Research Paper

Climate-Vegetation Response Relationship in Part of South-Eastern Nigeria

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Abstract

This study examines the trend and relationship of vegetation vigour with temperature and rainfall, as an indicator for measuring climate variability in the South Eastern Nigeria. The main objective of the study was to determine the trend of Normalized Difference Vegetative Index (NDVI) as derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) and its relationships with rainfall and temperature for the study area. Ten (2000-2009) years MODIS images data were analysed with geographical information techniques and the results were compared with the mean rainfall and temperature from 5 well distributed stations for same period. Vegetation vigour was quantified by NDVI and analysed for spatial correlation and temporal variations. The study showed that the mean annual temperature, rainfall and NDVI for the investigated period were 27.0-28.0 °C, 1700-2400 mm and 0.0-1.5, respectively. The study suggests that the relationship between vegetation vigour and climate factors (temperature and rainfall) is complex and it is affected by sensors’ spatial and spectral characteristics among others. It also identified data aggregation window as an important factor that should be considered in attempts to establish a vegetation vigour-climate relationship.

Keywords: Moderate Resolution Imaging Spectroradiometer, Normalized Difference Vegetative Index, Vegetation-climate Relationship

1. Introduction

Vegetation cover plays a crucial role in virtually all aspect of human activities at different spatial and temporal scales (Flavio et al, 2008 and Nwagbara, 2008). Vegetation has been described as an effective means of stabilising soils and controlling erosion, because it shields the soil from the direct impact of falling rain, reduces flow velocity, disperses flow, and provides a rough surface that slows the runoff velocity and promotes infiltration and deposition of sediment (Flavio et al, 2008). Vegetation study has been regarded as important to the understanding of climate variability and change (Woodward & Mckee, 1991 and PCCF, 2003), especially in the face of recent increasing rate of urbanization and climate change, as well as importance of vegetation studies to the understanding of ecological balance and climate response systems (Bakker et al, 1996 and Douville et al, 2000). The dynamics of vegetation controls the partitioning of incoming solar radiation in the sensible and latent heat fluxes. This suggests that changes in vegetation may result to long term change in global and local climate which could in turn affect vegetation growth, in a feedback scenario (PCCF, 2003).

Studies such as Bounoua et al (2010) have shown that vegetation vigour would vary due to change in weather and climate. This is probably as a result of response of vegetation vigour to distinct changes in weather and climate elements, hence the increasing use of vegetation vigour-weather relationship as a sensitive indicator on the study of global and local environmental changes. A number of studies have evaluated vegetation dynamics in the tropical Africa
and Nigeria in specific (Schneider et al, 1985; Rogers et al, 1996; Salami, 1999 and Salami et al, 1999), using the change detection capability of some remotely sensed images to account for rate of deforestation and land use changes in their study areas. While the results from these researches have been useful, most of them have been restricted to the Chad area and South Western Nigeria. Studies like Flavio et al (2008), Njoku (2008), Nwaigbara (2008) and Chima et al (2009) have also focused on long term changes in vegetation and pertinent climatic parameters. There is, therefore, a poor understanding of the short term variations, with use of available remotely sensed imageries in these areas and other geographical regions in Nigeria.

Climate is known to influence the variations in vegetation vigour by modifying the surface roughness, evapotranspiration and albedo in a feedback system. Little is, however, known about the use of responses of vegetation vigour to remote sensing imageries in many parts of tropical regions, especially in developing countries where space technology is not well developed (Habib et al, 2008). Although the development of space technology and better availability of the Nigeria Sat imageries have provided lots of opportunities for researchers and users to exploit its usefulness; many research papers have been published in the last decade on the Nigerian environment, especially on vegetation (Salami, 2006 and Salami & Balogun, 2006), most of their results have shown the need for larger resolution and shorter time composite imageries.

