International Journal of Advanced Geosciences, 12 (2) (2024) 75-79

International Journal of Advanced Geosciences

Website: www.sciencepubco.com/index.php/IJAG

Research paper

Assessment of vegetation health index (VHI) using Modis data in rivers state, Nigeria

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Abstract

Droughts have a significant impact on agricultural and agro-pastoral regions as they heavily rely on rainfall. Monitoring agricultural drought is of utmost importance to ensure global food security. Satellite remote sensing has emerged as a reliable method for assessing vegetation health and has proven to be an effective approach for detecting droughts on a global scale. Various indices, such as the Normalized Differ-ence Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI), and Vegetation Health Index (VHI), have been developed using remote sensing data. These indices are utilized to identify and monitor agricultural droughts by examining the vegetation and plant growth. The study employed MODIS data and leveraged Google Earth Engine to process it using codes before export-ing it to QGIS for visualization. The results revealed a mean value of 4.8(5) for VHI and 4.7(5) for VCI, indicating the absence of drought conditions. This signifies that the region is suitable for agricultural activities. Additionally, a TCI value of 4 indicated mild vegetation stress. It is advisable to continuously monitor the VHI over Rivers State for effective planning, decision-making, and providing guidance to local farmers.

Keywords: *Rivers State; Vegetation Condition; Droughts; Vegetation Health; Agricultural.*

1. Introduction

Remote sensing data derived from satellites provide a valuable and comprehensive array of information regarding land cover, vegetation, rainfall, temperature, and various other climate variables. The evaluation of vegetation health, specifically influenced by factors like biotic or abiotic stress such as drought or pest infestation, holds immense importance for countries where the economy heavily relies on crop harvests (Tripathi et al., 2013). Prompt assessment of potential reductions in crop yields can prevent a catastrophic scenario and aid in strategic planning to meet demands effectively (Tripathi et al., 2013). An efficient tool for retrieving various plant biophysical variables and ensuring their accuracy and reliability is a basic requirement for crop growth monitoring. Remote Sensing has been identified as a potentially valuable method for estimating these biophysical variables. The methods used to estimate canopy biophysical variables from reflectance data can be categorized into two approaches: (a) Statistical approach and (b) Process-based approach, utilizing Radiative Transfer Models (Tripathi et al., 2013). Empirical or statistical approaches involve observing spectral contrasts of reflectance and establishing a relationship between reflectance and certain biophysical variables, primarily through the utilization of vegetation indices (Tripathi et al., 2012).

Drought is typically defined as a condition marked by insufficient rainfall and elevated air temperatures (Masitoh and Rusydi, 2019). Assessing the extent of drought can be accomplished through the analysis of remote sensing satellite imagery. Remote sensing provides a rapid and efficient method for evaluating drought, utilizing spatial indices distributed over multiple time periods (Masitoh and Rusydi, 2019). VHI is a commonly employed drought index that relies on remote sensing data. It is formulated by combining two components, namely the Vegetation Condition Index (VCI) and the Thermal Condition Index (TCI), as proposed by Bento et al. in 2013. As per the findings of Bento et al., the VCI assesses moisture conditions and relies on data from the visible and near-infrared regions of the electromagnetic spectrum. On the other hand, the TCI evaluates thermal conditions and relies on data from the thermal infrared window. The estimation of vegetation condition and temperature on a global scale has become commonplace in the field of drought monitoring. The widely used Normalized Difference Vegetation Index (NDVI) and LST (or TOA brightness temperature) serve as indicators for the Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) respectively, as outlined by Bento et al. in 2013. Remote-sensing data, particularly the VCI derived from satellite-based vegetation indices like NDVI, has garnered significant attention from researchers worldwide in detecting and monitoring agricultural drought (Liu and Kogan 2002; Domenikiotis et al. 2014; Kuri et al. 2014).

