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Marathwada agro-climatic drought detection by utilization of temperature and vegetation index records.

Detección de sequía agroclimática de Marathwada mediante la utilización de registros de índice de temperatura y vegetación.

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Abstract

Semi-arid Marathwada economy depends on agricultural production and in recent decades the drought has been observed as an all part of the several recurrent climates related environmental hazards in region, frequently destroying livelihood, socio-economy, and food security of region. The economy of the nation affected due to less productivity of crops as well as decreases the soil moisture. In present work the remote sensing, image processing and geospatial techniques effectively using for drought management, mitigation practices, monitoring and assessment. The main objective of study is to analyze VCI and TCI indices. MOD11A2 and MOD13C2 data (year 2000, 2005, 2014 and 2016) is used for derive the TCI and VCI respectively. Time series of TCI and VCI shows that in certain years resembles each other's and their result helps to determined occurrence and severity drought. The result shows the seasonal VCI is directly related to the seasonal rainfall as well as TCI of region. The analysis reveals that the conformation of demonstrating extension and severity of aridity in the Marathwada region. The motivation behind the examination to compute the vegetation index (NDVI) and Temperature Condition Index helps to review of agricultural practices and water use.

Key words: Drought; GIS and Remote Sensing; NDVI; TCI; VCI; MODIS; Marathwada.

RESUMEN

La economía semiárida de Marathwada depende de la producción agrícola y, en las últimas décadas, la sequía se ha observado como parte de los diversos peligros ambientales recurrentes relacionados con el clima en la región, que con frecuencia destruyen los medios de subsistencia, la socioeconomía y la seguridad alimentaria de la región. La economía de la nación se vio afectada por la menor productividad de los cultivos y la disminución de la humedad del suelo. En el presente trabajo se utilizan técnicas de teledetección, procesamiento de imágenes y geoespaciales de manera efectiva para el manejo de sequías, prácticas de mitigación, monitoreo y evaluación. El objetivo principal del estudio es analizar los índices VCI y TCI. Los datos MOD11A2 y MOD13C2 (años 2000, 2005, 2014 y 2016) se utilizan para derivar el TCI y el VCI respectivamente. Las series temporales de TCI y VCI muestran que en ciertos años se asemejan entre sí y su resultado ayuda a determinar la ocurrencia y severidad de la sequía. El resultado muestra que el VCI estacional está directamente relacionado con la precipitación estacional, así como con el TCI de la región. El análisis revela que la conformación de demostrar la extensión y la severidad de la aridez en la región de Marathwada. La motivación detrás del examen para calcular el índice de vegetación (NDVI) y el índice de condición de temperatura ayuda a revisar las prácticas agrícolas y el uso del agua.

Palabras clave: Sequía; SIG y Teledetección; NDVI; TCI; VCI; MODIS; Marathwada.

ABBREVIATIONS

NDVI- Normalized Differential Vegetation Index; TCI- Temperature Condition Index; VCI- Vegetation Condition Index; CMG- Climate Modeling Grid; LST- Land Surface Temperature; VI- Vegetation Index; NDWI- Normalized Difference Water Index; SATVI- Soil Adjusted Total Vegetation Index; NDDI - Normalized Drought Dryness Index; TDVI- Temperature Vegetation Dryness Index; NDWI- Normalized Difference Water Index; NDDI- Normalized Drought Dryness Index

INTRODUCTION

Global concern for climate change has encouraged giving huge consideration for investigation drought in quantitative structures. Throughout the long term, various indices have been being used for drought spell depiction (Keyantash & Dracup, 2002; A. Mishra & Singh, 2011; A. K. Mishra & Singh, 2010; ZargarAmin, SadiqRehan, NaserBahman, & I., 2011) have inspected many such indices. However, drought indices depend on just precipitation data are easy to calculate and found to perform better (Olukayode Oladipo, 1985). Among the normally utilized indices that use precipitation data information, standard precipitation Index (SPI), is as often as possible applied around the world for the drought assessment and monitoring (Hosseinizadeh, SeyedKaboli, Zareie, Akhondali, & Farjad, 2015; Mckee, 1993).

The World Meteorological Organization (WMO) well-chosen SPI as a standard drought monitoring index (Hayes, Svoboda, Wall, & Widhalm, 2011). It is one of the two indices (other being Aridity Anomaly Index) utilized by the Indian Meteorological Department (IMD). Since SPI is standardized and has a probabilistic understanding (Guttman, 1998), the present examination will utilize this.

Droughts are related to the decrease in the amount of rainfall got throughout extended period of time, such as a season or a year. Other meteorological character such as temperature, high wind, low relative humidity, timing, behaviour (onset, termination) and intensity of rainfall, includes distribution of rainy spell during growth of crop. Which is play a significant role in the event of drought (A. K. Mishra & Singh, 2010).

The principle natural reason for harm in agriculture, economy and environment is because of drought and other natural hazards (Wilhite, 2012). A deficiency in rainfall is the main reason for drought (Vicente-Serrano, Beguería, & López-Moreno, 2010). A worldwide environmental change influences the time and space of water cycle component redistribution, as well as extreme weather events occurs more frequently and intensely (IPCC, 2014).

In the previous research, the impact of long and short term drought has been calculated through the estimation of green vegetation indices such as NDWI, SATVI, NDVI, LST and NDDI especially in an arid, semi-arid and moderate mediterranean ecosystem where vegetation is sporadic (Gu, Brown, Verdin, & Wardlow, 2007; I. Orimoloye, Kalumba, Mazinyo, & Nel, 2018).

