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Research Paper

Assessment of climate extremes and its long term spatial variability over the Jharkhand state of India

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ABSTRACT

This study examines the spatial climatic variability and climate extremes over the state of Jharkhand during 1984 to 2014. The climate extremes and the long-term fluctuation of climate parameters viz. maximum temperature, minimum temperature, rainfall, and solar radiation were assessed using least squares statistical method, for 71 locations in Jharkhand and interpolated spatially in Geographical Information System. The spatial analysis of the trend maps and climate index maps, demonstrates the regions with increasing number of summer days, increasing trend of maximum temperature and solar radiation, decreasing rainfall and thereby increased periods of consecutive dry days during monsoon season. The negative impact of climate extremes was observed as delay in transplanting/vegetative phase and reduced crop production, whereas an increase in the frequency of heat waves with 29 instances during 2004, 41 during 2005 and 100 during 2010 were observed. The findings of this study showed that average maximum temperature during 1984 to 2014 fluctuates with an increase of 1–1.5 °C to a decrease of 0.82–0.14 °C whereas the average minimum temperature fluctuates with a decrease of 0.79–0.39 °C to an increase of 0.59–0.41 °C. Rainfall fluctuates with a decrease of 26–270 mm to an increase of 19–440 mm. The highest average number of summer days is observed in Simdega with 340–348 days whereas the average consecutive dry days for the whole of Jharkhand has an increasing trend particularly in Palamu, Garhwa and Latehar districts, with 3.8–4.2 days of dryness during monsoon.

1. Introduction

Climate variability is amongst the major phenomenon occurring worldwide which has caused major changes in climate variables such as precipitation, air temperature, relative humidity, and solar radiation (Haskett et al., 2000; Bates et al., 2008; Yu et al., 2013). Because of these alterations, there is a consistent warming trend which is clearly reflected by the increasing occurrence of extreme climate events like droughts, floods and heat waves (Meehl et al., 2007). The natural disasters worldwide are a result of extreme events rather than just a variation of the mean climate (Plummer et al., 1999). According to the fifth report of Intergovernmental Panel on Climate Change (IPCC, 2013), the average maximum and minimum temperatures over land have increased worldwide by an excess of 0.1 °C per decade since 1950, including India, thereby affecting agriculture, water demands, and more rapid melting of glaciers. The report also stated that extended intervals of monsoon failures and dry spells have struck India and southeastern Asia, in the last few years leading to prolonged and intense droughts, which are a recurring feature of Holocene paleoclimate, also, the frequency of heavy precipitation events is increasing while light rain events are decreasing. The climate variability has lead to increased evapotranspiration rates, decline in soil moisture, and socio-economic consequences with longer dry periods, and greater number of extreme events (Izrael et al., 1997; Cruz et al., 2007; Ramos et al., 2012). Higher or lower rainfall or changes in its spatial and seasonal distribution influences the spatial and temporal distribution of runoff, soil moisture and groundwater reserves, and thereby affects the frequency of droughts and floods (Kumar et al., 2010; Jhajharia and Singh, 2011). In this context, several studies have been carried out to determine the impact of climatic variability on trends of annual and seasonal rainfall and its intensity (Parthasarathy et al., 1993; Naidu et al., 1999; Patra et al., 2005; Goswami et al., 2006; Ramesh and Goswami, 2007; Kothawale et al., 2010), the number of rainy days in various regions

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of India, and temperature trend (Feidas et al., 2004; Arora et al., 2005; Sen Roy and Balling, 2005; Andrighetti et al., 2009; Pal and Al-Tabbaa, 2010). Pant and Kumar (1974) analyzed the seasonal and annual air temperatures from 1881 to 1997 and observed an increasing trend of mean annual temperature, at the rate of 0.57 °C per 100 years. Rupakumar et al. (1994) pointed out that the countrywide mean maximum temperature of India has risen by 0.6 °C, and the mean minimum temperature has decreased by 0.1 °C. Rupakumar et al. (1992) observed that areas of the northeast peninsula, northeast India and northwest peninsula experienced a decreasing trend in summer monsoon rainfall while, Kothyari and Singh (1996) found that rainfall has a decreasing trend and temperature has increasing trends in the Ganga basin of India.

The changes in climate extremes have drawn the attention of researchers worldwide because of their critical impacts on human society, economic development, natural ecosystem, and environment (Vincent and Mekis, 2006; Torma et al., 2011; Ji-Yun et al., 2012). Indices for climate variability and extremes have been used for a long time, by assessing days with temperature or precipitation observations, which provide insight into local conditions, physically based on relative thresholds that describe features by examining the distributions of meteorological parameters through well distributed meteorological stations over the study area (Moberg and Jones, 2005; Zhang et al., 2011; Dutta et al., 2015). Amongst all the climate change indicators, the indicators for temperature and precipitation or their derivative quantities are widely used in monitoring and quantifying the extreme meteorological and hydrological climatic events (floods and droughts) (Wang et al., 2011). Researchers like Frich et al. (2002), found an increase in warm summer nights, decrease in the number of frost days, and a decrease in intra-annual extreme temperature ranges, while extreme precipitation showed more mixed patterns of change globally, and significant increases were seen in the amount derived from wet spells and the number of heavy rainfall events.

In applications of statistics to climatology for analyzing trends, both parametric and non-parametric methods are vastly used (Reghunath et al., 2005; Sarkar and Ali, 2009; Shamsudduha et al., 2009). Parametric trend tests are regarded to be more powerful than the non-parametric ones (Moberg and Jones, 2005; Hamed and Rao, 1998). The Sum of Least Squares (SLS) method is based on simple linear regression method and is widely used to calculate trend (Gupta and Gupta, 2008) in almost every field, from business forecasting, economics, engineering, physics, groundwater level fluctuations, climatological applications and so on (Korkmaz, 1988; Pal and Al-Tabbaa, 2011; Tirkey et al., 2012). The SLS method checks for a linear trend and is suitable for time series analysis and hence is applied in the present study to analyze the climate variability (viz. maximum temperature, minimum temperature, rainfall and solar radiation) of Jharkhand, India and to determine if climate over Jharkhand has a general increasing or decreasing trend with time.

The climatic variability over the state of Jharkhand has been analyzed in the present study as it follows a similar drift of global warming scenario as reflected worldwide. The northwestern region of Jharkhand like Palamu and Garhwa in particular, has been suffering from an extended dry spell which has led to a number of severe impacts in the region. Thus, detailed monitoring and assessment of climate trends over Jharkhand requires to be evaluated for analyzing the impact of rainfall and temperature on society, agriculture, and environment. The analysis of rainfall and temperature time series will help to recognize the long-term trends, temporal fluctuations and spatial distribution and magnitude of rainfall and temperature trends and thus provide an insight for economic planning and decision making. Hence, the major objective of the present study is to analyze the climatic fluctuations and the net change in the climate with respect to temperature (minimum and maximum temperature), rainfall, and solar radiation (during the Kharif crop growing season of June-Oct and Rabi season during Dec-March) in the Jharkhand state of India on spatial and temporal scales. Secondly, it aims at investigating the climate extremes based on climate indices using the daily data pertaining to temperature and precipitation, in Jharkhand.

2. Study area

The study was conducted for the entire state of Jharkhand which lies between 25°30′ N to 22°N latitude and 83°E to 88°E longitude covering an area of 79,714 km^2 where most of the state comes under the Chota Nagpur Plateau. Climatically, the state's weather is significantly variant with the northwest and west central parts of the state being hot with less rainfall and the southwest receiving more of rainfall. The three most prominent seasons in Jharkhand are characterized by summer, winter and rainy season, wherein the summer season comprises the months from March to June with May being the hottest month and the winter season consist of the months of November to February and is the most pleasant part of the year. The southwest monsoon precipitation from mid-June to October is primarily responsible for the state's annual rainfall where most of the precipitation falls in July and August. The annual precipitation ranges from about 1000 mm in the west-central part of the state to more than 1500 mm in the southwest (www.jharkhand.gov.in). The agricultural land and forest cover 49% and 30% of the total geographical area of Jharkhand respectively. The location map of the study area is shown in Fig. 1.

3. Material and methods

The daily time series data of rainfall, solar radiation, maximum temperature and minimum temperature, from 1984 to 2014 (30 years) were downloaded from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) dataset (globalweather.tamu.edu) in comma separated values (.csv) file format which are authenticated data sources (Sharma et al., 2015).

The world meteorological organization (WMO) has referred the period 1961 to 1990 as 'base line' and a significant shift of tropical rainfall is found during the period 1979 to 2003 (Lau and Wu, 2007). Therefore, only the second half of the 20th century is considered in many planning decisions. Keeping this in mind, in the present study, the 30 year period of 1984 to 2014 is considered. The CFSR weather data was obtained for a bounding box of latitude 25°30′ N to 22° N and longitude 83° E to 88° E covering the entire state of Jharkhand. The CFSR weather data included the information such as latitude/longitude, elevation, and the daily time series data of maximum temperature, minimum temperature, precipitation, and solar radiation for a period of 30 years for 193 NCEP CFSR data locations both in and around the state of Jharkhand.

The location data in .csv format was then projected as real world coordinates (as shapefile) in ArcGIS and assigned a coordinate system. The shapefile was then clipped by Jharkhand's boundary map, and out of the 193 locations, only 71 NCEP CFSR data locations fell entirely within the state's boundary, which were then processed for further analysis. The Fig. 2 depicts the spatial distribution of the NCEP CFSR data locations analyzed in this study.

