MAUSAM, **70**, 3 (July 2019), 523-532

551.583 (540)

Analysing long term seasonal and annual trends for precipitation and temperature in Central India

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(*Received 20 July 2018, Accepted 20 May 2019*)

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सार – क्षेत्रीय स्तर पर जलवायु के विश्लेषण ने प्राकृतिक संसाधनों और खाद्ध फसलों के वितरण और उत्पादन को प्रभावित करने की उसकी क्षमता के कारण विशेष महत्व हासिल कर लिया है। जलवायु परिवर्तन के अध्ययन के लिए उप-मंडल या जिले जैसी छोटी इकाइयों में लंबे समय से अध्ययन करने की आवश्यकता रही है, क्योंकि जलवायु परिवर्तन के कारण अधिक वैश्विक होते हैं, लेकिन इसके प्रभाव स्थानीय स्तर पर महसूस होते हैं। मध्य भारत अपने विशिष्ट रूप से समृद्ध वन संपदा, अच्छे कृषि उत्पादन और विभिन्न जैव विविधता को अत्यधिक प्रभावित करने के लिए जाना जाता है। मध्य भारत में बड़ी संख्या में आदिवासी लोग वन संसाधनों से अपनी आजीविका और पोषण सुरक्षा पाते हैं। जलवायु परिवर्तन से इन प्राकृतिक संसाधनों के वितरण पर उनके फेनोलॉजी और उत्पादन में परिवर्तन होने की संभावना है। इस अध्ययन का उद्देश्य पश्चिमी (होशंगाबाद) और पूर्वी (मंडला) मध्य प्रदेश में बहु-दशकीय (45 वर्षों की) अवधि के लिए जिला स्तर पर जलवायु मापदंडों, (तापमान और वर्षा) में भिन्नता का अध्ययन करना था। मान-केंडल टेस्ट और सेन की ढलान अनुमानक का उपयोग मापदंडों में परिवर्तन की दिशा और परिमाण का अध्ययन करने के लिए किया गया।

मंडला में औसत न्यूनतम तापमान में महत्वपूर्ण रूप से गिरावट का रूझान देखा गया है। मॉनसून और मॉनसूनोत्तर के महीने सूखे रहे हैं, जबकि मॉनसून पूर्व अवधि में वर्षा हो रही है। होशंगाबाद में हुई कुल वर्षा से वर्षा के रिकार्ड में बड़ा बदलाव दिखा है। राज्य में पश्चिम की तरफ वर्षा अधिक होने लगी है।

ABSTRACT. Analysis of climate on regional scales has acquired special importance due to its ability to influence distribution and production of natural resources and food crops. There has been a long felt need for doing the climate variability studies at smaller units like sub-division or district, as causes of climate change are more global but there impacts are felt locally. Central India is uniquely known for its rich forest wealth, good agricultural production and being home to varied bio diversity. Large number of tribal people in Central India derives their livelihood and nutrition security from forest resources. Climate change is likely to impact the distribution of these natural resources by altering their phenology and production. This study was aimed to study the variation in climatic parameters (temperature and precipitation) at district level for multi-decadal (45 years) period in Western (Hoshangabad) and Eastern (Mandla) Madhya Pradesh. Mann-Kendall Test and Sen's Slope Estimator was used for studying the direction and magnitude of change in the selected parameters.

Significant downward trends of Mean minimum temperature have been noticed at Mandla. Monsoon and post monsoon months are getting dried while pre-monsoon periods are becoming wetter. The rainfall records show a big shift in the total rains received at Hoshangabad. A westward shift in rainfall is seen in the state.

Key words – Climate change, Central India, Temperature, Precipitation, Mann-Kendall.

1. Introduction

Humanity has seen an unprecedented growth in the post-industrial era. Along with growth in gross domestic production humans have also increased their ecological footprints. Under the threat of global warming the monitoring of rise in greenhouse gases has become a must. According to the Intergovernmental Panel on Climate Change (2007) climate change will affect agriculture, increase the risk of hunger; water scarcity and will lead to rapid melting of glaciers in future. Hydrological cycles and pattern of stream flows are likely to change under the influence of global warming (Kumar *et al*., 2010; Kumar *et al*., 2016).