In their study, Bhuiyan and Kogan (2006) utilized NDVI data obtained from the NOAA-AVHRR satellite to analyze drought in the Aravalli region of India. They investigated various indicators including VCI, TCI, and VHI. The findings were then compared with ground-based statistical indicators like SWI and SPI, revealing significant correlations between the remote sensing data and the data collected on the ground. In a similar vein, Bhuiyan (2008) successfully employed NOAA-AVHRR satellite NDVI data to estimate droughts in the Thar Desert located in northwestern India and East Pakistan. This study covered the period between 1984 and 2003. The generated VCI, TCI, and VHI indicators proved effective in assessing the occurrence of droughts during this time frame.

Moghadam et al., (2014) examined the efficacy of agricultural drought indicators, specifically the Vegetation Condition Index (VCI), in assessing vegetation conditions. The study utilized satellite imagery data obtained from the Terra MODIS sensor, covering the period from 2000 to 2011, in the Sharghi Azerbaijan Province. The findings of the study highlighted that the years 2001, 2008, 2000, and 2009 exhibited the highest levels of drought, as indicated by the VCI. Conversely, the years 2010 and 2003 had the lowest levels of drought. This underscores the utility of the Remote Sensing VCI model in accurately evaluating agricultural drought, particularly in regions with limited weather stations or a lack of suitable drought estimation models. In conclusion, the research by Moghadam et al. (2014) demonstrates that the Remote Sensing VCI approach serves as a robust and reliable method for assessing agricultural drought in areas where conventional monitoring methods are scarce or unavailable.

In the conventional approach to drought monitoring, one had to undertake the laborious process of obtaining satellite images and executing extensive pre and post-processing procedures. However, leveraging the power of cloud computing and employing advanced machine learning algorithms like Google Earth Engine, one can now seamlessly achieve these tasks without the need to download satellite images. Drought is a gradual and devastating catastrophe that impacts agriculture and, consequently, the livelihoods of people in numerous regions around the globe. The toll of drought on vegetation is tremendously detrimental, making changes in vegetation condition an accurate indicator of the severity of drought. To effectively identify drought conditions, geospatial scientists have developed drought indices utilizing remote sensing data. Among these indices, the Normalized Difference Vegetation Index (NDVI) stands out as a simple and highly efficient measure. The NDVI calculates the normalized difference between near-infrared (NIR) and red reflectance. Due to its simplicity and effectiveness, the NDVI is widely employed for drought detection purposes.

In recent times, numerous indices have emerged in the field, including the Vegetation Condition Index (VCI). The VCI serves as a measure of the condition of vegetation cover, taking into account the minimum and maximum values of the Normalized Difference Vegetation Index (NDVI) observed within a specific ecosystem over an extended period. Similarly, the Vegetation Health Index (VHI) combines the VCI with land surface temperature. As a result, this research undertook an assessment of the Vegetation Health Index (VHI) in Rivers state, Nigeria, utilizing MODIS data.

2. Study area

Rivers State: Established on 27th May 1967 during General Gowon's tenure, Rivers State is comprised of twenty-three (23) Local Government Areas, with its administrative headquarters located in Port Harcourt. The state's boundaries can be geographically defined by the coordinates ranging from 210590.00m to 344490.00m in the northings direction, while the eastings extend from 477432.00m to 634925.00m, all referencing the UTM Zone 32N origin (Figure 1 and 2 provide visual representation). The southern border of Rivers State meets the vast Atlantic Ocean, while its northern boundaries connect with Imo, Abia, and Anambra States. Towards the east lies Akwa Ibom State, and to the west, it shares borders with Bayelsa and Delta states. The state is renowned for its vibrant community, consisting of diverse ethnic groups such as Abua, Andoni, Ekpeye, Engenni, Etche, Ibali, and Ikwerre Eludoyin et al (2011) observed that the drainage in the mentioned low-lying area experiences significant surface water and intense precipitation, varying from 3,420 mm to 7,300 mm. The main contributors to this region's hydrology are the freshwater systems, sourced from the River Niger, and the tidal systems, mainly originating from the Bonny New Calabar River.

