Assessing Rainfall and Temperature Trends in Maharashtra State, India: A Spatio-Temporal Analysis

ABSTRACT

Examining the effects of climate change is critically dependent on the spatio - temporal analysis of meteorological variables, particularly in areas where agriculture depends on rainfall. The present study analyses the change in temperature and rainfall using Mann-Kendall and Sen's slope estimator and also identifies the variations in rainfall by using Rainfall Anomaly Index (RAI). The main purpose of this study is to assess the variation in climatic variable (temperature and rainfall) across the regions of Maharashtra over 50 years (1968-2017) which might be helpful toidentify strategies that can aid in addressing the consequences of extreme climate events in the future and in formulating appropriateregion-specificstrategies. The trend of rainfall and temperature series for the kharif and rabi season revealed a significant increasing trend for maximum and minimum temperature, however nonsignificant decreasing trend for kharif and rabi rainfall. The RAI value indicates a relatively a greater number of dry periods in Marathwada and Vidarbha region in comparison to the Konkan, Western Maharashtra and Khandesh. The findings of the study can be useful in developing plans to manage water resources effectively and reduce the adverse impacts of droughts basically in the Marathwada and Vidarbha regions.

Keywords: Agriculture, drought, trend, temperature, rainfall, rainfall anomaly index

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Comment [D3]: When was this data collected?

1.INTRODUCTION

Increase in global surface air temperature during the recent decades is one of the most sensitive issues of recent times. The global mean temperature is steadily increasing and is projected to increase by 2 ^{o}Cuntil 2100, leading to significant economic damages at the global level (Malhi etal., 2021). India as a developing country is more vulnerable to climate change. The major reasons behind this are its reliance on agriculture, small landholdings, limited financial resources, insufficient technology, and inadequate institutions to manage the adverse impacts of climate related shocks (Rao et al., 2011). The farming community in India is also facing a significant challenge posed by climate change. The alterations in climatic variables such as temperature, rainfall, relative humidity, wind speed, and solar radiation have both direct and indirect impacts on farm productivity. The summer monsoon precipitation (June- September) has a direct impact on the total foodgrain yield during the Kharif season in India. It also indirectly affects the Rabi crop yield through water and soil moisture availability (Prasanna, 2014). The estimates suggest that climate change is likely to worsen the food and livelihood security, resulting in a decrease in yield of major crops by approximately 9-18 % (Pathak 2022).

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Maharashtra state is one of the developed and industrialized state, contributing highest in country's GDP. Despite its progress, around 50% of the area in the state is prone to drought and it faces rainfall deficits once in every 5 to 6 years, and severe drought conditions occur once every 8 to 9

Comment [D6]: Is drought the problem?

years(Katalakute et al., 2016). The estimates of rainfall deficiency in the state ranges from 43 to 73 % (Amrit etal., 2020). The future projection (2015–2100) for all the meteorological sub-division of Maharashtra reveals that these regions are likely to experience significant increase in monsoon rainfall by 150–210 mm, except Konkan. Whereas entire state shows an increase in annual mean temperature (AMT) by 0.5–2.5 ^{0}C up to 2050 (Todmal et al., 2021).

Comment [D7]: Reference on this 2015 – 2100 projection is important to add and the page.

The spatial and temporal analysis of temperature and rainfall is an essential tool to assess the climate variability and change in the climate. Although climate change has a global impact, it also affects regions and localities differently, highlighting the significance of evaluating trends, makingprojections,and developing localized strategies to mitigate its impact. The present study analyses the changes in temperature and rainfall during 1968-2017 in Maharashtra state by using Mann-Kendall and Sen's slope estimator statistical tests. The findings of this study shall be very useful for making regional as well as district-level strategies for mitigation and build resilience against extreme climate events.

Comment [D8]: Why is this study important?

