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Analysis of temporal trend of rainfall, temperature and extreme events over Jharkhand

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सार – यह अध्ययन में झारखंड में वर्षा, तापमान और चरम परिघटनाओं की कालिक परिवर्तिता की जांच की गई है। 1901 से 2018 की अवधि के लिए ऋतुनिष्ठ वर्षा की परिवर्तिता की जांच की गई और 1986 से 2018 की अवधि के लिए तीन स्टेशनों (रांची, जमशेदपुर और डाल्टनगंज) के लिए अत्यधिक वर्षा की परिघटनाओं और तापमान परिवर्तिता की जांच की गई है। कालिक प्रवृत्ति की जांच करने के लिए व्यापक रूप से उपयोग किए जाने वाले गैर प्राचलिक मान-केंडल परीक्षण को 95% विश्वासनियता स्तर के साथ लागू किया गया। प्रवृत्ति विश्लेषण से संकेत मिलता है कि अध्ययन अवधि के लिए झारखंड में प्रति दशक 13 मिमी की दर से ऋतुनिष्ठ वर्षा में उल्लेखनीय कमी आई है। वार्षिक औसत उच्चतम तापमान रांची, जमशेदपुर और डाल्टनगंज में क्रमशः 0.58 °C, 0.47 °C और 0.29 °C प्रति दशक की दर से उल्लेखनीय रूप से बढ़ती प्रवृत्ति को दर्शाता है। इसी प्रकार, औसत वार्षिक न्यूनतम तापमान भी रांची और जमशेदपुर में 0.46 °C प्रति दशक की दर से उल्लेखनीय रूप से बढ़ती प्रवृत्ति को दर्शाता है और डाल्टनगंज के लिए बढ़ती प्रवृत्ति 0.13 °C प्रति दशक है।

विश्लेषण से पता चलता है कि उक्त समय की अवधि में वर्षा में परिवर्तन सीधे तौर पर वर्षा के दिनों की संख्या, भारी वर्षा के दिनों और अत्यधिक वर्षा की परिघटनाओं से जुड़ा होता है। रांची (जमशेदपुर) में वार्षिक वर्षा की घटती (बढ़ती) प्रवृत्ति वर्षा के दिनों की घटती (बढ़ती) वार्षिक संख्या और भारी वर्षा के दिनों से जुड़ी है। डाल्टनगंज में वार्षिक वर्षा, अत्यधिक वर्षा और भारी वर्षा के दिनों में कोई महत्वपूर्ण प्रवृत्ति नहीं देखी गई है। परिणाम यह भी दर्शाता है कि इस अवधि के दौरान तापमान में वृद्धि हीट वेव दिनों की संख्या में वृद्धि और शीत लहर के दिनों में कमी के साथ जुड़ी हुई है। तीनों स्टेशनों में लू और भीषण लू में वृद्धि की प्रवृत्ति रही है और शीत लहर और भीषण शीत लहर के दिनों में कमी की प्रवृत्ति बनी हुई है।

ABSTRACT. This study investigates the temporal variability of rainfall, temperature and extreme events over Jharkhand. The seasonal rainfall variability is examined for the period 1901 to 2018 and extreme rainfall events and temperature variability is examined for three stations (Ranchi, Jamshedpur and Daltonganj) for the period 1986 to 2018. To examine the temporal trend, a widely used non parametric Mann-Kendall test applied at 95% confidence level. The trend analysis indicated that the seasonal rainfall significantly decreased for the study period at the rate of 13mm per decade over Jharkhand. The average annual maximum temperature shows significantly increasing trend at the rate of 0.58 °C, 0.47 °C and 0.29 °C per decade at Ranchi, Jamshedpur and Daltonganj respectively. Similarly, the average annual minimum temperature also shows significantly increasing trend at the rate of 0.46 °C per decade at Ranchi and Jamshedpur and the increasing trend is 0.13 °C per decade for Daltonganj.

The analysis reveals that the change in rainfall over the period of time is directly associated with number of rainy days, heavy rainy days and extreme rainfall events. The decreasing (increasing) trend of annual rainfall over Ranchi (Jamshedpur) is associated with decreasing (increasing) annual number of rainy days and heavy rainy days. No significant trend is observed in annual rainfall, extreme rainfall and heavy rainy days over Daltonganj. Result also shows that the increase in the temperature over the period is associated with the increase in number of heat wave days and decrease in cold wave days. All three stations have increasing trend of heat wave and severe heat wave and decreasing trend of cold wave and severe cold wave days.

Key words – Rainfall variability, Extreme events, Normal frequency distribution, Mann-Kendall, Return period.

1. Introduction

Jharkhand is located in the eastern region of India and agriculture is the mainstay for the people. About 80% of the total population are dependent on agriculture and allied activities for their livelihood. The primary source of water for agricultural production for the most parts of Jharkhand is rainfall. It is also the primary source of surface and ground water recharge.

Hydrological processes are usually regarded as stationary; however, there is growing evidence of trends, which may be related to anthropogenic influences and natural features of climate system. Serious concerns are drawn on the catastrophic nature of floods and droughts, storms, heat wave, cold wave etc. caused due to the significant variations in the regional climate including the rainfall pattern taking place on regional level. The IPCC's (Intergovernmental Panel on Climate Change) fifth climate Assessment Report show that the globally averaged combined land and ocean surface temperature increased by 0.85 °C, over the period 1880 to 2012. It is likely that in a warmer climate, heavy rainfall will increase and be produced by fewer more intense events. This could lead to longer dry spells and a higher risk of floods.

Variation in total rainfall over a period can be caused by a change in frequency of extreme rainfall events, number of rainy days or a combination of both. An attempt has been made to access the change in the rainfall and temperature pattern over Jharkhand. The state receives 91% of its annual rainfall during South-West monsoon, which is its principal rainy season. The contribution of winter, pre-monsoon and post-monsoon season's rainfall amounts to about 2%, 3% and 4% respectively of the annual total rainfall. Therefore, the temporal and spatial distribution of rainfall plays a vital role not only in the agricultural community but also in water resources management.

Many studies (Parthasarathy *et al*., 1974; Mooley *et al*., 1981; Parthasarathy *et al*., 1987; K. Rupa Kumar *et al*., 1992; P. Guhathakurta *et al*., 2007) showed trend or variability in precipitation over Indian region. All these studies examined long term trends of seasonal rainfall on spatial and temporal scale over India. Trends in rainfall in the regional scale (31 sub-divisions) over India were investigated by Parthasarathy *et al*. (1974). They found positive trends in rainfall over the central India and parts of northeast and northwest India. K. Rupa Kumar *et al*. (1992) found increasing trend in the monsoon seasonal rainfall along the west coast, north Andhra Pradesh and north-west India, and those of decreasing trend over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala. Sub-division wise seasonal rainfall trend over India was examined by P. Guhathakurta *et al.* (2007), where they found significant decreasing trend over three sub-divisions, *viz*., Jharkhand, Chhatisgarh and Kerala, significant decreasing trend over eight sub-divisions, *viz*., Gangetic WB, West UP, Jammu & Kashmir, Konkan & Goa, Madhaya Maharashtra, Rayalseema, coastal AP and North Interior Karnataka. Mahafooz Ali *et al*., (2005) analysed trends in monsoon onset, withdrawal and rainfall over Kerala and Rajasthan by using 63 years data for the period of 1941-2003. They found slight decreasing trends in monsoon onset, withdrawal, rainfall and duration over Rajasthan and slight increasing trend in onset over Kerala.

