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Spatial-Temporal Analysis of Vegetation Dynamics in the Semi Arid Belt of Nigeria

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Strictly as per the compliance and regulations of:

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I. Introduction

Vegetation is an important component of the ecosystem that provides habitat for wildlife and maintains the functioning of the ecosystem. However, improper use of this vital natural resource has undermined its integrity in meeting some of its objectives. Hence, there is the need to monitor and manage this natural resource for the benefit of the present and future generations. Remote sensing technique has been used in monitoring land cover change and in managing biological resources such as in forest management. This is mostly done using Vegetation index as a surrogate for vegetation greenness. Remote sensing is the technique of acquiring information without direct contact with the object. It consists of the interaction of measurements of electromagnetic energy reflected from or emitted by a target from a vantage point that is distance from the target (Mather, 1999). Understanding and interpretation of electromagnetic energy that the earth surface reflects or emits enables earth observation by remote sensing. This is because diverse objects on the earth surface behave differently in their reflectance and emission characteristics thereby making it possible to measure and analyze the various materials on the earth surface. The information received by remote sensing platforms are digital in nature, this has made it feasible to manipulate the acquired information using computer systems.

Remotely sensed images are acquired from different region of the electromagnetic spectrum which ranges from ultra violet to radio waves. The ones frequently used in land cover studies are those from visible to the thermal infrared spectrum. Landsat TM, and ETM+ images are the commonly used remotely sensed imageries that span from the visible to the thermal region of the electromagnetic spectrum. The different spectral signatures of the earth surface materials have allow application in different fields of environmental studies like vegetation, soil, hydrology and geology. Remote sensing and GIS have provided new tools for advanced ecosystem management. The acquisition of remotely sensed data facilitates the synoptic analyses of earth-system function, patterning, and change at local, regional, and global scales over time; such data also provide a link between intensive, localized ecological research at the regional, national, and international for conservation and management of biological diversity. Geoinformation which embraces the technology of Remote Sensing, Global Positioning Systems (GPS) and Geographic Information Systems (GIS) has been used in various studies in the earth sciences to explain the processes taking place on the earth surface.

Change detection has been used in the process of identifying differences in the state of an object or phenomenon over time. Timely and accurate change detection of Earth's surface features provide the foundation for better understanding of the relationships and interactions between human and natural phenomena towards the management of resources (Lu, et al. 2004). In general, change detection involves the application of multi-temporal datasets to quantitatively analyze the temporal effects of the phenomenon. Because of the advantages of repetitive data acquisition, its synoptic view, and digital format makes it suitable for computer processing. Remotely sensed data has become the major data source for different change detection applications.

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Analysis of vegetation and detection of changes in vegetation pattern are keys to natural resources assessment and monitoring. Green vegetation has a distinct interaction with energy in the visible and near-infrared regions of the electromagnetic spectrum. In the visible region, plant pigments (chlorophyll) cause strong absorption of energy, primarily for the purpose of photosynthesis. The absorption peaks at the red and blue area of the visible spectrum, thus leading to the typical green appearance of most leaves. In the near-infrared however, a very different behavior occurs, energy in this region is not used in photosynthesis, hence, it is strongly scattered by the internal structure of leaves, leading to a very high reflectance. It is this disparity between visible and infrared regions of the electromagnetic spectrum that has been used in remote sensing to develop quantitative indices of vegetation condition. There are many types of vegetation indices in use today. The ones used in this study are; Normalized Difference Vegetation Index (NDVI), Green Vegetation Index (GVI), Perpendicular Vegetation Index (PVI), Transformed Soil Adjusted Vegetation Index (TSAVI) and Weighted Difference Vegetation Index (WDVI). These vegetation indices were chosen partly due to their different behavior to soil background reflectance (Eastman, 2009). This study therefore, assesses the application of the common vegetation indices used in the study of arid land vegetation. This is in order to determine the factors influencing dynamics of vegetation cover in the area.

II. Study Area

The study area is located between latitude 12^0 58' N and 13^0 07' N, and longitude 10^0 12' E and 10^0 17' E (Figure 1). The area is found in Garanda which forms part of Michina Local Government Area of Yobe State. It is a part of the Sahelian region of Nigeria where desertification is threatening the ecology and livelihood of the inhabitants of the area (UNESCO, 2000; UNDP, 2009; Orounye, 2009). Yobe State is bordered to the North by Niger republic, to the East by Borno State, to the West by Jigawa and Bauchi States and to the South by Gombe and Borno States. It has a land area of 47,153 sq. km and a population of 2.7 million. Yobe State like other parts of the Sahel savanna has clearly defined wet and dry season largely determined by the properties and movement of the Inter-tropical Convergence Zone (ITCZ). Temperatures are generally high throughout the year, although there are significant variabilities. The highest air temperatures are normally in April before the onset of the rains and the minimum in December during the harmattan. The area has a mean maximum of 40.60 C and a mean minimum of 12.80C (Oguntoyinbo, 1983). The movement of the ITD controls the durations and amounts of rainfall received in most parts of West Africa including the study area. The state in general receives between 250 - 500 mm of rainfall in the northern parts lasting for three months and up to 1000 mm in the southern parts spread over 3 to 6 months (Oruonye, 2009). The main drainage system in the study area is the Komadugu-Yobe river systems. The system stretches from areas south of Kano State into the Lake Chad basin the largest inland water body located at the northeast corner of Borno State.