The freshwater zones in the northern region exhibit a remarkable increase in width and speed downstream, indicating the effectiveness of these systems. Along the riverbanks, levees clearly demarcate the area, while the slopes on either side of the valley show a remarkably gentle gradient. These slopes undergo substantial erosion and sediment accumulation processes. Ultimately, all the rivers converge into the expansive estuaries of the Bonny River, which act as vital pathways to the sea. These interconnected rivers are abundant sources of diverse marine life, providing valuable seafood like crabs, oysters, shrimps, and fish. Additionally, they offer crucial habitats for various species of mammals and birds, further enhancing their ecological significance

Fig. 1: Map of Africa with Location of Nigeria.

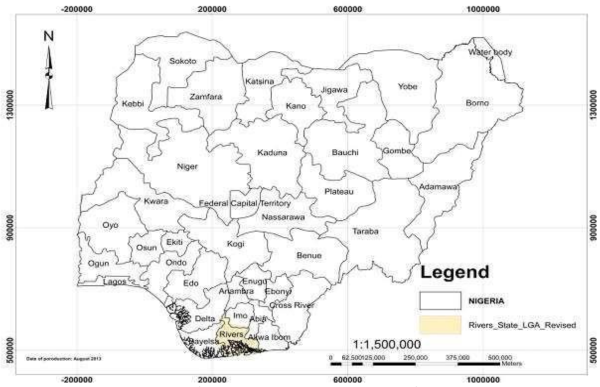

Fig. 2: Map of Nigeria with Location of Rivers State.

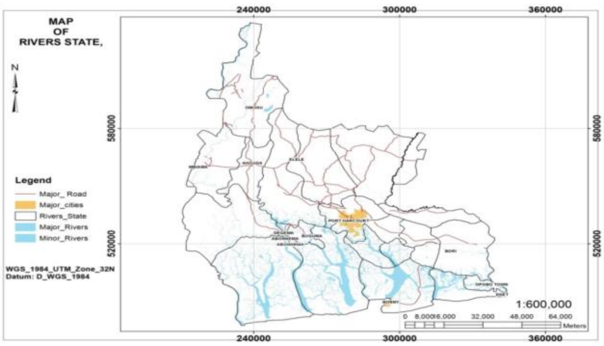

Fig. 3: Map of Rivers State.

3. Methodology

3.1. Data used and indices selection

The Aqua and Terra satellites are equipped with the MODIS sensor, which captures data in 36 different spectral bands. Among these bands, there are two at 250 meters resolution, bands at 500 meters resolution, and twenty-nine at 1000 meters resolution. The MODIS data holds significant value in analyzing landscape changes over time due to its exceptional temporal resolution. This feature enables effective monitoring of vegetation health by utilizing time-series analyses with vegetation indices. Notably, the data preparation and pre-processing tasks, involving index selection, are conducted within the Google Earth Engine environment.

The Normalized Difference Vegetation Index (NDVI) serves as a valuable indicator for assessing green biomass, leaf area index, and production patterns. It is based on the principle that when sunlight interacts with plants, chlorophyll in the leaves primarily absorbs the red bandwidth in the visible part of the electromagnetic radiation spectrum (0.4–0.7 mm), while near-infrared (NIR) radiation (0.7–1.1 mm) largely reflects off leaf cell structures. In the case of thriving vegetation, the absorption of red light is prominent, resulting in the reflection of NIR radiation. Typically, if there is a higher amount of reflected radiation in the NIR range compared to the visible range, it indicates the presence of healthy and dense vegetation. The range of NDVI spans from −1 to +1. A value close to zero implies the absence of green vegetation, whereas a value near +1 indicates the presence of the densest vegetation. Barren areas consisting of rock, sand, and snow exhibit NDVI values below 0.1, while shrub and grassland areas typically display values between 0.2 and 0.3. Temperate and tropical rainforests exhibit values ranging from 0.6 to 0.8. The NDVI formula is used to calculate the Normalized Difference Vegetation Index: NDVI = NIR – RED / NIR + RED