Climate is the average of long time weather conditions in an area. Though there are multiple climatic elements to study the changes but the most accepted and widely used ones are the variations in temperature and precipitation. Gradients of degree of hotness and moisture level govern the distribution of range of life forms. There has been a rise in frequency and intensity of extremes of higher temperatures and rainfall over many parts of India (Chakraborty and Srivastava, 2006; Roxy *et al*., 2017). Investigators have shown consistent trend of warming over Indian subcontinent over the last century (Hingane, 1996; O'Hare *et al*., 1998; Goswami *et al*., 2006; Singh *et al*., 2008).

Changing climate and vulnerabilities arising from it equally bother national governments. According to the estimates of the Indian Government impact of climate change will be non-linear and will be felt more in events of extremes (Economic Survey, 2018). Predicted impacts from shocks of extremes of rainfall are weighted to be more than the shock from extremes of temperature. Governments focus remains majorly on ensuring food security and hence it deciphers patterns of climate change mainly to take policy action for farm sector. Land under irrigation has increased from 20% in 1960s to around 48% (Financial express, Jan, 2018). The increased area under irrigation has its own drawbacks, spread of irrigation is taking place at the cost of groundwater depletion, which gets replenished majorly from rainwaters. Groundwater in India has declined by 61% between 2007 and 2017 (Hindustan Times, Apr, 2018). Unlike agriculture, forests have only two sources to meet the moisture requirements: atmospheric precipitation and the below ground water. With no source of irrigation, falling water table and inadequate rainfall, it is highly likely that in future species with deep root systems will be favoured over shallow rooted species.

Analysis of climate on regional scales has acquired special importance due their ability to influence geographic distribution of natural resources (Gupta *et al*., 2014; Srivastava and Bhattacharya, 2015) and altering food production. Central India is an important part of the country for its rich forest wealth, good agricultural production and home for biological diversity. Large number of tribal people in Central India derives their livelihood and nutrition security from forest resources. Climate change is likely to impact the distribution of these natural resources by altering their phenology and production. Most of the climate variability studies are at pan India level or at broader regional level. Kumar *et al*. (2010) has recognised the need for doing the variability studies at smaller units like sub-division or district. The causes of climate change are more global but there impacts are felt locally. Analysis of empirical evidences is

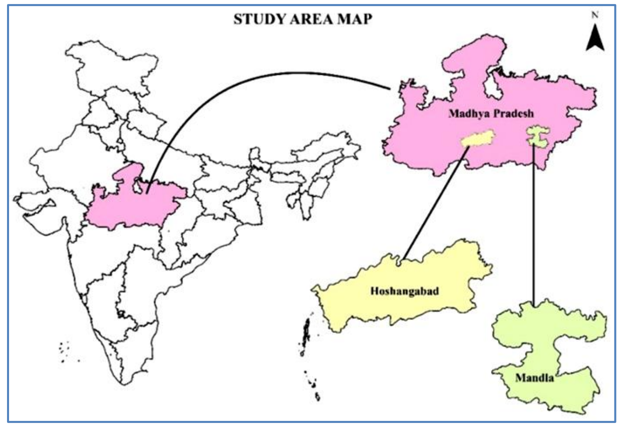

Fig. 1. Study area map

needed to prepare adaptation strategy to meet the local needs. This makes it an urgent need of analyzing the long term trends of temperature and precipitation and the implication of these changes at local level. This study was aimed to study the variation in climatic parameters at district level.

2. Methodology

2.1. *Study area and data used*

IMD has made two sub-divisions in Madhya Pradesh (M.P.) Western Madhya Pradesh and Eastern Madhya Pradesh (http://www.imd.gov.in). Western Madhya Pradesh is the drier part receiving less rainfall and high temperatures compared to eastern Madhya Pradesh. One district from each sub-division were selected for study, Hoshangabad from Western M.P. and Mandla from eastern M.P. Fig. 1 gives the study area map. Around 90% of Hoshangabad lies in the western part while Mandla lies completely in the eastern part of the state. Data for selected climatic parameters were obtained for two districts, *i.e*., Hoshangabad and Mandla from Regional Meteorological Centre, Nagpur, Maharashtra. Climatic data of 45 years' time period (1971-2015) was acquired. Monthly rainfalls for both the districts have been computed by arithmetic mean of the available stations in respective districts (Guhathakurta *et al*., 2011). Mean maximum Temperature and mean minimum Temperature were expressed in °C, Average monthly rainfall was expressed in mm and rainy days in numbers.

