ASSESSMENT OF IMPACTS OF AGRO-CLIMATOLOGICAL DROUGHTS OVER MARATHWADA, INDIA, USING REMOTE SENSING TECHNOLOGIES

Sneha Kulkarni[1], Shirishkumar Gedam[1] and Amit Dhorde[2]
[1]Indian Institute of Technology, Bombay, Powai, Mumbai-400076, India
Email: snehakulkarni@iitb.ac.in
shirish@csre.iitb.ac.in
[2]Department of Geography, University of Pune, Pune- 411007, Maharashtra, India
Email: amit.dhorde@unipune.ac.in

KEY WORDS: Drought-indices, Trends, TCI, VCI, MODIS

ABSTRACT: Marathwada meteorological subdivision is one of the highest rainfall deficit regions of agricultural India, known for its severe droughts and incessant farmer suicides in the recent years. Over these areas, droughts and exceptionally dicey weather hinders rural development to a major extent. The present study sheds light on unseasonal and deficient rainfall over Marathwada, and its battle with dismal droughts resulting this area as one of the most poorly developed region of the country. This study represents outcome of trend analysis for monsoonal precipitation over Marathwada for the period from 1951 to 2016. Monsoon rainfall variability reflects into drought scenarios in recurring months. Temperature Condition Index (TCI) and Vegetation Condition Index (VCI) were used to understand the spatio-temporal occurrences of droughts in the study area. The investigation of droughts includes use of remote sensing data acquired by Terra Moderate- Resolution Imaging Spectroradiometer (MODIS) MOD11A2 and MOD13A2. Standard algorithms for Land Surface Temperature (LST) and Normalize Deferential Vegetation Index (NDVI) were used to estimate TCI and VCI respectively. Linear regressions, Mann-Kendal rank test are the techniques used for analysis and to verify significant changing patterns in rainfall. The results obtained for overall monsoon rainfall series indicated negative rainfall trends over almost all parts of Marathwada, in which significantly decreasing rainfall trend was noticed over the Latur district. Declining rainfall trends follows with the brutal drought situations in the post monsoon season. During the last decade more than half of the study area had moderate to severe drought conditions. Particularly the parts of the Beed and Osmanabad districts of Marathwada, constantly recorded highest drought severity. Negative rainfall trends, increasing drought frequency are threatening the Rabi crops and overall agriculture. The study indicates that, water scarcity and pertinent drought conditions may continue in coming years.

1. INTRODUCTION:

Among the various natural hazards drought is one of the most devastating as it deals with many miseries on the human society. Drought condition takes place due to lack of rainfall. Intensity, Spatial coverage and Duration are the three main characteristics with which droughts can be described, but the concept of drought itself is controversial. Different disciplines, scientific areas define drought in a different way. In general, drought can be defined as, " less amount of rainfall prolonged on larger spatio-temporal scale, have an effect on all conventional human activities of the region" (Warrick, 1975) (Gupta, Tyagi & Sehgal, 2011).

In case of India, many researchers have studied droughts independently for different sub-divisions of India. Chowdhury and Dandekar (1989) have noticed climatology based aspects of drought, while Mooley et al., (1984) contributed for drought over peninsular regions of India. Parthasarthy et.al.,(1987) have studied the drought conditions over the summer monsoon for specific meteorological sub-divisions. In the further years, Chowdhury et.al has worked on drought conditions in statistical way. In the recent yeats, Mishra (2003), have noticed the probabilistic variations in drought conditions with respect to normal rainfall.

In India, drought is monitored on regular basis by the Indian Meteorological Department (IMD). Satellite data plays an important role to observe drought on a higher scale. Moderate and coarse both resolution satellite data are used for drought assessment. Drought studies are carried out on different spatio-temporal scales by the National Agricultural Drought Assessment and Monitoring System (NADAMS) projects. Various researchers have used satellite based data to study droughts. Patel et. al., (2008) observed the potential and strength of TVDI. They have used MODIS data to evaluate soil moisture conditions in sub-humid regions (western Uttar Pradesh) of India. Statistical Correlation and regression analysis studies were performed to relate the TVDI at different growth stages of sugarcane crop. Various researchers have studied drought conditions over Karnataka state using NDVI analysis. They have used METEOSAT-5 TIR imagery data sets for the mentioned study. They resulted that, 'regions having stable vegetation cover does not show higher variation in normal and drought years'. They also confirmed that, 'NDVI values are the correct indicators of agricultural drought'. Bhuiyan et al., (2006) noticed dynamic nature of droughts over Aravalli (Rajasthan) region. They verified their results with numerous vegetation based indices computed by NOAA, AVHRR satellite data.

