maximum daily values in years j and i, j > i, respectively.

If n<10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two-tailed test is used. At certain probability level H0 is rejected in favor of H1 if the absolute value of S equals or exceeds a specified value Sα/2,where Sα/2 is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend. For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E\,(S) = 0 \tag{3}$$

The variance (σ^2) for the S-statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{k=1}^{n} t_k(t_k-1)(2t_k+5)}{18} \tag{4}$$

where, n is the number of tied (zero difference between compared values) groups and tk the number of data points in the kth tied group. The standard normal deviate (Z-statistics) is then computed as [6] follows:

$$Z_s = \begin{cases} \frac{S-1}{\sigma} for \; S > 0 \\ 0 \quad for \; S = 0 \\ \frac{S+1}{\sigma} \; for \; S > 0 \end{cases} \tag{5}$$

The test statistic Zs is used to measure the significance of trend. When |Zs| > Zα/2 (α at 5% level significance), the null hypothesis is rejected and the alternate hypothesis is accepted. This represents a significant trend in the data series.

Results and discussion

Spatial variability of rainfall

From the analysis, it was observed that there is significant spatial and temporal variation in the mean monthly rainfall received at four meteorological stations of Jaraikela catchment [Table-1]. August receives the maximum rainfall at station 4 of 359.9 mm followed by 349.8 mm and 338.7 mm at station 1 and 3, respectively. Except the four months (Dec, Jan, Feb and Mar), all other months receive a considerable amount of rainfall [Table-1]. The catchment receives an annual rainfall of 1429.2 mm, out of which 79.54% (1136.8 mm) occurs during the southwest monsoon. The highest rainfall occurs at station 4 (1255.8 mm), whereas the lowest rainfall of 1054.0 mm received at station 1 during the monsoon, shown in [Table-2].

Spatial variability of maximum and minimum temperature

Maximum temperature is high in the month of May and low in the month of January at all stations [Table-3]. Highest maximum temperature of 38.3ºC has been recorded at station 1. Lowest maximum temperature of 25.6ºC has been seen in station 4. Minimum temperature is high during the month of June and low during January. The lowest minimum temperature of 13.6ºC has been recorded at station 3. The highest minimum temperature of 26.1ºC has been recorded at station 4. As far as spatial seasonal variation is concerned, high maximum temperature is recorded in pre-monsoon season and high minimum temperature is recorded during southwest monsoon season for all four stations [Table-4].

Trend analysis

Trend of rainfall

The trend analysis of monthly, seasonal and annual rainfall of four stations over the Jaraikela catchment has been shown in Tables 5 & 6. Among the four stations, the rainfall trend is statistically significant for the months of May and September at station 2 [Table-5]. At station 1 the the trend is significant for the month of October and for July at station 3 and 4. The rainfall trend is increasing during the post-monsoon period and the trend is decreasing during the winter season at all four stations. However, the statistically significant increasing trend in post-monsoon rainfall is only observed at station 1 and the decreasing trend of winter rainfall is not statistically significant for all the four stations. The annual rainfall trend at all the stations has shown an increasing trend and the trend is statistically significant at stations 2, 3 and 4. The highest increasing rainfall trend of 9.83 mm/year occurs at station 3 [Table-6].

Trend of maximum, minimum and mean temperature

Trend of maximum, minimum and mean monthly temperature is presented in [Tables-7]. The maximum temperature trend is significantly increasing in the month of February, March, April, May and August at station 1. Similarly, at station 2 the trends are increasing significantly in the months of February, March, May, July and August, respectively. The highest significant increasing trend of 0.07 ºC/month is observed in the month February at station 1, while the lowest significant increasing trend of 0.02ºC/month is noticed in the month of July at station 2. Other two stations have shown an insignificant trend in all months. The minimum temperature trend is increasing significantly in the months of March, April, May, June and July, respectively at station 2 and 3. The increasing trend of monthly minimum temperature to the order of 0.03 ºC/month has been noticed at station 2 in the month of June and 0.02 ºC/month in the months of March, April, May and June at station 3. The mean temperature trend is increasing in all months, except January at all stations, October at station 4, and December at station 3 and 4. The highest monthly mean temperature trend of 0.04 0C/month is noticed at station 2 in the month of May. The fluctuation in these temperature trends may be due to the complex topography and thereby different thermodynamic and orographic forcing at individual station. Trend of maximum, minimum and mean seasonal and annual temperature is presented in [Table-8]. Maximum temperature has shown an increasing trend in pre-monsoon and monsoon seasons.