Several multi-spectral vegetation indices have been employed to appraise growing vegetation attributes in recent decades (Adam, Mutanga, & Rugege, 2010; Viña, Gitelson, Nguy-Robertson, & Peng, 2011; Yang, Weisberg, & Bristow, 2012). These indices are important in terms of logical order of reflectance in the blue, green, Infrared and red spectral bands which have been acknowledged to be associated with green vegetation factors. These factors includes water index, leaf area index and drought index, (Rhee, Im, & Carbone, 2010; Viña et al., 2011), canopy cover (Garbulsky, Peñuelas, Gamon, Inoue, & Filella, 2011), the fraction of absorbed and reflected land surface temperature and surface radiation (I. R. Orimoloye, Mazinyo, Nel, & Kalumba, 2018).

Several environmental and climatological factors as well as the indices extracted from the satellite images have been utilized by different studies to monitor, quantify, and map dry spell. Furthermore, several indices such as VCI (Quiring & Ganesh, 2010), NDVI (Swain, Wardlow, Narumalani, Tadesse, & Callahan, 2011), TDVI (Gao, Gao, & Chang, 2011), and NDWI (El-Hendawy, Hassan, Al-Suhaibani, & Schmidhalter, 2017; I. Orimoloye et al., 2018) and NDDI (Gu et al., 2007; Rhee et al., 2010) were used for drought analysis based on LST and vegetation indices as well as NDDI (I. R. Orimoloye et al., 2018).

Hence; scientists have been started to focus on evaluation of drought by using the response of vegetation canopy and remote sensing investigation of vegetation.

Agricultural production and practices, and other water dependent activities are being affected by several factors such as climatic variability and changes, scarcity or shortfall of rainfall amount, inadequate monitoring by environmental stakeholder and insignificant irrigation supply in Marathwada region of Maharashtra state. Therefore, agricultural production, vegetation and practices might have been brutally affected during the severe as well moderate drought. If these factors are not properly and timely evaluated it can be devastating to people, food security and environmental health. So, proper monitoring and assessment of drought require more research based commitment.

Several studies have been suggested that droughts caused low food production especially in low-come nation or developing nation where the natural resources of water is life reliant and people have less option of livelihood which might result in ill-health and possibly demise (Epstein, 2000).

Accessibility and communication are poor and unusual in remote communities of developing nations. Moreover, individuals move from where there is water shortage to different areas looking for better day to day environment because of dry condition and this makes the region to be drought vulnerable, as large numbers of its habitants are force to relocate. Farming and other agrarian activities or practices endure more when individuals move. Drought mostly affects rural areas of the world put focus on family lives, individuals feel insecure and are threatened by forest extinction and wildfires. There could be also a loss of lives due to drought occurrence in any particular area (Leng, Tang, & Rayburg, 2015).

The current investigation focused on the landscape dynamics and drought event in Marathwada region. Also aims to detect and assess the severity and duration of drought of selected representative years, by evaluating the vegetation and temperature indices in semi-arid Marathwada region. In doing so, this study quantify the spatial configuration of drought indices in the study area.

MATERIALS AND METHODS

Study Region: The study area encompasses of eight districts namely Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad and Parbhani; also known as Marathwada region of Maharashtra state, India. The selected area is located on west side of country covers near about 64,590 Km2. from total geographical area with a population of 18,731,872 in 2021 reported in census India government report,2011 on website (https://censusindia.gov.in/2011). It is spread between 74° 21′ 42.219′′E- 20° 36′ 56.434′′N and 78° 14′ 36.761′′E- 17° 49′ 15.399′′N. The Marathwada is drought prone region and comes under arid band of nation. The weather of study region almost dries to moderately extreme and experiences large variation in summer and winter temperature. The highest temperature in summer goes upto 46°C.The area gets very low and erratic rainfall with an annual average rainfall 722.5mm (CGWB, 2013; IMD, January,2020). The livelihood of people in this region depends on the agricultural production. Agriculture in this region is mainly rain-fed but rainfall extremities put heavy stress on agricultural activities and other economic exercises. In this region there is a considerable decrease in monsoonal rainfall and increase in dry spell in recent decades(CGWB, 2013).

Data acquisition

Vegetation Index Data: The Moderate Resolution Imaging Spectro-radiometer (MODIS) NDVI/ Terra Vegetation indices monthly data of drought years (2000 and 2014) and wet years (2005 and 2016) is used for study respectively. The MOD13C2 version 6 product provides a VI value on a per pixel basis. There are two essential vegetation layers, first one is the NDVI is referred to as a continuity index to existing National Oceanic and Atmospheric Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR) derived NDVI. The second one is Enhanced Vegetation Index (EVI) which has improved sensitivity over high biomass regions. The Climate Modeling Grid (CMG) consists of 3,600 rows and 7,200 columns with 5,600 meters pixels.

