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Himanshu Bana (✉ hbana@ce.iitr.ac.in)

Indian Institute of Technology Roorkee

R. D Garg

Indian Institute of Technology Roorkee

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*Himanshu Bana,

R. DGarg

himanshu_roorkee1@yahoo.com garg_fce@iitr.ac.in

Research Scholar, Professor

Department of Civil Engineering, Indian Institute of Technology, Roorkee 247667, India

Abstract

The present research work conducts a seasonality and trend analysis of rainfall over the 8 districts of the Marathwada region of India. The study is carried out for the last 39 years, ranging from 1980 to 2018. The rainfall data analysed pertain to the premonsoon season, monsoon season (Kharif), and annual rainfall. The trend was estimated using Sen's slope estimation process along with the Mann-Kendal test. All eight districts of the region show a negative trend in the annual rainfall received. Nanded district showed the largest negative trend in annual rainfall. Out of eight districts, seven districts of the region show a decline in rainfall during the monsoon season. The district of Nanded showed the largest decline in the rainfall received during the monsoon season. The present research work concludes with a discussion on the possible causes of such estimated trends.

Keywords Seasonality Index, trend estimation, Marathwada

Introduction

The melting of glaciers, frequent droughts, and increases in regional temperature are some of the climate changes that are expected to affect the agricultural scenario of the world. Due to these adverse climate changes, it has been predicted by the Intergovernmental Panel on Climate Change that these unfavourable events might lead to a scarcity of drinking water and water resources. As per the panel, this scarcity of water resources will cause a drop in per capita freshwater availability. The effect of this drop would be visible by 2025.

Many researchers in the past have indicated that changes in climatic conditions will bring both scarcity of precipitation and increased intensity of precipitation. The increased intensity of precipitation will result in intense flooding, flash flooding, and higher run-off during the monsoon season. As the run-off will increase, less precipitation will percolate. This lesser percolation is bound to negatively affect ground water recharge. This negative effect on groundwater recharge will subsequently result in a decrease in the water table and a lower volume of water available for anthropometric activities. The prediction of the scarcity of water along with the occurrence of extreme events suggests that climate change affects precipitation at both local and regional scales.

(Cruz et al. 2007) indicated that in Asia-Pacific regions, agricultural activities are highly dependent on groundwater and monsoons. Thus, depleting the water table and less precipitation will adversely affect the cropping system in the region. As the cropping system will be affected, the production, productivity, and net area sown under the principal crops in the region will also be affected.

The IPCC has also predicted that there is a probability that the global surface temperature might increase by 1.8°C by the end of 2021. Many researchers in the past have worked upon the sensitivity of crops to surface temperature. (Aggarwal 2007) through his research work that focused

on assessing the probable impact of temperature rise on the production of wheat in India. Through mathematical modelling, the researcher determined that a 1°C rise in temperature is sufficient to drastically reduce the production of wheat.

The study of rainfall variation in India has been of special interest to researchers for a long time. Many researchers focused on studying the variations in different regions of India even before the subject of climate change was prominent. The special interest in studying the variations present in rainfall comes from the fact that Indian agriculture is entirely dependent on rainfall. No state in India has a proper network of canals and channels that can supply water for irrigation to farmers except Punjab and Haryana. Due to the unavailability of irrigation infrastructure, farmers in India are dependent on monsoons. If the monsoon system performs poorly in any year, the production of Kharif crops will be drastically affected. This monsoon-dependent characteristic of Indian agriculture is called 'Gamble on Rains'.

(Duhan and Pandey 2013) focused on determining the trend in rainfall in the northeastern states of India. The authors focused on determining the trend present in the northeastern states because these states suffer from both scarce rainfall and heavy rainfall. Due to the inadequacy of the irrigation system, decreased rainfall results in poor agricultural production, while increased rainfall always poses a certain danger of flooding due to Brahmaputra breaking its banks. Researchers in the past also indicated that monsoons present a decreasing trend in the states of Chhattisgarh, Jharkhand, and Kerala. In recent years, the monsoon in India has been weakened by the El Niño Southern Oscillations (ENSO). ENSO negatively affects the monsoon over India. This negative effect causes less than normal rainfall during phases of El Niño.

