Drought Assessment of Eastern Satara District of Maharashtra using Rainfall Anomaly Index

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Abstract
Drought is widely recognized as a phenomenon associated with scarcity of water. Proper evaluation and management of rainfall is a crucial need to reduce the severity of drought. Present work aims to study the spatial and temporal fluctuation in the rainfall of the eastern part of the Satara district of Maharashtra using the Rainfall Anomaly Index (RAI). Monthly and annual rainfall data of sixteen metrological stations were used for the period between 1979 and 2013. RAI was computed and prepared spatial distribution maps.

The present study reveals that the eastern and southern part of the study area are prone to drought condition. The present investigation is useful to delineate potential sites of drought and through this study, risk of future drought conditions can be curtailed.

Keywords: Rainfall Anomaly Index (RAI), Drought, GIS, Potential sites etc.

Introduction
Drought is very complicated hydrological process which create noticeable impact on different fields like agriculture, water resources and ecosystems. Throughout the world among the entire climatic hazard, drought is considered as one of the most disastrous climatic hazards.[18] The meteorological drought is defined as the degree of dryness which is quantified by insufficiencies of precipitation and the time of the dry spell.[13,20] Economy of agrarian countries like India is drastically affected by droughts because about 68% of people are associated with agricultural sector. Drought affect was observed over 16% of India's total area and annually 50 million people are affected. The arid area of the western part of India is under threat of severe droughts due to scarcity, abnormality of rainfall and severe climatic characteristics.[5]

Complicated relationship between various climatic parameters was simplified by drought Indices which are significant tools to monitor and to assess drought. In recent times, researchers and different organizations have developed different drought indices to assess a drought like PDSI, RAI, CMI, SWSI, SPI, TVDI, mTVDI and many more.[1,8,9,12,14-19] Van Rooy[15] in 1965 developed RAI index, which is used to categorize rainfall anomalies in the positive and negative severities. This is very simplified index because it requires only precipitation data.[2,3]

The RAI provides a greater degree of lucidity and tractability and requires a lower degree of sophistication than the SPI in term of evaluation criteria for drought indices as proposed by Keyantash and Dracup.[7]

According to Van Rooy[15], deviation in precipitation in various regions of the world is feasible with RAI index. The present study has been carried out to evaluate the magnitude and frequency of drought using RAI for the eastern Satara District of Maharashtra.

Study Area
The study area in this work concerns drought-prone area of the eastern Satara district of Maharashtra (Fig. 1). The study area has tropical monsoon type climate. There are mainly four seasons in study area: cold season from December to February, hot season from March to May, southwest monsoon season from June to September and post monsoon or the retreating monsoon season from October to November. The area experiences the semi-arid climate with a hot summer and dry season throughout the year. The mean annual precipitation over the study is about 975 mm. It extends between 17^0 22' 57" to 18^0 6' 03" north latitude and 74^0 09' 38" to 74^0 55' 32" east longitude.

The total area of the proposed study is 3894 km^2 and it comprises Man, Khatav and Phaltan tehsils of Satara district. The average height of the study area is about 713 meters. The maximum height is 1004 meters which is observed towards the western part of the study area. The lowest elevation is observed towards the extreme east part where the height is 423 meters.

Material and Methods
The database used in this study is of 16 meteorological stations for 35 years (1979-2013). The rainfall data was obtained from IMD, Pune. By employing precipitation data, the annual RAI was used to determine the frequency and magnitude of the dry and wet years in the study area. Besides that, the monthly RAI was computed for particular years of the historical series aiming to examine the distribution of rainfall in the years of greatest anomaly.

Van Rooy[15] introduced RAI in 1965 developed by Freitas[3] including the following equations:

$$RAI = 3 \quad \text{For positive anomalies} \tag{1}$$

$$RAI = \left[\frac{N - \bar{N}}{\bar{M} - \bar{N}}\right] - 3 \quad \text{For negative anomalies} \tag{2}$$

where N = annual rainfall (mm), $\overline{N}$ = annual average rainfall of the historical series (mm), $\overline{M}$= average of the ten highest annual precipitations of the historical series (mm), $\overline{X}$= average of the ten lowest annual precipitations of the historical series (mm) and positive anomalies have their values above average and negative anomalies have their values below average.