3.1. Trend analysis

The daily maximum temperature, daily minimum temperature, and daily solar radiation data of all the 71 NCEP CFSR data locations were averaged month wise in Microsoft office excel, for the obser-

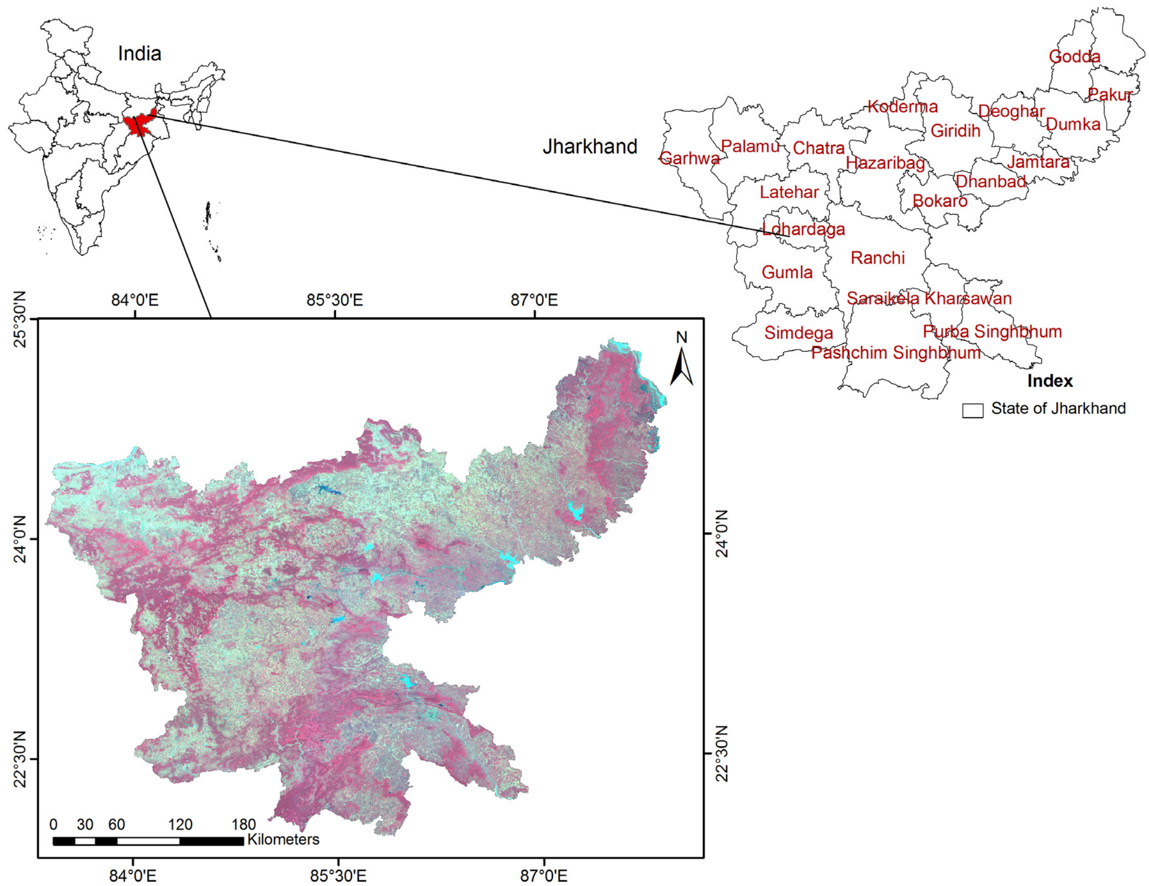

Fig. 1. Location map of the study area along with its Advanced Wide Field Sensor (AWiFs) satellite image in standard false colour composite (FCC) pertaining to the year 2008.

vation period of 30 years, so as to obtain the average monthly maximum temperature, average monthly minimum temperature, and average monthly solar radiation data. Similarly, the daily rainfall data for each of the 71 NCEP CFSR data locations was summed up as total monthly rainfall for each of the location, to obtain the cumulative monthly precipitation data for all the 71 locations during 1984 to 2014.

The long-term trend of the maximum temperature, minimum temperature, precipitation and solar radiation during the 30 year period (1984 to 2014) was then evaluated seasonally for each of them, by averaging yearly, the monthly maximum temperatures from March-June (for summer season) and averaging the monthly minimum temperature from November-February (for winter season). As, more than 70% rain falls in the monsoon season alone, therefore, in this study, the cumulative rainfall during the monsoon months (June-October) were summed up for each year, whereas, the monthly solar radiation was averaged separately for the crop growing season during Kharif (July-October) and solar radiation during the crop growing season during Rabi (December- March).

The time series regression analysis for assessing the trend and magnitude of the fluctuation (i.e. net change on account of increase or decrease) for all the five climate parameters (namely, maximum temperature, minimum temperature, rainfall and solar radiation during both Kharif and Rabi seasons) were carried out season wise from 1984 to 2014 using parametric simple linear regression test using sum of least squares statistical method, as used by Su et al. (2006), Subash et al. (2011), Tirkey et al. (2012), and Mondal et al. (2014), to show the trend, calculate slope, and analyze the magnitude or rate of the climatic fluctuation. The method of least squares is applied according to Gupta and Gupta (2008) and is shown below:

A trend line is fitted to the data in such a manner that the following two conditions are applied:

i) $\sum Y - Y_c = 0$

i.e. the sum of deviations of the actual values of Y and the computed values of Y is zero.

ii) $\sum (Y - Y_c)^2$ is least,

i.e. the sum of the squares of the deviations of the actual and computed values is least from this line. The method of least squares can be used either to fit a straight line trend or a parabolic trend. The straight line is represented by the equation

$$Y_c = a + bX \quad (1)$$

where

Y_c = trend values,
a = Y intercept or the value of the Y variable when X = 0,
b = slope of the line or the amount of change in Y variable that is associated with a change of one unit in X variable.
X = time (in time series analysis)

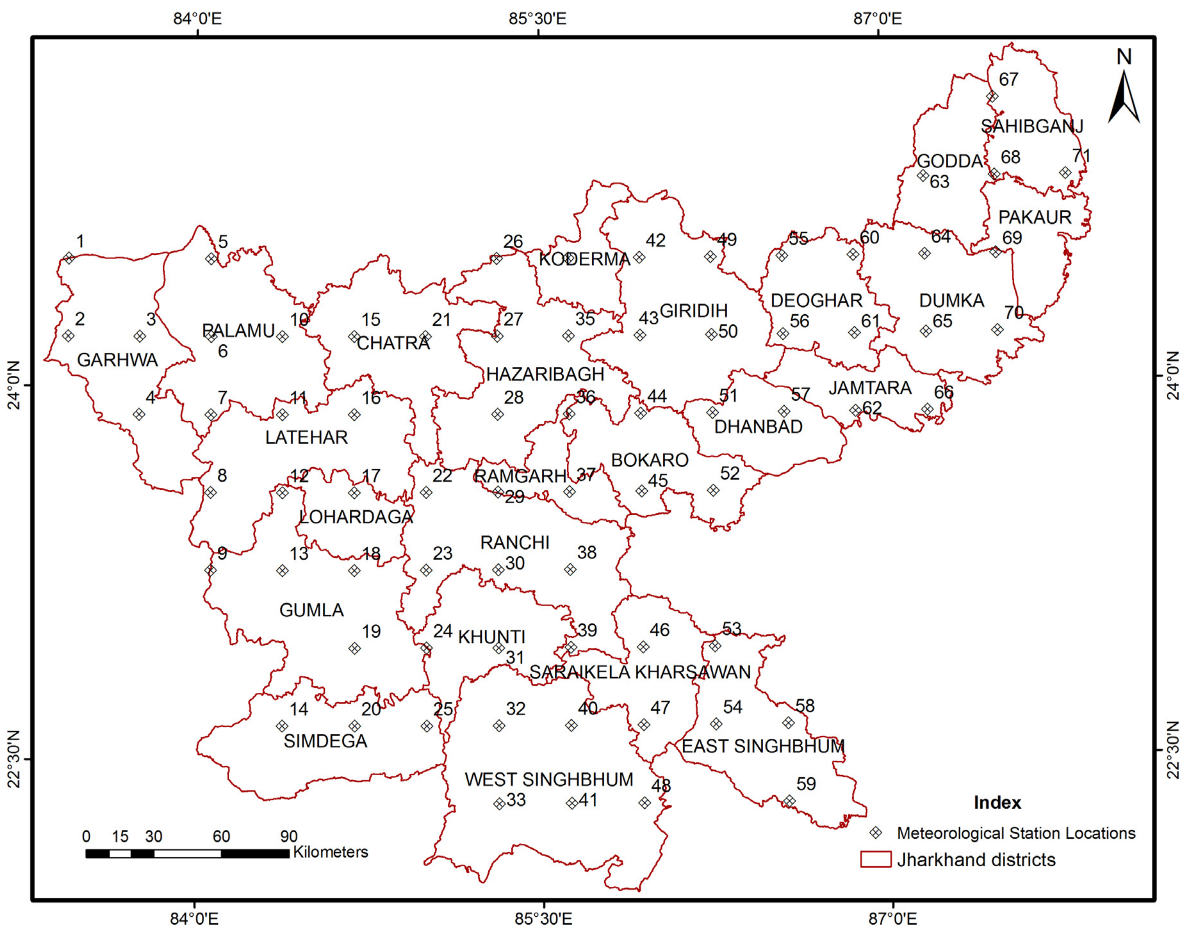

Fig. 2. Spatial distribution of NCEP CFSR data locations in Jharkhand.

To determine the value of the constants a and b, the following two equations are to be solved:

$$\sum Y = Na + b\sum X \tag{2}$$

$$\sum XY = a\sum X + b\sum X^2 \tag{3}$$

where N = number of years (months or any time period)

The time variable is measured as a deviation from its mean. Since, $\sum X = 0$, the Eq. (2) and Eq. (3) becomes;

$$\sum Y = Na \tag{4}$$

$$\sum XY = b\sum X^2 \tag{5}$$

The values of a and b can be determined as;

$$\sum Y = Na,$$

$$a = \frac{\sum Y}{N} = \overline{Y} \tag{6}$$

Since $\sum XY = b\sum X^2,$

$$b = \frac{\sum XY}{\sum X^2} \tag{7}$$

where

a = arithmetic mean of Y,
b = rate of change

It should be noted that in case of odd number of years when the deviations are taken from the middle year, $\sum X$ should always be zero, provided there is no gap in the data given. However, while taking even number of years $\sum X$ should always be zero if the X origin is placed midway between the two middle years.

Thus, after analyzing the 30 year trend of all the five climate parameters seasonally in Microsoft office excel, the fluctuation values were added as attributes to the climate parameters with respect to its respective location in ArcGIS 9.3. The fluctuation data was then spatially interpolated using Inverse Distance Weighted (IDW) technique of the spatial analyst tool in ArcMap. The spatially interpolated trend maps of rainfall, maximum temperature, minimum temperature, and solar radiation were then analyzed to study the climatic variability during 30 years over Jharkhand.