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2. STUDY AREA AND METHODOLOGY

Maharashtra is located between 15°35' N to 22°02' N latitude and 72°36' E to 80°54' E longitude and occupies the central and western part of the country. Maharashtra is the third largest state in terms of area, encompassing 9.4% (3,07,731 km^2) of the country's landmass. With a population of approximately 112 million people, it is the second most populous state in the country. The State is divided into five main regions viz., Vidarbha, Marathwada, Khandesh,Western Maharashtra and Konkan and four meteorological subdivisions, namely Konkan–Goa, Madhya Maharashtra, Marathwada and Vidarbha. The Western Ghat is one of the prominent biodiversity resource for the region and an important climatic divide of the state. The State also displays a significant disparity in the distribution of rainfall, with the Konkan region's coastal belt, spanning about 720 km along the Arabian Sea, receiving the maximum amount of rainfall, while the Marathwada and rain shadow regions suffer from a scarcity of rainfall which are prone to drought. In Maharashtra, drought is one of the major natural calamities which poses a substantial threat to the state's economy and agricultural progress.

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Comment [D13]: It is also important to talk about the soil type, vegetation, crops grown in the area, livestock and settlement types common in the study area.

2.1 Trend estimation

The detection of significant trends in time series data on climate variables can be calculated using either parametric or non-parametric methods. Parametric trend tests necessitate that the data be both independent and normally distributed, whereas non-parametric trend tests only require that the data be independent (Gocic and Trajkovic, 2013). This study utilized two non-parametric methods, namely Mann-Kendall and Sen's slope estimator, examining the direction and magnitude of trends in maximum temperature, minimum temperature, and rainfall. The Mann-Kendall test is a non-parametric method for detecting trends in time series data. It involves assessing the significance of the trend using a normalized test statistic, known as the Z-value. By examining the signs of the Z-values, it is possible to determine whether the trend is increasing or decreasing. A positive Z-value indicates an increasing trend, whereas a negative Z-value denotes a decreasing trend.

Comment [D14]: It is important to highlight data collection methods before tools.

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2.1.1 Mann-Kendall trend test

The Mann-Kendall test statistic is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \text{ .... } (1)$$

where n is the number observations, x_i and x_j are the values of climatic variable in time series i and j respectively given j>i

$$sgn\,(x_j - x_i) = \begin{cases} +1, & if\ \ x_j - x_i > 0 \\ 0, & if\ \ x_j - x_i = 0 \\ -1, & if\ \ x_j - x_i < 0 \end{cases} \text{ .... } (2)$$

If the number of observations is more than 10, Mann-Kendall statistic assumed to follow a normal distribution with variance equal to

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \text{ .... } (3)$$

We can use Z test to test the significance of the trend. The standard Z statistic is computed by using following equation,

$$Z_s = \begin{cases} \frac{S-1}{\sigma} \ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sigma} \ if\ S < 0 \end{cases} \text{ .... } (4)$$

If Z_s >Z_{table} value, the null hypothesis is rejected that no significant trend exists in the variable under consideration.

2.1.2 Sen's slope estimator

Sen's slope estimator is used to determine the magnitude of the underlying trend by calculating the slope, which represents the amount of change in measurement per unit of time.

$$Q = \frac{X_j - X_k}{j-k}, k \neq j \text{ .... } (5)$$

For a time, series X within observations, there are possible N = n (n -1)/2 values of Q that can be calculated. According to Sen's method, the overall estimator of slope is the median of Q's N values. The overall slope estimator, Q* is thus:

$$Q^* = \begin{cases} Q_{[(N+1)/2]}, & if\ N\ is\ odd \\ \frac{Q_{(N/2)} + Q_{[(N+2)/2]}}{2}, & if\ N\ is\ even \end{cases} \text{ .... } (6)$$

The Q* represent the trend in data, while its numerical value represents the degree of steepness of the trend.

2.2 Rainfall Anomaly Index (RAI)

RAI is basically developed to classify positive and negative anomalies in precipitation data. To determine these anomalies, the data is arranged in descending order and the ten highest values are averaged to establish a threshold for positive anomalies, while the ten lowest values are averaged for negative anomalies. The mean of the ten most extreme positive and negative anomalies are assigned arbitrary threshold values of +3 and -3, respectively. It uses a scale of numerical values to assign nine abnormality classes, which range from extremely wet to extremely dry conditions. Positive anomalies are characterized by values above the average, while negative anomalies are characterized by values below the average.