The result was plotted in a spatial distribution map in the Arc GIS 10.5 Software by applying the Kriging method.

Results and Discussion

Distribution of annual rainfall: The average annual distribution of rainfall of the sixteen stations of the study area is shown in figure 2. The box plot represents annual average rainfall variability in the rainfall stations over the period 1979-2013 to describe the behavior of annual rainfall in the study area. Each box includes a middle 50% of the data. The median values are displayed as line and mean value is displayed with ⊠ symbol. The top and bottom of the box represent the inter-quartile ranges (25-50% and 50-75%). The lines extended above and below in the box mark the maximum and minimum values that fall within acceptable range respectively.[11] The mean annual rainfall ranges from 267mm to 2089mm at station 12 and 1 respectively. The high and irregular variability in the distribution of rainfall is depicted with alternating wet and dry periods over the entire study area (Fig. 2).

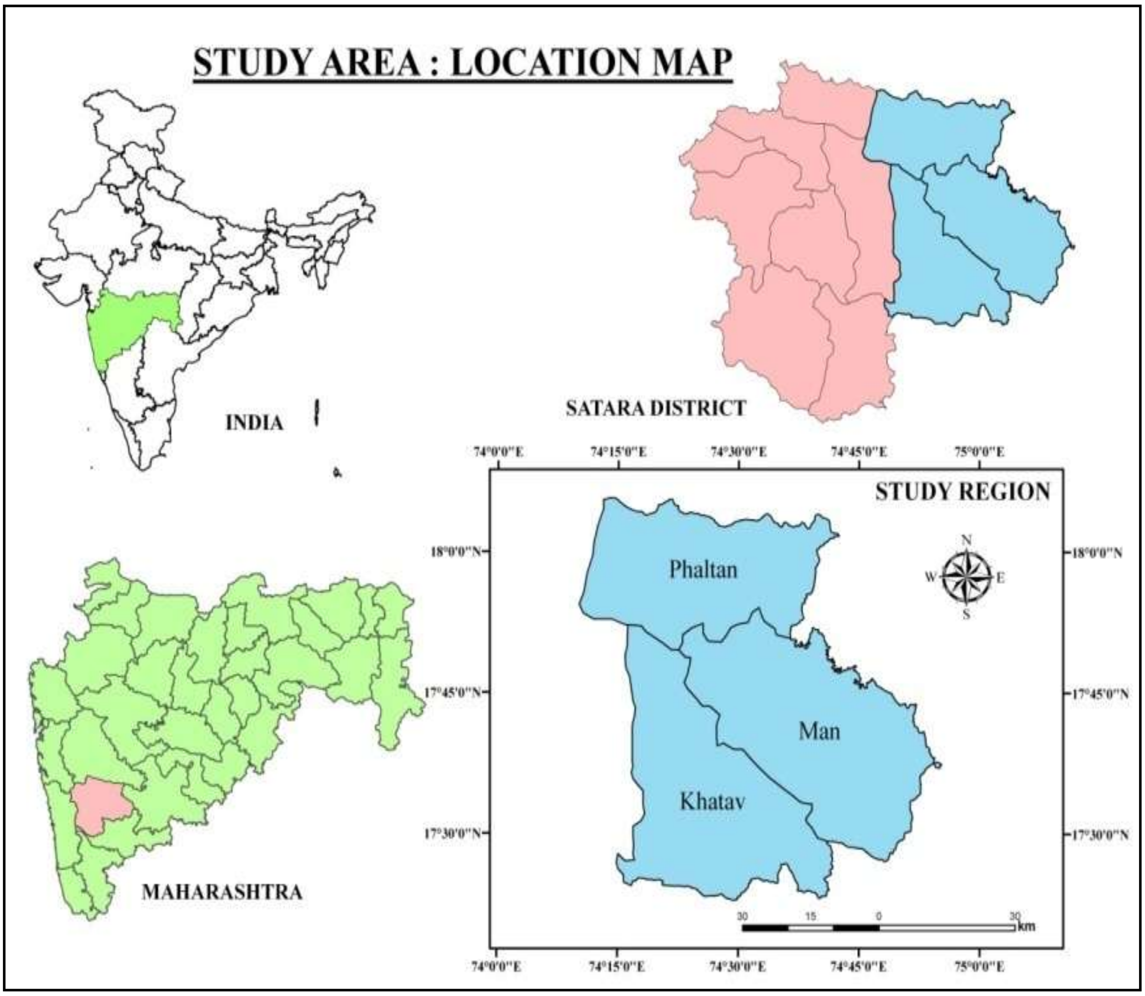

Fig.1: Geographical Location of the Study Area

Table 1
Classification of Rainfall Anomaly Index Intensity

	RAI range	Classification
Rainfall Anomaly Index (RAI)	Above 4	Extremely humid
	2 to 4	Very humid
	0 to 2	Humid
	-2 to 0	Dry
	-4 to -2	Very dry
	Below -4	Extremely dry

Source: Freitas[3]

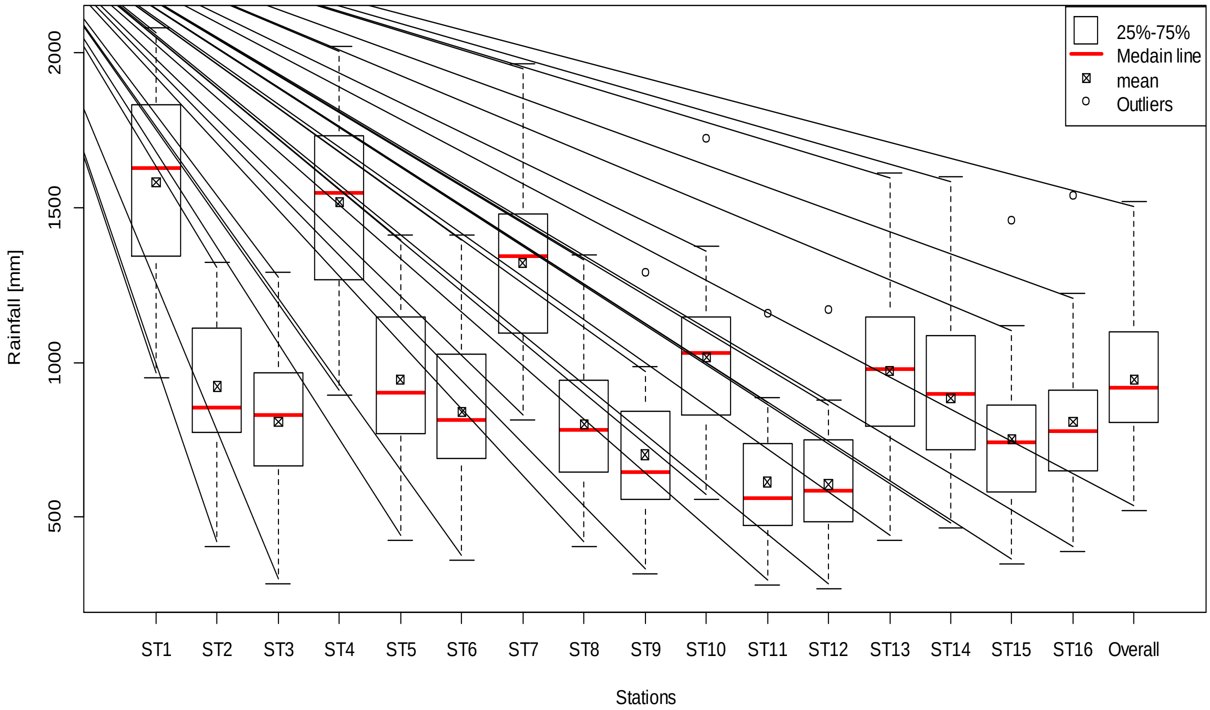

Fig. 2: Box plot of annual rainfall variability for every station and overall study area (1979-2013)

