Vegetation & Agriculture Health Monitoring using Worldview-2 Satellite Image derived indices: An Approach for Drought Assessment in Jharkhand, India

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Abstract

Drought is a recurrent phenomenon in Jharkhand. It affects the livelihoods of the majority of its people, particularly tribals and dalits living in rural areas. Twelve of the 24 districts of the state, covering 43% of the total land area, are covered under the Drought Prone Areas Programme (DPAP). Hunger and starvation deaths are reported almost every year. Because of the pervasive and varying degree of drought effects, it is important to develop methods for drought assessment. Vegetation chlorophyll content and moisture status is one of the key parameters in drought monitoring, agricultural modelling and forest health mapping. In the present study three new indices was developed to predict the drought. All the indices are evaluated in the GIS environment using weighted overlay technique to produce the final result. The final result is validated by correlating the monthly rainfall data and irrigation condition of the study area. The satellite data used for this study is 8 band Worldview-2 was provided by Digital Globe.

Introduction

Periods of persistent abnormally dry weather known as droughts, can produce a serious agricultural, ecological and hydrological imbalance. Drought harshness depends upon the degree of moisture deficiency, duration and the size of the affected area [Wilhite, D. A., and M. H. Glantz, 1985]. Remote sensing is now widely used to monitor and predict vegetation characteristics for sustainable development. Imaging spectrometry has great potential for monitoring vegetation type and biophysical characteristics [Goetz, A.F.H.,

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1995]. Vegetation reflectance spectra are often quite informative, containing information on the vegetation chlorophyll absorption bands in the visible region, the sustained high reflectance in the near infrared band, and the effects of plant water absorption in the middle infrared region.

Leaf chlorophyll and moisture content is one of the key parameters in forest health mapping, agricultural modelling and drought monitoring. The incident energy is absorbed in the Blue (0.4-0.5μm) and Red (0.6-0.7μm) region due to the absorption band of chlorophyll whereas the Near-Infrared region (0.7-1.3μm) shows a peak reflectance characteristics due to the spongy mesophyll layer. Using that absorption and reflection characteristics of vegetation many researcher has define many vegetation indices for monitoring vegetation parameters.

The researcher used classical indices method to measure the chlorophyll content and moisture status within the leaves. Now, the availability of 8 spectral bands of the Worldview-2 will create an opportunity to analyze and modify the indices previously used. The three new bands namely Yellow, Red-Edge and NIR-2 will be used for this study to analyze the vegetation characteristics. The yellow band is very much useful for detecting the yellowness of the plant leaves. The red-edge band has a strong reflectance of vegetations. It is used for measuring the red edge stress over vegetations and agriculture. The NIR-2 band is less affected by atmospheric influences and within the spectral range (0.86-1.047μm) water absorption portion (0.97μm) is found. So, this band is useful for vegetation water content estimation.

Study Area:

The present study area is a part of Hazaribag and Chatra district, Jharkhand (figure-1). Geographically the area is located in the north east part of the Chotanagpur Plateau. The area drained by Barka River and its tributaries. Maximum height of the area is 850 meter. The maximum temperature in summer rises to above 40°c and the minimum in winter falls to 08 - 10°c. The average annual rainfall is about 800 mm. The latitudinal and longitudinal extent of the study area is as follows - Latitudinal extent - 23°55’ N - 24° N and Longitudinal extent - 85°E - 85°06’25”E.