2.2. *Data analysis*

MAKESENS (Mann-Kendall Test and Sen's Slope Estimates for the Trend of Annual Data) 1.0 was used for analysis of data for different climatic variables for both the districts. It is a MS excel template, developed by

TABLE 1

Sen estimator of slope for monthly mean maximum and mean minimum temperature, average rainfall (mm) and rainy days (/month) at Hoshangabad (Bold values indicate statistical significance at 95% confidence interval)

Month ↓	Maximum temperature (Mean)		Minimum temperature (Mean)		Average rainfall (mm)		Rainy days/month (1980-2015)	
Time series →	Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q
January	**1.84**	0.038	0.31	0.006	0.36	0.000	-0.059	0.000
February	1.38	0.039	0.07	0.000	0.00	0.000	0.283	0.000
March	**2.92**	**0.054**	-0.45	-0.006	0.17	0.000	0.831	0.000
April	**2.93**	**0.033**	0.34	0.000	**2.01**	**0.000**	0.660	0.000
May	**2.76**	**0.026**	-0.13	0.000	0.59	0.022	1.337	0.000
June	0.18	0.000	0.75	0.014	-0.32	-0.335	-0.055	0.000
July	**2.69**	**0.028**	**1.68**	**0.015**	**1.76**	**3.858**	1.616	0.130
August	**2.38**	**0.021**	**1.79**	**0.015**	-0.98	-2.445	-0.985	-0.071
September	1.64	0.017	**2.41**	**0.017**	0.28	0.233	0.631	0.032
October	1.61	0.016	0.18	0.000	0.43	0.050	0.028	0.000
November	**2.23**	**0.026**	1.55	0.046	0.08	0.000	-0.080	0.000
December	1.08	0.024	0.77	0.013	-1.45	0.000	**-1.946**	**0.000**

TABLE 2

Sen estimator of slope for annual and seasonal mean maximum and mean minimum temperature, average rainfall (mm) and rainy days (/month) at Hoshangabad (Bold values indicate statistical significance at 95% confidence interval)

Season ↓	Max. temperature (Mean)		Mini. temperature (Mean)		Rainfall (mm)		Rainy days/month	
Time series →	Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q
Annual	**4.21**	**0.028**	1.48	0.012	-0.17	0.046	0.900	0.011
Pre-monsoon	**4.03**	**0.041**	0.11	0.001	0.82	0.051	1.375	0.011
Monsoon	**2.66**	**0.016**	**1.78**	**0.015**	-0.13	-0.098	0.628	0.023
Post-monsoon	**2.61**	**0.019**	1.13	0.020	-1.14	-0.110	-0.619	0.000
Winters	**2.26**	**0.037**	0.10	0.001	0.30	0.000	0.296	0.000

Finnish Meteorological Institute (Salmi *et al.*, 2002) to study the trends in time series data.

MAKESENS detects the presence of monotonic increasing or decreasing trend with non-parametric Mann-Kendall test. It also estimates a slope of linear trend with non-parametric Sens's method (Gilbert, 1997). Data need not conform to any particular distribution. Mann-Kendall test checks the null hypothesis of claiming no trend against the alternative hypothesis of the existence of a trend. A positive Z value indicates an upward trend while a negative Z value indicates a downward trend. The test was performed at alpha value of 0.05. The magnitude of the trend in the time series was determined using Sen's estimator (1968).

The Sen's method can be used where the trend is assumed to be linear.

$$f(t) = Qt + \mathrm{B}$$

where, B = constant and Q = slope

To get the slope estimate Q in the equation, we first need to calculate the slope of all data value pairs.

$$Q_i = \left(X_j - X_k / j - k\right); \qquad \text{where, } j > k$$

The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked

TABLE 3

Sen estimator of slope for monthly mean maximum and mean minimum temperature, average rainfall (mm) and rainy days (/month) at Mandla (Bold values indicate statistical significance at 95% confidence interval)

Season ↓	Mean Maximum temperature (°C)		Mean Minimum temperature (°C)		Rainfall (mm/month)		Rainy days/month	
Time series →	Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q
January	1.31	0.016	0.70	0.004	-0.60	0.000	-0.65882	0.000
February	1.86	0.021	0.19	0.000	-1.06	-0.252	-0.98538	0.000
March	0.08	0.000	-0.75	0.000	1.11	0.121	1.44095	0.006
April	-1.17	-0.013	-1.29	-0.011	0.83	0.062	1.091856	0.000
May	0.08	0.000	**-2.03**	**-0.019**	0.96	0.034	0.548545	0.000
June	0.49	0.000	-0.78	-0.009	-0.23	0.000	-0.27647	0.000
July	1.12	0.015	-1.53	-0.014	0.06	0.000	-1.19929	-0.040
August	0.92	0.005	**-2.69**	**-0.017**	-1.28	-2.029	**-2.56122**	**-0.040**
September	**2.17**	**0.019**	-1.75	-0.014	-1.03	-0.812	-0.69997	0.000
October	1.78	0.019	-1.43	-0.022	1.05	0.200	0.614786	0.000
November	**2.43**	**0.023**	1.32	0.024	0.16	0.000	0.010444	0.000
December	**2.78**	**0.029**	0.65	0.000	0.29	0.000	-0.05371	0.000