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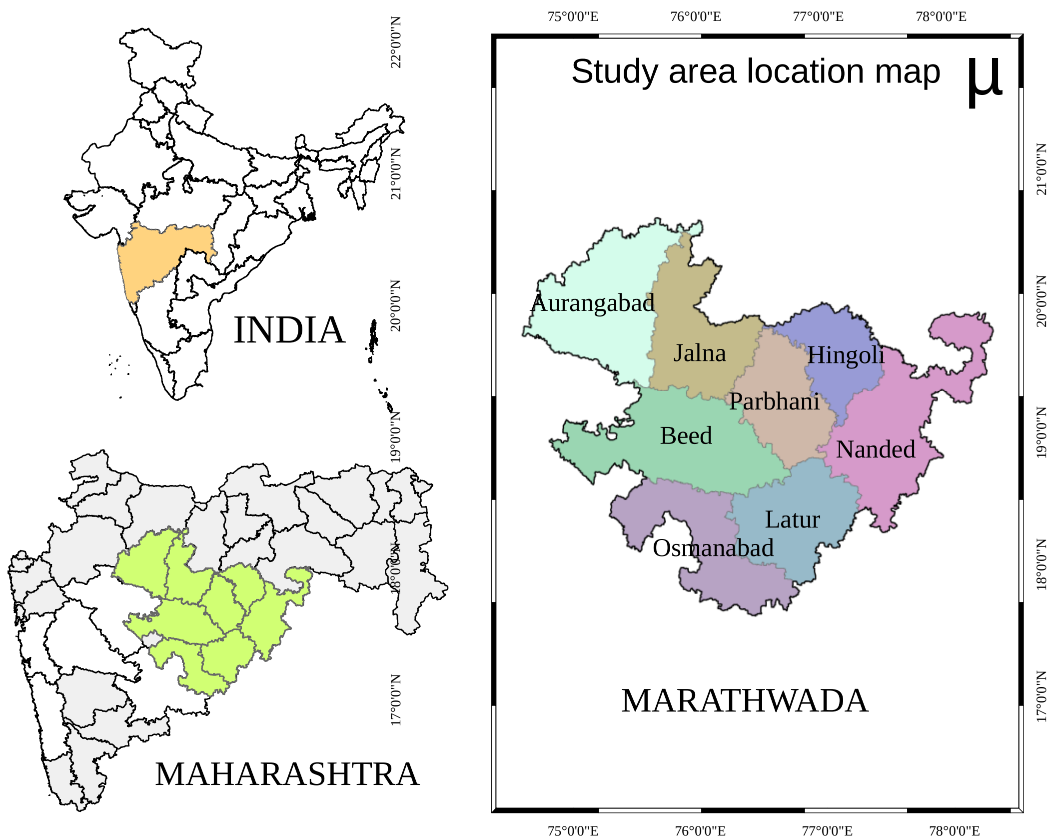

Figure 1. Representing the location map of study region.

Table 1. Specification of satellite data used for drought assessment.

Data	Year	Date of Acquisition	Crop season
MOD11C3 and MOD13C2	2000	01-11-2000	Oct - Dec
		01-03-2000	Jan - mar
		01-05-2000	Apr - June
		01-09-2000	July - Sept
MOD11C3 and MOD13C2	2005	01-11-2005	Oct - Dec
		01-02-2005	Jan - mar
		01-05-2005	Apr - June
		01-09-2005	July - Sept
MOD11C3 and MOD13C2	2014	01-11-2014	Oct - Dec
		01-02-2014	Jan - mar
		01-05-2014	Apr - June
		01-08-2014	July - Sept
MOD11C3 and MOD13C2	2016	01-11-2016	Oct - Dec
		01-02-2016	Jan - mar
		01-05-2016	Apr - June
		01-08-2016	July - Sept

To generating month to month product, the algorithm ingests all the (MOD13A2) products that overlap the month and employs weighted temporal average. Worldwide MOD13C1 data are cloud-free spatial composites provide a Level 3 product which projected on 0.05 degree (5,600 meters) geographic CMG. The 0.05 degree CMG resolution of MOD13C2 has information for NDVI, EVI, VI QA, reflectance data, angular information and spatial statistics. All were acquired from the website the NASA website (https://doi.org/10.5067/MODIS/MOD13A2.006).

Temperature Index Data: The 0.05 degree (5,600 meters at the equator) CMG MOD11C3 version 6 data, which provide LST and emissivity information is used for TCI analysis in drought years (2000 and 2014) and wet years (2005 and 2016). The MODIS LST products are created as a sequence of products beginning with a scene and progressing, through spatial and temporal transformations, to daily, eight-day and monthly global gridded products.

The MODIS satellite data specification acquired with their characteristics such as date of acquisition, year and cropping season which shows in table 1. The entire acquired data were analyzed by ArcGIS software (version 10.2).

Adoption of methodology: All remotely sensed satellite imagery of the study region were obtained from Earth-Data open access NASA's archive center. The satellite imageries were collected in four segment data ie. 2000, 2005, 2014 and 2016. The flow chart of methodology adopted was shown in figure 2.

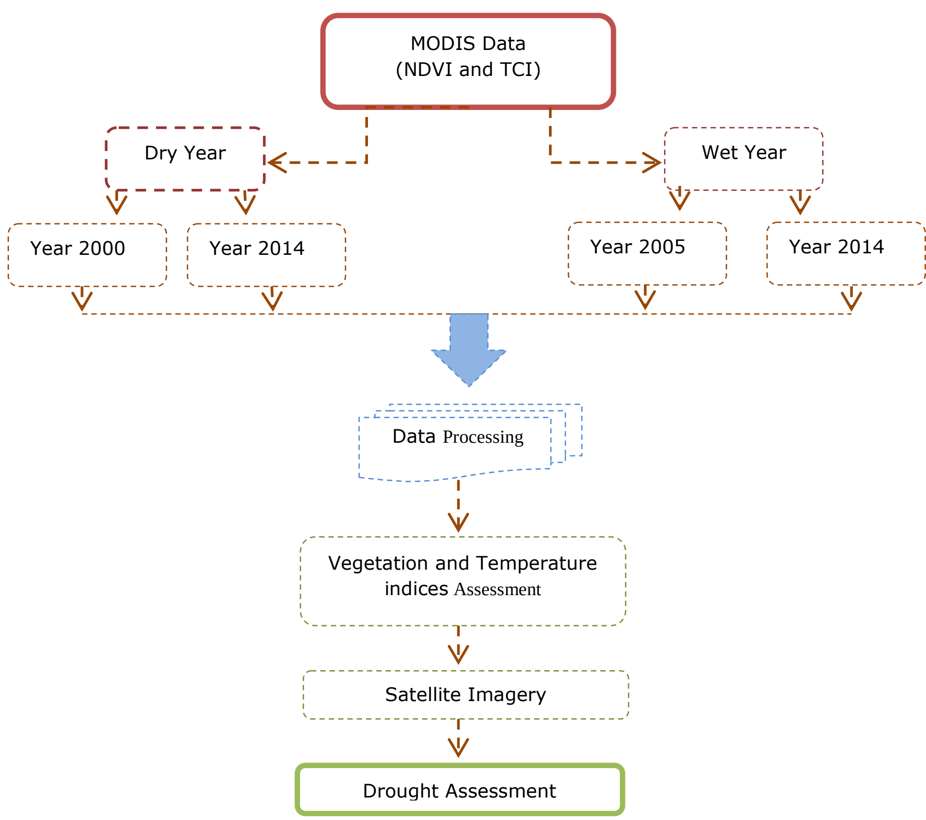

Figure 2. Flow chart for adapted methodology.