Rainfall and temperature on the sub-division and regional scale for the North-East Indian region were examined by S. K. Jain *et al*. (2013). They found the trend analysis of rainfall data series for 1871-2008 did not showed any clear trend for the region as a whole, although there are seasonal trends for some seasons and for some hydro-meteorological sub-divisions. They also observed raising trend of temperature.

In the changing pattern of rainfall and temperature, the frequency and intensity of extreme events like heat wave, cold wave, flood and droughts are also changing. Roxy *et al*. (2017) found the extreme events are on the rise at a rate of about 13 events per decade (more than one per year) and found the frequency of extreme rain events not only increasing, but the extremes themselves are intensifying over time. Michele Brunetti *et al*. (2001) found a negative trend in the number of wet days associated with an increase in the contribution of heavy rainfall events to total precipitation over Northeastern Italy.

Therefore, there is an urgent need to investigate the changing pattern of rainfall, temperature and extreme events over particular stations on a regional scale for making the long-term strategic plan to minimize adverse impact of extreme events and restore the ecosystem. An attempt has been made to investigate the temporal variation of rainfall and temperature and to examine the correlation between changing rainfall and extreme rainfall events, changing temperature and extreme temperature events over Jharkhand.

To bring out major findings of time series data, a nonparametric Mann-Kendall test has been applied. The Mann-Kendall test is the most common one used in studying hydrologic time series trends to detect monotonic trends in hydro meteorological data. There are two advantages of using non parametric test over parameter test. First, the non-parametric tests do not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series.

The following section 2 describes the data and methodology used in this study. Data analysis under study is given in section 3. Detail results are presented in section 4 and conclusions are given in section 5.

2. Data and methodology

India meteorological department has its own full-time observatories at three different locations Ranchi (23° 19' N, 85° 19' E), Jamshedpur (22° 49' N, 86° 11' E) and Daltonganj (24° 03' N, 84° 04' E) elevated at 652m, 142m & 221m above mean sea level respectively. The year wise monthly and seasonal (June, July, August, September (JJAS)) rainfall data for the state Jharkhand as whole has been taken from Meteorological Centre Ranchi & National Data Centre, India Meteorological Department. This study investigates the seasonal and mean decadal rainfall variability over the state by using past 118 years (1901-2018) data. Daily rainfall data at three different stations distributed in Jharkhand with long time series were used for the analysis of heavy rainy days, extreme rainfall events and annual number of rainy days by using past thirty three years (1986-2018) data. Missing data has been computed by using arithmetical average of surrounding stations for particular time period. The proportion of data reconstructed in this way was less than 0.5%. As per the classification of India Meteorological Department, the days with more than 64.5 mm was considered as heavy rainy days and more than 2.4 mm was considered as rainy days. The extreme annual one day rainfall depths for selected return periods on the basis of frequency analysis were investigated.

In the extreme rainfall analysis, first of all, one day maximum rainfall data were extracted for each year from daily data and tabulated corresponding stations. The year wise highest rainfall in a day were analysed by using a software package RAINBOW (Raes D., *et al*., 2006). In this study, a commonly used probability distribution functions namely : normal distribution is applied for frequency analysis. The main application of frequency distribution in water resource management involves the assignment of an exceedance probability P_e, of the design event. The average probability of exceedance and return period is estimated by Weibull method.

In temperature analysis, mean annual maximum and minimum temperatures have been computed by using daily maximum and minimum temperature data corresponding to different stations of Jharkhand. Extreme temperature events like heat wave in summer season and cold wave in winter season as per criteria defined by India Meteorological Department (IMD) is analysed and presented. The period examined for temperatures and extreme temperature events is from 1986 to 2018. As per IMD criteria, the heat wave is considered if maximum temperature of a station reaches at least 40 °C or more for plains and at least 30 °C or more for hilly regions.

The criterion for heat wave and cold wave condition as per IMD convention are given below :

(*i*) *Based on departure from normal*

Heat Wave : Departure from normal is 4.5 °C to 6.4 °C

Severe Heat Wave : Departure from normal is > 6.4°C

(*ii*) *Based on actual maximum temperature*

Heat Wave : When actual maximum temperature ≥ 45 °C

Severe Heat Wave : When actual maximum temperature ≥ 47 °C

Similarly, Cold Wave is considered when minimum temperature of a station is 10 °C or less for plains and 0 °C or less for Hilly regions.

(*iii*) *Based on departure from normal*

Cold Wave : Negative Departure from normal is 4.5 °C to 6.4 °C

Severe Cold Wave : Negative Departure from normal is more than 6.4 °C

(*iv*) *Based on Actual Minimum Temperature (For plain stations only)*

Cold Wave : When minimum temperature is ≤ 04 °C

Severe Cold Wave : When minimum temperature is ≤ 02 °C

To bring out major aspects of changing scenario of rainfall, rainy days, heavy rainy days, extreme rainfall, temperature variability, and extreme temperature events a non parametric Mann-Kendall test is applied at confidence level 95%.

3. Data analysis

The water management for agricultural activities, flood control system etc. should be considered upon average and extreme rainfall pattern over the region. The seasonal rainfall variability is an important parameter for disaster management, agricultural community, water resources management etc. The temporal trend is analysed using widely used sophisticated statistical tool Maan Kendall test which is discussed briefly in the following section.

3.1. *Mann Kendall test*

It is a statistical test widely used for the analysis of trend in climatological and in hydrologic time series. Mann-Kendall test had been formulated by Mann (1945) as non-parametric test for trend detection and the test statistic distribution had been given by Kendall (1975) for testing non-linear trend and turning point. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) in precipitation and this is tested against the alternative hypothesis H_1, which assumes that there is a trend (increasing or decreasing).

The computational procedure for the Mann Kendall test considers the time series of n data points and x_i and x_j as two subsets of data where $i = 1, 2, 3, \ldots n - 1$ and $j = i + 1, i + 2, i + 3 \ldots n$. Each of the data point x_i is taken as reference point which is compared with the rest of data points x_j. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

The Mann-Kendall S Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \tag{1}$$

where,

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} +1, & \Delta x > 0 \\ 0, & \Delta x = 0 \\ -1, & \Delta x < 0 \end{cases}$$

For moderate (n about 10) or larger series lengths, the sampling distribution of the test static in equation (1) is approximately Gaussian, and if the null hypothesis (no trend) is true this Gaussian null distribution will have zero mean. The variance of this distribution is depends on whether all the x's are distinct, or if some are repeated values. If there are no ties, the variance of the sampling distribution of S is

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5)}{18} \tag{2}$$

Otherwise the variance is

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^{J} t_j\left(t_j - 1\right)\left(2t_j + 5\right)}{18}$$

where J indicates the number of groups of repeated values, and t_j is the number of repeated values in the j^{th} group.