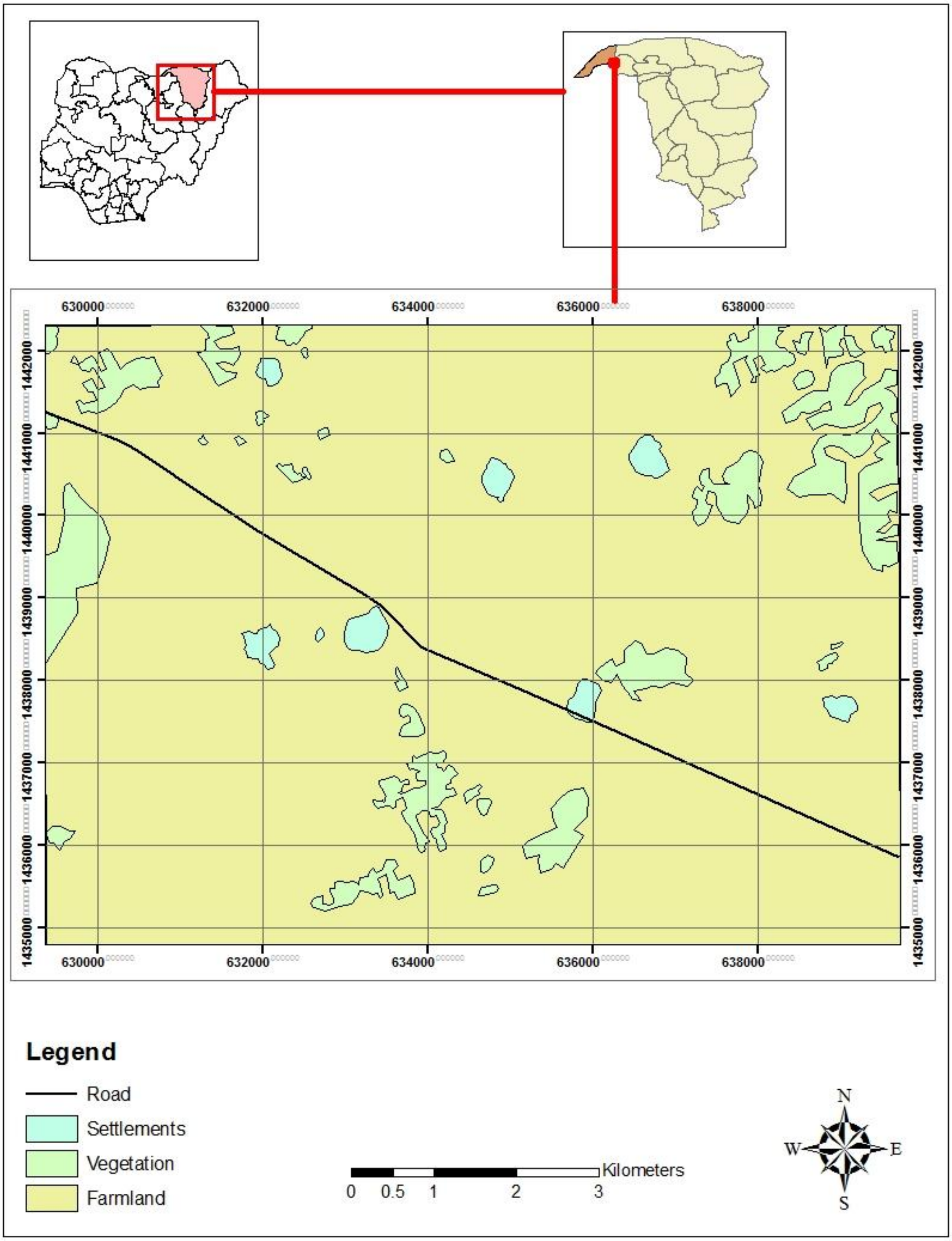

Figure 1: Map of the study Area

III. Material and Methods

Satellite imageries were used to generate basic data on the vegetation cover using different vegetation indices. The data and procedures used for this study are described in the sections below.

a) Satellite Imagery

A variety of remotely sensed images of the sites were acquired for the study. These include Landsat MSS of 1972, Landsat TM of 1986, Landsat ETM+ of 2000 and 2005, and ASTER of 2007. The images were so selected in part because they were taken in the same season of the year. This was to remove the effect of seasonal variation in vegetation cover (e.g. Pu et al., 2008). Pheneology difference in particular is controlled for in this way (Lu, et al., 2004; Mas, 1999; Singh, 1989). The satellite images selected ranges from low (Landsat MSS 80m) to medium spatial resolution, (TM (30m), ETM+ (30m) and ASTER (15m).

