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Full Length Research Paper

Sensitivity of vegetation to decadal variations in temperature and rainfall over Northern Nigeria

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The objective of this paper is to examine the extent vegetation has responded to decadal variations in temperature and rainfall over Northern Nigeria. The study covers four decades viz. the 1970s, 1980s, 1990s and the 2000s. Meteorological data from 11 stations covering 34 years (1971 to 2004) and satellite imageries of four dates, 1972, 1980, 1990 and 2000 taken during the wet season were analyzed in this work. Results obtained showed a compelling evidence that the vegetation of Northern Nigeria is sensitive to the decadal variations recorded in the region's temperature and rainfall during the period studied. The results indicated that the average temperature has been rising by the decade with 0.31°C in the 1980s and 0.09°C in the 1990s and 2000s while rainfall dropped in the 1980s by 103 mm, increased massively in the 1990s by 163 mm and decreased slightly by 2.42 mm in the 2000s. The highest maximum positive NDVI (normalized difference vegetation index) values of + 0.64 was recorded in 2000 while the lowest of + 0.21 occurred in 1990 and followed closely by + 0.27 of 1980.These results provide evidence as to the sensitivity of vegetation to decadal variations in temperature and rainfall over Northern Nigeria.

Key words: Variations, FCC (false colour composite), NDVI (normalized difference vegetation index).

INTRODUCTION

Basically, the elements that determine weather and climate are never static but dynamic. They change over time and space. These elements sometimes change within seconds, minutes, hours, days, weeks, months, years or decades and from one location to another. Even small variations in the general circulation of the earth's atmosphere where both weather and climate are made are nearly always reflected in changes in the elements.

The earth-atmosphere system to which weather and climate belong is never stable due to its components that are ever changing as they respond to some internal and external perturbations (Meyer, 1996; Danielson et al., 1998, and Pidwirny, 2004). And within this earth–atmosphere system, changes in the elements of weather and climate are often reflected in changes in the other components of the system, for example land cover. As these elements (temperature and rainfall, for example and in particular) change whether by a region getting warmer or cooler, or becoming wetter or drier, the landcover (which is here expressed in terms of vegetation cover or lack thereof) is likely to respond to such a change.

Generally, vegetation is highly sensitive to the behaviour of the prevailing temperature and rainfall of any area as these elements are necessary for the development and growth of plants. For example, more frequent and prolonged drought and expanding desertification are being experienced in the Sahel Savanna regions of Nigeria and Africa as a whole due to rising temperatures and reduction in rainfall (NEST, 1991, Tegen and Fung, 1995, Goudie, 2002, and Obioha, 2005). Equally, the reduction of rain-days and rainfall in some parts of Northern Nigeria is threatening food

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production in the area (Umar, 2010). Madu and Ayogu (2010) showed that rainfall variability accounts for 70% of variation in crop production in Northern Nigeria while Morishiona and Akasaka (2008) noted the great extent rainfall variability has accounted for variation in rice production in the Philippines.

In fact, temperature and rainfall are not only elements but also factors of climate in the sense that any change in them causes change in other elements. With rising global average surface temperatures by about 0.6±0.2°C since the late 19th century, and about 0.2 to 0.3°C over the past 25 years (considered as the period with the most credible data) (Intergovernmental Panel on Climate Change (IPCC), 2001; and United States National Climatic Data Center (USNCDC), 2001), changes in the temperatures and rainfalls of various regions of the world have been reported (De Gaeteno, 1996; Epstein et al., 1998; Kaser, 1999; Easterling et al., 1999; Plummer, 1999; Nicholson, 2001; Christy et al., 2001; Franke et al., 2004; Qian and Lin, 2004; Obioha, 2005; Nwagbara, 2008). Rainfall is changing too because temperature as a factor of climate influences the amount of water vapour in the atmosphere and the rate at which water molecules leave wet surfaces since higher temperature will increase the saturation point of air and the rate of evapo-transpiration. Ordinarily, the tendency for condensation is heightened with increased water molecules in the atmosphere and by extension, precipitation.