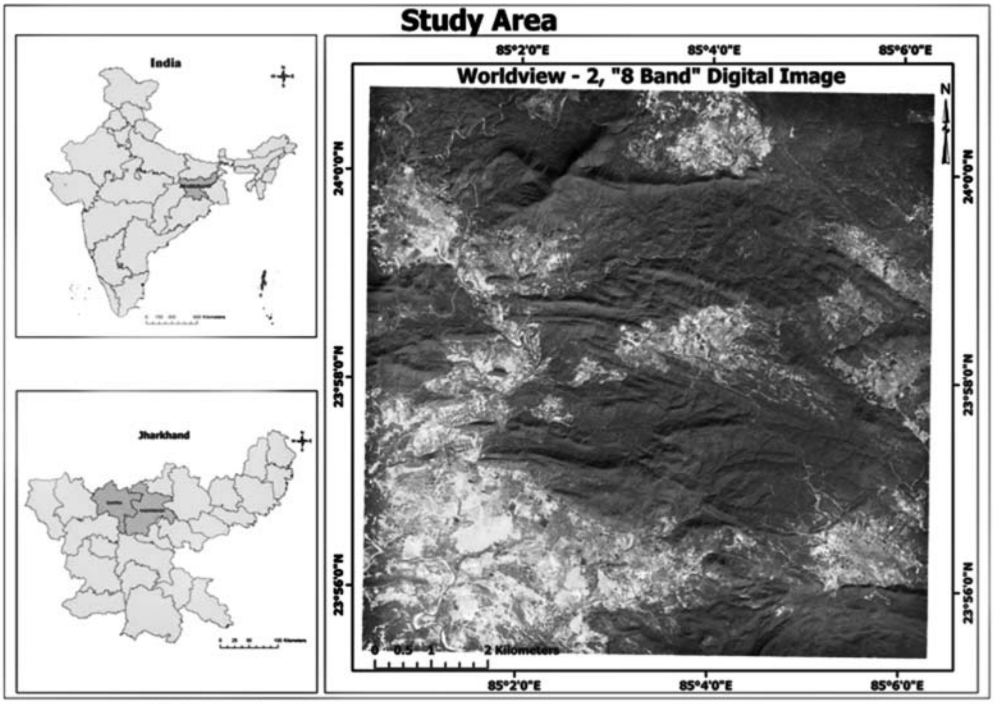


Fig 1. Location of the study area.

Data used and Methodology

Worldview-2, 8 band raw digital imagery provided by Digital Globe is used for this study. Apart from the satellite data Rainfall data and Jharkhand Agriculture Information System published report is used for this study. The flow chart shown in figure 2 illustrates the procedures followed in this study to monitor the drought condition of the area. The specification [Worldview white paper, 2010] of worldview-2 datasets is illustrated in table-1.

Table 1. Showing the specification of Worldview - 2 datasets.

Name of Bands	Spectral Bandwidths (nm)	Center Wavelength (nm)	Other Specification
Coastal Blue	400 - 450	427	**Launch Date:** October 8, 2009. **Spatial Resolution:** PAN - 0.46 Mts. MUL - 1.84 Mts. **Quantization Level:** 11 Bits. **Swath Width:** 16.4 Km. **Revisit:** 1.1 Days. **New Bands:** Coastal, Yellow, Red Edge and NIR - 2.
Blue	450 - 510	478	
Green	510 - 580	546	
Yellow	585 - 625	608	
Red	630 - 690	659	
Red Edge	705 - 745	724	
NIR-1	770 - 895	831	
NIR-2	860 - 1040	908	