Table-1 Mean monthly rainfall (mm) at four stations over Jaraikela catchment

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	15.0	14.8	16.5	17.6	53.2	229.2	279.0	349.8	196.1	69.3	11.4	6.6
2	13.8	18.1	22.6	32.0	81.5	267.2	302.7	320.5	216.9	79.9	14.4	6.9
3	17.8	19.5	22.4	38.0	91.8	247.8	308.2	338.7	235.5	99.6	14.8	7.5
4	12.7	20.6	29.4	46.6	109.4	275.3	313.9	359.9	306.6	133.1	25.0	7.8

Table-2 Mean seasonal and annual rainfall (mm) at four stations over Jaraikela catchment

Stations	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
1	36.4	87.3	1054.0	80.7	1258.4
2	38.7	136.1	1107.2	94.3	1376.4
3	44.8	152.1	1130.2	114.4	1441.6
4	41.1	185.4	1255.8	158.1	1640.4

Table-3 Mean monthly temperature (°C) of four stations over Jaraikela catchments

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temperature												
1	27.4	30.6	34.8	37.9	38.3	35.2	32.0	31.5	32.0	31.8	29.9	27.6
2	26.6	29.7	33.9	36.5	36.5	34.3	32.0	31.6	31.9	31.6	29.6	27.1
3	25.9	29.3	34.1	37.7	37.9	35.2	32.4	31.9	32.1	31.6	29.3	26.4
4	25.6	29.0	33.3	35.5	35.6	34.2	32.4	32.0	32.1	31.8	29.6	26.5
Minimum temperature												
1	13.4	16.5	20.5	23.9	25.6	25.6	24.8	24.6	24.3	21.9	17.4	13.4
2	13.6	16.9	21.1	24.2	25.5	25.8	25.2	25.1	24.8	22.5	18.0	13.8
3	12.4	15.7	20.0	23.8	25.6	25.9	25.4	25.2	24.7	22.0	17.3	12.8
4	13.4	17.0	21.6	24.8	26.0	26.5	26.2	26.1	25.7	23.5	18.8	14.2

Table-4 Mean seasonal and annual temperature (°C) of four stations over Jaraikela catchments

Stations	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Maximum temperature					
1	28.6	37.0	32.7	30.8	32.4
2	27.8	35.6	32.4	30.6	31.8
3	27.2	36.6	32.9	30.4	32.0
4	27.0	34.8	32.7	30.7	31.5
Minimum temperature					
1	14.4	23.4	24.8	19.6	21.0
2	14.8	23.6	25.2	20.3	21.4
3	13.6	23.1	25.3	19.6	29.9
4	14.9	24.2	26.1	21.2	22.0

Table-5 Sen estimator of slope (mm/month) for monthly rainfall of four stations over the catchment

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	-0.2	0.00	0.21	-0.16	-1.52	0.67	-0.69	2.16	**1.23**	0.00	0.00
2	0.02	-0.35	-0.01	-0.26	**1.66**	0.18	0.81	0.80	**3.33**	0.28	0.01	0.00
3	-0.01	-0.39	0.00	0.33	-0.82	-1.69	**3.65**	0.85	1.80	1.21	0.12	0.00
4	0.00	-0.32	0.00	0.39	1.83	-2.39	**2.98**	-2.78	2.97	1.19	0.20	0.00

Bold values indicate statistical significance (+ for increasing trend and – for decreasing trend)

Table-6 Sen estimator of slope (mm/period) for seasonal and annual rainfall of four stations over the catchment

Stations	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
1	-0.96	0.07	-1.42	**1.68**	1.43
2	-0.41	1.48	7.03	0.58	**7.67**
3	-0.57	-0.41	**9.61**	2.49	**9.83**
4	-0.28	**2.20**	2.39	1.71	**9.82**

Bold values indicate statistical significance (+ for increasing trend and – for decreasing trend)

Table-7 Sen estimator of slope (°C/ month) for monthly maximum, minimum and mean temperature of four stations over the catchment

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temperature												
1	0.02	**0.07**	**0.05**	**0.03**	**0.04**	0.04	0.02	**0.03**	0.01	0.01	0.02	0.02
2	0.01	**0.06**	**0.04**	0.03	**0.04**	0.04	**0.02**	**0.03**	0.01	0.01	0.02	0.02
3	-0.01	0.05	0.04	0.01	0.01	0.03	0.01	0.01	0.2	-0.02	0.01	0.00
4	-0.03	0.03	0.02	0.01	0.01	0.02	0.00	0.01	-0.01	-0.02	-0.01	-0.02
Minimum temperature												
1	-0.04	-0.01	0.01	0.01	0.02	0.00	0.00	0.01	-0.00	0.00	0.01	0.00
2	-0.02	-0.01	**0.02**	**0.02**	**0.02**	**0.03**	**0.01**	0.01	0.00	0.01	0.03	0.00
3	-0.03	0.00	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**	0.01	0.00	0.02	0.03	-0.01
4	-0.02	0.01	**0.02**	**0.02**	0.02	**0.02**	**0.01**	0.01	0.00	0.01	0.02	0.00
Mean temperature												
1	-0.01	0.02	0.03	0.02	0.03	0.02	0.01	0.01	0.00	0.01	0.02	0.00
2	-0.01	0.03	**0.03**	0.02	**0.04**	**0.03**	**0.02**	**0.02**	0.01	0.01	0.02	0.01
3	-0.02	0.02	**0.03**	0.02	0.02	0.03	**0.02**	0.01	0.00	0.00	0.01	-0.01
4	-0.03	0.02	**0.02**	0.01	0.02	0.02	0.01	0.01	0.00	-0.01	0.01	-0.01