Vegetation Condition Index (VCI): The MOD13C2 version 6 products give VI esteem for every pixel basis. There are two essential vegetation layers. The first one is the NDVI which indicated as continuity index to the existing National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) inferred NDVI.

The Normalized Vegetation Index was developed by (Rouse JW, 1974), which reflect the vegetation condition through ratio of response in Near Infrared (NIR) and visible bands. The agricultural and vegetative droughts reflect vegetation stresses which are closely related to local weather impacts. The VCI separates the short-term weather related NDVI fluctuation from the long term ecosystem changes (F. N. Kogan, 1990, 1995) and it is helpful to making comparative pixel based assessment. VCI is nothing but a minimal and maximal function of vegetation cover over the particular area, (Jain, Keshri, Goswami, & Sarkar, 2010; Quiring & Ganesh, 2010).

The VCI is calculated by the following equation:

$$VCI = \frac{(NDVI - NDVImin)}{(NDVImax - NDVImin)} * 100 \text{ ....} \quad (1)$$

Where, NDVI, NDVImin and NDVImax are the seasonal average and multi-year absolute minimum and maximum respectively. The VCI rescales vegetation dynamics ranges from 0 to 100 and table 2 shows the drought classification scheme. It is reveal comparative changes in moisture condition from wicked to finest (F. Kogan, Gitelson, Zakarin, Spivak, & Lebed, 2003).

Temperature Condition Index (TCI): The TCI proposed by (F. N. Kogan, 1995), which recommended the drought events will diminish soil moisture and cause land surface thermal stress, and a higher land surface temperature (LST) in the drought year than the same month of normal year. The higher land surface temperature in crops growing season demonstrate unfavorable or drought condition.

The TCI is calculated by the following formula:

$$TCIj = \frac{(LSTmax - LSTj)}{(LSTmax - LSTmin)} * 100 \text{ ....} \quad (2)$$

Where,

LSTj - land surface temperature month
LST_{min}- land surface temperature minimum
LST_{max}- land surface temperature maximum.

The low TCI correspond to vegetation stress because of high temperature and dryness. TCI helps to identify the subtle changes in vegetation health due to thermal effect. The moisture shortage along with high temperature leads the drought condition (F. Kogan, 2002).

However the present study has been calculated theses indices considering the seasonal agricultural crop seasons.

Table 2. Representing the VCI and TCI classification schemes (Bhuiyan, Singh, & Kogan, 2006).

Classification Scheme	
Drought Classes	VCI and TCI (%)
Extreme Drought	00 to 10
Severe Drought	10 to 19.9
Moderate Drought	20 to 29.9
Mild Drought	30 to 39.9
No Drought	40 to 49.9
No Drought	50 to 59.9
No Drought	60 to 69.9
No Drought	70 to 79.9
No Drought	80 to 89.9
No Drought	90 to 100

RESULT AND DISCUSSION

Rainfall analysis: The analysis of thirty years rainfall data from eight districts of Marathwada region was done. Based on the observation, none of the district as well as the last many rainfall year shows the continuous decreases in precipitation and not a single district of region undergone the increase in the rainfall pattern in last decades. However, the rainfall during monsoon season (kharif crop season) has significantly declined; is influenced succeeding rabi as well as summer/ zaid crop season in study region. The annual normal rainfall data of the districts namely Latur, Jalna, Aurangabad, Beed, Parbhani, Nanded, Hingoli and Osmanabad were presented. It is observed that the annual normal rainfall is below the annual average normal rainfall of entire study region shown in figure 3.

Based on analysis of long-term rainfall trend in Marathwada shows in figure 4. The rainfall has significantly decreases in years like 2000, 2014 (considering dry year) and 2005, 2016 selected for the further satellite based analysis of VCI and TCI for drought detection and assessment.

Table 3. Representing the district wise normal rainfall data of Marathwada.

District	Normal rainfall(mm)	Reference
Aurangabad	681.5	(CGWB, 2013; IMD, January,2020)
Beed	701.6	
Hingoli	869.1	
Jalna	695.6	
Latur	819.6	
Nanded	884.3	
Osmanabad	720.8	
Parbhani	837.6	

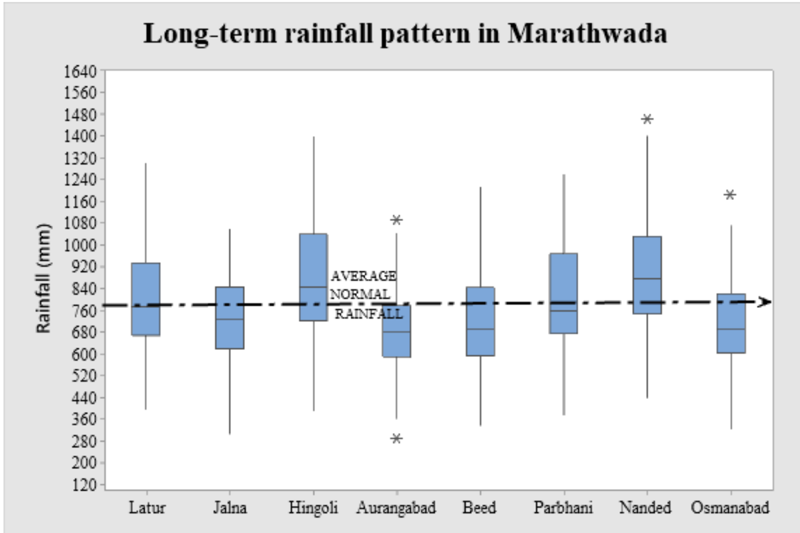

Figure 3. Representing the graph of rainfall pattern in Marathwada.