TABLE 4

Sen Estimator of slope for Annual and seasonal Mean maximum and Mean minimum temperature, Average Rainfall (mm) and Rainy days(/month) at Mandla (Bold values indicate statistical significance at 95% confidence interval)

Season ↓	Mean Maximum temperature (°C)		Mean Minimum temperature (°C)		Rainfall (mm)		Rainy days	
Time series →	Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q
Annual	**2.82**	**0.015**	-1.06	-0.009	-1.82	-0.473	-1.87039	-0.021
Pre-monsoon	-0.23	0.000	-1.57	-0.013	0.99	0.121	1.370051	0.0037
Monsoon	1.68	0.013	-1.83	-0.015	-1.66	-1.142	-1.99096	-0.044
Post-monsoon	**2.74**	**0.025**	0.46	0.004	0.17	0.004	-0.22667	0
Winters	**1.97**	**0.023**	0.96	0.003	-1.04	-0.216	-0.66919	0

from the smallest to the largest and the Sen's estimator is calculated using the following equation:

$$Q = {}^{1}\!/_{2}\left[Q_{[N/2]} + Q_{N+2/2}\right]$$

3. Results and discussion

The magnitude and direction of change detected in all studied parameters for the monthly trend analysis is given in Tables 1 and 3 for Hoshangabad and Mandla district, respectively. The magnitude and direction of trend for annual and seasonal time series is given in Tables 2 and 4 for Hoshangabad and Mandla respectively.

3.1. *Variations in temperature*

Great variations in the mean maximum temperatures have been noticed at both the sites. All months that are showing significant variations are indicating an upward trend in this parameter. At Hoshangabad for half of the total months in a year the mean maximum temperature has shown an increasing trend. As a result all the seasonal and the annual time series has also shown an upward trend, indicating intrusion of summers in winter months at this district. Magnitude of increase, interpreted by Q values from Table 1, is showing a maximum increment of 0.054 °C/ Year in pre-monsoon month of March. Temperature is clearly on an ascending path in Hoshangabad district.

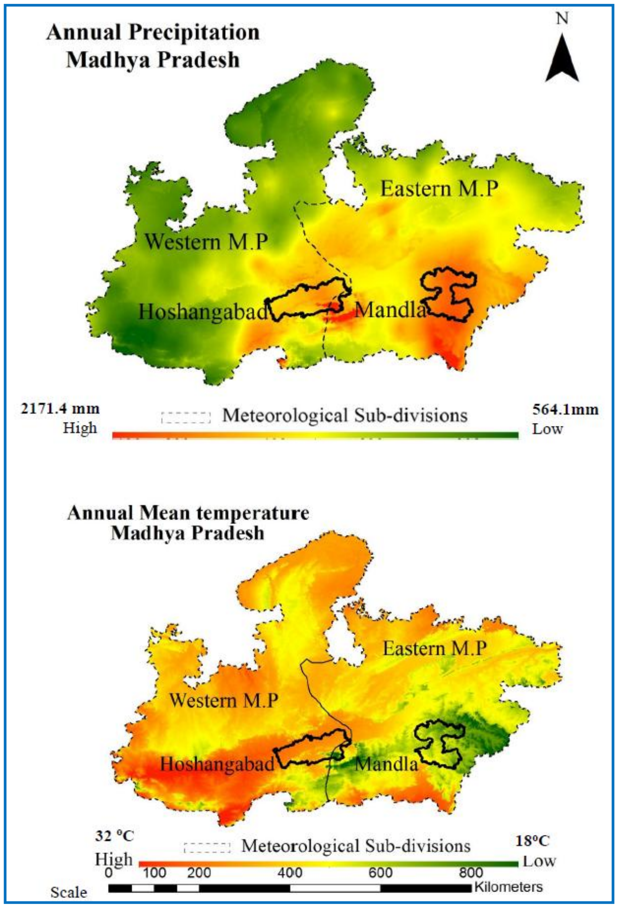

Fig. 2. Districts location and gradients in annual mean temperature and annual rainfall in Madhya Pradesh