Bold values indicate statistical significance (+ for increasing trend and – for decreasing trend)

The maximum increase in trend of 0.04 ºC/season is observed during winter and pre-monsoon seasons at station 2 and 1, respectively. Minimum increase in trend of 0.02 ºC/season is noticed during pre-monsoon, monsoon, and post-monsoon seasons at stations 2, 1 and 2, respectively. Increasing trend of annual maximum temperature has been noticed at all stations. The highest annual increase of maximum temperature to the order of 0.03 ºC/year is noticed at station 1 in winter season. Minimum temperature has shown a significantly decreasing trend during winter over all stations. The maximum significant increase in trend of 0.03ºC/season is noticed during pre-monsoon period at station 3. The minimum significant increase in minimum temperature trend of 0.01ºC/season is observed during pre-monsoon and monsoon seasons at stations 1 and 3, respectively. A significant increasing trend in annual minimum temperature of 0.01ºC/year has been noticed at three stations except station 1. The magnitude of the increasing trend of the annual maximum temperature compared to the minimum temperature indicates higher daytime evaporative demand and therefore a higher water requirement for crops. Mean temperature during pre-monsoon and monsoon seasons has shown significant trend at some stations. In winter mean temperature has shown no trend at stations 1, 2, 3 and at station 4 the trend is insignificantly decreasing. The highest mean temperature trend of 0.03ºC/season is observed during pre-monsoon season at stations 1 and 2. The lowest significant trend of mean temperature (0.01ºC/season) is noticed during the monsoon season at station 3. Annual mean temperature has shown an increasing trend; however, it is significant at three stations except station 4. The highest trend in annual mean temperature (0.02ºC/year) is observed at station 2.

Table-8 Sen estimator of slope (°C/ period) for seasonal and annual maximum, minimum and mean temperature of four stations over the catchment

Stations	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Maximum temperature					
1	**0.03**	**0.04**	**0.02**	0.02	**0.03**
2	**0.04**	**0.02**	0.01	**0.02**	**0.02**
3	0.00	0.02	0.00	0.01	**0.01**
4	-0.01	0.01	0.00	-0.01	0.00
Minimum temperature					
1	-0.02	**0.01**	0.00	0.01	0.00
2	-0.01	**0.02**	**0.02**	0.02	**0.01**
3	-0.01	**0.03**	**0.01**	0.02	**0.01**
4	-0.01	0.03	**0.02**	0.01	**0.01**
Mean temperature					
1	0.00	**0.03**	0.01	0.01	**0.01**
2	0.00	**0.03**	**0.02**	0.01	**0.02**
3	0.00	**0.02**	**0.01**	0.02	**0.01**
4	-0.01	0.02	0.01	0.00	0.01

Bold values indicate statistical significance (+ for increasing trend and – for decreasing trend)

Interaction of rainfall and temperature

An increasing trend has been noticed in annual maximum and minimum temperature (both significant at 95 % confidence level) and the annual rainfall (not significant) in Jaraikela catchment. This indicates that temperature along with the other factors of hydrological cycle play a major role for influencing hydrological processes in a broad spatial pattern with direct or indirect way, which leads to higher rates of evapotranspiration and thereby clouds formation and an increase in precipitation. There are spatial differences in the relation of trends in rainfall and maximum temperature over the catchment. This may be due to the difference in non-uniform changes in land use pattern, the intensity of irrigation development and variation in man-made developmental activities. As far as summer and post-monsoon seasons are concerned, both temperature and rainfall have shown an increasing trend. There is no clear relationship between trends in maximum and minimum temperature and rainfall during the monsoon months. This may be due to the undulating nature of the orography, and land use pattern, influenced the monsoonal systems locally/regionally and thereby modified the climate accordingly. As far as the monthly pattern is concerned, no definite pattern exists in the relation between trends in maximum temperature and rainfall in any month. Thus, from this study, it is concluded that the relation between the trends of rainfall and temperature have large-scale spatial and temporal dependence.

Conclusion

This paper deals with the variability and long-term trends in monthly, seasonal and annual rainfall, temperature (maximum, minimum, and mean temperature) over Jaraikela catchment. Trend analysis has shown there is a significant increase in annual rainfall and temperature at most of the stations and no clear trend is found in monthly and seasonal analysis of rainfall and temperature. The study provides a pattern of maximum, minimum, mean temperature and rainfall, which may be used for sensitivity analysis of water supply and demand of the catchment. The results of this study demonstrated the importance of spatial domain to be considered for analysis because of the conflicting outcome with regional/local landscape, orography or manmade land changes.

Application of research: This will help the farmers of the catchment area to reorient their agricultural activities as per the changes observed in climate parameters due to climate change.

Research Category: Agricultural Engineering / Civil Engineering

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