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Technical Paper

Remote Sensing Based Assessment of Agricultural Droughts in Sub-Watersheds of Upper Bhima Basin, India

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Abstract

Drought assessment for agricultural sector is vital in order to deal with the water scarcity in Ahmednagar and Pune districts, particularly in sub-watersheds of upper catchment of the River Bhima. Moderate Resolution Imaging Spectro-radiometer (MODIS) satellite data (2000, 2002, 2009, 2014, 2015 and 2017) for the years receiving less rainfall have been procured and various indices were computed to understand the intensity of agricultural droughts in the area. Vegetation health index (VHI) is computed on the basis of vegetation moisture, vegetation condition and land surface temperature condition. Most of the reviewed area shows moderate to extreme drought conditions.

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1 INTRODUCTION

Droughts largely influence the ecological, cultural and socio-economic sectors (Dalezios *et al*., 2014; Skakun *et al*., 2016; Amalo *et al*., 2017). Generally, droughts are categorized into meteorological, agricultural and hydrological (Zargar *et al*., 2011). Prediction of drought is associated with the monsoon conditions which are controlled by distribution of various regional and local factors like El Nino and Southern Oscillation (ENSO) events, atmospheric parameters, etc. (Ropelewski and Halpert, 1986). The impact of drought is prominently visualized on agricultural sector because of the reduction in crop cultivation, stunted growth and productivity (Sruthi and Aslam, 2015).

The share of *rainfed* crops is very high in semi-arid regions of India. Various indices based on remotely sensed data, statistical methods, GIS techniques and hydrogeological investigations have been introduced for monitoring and predicting drought characteristics such as duration, severity and areal extent (Khalil *et al*., 2013; Domenikiotis *et al*., 2004; Thenkabail and Gamage, 2004; Arshad *et al*., 2007; Murad and Islam, 2011; Wardlow *et al*., 2012; Melese *et al*., 2018). These indices are helpful for classification of the area into various drought zones viz. high, moderate, low and no drought (Kogan, 2001). Vegetation Health Index (VHI) is function of Temperature Condition Index (TCI) and Vegetation Condition Index (VCI), which is an indicator of green growth. In this study, the droughts in Bhima catchment area have been evaluated using VHI to understand the intensity.

2 STUDY AREA

Four sub-watersheds namely BM-7, BM-17, BM-33 and BM-34 (1778.16 km^2) of Upper Bhima catchment (73º 50′ 41″ E to 74º 40′ 07″ E and 18º 29′ 11″ N to 19º 10′ 23″ N) have been selected for the present study (Figure 1). It is a part of Deccan Basaltic Province from Pune

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(Ambegaon, Shirur and Junnar) and Ahmednagar (Parner and Shrigonda) districts. The regional relief decreases from west to east with the highest elevation of 965m and the lowest being 425m above MSL. The area experiences sub-tropical to tropical temperate monsoon climate with a hot summer and general dryness throughout the year except during the monsoon season (June to September). Average annual rainfall is 610mm which 75% occurs in four months, from June to September (IMD).

3 METHODOLOGY

3.1 Data

Rainfall data (1981 to 2017) have been procured from IMD to sort out scanty rainfall years. Considering the availability of 250m resolution and relative clarity in MODIS data, it was used in this research to derive Vegetation Health Index (VHI). The details of the satellite data are: MODIS/Terra, (16-day) NDVI product MOD13A2 and MOD11A2, Land Surface Temperature/Emissivity (8-days) LST product. Global MOD13A2 and MOD11A2 data are available for every 16 days and 8 days, respectively, at 1km spatial resolution as a griddedlevel-3 product in Sinusoidal projection. The data of pre-and post-monsoon seasons (April, May and November, December) has been used for the analysis for six low rainfall years (2000, 2002, 2009, 2014, 2015 and 2017).

3.2 Pre-processing of Satellite Data

The MODIS NDVI (16 bit signed integer) and LST (16bit unsigned integer) data are available in Hierarchical Data Format (HDF) with valid range from 2000 to 10,000 (NDVI) and 7500 to 65535 (LST). The data for the study area was covered in two tiles (h24v07 and h25v07) and converted to tiff format. The image mosaic and projection from sinusoidal to UTM (Zone-43N) was performed for the entire dataset. Normalized Difference Vegetation Index (NDVI) values were rescaled between +1 to -1 by multiply 0.0001 and Land Surface Temperature by 0.02 factors.