Being that temperature and rainfall are very much needed by plants for their development and growth, there is thus the likelihood that vegetation as a whole will respond to changes in these elements. This paper therefore examines the extent vegetation has responded to variations in temperature and precipitation (in this case here, rainfall) over Northern Nigeria based on decades starting from the 1970s to the 2000s.

Study area

Northern Nigeria covers about 75% of the area of Nigeria with its location between latitudes 7 and 14°N and Longitudes 3 and 15°E (Figure 1). The study area thus possesses an area of about 692,826 km^2 out of the country's total area of about 923,300 km^2. Northern Nigeria is a typical tropical region where relatively high temperatures are recorded all year round by its latitudinal location. While the regional mean temperature is about 27°C (Oguntoyinbo, 1983), the mean maximum temperatures are lowest in the southern borders with less than 35°C and increases to more than 40°C in the northernmost part, and the mean minimum temperature of about 18°C in the south decreases to about 12°C in the extreme north. Similarly, the rainfall of Northern Nigeria reduces in amount from the southern part to the north. For instance, the average annual rainfall has a mean of more than 1200 mm in the south, while it is less than 300 mm in the far north except in areas of altitudinal effects such as Jos. This pattern of rainfall is largely determined by the interplay of the tropical maritime airmass (MT) and tropical continental airmass (CT). The extent of influence exhibited by any of these air masses is controlled by the position of the inter-tropical discontinuity (ITD).

The pulsation of this discontinuity over the region determines which one of the airmasses whose characteristics become dominant. By this, MT comes with rain as its source region is the Atlantic Ocean while Sahara desert, the source region of CT makes it dry and dusty thus producing the condition termed Harmattan. Vegetation is thus less luxuriant from the southern borders northwards, though the area possesses one major vegetation type, the savanna which refers to tropical grassland. It is divided broadly into three depending on the luxuriance of the vegetation viz. Guinea, Sudan, and Sahel (Figure1), all extending from east to west with Guinea savanna being the most luxuriant as it is located at the wetter southern part. The Guinea savanna is followed by the Sudan savanna northwards and the Sahel savanna at the relatively dry extreme northeast. Apart from luxuriance, the grass, shrubs and woods get shorter and scantier northwards.

MATERIALS AND METHODS

Data used

Climatic data

Mean monthly maximum and minimum temperatures and monthly rainfall totals covering 34 years (1971 to 2004) for 11 meteorological stations in the study area (Figure 1) were obtained and transformed for this study. The mean monthly maximum and minimum temperatures were transformed to mean monthly temperatures, thence to annual means. Values for 8,950 months were available for transformation as against 26 months with missing values representing 0.29%. Linear regression was used to estimate the missing values using the available values (Hammond and McCullagh, 1978). It may be written as:

$$y = a + bx \tag{1}$$

$$\text{Where: } b = \frac{n\,\Sigma xy - (\Sigma x)\,(\Sigma y)}{n\,\Sigma x^2 - (\Sigma x)^2} \tag{2}$$

$$a = \frac{\Sigma y}{n} - \frac{b\Sigma x}{n} = \bar{y} - b\,x \tag{3}$$

a is the intercept; b, the regression coefficient or slope; y, the temperature values; x, the time in years; x, the mean time, and ȳ is the mean temperature value.

Rainfall data required for the study were complete as all rainfall totals for the 4488 months of the study period were available. These