In India, Rajasthan and some parts of Maharashtra (Vidarbha and Marathwada) are the rainfall deficit regions which are highly known for their severe droughts and increasing rate of farmer suicides in the recent years. The Indian agriculture sector, provides almost 28% to the GDP of the nation, which is largely affected by droughts (Act-Indian economic ministry, 2016). Changing seasonal climatic parameters are hindering agricultural actives, whereas changing land use patterns, crop modifications are playing a crucial role in day to day human life. Droughts and exceptionally dicey weather hampers rural development to the major extent.

2. METHODOLOGY:

2.1 Study area and data:

This study aimed at investigation of the various drought conditions over the sub-divisions of Marathwada-Maharashtra, India. Marathwada region includes eight district of Maharashtra, (divisional headquarters) named as Jalna, Aurangabad, Parbhani, Hingoli, Nanded, Latur, Osmanabad and Beed. This region occurs in the upper Godavari basin, with the absolute extend of 17° 35' North latitude to 20°41' North latitude and from 74° 40' East longitude to 78° 16' East longitude. Marathwada forms the central portion of Maharashtra (map). The horizontal East-West extent is 395 Km while the vertical North-South extend is 330Km. The overall geographical area covered by Marathwada is 64434 Sq. Km. It constitutes approximately 30 percent of the state (Figure 1).

Marathwada region falls under semi-arid tropic with highest maximum temperature of 430C during the month of May, while the lowest minimum temperature of 110C during the month of December. South-west monsoon is the major source of rainfall in the region with average annual rainfall of Parbhani as 890 mm with 48 rainy days. Most part of the state lies in rain shadow belt of Western Ghat where annual average precipitation ranges between 600 and 700mm (Dept. of Agriculture Maharashtra, 2011).

In recent years, satellite data has played a vital role in monitoring global vegetation change and its relation to climatic conditions. In this study, Moderate Resolution Imaging Spectroradiometer (MODIS) data are used. The data are aboard the Terra and Aqua satellites, a part of Earth Observing System (EOS) of NASA (National Aeronautics and Space Administration). In the present study 2 MODIS products from Terra satellite have been used: MOD11A2 and MOD13A2. MOD11A2 is a 1 km resolution Level- 3 MODIS global LST and emissivity product derived from MOD11A1 LST product 8 day composite. These derived products are stored on 1-km Sinusoidal grid as the average values of clear-sky LSTs during the 8-day period. MOD13A2 is a level 3 1km resolution MODIS global vegetation indices product 16 day composite which is stored on a sinusoidal grid.

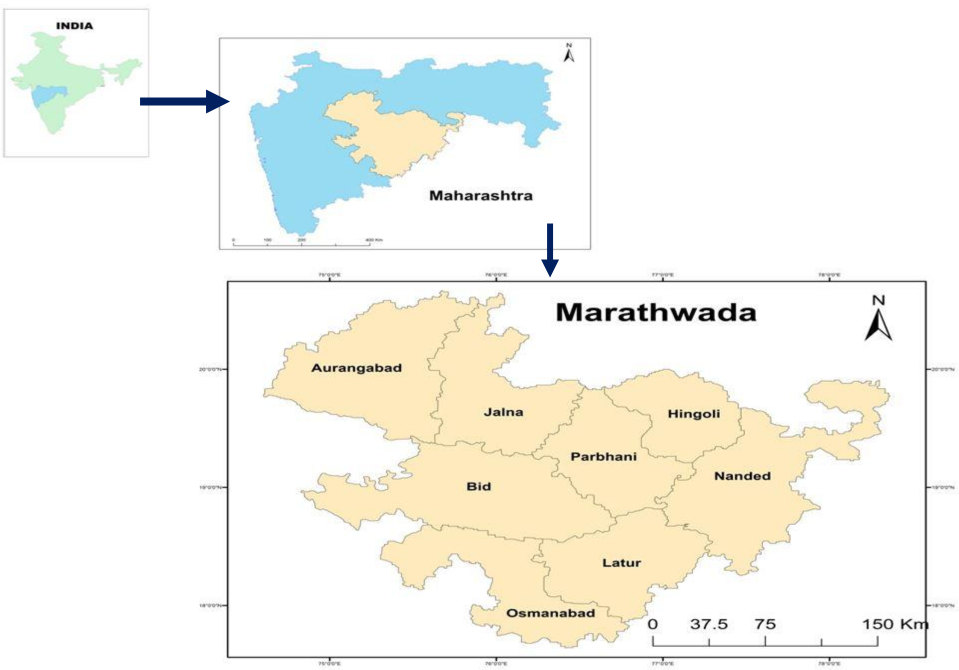

Figure 1. Study Area- Marathwada, Maharashtra

2.2 Techniques used:

This study is based on statistical analysis using different trend analysis techniques and various remote sensing based drought monitoring indices. Long term rainfall trends from 1951 to 2016 are studied in this paper to get overall idea of drought scenarios in case of Marathwada. The satellite based image analysis techniques have been used for the recent decades (2001 to 2016) to understand the variability and impacts of drought condition over the study area.