3.3 Drought Indices

3.3.1 Normalized Difference Vegetation Index (NDVI)

NDVI values were used to identify the area with green cover, health of plants, growth pattern of agriculture, water stressed crops and also the different type of crops as well as vegetation. (Dutta *et al*., 2015; Tarpley *et al*., 1984; Tucker *et al*., 1985). NDVI has been calculated using 'Raster Calculator' in GIS software as:

$$\text{NDVI} = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}}$$

where,
NIR= Reflectance in Near Infrared band.
RED= Reflectance in Red band.

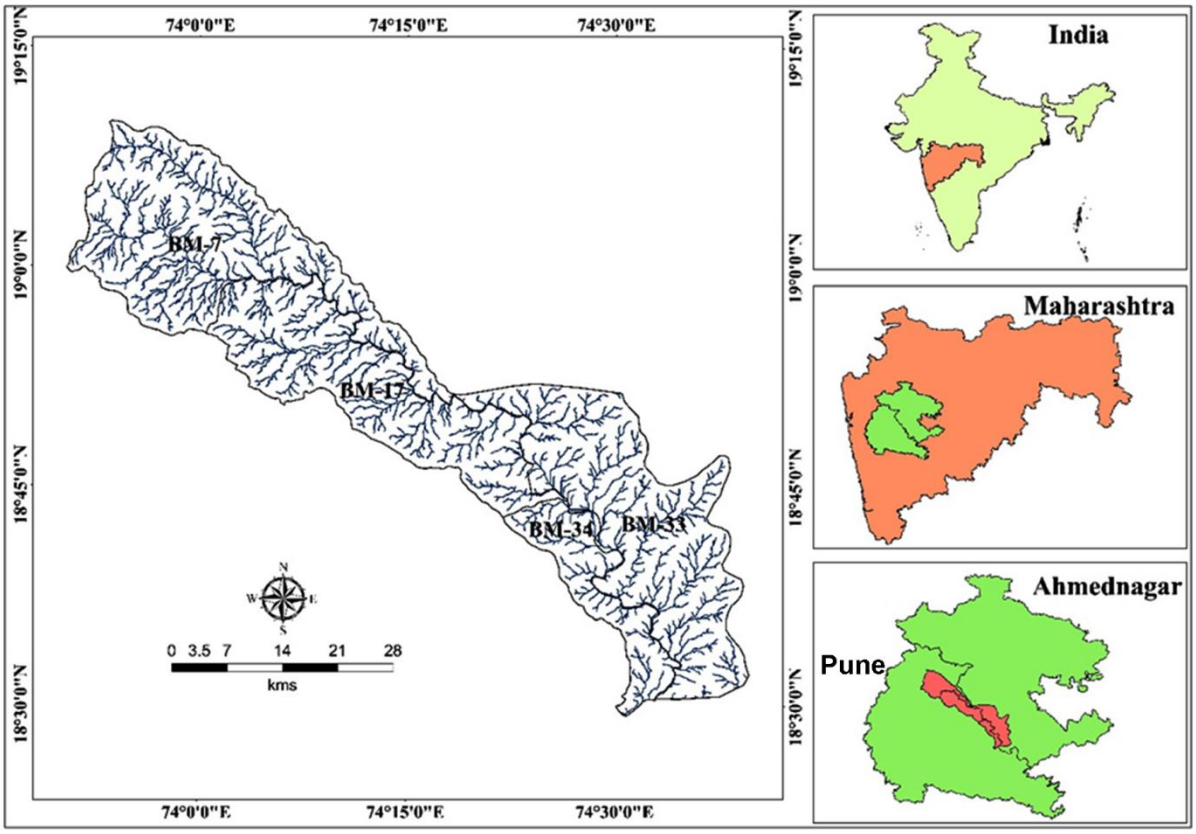

Figure 1. Study area

3.3.2 Vegetation Condition Index (VCI)

Vegetation Condition Index has been introduced by Kogan (1990). The VCI calculations are based on NDVI values with respect to its maximum amplitude. VCI is the function of NDVI values of specific area or pixel and it is the subtraction of NDVI value to the minimum NDVI values of that pixel or area divided by the sum of NDVI maximum value and NDVI minimum value of the entire area into 100. The maximum amplitude shows the highest possible variation from the values (Liu and Kogan, 1996).