Comment [D17]: How data was collected?

For positive anomalies

$$RAI = 3\left(\frac{RNF - RNF_m}{X - RNF_m}\right)$$

For negative anomalies

$$RAI = -3\left(\frac{RNF - RNF_m}{Y - RNF_m}\right)$$

Where, RNF = current yearly rainfall (mm)

RNF_m= yearly average rainfall of the historical series (mm)

X= average of the ten highest yearly rainfall of the historical series (mm)

Y= average of the ten lowest yearly rainfall of the historical series (mm)

3. RESULT AND DISCUSSION

3.1 Temperature trend analysis

In order to analyse the impact of climate variables on crop production, it is important to first understand the rate of change and direction of changes in the maximum and minimum temperatures over time. Mann-Kendall (MK) test was used to test the significance of trends in temperature and rainfall. Whereas magnitude of trend was computed using Sen's slope estimator. The results for kharif season temperature are presented in Table 1. As evident from the table, the positive sign of Kendall's tau statistics indicated the maximum and minimum temperatureincreased over time in all theregions. The annual rate of increment in maximum temperature was found to be highest for Vidarbha (0.0140 ^{o}C) followed by Western Maharashtra (0.0134 ^{o}C), Konkan (0.0130^{o}C),Khandesh (0.0119 ^{o}C) and lowest in Marathwada region (0.0118 ^{o}C). A significant increasing trend was also observed in minimum temperature in all the regions, at highest rate in Vidarbha (0.0138 ^{o}C) and lowest was reported in Khandesh region (0.0109 ^{o}C).For overall Maharashtra, it also shows the increasing trend for both maximum (0.0126^{o}C) and minimum (0.0120^{o}C) temperature. The highest value for maximum and minimum temperature was reported by Vidarbha (31.86^{o}C) and Konkan (23.86^{o}C), respectively. In all the regions rate of change was faster in maximum temperature in comparison to minimum temperature which may leads to increase in diurnal temperature range. Similar finding was also reported by Dhorde et. al. (2017) that the over the period of 1969 to 2006, increasing trend of mean maximum temperature and mean minimum temperature on an annual and seasonal basis.

Comment [D18]: Use proper symbols

Table 1. Region wise trend in kharif season temperature

	T_{max}				T_{min}			
Region	Mean (^{o}C)	Kendall's tau	Z-Statistics	Sen's Slope	Mean (^{o}C)	Kendall's tau	Z-Statistics	Sen's Slope
Konkan	30.50	0.3194	3.26***	0.0130	23.86	0.3054	3.12***	0.0113
Western Maharashtra	29.90	0.3626	3.71***	0.0134	21.47	0.3283	3.35***	0.0117
Khandesh	31.44	0.2835	2.89***	0.0119	21.54	0.2893	2.95***	0.0109
Marathwada	31.53	0.3201	3.27***	0.0118	21.77	0.3162	3.23***	0.0117
Vidarbha	31.86	0.3665	3.75***	0.0140	22.91	0.3806	3.89***	0.0138
Maharashtra	31.24	0.348	3.56***	0.0126	22.37	0. 346	3.54***	0.0120

Table 2 demonstrates the trend in maximum and minimum temperature in rabi season. As like kharif season, MK trend test result revealed that both maximum and minimum temperaturehad increased significantly. The rabi season maximum temperature indicated a highly significant (at 1 % level of significance) increasing trends for all the regions. Similarly, minimum temperature registered increasing trend with 95 % confidence level in all the regions. Among the regions, Western Maharashtra reportedthe highest rate of warmingin terms of both maximum and minimum temperature (0.0250^{o}C & 0.0200 ^{o}C, respectively). It was also observed that, across all regionsthe trend of rising temperatures in maximum temperature was greater than minimum temperature.Further, konkan regions reported highest maximum (31.69^{o}C) and minimum (18.86^{o}C) temperature.