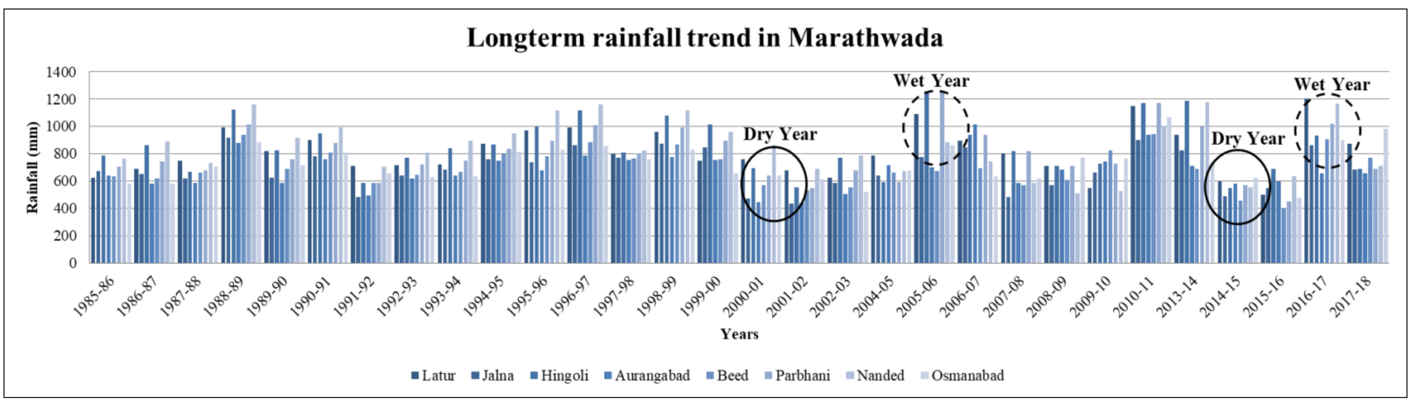

Figure 4. Illustrating the long-term rainfall trend in study area.

Drought detection and assessment: The year-wise analysis of VCI and TCI are used for drought detection and assessment in wet and dry years. That shows the dry years 2000 and 2014 kharif crop season (monsoon-season) and Rabi crop season (winter-season) in Marathwada appears drought with different intensities. The VCI and TCI values for year 2000 shows in figure 5; that except some small portion of Nanded, Hingoli and Parbhani. The pattern of drought intensity in region falls under moderate to extreme drought condition category. Due to shortage of rainfall and long dry spell with high temperature results into less or no production of agricultural crops during all cropping season in the region.

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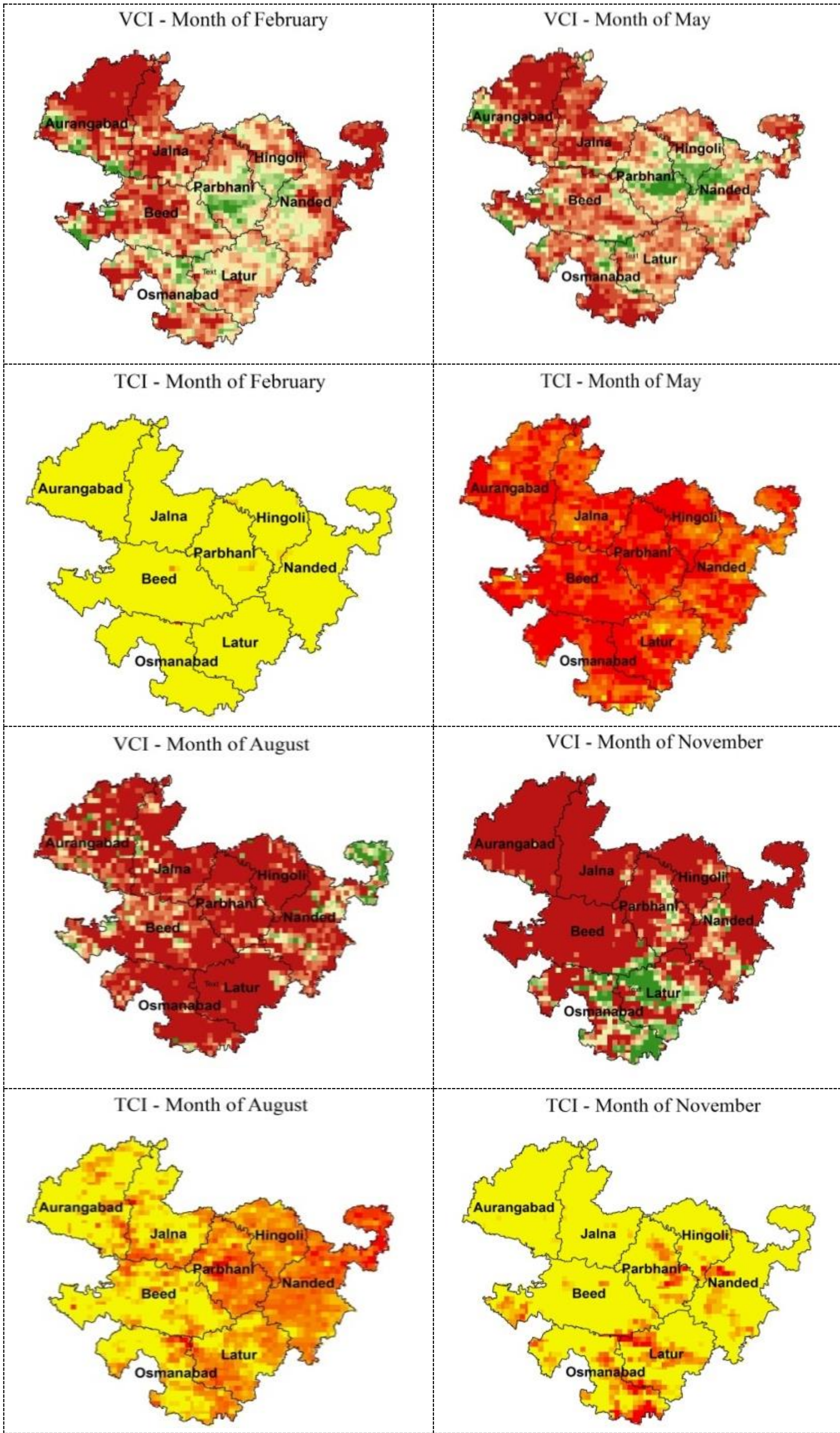