The Marathwada region of Maharashtra is a drought-prone area. The Latur and Osmanabad districts of the region are some of the worst affected regions of the country. In 2016, numerous full capacity trains with tankers attached that were converted as water storage tanks were ferried to Latur to meet the water scarcity requirements of the district. The year 2016 was not the first time Latur suffered from severe water shortages in April 2016. Latur faced droughts in the 1980s as well in the 1990s. However, the scarcity of water event in April 2016 was an extreme event. The research work tries to explore the probable reasons for such extreme events through rainfall time series analysis.

Materials and Methods

The region selected for the study is Marathwada. The Marathwada region is a group of districts located in the southwestern region of the state of Maharashtra. The region comprises districts namely, Beed, Latur, Parbhani, Hingoli, Jalna, Aurangabad, Osmananbad, and Nanded. The region lies near the northern ranges of western Ghant. The location of the study region is shown in Figure 1. The region was previously known for its sugarcane and cotton production. However, the region has started to witness an increased frequency of below normal rainfall during the monsoon season, which has reduced sugarcane cultivation in the region. Furthermore, the area becomes an area of interest for the study because the district of Latur recently faced one of the worst water crises in the history of Independent India. Special trains across the country ferried fresh water to the district to meet its drinking water demand during the premonsoon period.

The present study is based on data recorded at 8 stations in the Marathwada region of the state of Maharashtra. The period of the data is from 1980 to 2018 (last 39 years). The data were procured from the India Meteorological Department (IMD). The rainfall data used in this research work were recorded at the stations in the form of direct observations. The rainfall data utilized in this research work were subjected to a homogeneity test for homogenization. The data contained no missing values. The trend in the rainfall in the selected districts was estimated on an annual, premonsoon, and Kharif

season. The premonsoon months were selected as March, April, May. The Kharif season was selected as June-July August and September.

Figure 1 Study Area: Eight districts of Marathwada region

Analysis

For the study seasonality index (SI), standard deviation (SD), coefficient of variance (CV), Sen Slope and Mann-Kendall test were utilized. The seasonality index helps in determining the contrast in the rainfall regime. This process is done by utilization of rainfall monthly distribution data. In other words, the seasonality index helps in the identification of monthly rainfall variability (Kanellopoulou, 2002). Seasonality is a function of the mean monthly rainfall and mean annual rainfall. The seasonality index is computed as

$$SI = \frac{1}{A} \sum_{n=1}^{12} \left| X_n - \frac{A}{12} \right|, (1)$$

X_n is the rainfall calculated for the n^{th} month. A is the total annual rainfall. Theoretical variations in the seasonality index can be from 0 to 1.83. If all the months record equal rainfall, then the SI becomes zero. If all rainfall occurs in one month, then the SI becomes 1.83 (Ingle, Patil, Mahale, & Mahajan, 2018). The SI also suggests changes in rainfall pattern (Walsh & Lawer, 1981).

The rainfall regimes associated with the different values of the seasonality index are shown in Table 1.

Table 1 Rainfall regimes and associated seasonality index

Regimes	Seasonality Index (SI)
Very Equable	Less than or equals 0.19
Equable, but with a definite wetter season	0.20-0.39
Rather Seasonal with short drier season	0.40-0.59
Seasonal	0.60-0.79
Marked Seasonal with long drier season	0.80-0.99
Mostly rain in 3 months or less	1.00-1.19
Extreme, almost rain in 1 to 3 months	Greater than or equals 1.20

Along with the identification of rainfall regime seasonality index indicates towards soil and vegetation characteristics along with hydric stress in the region.

Rainfall trend analysis can be performed by using different available parametric and nonparametric methods (Yadav, Tripathi, Pranuthi, & Dubey, 2014). These analyses are generally

meant to analyse the trend present in long-term datasets. However, these techniques are also used to determine trends in short-term data series(Ahmad, Tang, Wang, Wang, & Wagan, 2015). These short-term data series can be shortened to ten data points. The restriction associated with the use of parametric tests in trend determination is that the data points in the time series should follow a distribution. Nonparametric tests do not pose such restrictions and are minimally affected by any outliers present in the dataset. In the present work, the trend present in the rainfall data was analysed using the Mann-Kendal test and slope estimates. The slope estimates were determined using the Sen slope estimation process. Mann-Kendall tests are widely utilized for the determination of trends that are monotonous in nature in noncyclic data sets(Tabari, Marofi, & Ahmadi, 2011). The wide popularity in determining the trend present in rainfall data using the Mann-Kendall test is because the Mann-Kendal test does not require a particular distribution. Another important characteristic of the Mann-Kendal test is that it is least sensitive towards inhomogeneity present in the time series(Karmeshu, 2012). The time series is thus assumed to obey the following model.