Table 2. Region wise trend in rabi season temperature

	T_{max}				T_{min}			
Region	Mean	Kendall's tau	Z-Statistics	Slope	Mean	Kendall's tau	Z-Statistics	Slope
Konkan	31.69	0.4387	4.48***	0.0250	18.86	0.2639	2.69***	0.0196
Western Maharashtra	30.95	0.4240	4.33***	0.0250	16.13	0.2751	2.81***	0.0200
Khandesh	30.88	0.3652	3.73***	0.0224	13.64	0.2419	2.47**	0.0171
Marathwada	31.19	0.3799	3.88***	0.0224	15.99	0.2424	2.48**	0.0181
Vidarbha	30.45	0.3440	3.51***	0.0205	15.12	0.3185	3.25***	0.0196
Maharashtra	30.95	0.388	3.97***	0.0225	15.81	0.263	2.69***	0.0178

The coastal belt of Maharashtra (konkan region) receives highest mean kharif season rainfall (1494.21 mm) with standard deviation of 385.74 mm (table 3). It also depicts the large difference between maximum and minimum rainfall. On the other side, lowest mean rainfall was observed in

Western Maharashtra (628.44 mm). MK test statistics and Sen's slope estimates for all the region shows anon-significant increasing trend in kharif season rainfall. Maharashtra receives its kharif season rainfall mainly from the southwest monsoon and its dependency and variation in monsoon rainfall affects the crop production and livelihood of the people. The state is more prone to significant climate fluctuations, which have resulted in recurrent droughts leading to agricultural poverty and distress as evidenced by the high suicide rates (Todmal 2022). Similarly, rabi season rainfall also indicated a non-significant but decreasing trend (except for Khandesh). The highest mean rainfall for rabi season was received by Vidarbha region (44.15 mm) with standard deviation of 38.45mm and lowest was reported for Khandesh (29.17 mm).

Table 3. Trend in kharif season rainfall (1967-2017)

Region	Minimum	Maximum	Mean	Std. deviation	Kendall's tau	Z-Statistics	Sen's Slope
Konkan	761.88	2492.16	1494.21	385.74	0.097	0.99	4.571
Western Maharashtra	329.78	931.96	628.44	151.54	0.097	0.99	1.155
Khandesh	341.32	952.24	646.36	143.55	0.064	0.65	1.022
Marathwada	267.71	1008.86	633.18	148.81	0.104	1.05	1.669
Vidarbha	476.50	1172.06	802.42	151.89	0.047	0.47	0.570
Maharashtra	445.34	1192.34	815.80	169.47	0.0857	0.86	1.790

Table 4 Trend in rabi season rainfall (1967-2017)

Region	Minimum	Maximum	Mean	Std. deviation	Kendall's tau	Z-Statistics	Slope
Konkan	0.18	150.62	28.31	32.10	-0.013	-0.14	-0.020
Western Maharashtra	0.16	152.76	34.77	33.30	-0.007	-0.08	-0.009
Khandesh	0.30	144.82	29.17	32.49	0.002	0.02	0.008
Marathwada	0.71	132.28	37.74	28.58	-0.071	-0.74	-0.211
Vidarbha	1.01	157.17	44.15	38.45	-0.112	-1.15	-0.399
Maharashtra	1.96	121.42	36.73	30.26	-0.0628	-0.635	-0.161

3.2 Rainfall Anomaly Index (RAI)

On the basis of Rainfall Anomaly Index (RAI) values 50 years have been categorised into total nine categories, viz., extremely wet, very wet, moderately wet, slightly wet, near normal, slightly dry,

Comment [D19]: 50 yrs might not be very feasible and validity of results spanning 50 yrs are difficult to accept especially for this study where we want to capture variability. I suggest 10 and maximum 20.

moderately dry, very dry, and extremely dry years as depicted in table 5. The distribution of years in all categories are not similar across the regions.The Khandesh region experiences greater fluctuations in rainfall and a higher number of years with below-average precipitation of Maharashtra state. Over a 50-year period, 13 years are categorized as moderately dry, while 10 years are characterized by very wet years. In contrast, only 4 years fall within the near-normal range. On the other side, Konkan and Western Maharashtra shows less variation in rainfall, with a greater number of years falling within the near-normal category. Specifically, 15 years in the Konkan region and 14 years in Western Maharashtra exhibit the near-normal years. The regions of Marathwada and Vidarbha experience dry conditions for half of the years, with 25 years of the total considered period falling under the categories of slightly dry to extremely dry. On the other hand, only 7 years are characterized by near normal levels of rainfall.

