ASSESSMENT AND MONITORING OF AGRICULTURAL DROUGHT USING REMOTE SENSING BASED DROUGHT INDICES AND THEIR INTER-COMPARISON

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ABSTRACT: Drought is a condition of prolonged low rainfall leading to acute water shortage which has a huge social and economic impact. Drought is classified as meteorological, hydrological, agriculture and socio-economic drought. As per the Ministry of Agriculture and Farmer's Welfare, Government of India, 266 districts across 11 states in India were declared drought prone in 2016. Chhatarpur is a drought affected district of Bhundelkhand region, India. Around 60% of agricultural land of the district was transformed to fallow land, which has reduced the agricultural productivity by approximately 35% due to the effect of drought during year 2015-16. Therefore, assessment and monitoring of agriculture drought is very essential activity for supporting management and mitigation planning in the district. In the present study, Standard Precipitation Index (SPI) was used to identify and characterize the meteorological droughts. Impact of each meteorological drought on agriculture system was assessed using Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Temperature Condition Index (VTCI) derived using remote sensing data from Moderate Resolution Imaging Spectroradiometer (MODIS). SPI was computed using daily gridded rainfall data, provided by Indian Meteorological Department (IMD), of 21 grids covering entire Chhatarpur district and surrounding area. VCI, TCI and VTCI were also calculated for Rabi seasons of all these 15 years. The results of agricultural drought mapping using VCI were compared with results of agricultural drought assessment using multiple indices (VCI, TCI, and VTCI). It was observed that VCI fails to accurately map actual extent of agricultural drought during early sowing period. This limitation of VCI is mainly contributed to its dependence on vegetation index (NDVI) for drought mapping. However, combination of multiple indices gives better assessment of agricultural drought condition during entire season including early sowing condition. The study has highlighted the importance of using multiple indices for agricultural drought mapping.

1. INTRODUCTION

Drought is a condition of prolonged low rainfall leading to acute water shortage which has a huge social and economic impact. Globally, more than 11 million people has died due to drought since 1900 and 2 billion people were adversely affected by drought. According to Food Security Information Network's report of year 2016, approximately 108 million people from all around the world were affected by food insecurity, which was primarily due to the El Nino induced droughts (FISN, 2016). Drought can be described in terms of rainfall deficit, decreased water level in reservoir, reduction in agricultural productivity, and economic impacts and accordingly classified as meteorological, hydrological, agriculture and socio-economic drought. In India, around 330 million people were drought affected in year 2015-16. Drought had affected 2,55,923 villages in 254 districts of 10 states (UNICEF, 2015). India has faced severe drought over the past many years. 22 major drought had hit the country between the years 1871-2002 (DOAC&FW, 2016). Many regions in India had been in headlines for its arid and dry conditions, one such region which has gained significant attention is Bhundelkand region. This region had seen the worst drought and famines which the country had faced (NIDM, 2014). Administratively this region falls in the state of Madhya Pradesh and Uttar Pradesh, comprising of 13 districts. The state of Madhya Pradesh has witnessed serious drought conditions in the year 1986-87, 1987-88, 2000-01, 2004-05, 2007-08, and 2009-10. Chhatarpur is among the majorly drought affected districts of Madhya Pradesh.

Drought, being an extreme event affects the environment and society severely. A major impact of drought can be seen on the global agriculture and on the food production. For a country like India, where majority of the people depend on agriculture for livelihood, society gets drastically affected by drought. Considering the changing climatic pattern and subsequent variation in rainfall pattern, the risk of drought occurrence increase (Zhang et al., 2017). Studying the different kinds of drought and its impact on the lives of people will help in reducing the impact of severity of the drought from the agriculture as well as the social point of view. Thus, drought monitoring is of great importance, which can be accomplished with different indices. The meteorological drought is monitored using the Standardized Precipitation Index (SPI) (Mckee et al., 1993), which is solely based on rainfall data. SPI is been categorized under the traditional meteorological drought monitoring index. SPI is used to define drought in a quantitative way for different time periods (3, 6, 12, 24 and 48 months). SPI values are estimated using monthly rainfall data and when the value of SPI reaches -1 or less, a drought event is said to occur. Depending on the value of SPI, the intensity of drought can be assessed (Mckee et al.,1993).