At Mandla, three out of twelve months have shown significant variation in mean maximum temperature since 1971. All these three months are pointing towards an upward trend of mean maximum temperature. Maximum increase was found in the post-monsoon months of November and December, *i.e.*, 0.023 °C/Year and 0.029 °C/Year respectively. Among monsoon months September has become warmer by 0.019 °C/Year. Post-monsoon and winter temperatures have increased resulting in an overall increase of 0.015 °C/Year in annual temperature at Mandla district.

Heterogeneity in Mean minimum temperature was seen at Mandla. Significant downward trends of Mean minimum temperature have been noticed in the months of May and August at Mandla, while winter and post monsoon months show an upward trend. Homogeneously rising Mean minimum temperature was observed at Hoshangabad. Sheikh *et al*. (2014) have analysed the extreme weather trends in South Asia region and found that warm extremes have become more common than cold extremes in this part of the world.

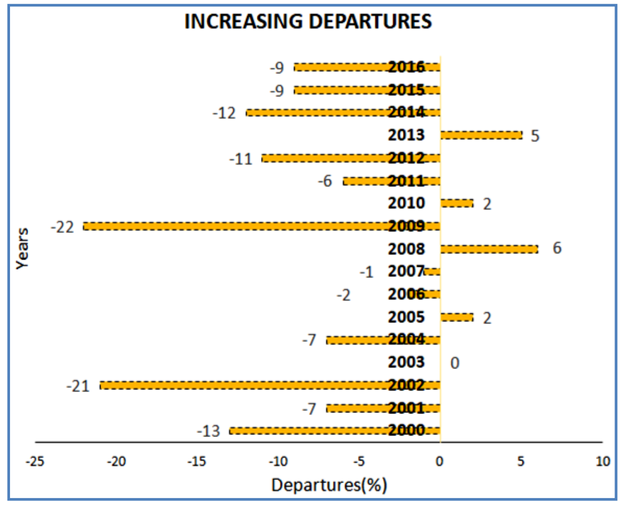

Fig. 3. National Yearly departure of annual rainfall from normal for period 2000-2016

The great variations in temperatures at both the district could be due to their geographical locations. Western Madhya Pradesh is the direr part receiving less rainfall and high temperatures compared to eastern Madhya Pradesh. Maps depicting study districts' location, gradients in annual temperature and annual precipitation, along with IMD's meteorological sub-divisions of Madhya Pradesh are shown in Fig. 2. Annual mean temperatures are lower in Mandla than in Hoshangabad.

3.2. *Rainfall and rainy days*

According to India Metrological Department (IMD), a rainy day has been defined as a day with rainfall of 2.5 mm or more. Rainfall can be as high as 25 cm or there can be no rain in a day. On the basis of the amount of rainfall received (mm), IMD has divided the rainy days into five categories as given in Table 5. "% Departure" is the departure of realised rainfall from the long-time average precipitation (rainfall normal). "Rainfall Normal" (RN) is based on the rainfall records at 2412 locations spread across the country from 1951-2000 (Kaur and Purohit, 2015). If the precipitation is at least 20% more than the normal, it is counted as "Excess". Negative departure of 60% or more is defined as "scanty" rains. 100% negative departure from the normal is "No rain".

3.3. *National annual precipitation trends*

During last 16 years, the country received annual rainfall of less than 5% of its normal rainfall (Kaur and Purohit, 2015). Positive departures were seen only in four years out of sixteen, rest of the years showed negative departure from the normal. A maximum negative

TABLE 5

Classification of % departure range

Category	Departure from normal
Excess	Percentage departure of realised rainfall from normal rainfall is + 20% or more
Normal	Percentage departure of realised rainfall from normal rainfall is between – 19 % to + 19 %
Deficient	Percentage departure of realised rainfall from normal rainfall is between – 20 % to – 59 %
Scanty	Percentage departure of realised rainfall from normal rainfall is between – 60 % to – 99 %
No Rain	Percentage departure of realised rainfall from normal rainfall is – 100 %

Source : http://imd.gov.in

TABLE 6

Seasonal departure from normal for Madhya Pradesh, Mandla and Hoshangabad for 2012-2016 period