2.2.1 Trend analysis:

Magnitude of trend and its statistical significance are the two major components of trend analysis. For general trend analysis several parametric and non- parametric tests are available among which Linear regression, Mann-Kendal rank test, Sequential Mann-Kendal and BFAST analysis are the four techniques used for analysis and to verify significant changing patterns in rainfall. Detailed of the techniques are mentioned below.

Liner trend method is widely used across the globe to find the trend in data .This is a simple model which is expressed in the form of an equation.

$$\mathrm{Y} = \mathrm{a} + \mathrm{bx} \tag{1}$$

Where 'a' is the y-intercept, 'b' represents the slope of the regression line and x is the independent variable which in this case is time.

Mann-Kendall rank test: The Mann-Kendall test is a widely used statistical method by modern climatologists to analyze trends in temperature, temperature range and rainfall. This non parametric test is directly applicable to climatic data for a given month or season. Relative values of all terms in the series are the basic input for this test. For calculating P statistics the rank for first value is compared with later values, similar procedure is used for all the values in the series. The procedure continued still each of the values in the series ending with the K_{n-1} and its corresponding number N_{n-1}. In further stapes statistical τ is calculated. The negative value of 'τ' indicates declining trend. The tg represents preferred probability point of the Gaussian normal distribution, for this study it is at 1% and 5%.

2.2.2 Remote sensing based indices:

Vegetation Condition Index (VCI):
This index is a pixel-based normalization of NDVI which is mostly helpful for making comparative pixel based assessment. Jain et al., (2010) and (Quiring and Ganesh, 2010) defined VCI as a minimal and maximal function of status of vegetation cover over the specific area. The high significance of VCI is highly linked with the relation of vegetation index and the strength of the high vegetation cover over the area (Bhuiyan, 2004). VCI is defined as:

$$\mathrm{VCI} = \frac{(\mathrm{NDVI}-\mathrm{NDVImin})}{(\mathrm{NDVImax}-\mathrm{NDVImin})} * 100 \tag{2}$$

Where, NDVI, NDVImin, and NDVImax represent the value for each grid cell. VCI ranges from 0 to100, which results in extremely unfavorable to optimal conditions. In the extremely dry month, observed values for VCI are close to zero. In the optimal vegetation condition, VCI is near to 100. VCI values near 50 reflect lightly good vegetation condition. VCI studies gives an estimation of spatial based drought characteristics, its duration with respect to severity.

Temperature condition Index (TCI):

This index was proposed by Kogan (1995, 1997) while monitoring drought conditions along with VCI. It is used to eliminate the effects occurred due to contamination in satellite observations of vegetation environment. It is given by the formula:

$$\mathrm{TCI} = \frac{(\mathrm{BTmax}-\mathrm{BT})}{(\mathrm{BTmax}-\mathrm{BTmin})} * 100 \tag{3}$$

The above mentioned formula highlighted the different response of vegetation towards temperature. Where BT, BTmax and BTmin are the average values of brightness temperature (BT). In this case multiyear total maximum and its absolute minimum temperature values are considered (Owrangi et al., 2011). Like VCI, TCI values are also represent in percentages and follows the same mathematical algorithm as VCI. Higher temperature values in the middle of the developing period results in adverse conditions of drought, higher temperatures values may lead to soil moisture loss which directly leading to droughts. On the other hand low temperature values indicate the maximum favorable conditions.

Vegetation Health Index (VHI):

This index is based on a grouping of products resulted from two vegetation signals named as NDVI and brightness temperature/ LST. Kogan (1995) proposed this another vegetation based index, which is combination of VCI and TCI.

$$\mathrm{VHI} = \alpha\,\mathrm{VCI} + (1 - \alpha)\mathrm{TCI} \qquad (4)$$

Here, α (alfa) is the contribution of VCI and TCI for VHI. In most of the cases α has been used as 0.5, assuming that, both input elements (VCI and TCI) are contributing evenly (Kogan, 2000). The VHI has been used for different application based studies, like drought identification, severity, duration etc. (Seiler et al., 1998). These drought based applications have been confirmed in various scales in various parts of the world,at global level by Kogan (1997) and Kogen (2000), on regional scale (Liu and Kogan, 1996) and at national level (Seiler et al., 1998).