At certain probability level H_0 is rejected in favor of H_1 if the absolute 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 (negative) value of S indicates an upward (downward) trend.

The test statistic Z_s is used a measure of significance of trend. The test statistic Z_s is given by:

$$Z_s = \begin{cases} \dfrac{S-1}{\left[\operatorname{Var}(S)\right]^{1/2}}, & S > 0 \\ \dfrac{S+1}{\left[\operatorname{Var}(S)\right]^{1/2}}, & S < 0 \end{cases} \tag{3}$$

Test statistic Z_s is used to test the null hypothesis, H_0. If $|Z_s|$ is greater than $Z_{\alpha/2}$, where α represents the chosen significance level (*e.g.*, 5% with $Z_{0.025} = 1.96$) then the null hypothesis is invalid implying that the trend is significant.

4. Results and discussion

4.1. *Variability of South-West Monsoon Rainfall over Jharkhand*

The Mean seasonal rainfall observed over the state Jharkhand is 1081.2 mm for the period of 118 years from 1901 to 2018 during South-West Monsoon season (JJAS). The seasonal rainfall varied between 1539.0 mm and 578.4 mm in the year 1971 and 2010 respectively with standard deviation 166.49 mm for the study period. Seasonal percentage rainfall anomaly has been computed from long period (1950-2000) average rainfall 1092 mm

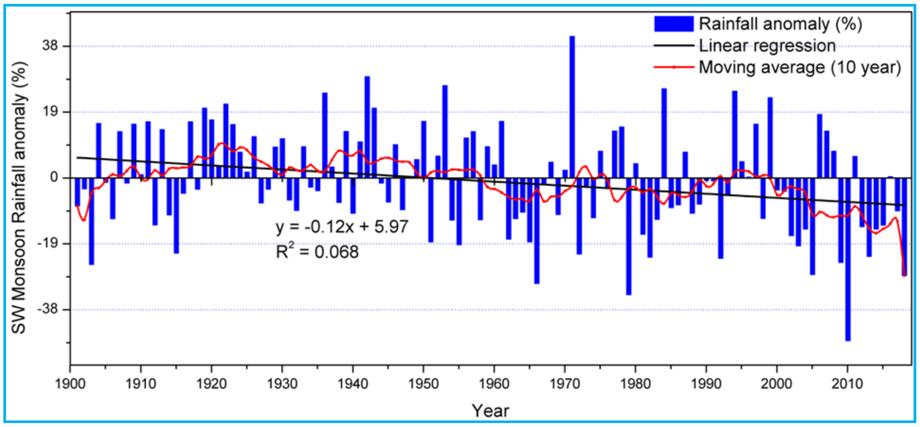


Fig. 1. Seasonal rainfall variability over Jharkhand (1901-2018)

TABLE 1

Decadal SW monsoon rainfall variability over Jharkhand (1901-2018)

Decade	Decadal mean rainfall (mm)	Decadal mean departure (%)	No. of deficient year (Departure <-19%)	No. of excess rainfall year (departure >19%)
1901-1910	1086.6	-0.5	1	0
1911-1920	1124.6	3.0	1	1
1921-1930	1169.7	7.1	0	1
1931-1940	1104	1.1	0	1
1941-1950	1172.9	7.4	0	2
1951-1960	1101.6	0.9	1	1
1961-1970	1007.8	-7.7	1	0
1971-1980	1102.2	0.9	2	1
1981-1990	1034.5	-5.3	1	1
1991-2000	1118.7	2.4	1	2
2001-2010	967	-11.4	4	0
2011-2018*	960.7	-12.0	2	0

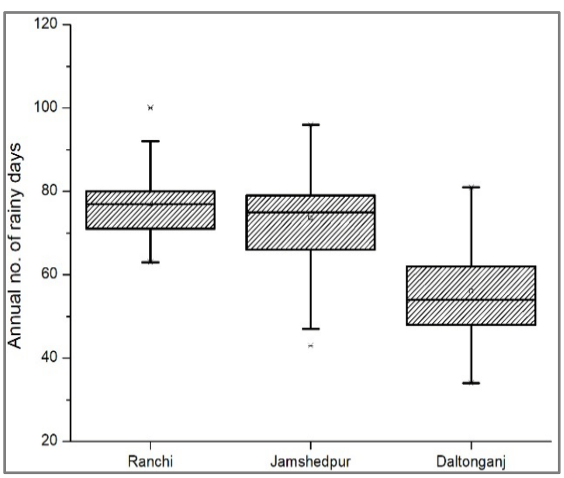


Fig. 2. Annual number of rainy days (>2.5 mm) over different stations of Jharkhand (1986-2018)

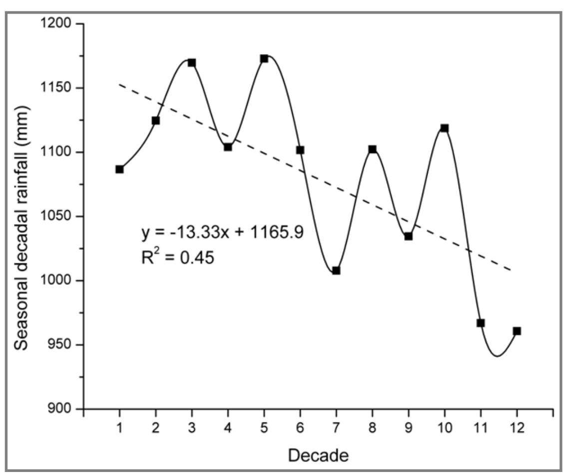
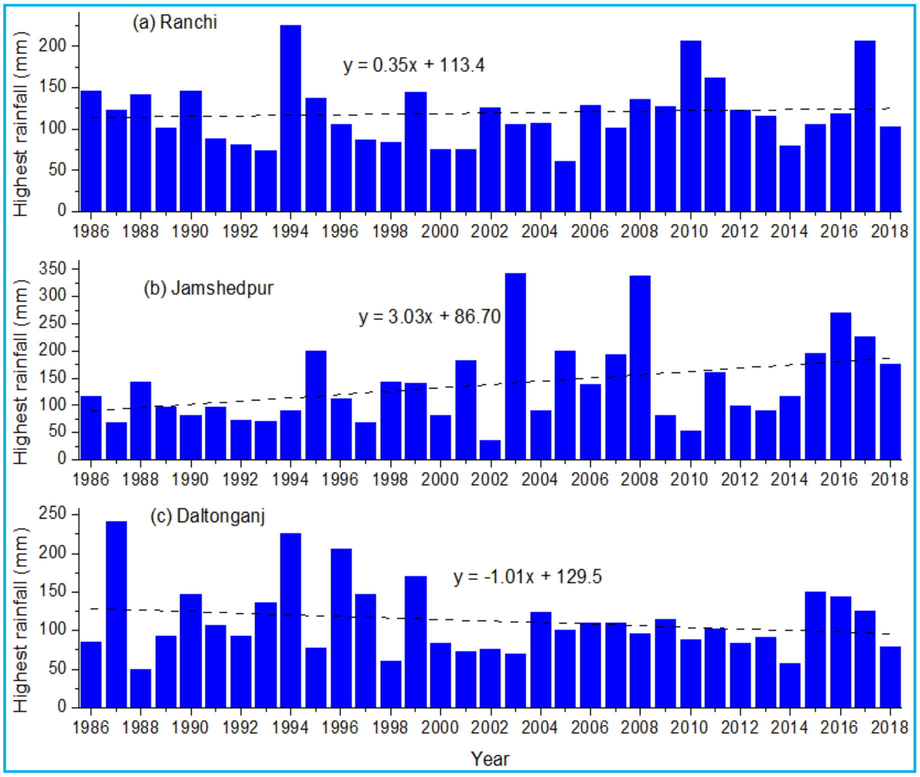