$$x_i = f(t_i) + e_i(2)$$

where $f(t)$ is the monotonic decreasing or increasing function of time. The residual is represented by e_i . It is also assumed further that the variance of the distribution is constant over time. Furthermore, it is also assumed that the autocorrelation in the data set is zero(Yue, Pilon, & Phinney, & Cavadias, 2002).

The estimate of the slope, which is denoted by Q , is calculated by the following process(Shahid, 2011):

First, the slope between all pairs of data values is determined. The procedure for the same is as followed.

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i=1,2,3,\dots,k \quad (3)$$

Where, x_j and x_k are the data values at time j and k ($j > k$).

For a time series that contains n values, N is determined using -

$$N = n(n-1)/2$$

The N values are ordered ascendingly before the application of T in the equation presented below. Estimator of Sen's slope is representative of the median of these N values of Q_i

The Q is thus given by,

If N is odd,

$$Q = T_{(N+1)/2} \quad (4)$$

If N is even,

$$Q = \frac{1}{2} (T_{N/2} + T_{N/2+1}) \quad (5)$$

A normal distribution is applied for the determination of the two-sided confidence interval related to the estimate of the slope. In the dataset of the time series, the downward or decreasing trend is indicated by the negative value of Q , while an upward or increasing trend is determined by the positive value of Q .

Mann-Kendal test null hypothesis that the data series are from normal distribution. The alternate hypothesis is that there exists a monotonic linear trend in the data. To test the hypothesis at

the significance level, the following example is presented. If the significance level of 0.001 is kept for the test, it indicates that there exists a 0.01% probability that the values of the time series are from a random distribution. Similarly, if the significance level is kept at 0.05, then it is assumed that there exists a 5% probability that the values of the time series are from a random distribution. The Mann-Kendall test statistic S is determined using the formula (Gilbert, 1987)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (6)$$

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad (7)$$

The number of data points in the time series under consideration is denoted by n, x_j is the rainfall sum in year j, and x_k is the rainfall sum in year k. Here, the j^{th} value is greater than the k^{th} value. The present work fixes the significance level as 0.05 for the test. Since the number of data points would be greater than ten, the distribution of S was approximated using a normal distribution. The estimation of the trend line was performed using the linear regression method (Wang, et al., 2020).

Result

Seasonality Index

The results of the seasonality index are presented in Table 2. The seasonality index reveals that in Beed, Latur and Osmanabad face, frequent long drier seasons (SI ranging between 0.8 and 0.99, marked in red colored cells). In these districts, the long drier season occurred 11, 13, and 9 times, respectively, in 39 years. Parbhani, Hingoli, Jalna, Aurangabad, and Nanded also face long drier seasons, but in these districts, the occurrence of long drier seasons is less than that in the other three districts. The district of Nanded faced the least number of long drier seasons in the last 39 years. The seasonality index in the Nanded district for most of the years is greater than 1, which indicates that the district receives rains in almost three months or less. The district of Latur faced two consecutive long drier seasons in the last 39 years. The first occurred from 1985 to 1987, and the second occurred from 2013 to 2015. Furthermore, the district of Latur faced a long drier season in alternate years from 1987 to 1992 and from 2002 to 2006.