Location	Period	Departure (%)				
		Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Rainfall Normal for Madhya Pradesh (mm)	1951-2000	23.3	18	952.3	54.8	1048.4
Madhya Pradesh	2012	11	-74	6	-80	0
	2013	64	-5	37	74	38
	2014	198	-15	0	-17	-15
	2015	103	372	-11	-55	-5
	2016	-45	25	19	-35	11
Mandla	2012	83	-100	2	-54	-1
	2013	2	38	28	103	31
	2014	26	-49	-15	43	-12
	2015	-37	300	-21	-59	-14
	2016	-49	-14	16	-36	11
Hoshangabad	2012	20	-33	30	-74	24
	2013	234	52	51	-7.1	51
	2014	266	-53	-22	-14	-18
	2015	182	437	-11	-59	-4
	2016	-57	-37	63	-22	56

departure of more than 20% was seen in the years 2002 and 2009. As per Indian Meteorological Department (2017), India's five hottest years since 1901 came in last 15 years only. All five hottest years (2016>2009>2010> 2015>2002) were El-Niño years. The annual mean land surface air temperatures were more than the normal global climate during these years. Past decade was also the hottest decade on record. Years 2000, 2002, 2009, 2012 and 2014 had negative rainfall departures of more than 10%. Fig. 3 is showing the yearly national departure of rainfall for the period 2000-2016.

3.4. *Local departing trends*

To see whether the local precipitation patterns are varying as per the national rainfall trends, we studied the precipitation patterns of our state of interest, Madhya Pradesh and of its two districts Mandla and Hoshangabad. Table 6 contains information about the normal seasonal rainfall and the departure trends for the state and districts of interest for the period 2012-2016. Monthly departure trends from normal, for the period 2012-2016, are given in Table 7.

TABLE 7

Monthly departure from normal for Madhya Pradesh for 2012-2016 period

Month	Departure (%)					
	Normal (mm)	2012	2013	2014	2015	2016
January	13.4	84	-86	108	184	-15
February	9.6	-92	280	328	-13	-89
March	7.9	-94	39	32	688	14
April	3.3	-64	74	-9	469	-99
May	6.8	-54	-95	-72	-43	98
June	117.7	-57	142	-51	27	-10
July	316.2	28	49	-1	12	53
August	335.2	9	35	-34	-17	27
September	183.2	2	-51	-8	-66	-36
October	35.4	-83	163	-19	-35	0
November	10.4	-57	-96	-76	-93	-100
December	9	-80	-80	61	-89	-100

TABLE 8

Seasonal variations in Rainfall (mm) at Mandla and Hoshangabad

Period	Mandla				Hoshangabad			
	Winter	Pre-monsoon	Monsoon	Post-monsoon	Winter	Pre-monsoon	Monsoon	Post-monsoon
1971-75	227.4	164.8	6408.9	689.5	97.2	43.5	6263.5	262
1976-80	360	170.3	5386.1	479.3	129.4	139.4	4876.2	355.5
1981-85	467.3	183.7	5957.9	202.1	151.9	145.4	5176.2	364.5
1986-90	423	241.2	6116.8	251.6	143.6	141.4	5460.9	299
1991-95	134.7	241.1	5535.6	203	65.5	135.5	6619.3	62.6
1996-00	335.9	225.6	5426	387.3	166.5	442.4	5398.3	359.6
2001-05	211.3	235.1	5377.5	395.3	128	110.9	5764.1	143.2
2006-10	168	274.4	5193.9	488.9	64.4	190.3	5590	307.3
2011-15	237.1	233.9	4967.6	300.3	171.4	135.5	6123	126.8

In pre-monsoon months of March and April 2015, Madhya Pradesh received excess rainfall, than normal. During post-monsoon season of 2015, different parts of the state reported deficient, scanty or no rain. Out of twelve months of the year 2015, only three months (February, July and August) had normal rainfall. In the year 2012, the state saw negative departure for most part of the year (eight months). In 2014, the winter period recorded excessive rain, while most part of the year reported rainfall deficit. The decreasing trend is due to the decline in rainfall during winter, monsoon and post monsoon periods. Monsoon periods are getting dried while pre-monsoon periods are getting wetter. Out of 4 months that are counted as monsoon months in India, three of them faced negative departures.