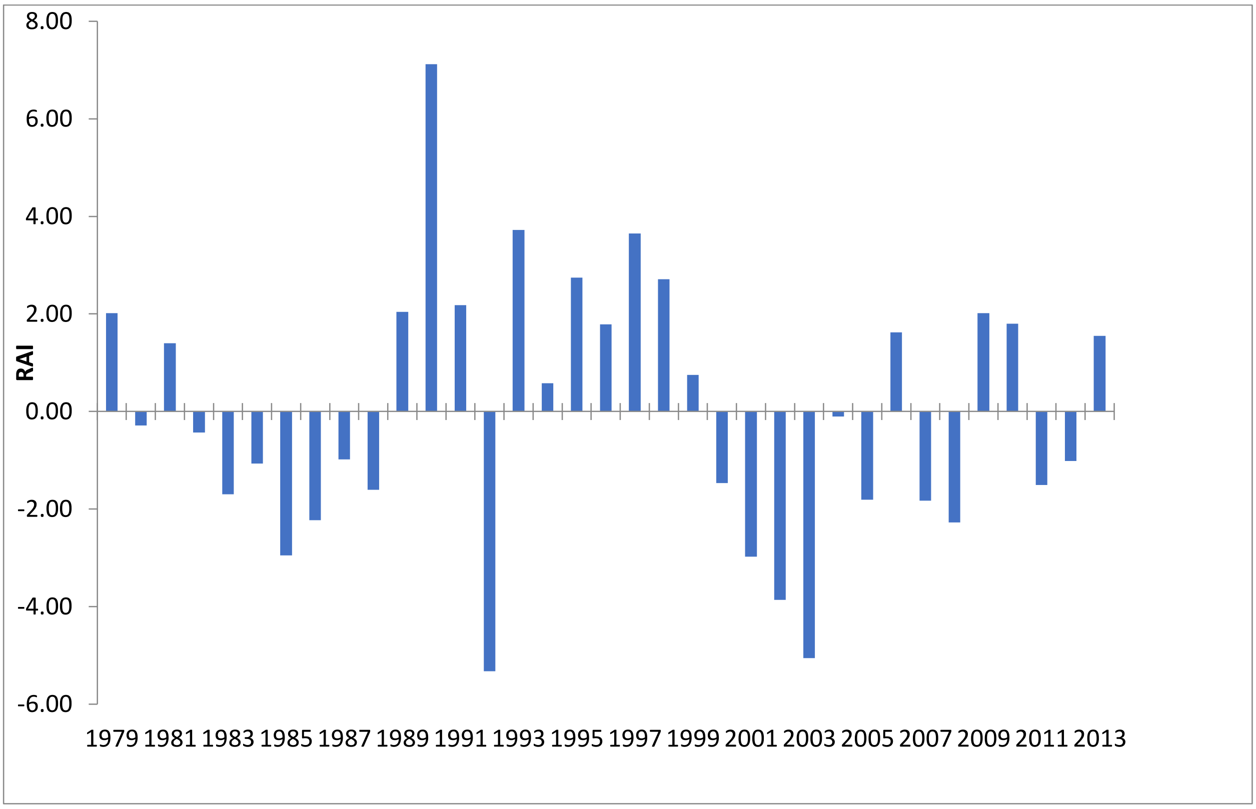

Fig. 3: Rainfall Anomaly Index for the study area

Analysis of RAI: The RAI index was used to analyse the dry and wet years from 1979 to 2013 (Figure 3). Therefore, it is helpful to identify hydrological extreme in selected years. The positive index observed in figure 3 denotes wet years and the negative index shows the dry years with different degrees of intensity. According to historical series analysis, wet to humid conditions observed over 16 years were represented by positive index value whereas very dry and dry climatic conditions were observed over 19 years with negative RAI index value. The duration from 1982 to 1988 experiencing drought like situation was fallowed by 2000 to 2005 and from 2011 to 2012 (Figure 3). The highest negative RAI index value (-5.33) was observed in 1992 classified as extremely dry whereas the highest positive RAI index value (7.12) was observed in 1990 classified as extremely humid.

Figure 4 shows the spatial distribution of the RAI for the entire study area. For the whole study area, the negative average RAI was observed. The northeast portion has higher RAI than in the southwest. The entire study area falls under the dry RAI category.