Table 2 Seasonality Index for the last 39 years for Districts of Marathwada Region

Year	Beed	Parbhani	Hingoli	Latur	Jalna	Aurangabad	Osmanabad	Nanded
1980	1.21	1.07	1.3	1.19	1.25	1.24	1.25	1.24
1981	0.85	1.15	1.03	1.02	1.24	0.9	0.94	1.16
1982	1.05	1.06	0.94	1.04	0.9	0.92	0.95	1.05
1983	1.17	1.04	1.19	1.15	0.92	1.24	1.12	1.17
1984	1.11	1.04	1.11	1.07	1.24	1.1	1.11	1.09
1985	1.09	1.09	1.07	0.97	1.1	1.15	1.05	1.03
1986	1.1	1.28	1.14	0.87	1.15	1.22	1.11	1.07
1987	0.99	1.18	1.12	0.92	1.22	1.05	0.94	1.03
1988	1.26	0.98	1.24	1.27	1.05	1.09	1.19	1.16
1989	1.14	1.39	1.2	1.11	1.09	1.2	1.08	1.22
1990	0.98	1.06	1.03	0.97	1.2	0.95	0.92	0.97
1991	1.27	0.95	1.38	1.12	0.95	1.33	1.09	1.25
1992	1.14	1.03	1.11	0.97	1.33	1.15	1.01	1.13

1993	0.95	0.86	1	1.04	1.15	1.01	1	1.05
1994	0.88	1.24	1.16	1.05	1.01	0.92	1.02	1.11
1995	0.93	0.78	0.94	0.92	0.92	1.1	0.9	1.02
1996	1.17	1.08	1.2	1.14	1.1	1.12	1.1	1.16
1997	0.75	1.13	0.91	0.71	1.12	0.87	0.76	0.78
1998	1.1	1.31	1.04	1.06	0.87	1.07	1.12	1.08
1999	1.05	1.2	1.14	0.95	1.07	1.09	1	1.13
2000	1.2	1.17	1.37	1.13	1.09	1.12	1.11	1.2
2001	1.2	1.23	1.23	1.14	1.12	1.13	1.17	1.2
2002	1.14	1	1.26	0.94	1.13	1.17	1	1.25
2003	1.06	1.13	1.25	1.18	1.17	1.04	1.01	1.18
2004	0.89	1.13	1.07	0.89	1.04	1.12	0.83	1.01
2005	1.16	1.31	1.12	1.09	1.12	1.2	1.16	1.11
2006	0.95	1.21	1.17	0.96	1.2	1.11	1	1.19
2007	1.28	0.91	1.31	1.26	1.11	1.22	1.15	1.23
2008	1.05	1.14	1.24	1.13	1.22	1.24	1.14	1.22
2009	0.84	1.23	0.89	1.02	1.24	1.05	0.92	1.05
2010	1.05	1.17	1.12	1	1.05	0.94	1.01	1.07
2011	1.18	1.02	1.28	1.3	0.94	1.25	1.15	1.26
2012	1.15	0.98	1.17	1.16	1.25	1.17	1.13	1.15
2013	1.01	0.99	1.07	0.96	1.17	1.09	1.01	1.01
2014	0.9	1.13	1.1	0.85	1.09	0.91	0.79	1.08
2015	0.87	1.16	1.01	0.81	0.91	1.05	0.82	0.87
2016	1.12	1.27	1.12	1.07	1.05	1.2	1.09	1.09
2017	1.14	1.2	1.15	1.1	1.2	1.15	1.1	1.1
2018	1.18	1.11	1.33	1.05	1.15	1.23	0.95	1.19

Rainfall Trend

The trend in the annual rainfall for the various districts of the Marathwada region is shown in Table 3.

Table 3 Annual Rainfall Trend Analysis for the last 39 Years (1980-2018)

District	Mean (mm)	Standard Deviation (mm)	Sen's Slope (mm/Year)
Beed	745.33	187.45	-1.962
Parbhani	872.20	246.12	-6.090
Hingoli	903.80	250.53	-4.771
Latur	814.83	210.11	-0.460
Jalna	747.47	167.87	-1.703
Aurangabad	680.276	156.01	-1.787
Osmanabad	737.724	193.05	0.021
Nanded	985.91	311.88	-5.60*