3. RESULTS AND DISCUSSION:

3.1 Trend analysis:

The districts of Marathwada portray overall decrease in the monsoon rainfall from the year of 1951. None of the district undergoes increase in rainfall per decade. However, the significant decrease is observed for the Latur district (r value= -0.211). The rainfall for Latur during the monsoon season has decreased significantly at the rate of 48 mm/decade, which is the highest rate of decrease among all 8 districts of Marathwada. On the contrary the rainfall indicates decrease but not statistically significant over remaining districts, decadal decrease in rainfall over these remaining districts is in the range of 2 mm to 23 mm per decade. More or less same trend is continued for all other districts. The rainfall is non significantly decreasing at the rate of 20 mm/decade for Osmanabad, Nanded and Aurangabad. The rainfall for Beed during the monsoon season has decreased non-significantly at the rate of 2 mm/decade, which is the lowest rate of decrease among all 8 districts of Marathwada (Figure 2).

In the comparison with other months, highly declining rainfall in the month of July is of major concern. All the districts of Marathwada observed decreasing rainfall trend in the month of July. However Osmanabad(r= -0.374), Aurangabad (r= -0.238) and Latur(r= -0.203) observes statistically significant negative trend. Over the Osmanabad rainfall is significantly decreasing at the rate of 19mm/decade. While Latur experiences significantly decreasing rainfall at the rate of 21mm/decade. Overall decreasing nature of rainfall in the month of July may not be a good sign for agriculture as well as for hydrological water balance (Table 1).

Table 1. Correlation values for districts of Maharashtra and rainfall per year

MARATHWADA	DISTRICT	JUNE	JULY	AUGUST	SEPTEMBER	MONSOON
1	AURANGABAD	-0.119	-0.238*	0.001	-0.17	-0.136
2	BEED	0.105	-0.165	0.032	-0.007	-0.081
3	HINGOLI	-0.037	-0.161	-0.078	-0.098	-0.153
4	JALNA	-0.01	-0.147	0.015	-0.078	-0.133
5	LATUR	-0.196*	-0.203*	-0.016	-0.085	-0.211*
6	NANDED	-0.11	-0.096	0.009	-0.19	-0.111
7	PARBHANI	0.165	-0.22*	0	-0.08	-0.060
8	OSMANABAD	-0.122	-0.374**	-0.036	-0.002	-0.151