Agriculture sector absorbs about 22 % of the total damage and losses caused by natural hazards like drought. However, assessment and monitoring of agricultural drought becomes more difficult using traditional field based observation due to spatial variability of the crop type, stage and health. Advent of remote sensing has paved a way for operational monitoring of agricultural system to assess the health of crop. Application of remote sensing in assessment and monitoring agricultural drought is practiced by various national agencies for around last two decades. Various indices are being developed using remote sensing data for assessment and monitoring of agricultural drought. The most popular remote sensing based indices involve in agricultural drought assessment are Vegetation condition index (VCI), Temperature condition index (TCI) and Vegetation temperature condition index (VTCI). VCI is calculated based on Normalized Difference Vegetation Index (NDVI). Depending upon the variation in NDVI values the VCI values ranges from 0 to 100. In case of data with large cloud cover, the VCI fails as the NDVI values drops down and this may be erroneously interpreted as drought. Other remotely sensed indices involve TCI, which takes into account the brightness temperature values. Similar to VCI, TCI values also ranges from 0 to 100, as the brightness temperature varies from high to low (Kogan, 1995). Moreover, a combination of these two can be used as a better tool for drought monitoring and assessment (Wan et al., 2004). VTCI integrates the vegetation status of the area along with the temperature conditions. The vegetation status is represented using NDVI values while the LST are indicators of temperature status of the surface. The plot of LST and NDVI, gives a triangular space, which is further used to determine VTCI (Wan et al., 2004). VTCI represents the effect of drought stress on crop performance. Furthermore, this combined approach helps in exploring the sensitivity of drought monitoring index towards soil moisture in terms of crop moisture index (CMI) (Patel et al., 2012). Hence the integrated approach combining of LST and NDVI is critical for drought monitoring in agricultural sector.

This study focuses on the comparison between the different drought monitoring indices, which includes the meteorological index, SPI and the various remote sensing index. The remote sensing index, VTCI highlights the advantages of combination of NDVI and LST for over the VCI and TCI.

2. STUDY AREA

The study area selected for the present study is a Chhatarpur district of Madhya Pradesh. With an area of 8687.36 km^2 (CGWB, 2013), the district houses a total of 1762857 people (Pal, 2011). Located between 24°06’N to 25°20’N and 79°59’E to 80°26’E, the district occupies the central place on Bhundelkand plateau. The districts comprises of 6 tehsils and 8 developmental block, with a total 1080 inhabited villages. Being one of the severely drought affected districts in Bhundelkand region, the social and economic life of people has been miserably disrupted (NIDM,2016). The source of water include the Yamuna’s right bank tributary Dhasen River and left bank tributary Ken River. Major crops cultivated in the district involves Paddy, *Jowar* , Maize, *Tuar*, *Til*, Groundnut, Soyabean, Sugarcane during *Kharif* season and Wheat, Gram, *Alsi*, *Rai*, and vegetables during *Rabi* season. As per Indian Meteorological Department (Kaur & Purohit, 2016), the district has received a total annual rainfall of 799.1 mm in 2015 as compared to the normal annual rainfall of 1068.3 mm (CGWB,2015). Out of the total cultivable area of 5469.27 km^2, only 2085 km^2 is irrigated from different sources and the remaining (3988.75 km^2) is rainfed. Hence, a decrease in rainfall amount drastically affects the agriculture sector in Chhatarpur districts. The district was under meteorological drought during years 1998, 2000, 2002, 2006, 2007, 2009 (NIDM, 2014). The district was declared drought prone by Madhya Pradesh state government during the year 2015-16 (JNA, 2016)

3. DATA USED

Daily meteorological data is used in the present study to assess and analyze the meteorological droughts in the district and remote sensing data is used to assess the impact of each meteorological drought on agricultural system. The meteorological data constitutes the gridded daily rainfall data obtained from IMD, Pune, with a spatial resolution of 0.25 °. The data was obtained of 21 grids which lies across the study area and was used to compute SPI. The remote sensing data used is Moderate Resolution Imaging spectroradiometer (MODIS) Land Surface Temperature (LST) product, MOD11A1 and NDVI product, MOD13A2, acquired from earthdata portal of NASA (https://search.earthdata.nasa.gov).

The LST product (MOD11A1) has a temporal resolution of 8 days and spatial resolution of 1 Km. The NDVI product (MOD13A2) has a 500m spatial resolution, 16 days composite. The LST and NDVI product obtained were used to calculate VCI and TCI respectively, whereas both LST and NDVI were used to calculate VTCI.

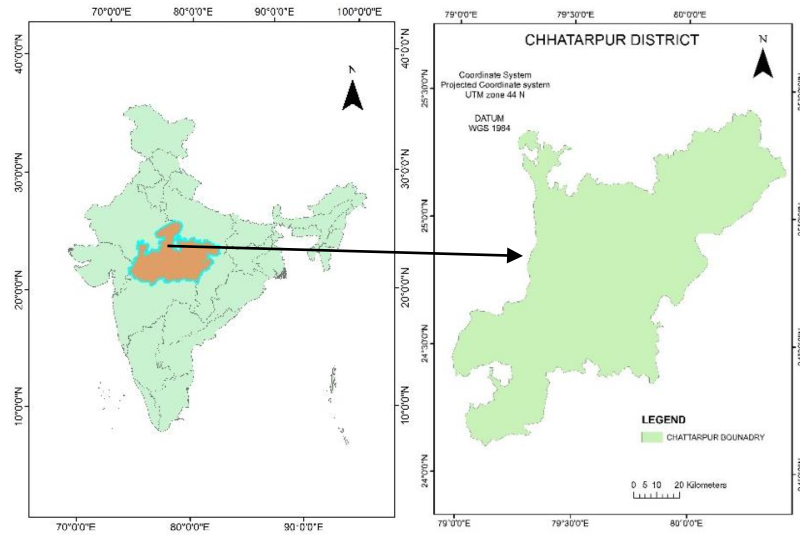


Fig. 1 Location map of study area

4. METHODOLOGY

Meteorological drought monitoring can be accomplished by using various meteorological indices. In the present study SPI developed by Mckee et al. (1993) for drought monitoring, has been used for the analysis of meteorological drought. One of the greatest advantage SPI offers is the simplicity, SPI is relies only on precipitation data. SPI is adaptable to different time scales and it characterizes both wet and dry time periods (Zargar at al., 2011).