The World Meteorological Organization (WMO) CCL/CLIVAR Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) has recommended a comprehensive list of indices, accompanied by definitions, procedures and guidance, for large-scale regional studies (Karl et al., 1999; Peterson et al., 2001; Zhang et al., 2011). They have also coordinated a series of international workshops for the preparation of climate change indices for those regions lacking data that are available internationally: these indices are used for a global analysis being prepared for the next IPCC assessment report. Thus, the climate indices have been used in the present study for analyzing the climate extremes of temperature and precipitation and were evaluated using the formulae given below:

3.2. Climate index analysis

3.2.1. Number of summer days (SU)

Summer days index estimates the warm days with a maximum temperature higher than 25 °C. Thus, it is the annual count of days when TX (daily maximum temperature) >25 °C. Count the number of days where:

$$TX_{ij} > 25^{\circ}C$$

where TX_{ij} = daily maximum temperature on day i in year j.

This index is calculated for all the 71 NCEP CFSR data locations on daily basis from 1984 to 2014. The number of days with a maximum temperature greater than 25°C was counted year wise and location wise and thereafter, averaged so as to obtain the average annual SU index from 1984 to 2014. The average annual SU index for each location was added to the attribute table of the respective location's shapefile in ArcGIS 9.3, which was then interpolated using IDW technique of the spatial analyst tool of ArcGIS. The spatially interpolated map was used to access spatially, the regions having increasing/decreasing number of summer days.

A graph was plotted to analyze the overall trend of SU over Jharkhand by averaging together the SU index of all the NCEP CFSR data locations yearly from 1984 to 2014 and thereby plotting it against time (year).

3.2.2. Annual total precipitation in wet days (PRCPTOT)

This index quantifies the average amount of rainfall capable of wetting the ground surface and considers only those rainfall events when precipitation is greater than 1 mm. This index is estimated as:

$$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$$

where

RR_{ij} = Daily rainfall amount on a particular day i in period j (Monsoon season i.e. June-October)
i = rainfall >1 mm
I = number of days in period j i.e. total duration of monsoon season (153 days)

In the present study, this index has been estimated for only those places where there is a decreasing trend of rainfall. This index will quantify the average annual total precipitation in wet days during monsoon months over the 30 year period at the selected locations.

3.2.3. Consecutive dry days (CDD)

The CDD measures the length of dry periods and is a drought indicator. A dry day is allowed to have a small amount of precipitation, but generally small enough for the ground not to recover after a long period of dryness (Moberg and Jones, 2005). It is calculated as:

Maximum length of dry spell, maximum number of consecutive days with RR < 1 mm:

The largest number of consecutive days is counted when:

$$RR_{ij} < 1mm$$

where

RR_{ij} = daily rainfall amount on day i, in period j (rainfall <1 mm)

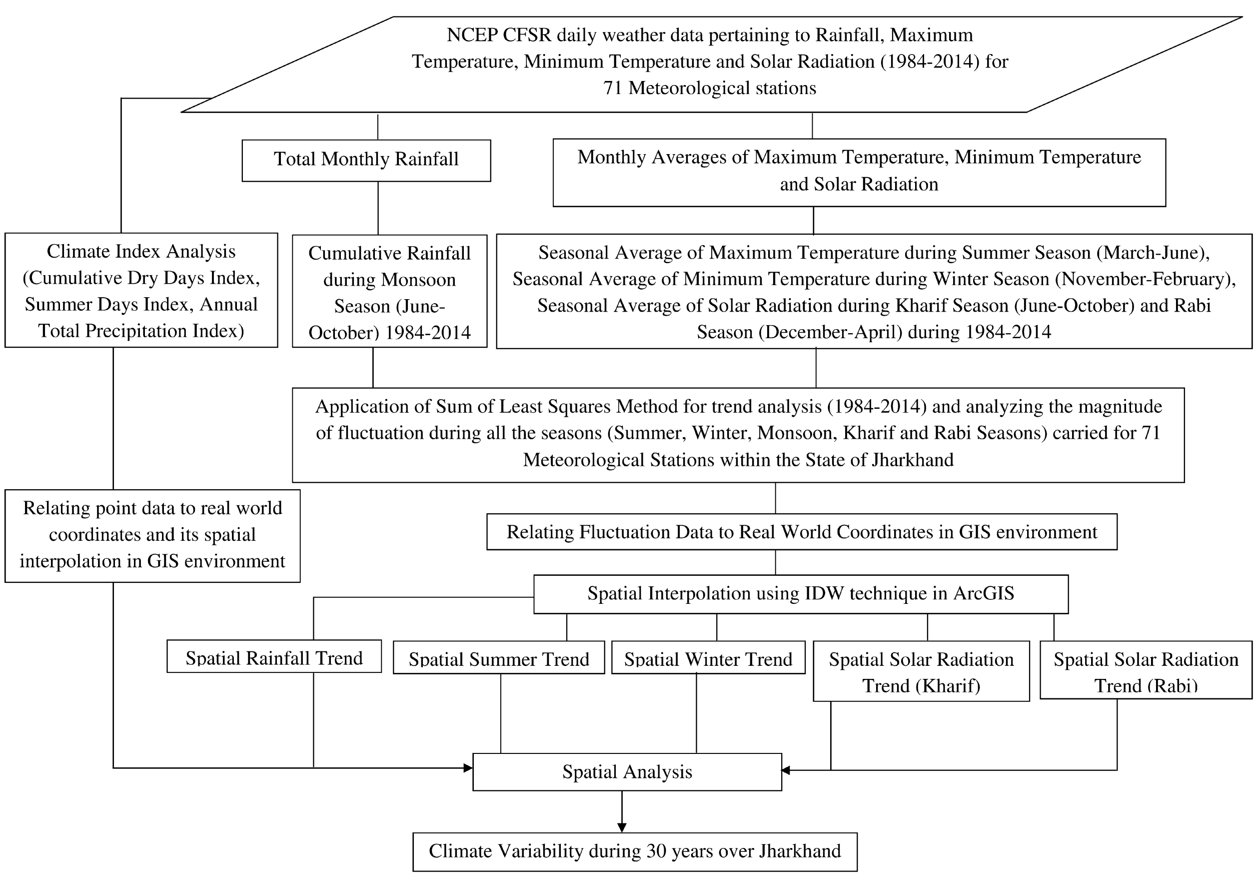

Fig. 3. Schematic representation of methodology.

j = monsoon season (June-October)

In the present study, the dry day index was calculated only for the monsoon months (June-October) as maximum rainfall is during this season, and the dryness of this season will be a good indicator for highlighting drought conditions.

The CDD was calculated for the monsoon season for each year from 1984 to 2014. The longest number of consecutive dry days for each location was counted yearly and then averaged so as to obtain the average annual CDD at each location. The average annual CDD values were added as attributes to the respective location's shapefile in ArcGIS 9.3 which was then interpolated spatially using the spatial analyst tool of ArcGIS using Inverse Distance Weighted (IDW) technique. This interpolated map was then used to access the dry regions and the regions prone to drought conditions. A graph was plotted to analyze the overall trend of dry days in Jharkhand by averaging the longest dry days of all the 71 NCEP CFSR data locations during 1984–2014 and thereby plotting it against time (year).

After studying the spatial distribution and trends of the climate parameters, the results of the climate indices focusing on climatic extremes were considered together to come to a common conclusion about the climatic variability over Jharkhand in the past 30 years. The flowchart showing the detailed methodology adopted in the present study has been depicted in Fig. 3.

4. Results and discussion

4.1. Trend analysis

The findings on the trend, magnitude of fluctuation and the spatial variation of the increase or decrease of all the five climate parameters from 1984 to 2014 over the state of Jharkhand is presented as respective figures. The results of the climate index analysis are also shown in figures.

4.1.1. Seasonal trend of maximum temperature

An overall increasing trend of maximum temperature during summer season (March-June) over Jharkhand during the 30 years is extremely noteworthy (Fig. 4a).

The spatial distribution map of average maximum temperature trend, shows a significant increasing trend and is particularly prevalent in the northwestern districts of Jharkhand (Fig. 5), where an increase is observed from 1–1.5 °C in the Palamu and Garhwa districts and with different rates of increase (0.55–0.99 °C) in the Latehar, Chatra, Lohardaga and parts of Hazaribagh, Ramgarh,