Change in weather conditions and vegetation vigour, as captured by remote sensing imageries have been used to explain weather and climate conditions and vice versa. Chima et al (2009), for example, argued that positive trends of vegetation vigour in part of the northern Nigeria is directly proportional to increase in rainfall, but inversely proportional to temperature increase. Flavio et al (2008) and Habib et al (2008) also showed that vegetation vigour has been used to show changes in the ecology of the Sudan vegetation in Africa. Njoku (2008) revealed an apparent negative trend of vegetation vigour in the south eastern Nigeria with NDVI deficit of -0.5 to -0.7 between 1970 and 1980s and a concomitant loss of 78% (166,338 m²) vegetation covers. The objective of the present study is to determine indices of the Normalized Difference Vegetative Index (NDVI) from Moderate Resolution Imaging Spectroradiometer (MODIS) data in order to assess its relationships between the vigour and climatic variables. Normalized Difference Vegetative Index (NDVI), which is a measure of the relationship between the red and near-infrared bands of the spectral bands of the MODIS, was calculated for two bands in each period. This was achieved by selecting Granule via Global Visualization (GloVIS) java package of the United States Geological Survey at the Land Processing Distributed Active Achieve (LAPDD)

2. Study Area

This study was carried out in the part of the South Eastern Nigeria, which constituted Imo State until 1976 and will subsequently be referred to in this study as ‘old Imo State’. The study area is located in the 4°45’N, 6°30’E and 6°15’N, 8°09’E (Figure 1). The climate of the study area has two main regimes; dry (November-February) and rainy or wet (March-October) seasons. The variation in the characteristics and seasons in Nigeria have been reported in literature (Odekunle, 2004). Rainfall in the study area is between 1800 and 2700 mm and temperatures ranges are 28-35 °C and 19-24 °C for mean maximum and average, respectively. The study is topographically divided into lowlands, averagely below 70 m above the mean sea level and the plateau and escarpment area, which is characterized by a very complicated morphology created by a number of East-West cuestas in which geologically younger outcrop above the older formation (Iloeje, 1965 and Ibe & Sowa, 1995).

3. Materials and Methods

The ten year (2000-2009) mean monthly maximum and minimum temperatures and rainfall totals of the five based ground-based meteorological stations i.e. Umudike, Owerri, Isiagu, Uturu, and Okigwe, were used for this study. MODIS vegetation composites for same period were also sourced. Vegetation response values were extracted from the MODIS imageries and used to explore the numeric trend relationships between the vigour and climatic variables. Normalized Difference Vegetative Index (NDVI), which is a measure of the relationship between the red and near-infrared bands of the spectral bands of the MODIS, was calculated for two bands in each period. This was achieved by selecting Granule via Global Visualization (GloVIS) java package of the United States Geological Survey at the Land Processing Distributed Active Achieve (LAPDD)
Centre was imported into the Environment for Visualizing Images software (ENVI) by selecting the Hierarchal Data Format (HDF) Platforms to select the required bands. The specific granule which is a tagged “level 3” by National Airspace Administrator was 1 km (1200 x 1200), and 250 m spatial resolution. Consequently, a spatial sub-setting operation using ENVI was performed after which the specific latitude and longitude values were inputted to extract the study location from the entire granule. Data were analysed using MINITAB statistical package.

Temperature, precipitation and vegetation trends, anomalies and relationships were determined using the Mann-Kendall non-parametric test. Environment for Visualizing Images, (ENVI), version 4.3, and Integrated Land and Water Information System (ILWIS), version 3.3, were used to process the satellite imageries. The macro file for ‘Mann-Kendall S’ for MINITAB was invoked using the line editor of the software package. Using this, it was assumed that the variations in the data collection procedure were not large enough to produce a bias in the trend statistics. This was necessary because Mann-Kendall analysis requires only one data point at a given time. The Mann-Kendall trend evaluation is dependent on the statistic ‘S’, the Coefficient of Variation (CoV) and the Confidence Factor (CF). The trend is said to be decreasing if Z is negative and the computed probability is greater than 0. The trend is said to be increasing if Z is positive and the probability value is greater than the level of significance. If the compared probability is less, the level of significance there is no trend.