The meteorological drought index (SPI) was calculated using a 50 years gridded rainfall data for over 21 grids. The first step in SPI computation involves the determination of probability density function which explains the long term time series of precipitation data. This is followed by the estimation of cumulative probability. The inverse normal function with mean zero and variance one is applied to cumulative probability function to obtain the required SPI values (Guttman, 1999). SPI computation involves fitting the rainfall values to the gamma distribution by using the following equations.

$$G(x) = \frac{\int_0^x x^{\alpha-1} e^{-x/\beta} dx}{\beta^{\alpha}\, \Gamma\alpha} \qquad (1)$$

Where α >0, α is a shape factor, β >0, β is the scale factor and x represents the precipitation data.

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dt \qquad (2)$$

Where, Γ (α) is the gamma function.

$$\text{Shape parameter} = \beta = \frac{1+\sqrt{(1+\frac{4U}{3})}}{4U} \quad , A = \ln x - \frac{\Sigma \ln(Xi)}{N}$$

$$\text{Scale parameter} = \alpha = \frac{x}{\beta}$$

Where X_i represents all non-zero precipitation values and N is the number of non-zero precipitation values. The value of A is obtained by subtracting the log of all precipitation data from the log of mean of all rainfall amount. The scale parameter and shape parameter can be calculated from the equation mentioned above. (Shah et al., 2015)

For zero values of precipitation, the gamma function is not defined, to incorporate those values. The cumulative probability is modified by the given formula

$$H(x) = q + (1-q)\,G(x) \tag{3}$$

Where q is the probability of a zero rainfall value. If the number of zero rainfall values is represented by m, then q can be estimated by m/n.

The cumulative probability H(x) is then converted to SPI values by converting them into standard normal random variable (Z). Based on the Z values, the area can be classified as wet and dry, as positive SPI indicate wetness and negative SPI values indicate dryness.(Shah et al., 2015)

SPI highlights the status of meteorological drought alone. The impact of meteorological drought on agriculture sector cannot be assessed using SPI. However, apart from the meteorological drought indices there are other indices for better drought monitoring of agriculture drought. The remote sensing based agriculture drought monitoring indices area used in the present study for mapping and analyzing agriculture droughts in the district. The advantages offered by remote sensing based indices include near real time drought monitoring which are more economical and at the same time requires less labour input.

The remote sensing based indices used in the present study include, VCI, TCI and VTCI. While VCI is predominantly NDVI based, TCI is LST based. VTCI includes a combination of both NDVI and LST. This integrated approach provides a better insight to drought monitoring. Agriculture drought is always marked by a decrease in amount of vegetation in fields (Tsiros et al., 2004). Favorable conditions for plant crops can be distinguished from the unfavorable one by the presence of good vegetation cover. VCI also uses similar principle; it uses the NDVI values of the pixels to distinguish between a drought affected pixel and non-drought pixel. It involves the normalization of NDVI values (Quiring & Ganesh, 2010). The maximum and minimum NDVI values denoted by 100 and 0 are linearly scaled (Kogan, 1995). The VCI values also ranges from 0 to 100 depending upon the absence or presence of vegetation in field.

$$VCI = 100 * \frac{NDVI - NDVImin}{NDVImax - NDVImin} \tag{4}$$

Where NDVI, $NDVI_{min}$, $NDVI_{max}$ are multiyear maximum and minimum values of NDVI

In case of large cloud cover or excessive wetness, VCI values are very low, which are wrongly interpreted as drought. In such case the temperature derived TCI can be used. TCI is computed using the thermal band derived brightness temperature values. A high temperature value corresponds to drought condition, while a low temperature value corresponds to normal soil condition. TCI focuses on vegetation stresses (Kogan, 1995). It improves the VCI results by incorporating the information on vegetation stresses.

$$TCI = 100 * \frac{BTmax - BT}{BTmax - BTmin} \tag{5}$$

Where BT, BT_{max}, BT_{min} are multiyear maximum and minimum of brightness temperature. The TCI values changes from 0 to 100 depending on the variation of LST values of pixel. TCI value of 0 denotes drought condition, while 100 denotes a favorable condition.