Figure 5. Spatial variation of VCI and TCI for year 2000 (dry year) in Marathwada region.

VCI	Color	Drought Classess
0-10%		Extreme Drought
10-20%		Severe Drought
20-30%		Moderate Drought
30-40%		Mild Drought
40-50%		No Drought
50-60%		No Drought
60-70%		No Drought
70-80%		No Drought
80-90%		No Drought
90-100%		No Drought

TCI	Color	Drought Classess
0-10%		Extreme Drought
10-20%		Severe Drought
20-30%		Moderate Drought
30-40%		Mild Drought
40-50%		No Drought
50-60%		No Drought
60-70%		No Drought
70-80%		No Drought
80-90%		No Drought
90-100%		No Drought

Drought condition resulted due to less rainfall, moisture stress, whereas in the next cropping season of next succeeding year also experience impact of drought. The figure 5 shows that, the impart temperature condition directly proportional to the moisture condition in the region and vice-versa.

In the figure 6, TCI and VCI values shows that there is no drought-like situation in the month of February and May, but immediately during the kharif and rabi crop season that is august and November shows thermal stress resulted into loss of soil moisture and deteriorate the vegetation health in drought year of 2014.

However, even though the rainfall during February and May, the crop condition of study region were not healthy because of shortfall of precipitation and long dry spell during cropping season. But favourable thermal condition helps to maintain the vegetation vigour. So that the healthy or favourable thermal condition in vegetation helps to maintain the moisture and reduces drought severity. Such condition in Marathwada experiences during the wet years i.e. 2005 and 2016 were shown in figure 7 and 8. In this year, the favourable thermal condition counters the moisture stress and dry spell in the region to avoid the drought condition and good moisture condition helps to good growth of crops and maintain the vegetation health and vigour in the region.

The VCI or NDVI and TCI relationship with the precipitation is a vital indicator for the detection of vegetation health and drought detection. The figure 7 and 8 shows the good relationship between the rainfall and VCI on seasonal time scale. The present study shows a close relationship between TCI and VCI which helps to detect the drought situation and severity pattern in both dry and wet years. Likewise precipitation, the temperature condition also affects the growth and health of vegetation as well as crops in both positive and negative sense.

The productivity of agricultural crops in the Marathwada region during monsoon season, VCI governed by the moisture and rainfall. The higher temperature of summer (from February to May) impart higher stress on vegetation health and soil moisture.

After the time-series analysis of TCI and VCI indices infers, that overall vegetation and crop health is sensitive to moisture availability, temperature condition and intensity, which is controlled by rainfall pattern and temperature of the region.