Fig. 3. Decadal variation of seasonal rainfall variability over Jharkhand (1901-2018)



Figs. 4. Annual variation of one day highest rainfall over different stations of Jharkhand (1986-2018)

for Jharkhand and presented in Fig. 1. Decreasing trend in seasonal rainfall at the rate of 13 mm/decade is observed. Moving average with ten years window followed alternate positive and negative epoch. It also shows, the negative epoch is continuing after year 2000. The rate of decreasing rainfall is much higher after the year 1970 than previous years.

Annual number of rainy days (>2.5 mm) over different stations of Jharkhand (1986-2018) is shown in Fig. 2. The figure shows that the station Ranchi has maximum number of rainy days and Daltonganj has lowest number of rainy days. Decadal annual average rainfall varies between 1173 mm and 961 mm during 1941-1950 and 2011-2018 respectively and showed in Fig. 3. Percentage departure of decadal mean rainfall is shown in Table 1.

Highest negative departure is found -11% and -12.3% during the recent last two decades. Highest four numbers of deficient rainfall (below -19%) years were found during the decade 1901-2010 followed by two in 1971-1980 & 2011-2018. The value of Kendall score is found -2.88 for seasonal rainfall which reveals that the decreasing trend in seasonal rainfall over Jharkhand is significant at 95% significance level.

4.2. *Extreme rainfall events*

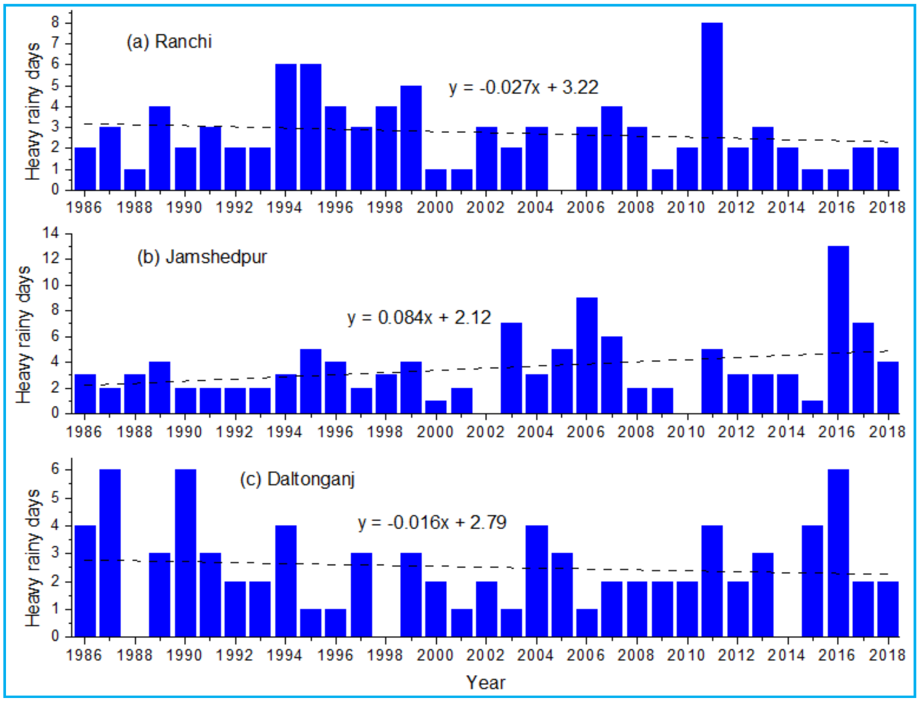
Daily rainfall data is analysed for extreme rainfall events for the period of 1986-2018. In the frequency analysis of extreme rainfall events, year wise one day maximum rainfall data extracted for each station and depicted in Fig. 4. In this study, normal distribution is applied for frequency analysis. Particular rainfall depths that can be expected for a specific period is called return period and it is a vital parameter for disaster risk reduction and water management system. Return period for a station is obtained by using frequency analysis of long time series rainfall data.

The average probability of exceedance and return period is estimated by Weibull method. Weibull estimates the probability of exceedance as:

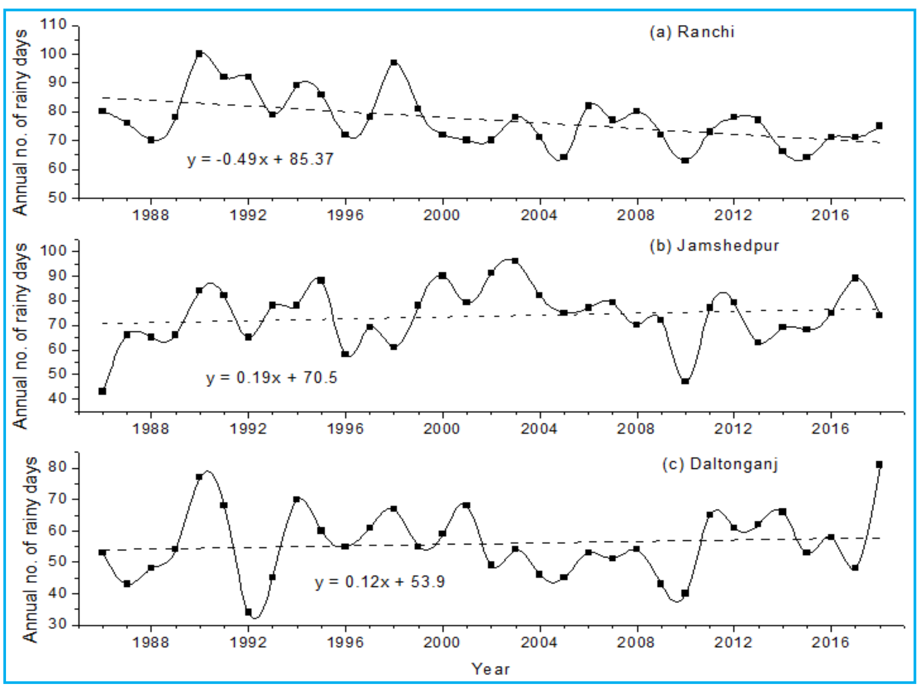
$$P_e = \frac{r}{n+1}$$

Where, r is the rank number and n is the number of observations.