To evaluate the distribution of rainfall in the study area during years of extreme anomalies, the monthly RAI of specific years was analyzed (Figure 5A and B). The two most humid indexes (1990 and 1998) and the two driest ones (1985 and 1992) of the historical series were chosen. The driest years in 1985 in the historical series denoted only average precipitation in July, remaining rainy months are of acute stress of precipitation and another dry year 1992 depicts same conditions.

Year 1992 and 2003 are extreme negative anomalies (figure 6A and B). It is clearly identified that the year 1992 is the most negative anomalies year in the historical series, the RAI of this year which is -5.33, this is under extremely dry category. The northeast part of the study area presented extreme negative anomalies. For the year 2003, which has most negative anomalies concentrated in southern portion of the study area; the RAI of this year is -5.06 which falls in extremely dry category.

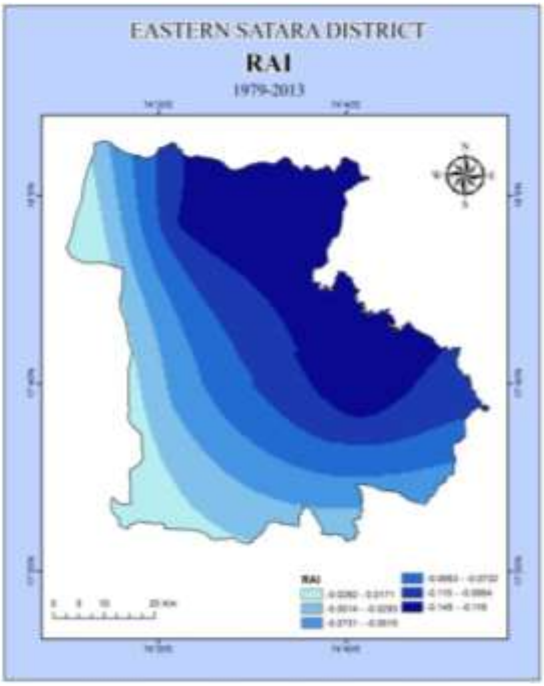

Fig. 4: Spatial distribution of the rainfall anomaly index

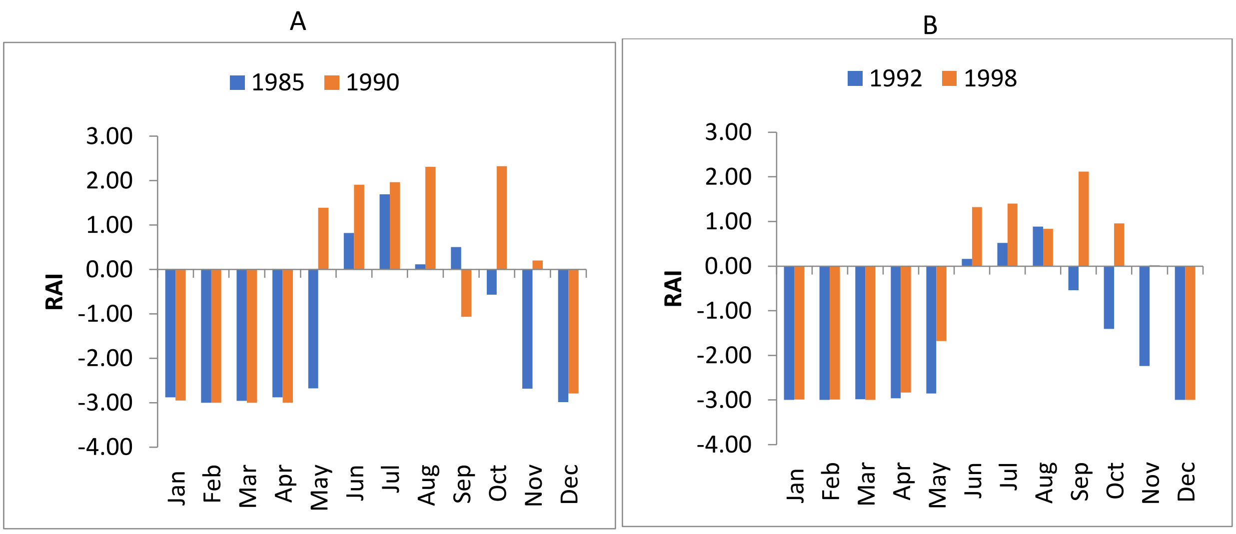

Fig. 5 A and B: Monthly RAI of the study area: rainy years and dry years

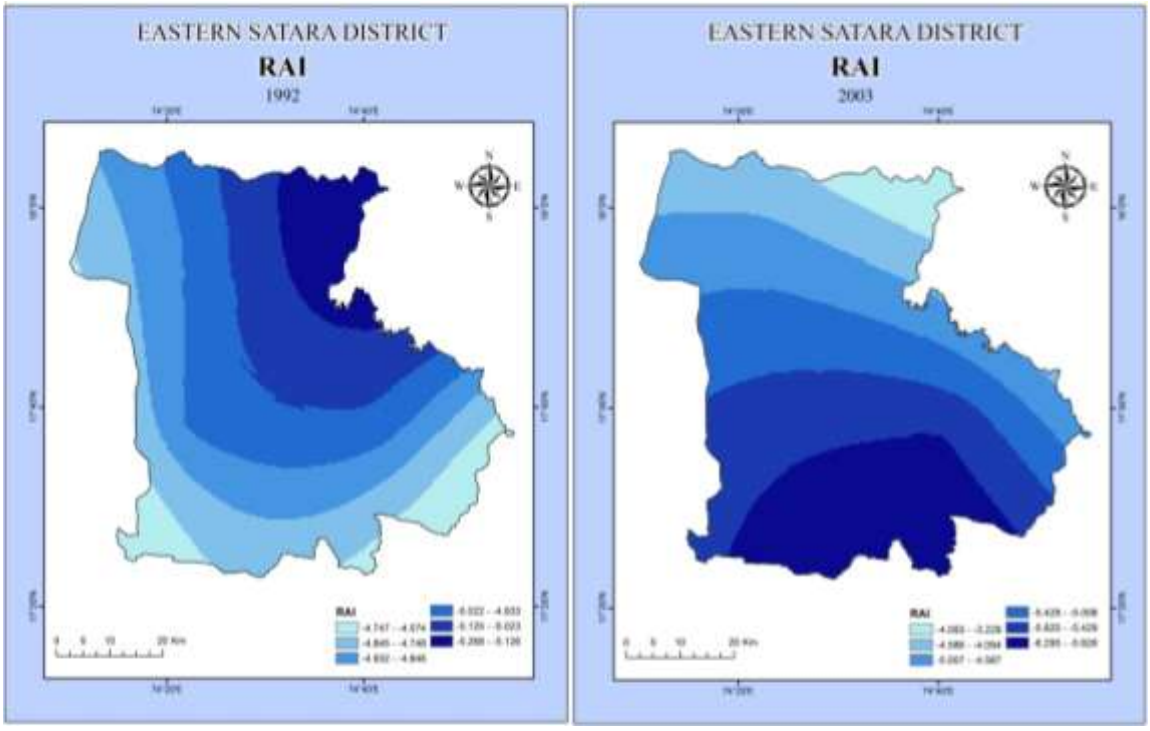

Fig. 6: Specialization of RAI in the most extreme years: (A) 1992 and (B) 2003

Conclusion

The present investigation attempts to identify and assess the intensity and frequency of droughts in the eastern part of the Satara district. The RAI method was utilized to assess the drought severity in the study area. The distribution of rainfall shows that 1992 and 2003 have minimum average rainfall which represents 918 and 709 mm respectively. The rainfall station 1, 4 and 7 are having the highest annual average rainfall whereas the lowest annual average rainfall dominants at 11 and 12 station in the study area. The historical series data has 16 rainy years and 19 dry years, with 1990 as the wettest year and 1992 as the driest.

The overall investigation reveals that the eastern and southern parts of the study area are prone to dry conditions. RAI is facilitated to make the comparison between precipitation deviations in different regions and it also assesses the intensity and frequency of drought. Consequently, RAI will useful to indicate rainfall station history of a particular location. The present study will be helpful to demarcate potential sites of drought and will be useful for planning and mitigation purposes.

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