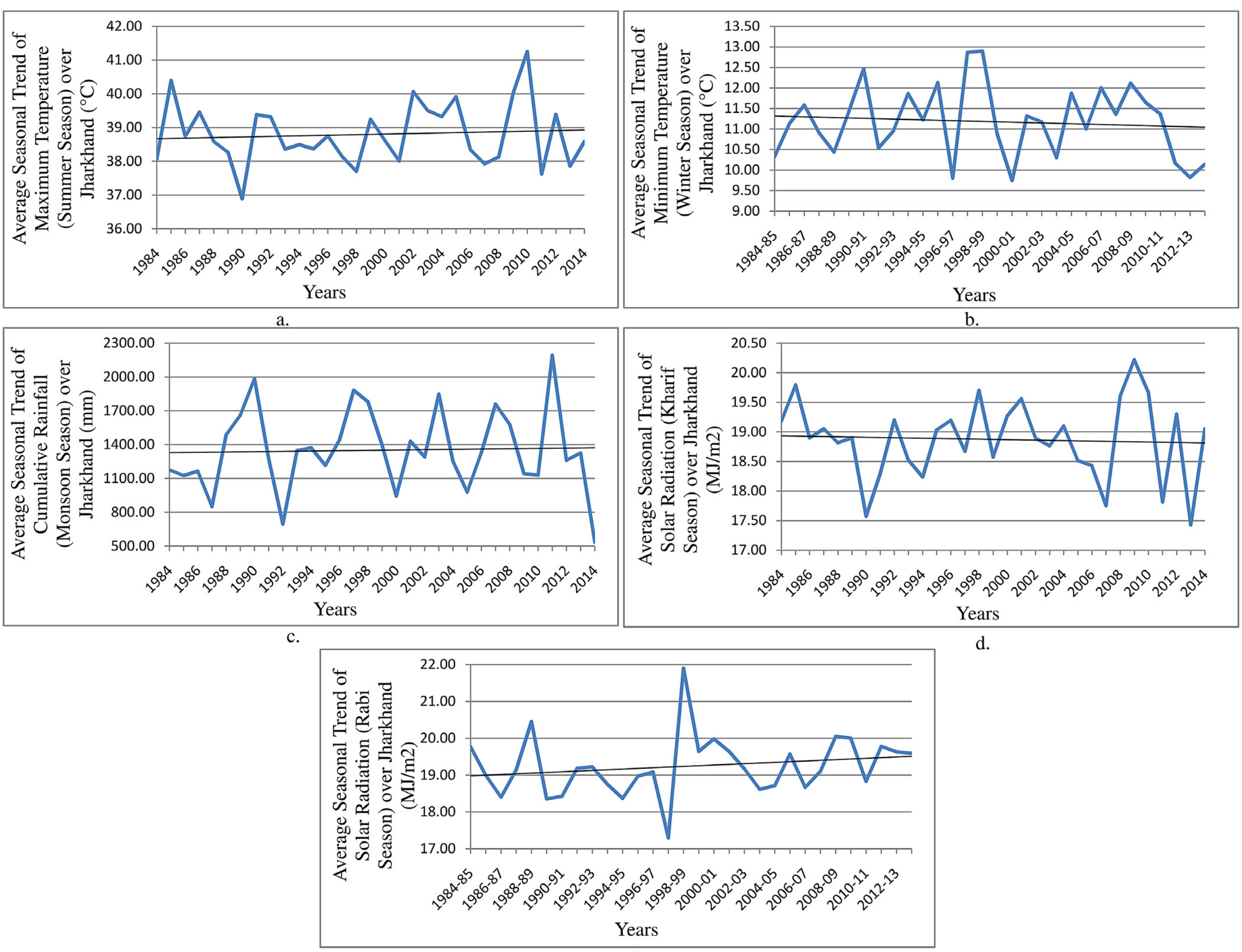

Fig. 4. Overall average seasonal trends in Jharkhand during 1984–2014 (a) average seasonal trend of maximum temperature during summer season (b) average seasonal trend of minimum temperature during winter season (c) average seasonal trend of cumulative rainfall during monsoon season (d) average seasonal trend of solar radiation during kharif season (e) average seasonal trend of solar radiation during rabi season.

Ranchi and Gumla districts. The maximum temperature is observed to fluctuate with an increase of 0.55–1.5 °C in the northwestern districts (Palamu, Garhwa, Chatra, Latehar, Lohardaga, Gumla and part of Ranchi, Ramgarh and Hazaribagh) to a decrease of 0.82–0.14 °C in the northeastern (Sahibganj, Pakur, Godda and Dumka) and southeastern districts (East Singhbhum and Saraikela Kharsawan). The negative values in the trend analysis map (Fig. 5) show the magnitude of decrease, whereas, the positive values shows the magnitude of increase.

It is observed from the analysis that summer season has become warmer over the past 30 years, and its intensity has severed for most parts of the state. Apart from the high increase of up to 1.5 °C in northwestern part a moderate increase of temperature with 0.2–0.54 °C is observed in the northern and southwestern parts of the state, which may lead to water scarcity in the area (Fig. 5). An increase of 0.077–0.54 °C is observed in the central, southwestern and northern regions (Simdega, West Singhbhum, Saraikela Kharsawan, Khunti, Ranchi, Bokaro, Dhanbad Giridih, Koderma, Deoghar and Jamtara). A rise of maximum temperature in eastern part of India was also observed by Subash and Sikka (2014) and Mondal et al. (2014).

The Jharkhand Action plan on climate change (2014) has documented the detrimental effects of increasing maximum temperature over Jharkhand. The report stated that Jharkhand experienced the highest number of heat waves during 2000 to 2010 which mainly affected the poor due to their lack of coping abilities. The report also pointed that during the summer season (March–June), there were 29 instances of heat waves in the year 2004, 41 during 2005 and 100 during 2010 (Jharkhand Disaster Management Plan, 2011).

The most noted impact of climate variability is an observed increasing trend of maximum temperature in Jharkhand (Fig. 5), which has reduced the rice production by 10.2 q/ha with each 1 °C rise in maximum temperature, whereas the decreasing trend of minimum temperature at grain filling stages decreases the rice yield by 2.7 q/ha per 1 °C decrease in minimum temperature (Jharkhand Action Plan on Climate Change, 2014). High maximum temperature during vegetative stage causes brown spot disease while high rainfall at flowering stage causes chaffy grain of rice. Thus, a yield reduction of 10–15 q/ha is reported (Jharkhand Action Plan on Climate Change, 2014). The increasing maximum temperature during flowering stage of wheat and other *rabi* crops has caused pollen/flower sterility at many instances, thereby causing substantial yield reduction of *rabi* crops. Appearance of new strains of disease/pests-Bristle Beetle in *Arhar*, Sheeth Blight and Rust in *Kharif* maize, Powdery mildew in Lentil, Alternaria Blight in Rapeseed-Mustard, Swarming caterpillar in Rice, root Knot Nematode in rice were also observed owing to the climate extremes and its fluctuation (Jharkhand Action Plan on Climate Change, 2014). Wadood and Kumari (2009) observed a considerable increase in the maximum temperature of Jharkhand which caused sterility in wheat crop. Their study pointed out that the years preceded by below normal rainfall coupled with its erratic distribution and prolonged dry spells are the worse victims of temperature rise.

A significant decreasing trend is observed in the northeastern districts (Dumka, Pakur, Godda, Sahibganj) and southeastern districts (East Singhbhum and part of Saraikela Kharsawan). The amount of decrease was found to lie in the range 0.14–0.82 °C. The fluctuation in trends may be due to diverse topography and

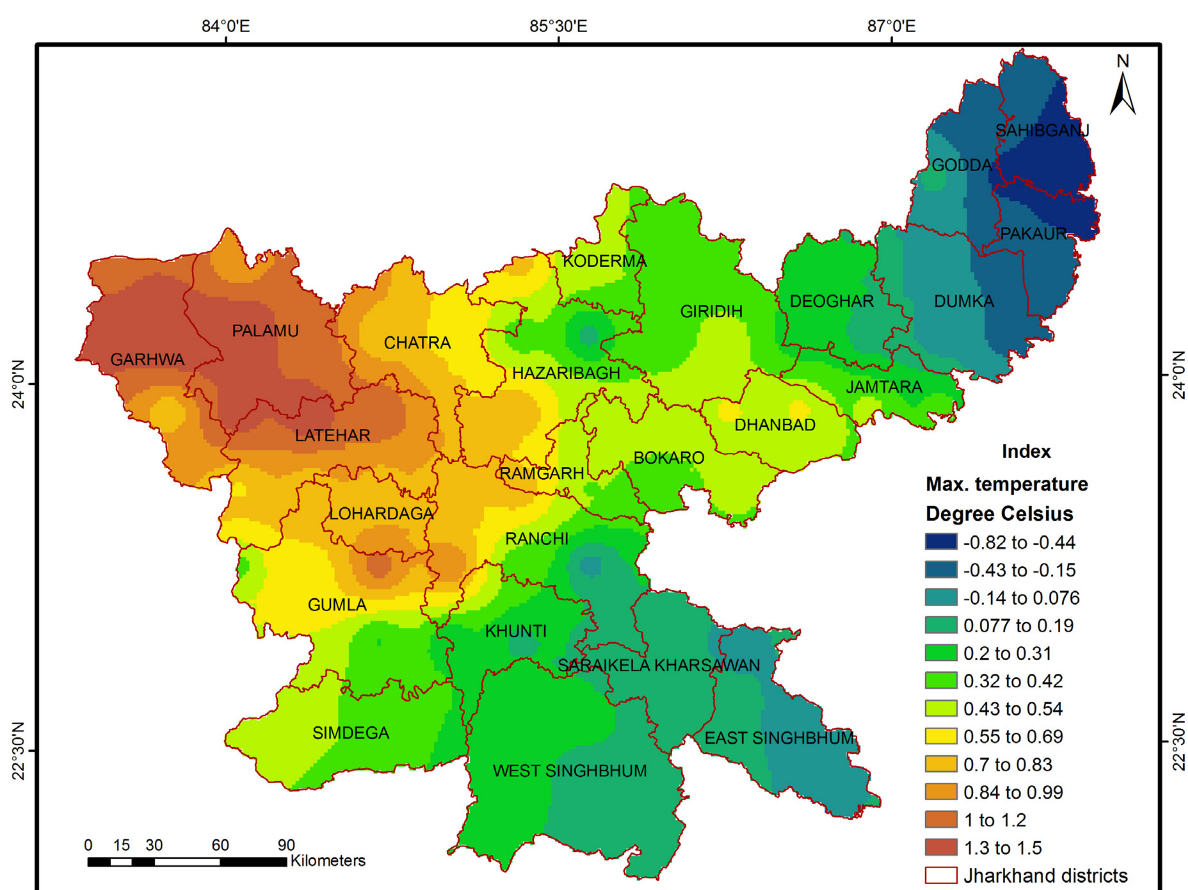

Fig. 5. Spatial distribution map of seasonal maximum temperature trend during 1984–2014 in Jharkhand.

different thermodynamic and orographic forcing at individual NCEP CFSR data locations. The diverse land use changes through increased agricultural activities, forest degradation, deforestation, and rapid expansion of urban areas lead to substantial variability in temperature (Riebsame et al., 1994; Zhou et al., 2004; Hu et al., 2010; Rawat and Kumar, 2015) and this may be the reason behind different magnitudes of increase or decrease in different parts of Jharkhand.

The findings of this study will help in spatially accessing the zones severely affected due to increasing trend of maximum temperature and help government personnel to provide relief instantly. The further increasing trend may severely affect the agricultural productivity under warmer climate as, arid and semiarid regions could experience severe water stress due to a decline of soil moisture due to high temperatures.

4.1.2. Seasonal trend of minimum temperature

The overall average minimum temperature during winters (November-December) over the state of Jharkhand is observed to decrease in the past 30 years (Fig. 4b).

The result of trend analysis of minimum temperature conducted for the winter season (November-February) in Jharkhand state, projects a colder drift in the central regions, particularly, in Ranchi, Ramgarh, Khunti, Lohardaga, Gumla and parts of Hazaribagh and Simdega districts of Jharkhand with a decrease of 0.39–0.79 °C. The overall increase or decrease of minimum temperature fluctuates with a decrease of 0.79–0.39 °C in the central and southwestern regions to an increase of 0.59–0.41 °C in the northeastern districts (Sahibganj, Godda, Dumka, Deoghar, Jamtara, Dhanbad and Giridih) of the state (Fig. 6). The study also points that the duration of the winter season has decreased, with a lowering of the minimum temperature. The intensity of chilliness is also observed to have increased in the winter season over the central regions.