The return period T in years is related to the annual exceedance probability:



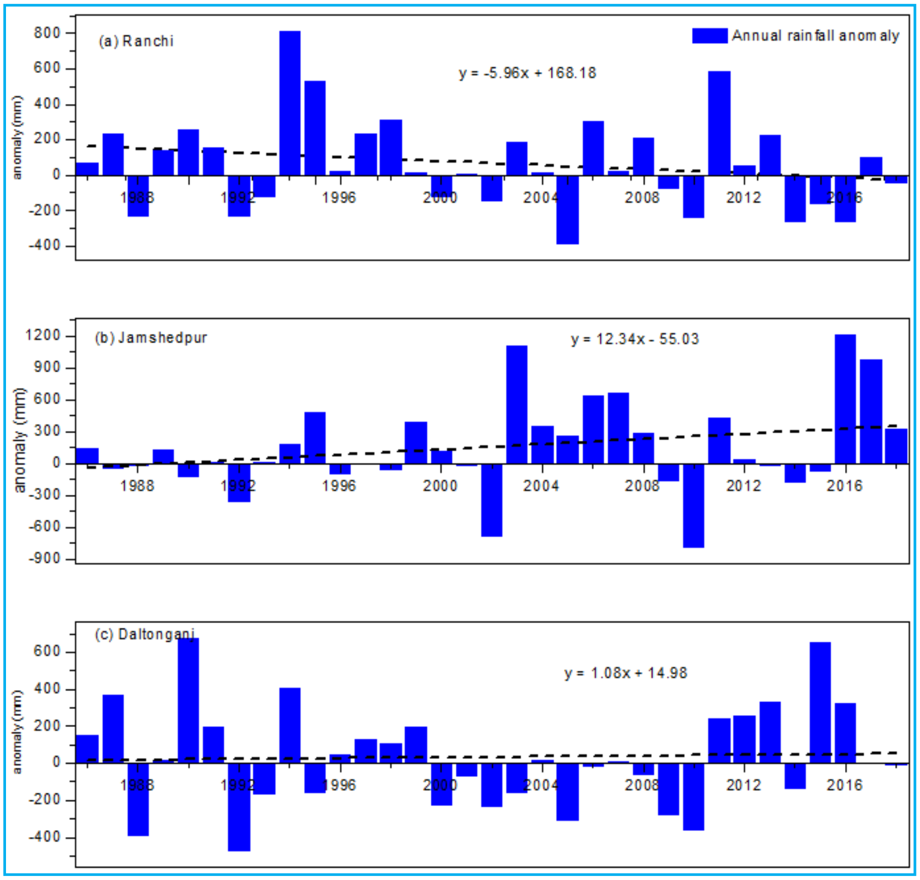
Figs. 5. Annual variation of heavy rainy days (rainfall >64.5 mm) over different stations (1986-2018).



Figs. 6. Annual variation of rainy days (rainfall >2.5 mm) over different stations over Jharkhand (1986-2018)

$$T = \frac{1}{P_e}$$

Table 2 represents the probability of exceedance and return period for all three stations. Return period of extremely heavy rainfall (greater than or equal to 204.5 mm) in a day is 5.3, 46 and 75.2 years and probability of exceedance is about 18%, 2% and 1% at Jamshedpur, Daltonganj & Ranchi respectively. For estimation of probability of exceedance of annual one day



Figs. 7. Annual rainfall anomaly

TABLE 2

Probability of exceedance and return period (1986-2018)

	Return Period (Year)	Rainfall (mm)		
		Ranchi	Jamshedpur	Daltonganj
-	25	186.6	269.2	192.3
10	10	168.6	234.1	170.8
20	5	151.7	201.1	150.7
30	3.33	139.5	177.4	136.2
40	2.5	129.1	157.1	123.8
50	2	119.4	138.1	112.3
60	1.67	109.7	119.2	100.7
70	1.43	99.3	98.9	88.3
80	1.25	87.1	75.2	73.8
90	1.11	70.2	42.2	53.7

maximum rainfall, normal distribution is used in this study.

To analyze the trend in heavy rainfall events, annual heavy rainy days (more than 64.5 mm) is considered from daily rainfall data for all the three stations. Highest 13 numbers of heavy rainy days in a year were found during 2016 at Jamshedpur. Variabilty of annual heavy rainy days are represented in Fig. 5. An increasing trend is found in annual heavy rainy days over Jamshedpur, decreasing trend over Ranchi and Daltonganj. However, no significant trend is found over all the stations. The linear trend line suggests that there is an increasing trend in annual heavy rainy days over Jamshedpur and decreasing trend over Ranchi and Daltonganj. However, the trend in number of heavy rainy days is non-significant at 95% confidence level.

Depth of one day maximum rainfall is found highest over Jamshedpur. The highest rainfall observed in a day is 224.3 mm at Ranchi, 341.0 mm at Jamshedpur and 240.4 mm at Daltonganj during the study period. An increasing trend is found in annual heavy rainy days over Jamshedpur and the value of Kendall test statictics Z_s for Jamshedpur is +2.43, which reveals that the increasing trend in number of heavy rainy days is significant at 5%

TABLE 3

Statistical Parameters of temperature variability

S. No.	Particulars	Variable	Kendall Score '**S**'	Test Statistic $\mathbf{Z_s}$	Hypothesis Test
1.	Ranchi	Maximum temperature	306	**4.73**	H_o accepted
		Minimum temperature	203	**3.13**	H_o accepted
		Heat wave days	109	1.69	H_o rejected
		Cold wave days	-180	**-2.84**	H_o accepted
2.	Jamshedpur	Maximum temperature	277	**4.28**	H_o accepted
		Minimum temperature	66	1.0	H_o rejected
		Heat wave days	132	**2.05**	H_o accepted
		Cold wave days	-19	-0.32	H_o rejected
3.	Daltonganj	Maximum temperature	165	**2.54**	H_o accepted
		Minimum temperature	273	**4.22**	H_o accepted
		Heat wave days	117	1.82	H_o rejected
		Cold wave days	-14	-0.24	H_o rejected

significance level. However, no significant trend is found over Ranchi and Daltonganj.

4.3. *Rainy days*

Annual number of rainy days significantly varies over different parts of Jharkhand and depicted in Fig. 2. As per the India Meteorological Department criteria, a day with rainfall more than or equal to 2.5 mm is considered rainy day. Mean annual number of rainy days observed at Ranchi, Jamshedpur and Daltonganj are 77, 74 and 56 with coefficient of variance 11.7, 15.7, 18.7 respectively. Variation in annual rainy days and rainfall anomaly are depicted in Fig. 6 and Fig. 7 respectively. The linear trend line suggests decreasing trend in annual number of rainy days at Ranchi. However, slightly increasing trend is observed at Jamshedpur & Daltonganj. The increasing trend at Ranchi is statistically significant but no statistically significant trend is observed for Jamshedpur and Daltonganj.

The study reveals that the change in the rainfall over a period is directly associated with number of rainy days, heavy rainy days and extreme rainfall. The decreasing (increasing) trend of annual rainfall over Ranchi (Jamshedpur) is associated with decreasing (increasing) trend of annual rainy days and heavy rainy days. No trend is observed in annual rainfall, extreme rainfall and heavy rainy days over Daltonganj.