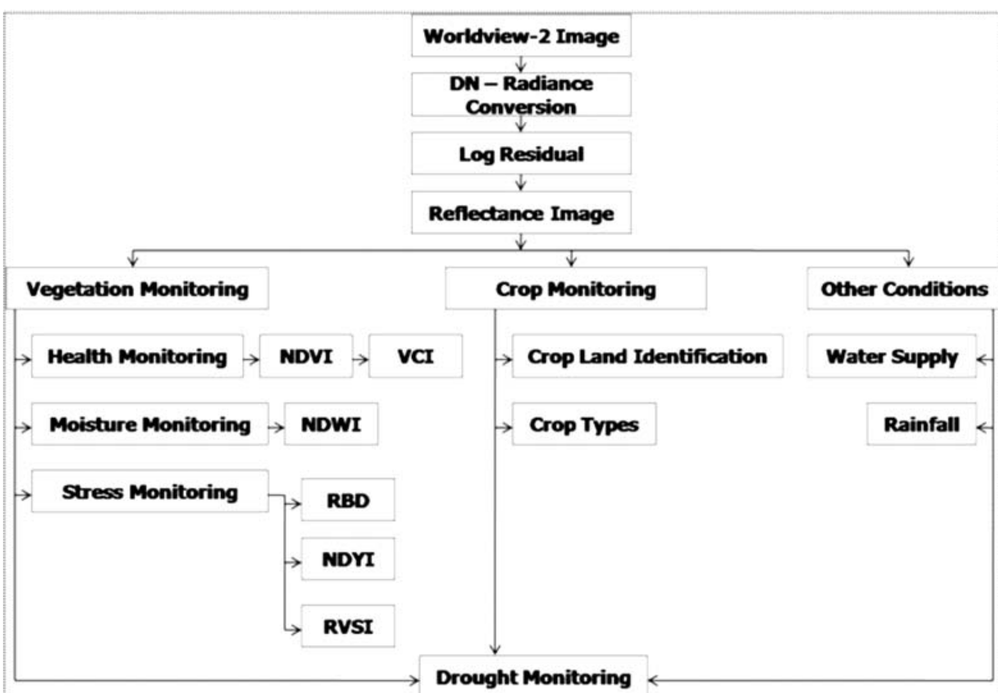


Fig 2. Processing flow of overall methodology

Pre-Processing

The DN values of Worldview-2 digital image is converted to the radiance values using ENVI based Worldview radiance conversion algorithm. The absolute calibration factor values (within the .imd file) are used to calculate the radiance image. The surface reflectance is calculated using ENVI based Log Residual method. The Log Residuals calibration tool is designed to remove solar irradiance, atmospheric transmittance, instrument gain, topographic effects, and albedo effects from radiance data [Envi User Guide, 2008]. This transform creates a pseudo reflectance image that is useful for analyzing vegetation related absorption features.

The logarithmic residuals of a dataset are defined as the input spectrum divided by the spectral geometric mean, then divided by the spatial geometric mean. The geometric mean is used because the transmittance and other effects are considered multiplicative; it is calculated using logarithms of the data values. The spectral mean is the mean of all bands for each pixel and removes topographic effects. The spatial mean is the mean of all pixels for each band and accounts for the solar irradiance, atmospheric transmittance, and instrument gain.

Health Monitoring

Normalised Difference Vegetation Index:

The most common vegetation index in use today is the Normalized Difference Vegetation Index, or NDVI [Rouse, 1972]. It is defined as:

$$NDVI = \frac{NIR_{\rho} - R_{\rho}}{NIR_{\rho} + R_{\rho}}$$

Where, stands for the reflectance in the near-infrared band and R_? stands for the reflectance in the red band. This index is based on healthy vegetation having a high reflectance in the infrared band and a low reflectance in the red band, while stressed vegetation will have a lower IR reflectance and progressively higher red band reflectance. The NDVI values (figure-3, A&B) range from -1 to 1, with values below 0 indicating poor vegetation conditions or non-vegetation targets such as soil. Higher the NIR reflectance indicates the better forest/crop growth and lower the red reflectance indicates higher the biomass of the forest/crop. The index is sensitive to the presence of green vegetation [Sellers, 1987] and permits the prediction of agricultural crops (Tucker and Sellers, 1986). It has also been used to predict monthly evaporation [Szilagyi, *et al*, 1998] and used as the basis for drought detection using remote sensing [Wan *et al*, 2004].