*Statistically significant

The mean rainfall in the Beed district was 745.33 mm from 1980 to 2018. The annual rainfall trend for the last 39 years shows a negative trend in the annual rainfall received by the district. The Sen's slope determined for the annual rainfall received by the district in the last 39 years is -1.962 mm/Year. The mean rainfall in the Parbhani district was 872.20 mm from 1980 to 2018. The annual rainfall trend for the last 39 years shows a negative trend in the annual rainfall received by the district. The Sen's slope determined for the annual rainfall received by the district in the last 39 years is -6.090 mm/Year. The mean rainfall in the country's one of most severe and frequent drought-affected district Latur was 814.83 mm from 1980 to 2018. The annual rainfall trend for the last 39 years shows a negative trend in the annual rainfall received by the district. The Sen's slope determined for the annual rainfall received by the district in the last 39 years is -4.771 mm/Year. The mean rainfall in the Nanded district was 985.91 mm from 1980 to 2018. Out of the 8 selected districts, Nanded received the highest mean annual rainfall during the last 39 years. The annual rainfall trend for the last 39 years shows a negative trend in the annual rainfall received by the district. The Sen's slope determined for the annual rainfall received by the district in the last 39 years was -5.60 mm/year, which was a statistically significant negative trend.

The premonsoon season holds special importance in the Marathwada region. The region is known for its water-intensive crops, such as sugarcane (GWP, 2016). Industries in and around the Marathwada region are also known to use water intensively. These industries include sugar mills and cotton dying industries. Real estate activities are also on the rise in the region (Sandbhor, 2013). The traditional construction approach adopted in the region requires excessive use of water for curing cement and wall plaster. The demand for sugarcane increases in the summer season because fresh juice stalls and sugar mills boost their production to stock sugar for the upcoming festive seasons (Singh R., 2011). Farmers increase the brix content of the crop and increase the internodal gap in the sugarcane, and farmers use excessive water in the fields during the premonsoon season (Manwar & Vadiya, 2015). Farmers in the region typically use the drenching method of irrigation, which also accounts for the loss of precious water reserves (Sabesh, Ramesh, Prakash, & Bhaskaran, 2014). Such anthropogenic activities that require water intensively pose a certain threat to the water availability in this already drought-susceptible region. From Table 4, it is evident that the premonsoon rainfall trend is positive for all 8 districts under consideration. The districts of Jalna and Aurangabad show a positive trend in the premonsoon rainfall, but the trend determined is minuscule. The largest positive trend in the premonsoon rainfall was observed for the Osmanabad district. The increasing positive trend is beneficial for the water-intensive crops sown in the district.

Table 4 Premonsoon rainfall trend analysis for the last 39 years (1980-2018)

District	Mean (mm)	Standard Deviation (mm)	Sen's Slope (mm/Year)
Beed	31.86	29.81	0.295
Parbhani	27.67	28.30	0.192
Hingoli	22.02	24.33	0.108
Latur	43.82	33.28	0.393
Jalna	20.76	24.23	0.017
Aurangabad	16.55	23.58	0.049
Osmanabad	36.92	29.72	0.485
Nanded	29.82	31.34	0.254

However, the positive trend determined for the premonsoon rainfall in the districts was not statistically significant.

Table 5 Kharif rainfall trend analysis for the last 39 years (1980-2018)

District	Mean (mm)	Standard Deviation (mm)	Sen's Slope (mm/Year)
Beed	609.66	179.318	-0.956
Parbhani	744.89	229.24	-2.809
Hingoli	792.54	227.45	-3.154
Latur	656.82	191.40	0.458
Jalna	620.59	152.30	-1.385
Aurangabad	557.71	131.31	-1.669
Osmanabad	571.12	167.68	-0.266
Nanded	836.07	274.27	-3.996

The monsoon season is the time to sow the Kharif crops. Kharif crops are known to be water intensive. Farmers in the region have a strong affinity for sowing water-intensive crops in the region. Scarcity of water in the germination and early development stages results in osmotic stress (Pote & Kale, 2019). Such stress stunts the growth of the crop. Farmers are known to sow crops such as cotton and groundnut in the early monsoon season. Water-intensive crops such as sugarcane are sown in the middle of the monsoon season so that the crop can be harvested by March to May (Garkar, 2017). Therefore, good monsoons are essential for the Marathwada region from an agricultural perspective. Table 4 shows that the highest mean rainfall in the monsoon season was received by the Nanded district. The districts of Aurangabad and Osmanabad received mean rainfall of 557.71 mm and 571.12 mm, respectively. Latur, which is one of the drought-susceptible districts of the country, received a mean rainfall of 656.82 mm in the monsoon season. Sen's slope estimate shows a negative trend in the rainfall received by the districts during the monsoon season. As per Table 5, the Beed district shows a negative trend of -0.956 mm/year. The district of Parbhani shows a negative trend of -2.809 mm/year. The district of Nanded shows the highest negative trend of -3.996 mm/Year, followed by the district of Hingoli, which shows a negative trend of -3.154 mm/Year. Only the district of Latur shows a positive trend of 0.458 mm/Year for the rainfall received in the monsoon season. The negative trend in seven out of eight districts of the region is bad from the perspective of sugarcane producers of the region. Figures 2 to 9 show the trend obtained for the rainfall received by the districts in the monsoon season.

