Characteristic of drought using remote sensing data and analyzing relation between different indices: A case study of Davanagere district of Karnataka state, India

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Abstract:
Drought is a natural disaster that impacts the economy, the environment, society, and agriculture. Drought occurs due to a rainfall deficit. This paper discusses the characteristics of drought for Davanagere district of Karnataka state using the remotely sensed data. The Davanagere district falls under the central dry agro-climatic zone and is categorized as a drought-prone area. The average rainfall for the whole district is 325mm. The monsoon generally reaches the district by June and lasts till September. Although the total rainfall is not high, the district benefits both from the southwest and northeast monsoons. The Davanagere district is declared as a drought-prone area in the year 2017. It is imperative to monitoring drought to prevent and mitigate the effects of drought. Drought assessment using remote sensing-based indices has been widely in practiced in recent years for monitoring droughts. The present work demonstrates the establishment of relationship between different indices such as NDVI & LST, VCI, VHI, and LST & VCI, for autumn season of year 2000, 2010, and 2020, VHI & SPI and LST & VHI from May to November of 21 years (2000-2020). The correlation between NDVI & VCI, VHI, and LST & VCI shows a positive for the autumn season, whereas VHI & SPI gives no relationship because SPI purely dependent on rainfall and hence VHI is dependent on precipitation. Similarly, LST and VHI relation shows a negative correlation from May to November.

Index Terms: Drought indices, Precipitation, monitoring, correlation.

I. INTRODUCTION
Drought is an extended period of extremely low rainfall that causes a shortage of water. Drought is one of the hydro meteorological phenomenon that occurs in many parts of the country. India has been one of the most drought-prone countries, with drought occurring at least once every three years (Binod Baniya, et al., 2019). Drought affects 28 percent of India's land area, ranging from mild to severe (Patil Abijith, et al., 2021). Drought management is a part of water resources management policies and strategies. Drought is a slow-moving phenomenon that affects the hydrological system over time. Therefore, understanding and studying drought is crucial. Drought is tracked and analyzed using a variety of indicators and indices (Murat Akesel, et al., 2021). Vegetative cover is an indication of severity of drought in a season which is evaluated through the various vegetation indices. Remote sensing methods are commonly used to determine vegetation indices. They have wide application in view of high reflective values for greenery in the near-infrared region of the electromagnetic spectrum (Murat Akesel, et al., 2021). Different vegetation indices are available to determine agricultural drought, they are, NDVI (Normalized difference vegetation index), VCI (Vegetation condition index), LST (Land surface temperature), VHI (Vegetation health index) and SPI (Standard precipitation index). The Davanagere district falls under central and northern agro climatic dry zone as it receives an average annual rainfall of 325mm. The drought occurrence in the region will reduce crop yield and thereby economy of the farmer gets affected. The general impacts due to drought can be any of the following mentioned aspects or in combination:

- Economical
- Environmental
- Social

It also causes

- Reduction of crop yield
- Deforestation
- Lack of water availability to vegetation and also for human beings

In the present work, an attempt is made by the author to study the agricultural drought condition using remote sensing data for Davanagere district. The prime objective of this study is to analyze the intensity of agricultural drought and its spatial extent by VCI and VHI through the estimation of NDVI, LST and TCI for the Davanagere district. In order to know the relationship between the different indices, a correlation is established between NDVI and VCI, LST, VHI and LST & VCI for autumn season for 2000, 2010 and 2020. Also the correlation between VHI with LST and SPI is determined for months of May to November from year 2000 to 2020 to know the relation between the indices.

II. LITERATURE REVIEW
The following paragraph discusses the work carried out by few of the researcher on drought analysis using remote sensed data.