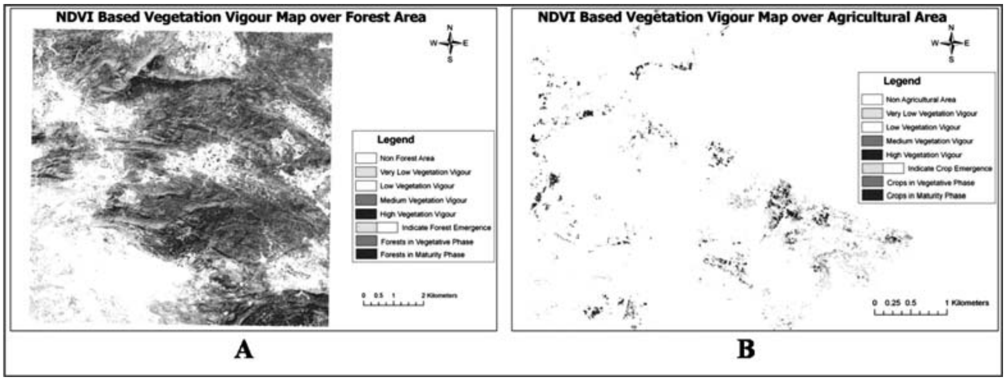


Fig 3. A- Showing the forest health of the study area and B- Showing the agriculture health of the study area.

Vegetation Condition Index:

Kogan [1997] developed the Vegetation Condition Index (VCI) which is defined in terms of NDVI. This index compares the vegetation of a region to the maximum values thus:

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} * 100$$

Where, $NDVI_{max}$ and $NDVI_{min}$ the maximum and minimum NDVI measured in the study area respectively.

Moisture Monitoring:

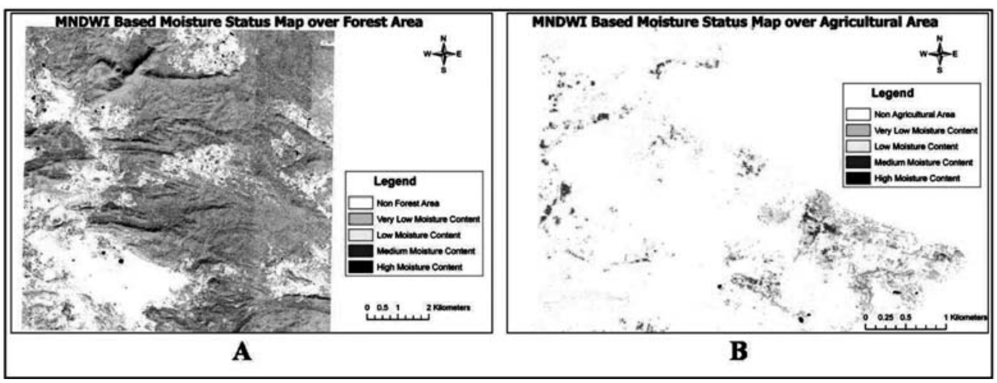
NDWI:

When radiation corresponding to the wavelengths of the water absorption bands is incident upon green vegetation, the reflectance is reduced to a varying extent, depending on the tissue water content [Thomas *et al.* 1971; Tucker 1980]. Therefore, the measurement of radiation reflected by leaves and canopies provides a basis for estimating leaf and canopy water contents. The Normalized Difference Water Index (NDWI) was proposed by Gao [1996] for remote sensing of vegetation liquid water from space. It uses two infra-red channels, one at 0.86 μm and the other at 1.24 μm. The index is defined as:

$$NDWI = \frac{\rho(0.86\,\mu m) - \rho(1.24\,\mu m)}{\rho(0.86\,\mu m) + \rho(1.24\,\mu m)}$$

Where, $\rho(0.86\ \mu m)$ and $\rho(1.24\ \mu m)$ is the reflectance at the given wavelength. These wavelengths were chosen because of their reflectance properties when considering absorption by water. . The one fundamental vibrational water absorption band (0.97µm) [Gates *et al.* 1965] was exist within the NIR-2 band of the Worldview-2. So, there is a possibility to measure the water content within the plant leaves using NIR-1 and NIR-2 band. The modified normalised difference water index (MNDVI) is developed in this study to measure the moisture status within the plant leaf (figure 4, A&B).

$$MNDWI = \frac{\rho NIR1 - \rho NIR2}{\rho NIR1 + \rho NIR2}$$



Where, $\rho NIR1$ and $\rho NIR2$ are the relectance of Worldview-2 NIR band 1 and 2 respectively.