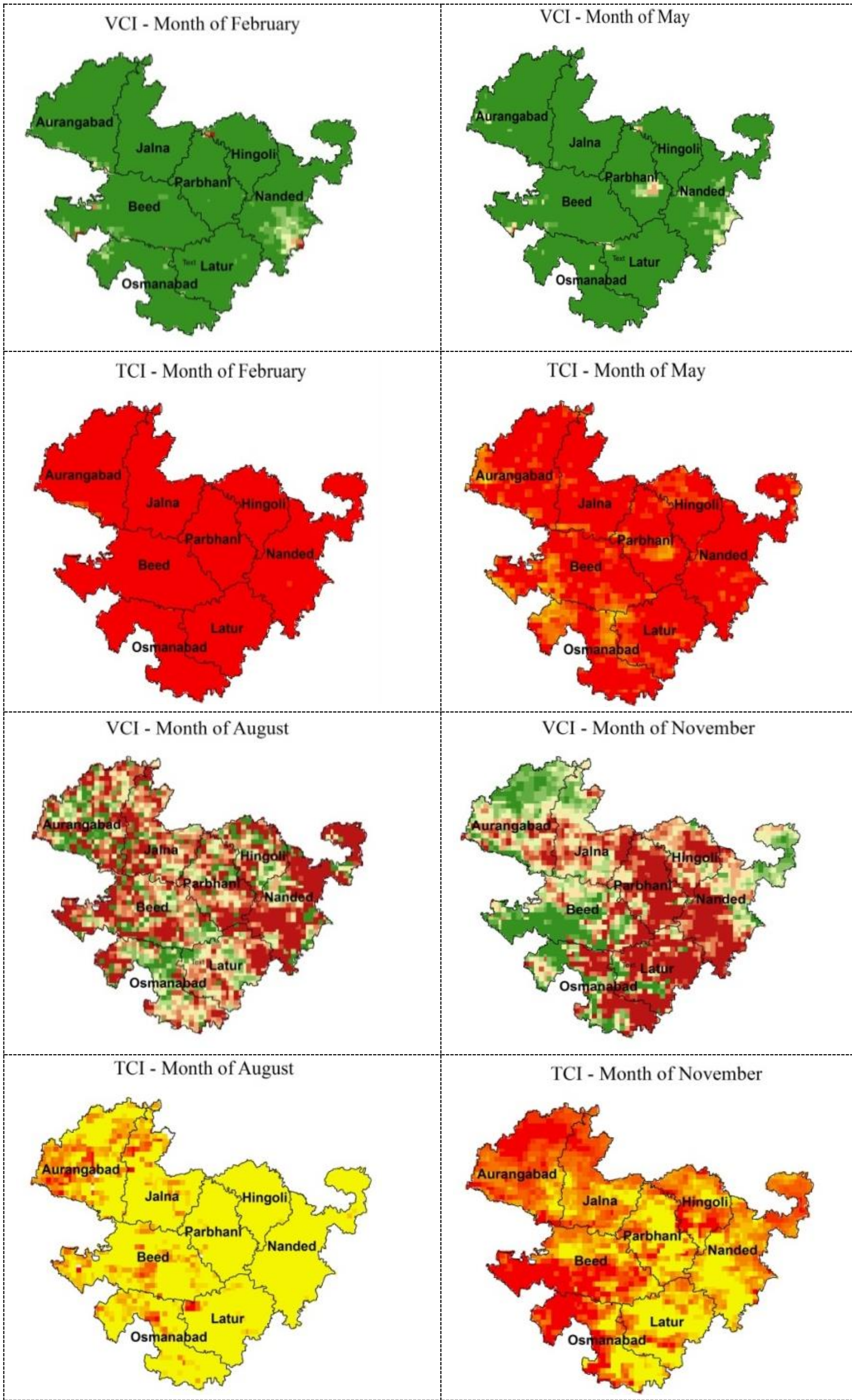

Figure 6. Spatial variation of VCI and TCI for year 2014 (dry year) in Marathwada region.

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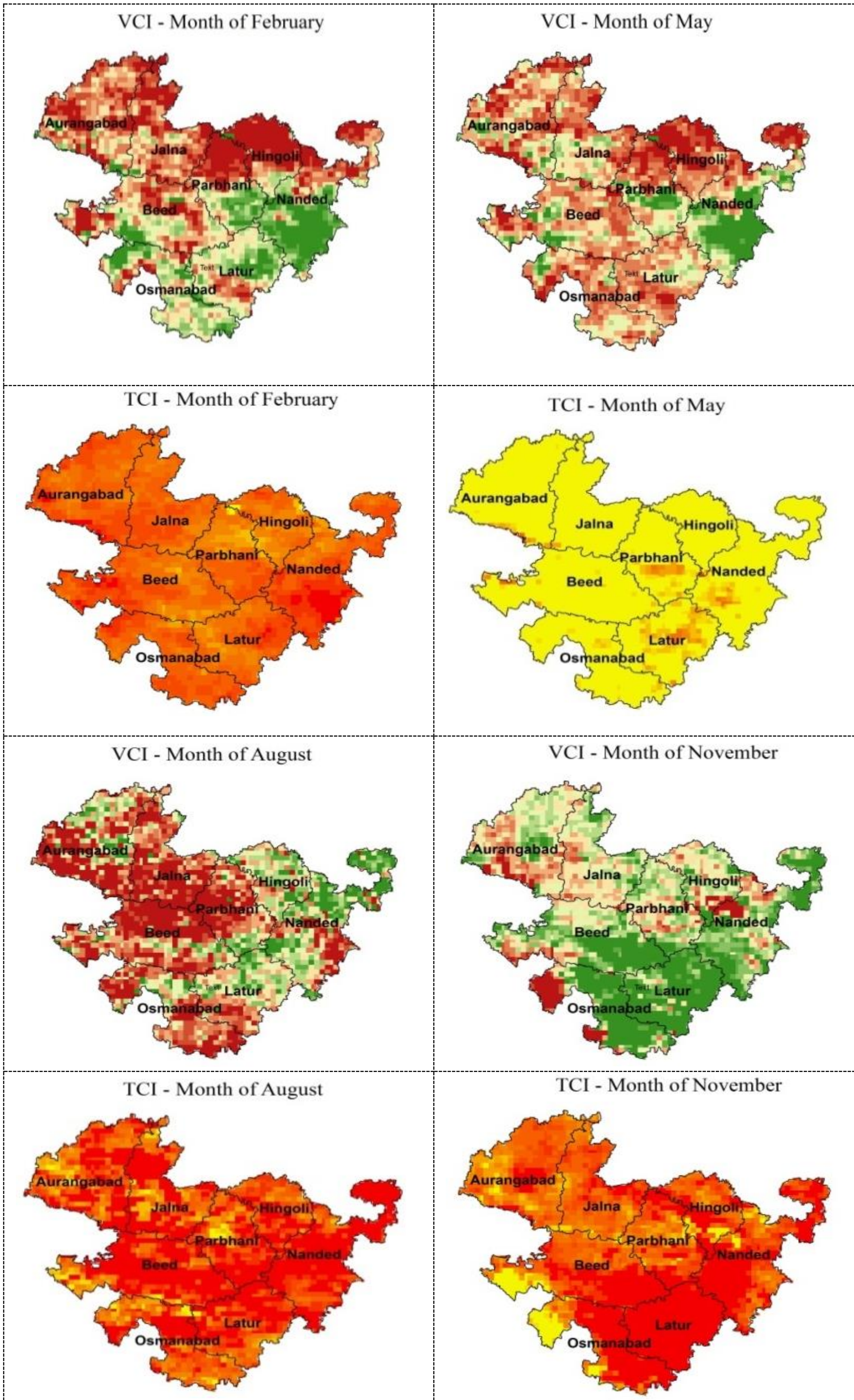

Figure 7. Spatial variation of VCI and TCI for year 2005 (wet year) in Marathwada region.