From the analysis of annual rainfall received by the districts and rainfall received by the districts in the monsoon season, it is evident that the scarcity of rainfall in the region is on the rise. Seven out of eight districts of the region showed a negative trend in the annual rainfall received.

Figure 2 Monsoon rainfall trend from 1980 to 2018 in the Beed District

Figure 4 Monsoon rainfall trend from 1980 to 2018 in Hingoli District

Figure 3 Monsoon rainfall trend from 1980 to 2018 in Parbani District

Figure 5 Monsoon rainfall trend from 1980 to 2018 in Latur District

Figure 6 Monsoon rainfall trend from 1980 to 2018 in Jalna District

Figure 8 Monsoon rainfall trend from 1980 to 2018 in Osmanabad District

Figure 7 Monsoon rainfall trend from 1980 to 2018 in Aurangabad District

Figure 9 Monsoon rainfall trend from 1980 to 2018 in Nanded District

Discussion

The Thar Desert and adjoining areas of the central and northern subcontinents heat up during the summers. This creates a void. To fill up the void, the air from the Indian Ocean rushes into the mainland. The air is laden with moisture picked up from the ocean surface. The Himalayas checks the rushing in air and presents a block to it so that the air does not rush into central Asia. As wind rises, precipitation occurs, and India receives rainfall (Rajeevan, Pai, Kumar, & Lal, 2007). This rainfall season is also known as the Southwest Monsoon. The Marathwada region of the state of Maharashtra receives the southwest (SW) monsoon. The period of Southwest Monsoon starts in June and ends in early to mid-October. The southwest monsoon is considered the principal rainy season in India. Nearly the whole country receives rainfall during this period. The southwest monsoon accounts for nearly 75% of rainfall in the country; thus, agrarian activities are dependent on it (Sasane, 2017).

The SW monsoon is important from India's agricultural perspective. India does not possess any significant irrigation network. Only the states of Punjab and Haryana have proper irrigation infrastructure in place (Skutsch & Rydzewski, 2001) (Jain, Kishore, & Singh, 2019). Agriculture in the rest of the country either survives on monsoons or depends upon the groundwater source (Kumar K., 2004). This is due to this high dependency on monsoon Indian agriculture, which is often referred to as gamble on rains (Gadgails & S, 2006). The characteristics of Indian agriculture are such that farmers, despite being heavily dependent on rains, sow water-intensive crops on a large scale in the Kharif season (monsoon). Such crops are Paddy and Sugarcane. Paddy is prominently grown in the central and eastern regions of India, such as Chhattisgarh and West Bengal, while sugarcane is a prominent Kharif crop of Maharashtra that belongs to the western region of India. These crops are sensitive to climate change, as it brings rise in temperature and water scarcity (Assessing Paddy Rice Yield Sensitivity to Temperature and Rainfall Variability in Peninsular Malaysia Using DSSAT Model, 2017). These effects, along with ENSO, bring uncertainty over the amount of rainfall (Tamaddun, 2019). Thus, climate change poses a certain threat to Indian agriculture.