Sruthi, S. et al., (2015) have reported their study by determining correlation between NDVI and LST for each month of the year.
2002 and 2012 for Raichur district as - 0.653 & -0.586 (negative correlations). Patil, et al., (2012) have studied a drought using Vegetation indices and correlation between NDVI and LST and LST and VHI is negative, whereas NDVI and VHI is positive, for Manganga watershed. U. Marufah, et al.,(2008) have reported their study on meteorological and agricultural drought using monthly SPI and VHI. The Indonesia experiences a Meteorological drought during June to November and agricultural drought during August to November. It has been reported that a strong El Nino (2015) has extent and severity of meteorological drought than in weak El Nino (2002) and severity of meteorological drought increase in each month and peak in October. S. Kloss, et al., (2021) have investigated correlation between NDVI and LST for Bavaria region to investigate the drought situation by determining TCI, VCI and VHI using the satellite imagery data of 2001 to 2020 for growing season and evaluated for both soil moisture and yield anomalies of agricultural crops. They found that the Bavaria experience a limited plant growth in the summer months namely July and August. They also found the existence of strong correlation between TCI and VHI, with soil moisture and agricultural yield anomalies.

III. STUDY AREA
The Davanagere district is located in the central northern parts of Karnataka and it lies between 14° 28’ longitude and 75° 59’ latitude, with its average elevation at 602.5 m above MSL and an average annual rainfall of 325mm. The district lies in the plain region on the Deccan plateau known as Bayaluseeme, with its boundary sharing with Haveri district in the northwest, Shivamoga district in the southwest, Chikkamagaluru in the south, Chitradurga district in the southeast and Vijayanagara district in the North. The district has six talukas namely, Chennagiri, Jagalur, Harihar, Honnali, Nyamti and Davanagere itself. The district generally receives monsoon by June and last till September. The district receives rainfall during south west and the north east monsoons with varied rainfall over different parts of the district.

IV. DATA USED
Rainfall data:
Precipitation data of monthly rainfall for the period 1990 to 2020 is collected from the Karnataka State Natural Disaster Monitoring Center, Bangalore.

Satellite data:
The MODIS satellite data is downloaded from United States Geological Survey (USGS) website. From the, MODIS vegetation indices (MOD13Q1) satellite imagery is collected from 2000 to 2020 on a monthly basis. It is generated every 16 days at a 250m spatial resolution. Similarly the MODIS LST & E (MOD11A2) satellite imagery is collected at every 8 days period providing daytime and nighttime surface temperature bands. The study uses a daytime land surface temperature with a 1 km resolution. These MODIS data does not require atmospheric correction (Murat aksel, et al. (2021)).

V. DROUGHT INDICES
Drought measurements can be made through several indices. These indices are being used in many regions of the world for different purposes to understand the hydrology, environment and other aspects. Indices estimation involves use of various kinds of data such as rainfall over a period, data extracted from Satellite imageries, crop yield and water availability etc. There are board types of indices available, those are Rainfall related indices, Remote sensing based vegetation indices, Crop related indices
and Hydrological indices. The present study deals with indices which depend on rainfall and indices derived from remote sensing imagery data. The indices which are considered in the present study are briefly discussed below:

a. **Standard Precipitation Index (SPI)**
It is a drought index based on the rainfall data. The SPI method is widely used to determine the meteorological drought on different timescales. SPI is calculated using following equation (1) (C. Bhuiyan, 2004).

\[
SPI = \frac{(X_{ij} - X_{im})}{\sigma}
\]

Where, \(X_{ij}\) is the seasonal precipitation at the \(i^{th}\) rain gauge station and \(j^{th}\) observation, \(X_{im}\) is its long term seasonal mean and \(\sigma\) is its standard deviation.

b. **Normalized Difference Vegetation Index (NDVI)**
It is a simple method to indicate a drought using remote sensing data (Sruthi, S. et al.,(2015)). It is a measure of reflected light at certain frequencies. It is calculated for MODIS data using the formula

\[
NDVI = \text{Raster data} \times \text{Scale factor}
\]

Where, Scale factor = 0.0001

c. **Land Surface Temperature (LST)**
LST is derived from the MODIS data through USGS website. It measures the release of heat transfer from the land or the surface of the canopy in vegetated areas, where incoming solar energy interacts with the ground. LST can be derived from the measured thermal infrared radiation. LST is determined using following Equation (3),

\[
LST = (\text{Raster data} \times \text{Scale factor})
\]

Where, raster data is for a study area, Scale factor = 0.02

d. **Temperature Condition Index (TCI)**
It is employed to assess the impact of warmth and excessive moisture on vegetation. In order to depict diverse vegetation responses to temperature, conditions are evaluated relative to the maximum and minimum temperature. If a lack of moisture is coupled with a high temperature, TCI offers the chance to identify changes in the health of the vegetation caused by the thermal effect.