3.5. *Declining precipitation and fewer rainy days*

Analysis of seasonal as well as monthly rainfall variations clearly shows that, over the years, the readings on the rain gauge for India are on a declining path. Fig. 4 shows distribution of rainfall received (as total of five

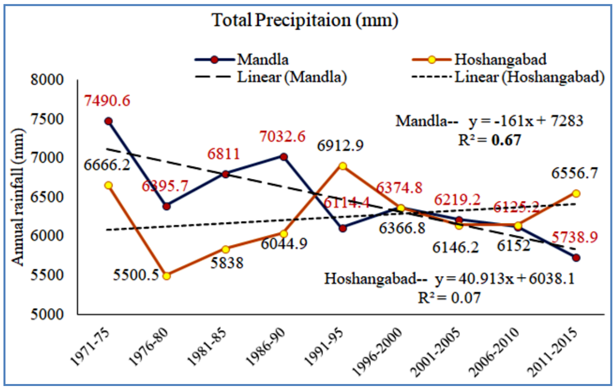

Fig. 4. Total rainfall received at Mandla and Hoshangabad (Five years total)

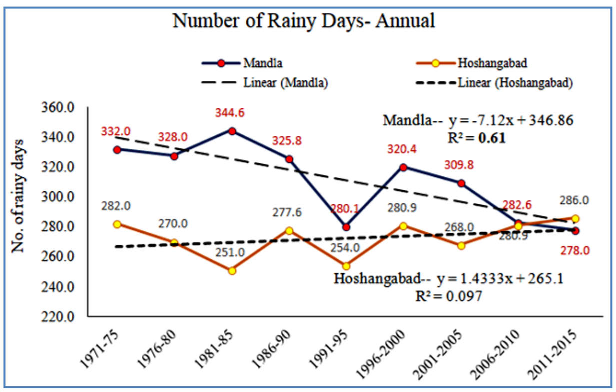

Fig. 5. Number of rainy days at Mandla and Hoshangabad (Five years total)

years) over a time period of 45 years. Table 8 gives the seasonal distribution of realised rainfall in Mandla and Hoshangabad.

Mandla received 7490.6 mm of total annual rainfall in the period 1971-1975, however in the period 2011-2015, it received only 5738.9 mm, indicating towards loss in yearly precipitations (R^2 = 0.67). The annual rainfall received in the period 2011-15 is less than what the district has received in the monsoon season alone during the period 1971-75. June, August and September are the monsoon months in India and there is a significant loss of water received in these months. In the studied years, winter rainfall was the lowest in the period 1991-1995. If this period (1991-95) is excluded from the analysis, then the average rainfall received in winter months shows an increase with each passing year. Pre-monsoon period has shown a gradual uplift in precipitation received. In the period 1971-75, Mandla district received a total of 164.8 mm of pre-monsoon showers, while during the period 2011-2015 it received 233.9 mm of downpour. During monsoon, except for the period 1991-1995, all other years have seen a downward slope in realized rainfall. Rainfall in monsoon period in 1971

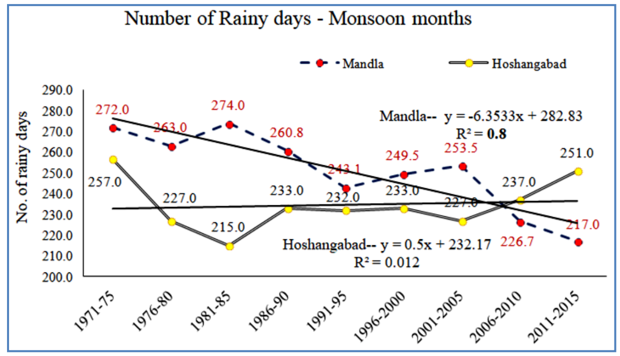

Fig. 6. Number of rainy days in monsoon months at Mandla and Hoshangabad (Five years total)

was 6408.9 mm, whereas the district received only 4967.6 mm rainfall in 2015. In post-monsoon period too, a deficit in precipitation has been noticed, from 689.5 mm in 1971 to 300.3 mm in 2015. Fig. 5 gives total number of rainy days observed at Mandla and Hoshangabad whereas Fig. 6 gives the number of rainy days in monsoon months at Mandla and Hoshangabad.