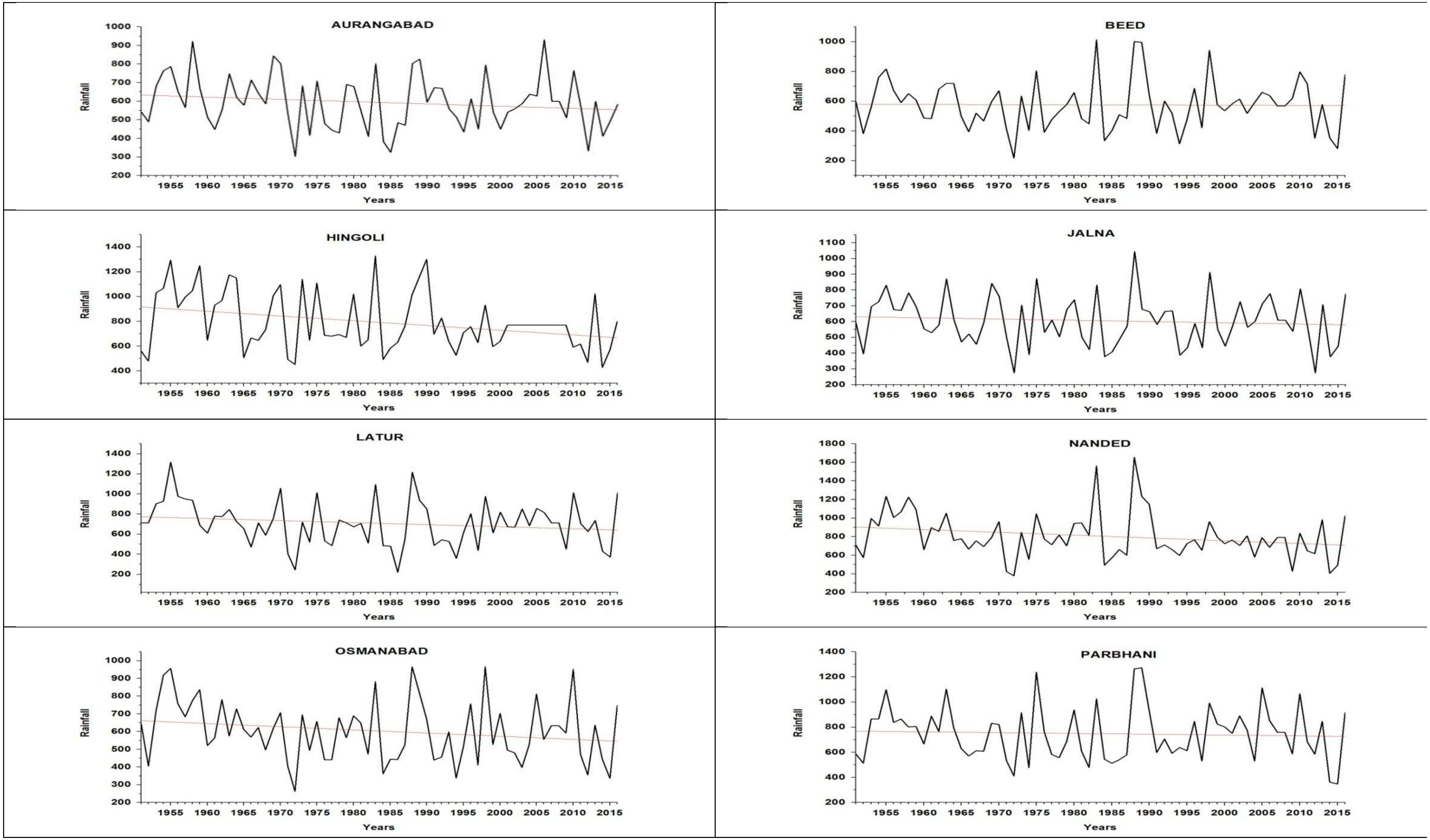

Figure 2. Long term rainfall trends- Overall Monsoon

3.2 SPI analysis:

The Standardized Precipitation Index (SPI) for defining the meteorological drought is an important tool to estimation the intensity and duration of drought event. This index is useful for large as well as short duration. The shorter duration results are useful for agro based studies, while longer range results can be helpful to understand underground recourses and Lake water level, etc. in better way.

In this study SPI was studied for the long duration rainfall values. In general 50% observed years are showing negative values which are reflection of drying conditions over that specific year. In the decade of 1960's -1970's, year 1984 to 1987 and few continues years after 2010 are showing the severe drought situation overall the Marathwada.

District as a particular, most of the severe drought years are noticed over the Latur, Jalna, Nanded and Parabhani. The year of 1971, 1972, 1982, 1987 were the most affected drought years from earlier century. The rate of SPI was nearby -2 which reflect the highly impactful drought condition for Marathwada, Maharashtra. In the recent century after 2000 the brutal drought cases are noticed over the year of 2002, 2009, 2013-14 (Figure 3). The SPI values for Hingoli and Parabhani were more than -1.5; these negative values are of major concern with respect to food security and countries economy. From last few years, these negative values are becoming a major reason for farmer's suicide in these places, due to severe drought cases.