VCI (%) is calculated as:

$$VCI_j = \frac{NDVI_j - NDVI_{min}}{NDVI_{max} + NDVI_{min}} \times 100$$

Where,
VCI_j= VCI at the j^{th} period in a specific month.
$NDVI_j$ = NDVI at the j^{th} period in a specific month.
$NDVI_{max}$ = Maximum value of the NDVI for that year.
$NDVI_{min}$ = Minimum value of the NDVI.

VCI (%) value ranges between 50 and 100 are indicating good condition of vegetation, while values less than 35 show severe drought condition. Although there are many other vegetation and derived indices, but VCI and NDVI deviation from historic NDVI are being used on operational basis to assess drought situation (Kogan, 1995). VCI is the average greenness of the same area over given defined time based on pixel values of same location.

3.3.3 Land Surface Temperature (LST)

The MODIS data provides LST as well as the Emissivity (E) values for every pixel based on its radiances. The temperature is also calculated using scale factor from kelvin. The precise DN values were calculated using following equation:

$$\text{Temperature} = (DN \times 0.02) - 273.15^{o}C$$

3.3.4 Temperature Condition Index (TCI)

Generally, VCI is recommended for drought assessment, however, it has been seen that only VCI is not helpful for precise drought identification. Therefore the atmospheric parameter such as temperature is also used for the assessment of drought in the area. Hence, to improve the drought assessment results, TCI was recommended to capture different responses of vegetation to in-situ temperature that provide additional information. TCI can be obtained by employing thermal channels of MODIS (Kogan, 1995). The TCI was calculated using the following formula:

$$TCI = \frac{LST_{max} - LST_a}{LST_{max} + LST_{min}} \times 100$$

where,
LST_a = LST value of current month.
LST_{min} = Minimum LST value calculated from multiyear time series data.
LST_{max} = Maximum LST value calculated from multiyear time series data.

3.3.5 Vegetation Health Index (VHI)

Vegetation Health Index was calculated to assess both vegetation and temperature condition that together helpful in understanding the drought intensity. The VHI is expressed as following formula:

$$VHI = ((a \times TCI) + (a \times VCI))$$

Where, VHI is related to VCI and TCI by 'a' equals to 0.5 (Rojas *et al*., 2011; Kogan, 2001).

The VHI pixel values were classified into five categories to understand the distribution of drought intensity based on classification scheme given by Kogan (2002) (Table 1).

Table 1. VHI based classification scheme for drought mapping (Kogan, 2002)

Classes	VHI values
Extreme drought	<10
Severe drought	10-20
Moderate drought	20-30
Mild drought	30-40
No drought	>40

4 RESULTS AND DISCUSSIONS

4.1 NDVI and LST

The study area was having different drought condition with change in temperature and vegetation, which was studied with the help of NDVI and LST as basic parameter for deriving the associated parameter. NDVI and LST values for the months of April and May (pre-monsoon) and November and December (post-monsoon) of the low rainfall years (2000, 2002, 2009, 2014, 2015 and 2017) have been plotted (Figure 2 and 3) and inverse proportion to each other. There is a decrease in temperature results into increasing the vegetation with high NDVI values and vice versa. The study shows that the NDVI decreases with increasing atmospheric temperature. This severity of drought is increasing in per-monsoon season (Jan-May) and goes on decreasing from post-monsoon season (November-December). NDVI values are decreasing during the pre-monsoon months of April and May whereas November and December show increasing vegetation density. The change study of these droughts indicates considerable alterations ($p < 0.05$) between the years of study. The association among NDVI and periodic precipitation was statistically noteworthy. There were substantial variations in NDVI and precipitation values. The maximum NDVI value was detected when the mean periodic precipitation was well scattered and the minimum NDVI value was documented when precipitation was less. Precipitation was less during the years 2000, 2002, 2009, 2014, 2015 and 2017. The lowest NDVI retorted as precipitation altered throughout the dry years, particularly 2000, 2002 and 2009, Higher NDVI values observed for both the seasons in 2014 as compare to other scanty rainfall years (Figure 2).