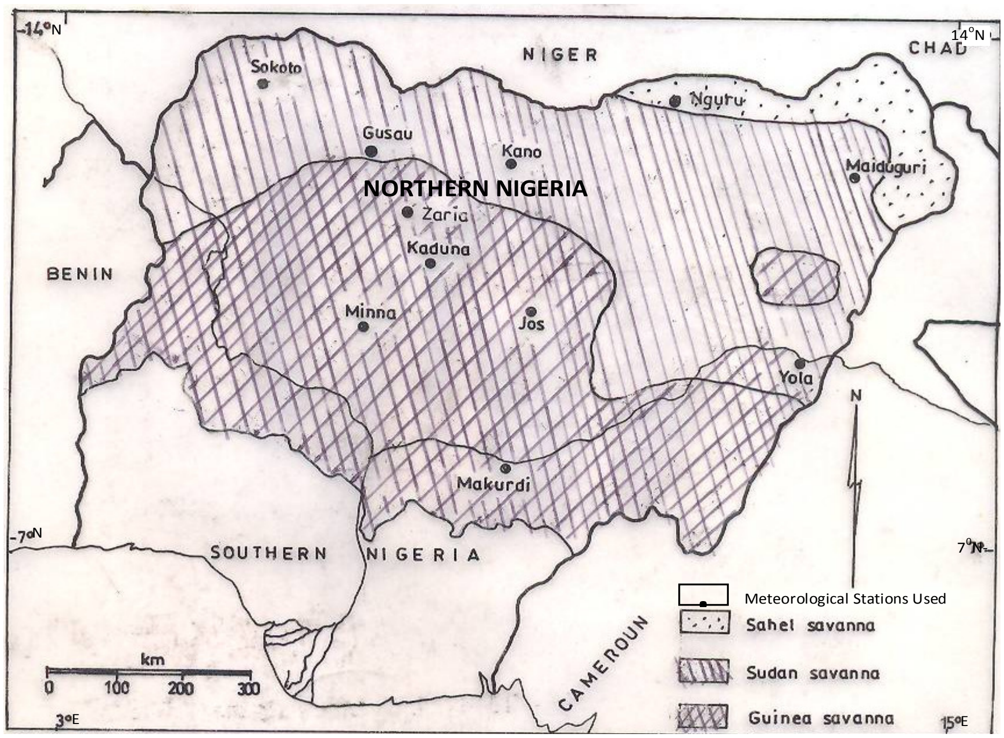

Figure 1. Northern Nigeria: Vegetation zones and selected meteorological stations.

monthly totals were transformed to annual totals. Both the mean annual temperatures and annual rainfall totals were further combined to give the mean annual temperatures and annual rainfall totals of Northern Nigeria as a whole respectively.

These climatic data were sourced from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos. The 11 stations for which data were sourced are Gusau, Jos, Kaduna, Kano, Maiduguri, Makurdi, Minna, Nguru, Sokoto, Yola and Zaria. Their selection was done with due consideration of their spread over the three main climatic zones of Northern Nigeria that is, Tropical Hinterland, Tropical Continental North and High plateau (Figure 2), and the availability of the necessary data.

Landcover data

Four satellite imageries of four dates namely 1972, 1980, 1990 and 2000 taken between the months of August and September (rainy season) of those various years were collected and used for this study. The imageries came as raw data in a compact disc (CD) and imported via geogateway (a GIS operation). Some GIS operations using the ILWIS software package were carried out on these imageries to make them become better interpretable as they remove all the geometric and atmospheric distortions and thus getting the imageries ready for the calculation of the normalized difference vegetation index (NDVI). These operations are geo-referencing, stretching, filtering, band rationing and classification.

The 1972 imagery was not georeferenced (that is, without coordinates) when collected. It had to be made uniform with the co-ordinate system of the other three imageries so as to be worked with. Thereafter, the linear stretch method was applied to enhance the contrasts of the imageries by expanding the ranges of the image values to the full range of display levels that is, 0 to 255.

This was followed by filtering which helped in correcting and restoring the image wherever they were affected by system malfunctioning through a mathematical operation known as convolution. It is expressed as:

$$\sum_{i.j} (wij.rij) / \sum_{i.j} |wij| , \qquad (4)$$

Where rij denotes the input raster cell values, and wij the corresponding filter values.

In the band rationing, the in-built principal component analysis (PCA) in the ILWIS package was applied in selecting the best bands from 1 to 7 based on variance. As PCA transforms a set of image bands, the new layers (or components) are not correlated with one another, thus allowing each component carry new spectral information which are ordered in terms of the amount of variance explained. The spectral information stored in the separated bands was integrated by combining the bands into a false colour composite (FCC). In this FCC, the red colour is assigned to the near infrared band, the green to the red visible band and the blue to the green visible band. Classification was then employed to assign the features in the data layer (the satellite imageries) a thematic and characteristic value for easy differentiation based on the FCC.