The Normalized Difference Vegetative Index (NDVI) was used to describe the vegetation responses in the study. NDVI from MODIS is generated by combining two (or more) different wavebands, often in the red (0.6-6.7 µm) and near-infrared (nir) wavelengths (0.7-1.1µm) in equation 1 (see also Wang et al, 2003).

\[
NDVI = \frac{Pixel_{near\text{}}\text{infrared} - Pixel_{red}}{ Pixel_{near\text{}}\text{infrared} + Pixel_{red}} \tag{1}
\]

The test statistic Kendall S is calculated as:

\[
S = \sum_{j=1}^{n} \sum_{j=k+1}^{n} \text{sgn} \left( x_j - x_k \right) \tag{2}
\]

Where \( s \) are the data values at times \( j \) and \( k \). \( n = \text{length of the dataset} \)

\[
\text{sgn} \left( x_j - x_k \right) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \tag{3}
\]

\[
\text{Var}(s) = \frac{n(n-1)(2n+5)}{18} - \frac{\sum(t-1)(2t+5)}{18} \tag{4}
\]

The Mann-Kendall test has two parameters that are of importance for trend detection. These parameters are the significance level that indicates the test strength and the slope which indicate the direction as well as the magnitude of the trend. The notation \( t \) is the extent of any given tie and \( \sum t \) denotes the summation over all ties. In cases where the size \( n > 10 \), the standard normal value \( Z \) is computed by using Equation 5.

\[
Z = \sqrt{\frac{s-1}{\text{var}(s)}} \tag{5}
\]

4. Results and Discussion

4.1. Changes in Annual Trend of Temperature, Rainfall and Vegetation

Figure 2 shows the pattern of the annual mean rainfall and temperature in the study area within the period of the research. Rainfall generally was high throughout the period (1600-2240 mm), which is an attribute of a tropical environment. The least rainfall, however, occurred in 2000 and rainfall was generally lower in 2000, 2004-2006 and 2009 as shown by the 2% moving average. Temperature on the other hand has exhibited steady increase in both observed values and the moving average from 2000 till 2009.

The average NDVI generated for the vegetation vigour is shown in Figure 3. The lowest value occurred in 2002; while 2004 exhibited the highest value. There was a rapid increase from 2002 to 2004 and a subsequent gradual decline between 2005 and 2009.

A comparison with Figure 4 shows that the annual variati-
on of the NDVI appears to increase during the years with lower rainfall (2004-2006) and reduced in years with rainfall increase. Figure 5 shows the results of the calculated Z for vegetation, rainfall and temperature. The results showed a complex relationship, with a decreasing trend in rainfall between 2000 and 2004 before a rise and subsequent decrease. While rainfall appears to be in a cycle, the trend for Z values for temperature also exhibited obvious fluctuations. The results of a trend analysis of the NDVI and rainfall and temperature, however, exhibited a weak relationship with both indices (temperature: \( r=0.42; \ p<0.05 \); rainfall: \( r= -0.21; \ p<0.05 \) (Table 1).

![Figure 3. Pattern of NDVI for the Vegetation in The Study Area](image)

![Figure 4. Pattern of Calculated Z for Rainfall, Temperature and Vegetation for 2000-2009 in Part of Southeast Nigeria](image)

Table 1 also shows the trend analysis (using regression analysis) on the investigated variables within the study period. Rainfall and vegetation vigour, however, only exhibited significant trends; both decreasing with years (Table 1). Table 1 also shows the relationship between the three variables (temperature, rainfall and vegetation) from the results of Pearson correlation coefficients. Except a fair correlation (\( r=0.43 \)) correlation between temperature and rainfall, which is an indicative of prevalence of other types of rainfall other than the convective type, relationship among the three indices were generally low (\( r<0.1 \)), probably because the relationships were not strong or the time selection was not wide enough to reveal significant differences. This is not unexpected, since variability in climate often become obvious with time width, except perhaps in cases of serious anthropogenic destruction or a massive natural disaster, none of which was experienced in the study area within the study window.