The higher NDVI values indicate healthy and dense vegetation. To enhance the prediction accuracy, it is necessary to integrate another parameter and hence the present study incorporates LST as a subsequent parameter. LST is between 32.9°C to 40.5°C (Figure 3) but in the year 2009, it has decreased. Dry soil usually has high LST and low NDVI.

4.2 Vegetation Health Index (VHI)

The Vegetation Health Index (VHI) maps are prepared by combining LST day time temperature and NDVI (Figure 4A, B, C and D). It shows varying severity levels of agricultural drought mostly in the central, western and south western parts of the study area.

The central part of the study area shows severe to extreme drought condition in pre- and post-monsoon seasons for all six years. Upper part of the area having mild to no drought condition in most of the years because this area is in proximity to Western Ghats and hence receives high rainfall. The area under extreme drought category is high in April than May for the years 2000 and 2017.

VHI for the month of April in year 2000, 2002 and 2009, cover 27%, 28% and 29.9% area, respectively under severe drought conditions. Similarly, year 2014, 2015 and 2017 had a moderate drought covering 24.3%, 26.1% and 22.8% areas, respectively. Month of May for all the years under study except 2015 has recorded severe drought conditions covering 29.5%, 28.3%, 24.5%, 25.2% and 25% the total area correspondingly. Two post-monsoon months were November and December show a slight change in drought severity. In the month of November all the years excluding 2017 have recorded moderate drought condition covering the largest areas of 26%, 28%, 31%, 29.5% and 25% while 2017 records mild drought in the area of 28.3%. In December of 2000, 2002, 2009 and 2015 show moderate drought conditions in 23.8%, 25.8%, 28.4% and 30.4% of the total area, respectively. It has come down during 2014 and 2017 to mild drought conditions for 30.6% and 28.5% area, respectively.