The four imageries were sourced from the Environmental Resources Management Unit, Federal Department of Agricultural Land Resources, Kaduna. They were selected to represent the four decades covered by the climatic data that is, the 1970s, 1980s, 1990s and the 2000s. The 1972 imagery thus represents the 1970s while those of 1980, 1990 and 2000 represent 1980s, 1990s and 2000s, respectively.

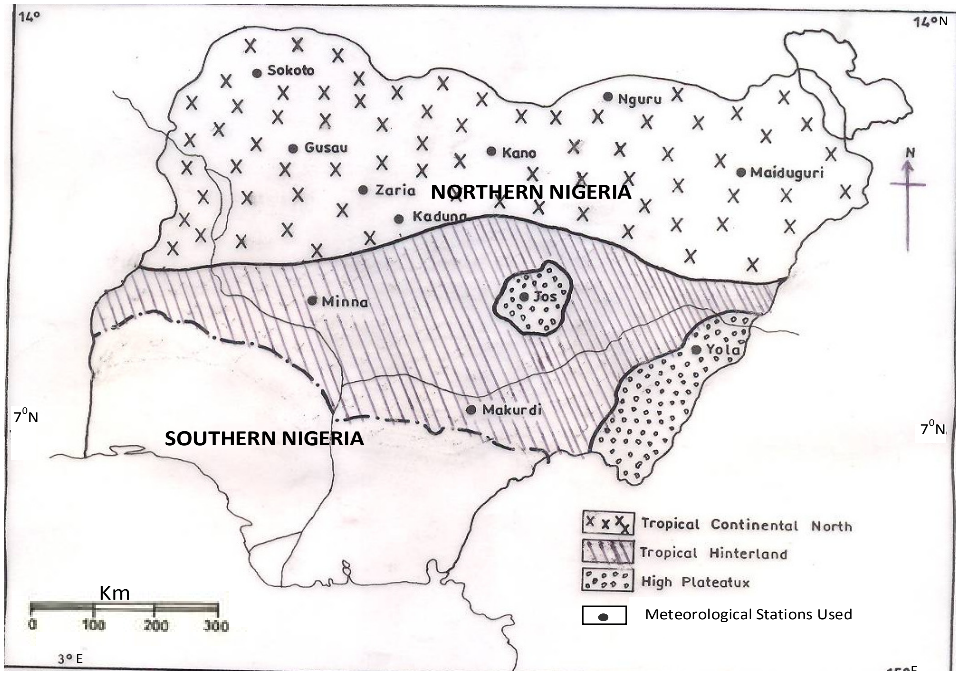

Figure 2. Climate regions of North Nigeria.

Techniques used

The mean statistical technique was employed to aid in determining the differences in the decadal means of temperature and rainfall. This is meant to show decadal variability between 1971 and 2004, thus providing a basis for comparison with decadal variability of vegetation in the study area. It may be written thus:

$$\frac{\sum_{i-1}^{n} x_i}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Several mathematical combinations of satellite bands have been found to be sensitive indicators of the presence and condition of green vegetation (ITC –ILWIS, 2001). Thus, these combinations are known as vegetation indices with NDVI being the most popular because it is a normalized index and compensates for changes in illumination conditions, surface slopes and aspect. Ordinarily, green leaves have a reflection of 20% or less in the 0.5- 0.7 micron range (green to red) and about 60% in the 0.7- 1.3 micron range (near infrared) with the visible channel given same degree of atmospheric correction. The value is then normalized to the range $-1 <= NDVI <= 1$ to partially account for difference in illumination and surface slope. NDVI can be expressed mathematically as:

(NIR-VIS) / (NIR + VIS)……………………………… (6)
Where NIR refers to near –infrared and VIS, the visible.

RESULTS

The results of the application of mean statistic to the mean annual temperatures are annual rainfall totals decade by decade, and shown in Tables 1 and 2. An inspection of Table 1 reveals that annual mean temperature of Northern Nigeria increased by the decade.