Vegetation Condition Index (VCI): The Vegetation Condition Index (VCI) serves as a valuable metric for assessing vegetation cover by considering the minimum and maximum values of Normalized Difference Vegetation Index (NDVI) observed in a specific ecosystem over an extended period. It surpasses the NDVI in accurately determining the level of water stress experienced. Furthermore, deviations in vegetation condition refer to the extent of the adverse effects of drought on plant growth. The VCI is calculated using the subsequent formula:

$$VCIj = (NDVIj - NDVImin) / (NDVImax - NDVImin) \times 100$$

Where, NDVImax and NDVImin are the maximum and minimum NDVI values in a multi-year dataset. The 'j' is the NDVI value for the current month.

Temperature Condition Index (TCI): The measurement of Land Surface Temperature (LST) obtained through thermal radiance bands serves as a reliable indicator for assessing the energy equilibrium of the Earth's surface. This is especially relevant because elevated temperatures can rapidly occur when water stress is experienced. Meanwhile, the Thermal Condition Index (TCI) acts as an introductory metric to evaluate water stress and drought conditions. Its calculation includes the utilization of the following formula:

$$TCIj = (TCIj - TCImin) / (TCImax - TCImin) \times 100$$

Where, TCImax and TCImin are the maximum and minimum TCI values in a multi-year dataset. The 'j' is the TCI value for the current month.

Vegetation Health Index (VHI): The VHI is an effective tool for assessing drought conditions as it combines the constructed VCI and TCI. A straightforward formula can be applied to calculate the VHI efficiently. $VHI = \alpha \times VCI + (1 - \alpha) \times TCI$

Where α is the weight to measure the contribution of the VCI and TCI for assessing the status of drought. Typically, the value of α is chosen as 0.5, as it becomes challenging to discern the individual impact of surface temperature and NDVI while assessing drought stress.

3.2. Methods

The assessment of Vegetation Health Index (VHI) conditions using MODIS data is conducted in this study by integrating Google Earth Engine. The NDVI, VCI, TCI, and VHI are prepared utilizing the powerful capabilities of Google Earth Engine. The VCI, TCI, and VHI values are calculated for the complete MODIS operation period, ranging from 2000 to the present or a user-defined end time. The resulting output is seamlessly exported to a Google Drive account. Subsequently, the output raster is downloaded and incorporated into QGIS, enabling further statistical analysis specifically focused on evaluating the VHI conditions in Rivers State

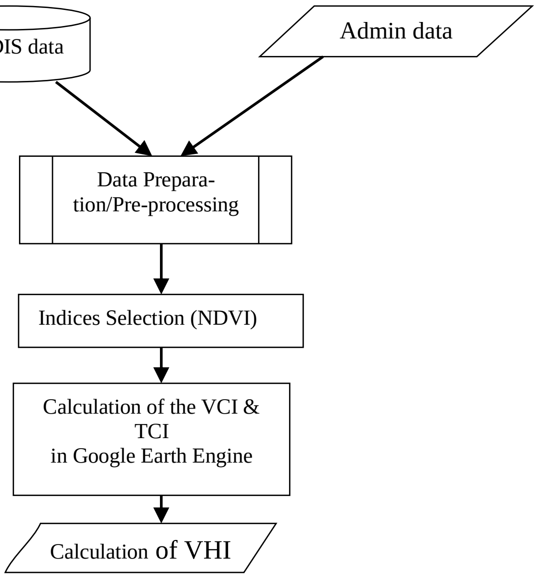

Fig. 4: Methodology Workflow.

4. Results

The output raster represents the results of applying all the steps involved in categorizing the drought severity zones, enabling a thorough analysis of the extent of drought in the affected region. VHI values range from 1 to 5, and the raster image was classified based on the criteria defined in table 1 and implemented through the provided code. The resulting classified image (in tiff format) is presented in Figures 4 to 6.