Table 5. Classification of Rainfall Anomaly Index (RAI)

	RAI range	Description	Number of years (50 years)				
			Konkan	Western Maharashtra	Khandesh	Marathwada	Vidarbha
1	≥ 3	Extremely wet	4	5	4	5	5
2	2.00 to 2.99	Very wet	3	4	10	2	4
3	1.00 to 1.99	Moderately wet	3	3	4	7	5
4	0.50 to 0.99	Slightly wet	6	5	5	4	4
5	-0.49 to 0.49	Near normal	15	14	4	7	7
6	-0.99 to -0.50	Slightly dry	4	4	2	9	7
7	-1.99 to -1.00	Moderately dry	4	6	13	7	7
8	-2.99 to -2.00	Very dry	6	4	4	Sl.no	8
9	≤ -3.00	Extremely dry	5	5	4	4	3

Source: RAI classification from Van-Rooy (1965)

Figure 1-5 illustrates the RAI values over the 50 years period (1967-2017) for Konkan, Western Maharashtra, Khandesh, Marathwada and Vidarbha region, respectively. The precipitation in the years of 1968, 1971, 1972, 1980, 1982, 1984, 1986, 1987, 1989, 1991 1992, 1999, 2001, 2002 and 2003 shows dry period across all the regions (RAI < 0). The severe drought (RAI < -3) was faced by all the regions with varying intensity in the year of 1972. The maximum RAI values for 1972 is reported by Marathwada region (-6.36) followed by Vidarbha (-5.97), Khandesh (-5.60), Western Maharashtra (-5.04) and Konkan (-4.26).

The RAI values for konkan region varies from -4.26 (1971) to 5.21 (1983). Out of 50 years, 14 years are under wet period, 15 are normal and 19 were dry periods. The extreme dry period (RAI >-3)

Comment [D20]: There is need for revision and consider a simple way of presenting such kind of data which is easy to follow. I suggest a graph was ideal

Comment [D21]: Van Rooy 1965 but we captured up to 2017 in 2023?? We need to add recent studies, recent references.

Comment [D22]: Feasibility remains in doubt. Since data collection methods were not clearly outlined. Was this primary or secondary data being presented?

occurred in 1972, 1985, 2002, 2001, 2012 and extreme wet periods for 4 years in 2005, 2011, 2010 and 1983. In Western Maharashtra, the dry years was observed for 19 years with 5 severe drought years reported in 1972, 2002, 1986, 2003 and 2001and RAI values for these years are -5.04, -3.67, -3.64, -3.37 and -3.16 respectively. About 5 years (1975, 2005, 2006, 2010 and 2011) are under extreme wet category. In Khandesh, the dry years observed for 23 years (RAI < 0). Out of these 4 years recorded extremely dry period in the year 1972, 1991, 2001 and 2002 with RAI value less than -3. About 4 years (1983, 1988, 2006, and 2010) falls under extremely wet years. Majority of the years falls in the dry category followed by wet category and only 4 years shows the normal rainfall years. Whereas Marathwada region reported the weak and medium drought for about 25 years with RAI values ranges from -0.53 to -6.36. The extreme drought condition occurred in the year 1972, 1984, 1991 and 2003 (< -3 RAI). Only seven years comes under near normal category. Similarly, Vidarbha region reported 25 dry years with 3 severe drought years in 1972, 1984 and 1991. The trend lines of moving average over a period of 5 years are not uniform throughout the study period of 50 years. The findings of present study highlight the less variations of rainfall in Konkan and Western Maharashtra regions. In contrast to this Marathwada and Vidarbha regions can be considered as most vulnerable drought zone since it is more prone to drought occurrence for 25 years with a smaller number of near normal years during study period of 1967-2017. On the similar line Swami et. al. (2017) also found that the districts in the Vidarbha and Marathwada regions were at a greater risk due to monsoon variability and need immediate attention from policymakers and scientists.