The scenario over the northern, eastern and southern parts (Dhanbad, Giridih, Deoghar, Jamtara, Dumka, Godda, Sahibganj, Pakur and Garhwa) of Jharkhand show an increasing trend whereas the Palamu district show a moderate temperature decrease from 0.01–0.07 °C. It is notable, that except for Palamu and Garhwa (where maximum temperature has an increasing trend), all the rest of the districts project a decreasing trend of maximum temperature, which points that with the decreasing maximum temperature and increasing minimum temperature, the overall mean temperature in these northeastern districts is generalized, whereas, Palamu and Garhwa face both increasing minimum and maximum temperature which ultimately increases the mean heating of atmosphere. It is therefore understood that Palamu and Garhwa have elevated temperature levels throughout the year, which is trending consistently. The rest of the districts viz. Hazaribagh, Latehar, Chatra, Bokaro, West Singhbhum, East Singhbhum and Saraikela Kharsawan also project a decreasing trend of minimum temperature (Fig. 6) with a comparatively lesser magnitude of 0.01–0.38 °C and hence are not prominent.

Jharkhand being an important producer of Lac has suffered tremendously during the past 3–4 years, as *lac* host trees get affected by unseasonal, short, and heavy rains followed by extreme cold weather and week-long fog and frost around mid-March, when the insect is ready to produce *lac* (Jharkhand Action Plan on Climate Change, 2014). As a result of extreme cold, the insects tend to die. This has occurred since 2006, reducing the production

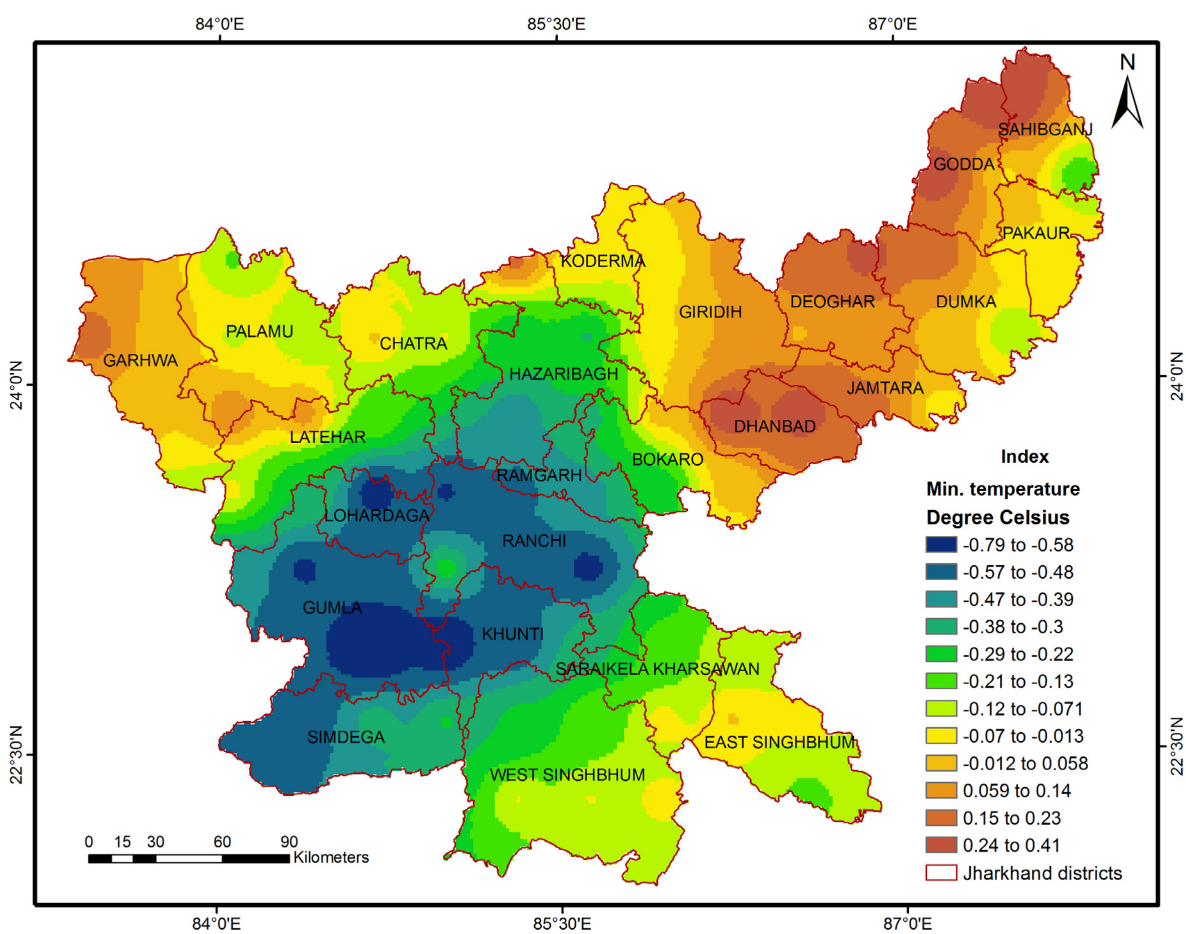

Fig. 6. Spatial distribution map of seasonal minimum temperature trend during 1984–2014 in Jharkhand.

of lac up to 25% of what was harvested in 2004–05 (Jharkhand Action Plan on Climate Change, 2014).

4.1.3. Seasonal trend of rainfall

The overall cumulative rainfall during the monsoon season (June-October) for the entire state of Jharkhand was found to be almost constant over the 30 years (Fig. 4c). However, the trend analysis of cumulative rainfall during the monsoon season shows that rainfall has a fluctuating trend with a decrease of 26–270 mm in the northwestern districts (Fig. 7) to an increase of 19–440 mm in the rest parts of the state. The spatial distribution of cumulative rainfall shows that the north, northwestern and central regions of the state, particularly, Palamu, Garhwa, and parts of the Ranchi, Ramgarh, Hazaribagh, Kodarma, Giridih and Gumla show a declining trend of cumulative rainfall with magnitude 26–270 mm.

It is noteworthy, that the Palamu and Garhwa districts may have suffered severely during summers. The decrease in rainfall, coupled with elevated temperature levels, implies lesser storage and greater water stress, and thereby exaggerates the severity of the extreme climatic conditions and inflicts harsh living situations. Rice being an important kharif crop (May–October) in Jharkhand, the decreasing trend of rainfall is observed to delay/affect the transplanting/vegetative phase of the crop, for which assured irrigation is very much needed to tackle the drought situation (Jharkhand Action Plan on Climate Change, 2014). Owing to the recent increase in extreme climatic events, high rainfall at rice flowering stage has been found deleterious, causing a yield reduction of up to 7 q/ha whereas at grain filling stage the high rainfall was found to be beneficial causing yield increase up to 6.3 q/ha (Jharkhand Action Plan on Climate Change, 2014). High evening RH at emergence-flowering stage has caused rice yield reduction (up to 3 q/ha). In addition there were instances of flash flood and heavy rains.

The decreasing trend of rainfall and increasing maximum temperatures trend in the northwestern regions may lead to severe socio-economic consequences, including loss in agricultural productivity, soil degradation, and disasters like droughts.

It is interesting to note that the daily rainfall data during the study period, points that, along with a decrease in cumulative monsoon rainfall, the onset of monsoon in the entire state of Jharkhand has been delayed time and again, and instead of beginning by the mid of July, the monsoon season is starting by the 1st or 2nd week of June. This has resulted in rainfall anomaly leading to high intensity storm events for short durations, both in and around Jharkhand. The late onset has also forced the shifting of sowing season from July to August wherein the high intensity storm sometimes destroys the crops. This temporal change in precipitation distribution has also been recorded by several other researchers in their studies (Mall et al., 2007; Lal, 2001). High intensity storm events destroy the crops and productivity in the kharif season (Kumar et al., 2010), and produces immense sediment and nutrient load which affects the water quality. Mahato (2014) pointed out that although the number of rainy days may decrease, however, their intensity is expected to increase at most of the parts of India, particularly in the North East. Further, it is expected that the

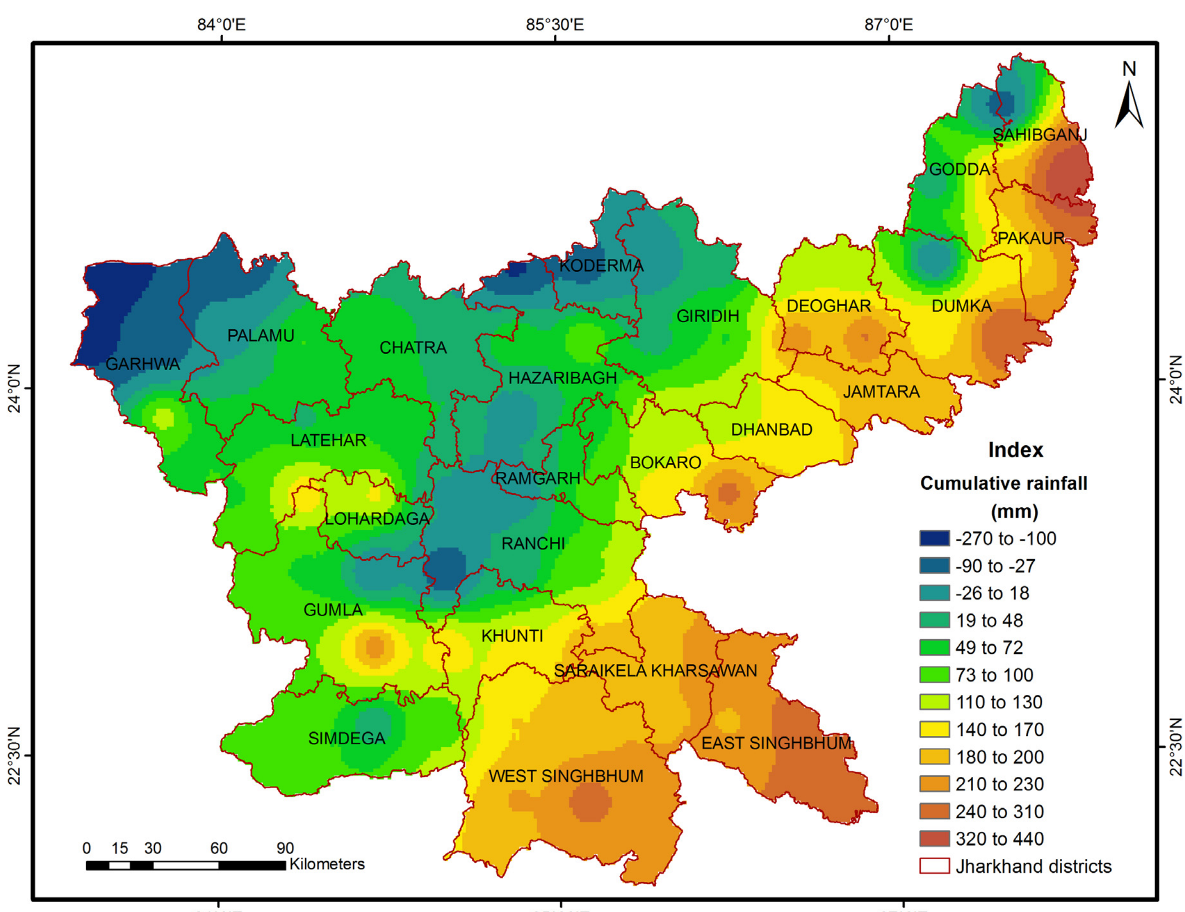

Fig. 7. Spatial distribution map of seasonal cumulative rainfall trend during 1984–2014 in Jharkhand.

response of hydrological systems, erosion processes and sedimentation, changes in runoff and their spatial distribution could significantly alter due to the climatic variability in Jharkhand.