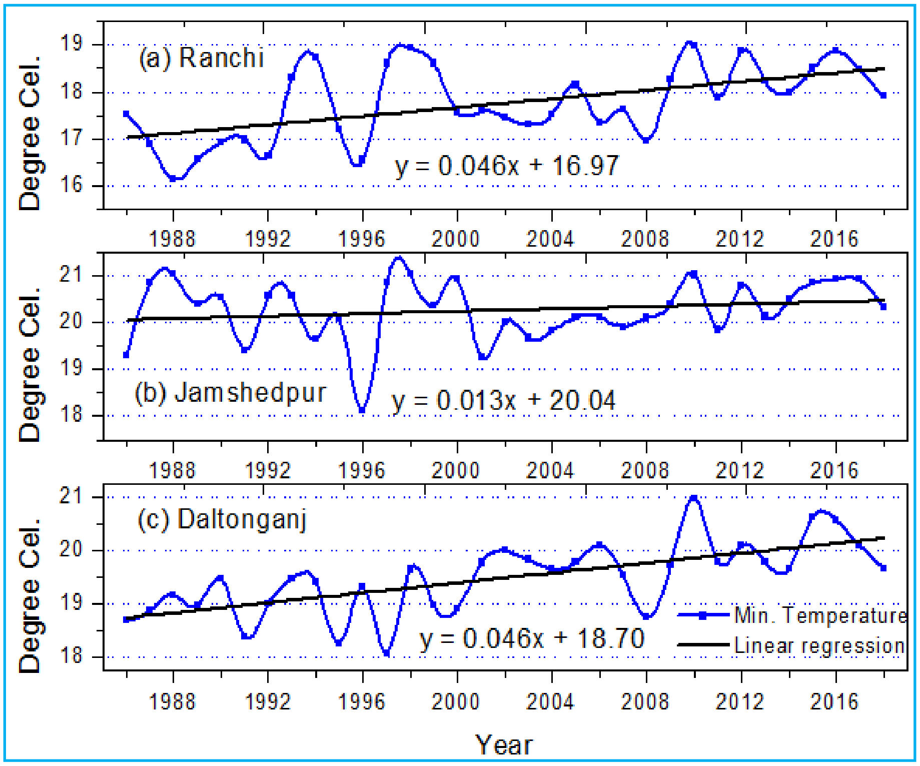
4.4. *Variability of Temperature*

For the analysis of temperature variability, mean annual maximum and minimum temperatures have been computed by using daily maximum and minimum temperatures of selected stations and shown in Fig. 8 and Fig. 9. Result shows that, both the annual minimum and maximum temperatures have increasing trend over all the three stations during 1986-2018. The rapid increase in the annual maximum temperature observed after the year 2000 than ever before. The statistical parameters of temperature variability are depicted in Table 3. The maximum temperature of all three stations have significant increasing trend. The minimum temperature also has significant increasing trend except Jamshedpur at 95% confidence level.

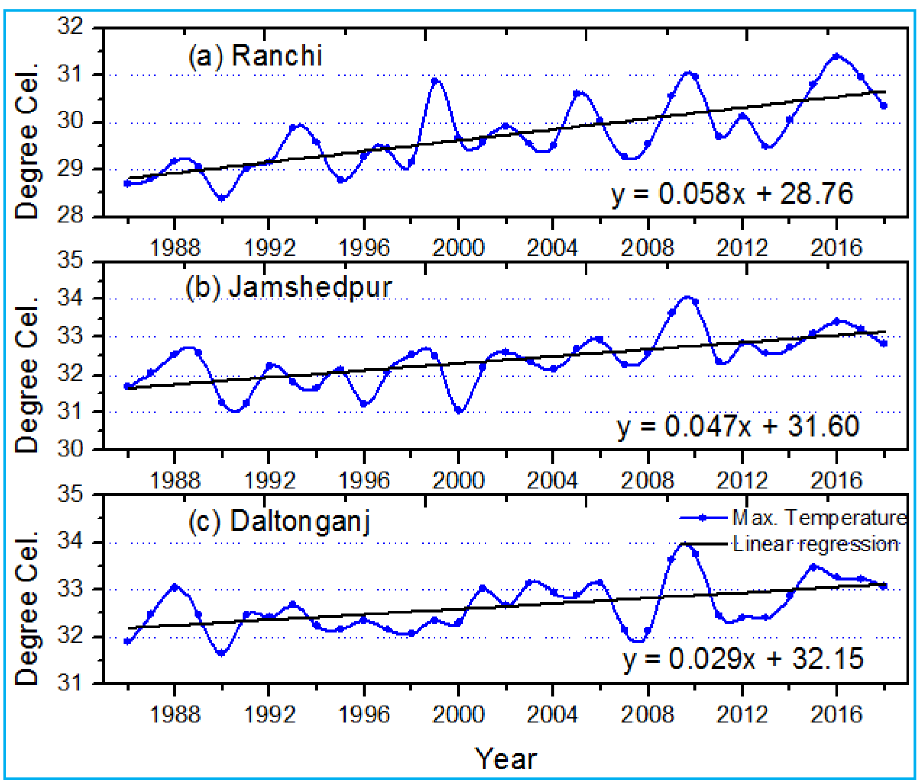
4.5. *Extreme temperature events*

Result show the increase in the temperature over a period is associated with increase in number of heat wave days in summer season and decrease in cold wave days in winter season. All three stations have increasing trend of heat wave and severe heat wave days. After the year 2000, the number of heat wave days has been rapidly increased than the previous years. The highest number of heat wave events observed in the year 2010 followed by 2012. The year 2010 is also a witness of least annual rainfall over Jharkhand with highest deficiency of -47% of long period average.