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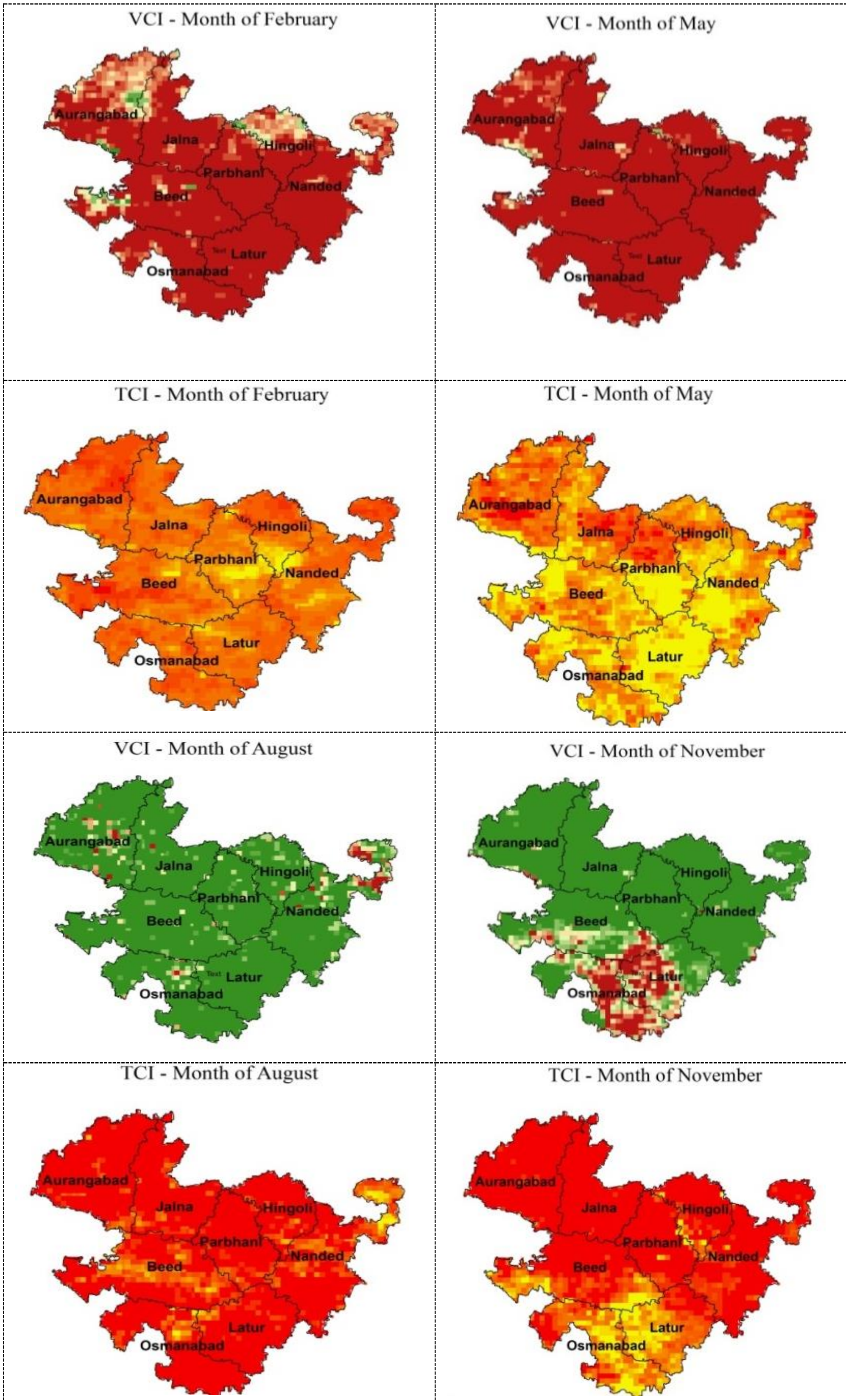

Figure 8. Spatial variation of VCI and TCI for year 2014 (wet year) in Marathwada region.

As conclusion, based on calculated indices, authors are concluding that, the rainfall pattern, timing and intensity indicate the declining nature and region is very vulnerable to meteorological drought. The vulnerability drought index were calculated by incorporating the TCI and VCI drought severity maps at different drought classes which is helpful to identifying the frequency of drought events in Marathwada region. Almost all region were experienced the moderate to extreme drought condition throughout different cropping season.

The correlation of temperature and vegetation condition indices of the region can be successfully utilized to detect agricultural climatic drought in Marathwada, as demonstrated in current investigation. The time-series and analysis of the vegetation and temperature indices has proven and conformed that, the meteorological factors govern the crop and vegetation condition of study region.

The assessment and detection examination uncovered the significance of RS and GIS in evaluating drought severity. In any case, with the guide of progress in current RS advancement, correlations were promptly completed to evaluate natural hazards and other conceivable related environmental disaster.

The spatial pattern of indices have seen increased in recent decades with values going between moderate to extreme drought condition during cropping season. Thus, in case this increment persists such development will have unfavorable and detrimental effect of food security, livelihood and degradation the land quality.

In a nutshell, increase in uneven and unseasonal rainfall limits and extension of drought events in cropping season of Marathwada shows possible risk to the rain-fed agriculture, agribusiness and socio-economic vulnerability in the region. Hence, a more step by step study to assess and investigate the impact of trend and pattern of the agro-climatic drought variables in fundamental.

Therefore, the conclusion of the study can be fundamental advance to improve the risk management techniques, review of agricultural practices, cropping pattern and water use in semi-arid Marathwada region. The TCI and VCI drought indices maps are useful in developing the drought preparedness plan by administrative bodies for the farmers of Marathwada region to their livelihood and social development. Also helps to formulating the mitigation strategy, sustainable water resource management in future era.

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