\[
TCI = \frac{L_{\text{max}} - L}{L_{\text{max}} - L_{\text{min}}}
\]

Where, \(L\) is the LST value for the given month. The multiyear time series variables \(L_{\text{min}}\) and \(L_{\text{max}}\) represents the maximum and minimum LST values, respectively, during the month.

e. **Vegetation Condition Index (VCI)**
It compares the observed values for the same period in prior years to the current NDVI. VCI is expressed in percentage. By using NDVI data VCI can be calculated shown below.

\[
VCI = \frac{NDVI - NDVI_{\text{min}}}{NDVI_{\text{max}} - NDVI_{\text{min}}} \times 100
\]

Where, \(NDVI_{\text{max}}\) and \(NDVI_{\text{min}}\) represent maximum and minimum NDVI of each pixel calculated for each month and NDVI is the index of current month. The drought conditions are defined by the range of VCI values as shown in Table 1 below.

<table>
<thead>
<tr>
<th>VCI ranges</th>
<th>Drought conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10%</td>
<td>Extreme drought</td>
</tr>
<tr>
<td>10%-20%</td>
<td>Severe drought</td>
</tr>
<tr>
<td>20%-35%</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>35%-50%</td>
<td>No drought</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>Wet</td>
</tr>
</tbody>
</table>

f. **Vegetation Health Index (VHI)**
It is a combination of products extracted from vegetation signals, namely VCI and TCI. It is used to identify the drought related to agricultural impacts using remotely sensed data. The VHI value can range from 0 to 100. The drought condition can be defined based on VHI value as shown on Table 2 below.

Vegetation health index can be calculated using following equation,

\[
VHI = \alpha \times VCI + (1 - \alpha)TCI
\]

Where, \(VHI\) = vegetation health index, \(\alpha=0.5\) (contribution of VCI and TCI), \(VCI=\)vegetation condition index, \(TCI=\)temperature condition index.

Table 2: Drought condition based on VHI value
g. Relation between different indices

The present study determines the relation between different indices to know the relative significance. The correlation coefficient helps us to know the degree of relationship between the indices; thereby their characteristics can be evaluated. The strength of the correlation is defined by the correlation coefficient between the indices (refer Table 3).

<table>
<thead>
<tr>
<th>VHI values</th>
<th>Drought condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 10</td>
<td>Extreme</td>
</tr>
<tr>
<td>10 to 20</td>
<td>Severe</td>
</tr>
<tr>
<td>20 to 30</td>
<td>Moderate</td>
</tr>
<tr>
<td>30 to 40</td>
<td>Light</td>
</tr>
<tr>
<td>40 to 100</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 3: Degree of Correlation:

<table>
<thead>
<tr>
<th>Correlation coefficient range</th>
<th>Strength of correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>±0.9 to ±1</td>
<td>Very high correlation</td>
</tr>
<tr>
<td>±0.7 to ±0.89</td>
<td>High correlation</td>
</tr>
<tr>
<td>±0.5 to ±0.69</td>
<td>Moderate correlation</td>
</tr>
<tr>
<td>±0.3 to ±0.49</td>
<td>Low correlation</td>
</tr>
<tr>
<td>±0.0 to ±0.29</td>
<td>No correlation</td>
</tr>
</tbody>
</table>

VI. METHODOLOGY

The present study is done on the agricultural drought for the Davanagere district by evaluating the southwest monsoon for years 2000 to 2020 using VCI and VHI drought indices. The southwest monsoon consists of four months i.e. June to September. The study on the correlation between the NDVI, VCI, LST, VHI and LST & VCI for autumn season of 2000, 2010 and 2020 has been attempted. Similarly the study on LST & VHI and VHI & SPI for month may to November of 21 years (2000-2020) has been attempted.

Multi-temporal MODIS satellite images from 2000 to 2020 at a spatial resolution of 250 m and 1000 m respectively are taken from USGS. In order to derive VCI and VHI, it is necessary to process various indices that are mentioned below. Figure 2 gives methodology used in the present study for the analysis.