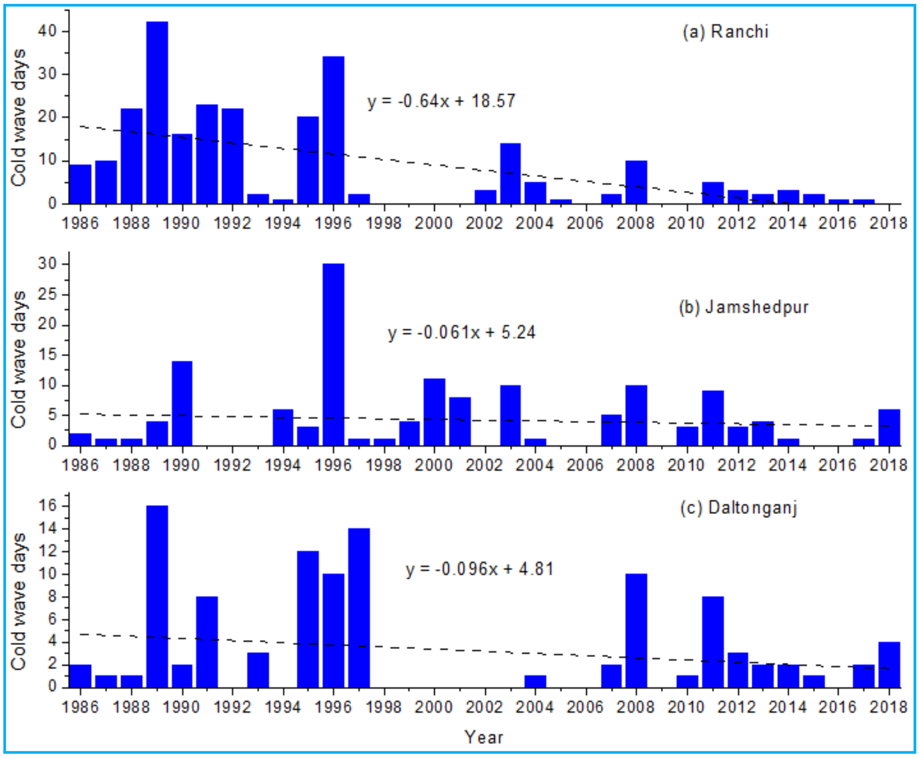
Annual variation of cold wave days and heat wave days are depicted in Fig. 10 & Fig. 11 respectively. The number of cold wave events shows rapidly falling trend after the year 1997. The highest 42 number of cold wave days is observed in the year 1989 followed by 34 days in the year 1996 at Ranchi. Increasing annual number of heat wave days at Jamshedpur is statistically significant however, no statistically significant trend at 95% confidence level is observed over the stations of Ranchi and Daltonganj (Table 3). The annual variation of extreme



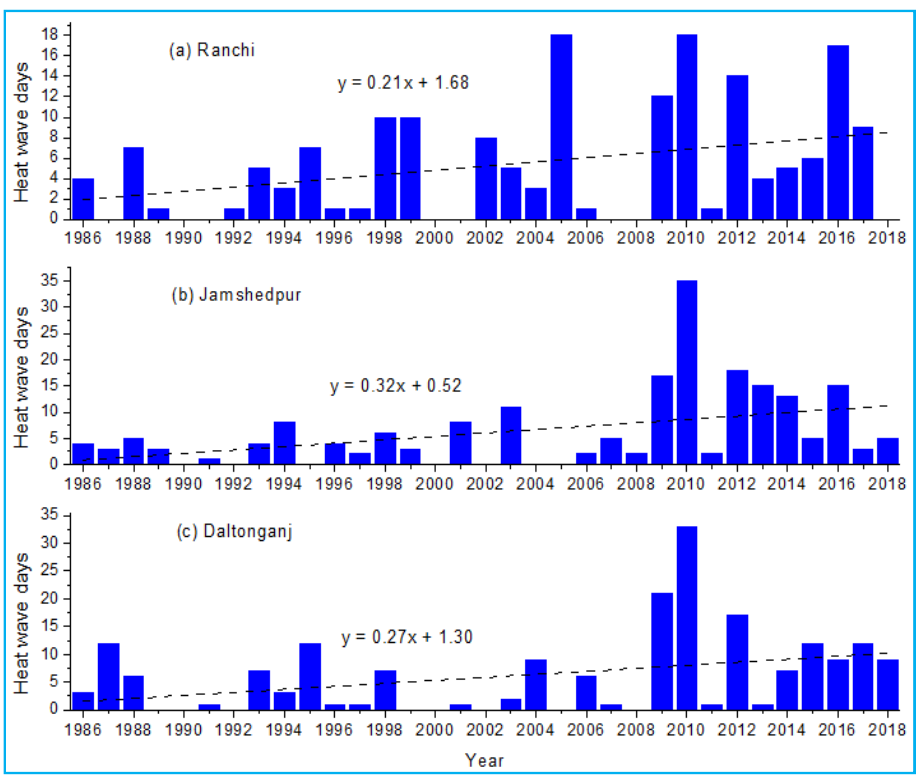
Figs. 8. Mean annual minimum temperature variation over different stations of Jharkhand (1986-2018)



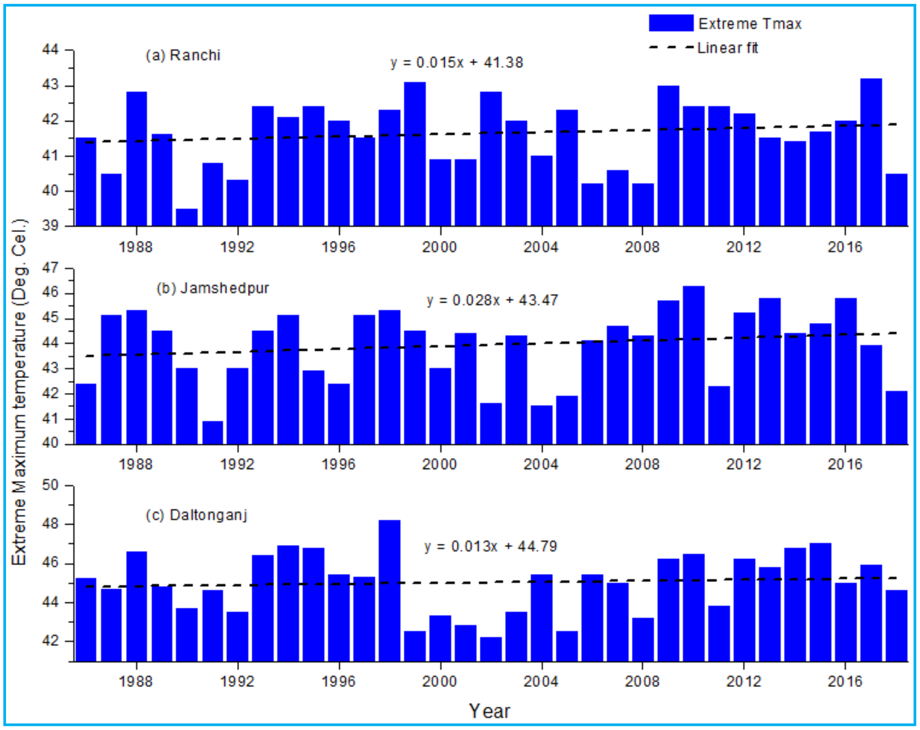
Figs. 9. Mean annual maximum temperature variation over different stations of Jharkhand (1986-2018)