For the present study, initially SPI was computed, which helped in identifying the drought and non-drought periods. Further, TCI and VCI were calculated by considering the temporal changes in LST and NDVI respectively for a period of 15 years. The analysis was carried out for a drought year and a non-drought year for two time periods i.e. sowing period and harvest period. The results obtained were analyzed for occurrence of drought, a low TCI or VCI value indicate drought and high value indicate non-drought, as the values ranges from 0 to 100. The area under drought obtained from VCI, TCI was studied and the merits and demerits of VCI and TCI were analyzed. Moreover, a combined approach of LST and NDVI, VTCI was also used to better understand and map the drought affected areas.
An integration of reflectance based NDVI and thermal based LST is used as an alternate option for better drought monitoring. VCI based drought monitoring fails in some cases, due to the lagged vegetation response to drought. Similarly, LST based TCI is sensitive to water stresses (Patel et al., 2012). The index combining advantages of both vegetation and LST based approach, VTCI, can be estimated as;

$$VTCI = \frac{LSTndvimax - LSTndvi}{LSTndvimax - LSTndvimin} \tag{6}$$

$$LST_{NDVImax} = a + b\,NDVI_i \quad \& \quad LST_{NDVImin} = a' + b' NDVI_i$$

The $LST_{NDVImax}$ and $LST_{NDVImin}$ are the maximum and minimum LST's of pixel which has same NDVI values in the study region on time period of study. $LST_{NDVI\,i}$ denotes the LST of a pixel with NDVI value NDVIi. The coefficients a, b, a', b' are determined from an area which has soil moisture varying from the wilting point to field capacity.

The LST vs NDVI scatterplots are generated, which are triangular in shape. The triangle has a warm edge and a cold edge, the LST_{max} is considered as the warm edge, while the LST_{min} is regarded as the cold edge. Warm edge denote the dry conditions, with less soil moisture condition, while cold edge signifies the favorable condition for plant growth (Wan et al., 2004). Warm edge and cold edge were extracted from the scatterplot by categorizing the NDVI values into different classes with an interval of 0.05, and sorting the maximum and minimum values of LST for every interval. The equations of warm edge and cold edge lines were used to derive the coefficient a, b, a', b'. All the values of LST were fitted into the equation of $LST_{NDVImax}$ and $LST_{NDVImin}$, VTCI was calculated by using the standard formula. The lower values of VTCI indicate higher magnitude of drought stress. (Patel et al., 2012)

5. RESULTS

5.1 Meteorological Drought Monitoring

The IMD gridded daily rainfall data was converted to monthly rainfall data and then SPI was computed for a time period 1951 to 2015 for all the 21 grids. The season under consideration was winter season, for the months October to February. Month of October is considered as the sowing period, while February is considered as the harvest period. For both drought and non-drought years, the months of October and February were studied separately. The onset, severity and persistence of each drought event has been analyzed for Chhatarpur district. Further for combining remote sensing inputs with meteorological inputs time period of 2000-2015 has been considered. During this time period (2000-2015) based on SPI analysis the years 2000-01, 2003-04, 2005-06 and 2007-08 were recognized as meteorological drought year and the years 2013-14, and 2014-15 were identified as non-drought years.

The SPI values of all the 21 grids (of IMD data) were interpolated and the SPI maps were generated for better visualization of the results. The SPI maps generated for drought year (2000-01) and non-drought year (2013-14) are shown in Figure 2. The SPI values were classified according to its values given in the table (Shah et al., 2015)

Table 1: SPI values and their respective categories.

SPI RANGE	CATEGORY
+2 or more	Extremely wet
1.55 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

As per SPI, a drought event is begins when SPI value falls below zero (Mckee et al., 1993). When the meteorological drought was analyzed for Chhatapur area for sowing period, it was observed that for drought year 2000-01, the whole area was under near normal (-0.99 to 0.99) condition, but 84% of the area indicated drought as the SPI values were negative. For same year the harvest period noticed a 91% area under drought. While for the non-drought year during sowing period and harvest period, 4 % and 36.8% of total area was under near normal condition respectively.