The rainfall trend map (Fig. 7) projects an increasing trend of cumulative rainfall in the southeastern and northeastern districts of Jharkhand, viz. East Singhbhum, West Singhbhum, Saraikela Kharsawan, Deogarh, Jamtara, Dumka, Pakur and part of Dhanbad, Bokaro and Khunti where an increase of 140–440 mm in cumulative rainfall is observed. A moderate increase in the cumulative rainfall is observed in the western regions (Simdega, part of Gumla, Lohardaga, Latehar, Palamu and Chatra), part of central regions (Ranchi, Bokaro, Hazaribagh, Giridih and Dhanbad) and northeastern regions (part of Deoghar, Dumka, Godda and Sahibganj) projecting an increase of 19–100 mm (Fig. 7). The result of this trend analysis study runs parallel with the findings of several other researches (Dash et al., 2007; Subash et al., 2011), who found that northeast India has significant temperature rise and decreasing rainfall trend particularly in the monsoon season. A similar finding was also observed in the Blue Nile catchment which indicated that its tributaries have been drying up due to significant variability of rainfall and prolonged dry season (El Bastawesy et al., 2015).

The cause for a significant variable rainfall pattern in the state of Jharkhand, may be credited to several factors like, North Atlantic SST, Equatorial SE Indian ocean SST, East Asia mean sea level pressure, North Atlantic mean sea level pressure and North central pacific wind at 1.5 km above sea level (Krishna Kumar et al., 2006). As per Singh and Oh (2007) and Roxy and Tanimoto (2007), the regional warming of Sea Surface Temperature (SST) over the Indian Ocean, are likely to impact the Indian monsoon circulations and thereby reduce the precipitation over northeast India covering the state of Jharkhand.

4.1.4. Seasonal trend of solar radiation (kharif season)

The overall solar radiation during kharif season has remained constant at 19 MJ/m^2 during the 30 year period in Jharkhand (Fig. 4d). The trend analysis of solar radiation during the kharif season varies spatially (Fig. 8) with a decrease of 0.7–0.32 MJ/m^2 in the north (Giridih, Deoghar, Dhanbad, Jamtara and part of Bokaro, Hazaribagh, Koderma and Dumka) to an increase of 0.2–0.99 MJ/m^2 in the southern and central districts (Simdega, West Singhbhum, East Singhbhum, Saraikela Kharsawan, Khunti, and part of Gumla and Ranchi).

It moderately decreases from 0.047–0.31 MJ/m^2 in the central and northwestern districts of Palamu, Garhwa, Latehar, Chatra, Ramgarh and part of Ranchi, Hazaribagh and Gumla districts. It is noteworthy, that solar radiation has increased at places where the rainfall activity has also increased over the years during this season.

As observed by Bert et al. (2007), under non-limiting water conditions, higher radiation values help to maintain higher photosynthesis rates, resulting in greater aboveground biomass production and yields. High solar radiation rates therefore is a good indicator of better crop productivity in these districts, by providing sufficient required energy for evapotranspiration, photosynthesis, including carbohydrate partitioning and biomass growth (Boote and Loomis, 1991).

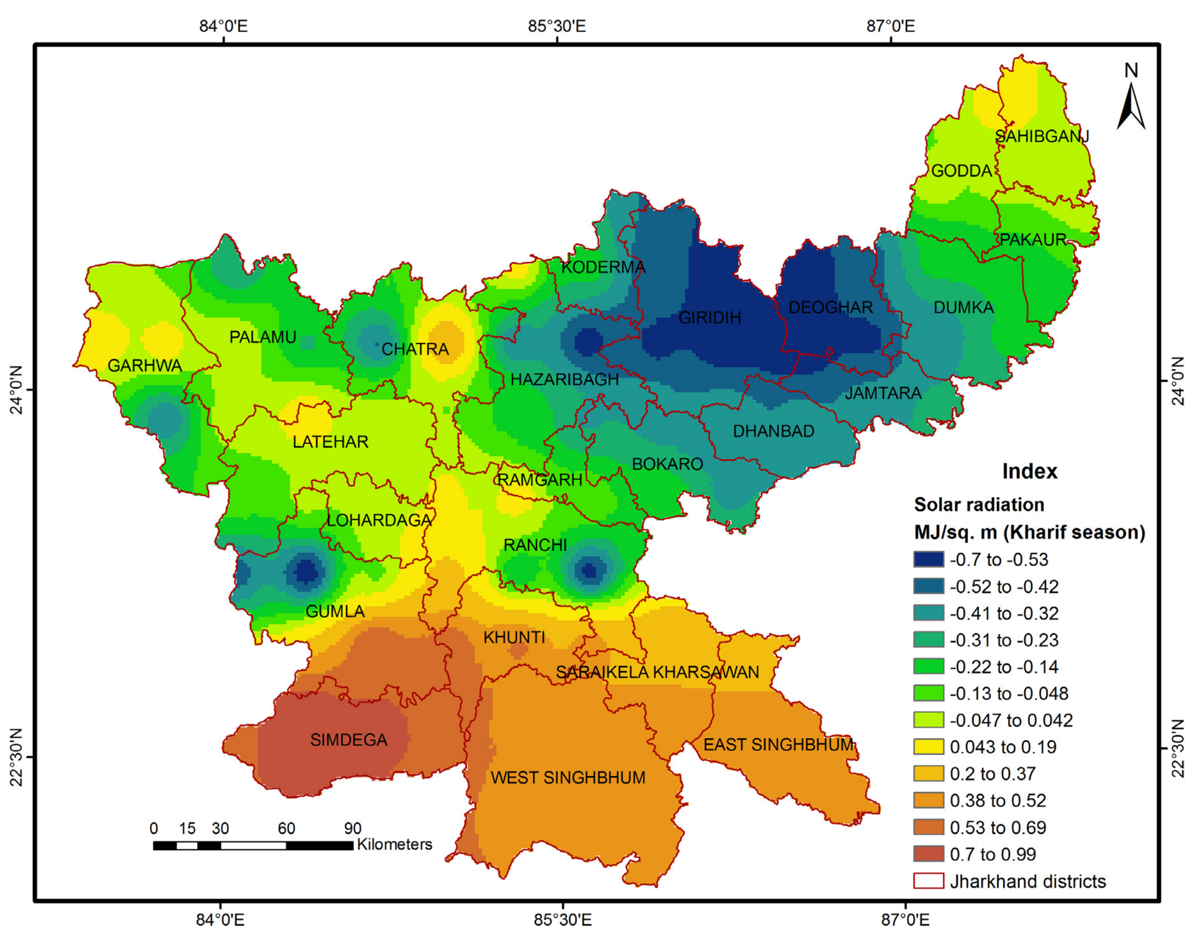

Fig. 8. Spatial distribution map of solar radiation trend (kharif season) during 1984–2014 in Jharkhand.

4.1.5. Seasonal trend of solar radiation (rabi season)

The net solar radiation during rabi season has remained constant at 19 MJ/m^2 during the observation period (Fig. 4e).

The spatial distribution map of solar radiation trend (Fig. 9) shows that it fluctuates with an increase of 0.55–0.94 MJ/m^2 in the central region (Ranchi, Lohardaga, Ramgarh, Latehar, Garhwa, Bokaro and part of Gumla and Hazariagh) and northwest region (Palamu and Garhwa) to a decrease of 0.13–0.72 MJ/m^2 in the southern region (Simdega, West Singhbhum, East Singhbhum, Saraikela Kharsawan and Khunti). A moderate increasing trend from 0.063–0.54 MJ/m^2 is observed in the eastern and northern districts of Dhanbad, Jamtara, Dumka, Pakur, Sahibganj, Godda, Deoghar and parts of Giridih, Hazaribagh, Chatra and Gumla districts.

4.2. Climate index analysis

4.2.1. Summer days (SU)

The present study shows an interesting scenario of the SU index (Fig. 10), where the average number of summer days is found to be highest (336–348 days) in the southern and northeastern districts of West Singhbhum, East Singhbhum, Saraikela Kharsawan and Sahibganj respectively (337–346.8 days) while Simdega recorded the highest average number of summer days (340–348 days). The northeastern districts of Bokaro, Dhanbad, Jamtara, Dumka, Pakur and Godda have 329.8–336.2 days of summer on an average. The Palamu and Garhwa districts also have moderately high average number of summer days (323.4–336.2 days), whereas, the central and part of the northern regions are comparatively less warm with less number of summer days (277.5–316.1 days).

It is noteworthy, that a decreasing trend of minimum temperature is also observed in these regions, and hence it is obvious that a decrease in the number of summer days has also lowered the minimum temperature in these regions. It is also noted that the intensity of maximum temperature in the western region is high while, the SU index projects a moderately high average number of summer days in this part of the state. On the whole, although the climate over the state of Jharkhand has become warmer, (with different spatial variations of temperature and rainfall in the district) the average number of summer days in the state has been decreasing over the years (Fig. 11a).

A recent study conducted in Wular Lake, Kashmir suggests similar findings where the annual precipitation pattern and maximum and minimum annual average temperatures were found to increase during past few decades (Mushtaq and Lala, 2016). The summer days index suggested increased warming trend with more number of warm days. The fifth IPCC report suggests that the variability in average precipitation in warmer world will exhibit substantial spatial variation where some regions will experience increases, other regions will experience decreases and yet there will be some places where there will not be any change at all.