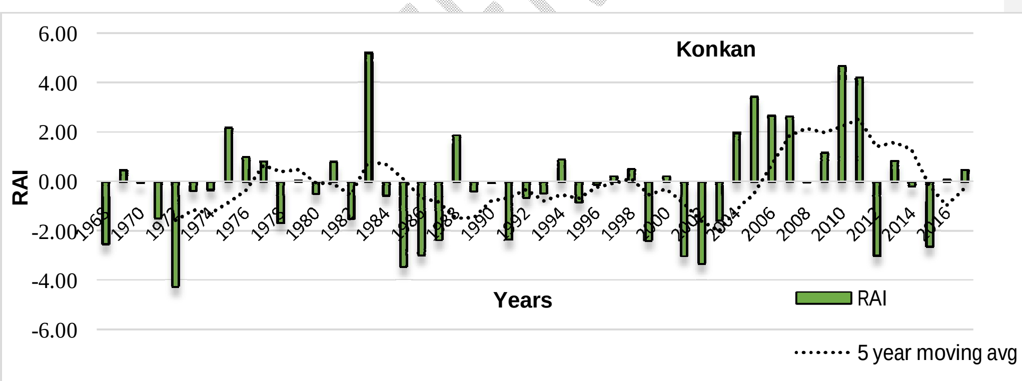

Fig 1. Rainfall Anomaly Index (RAI) and 5-year moving average analysis for Konkan.

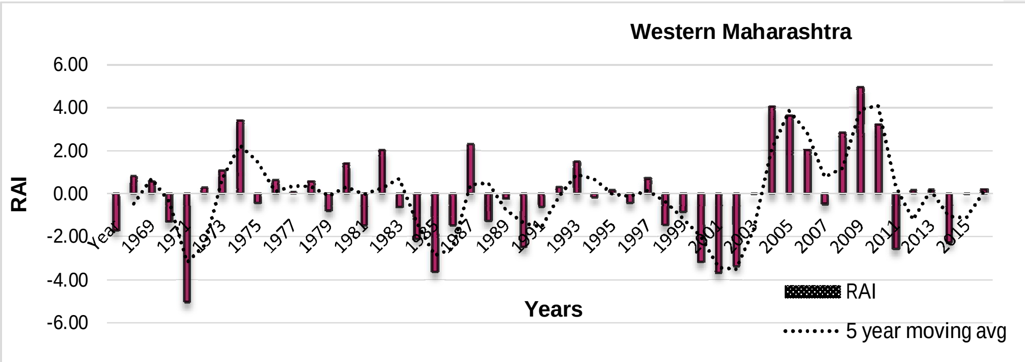

Fig 2. Rainfall Anomaly Index (RAI) and 5-year moving average analysis for Western Maharashtra.

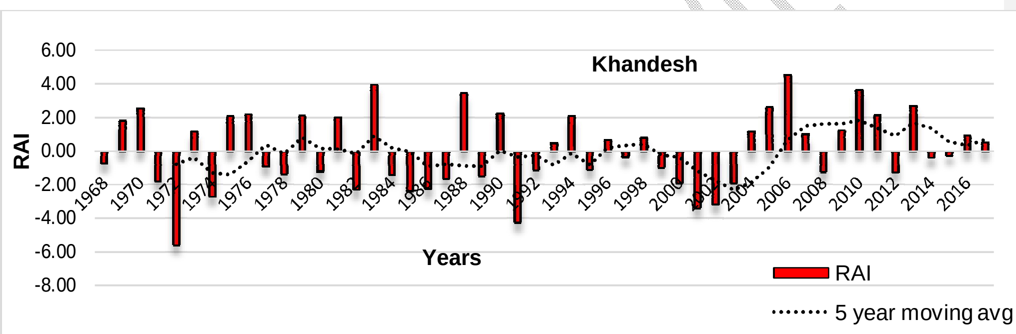

Fig 3. Rainfall Anomaly Index (RAI) and 5-year moving average analysis for Khandesh.