Hoshangabad is located in less rainfall receiving western part of Madhya Pradesh. The rainfall records show a big shift in the total rains received at Hoshangabad. Since 1991, this district has received rains nearly equal to or more than the wetter Mandla. A westward shift in rainfall activity over the Indo-Gangetic Plain region has been reported by Mall *et al.* (2007). Hoshangabad received 798.5 mm of more rains than what was received by Mandla during the period 1991-95. For the period 2011-2015, Hoshangabad received 817.8mm of more rains than the wetter district Mandla. Seasonally, the precipitation patterns are heterogeneous for Hoshangabad. Rainfall trends at Hoshangabad, except for the month of April, don't show any significant difference in our analysis performed using Mann-Kendall test. Though not statistically significant, annual and monsoonal rainfall have shown a declining trend, while winter and pre-monsoon rains show an increasing pattern. Trends show that annual rainfall in Mandla has decreased in last 45 years and both the districts are receiving nearly the same amount of annual rainfall from 1996 onwards.

Kumar *et al.* (2010) too reported trends of rainfall for Central India based on larger data set (135 years). They studied the long term trends of rainfall in India, covering all 32 meteorological sub-divisions made by IMD. Decline in annual and monsoon rainfall was reported for both Madhya Pradesh and West central region. Drying up of monsoon months (−15 mm decade^{-1}) and fewer rainy days has also been reported by Lacombe & McCartney (2014), who studied consistency patterns of rainfall trends in India. Numbers of rainy days in Mandla for the month of August have decreased significantly over the years. August is one of the good rainfall receiving months in Central India; a decline in rainy days in this month alone has impacted the total rainy days in the monsoon season.

India receives majority of its rainfall from south-west monsoon winds, majority of Central Indian sub-divisions (Jharkhand, Chhattisgarh) are facing a rainfall deficit in monsoon months (June-September) and significant changes in number of rainy days (Guhathakurta and Rajeevan, 2007; Kumar *et al*., 2016). Both the Figs. 5 and 6 are clearly indicating a decline in number of rainy days for both monsoon months as well as for whole of the year in studied districts. Goswami *et al*., 2006 reported increasing events of heavy to very heavy rainfall, whereas the events of low rainfall are declining in their frequency over the central parts of India. Reduction in observed rainy days has been bigger in Mandla (R^2 = 0.6) than in Hoshangabad. After 2001, an increase in number of rainy days has been observed at Hoshangabad for both annual and monsoon months, whereas Numbers of rainy days have decreased significantly at Mandla (R^2 = 0.8) for the same time periods.

4. Implications of climate change in Central India

The present study has analysed trends of temperature, rainfall and number of rainy days at the district level. Minimum 30 years of data is often considered as enough to detect any change in climate of the region. Reduction in total precipitation received, fall in number of rain days and increasing temperatures is evident from analysis of 45 years of data. This indicates towards changing climatic conditions in the region, ushering the region into harsher and drier climate.

Central India is home to large number of tribal population that derives its livelihood from forests and forest based industry. Climate change will have sever implications for people who are dependent of forest resources. Bhattacharya and Prasad (2009) documented the drying up of Indian Monsoon. They reported the failure of agricultural crops and forest resources due to erratic rainfall and drought like conditions in Sheopur district of Madhya Pradesh. Nearly 173,000 of villages in India are classified as forest villages (Chaturvedi *et al*., 2010), pointing towards higher vulnerable population. Continuous deficient rainfall period coupled with warm extremes is catastrophic for natural forests, as it robs the soil of its moisture and compromises the survival of root inhabiting my corrhizal fungi essential for nutrient uptake, seedlings survival and maintenance of diversity (Devi *et al*., 2017).The negative changes in the ecosystem resulting from climate change can affect tree health and nutrition. Change in phenology is the first response of flora towards climate change, which leads to range shifts. Signs of malnutrition in plants can be seen in the form of excessive leaf drop and discoloration of leaves (The Hindu, June, 2018). The irony is that forests are not covered under any type of insurance schemes and no compensation is paid in the event of forest failure year as in the case of crop failures. As World Bank put it the impact of climate change on agriculture and livelihoods may increase the number of climate refugees (World Bank, 2013). Planning, while keeping in mind the changes at micro - level, will help in reducing such vulnerabilities.

Acknowledgements

Authors thank the India Meteorological Department, Pune for providing the required data on time. The institutional support provided by the Dean, University School of Environment Management, Guru Gobind Singh Indraprastha University, Delhi is greatly acknowledged. Thanks are due to the University Grants Commission, New Delhi, for financial support under Junior Research Fellowship Scheme to Seema Yadav. Authors are also thankful to Dr. D. R. Pattanaik, Scientist ‘E’, IMD for his valuable suggestions during discussion.

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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