![Figure 5. Relationship of Rainfall, Temperature and NDVI in the 2000-2009 Period](image)

4.2. Temporal Variations

Table 2 summarizes some results of the Mann-Kendall trend analysis in this study. The Table shows that vegetation exhibited increasing trends in most years within the period of study, 2000-2009 and that maximum NDVI occurred in the rainy season i.e. May-October. The annual Mann-Kendall trend for temperature has increased only between 2005 and 2008, while it remained relatively stable in the rest of the years. Rainfall, however, declined in 2000 and 2007 but exhibited increased trends in 2005, 2006, 2008 and 2009, while it exhibited a relative stability between 2001 and 2004.

The results of the decadal pattern showed an insignificant trend in the variation of vegetation from the calculated Z
Table 1. Results of Pearson Correlation and Linear Regression Performed on the Climate and Vegetation Z Values

<table>
<thead>
<tr>
<th>Variables</th>
<th>Correlation Coefficients</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfall</td>
<td>Temperature</td>
</tr>
<tr>
<td>Rainfall</td>
<td>1</td>
<td>0.43*</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.42*</td>
<td>1</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.09</td>
<td>0.42*</td>
</tr>
</tbody>
</table>

*Pearson Correlations or Regression Equation is Significant at $p \leq 0.05$

Table 2. Results of the Mann Kendall Trend to Show the Summary of The Temporal Changes in Vegetation Based on Computation from MODIS Imageries

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall</th>
<th>Temperature</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Negative</td>
<td>None</td>
<td>Positive (July)</td>
</tr>
<tr>
<td>2001</td>
<td>None</td>
<td>None</td>
<td>Positive (July)</td>
</tr>
<tr>
<td>2002</td>
<td>None</td>
<td>None</td>
<td>None (May)</td>
</tr>
<tr>
<td>2003</td>
<td>None</td>
<td>None</td>
<td>Positive (April)</td>
</tr>
<tr>
<td>2004</td>
<td>None</td>
<td>None</td>
<td>Positive (June)</td>
</tr>
<tr>
<td>2006</td>
<td>Positive</td>
<td>None</td>
<td>Negative (Aug.-Oct)</td>
</tr>
<tr>
<td>2007</td>
<td>Negative</td>
<td>None</td>
<td>Positive (August)</td>
</tr>
<tr>
<td>2008</td>
<td>Positive</td>
<td>Positive</td>
<td>Negative (July)</td>
</tr>
<tr>
<td>2009</td>
<td>Positive</td>
<td>None</td>
<td>Positive (August)</td>
</tr>
</tbody>
</table>

Negative = Decreasing trend in the average monthly Mann-Kendall trend ($p \leq 0.05$)
Positive = Increasing trend in the average monthly Mann-Kendall trend ($p \leq 0.05$)
None = Relatively stable trend at $p \leq 0.05$

values of the NDVI, the results on monthly variation had shown that rainfall has significantly increased (Table 1). In addition, mean vegetation vigour, temperature and rainfall calculations applied for monthly and yearly trends are presented in Figure 5 shows that periods with significant variations in temperature exhibited significant variations in vegetation vigour. For example, in 2004, both vegetation vigour and temperature peaked in March (NDVI=0.474; temperature = 30°C) while both variables exhibited their lowest values in 2006, albeit at different month i.e. temperature was 25.5°C in August and 2006 with the third highest vegetation vigour of 0.470 has the second highest temperature value of 29.5°C (as with other years) and a record low 25.5°C (August).

5. Conclusion
This study has shown that a complex relationship exists between vegetation and climate elements. Neither temperature nor rainfall has separately exhibited a very strong correlation with vegetation vigour. The regression model also suggested a decrease in vegetation response even with increasing rainfall. Similarly, results of monthly analysis were significantly different from the annual and decadal results. The study concludes that the climate-vegetation relationship is complex and interactive with other factors which were not investigated in the present study. Further study of climate-vegetation in this region should consider more climate variables, land use and soil properties which are likely to influence such relationship. A complementary use of more remote sensing products is also recommended.

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