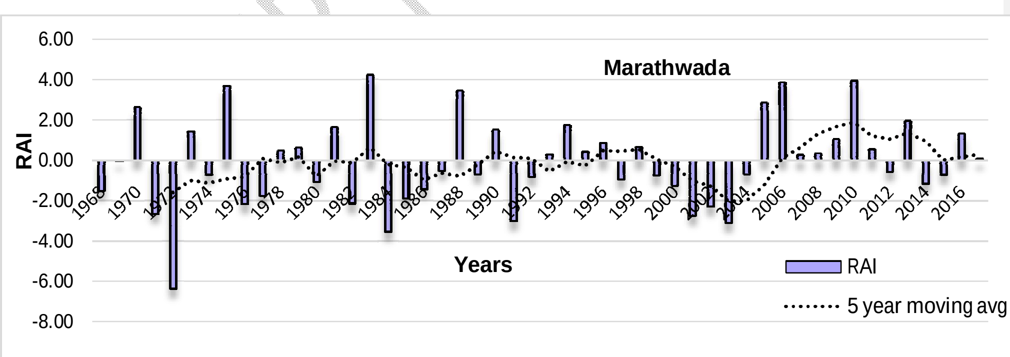

Fig 4. Rainfall Anomaly Index (RAI) and 5-year moving average analysis for Marathwada.

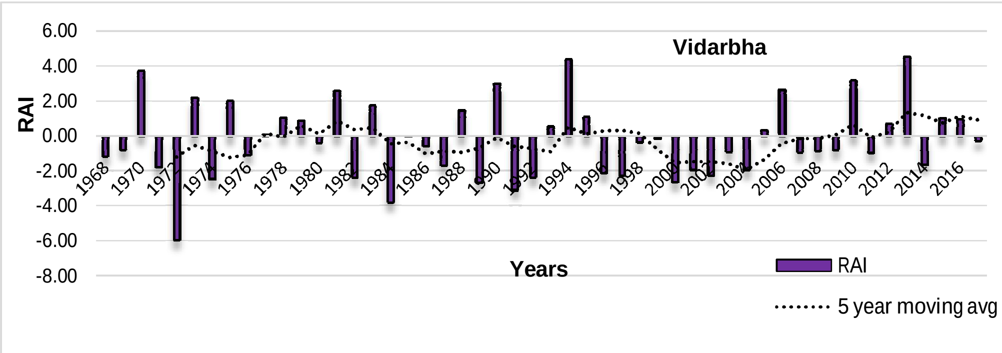

Fig 5. Rainfall Anomaly Index (RAI) and 5-year moving average analysis for Vidarbha.

4. CONCLUSION

The effects of climate change on agriculture are extensive because agriculture is heavily depending on climate and has interconnections with socio-economic systems on a regional, national, and global scale. The analysis of variations and trend in climate variable such as temperature and rainfall at regional level highlights it's importance in formulating adaptation and mitigation strategies to cope with adverse impacts of extreme weather events at regional level. The present study has undertaken to understand the trend and variation for five regions of Maharashtra which are almost similar to the meteorological divisions of Maharashtra. The trend analysis of rainfall and temperature series for the kharif and rabi season revealed a significant increasing trend for maximum and minimum temperature for both the seasons, however nonsignificant decreasing trend for kharif and rabi rainfall. The rainfall variability across the regions of Maharashtra has resulted in a higher frequency of dry periods. Moreover, the study has observed the spatial inconsistency in rainfall deficiency across the region has the potential to develop a region-specific adaptation strategy. The RAI value indicates a relatively a greater number of dry periods in Marathwada and Vidarbha region in comparison to the Konkan, Western Maharashtra and Khandesh. The findings of the present study can be useful in developing plans to manage water resources effectively and reduce the adverse impacts of droughts basically in the Marathwada and Vidarbha regions, which are more vulnerable to climate change and dominated by monsoons rainfall.

Comment [D23]: Its important for studies of this nature to suggest two or three recommendations.

REFERENCES

Comment [D24]: 12 references are not enough for topical studies of this nature where we expect the introduction to be very broad and start with a global overview zeroing into the study area and also contribute to UN SDGs.

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