Table 1: Raster Values in the Final Product

Raster values	VHI drought indices
1	Extreme
2	severe
3	moderate
4	mild
5	No drought

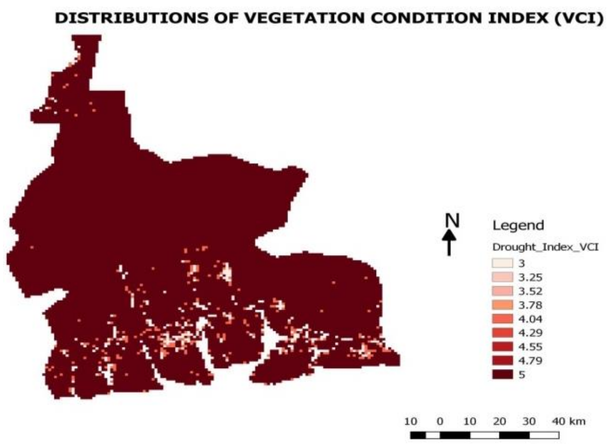

Fig. 5: Distributions of Vegetation Condition Index (VCI) over Rivers State.

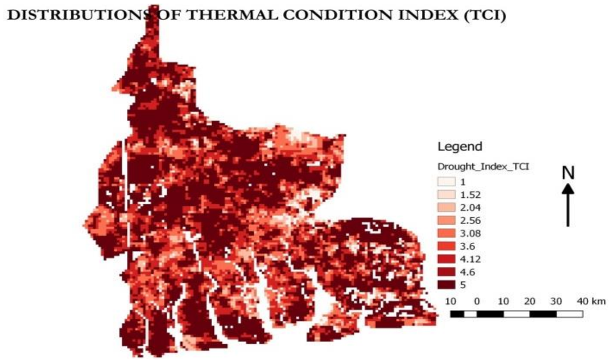

Fig. 6: Distributions of Temperature Condition Index (TCI) Over Rivers State.

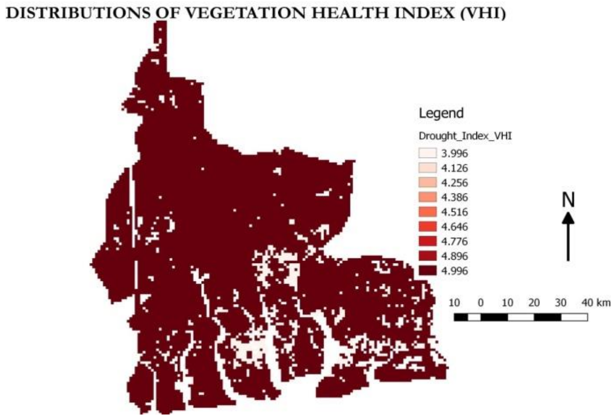

Fig. 7: Distributions of Vegetation Health Index (VHI) Over Rivers State.

5. Discussion and conclusion

The Vegetation Health Index (VHI) has a raster mean value of 4.8, indicating a lack of drought and optimal conditions for agricultural production throughout the year. Similarly, the average Vegetation Condition Index (VCI) for the same period is 4.9, highlighting the absence of drought and the presence of healthy vegetation suitable for agricultural activities in all seasons. On the other hand, the Temperature Condition Index (TCI) exhibits a moderately elevated value of 4.0, signifying the presence of vegetation stress within the average range.

The scientific community employs VCI (Vegetation Condition Index) and VHI (Vegetation Health Index) in their analysis of the impact of greenness on agriculture, specifically in assessing drought conditions. TCI (Temperature Condition Index), on the other hand, is utilized to evaluate vegetation stress resulting from temperature fluctuations. Consequently, both VCI and VHI are valuable tools for monitoring and assessing drought. However, VHI is considered more robust and effective due to its ability to accurately represent occurrences of drought. The provided figure vividly demonstrates the absence of drought-like conditions during the observed time period. This study successfully highlights the practicality of utilizing satellite-based vegetation indices and advocates incorporating them into the agricultural planning scheme in Rivers State where the livelihoods of the majority of rural inhabitants depend heavily on farming.

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