In the 1970s, the average temperature was 26.45°C while it was 26.77°C in the 1980s, thus giving a variation of 0.31°C, which is the highest for the study period. This increase continued in the 1990s, though not as much as that of the 1980s from that of 1970s. Between the 1980s and 1990s the temperature went up by 0.09°C that is, 26.77°C in the 1980s and 26.85°C in the 1990s. Equally, between the 1990s and 2000s the temperature increased by 0.09°C that is, 26.85°C in the 1990s and 26.94°C in the 2000s.

Table 2 shows the behaviour of annual rainfall totals of Northern Nigeria over the decades studied.

The rainfall totals dropped by 102 mm between the 1970s and 1980s since the decadal average of the 1980s was 823.92 mm and that of the 1970s was 926.62 mm. But by the 1990s, the totals went up with 163 mm that is, the difference between the 987.18 mm decadal average of the 1990s and the 823.92 mm of the 1980s. By the third decade, the rainfall dropped again though by -2.42 mm which is very little relative to the -102 mm between the 1970s and 1980s. The creation of the NDVI was done with the aid of the map calculator which is embedded in the ILWIS software. The NDVI calculations were done for each of the four imageries with the domain value set to range between -1 and + 1, and the precision to 0.01 following ITC-ILWIS (2001). Figures 3, 4, 5 and 6 were

Table 1. Variation in decadal temperature (°C).

S/N	Decades	Decadal average (°C)		Variation (°C)
		Upper decade	Lower decade	
1	1970s -1980s	26.77 (1981 - 1990)	26.45(1971 - 1980)	0.31
2	1980s - 1990s	26.85 (1991 - 2000)	26.77(1981 - 1990)	0.09
3	1990s - 2000s	26.94 (2001 - 2004)	26.85(1991 - 2000)	0.09

Table 2. Variations in decadal rainfall (mm).

S/N	Decades	Decadal average (mm)		Variation (mm)
		Upper decade	Lower decade	
1	1970s - 1980s	823.92 (1981 - 1990)	926.62 (1971 - 1980)	-102
2	1980s - 1990s	987.18 (1991 - 2000)	823.92 (1981 - 1990)	163
3	1990s - 2000s	984.76 (2001 - 2004)	987.18 (1991 - 2000)	-2.42

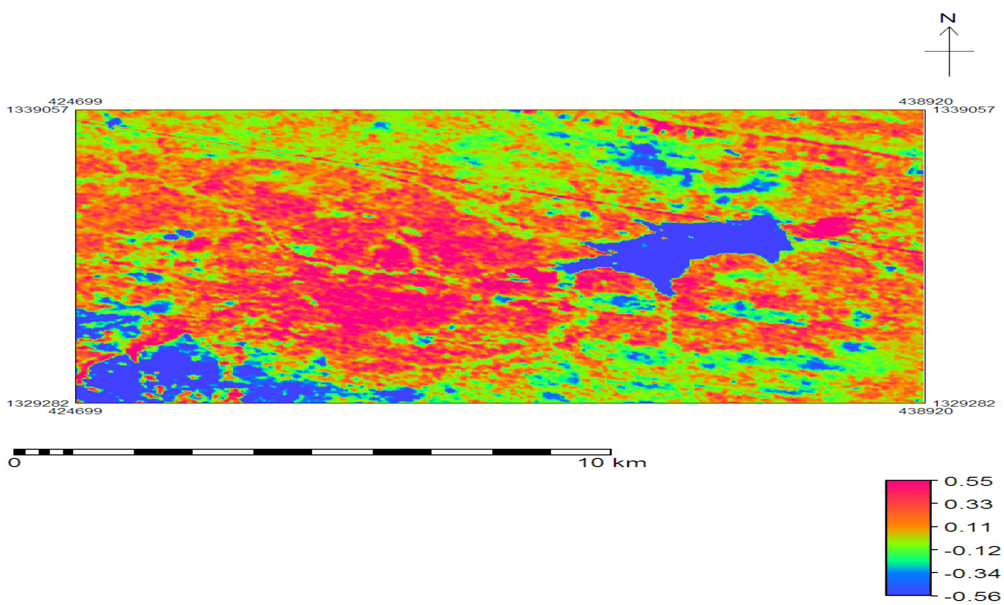

Figure 3. NDVI values of study area for 1972.

generated through this process. The reddish patches in them represent green vegetation and thus, the deeper the red colour, the healthier the green vegetation because healthier green vegetation has greater reflectivity. Also, the greater the area covered by the red patches, the more the presence of green vegetation. The legends that appear on the bottom right hand corner of the figures show the NDVI values. And since, ordinarily, green vegetation yields high values for the index, it means that greener vegetation in the legend show higher index value.