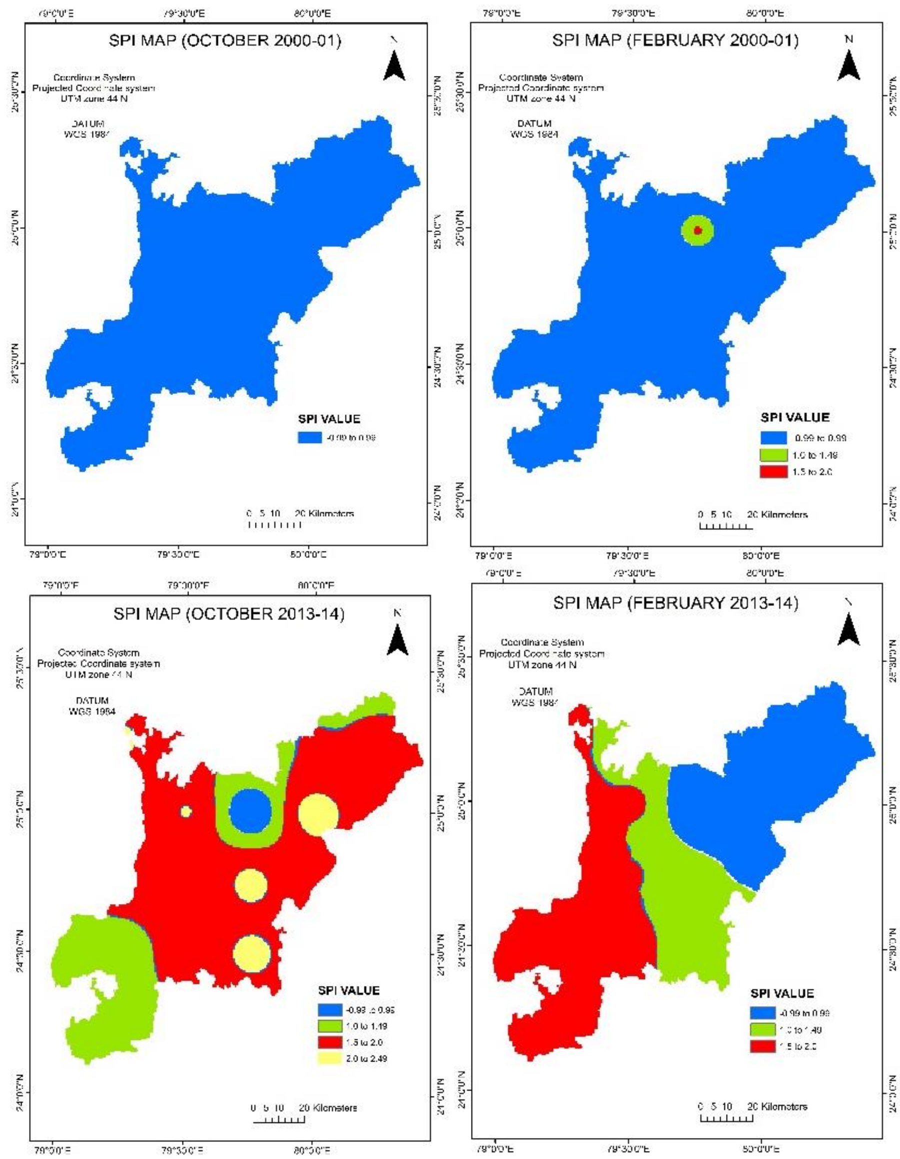


Figure 2: SPI maps for drought year (October and February) and non-drought year (October and February)

5.2 Agricultural Drought Monitoring using VCI

VCI was calculated for sowing period and harvest period of both the drought and non-drought years. VCI value of 35 was used as threshold value to differentiate drought and non – drought. During the sowing period of a drought year 2000-01, VCI analysis indicates around 349.42 km^2 of agriculture land under drought (Agricultural) and only 46.08 km^2 of land was not affected by drought. However for non-drought year 2013-14 during sowing period the VCI results shows around 2349.27 km^2 (27 % of total geographical area of district) under agricultural drought. This is contradictory to the statistics of meteorological drought analysis. For sowing period around 7375.15 km^2 and 356.54 km^2 are was found to be drought (meteorological) affected in years 2000-01 and 2013-14, respectively. Since very small area of Chhatarpur district has irrigation facility, so rainfall is the only source of water for remaining area in the district. Deficit in rainfall is expected to affect agricultural system. However, more area was observed to be drought affected in sowing period during year 2013-14 compared to year 2000-01. This contradiction may be due to actual spatiotemporal variation of rainfall which goes unnoticed in IMD’s gridded rainfall data or may be due to incapability of VCI to monitor drought during sowing period. The analysis of agricultural drought area in harvest period during both 2000-01 and 2013-14 indicate obvious trend, the agricultural area under drought is more in year 2000-01 (1176.45 km^2) compared to that in 2013-14 (893.48 km^2). The possibility of contradiction during sowing period due to coarser resolution rainfall data cannot be verified since IMD gridded data is the only long-term rainfall data available for the entire area. However, the possibility of contradiction due to incapability of VCI to map and monitor drought during sowing period can be validated using multi-indices based drought mapping approach. To do so, in the present study, two more remote sensing based agricultural drought indices are estimated using MODIS data/products. The results of agricultural drought mapping these two drought indices (TCI and VTCI) are discussed in the subsequent sections.