Whereas the various steps followed for the analysis of a drought of the region is briefly discussed in the following paragraphs. Firstly MODIS data such as MOD13Q1 and MOD11A2 from a USGS website is collected and then NDVI and LST data were evaluated. Subsequently VCI, VHI was calculated using equation 1 and 2 respectively. These values are used to analysis the drought of Davanagere district. The NDVI, LST, VCI and VHI for 3 months of years 2000, 2010 and 2020 and also for 7 months of 21 years of data (2000-2020) have been estimated. Procedure to establish correlation between different indices for 3 months data:

1) Firstly MODIS MOD13Q1 and MOD11A2 data from the USGS EarthExplorer from September to November 2000, 2010,
and 2020 were collected.

4) Extraction of study area by clipping is done.
5) Created fishnet for the desired two indices.
6) A scattered graph indicating correlation between two indices is prepared.

Procedure to establish correlation between different indices for 7 months data:
1) Firstly MODIS MOD13Q1 and MOD11A2 data from the USGS Earth Explorer from May to November 2000 to 2020 were collected.
2) Using these data, LST, VCI and VHI values were calculated.
3) Then SPI is calculated for seven months using rainfall data
4) Mean values of different indices is calculated.
5) The correlation plot is prepared between LST and VCI, and VHI and SPI.

VII. RESULT AND DISCUSSION

A: Characteristics of Drought
The VCI for the district for all the 21 years is shown in Fig 3. The study reveals that the year 2000 and 2003 experience a severe drought in the northeast part and also some west part of the district. The year 2006 experienced severe drought in the northeast part. The year 2008, 2011, and 2012 experience an extreme drought in the northeast part of district. Mild drought is seen in the year 2001 majorly in all parts except northwest, northeast experienced extreme and moderate drought. In the year 2010 all part of district experienced moderate drought. The year 2014 had no drought, especially in the northern and southern parts of the Davanagere district, as that year had sufficient rainfall.

In the northeast part, which includes Jagalur taluk of Davanagere district experience more drought compare to other regions of district. Since it is a semi-arid climate and it is under Torrid Zone prevails in major part of the year.

The VHI for the district for all 21 years is shown in Figure 4. The study reveals that the year 2001 experienced extreme drought in the northeast and severe drought in the west, northwest, and few parts of the northeast district. However, the entire Davanagere district was suffering from drought ranging from extreme to light in different parts of the district in the year 2001. From 2012 to 2020, the Davanagere district experienced moderate drought in almost all parts of the district, whereas the central part experienced no drought except in the year 2017. However, the year 2018 has experienced moderate and light drought conditions. In the year 2017 the district experienced moderate drought in the northeast, whereas the central and north parts experience extreme to severe drought condition. Interestingly the western parts do not have any kind of drought. Of all the years of study, the year 2001 has experienced moderate to extreme drought, drought being extreme in the north eastern parts of the district.

Fig. 3: Vegetation Condition Index

The VHI for the district for all 21 years is shown in Figure 4. The study reveals that the year 2001 experienced extreme drought in the northeast and severe drought in the west, northwest, and few parts of the northeast district. However, the entire Davanagere district was suffering from drought ranging from extreme to light in different parts of the district in the year 2001. From 2012 to 2020, the Davanagere district experienced moderate drought in almost all parts of the district, whereas the central part experienced no drought except in the year 2017. However, the year 2018 has experienced moderate and light drought conditions. In the year 2017 the district experienced moderate drought in the northeast, whereas the central and north parts experience extreme to severe drought condition. Interestingly the western parts do not have any kind of drought. Of all the years of study, the year 2001 has experienced moderate to extreme drought, drought being extreme in the north eastern parts of the district.
B. Analysis of relation between different indices

The goal of the analysis of the correlation between different indices is to measure how one variable has dependency on another variable. In this analysis, the correlation between different indices has been carried out between NDVI & LST, VCI, VHI, and LST & VCI for the autumn seasons of 2000, 2010, and 2020; LST & VHI and SPI & VHI for May to November for 21 years (2000–2021). The analysis is based on the Pearson correlation coefficient with different months for the indices.