The highest NDVI values for the four maps are summarized in Table 3.

Figure 3 indicates that the NDVI values for the 1970s range between -0.56 to +0.55 with the implication that the green area reached a maximum of +0.55. The values can be described as being reasonable being that the maximum in the scale is +1. The NDVI maximum values for the green are dropped by the 1980s to +0.27, and further to +0.21 in the 1990s. But by the 2000s the maximum value increased dramatically to +0.64, implying a greater presence of green vegetation in the study area

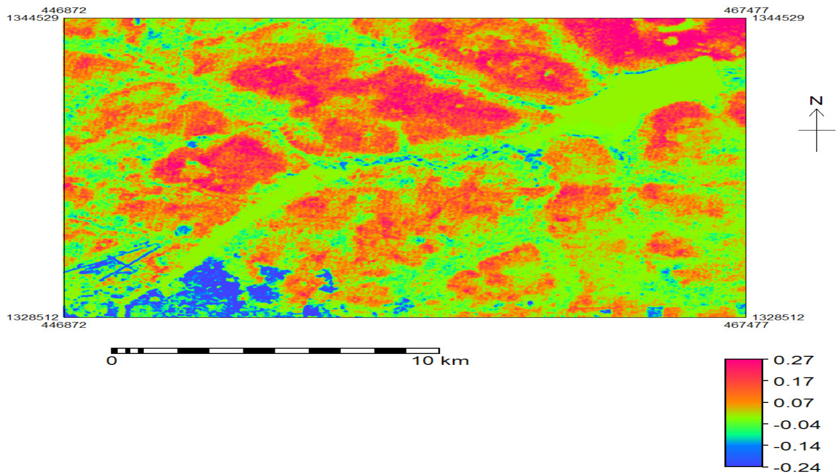

Figure 4. NDVI values of study area for 1980.

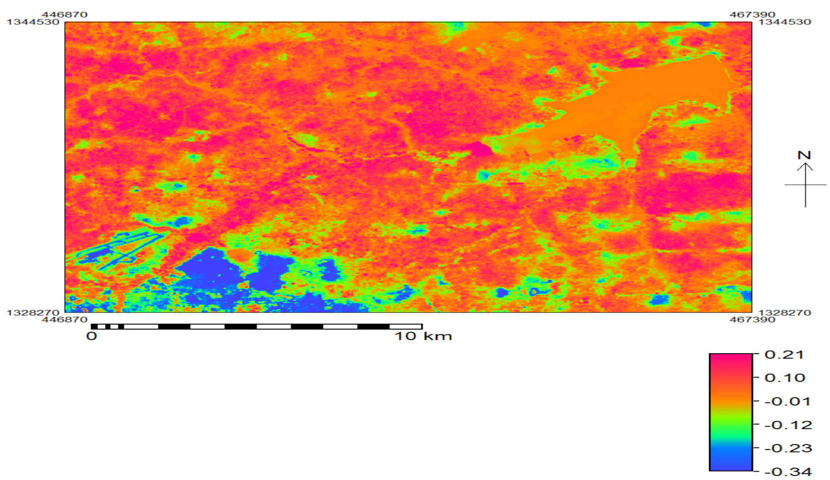

Figure 5. NDVI values of study area for 1990.