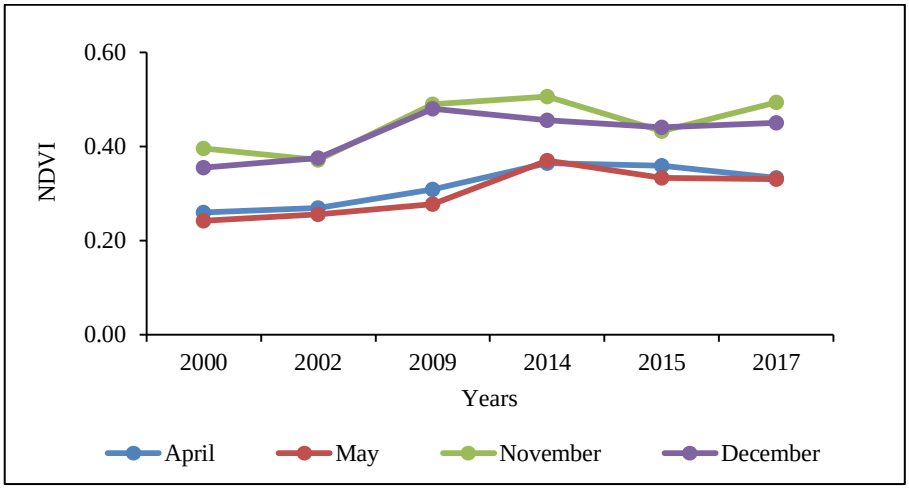

Figure 2. Normalized Difference Vegetation Index

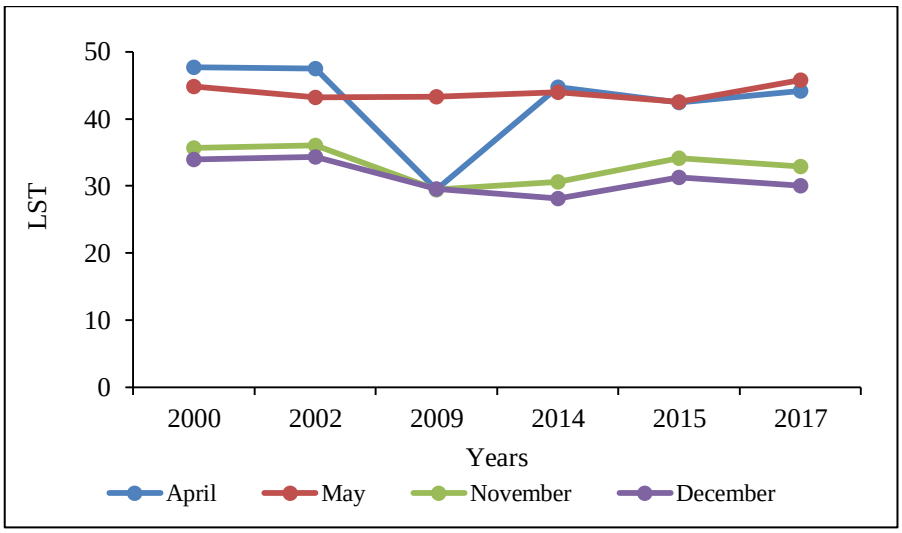

Figure 3. Land Surface Temperature

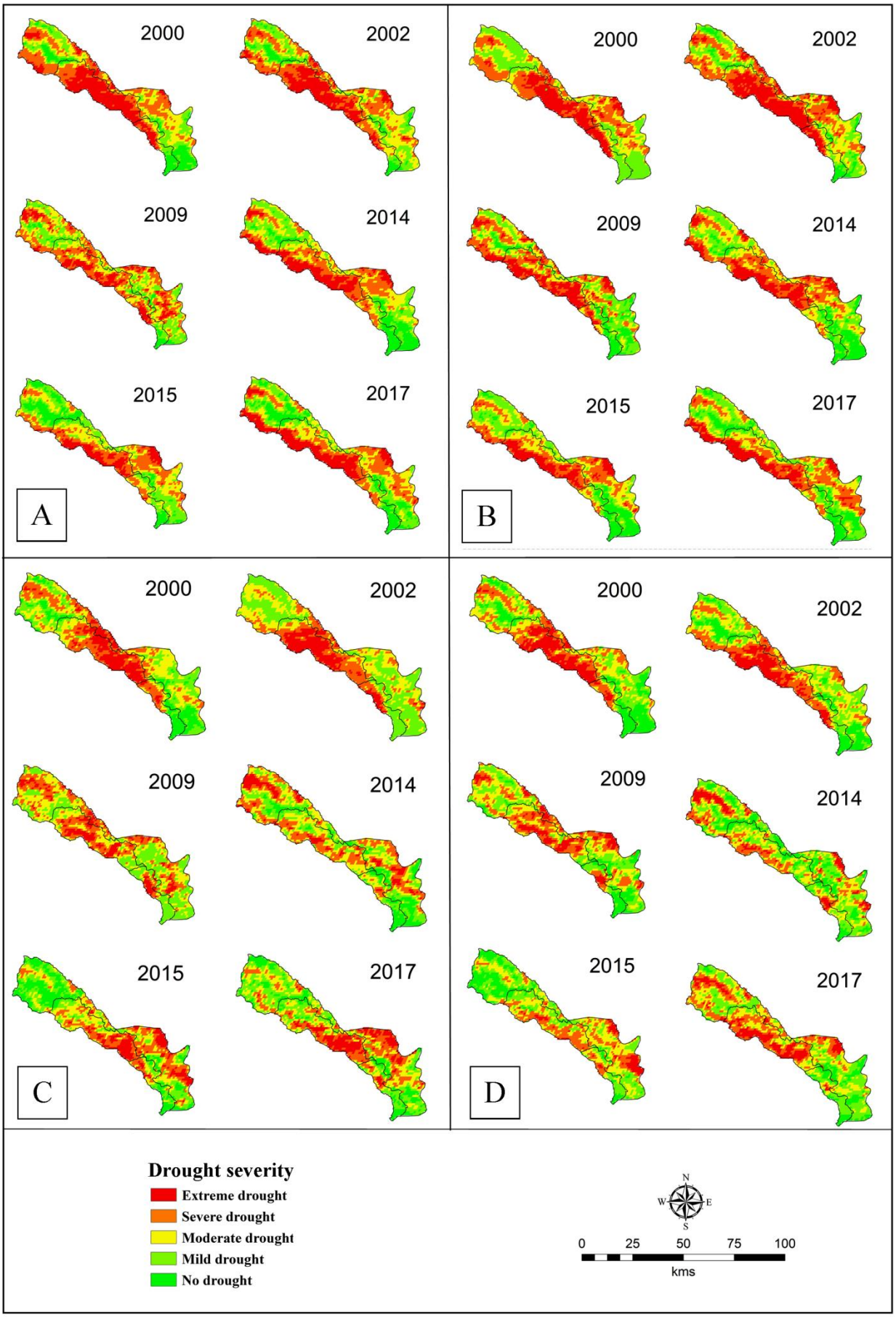

Figure 4. Vegetation Health Index: A) April, B) May, C) November and D) December

Table 2. Distribution of drought severity

Years	Drought severity	Area (%)			
		April	May	November	December
2000	Extreme drought	24.3	19.7	14.3	16.0
	Severe drought	27.0	29.5	24.8	22.4
	Moderate drought	22.2	22.4	26.3	23.8
	Mild drought	15.7	28.4	21.8	20.5
	No drought	10.9	0.0	12.9	17.2
2002	Extreme drought	21.5	25.8	14.9	13.7
	Severe drought	28.9	28.3	20.3	23.1
	Moderate drought	24.4	23.0	28.5	25.8
	Mild drought	19.2	17.2	36.2	24.2
	No drought	6.0	5.7	0.0	13.2
2009	Extreme drought	15.1	19.5	12.1	11.5
	Severe drought	29.9	24.5	26.3	24.8
	Moderate drought	28.6	21.7	31.1	28.4
	Mild drought	22.7	23.4	30.5	25.2
	No drought	3.8	10.8	0.0	10.0
2014	Extreme drought	16.8	16.8	8.9	8.5
	Severe drought	24.1	25.2	25.0	17.0
	Moderate drought	24.3	25.1	29.5	27.5
	Mild drought	21.5	20.2	24.1	30.6
	No drought	13.3	12.7	12.5	16.4
2015	Extreme drought	11.0	13.9	11.4	5.3
	Severe drought	24.5	24.0	21.6	20.2
	Moderate drought	26.1	25.2	25.6	30.4
	Mild drought	24.9	23.5	22.7	29.2
	No drought	13.4	13.4	18.7	14.9
2017	Extreme drought	19.8	15.8	12.1	12.3
	Severe drought	22.8	25.0	21.7	22.2
	Moderate drought	22.8	22.3	25.5	28.0
	Mild drought	20.3	23.4	28.3	28.5
	No drought	14.3	13.5	12.5	8.9

5 CONCLUSION

Drought signatures are delayed visibility as compared to other disasters. The harshness of drought differs from sector to sector viz. hydrological, agricultural and meteorological. Due to the change in rainfall pattern and vagaries of monsoon, the average annual rainfall may be satisfactory but lack of rains in the month of June/July poses the pressure on *rainfed* crops. Thus, there may not be a drought prone situation for meteorologists but farmers could face this severity. Thus, to address this issue of changing rainfall pattern there is an urgent need to assess drought for each sector, separately. The study reveals the intensity of drought vary between extreme to moderate in all these years. The result also indicates no significant difference in drought condition of pre-monsoon and post-monsoon months. Thus, rising temperature could be one of the significant reasons for drought in the study area.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

DN: Digital Number; **ENSO**: El Nino and Southern Oscillation; **LST**: Land Surface Temperature; **MODIS**: Moderate Resolution Imaging Spectroradiometer; **NDVI**: Normalized Difference Vegetation Index; **TCI**: Temperature Condition Index; **UTM**: Universal Transverse Mercator; **VCI**: Vegetation Condition Index; **VHI**: Vegetation Health Index.

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