(i) Relation between NDVI with LST

The Figure 5 shows the Pearson correlation coefficient values for the correlation between NDVI and LST for different years. The above graphs show that the values are within the range of 0.9 to 1, for September to November for the years 2000, 2010, and 2020, which means that these are values with a high correlation. It can be inferred that as the land surface temperature increases NDVI also increases which indicates increasing soil moisture deficiency in the region. Vice versa is also true.

(ii) Relation between NDVI with VCI

The Figure 6 shows the Pearson correlation coefficient values for the correlation between NDVI and VCI for different years. The above graphs show that the values are within the range of 0.9 to 1, with an average value of 0.96 for 200 and 2010, for September to October for the years 2000 and 2010. It means there is a high correlation between NDVI and VCI. At the same time, the correlation is very high for the month October and November in the year 2020. The analysis shows that there is a good relation between NDVI and VCI exist and is also shows that NDVI and VCI are directly proportional to each other.
(iii) **Relation between NDVI with VCI**

The Figure 7 shows the Pearson correlation coefficient between NDVI and VHI for different years, ranging from 0.9 to 1.0 for September to November for the years 2000, 2010, and 2020. It represents a direct proportion of NDVI and VHI.

![Fig. 6: Pearson correlation coefficient Verses Months for NDVI with VCI relation](image)

(iv) **Relation between LST with VCI**

The Figure 8 shows the Pearson correlation coefficient between LST and VCI for all the years studied. The average correlation of 0.95 is observed in October for the year 200 and 2020, whereas 2010 has an correlation of 0.82 for the same month may be because the 2020 experience moderate drought in the entire district. An average correlation of 0.93 is found for the month of September in 2000 and 2010, whereas 2020 has an average value of correlation as 0.85 may be due to moderate drought experience by the district. At the same time the year 2020 gives a highest correlation coefficient in the month of November may be due to the onset of winter season in the region. The study reveals that there is a direct relation between LST and VCI.

![Fig. 7: Pearson correlation coefficient verses months for NDVI with VHI relation](image)

(v) **Relation between NDVI with VCI**

The Figure 9 shows average values of Pearson correlation coefficient between LST and VHI for each of the months (May to November) for all the 21 years (2000 to 2020) considered for the study. The months May, July and November shows correlation coefficients close -0.9, whereas the September has a correlation of -0.5. At the same time June and October have a correlation on approximately -0.7 as correlation coefficient. The above study reveals that though there is a good correlation between LST and VHI, but they are negatively correlated. In the sense, as the land surface temperature increases vegetation health decreases in other words soil moisture deficiency increases.

![Fig. 8: Pearson correlation coefficient Verses Months for LST with VCI relation](image)

(vi) **Relation between SPI with VHI**

The Figure 10 shows the variation of average coefficient of all the 21 year of study (200 to 2020) corresponding to seven 7 months considered i.e. May to November. My to July and October, November shows a positive correlation, whereas August and September months shows a negative correlation. However all the year shows very low correlation between SPI and VHI indicating there is no relation exists between SPI and VHI. It is due to the reason the SPI is derived from rainfall records and VHI depends on soil moisture conditions.

![Fig. 9: Pearson correlation coefficient Verses Months for LST with VHI relation](image)
condition and moisture presence in the soil.

Fig. 10: Pearson correlation coefficient Verses Months for SPI with VHI relation

VIII. CONCLUSION

The study attempts to analyze the intensity of agricultural drought and its spatial variation using VCI and VHI indices for the Davanagere district of Karnataka State, India. It helps to identify the severity of drought in different regions of the district. The study reveals that the northeast part of the district experiences moderate to extreme droughts frequently whereas western and central parts experience mild droughts. It has been experienced that VCI is found to be more useful in analyzing the drought condition of the region better than the VHI. The district Davanagere experience severe to moderate drought in different regions of the district over the 21 years of study period. Northeast being severely affected. The study on the relation between NDVI & LST, VCI, and VHI shows there is a positive correlation between NDVI and other indices. The relation of LST with VCI shows a positive correlation, whereas with VHI shows negative correlation. At the same time the relation between VHI and SPI indicates no correlation. These indices help us to know the conditions of the health of the vegetation and the condition of soil moisture in the region. Such study could help the decision makers in the management of drought situation in the region.

REFERENCES