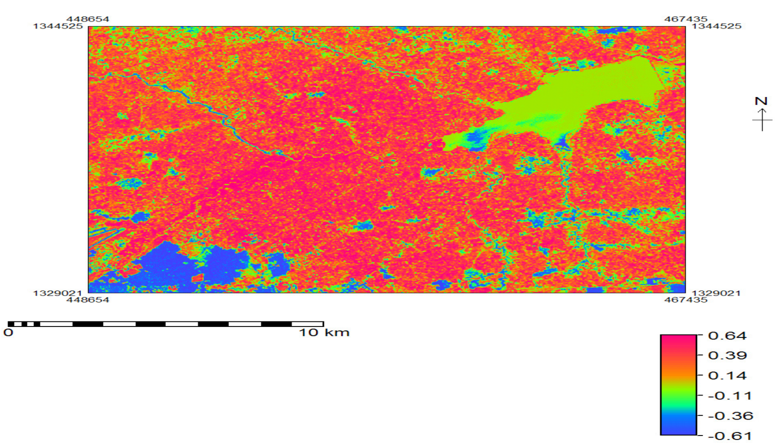

Figure 6. NDVI values of study area for 2000.

Table 3. Summary of NDVI maximum values.

S/N	Date	Value
1.	1972 (For the 1970s)	+0.55
2.	1980 (For the 1980s)	+0.27
3.	1990 (For the 1990s)	+0.21
4.	2000 (For the 2000s)	+0.64

relative to any of the other decades. This is a great improvement in the vegetation of the study area (Nwagbara, 2008).

DISCUSSION

Temperature values

Plants do not generate their own heat but dependent on atmospheric temperature as a source of heat. Thus, their existence, development and growth are highly influenced by temperature. Temperature requirement for survival by plants varies with species (Kellman, 1975 and Mothershead, 1980). Three critical temperatures for each plant species have been identified viz. minimum, maximum and optimum temperatures. Minimum temperature or specific zero which is that temperature below which plants cease to grow and generally remain dormant is 6°C for most plants while the maximum temperature is 55°C beyond which most plants cannot live without water. And optimum temperature is that temperature that is most favourable to plants and differ with species.

Since the mean annual temperature of Northern Nigeria is on the increase over the decades (Table 1) and since the mean monthly minimum temperature in the region in general rarely goes below 10°C (except for Jos with altitudinal effect) the minimum temperature for plant growth is not a usual occurrence in Northern Nigeria. Thus, of great concern in this paper are the maximum and optimum temperatures. Whatever the increase in the decadal temperature of Northern Nigeria over the study period it could still make some difference in the maximum and optimum temperatures of plant growth.

For a region that is relatively hot, a steady rise in temperature such as it is now would push some plant species off their critical maximum and optimum temperatures. And when this happens, difficulty in the existence and poor growth of some species may set in. Equally, this rising temperature could mean better life for most plants since evapo-transpiration and convective activities are increased with the implication of increasing the tendencies for condensation, cloud formation and precipitation. Similarly, tendency towards withering for plants will increase if not irrigated or without increased rainfall.

Rainfall values

The vegetation cover of any area to a good extent anchors its growth development and survival on water as water in the soil and air help in dissolving minerals for plants. This water is sourced from precipitation (rainfall, snow etc.), dew, humidity, rivers, lakes, streams etc. Rainfall is the freest and cheapest source of water for plants and while some plants love plenty water for their survival, some others love very little of it and for others a moderate supply of it.