Stress Monitoring:

Normalized Difference Yellowness Index (NDYI):

The Normalized Difference Yellowness Index (figure-5, C&D) is generated in this study for measuring the yellowness of the plant leaves. When the chlorophyll content within the plant leaves are decreased, the yellowness of the leaves are become increased. So, this index also measures the vegetation health. This index is defined as:

$$NDYI = \frac{Yellow_{\rho} - Red_{\rho}}{Yellow_{\rho} + Red_{\rho}}$$

Where, $Yellow_{\rho}$ and Red_{ρ} are the surface reflectance of yellow and red band of worldview -2 respectively.

Relative-absorption Band Depth (RBD)

This concept is used in Remote Sensing to map the mineral assemblages on the basis of their unique absorption and reflectance characteristics. It is seen that in the yellow and red-edge band of Worldview-2 having reflectance and absorption characteristics respectively. So, using this absorption and reflectance pattern of vegetation and crop spectra an attempt is made to map the yellowness stress of vegetations in the study area.

$$\mathrm{RBD} = \frac{\rho Yellow + \rho Red\ Edge}{\rho Red}$$

Where, $\rho Yellow, \rho Red\ Edge$ and ρRed are the reflectance of the yellow, red-edge and red band respectively.

Red Edge Vegetation Stress Detection:

The red-edge, centered at the largest change in reflectance per wavelength change, is located between the widely used red band and NIR band and may hold valuable information that may benefit aspects of vegetation stress study. The RVSI was developed to identify inter- and intra-community vegetation stress trends based on spectral changes in upper red-edge geometry [Merton and Huntington, 2002]. It is defined by them using AVIRIS data as-

$$RVSI = \left(\frac{\rho_{714} + \rho_{752}}{2}\right) - \rho_{733}$$

But that ratio is not applicable here. So, we developed a modified Red-Edge Vegetation Stress Index (MRVSI) index based on the worldview-2 data.

$$MRVSI = \left(\frac{\rho_{Red-Edge} + \rho_{NIR}}{2}\right) - \rho_{Red}$$

Where, ρ_{Red}, ρ_{NIR} and $\rho_{Red\ Edge}$ are the surface reflectance of the Red, NIR and Red-Edge band respectively. This ratio is better able to discriminate between healthy trees, and those impacted by disease (figure-5, A&B). In simple terms, reflectance spectra with upper red-edge convexity calculate negative RVSI values indicating low vegetation stress, whereas upper red-edge spectra with near-linear or concave curves indicate an "apparent stress" response.