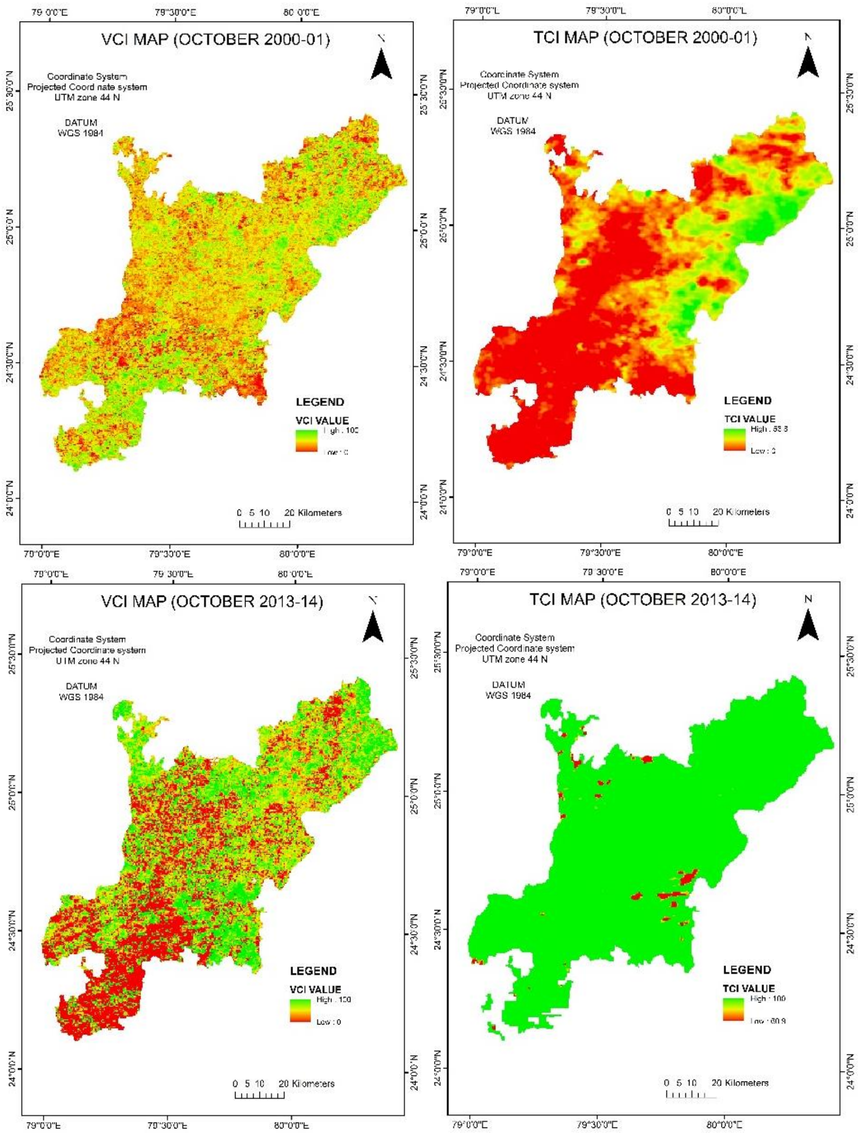


Figure 3: VCI and TCI maps for Drought and Non Drought year for the month of october