The decadal variations in annual rainfalls of Northern Nigeria (Table 2) suggest some influence of the rising temperature of the region (Table 1). Increased temperature means increased evapo-transpiration and convective activities and by extension increased rainfall. The creation of more wet surfaces in Northern Nigeria by the construction of new and enlargement of old dams for irrigation, flood control, power generation, domestic and industrial water supply, and the plants and lands themselves is adding to the evapo-transpiration (Nwagbara, 2008). Before and during the 1970s a total of seven (7) notable dams (namely Kainji, Zaria, Kangimi, Tiga, Tomas, Jakar and Alau) existed in Northern Nigeria with a total active capacity of 13,651.2 million cubic metres (mcm). In the 1980s a total active capacity of 11, 130.7 mcm was added by the construction of Zobe, Bakolari, Goronya, Jebba, Shiroro Usuma, Balanga, Dadin Kowa, Kiri Doma, Erinle, Gari, and Watari dams. And in the 1990s and 1,083 mcm was added to the existing active capacity from Zibiya, Kubli, and Challawa Gorge dams. Then in the 2000s the active capacity increased by about 3,007.5 mcm from Kontagora, Asa, Kagara, Omi, Suleja and Kafin Zaki dams. Also, irrigated lands have been enlarged. For examples, the irrigated area of Tiga Dam completed in 1975 has moved from less than 10,000 ha at on completion to about 22,000 ha at present while that of Challawa Gorge Dam enlarged from 1,000 ha in 1992 to 6,000 ha at present. The more the wet surfaces, the more the water molecules that leaves them into the atmosphere which could cause condensation, cloud formation and possibly precipitation (rainfall in this case). The combined effects of the droughts of the early 1970s and 1980s that crept into the region from the Sahara may not be disassociated from the significant drop in the rainfall total of the 1980s relative to that of the 1970s. But with the effects gone and with increasing number and sizes of dams/irrigation projects in the region, there was a great increase in the totals. The -2.42 mm variation between the totals of the 1990s and 2000s is probably because of the difference in years used for the calculation that is, 10 for the 1990s and 4 for the 2000s. In general, therefore, the increase in rainfall in Northern Nigeria as a result of increasing temperature could be associated with the NDVI values in Table 3.

NDVI values

The relatively high maximum positive NDVI value of 1972 (that is, +0.55) means a large presence of green vegetation which reflects highly in the near-infrared portion of the spectrum such as evergreen trees if the NDVI values for the periods studied are collectively examined and using 1972 as a base. The drop of the value to +0.21 in 1980 implies a reduction in the presence of high reflectance in the near-infrared. A further reduction in the value to +0.21 was witnessed in 1990 but in 2000 the downward trend turned dramatically to give +0.64.

Though part of these results could be attributed to the differences in the technology of the sensors used to get the satellite images as the technology kept improving over the decades studied (that is, MSS for that of 1972, TM for 1980, SPOT XS for 1990 and ETM+ for that of 2000), largely they are attributable to the variations in temperature and rainfall and man's activities of deforestation and afforestation. This is because the effect of the differences in the technology of the sensors used (mainly in their spectral ranges: MSS, 0.5 to 1.1 µm, TM 0.45 to 2.35 µm; SPOT XS, 1.58 to 1.75 µm; and ETM+, 0.45 to 2.35 µm) on the NDVI values were made insignificant as the imageries were orthorectified and terrain corrected. While not exonerating deforestation for timber, settlement, agriculture, industries, roads etc., and afforestation to check desertification (as in Northern Nigeria) (NEST, 1991), the droughts that occurred in the region in the 1970s and 1980s may be implicated in the relatively and progressively low NDVI values in 1980 and 1990. This is because the effect of the drought of the 1970s might have continued manifesting in poor natural vegetation in the 1980s and that of the 1980s in the 1990s. The lower value in 1990 may therefore not be surprising as that year or period had the combined effects of two droughts. But by 2000 the effects of the drought had waned and the vegetation fully recovered. Hence the high NDVI value of + 0.64 recorded.

CONCLUSION

The minerals and other nutrients that plants draw from the soil and air will be useless to them except if in liquid form. It is water that dissolves these minerals and nutrients to liquid. Thus, water controls the health of vegetation (Watts, 1971). The experience of the droughts of the early 1970s and 1980s over Northern Nigeria are examples. The role of water from rainfall here is further strengthened by it being freely and cheaply given by nature. With increasing temperature and the number and size of dams/irrigation projects in the region, it is expected that rainfall too will keep increasing. And with this, the vegetation, whether natural or man-made will as usual follow rainfall trend which in this study shows signs of increase. Generally, vegetation was quite sensitive to the decadal variations in temperature and rainfall over Northern Nigeria. An implication of this is that the production of livestock and food crops will improve.

This will in no small measure increase the food security of Nigeria as a whole since Northern Nigeria produces bulk of the country's food needs (Nnaji, 2001; Obioha, 2005).

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