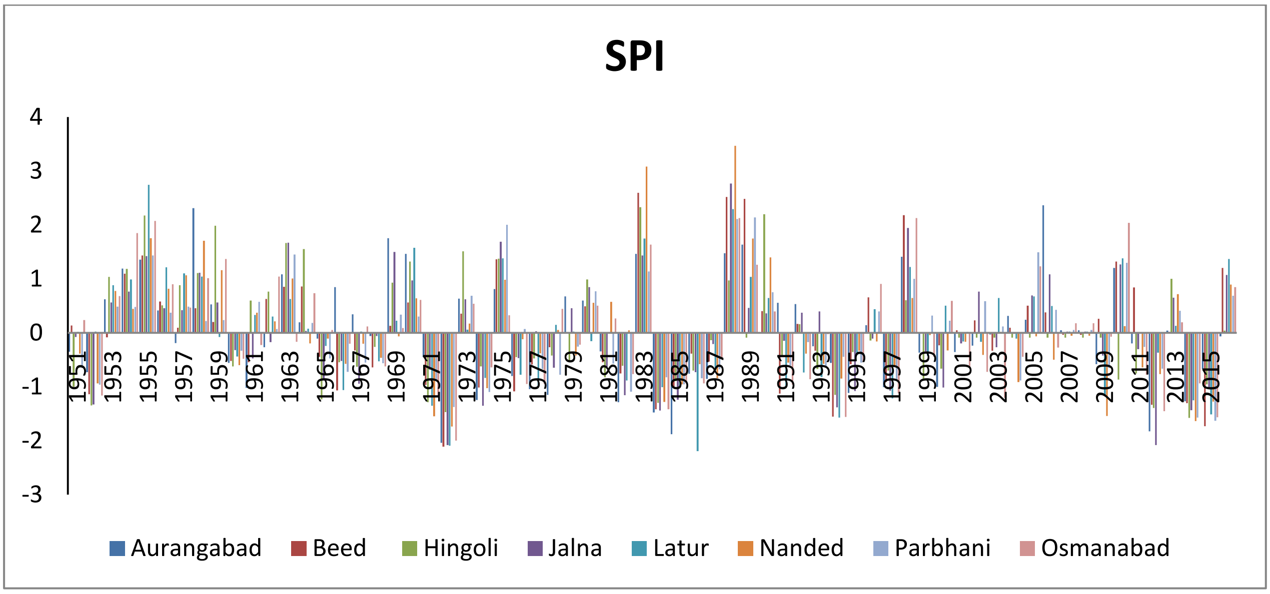

Figure 3. Long term plot for SPI

3.3 Remote sensing based analysis:

In this study, remote sensing based analysis was carried out for the year 2001 to 2016. TCI, VCI and VHI were calculated for each year, which is giving year wise changing patterns of drought condition and differentiation between drought and non- drought events over Marathwada. As a result of rainfall trends, it is observed that, for the selected years, the rainfall was below normal, temperature values were always high, due to which over the drought year's, low TCI values were seen. It is also noticed that, because of heavy rainfall, soil moisture is excessively available for the crops. This is resulting on changing values of NDVI and low VCI values.

TCI, VCI and VHI results were studied for the post monsoon season (October, Novemner and the month of December). In these 16 years of time span mix nature of dry and wet conditions were observed as a result of VCI and TCI over various parts of the study area. In these years, some severe drought conditions were noticed over few parts of Marathwada during the years 2001, 2002, 2009, 2012 and 2015. The results of VCI showed that, the districts of Latur, Nanded and Hingoli were highly affected due to these severe droughts in the month of October which is followed by rest of the post monsoon season. During the rest of the years many districts had moderate droughts or normal conditions. The outputs from TCI were also supportive to the VCI results with some minor differences.

The years 2004, 2010 showed comparatively good wet conditions over Marathwada. During the drought years 2001, 2002 and 2015 more than 40, 000 km2 of area was affected by severe drought. But on the other hand it is also observed that, the area under normal conditions has increased during the period 2001-2016.

It was noticed that, in the month of November and December, the eastern part of Marathwada is mostly frequented by drought, and this is the area which has lowest TCI values throughout the period of 14 years. The area measured about 1458 km2. This area is part of Nanded district. In the post monsoon season, Southern and western parts were majorly dominated by moderate drought. The VCI results over extreme north, parts of Jalna and Aurangabad experience moderate drought conditions in most of the months. With compare to sever drought cases over marathwada the area under moderate drought was bit higher.