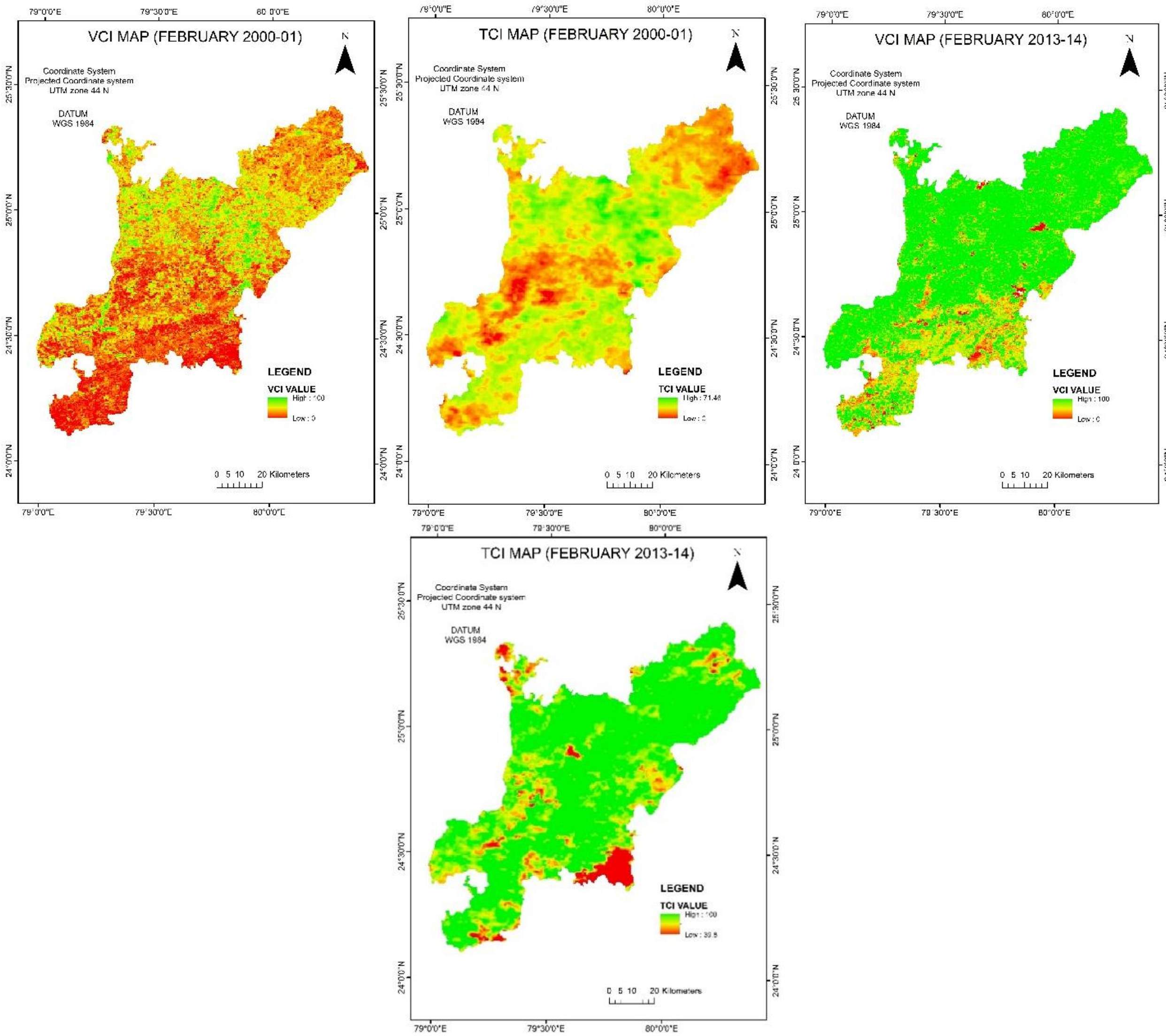


Figure 4: VCI and TCI maps for Drought and Non Drought year for the month of february

5.3 Agricultural Drought Monitoring using TCI

TCI works with the brightness temperature of land surface to map the drought condition of the area. TCI of the study area has been estimated using MODIS data/products. The TCI value of 35 was used as a threshold to distinguish between the drought prone areas and non-drought prone areas. As per the TCI results, the total area under drought (agricultural) during the sowing period for the drought year 2000-01, is 8683.74 km^2 ,which is around 99.9% of the total area under consideration, while for the non-drought year 2013-14, 0 km^2 area was under drought. The results of drought year, 2000-01, matches with the meteorological results to some extent, as the total area was under near normal condition (-0.99 to 0.99) with an 84% area under drought. On the other hand, a per TCI during the harvest period, 5695.999 km^2 (65%) of area was under drought (agricultural) in the year 2000-01 and 0 km^2 of area was under drought in non-drought year. The possible reason for this difference in drought area during the harvest and sowing period might be the higher LST values from a barren field as compared to the vegetated field. As per SPI values, 91% area was under drought in harvest period of the drought year. The land surface temperature of field in harvest period will be less as compared to that of a field during sowing period. The results of TCI depends on the vegetation condition of field. Thus, the inability of TCI to monitor drought can be corrected by using a combined approach of LST and NDVI. Therefore VTCI is been used to monitor drought.

Analyzing the results of VCI and TCI, it is observed that there are a few limitations of these indices which include the inability of VCI to predict drought during the sowing season, as there is very less vegetation in the field, which decreases the NDVI values. Similarly for the TCI based analysis of sowing period, the LST values are very high, which indicate a low TCI value, indicating the possibility of drought. In order to check these shortcomings, a combined approach of using NDVI and LST was employed. The results of drought assessment done using VTCI is discussed in the next section.

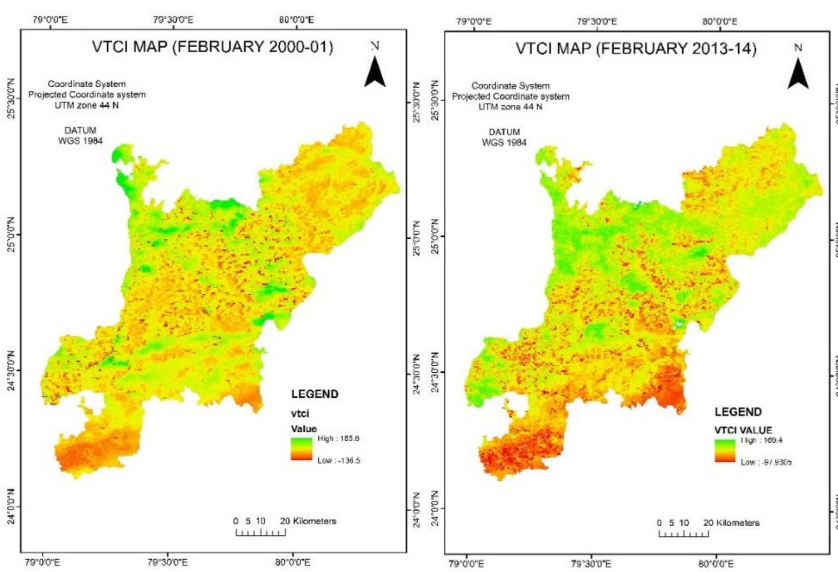
5.4 VTCI for Agricultural Drought Monitoring

VTCI takes the vegetation and LST conditions into consideration for mapping agricultural drought area. This index combines the advantages of both vegetation index and surface temperature based approach. The LST and NDVI values of sowing and harvest periods for both drought and non-drought years were considered. The LST values and corresponding NDVI values of same time period were used to obtain the warm edge and cold edge. This was accomplished by generating the LST- NDVI scatterplot, by using the SAGA GIS. The scatterplot depicts the distribution of NDVI and LST distribution with respect to each other. The warm edge and cold edge are identified. NDVI values were classified into small intervals and the maximum and minimum LST were identified and then the coefficients a, b, a', b' were obtained by fitting the straight line equation.