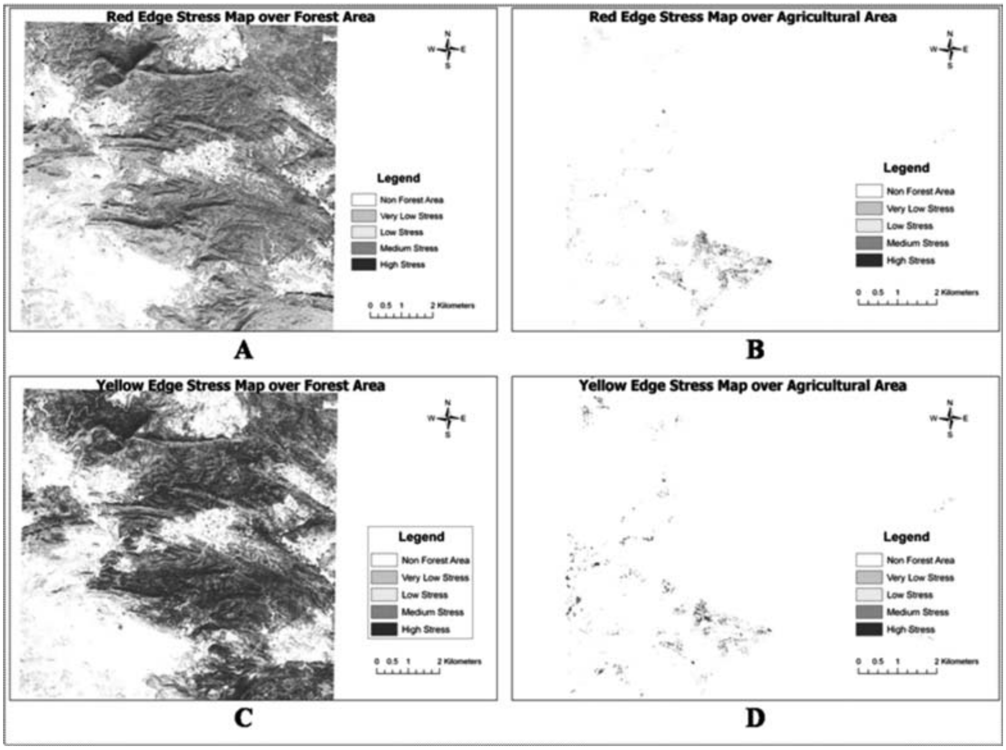


Fig 5. A & B - Red-Edge Vegetation and Crop stress and C & D - Yellow-Edge vegetation and crop stress.

Result and Discussion:

The land use & land cover classification using spectral angle mapper technique shows that the study area covered 7107.03 hectare forest land and 127.85 hectare agricultural land. The three methods Vegetation and Crop health, moisture status and stress analysis shows that the study area is under stress.

Table 2. Showing the statistics of different indices.

Methods	Over Forest		Over Crop	
	Max	Min	Max	Min
NDVI	0.47	-0.39	0.63	-0.24
MNDWI	0.19	-0.47	0.26	-0.32
NDYI	0.47	0.005	0.31	0.17
MRVSI	0.82	-0.16	0.69	-0.23

The comparative NDVI values (table-2) indicate that the crops having much vegetation vigour than the forest areas. MNDWI values shows that the water contents are less within the leaves than the crops. The NDYI and MRSVI value shows that forests are under stress. The crop areas are healthier due to the Barka river. Irrigation facilities are provided by the government in the crop lands. According to Jharkhand Agriculture Information System published report the major crop types in this area is Paddy and Maize, which require less water for growing.

As per Indian Metrological Department (IMD) in 2009 monsoon season the study area received significantly less rainfall than normal (figure-6). According to IMD advice to farmers Arhar, Moong, Paddy, Maize etc are best suitable for farming in December, 2009.

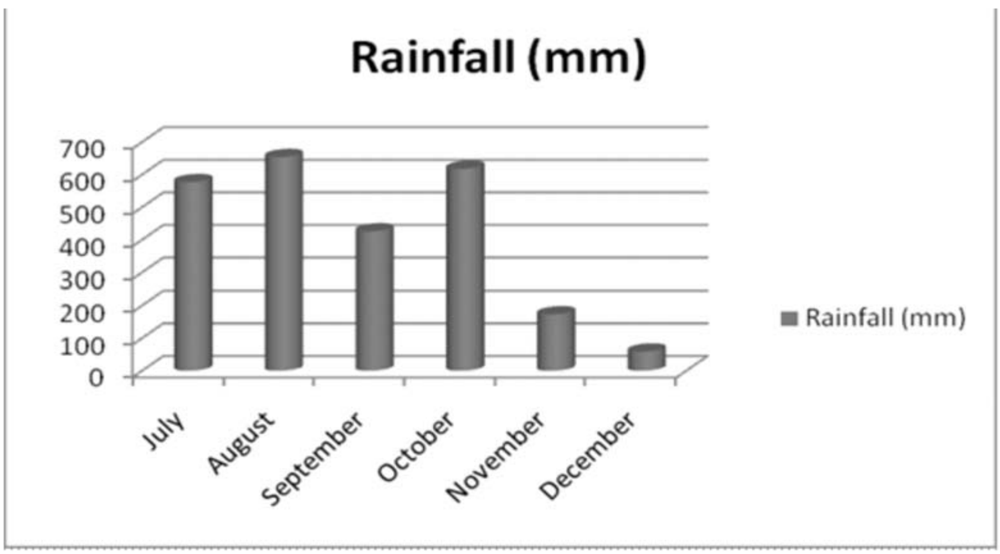


Fig 6. Showing the month wise rainfall distribution over the study area.