4.2.2. Annual total precipitation in wet days (PRCPTOT)

This index is estimated only for those places where a decreasing trend of rainfall is observed viz. Garhwa, Palamu, Chatra, Latehar, Koderma, Ramgarh, Ranchi, Hazaribagh, Giridih, and part of Gumla, Dumka, Godda and Sahibganj which corresponds to 30 NCEP CFSR data locations within the state of Jharkhand. The geographic locations (Fig. 2) and corresponding village names along with the

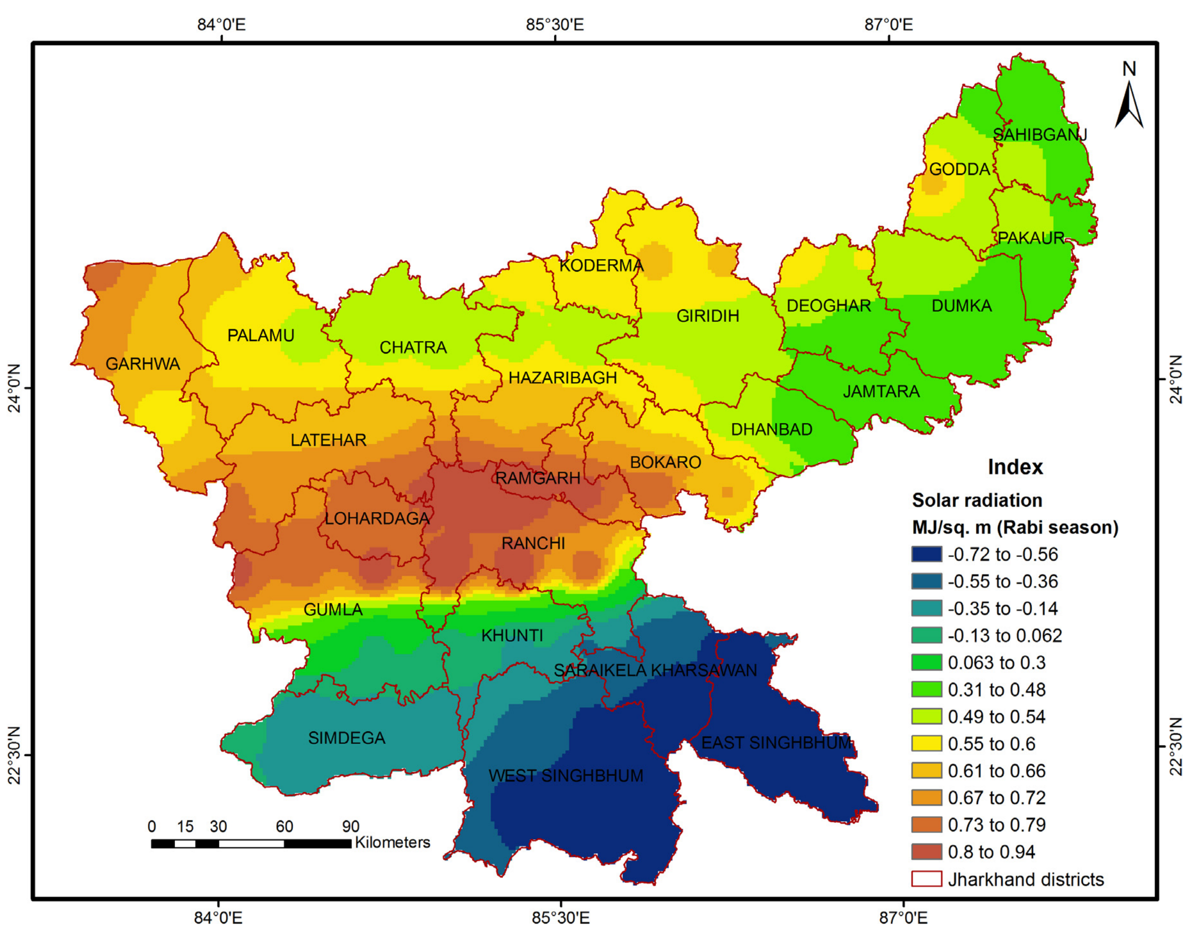

Fig. 9. Spatial distribution map of solar radiation trend (rabi season) during 1984–2014 in Jharkhand.

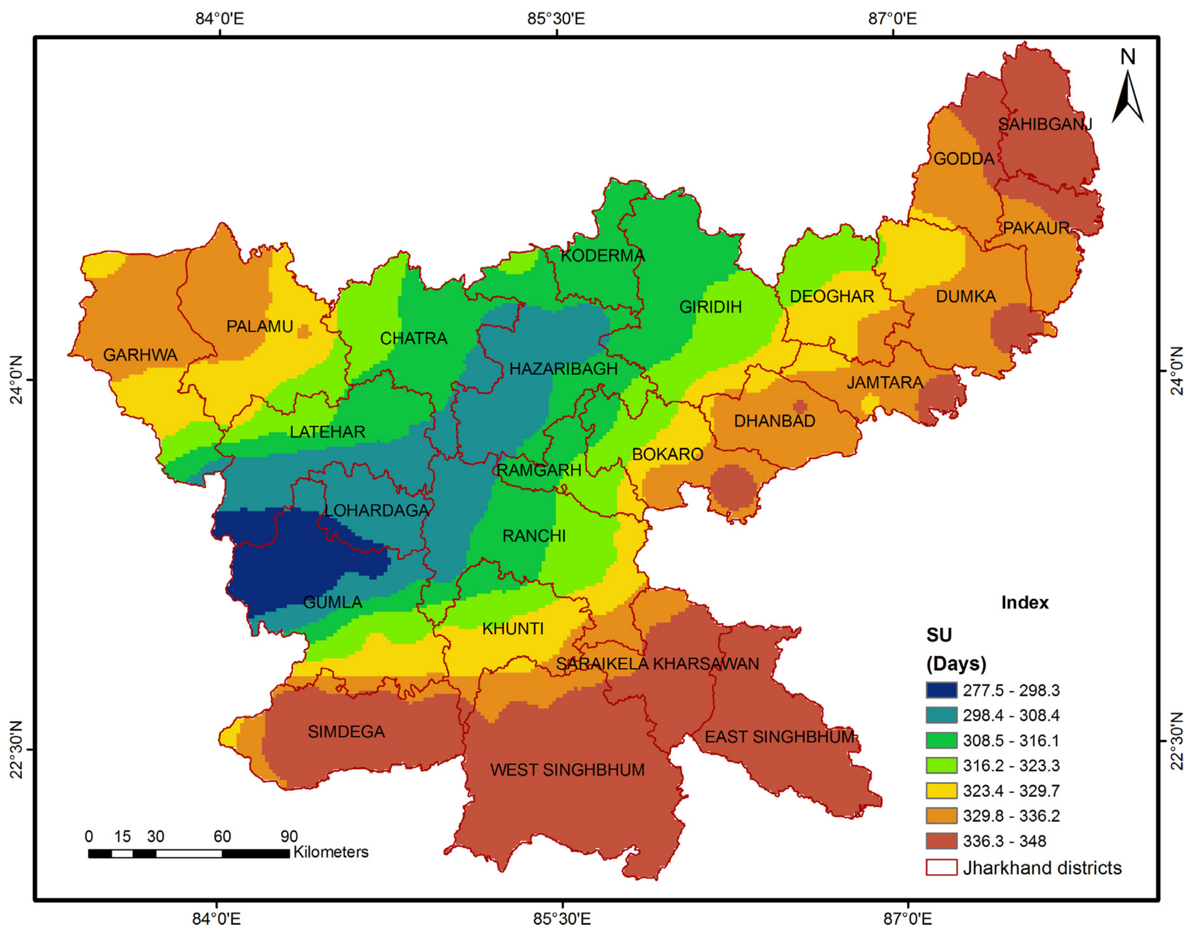

Fig. 10. Spatial distribution map of average number of summer days (SU index) during 1984–2014 in Jharkhand.

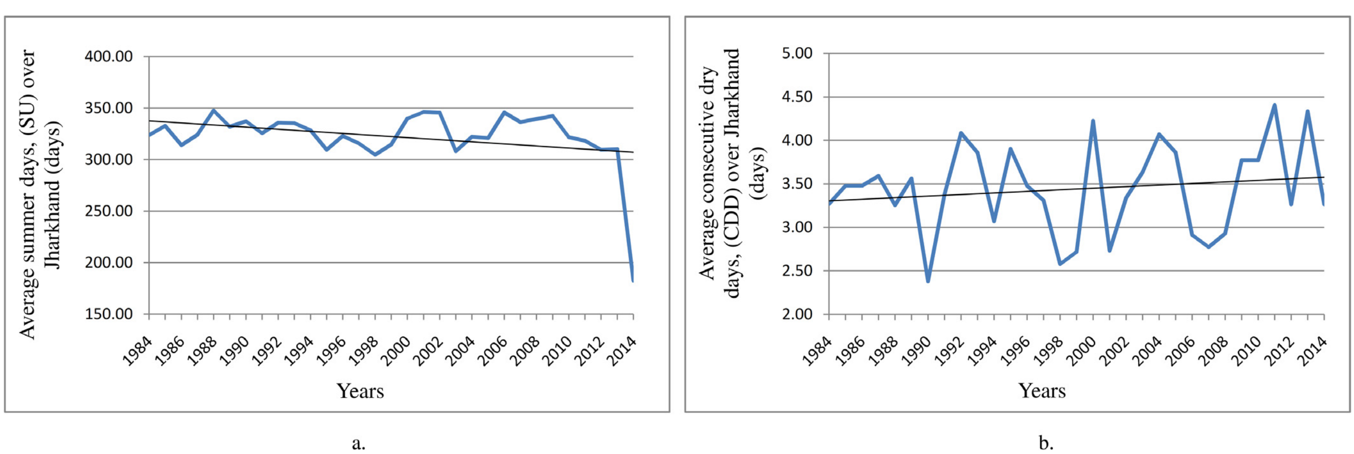

Fig. 11. Overall trends of climate extremes in Jharkhand during 1984–2014 depicting (a) average number of summer days (SU index) and (b) average consecutive dry days (CDD index).

district names of the NCEP CFSR data locations preferred for the analysis of PRCPTOT index is shown in Table 1. The Table 1 also shows the average annual PRCPTOT index values capable of wetting the ground at the corresponding locations having decreasing rainfall trend. The index helped in estimating the average annual number of rainy days during the monsoon season which were capable of wetting the ground (i.e. rainfall > 1 mm).