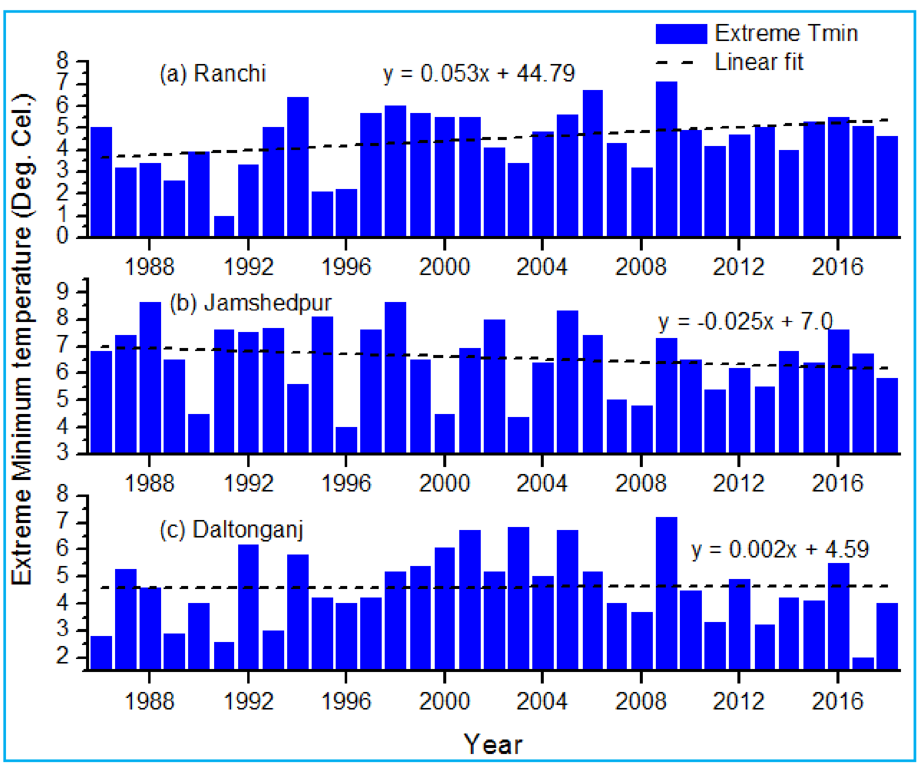
Figs. 10. Annual variation of cold wave days over different stations of Jharkhand (1986-2018)



Figs. 11. Annual variation of Heat wave days over different stations of Jharkhand (1986-2018)



Figs. 12. Annual variation of Extreme maximum temperature over different stations of Jharkhand (1986-2018)



Figs. 13. Annual variation of Extreme minimum temperature over different stations of Jharkhand (1986-2018)

TABLE 4

Statistical parameters of rainfall variability

S. No.	Particulars	Variable	Mean	CV	Kendall Score '**S**'	Test Statistic Z_s	Hypothesis Test
1.	Jharkhand (as whole)	Seasonal rainfall (1901-2018)	1081mm	15.4	-1239	**-2.88**	H_o accepted
2.	Ranchi	Annual rainfall	1465 mm	17.7	-90	-1.38	H_o rejected
		Extreme rainfall	119 mm	32.1	5	0.06	H_o rejected
		Heavy rainy days	2.76	60.6	-79	-1.24	H_o rejected
		Rainy days	77	11.7	-185	**-2.86**	H_o accepted
3.	Jamshedpur	Annual rainfall	1556 mm	27.4	76	1.16	H_o rejected
		Extreme rainfall	138 mm	54.2	130	**2.19**	H_o accepted
		Heavy rainy days	3.55	72.5	89	1.53	H_o rejected
		Rainy days	74	15.7	32	0.48	H_o rejected
4.	Daltonganj	Annual rainfall	1083 mm	25.3	5	0.06	H_o rejected
		Extreme rainfall	112 mm	40.7	-33	-0.49	H_o rejected
		heavy rainy days	2.52	62.7	-26	-0.40	H_o rejected
		Rainy days	56	18.7	18	0.26	H_o rejected

maximum and minimum temperatures over different stations of Jharkhand depicted in Fig. 12 and Fig. 13 respectively. The figures show slight increasing trend in extreme maximum temperature at all three stations for study period. However, the extreme minimum temperatures show slight increasing trend at Ranchi, decreasing at Jamshedpur & no significant change for Daltonganj.

4.6. *Non Parametric test*

In this study, a non-parametric Mann-Kendall test is applied to investigate the trend in seasonal rainfall and extreme events over Jharkhand. The value of Kendall score (Table 4) for South West Monsoon rainfall over Jharkhand is -1239 and test statistics Z_s is -2.88, which reveals that the decreasing trend in seasonal rainfall is statistically significant at confidence level 95%. The result is consistent with the previous study (P. Guhathakurta *et al*., 2007) for Jharkhand sub division for the study period 1901-2003. The test is also applied for variability of annual rainfall, extreme rainfall, annual heavy rainy days and annual rainy days correspond to the stations. The values of different parameters are depicted in Table 4. The negative Kendal score of annual rainfall, rainy days and heavy rainy days over Ranchi shows decreasing trend. The Kendal Score of annual rainfall for Ranchi is negative, while for Jamshedpur and Daltonganj is positive. The negative value of Kendall score represents decreasing trend, but the decreasing trend is not significant. The Kendall score for annual number of rainy days over Ranchi is -185 shows significantly decreasing trend however, it is positive for Jamshedpur and Daltonganj. Similarly, the value of Kendall score of annual one day maximum rainfall over Jamshedpur is 144 and test statistics Z_s is 2.43, which indicates that the increasing trend in extreme rainfall events is statistically significant.

5. Conclusions

Temporal trend of rainfall, temperature and extreme events over Jharkhand is examined in this study. The result indicates a significant change in the seasonal, annual and decadal rainfall pattern, extreme rainfall, heavy rainy days and number of rainy days over Jharkhand. Seasonal rainfall over Jharkhand shows significant decreasing trend at the rate of 13 mm/decade. Moving average with ten years window followed an alternative sequence of positive and negative epoch. It also shows, rapidly decreasing trend in the alternative sequence after the year 2000. The rate of decreasing rainfall is much higher after the year 1970.

Decadal average rainfall varies between 1173 mm and 961 mm during decade 1941-1950 and 2011-2018 respectively. The decadal mean rainfall is rapidly falling by -11% and -12.3% of long period average during the recent past two decades. Highest four numbers of deficient rainfall (below -19%) years were found during the decade 2001-2010 followed by two decades in 1971-1980 & 2011-2018. The value of Kendall score is found -2.88 for seasonal rainfall which reveals that the decreasing trend in seasonal rainfall over Jharkhand is significant at 95% significance level.

The study also reveals that the change in the rainfall over a period is directly associated with number of rainy days, heavy rainy days and extreme rainfall events. The decreasing (increasing) trend of annual rainfall over Ranchi (Jamshedpur) is associated with decreasing (increasing) trend of annual rainy days and heavy rainy days. No trend is observed in annual rainfall, extreme rainfall and heavy rainy days over Daltonganj.

It is also noticed that, both the annual minimum and maximum temperatures have increasing trend over all three stations of Jharkhand. The rapid increase in the annual maximum temperature observed after the year 2000. The maximum temperature of all three stations have significant increasing trend. The minimum temperature also has significant increasing trend except Jamshedpur at 95% confidence level.

Results show that the increase in the mean temperature is associated with increase in heat wave and decrease in cold wave events. All three stations have increasing trend of heat wave and severe heat wave days. The highest number of heat wave events observed in the year 2010 followed by 2012 at all three stations. The year 2010 witnessed least annual rainfall over Jharkhand with highest deficiency of -47% of long period average. Increasing annual number of heat wave days at Jamshedpur is statistically significant however, no statistically significant trend at 95% confidence level is observed over the stations of Ranchi and Daltonganj.

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