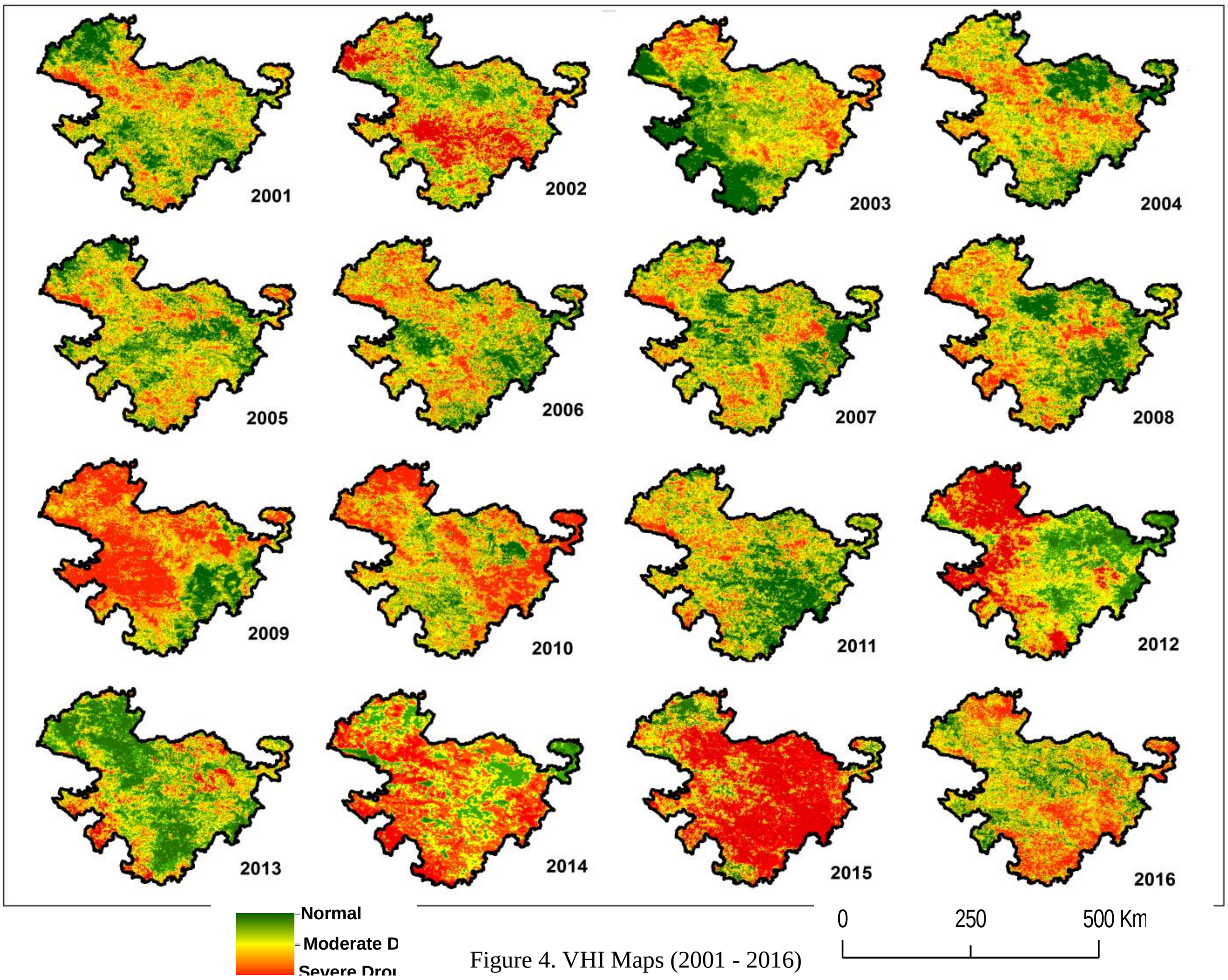

Figure 4. VHI Maps (2001 - 2016)

Vegetation Health Index (VHI) is one of the major drought monitoring indexes, as it combine results from VCI and TCI respectively. In this study VHI was calculated for the year 2001 to 2016 for every post monsoon month. In general 2002, 2009, 2015 were the most crucial drought years with respect to VHI (Figure 4). The years after 2000 were continually noticed drought scenarios, over different parts of the study area. The VHI index in general shows stressed vegetation health conditions over major parts of Marathwada after the year 2000 except for a few years. It means that, the vegetation conditions over Marathwada have not improved and continuously declining from past few years. It was noticed that, in the year of 2015, which was the most harmful drought year from last many decades, more than 70% area was under severe drought situation while remaining parts also faced drought effects in more or less percent.

The study observed that, from last 10-12 years the vegetation health condition was comparatively better in the month of October, but further it was significantly declining in the month of November and December. Less amount of soil moisture due to fewer amount of rainfall in the monsoon months and depleting ground water resources over the study area are may be the reasons for highly changing vegetation health in post monsoon season.

The central and northern parts of the Marathwada (i.e. Beed, Aurangabad and Latur) are frequently under severe or moderate drought cases. These severe conditions are of major concern for crop production and day today human activities.

The VHI studies observed that, the droughts occurred in past years, were mainly, late season or mid-season drought which affects the productive or maturity phase of crop in the further months. The normal VHI condition, noticed in the years 2003, 2008 and 2010 helps us to infer that crop production in these years must have been good. These positive cases may have occurred due to good amount of rainfall in that particular year or moisture levels may have improved may because of irrigation activities.

Specific drought years:

To distinguish between drought and non drought years and to identify their spatio-temporal characteristics, three drought years (2002, 2009 2015) and one normal year (2004) were considered for further analysis. Map shows that, the vegetation was under stress condition and the drought scenarios have increased significantly in the year of 2002, 2009 and 2015 (Figure 5). In some cases, due to stressed vegetation conditions, VCI values are found to be unfavorable. In this case TCI provides the reason to identify the vegetation stress and whether stress is due to dryness or excessive wetness.

With compare to year 2002 and 2009 year 2015 is under highly severe stress condition, which has covered more than 60% part of the study area. From all the drought years from a map, central part of the study area (Beed, Parbhani and latur) is continuously under high stress condition which is of major concern in every socio-economic aspect.