The reasons behind the decrease in annual precipitation in the northwestern districts of Jharkhand could be a shrink in the monsoon season (late onset and early withdrawal), increase in dry days or significant decreasing trend of rainfall (Guhathakurta and Rajeevan, 2008) as was also observed by Ramesh and Goswami (2007).

The study on assessment of the annual average rainfall during wet days, at spatial and temporal scale in these places highlight the importance of managing water availability in these places in response to climatic fluctuations, and help management personnel to solve problems associated with flash floods, and store the excess

Table 1
Village names of the NCEP CFSR data location points along with their corresponding PRCPTOT index values.

NCEP CFSR data location points	Village name and District	PRCPTOT index values (mm)
1	Chandna, Garhwa	1488.73
2	Putor, Garhwa	964.86
3	Danrai, Garhwa	948.24
4	Bisrampur, Garhwa	881.54
5	Nemha, Palamu	1321.16
6	Tukber, Palamu	911.57
7	Kokar, Palamu	822.18
8	Tisia, Latehar	1253.83
10	Naudih, Palamu	996.89
11	Bandua, Latehar	866.09
13	Gutuajokari, Gumla	1332.03
15	Kamal, Chatra	1204.35
16	Chiru, Latehar	1041.29
18	Dari, Gumla	1253.09
20	Taisera, Simdega	1232.09
21	Peksa, Chatra	1376.32
22	Chamranga, Ranchi	1106.25
23	Bhasnando, Ranchi	1308.46
26	Lohra, Hazaribagh	1239.94
27	Nawadih, Hazaribagh	1379.18
28	Haram, Hazaribagh	1214.82
29	Hariharpur, Ramgarh	1158.29
30	Namkum Block, Ranchi	1473.4
34	Sitwajunrormin, Koderma	1310.75
42	Arwaria, Giridih	1398.4
43	Arjunbandh, Giridih	1351.52
49	Dalouri, Giridih	1459.9
63	Godda, Godda District	1595.76
64	Ramgarh(Jamtar)Block, Dumka	1921.06
67	Mandro Block, Sahibganj	1455.07

water during floods for its utilization during droughts, allocation of water for agriculture, industry, hydropower generation, domestic and industrial use.

4.2.3. Consecutive dry days (CDD)

After observing a decreasing trend of rainfall and an increasing trend of maximum temperature in the northwestern districts of Palamu and Garhwa, an increase in the number of consecutive dry days is also observed in these regions (Fig. 12). This points that these parts of the state have been becoming extremely dry and warm, leading to water scarcity and ultimately to an alarming state of socio-economic and hydrological condition.

The Fig. 11(b) shows that the overall average consecutive dry days for the whole of Jharkhand have increased during the study period. Also, the spatial distribution map of average CDD (Fig. 12) shows that for Palamu, Garhwa and Latehar districts, the scenario is particularly serious, with 3.8–4.2 days on an average without any consecutive number of rainy days during monsoon. This leads to further drying up of the soil moisture due to heat. The districts of Chatra, Lohardaga, Hazaribagh, Ramgarh, Ranchi, Bokaro, Khunti, West Singhbhum, Dhanbad and part of Gumla and Giridih also show an increase in the number of average consecutive dry days (3.5–3.7 days of dryness on an average). Only the districts of Simdega, Gumla and Dumka show better hydrological conditions with comparatively lesser average number of dry days or vice-verse with more wet conditions hydrologically.

Thus, the CDD index analysis points that Palamu and Garhwa are the most vulnerable regions to drought and are also the most affected regions due to climate variability in Jharkhand. This index also summarizes clearly, the increase of warmer days and lack of

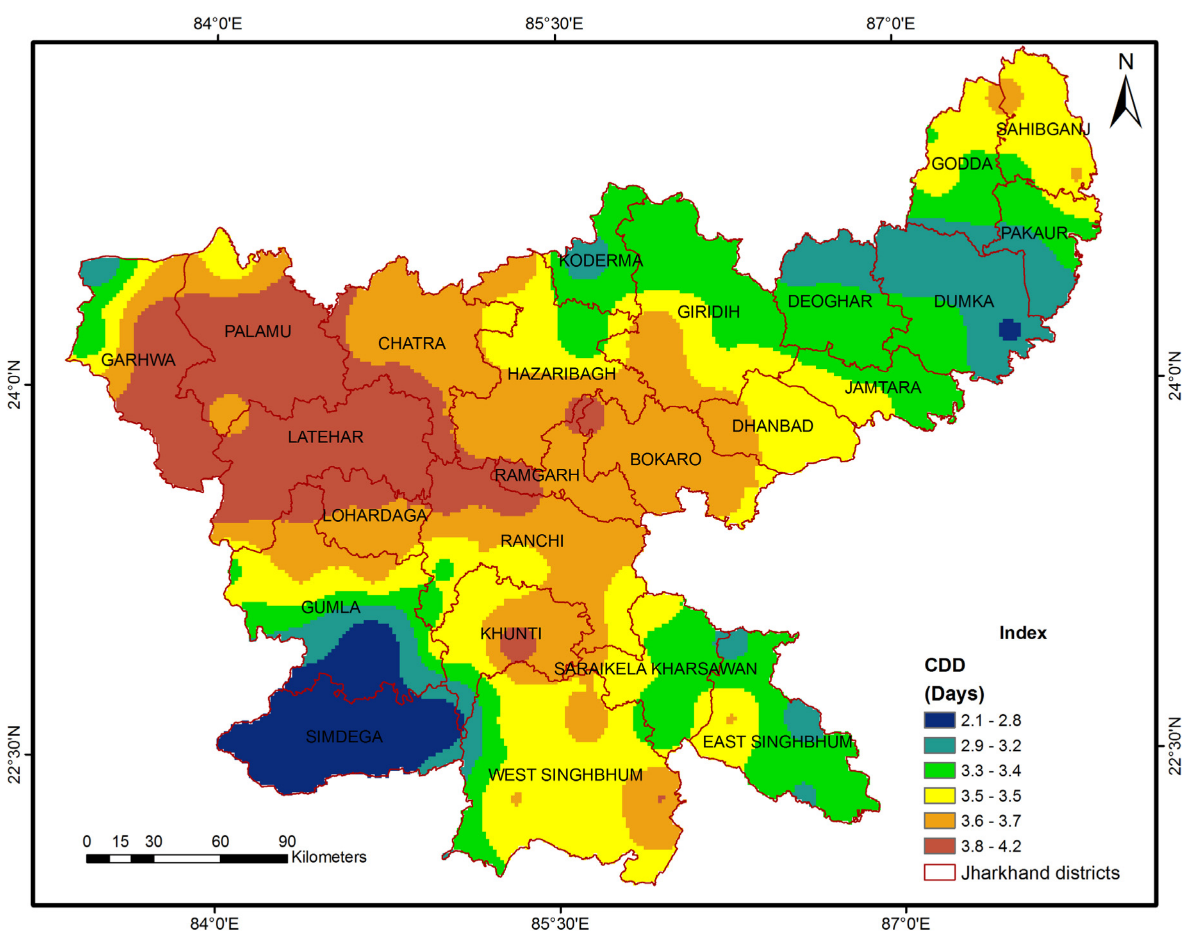

Fig. 12. Spatial distribution map of average number of consecutive dry days (CDD index) during 1984–2014 in Jharkhand.

sufficient rainfall which draws the attention for adopting appropriate watershed management techniques to improve the living conditions of people in these districts.

5. Conclusion

The present study highlights the climate variability over the state of Jharkhand. The spatial distribution of long-term trends of seasonal averages of maximum temperature, minimum temperature, solar radiation and rainfall evaluated for Jharkhand on monthly basis, illustrates different rates of increase and decrease of the climate parameters in the state.

The study shows that the average maximum temperature has significant increasing trend over the past 30 years and is particularly prevalent in the northwestern districts of Jharkhand (Palamu and Garhwa) where an increase is observed from 1–1.5 °C to a decrease of 0.82–0.14 °C in the northeastern and southeastern districts. The trend analysis of minimum temperature projects a colder drift in the central regions, (particularly in Ranchi, Ramgarh, and Khunti) where the decrease is observed from 0.39–0.79 °C to an increase of 0.59–0.41 °C in the northeastern districts. The trend analysis of cumulative rainfall shows that rainfall has a fluctuating trend with a decrease of 26–270 mm in the northwestern districts (particularly Palamu and Garhwa) to an increase of 19–440 mm in the rest parts of the state. The solar radiation during the kharif season decreases with a magnitude of 0.7–0.32 MJ/m^2 in the northern districts to an increase of 0.2–0.99 MJ/m^2 in the southern and central districts, whereas the solar radiation during rabi season fluctuates with an increase of 0.55–0.94 MJ/m^2 in the central and northwest region (Palamu and Garhwa) to a decrease of 0.13–0.72 MJ/m^2 in the southern regions.

The SU index analysis showed that the average number of summer days was highest (336–348 days) in the southern and northeastern districts particularly Simdega which recorded the highest average number of summer days (340–348 days). The northeastern districts recorded an average of 329.8–336.2 days of summer days. The Palamu and Garhwa districts also depicted moderately high average number of summer days (323.4–336.2 days).

The overall average CDD was also found to have increased during the study period. The scenario is particularly serious for Palamu, Garhwa, and Latehar districts, with 3.8–4.2 days on an average without any consecutive number of rainy days during monsoon. Thus, the CDD index analysis points that Palamu and Garhwa are the most vulnerable regions to drought and are also the most affected regions due to climate variability in Jharkhand.

The spatial analysis of the trend maps together with climate index maps, demonstrates the regions with increasing number of summer days, increasing maximum temperature and solar radiation, decreasing rainfall and thereby increased periods of consecutive dry days during the monsoon season particularly in the northwestern districts of Palamu and Garhwa. This focuses the need to conserve the water resources and manage the rapid land use land cover changes, mainly through urbanization and deforestation, and limit the climate fluctuations to some extent. The dry monsoon along with high temperatures implies higher drought risk and consequently a decrease in crop yields, socio-economic instability, and more undernourished people. The pressure on water resources needs to be regulated, as the society remains vulnerable when prolonged dry periods follow one another.

The results of this study demonstrated the importance of spatial domain for analysis because of the conflicting outcome with regional/local landscape, orography, or manmade land changes. The spatial maps provide easy access to government personnel in identifying the severely affected districts for immediate response and provide help accordingly.

Acknowledgements

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