From the analysis, it is evident that the amount of rainfall in the districts of Marathwada is decreasing. The decreasing trend was determined for the annual rainfall in all districts. Farmers in the region are known to produce sugarcane. Sugarcane demands extensive irrigation to increase the brix content, grass weight, and node-to-node distance. With decreasing rainfall in the region, farmers are facing a loss in production. The average productivity of sugarcane crops in the Marathwada region is 50 tons per acre, while the average productivity of the crop in the state of Maharashtra is 80 tons per acre (Upreti & Singh, 2017). Thus, it can be concluded that the decline in rainfall in the monsoon season (Kharif) shows its effect on the productivity of the crop in the region. The absence of irrigation infrastructure in the region renders farmers utilize groundwater for irrigation purposes. This activity further adds up to the woes of the farmers themselves. With a decline in rainfall, the percolation of water during the rainy season also declines, which restricts the recharge of the water table (Dias, et al., 2015). Utilization of ground water in such cases only degrades the water table. Farmers who are not sowing sugarcane are also facing the effects of decreased rainfall. In recent years, farmers of the Latur district had to resow their crops because of the long drier season (Jamwal, 2017).

It is observed that along with annual rainfall, monsoon rainfall also depicts a negative trend. The trends are huge for districts such as Hingoli, Parbhani, and Nanded. Latur and Osmanabad are the districts that are already receiving less rainfall. In such cases, when the amount of rainfall received is declining, farmers should shift from sugarcane crops to less water-intensive crops. The crop area under the water guzzling sugarcane crop from impulsive growth. The agricultural activity of such water intensity is an anthropogenic activity that is added to the water crisis of the region. The seasonality index indicates that the Latur frequently faces long drier seasons. The inferior quality of

soil in the Udgir, Ausa, and Ahmedpur taluka of the Latur district becomes hard during the long drier seasons, which, along with the steep terrain of the region, restricts the percolation of water during the rainy season, thus further restricting groundwater recharge.

Agriculture is not the only anthropogenic activity that is creating a water crisis in the region. Jhum style or the shifting style of agriculture is also prominent in the region. Illegal encroachment of forestland is common in the region. The land is cleared by burning the vegetation present (Gabhiye & Mandal, 2000). The burning of vegetation leads to minimization of the temperature difference between the land and the Indian Ocean (Singh & Singh, 2012). This reduction in the temperature between land and sea restricts the draft of air from the ocean, which further decreases the rainfall amount. Sugarcane crops not sold to sugar mills are crushed down in makeshift factories to produce jaggery and country liquor. Bagasse is used as a biofuel for the production of heat needed for making jaggery and liquor. The burning of such biofuels is a prominent activity in the region (Kulkarni S. , 2018). Although bagasse has a low sulfur content, burning it on a large scale releases ample amounts of sulfur dioxide, greenhouse gases and nitrogen oxides into the atmosphere (Halofsky & Harvey, 2020). These emissions further reduce the difference between land and ocean temperatures and thus act as a weakening force for the monsoon system. The warming of the Indian Ocean also leads to rainfall woes in India. The warming of the Indian Ocean is leading to a decrease in the difference between ocean and land temperatures. This further reduces the rainfall received by the region. Warming of the Indian Ocean also results in the occurrence of extreme events (Roxy & Gnanaseelan, 2020). The extreme rainfall event in the district of the Latur and Nanded Marathwada region has been credited with the warming of the Indian Ocean (Yaduvanshi & Kulkarni, 2020). The occurrence of such extreme rainfall events in the backdrop of monsoon reduction might lead to a sequence of catastrophic events, such as the loss of livestock, poverty, and agrarian crises.

Conclusion

All the districts of the Marathwada region of Maharashtra state are witnessing a decline in annual rainfall. The decline in the annual rainfall was largest for the Nanded and Parbhani districts. The decline in the annual rainfall in the Nanded district was found to be statistically significant. Out of eight districts, seven districts of the region have witnessed a decline in monsoon rainfall over the last 39 years. The calculated seasonality index indicates that Latur, Beed, and Osmanabad are the drier districts of the region that receive rainfall for more than 3 months. The negative rainfall trend observed might pose a threat to the highly monsoon-dependent agriculture of the region. The farmers of the region therefore should migrate from sowing water-intensive crops to less water-intensive crops such as sorghum and pearl millet. Sugarcane can also be replaced with mandarin, which is a less water-intensive cash crop. In cases where farmers are not able to shift to other crops, irrigation management systems, such as irrigation through drip irrigation and rain pipes, should be implemented. If a negative trend in rainfall is not effectively managed through changes in crops and the control of anthropogenic activities, the region of Marathwada might enter advanced phases of agrarian crisis, which might also lead to the collapse of the agricultural system of the districts comprising it.

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