The warm edge and cold edge equations are given below. These equations are used to determine the $LST_{NDVImax}$ and $LST_{NDVImin}$ and thus calculate VTCI.

$$LST_{NDVImax} = -13.723x + 309.65 \quad (7)$$
$$LST_{NDVImin} = 4.4743x + 296.24 \quad (8)$$

LST-NDVI plots were generated for both the drought and non-drought years for both the sowing as well as the harvest period. The cold edge and warm edge was obtained and VTCI was calculated for sowing as well as harvest periods of drought (2000-01) and non- drought year (2013-14). A value of 0.45 was used a threshold to identify the drought prone areas. As per VTCI, the area under drought for year 2000-01(drought year) during the sowing period is 62.3% (5412.74 km^2) of the total area under consideration, while during harvest period 75.2% (6533.538 km^2) of the total area was under drought. As per meteorological index, SPI, for the year 2000-01 for sowing period was 84%, while for harvest period, it was 91% of the total area. The percentage area under drought is more in harvest period for both SPI and VTCI approach. Similarly when VTCI was used to analyze the area under drought for sowing period during year 2013-14 (non-drought year), 16.5 % (1436.915 km^2) of the total area was under drought. On the other hand the area under drought for the harvest period was 3.18% (276.536 km^2) for the same year. Having said that, the area under drought as per SPI for 2013-14 for sowing period is 4% while its 37% for harvest period.



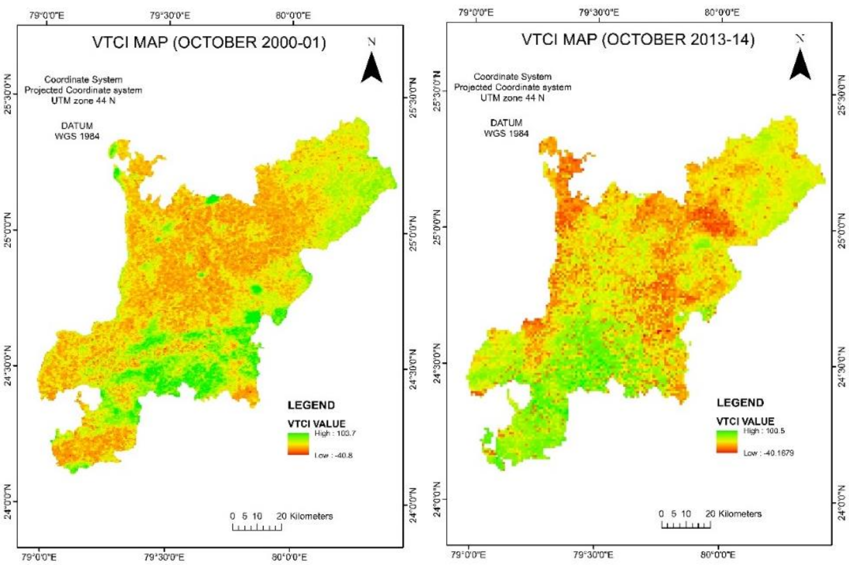


Figure 6: VTCI maps of the study area

The study compares the meteorological and remote sensing indices available for drought monitoring for the Chhatarpur district of Madhya Pradesh. The study also highlights the advantages of using the different parameters individually and as well as in a combined form.

CONCLUSION

Chhatarpur district was analyzed for the occurrence of drought. The onset, severity and persistence of drought in the district was determined. SPI was computed, as this marks the primary drought monitoring index. According to SPI values the years 2000-01, 2005-06 and 2007-08 were considered as drought year and the year 2013-14 and 2014-15 were considered as non-drought year. These years were further analyzed in two season, harvest and sowing season by using the remote sensing indices VCI and TCI. The use of this indices had limitations as these were based only on one parameter. This is clearly understood from the comparison of the sowing and harvesting period maps from computed using VCI. As VCI is solely depended on vegetation index, it is unable to depict the difference in drought condition during the sowing season. This is rectified by using a combined approach, VTCI, which includes both the LST and NDVI values. VTCI maps the area under drought for sowing season more effectively than done by VCI and TCI. As it includes both the values of LST and NDVI, it helps in better drought monitoring. The area under drought as per VTCI matches the area under drought as per SPI. This proves that VTCI is more efficient in drought monitoring.

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