So, by analyzing the measured vegetation indices in correlation with other conditions such as irrigation facilities, rainfall amount, it is clear that the area under unhealthy plants and crops, low water content within the plant leaves. The leaves are yellow due to low chlorophyll content.

All the raster indices maps are imported to the GIS environment and a weighted overly method is applied to generate the drought prone map (figure-7). The weight (table-3) of each class is assigned on the basis of their influence for producing drought.

Table 3: Showing the weightage values assigned for overlay analysis

Methods Used	Weightage
NDVI	17
VCI	15
MNDWI	25
MRVSI	16
NDYI	13
RBD	14

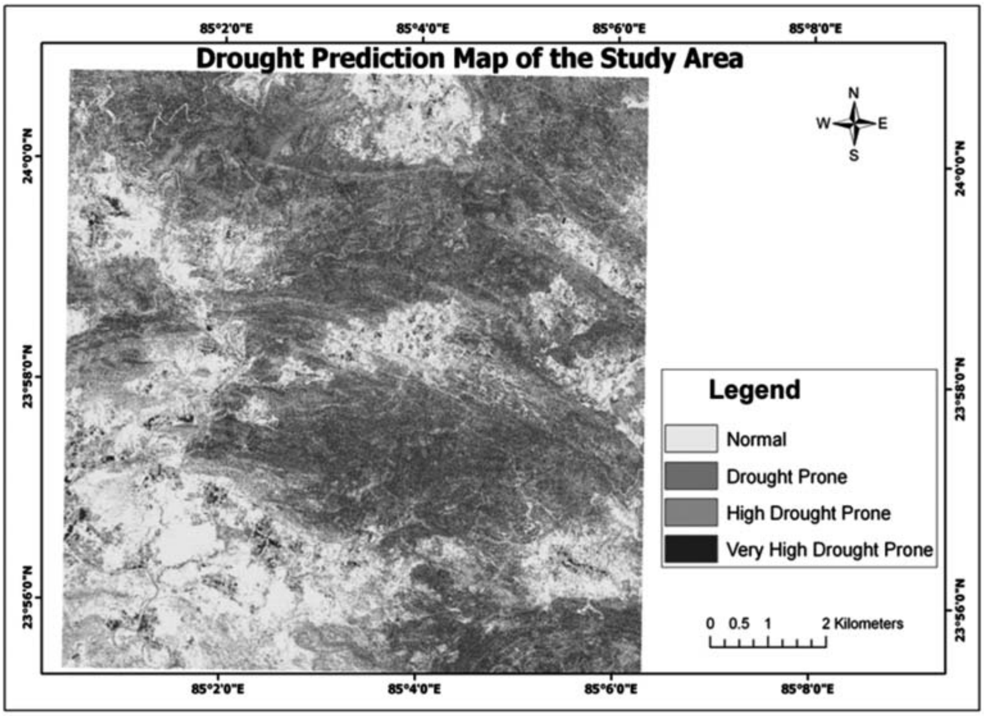


Fig 7. Showing the drought prediction maps of the study area.

Conclusion:

Meanwhile the area suffer drought year after year. So, for identifying the situation of drought, this study was carried out. It is concluded that NDVI, MNDWI, MRVSI, NDYI and RBD are good proxy indicators of drought. The red-edge stress detection is very good for measuring the forest and crop health whether these are affected by disease or not. The yellow band is very much useful measuring the yellowness of the leaves. The Worldview-2, 8 band data analysis has revealed some new findings on the prediction of droughts using Remote Sensing.

For better studying the drought time series data is needed from the growing season to the maturity season. Three new indices are generated for this study and a future research is needed.

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