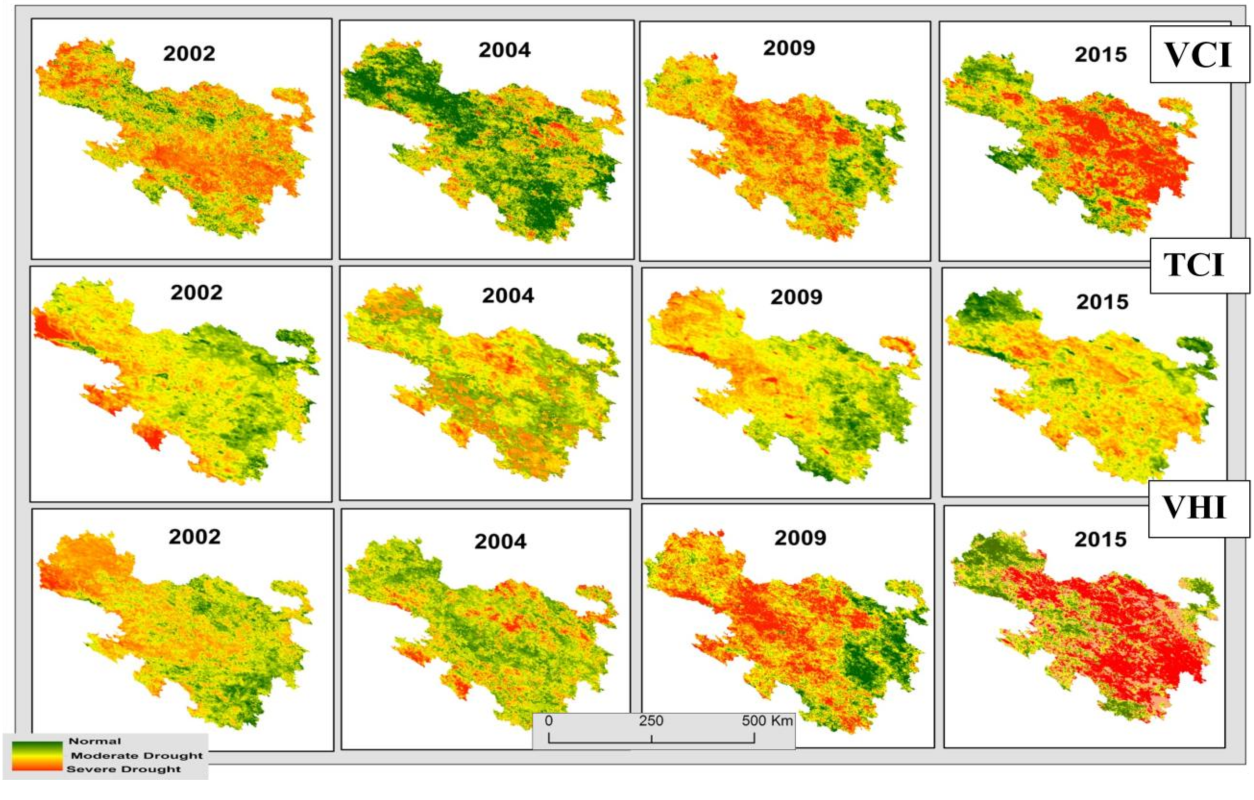

Figure 5. VCI, THI, and VHI Maps (October) for drought and non-drought year

4. CONCLUSION:

The VCI index is showing highly accurate drought conditions for the study area. This index is giving better observations for prolonged, extensive drought scenarios. On the other hand it is suitable for extremely localized, not well defined and short term drought areas as well. The TCI index is resulting for temperature-based vegetation stress conditions and also stress occurred due to an excessive wetness. Comparison and validation with rainfall trends shows that, these indices are giving relatively accurate drought conditions; therefore, this study state that, these indices can be useful for further studies and other drought monitoring based researches for Marathwada.

Another significant finding of the study is related to rainfall trends of July month. Rainfall during July is of great significance to agriculture and it was observed that during this month rainfall has significantly decreased over three districts of Marathwada. This is not a good sign because Marathwada gets low to moderate amount of rainfall, and if this also decreasing then it will affect agriculture adversely.

Various researchers have found that for country as a whole there is no significant long-term trend observed in monsoonal rainfall. The present study also is in line with these findings for Marathwada meteorological subdivision. Having said this, it is noticed that over Marathwada, the rainfall trends indicate declining trend. Though this trend is not statistically significant for all districts it is a matter of concern since it indicates that in the coming years one should not expect normal or above normal performance of monsoon which may result in severe drought conditions.

Therefore, planning of water resources will have to be done very wisely in the near future. Though there have been efforts for water conservation and planning these have to be intensified and properly regulated to avoid any water crisis, which are already evident in the last few years.

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