The four sets of the Landsat images were acquired from Global Land Cover Facility website (http://glcfapp. umiacs.umd.edu:8080/esdi/index.jsp) and from Earth Resources Observation and Science Center (EROS). Landsat MSS of 1972 and Landsat TM of 1986 were acquired from Global Land Cover Facility while Landsat ETM+ of 2000 and 2005 were acquired from EROS. The ASTER image was acquired through partnership with ITC Netherlands. Table 1 shows the detail characteristics of the images used for the image analysis.

Table 1 : Spatial and Spectral Characteristics of LandSat (MSS, TM and ETM+) and ASTER Images

Spatial Resolution			Spectral Resolution		Date of Acquisition	
Band	MSS	ASTER	MSS	ASTER	MSS	ASTER
1 (Green)	80 m	15 m	0.5-0.6 μm	0.52-0.62 μm	04/11/1972	03/11/2007
2 (Red)	80 m	15m	0.6-0.7 μm	0.63-0.69 μm		
3 (Near IR)	80 m	15 m	0.7-0.8 μm	0.76-0.90 μm		
4 (Near IR)	80 m		0.8-1.1 μm			
	TM	ETM+	TM	ETM+	TM	ETM+
1 (Blue)	30 m	30 m	0.45-0.52 μm	0.45-0.52 μm	09/10/1986	06/11/2000
						06/11/2005
2 (Green)	30 m	30 m	0.52-0.60 μm	0.53-0.61 μm		
3 (Red)	30 m	30 m	0.63-0.69 μm	0.63-0.69 μm		
4 (Near IR)	30 m	30 m	0.76-0.90 μm	0.78-0.90 μm		
5 (Middle IR)	30 m	30 m	1.55-1.75 μm	1.55-1.75 μm		
6 (Thermal IR)	120 m	60 m	10.4-12.5 μm	10.4-12.5 μm		
7 (Middle IR)	30 m	30 m	2.08-2.35μm	2.09-2.35 μm		
8 (Panchromatic)		15 m		0.52-0.90 μm		

Source: USGS Website

b) Preparing Images For Analyses

The acquired images were first resampled and image regression performed on them before getting the images sub-mapped in order to extract the Area of Interest (AOI) for further analyses. These operations were performed so as to correct geometric and radiometric distortions as a result of satellite sensor differences or errors, atmospheric attenuations and to properly align multi-date imageries that were used in the study (Lu, et al., 2004; Pu, et al., 2008; Eastman, 2009). The resampled images were co-registered into the same coordinate system as suggested by some authors (Washington-Allen, et al., 1998; Pu, et al., 2008).

c) Creation of Vegetation Indices

On the corrected images, Vegetation Indices (VIs) were calculated to determine the biomass before change detection was carryout. All the vegetation indices used in this study are the ones that have been corrected for soil background reflectance except the Normalized Difference Vegetation Index (NDVI). IDRISI Taiga software was used in creating all the vegetation indices used in this study.

In the creation of PVI, TSAVI and WDVI images, soil line was required. Soil line represents a linear equation that describes the relation between reflectance values in the red and near infrared bands for bare soil pixels. In other words, the pixels that fall far from the soil line due to high reflectance value in the near infrared band are assumed to be vegetation while the pixels that fall far from the soil line due to high reflectance value in the red band are assumed to be water. Soil line is typically the signature of soils in the red and near infrared bi-spectral plot. A regression analysis was carried out to relate the soil line between NIR and RED bands (Eastman, 2009).

d) Image Regression Differencing

'Image regression differencing' is a form of image differencing that involves the regression of the two images before differencing operation is applied. The advantage of this operation over the conventional method of image differencing is that it corrects sensor difference and errors between the two dates. In carrying out 'image regression differencing' of the vegetation

indices, the earlier images in the series were used as independent variable and the later images as dependent variable in the regression analysis. For example the Landsat MSS image of 1972 was used as the independent variable and the later Landsat TM image of 1986 as dependent variable. Intercept and the slope of the regression were used to adjust the earlier image in order to have comparable characteristics with later image. The equation for adjusting the earlier image is given as;

Adjusted Image = (earlier image*slope) + intercept (1)

After adjusting the earlier image, differencing of the images was carried out to get a difference image.

In order to avoid the confusion associated with identifying areas of change (decrease or increase) in a difference image, 'thresholding' was applied (Eastman, 2009; Wojtek, 2007). With 'threshold' one can establish a lower and upper limit to a normal variation beyond which it is considered that true change has occurred. Histogram was used to establish the threshold limits of the normal variation. A normal distribution has a bell-shaped curve with a single peak and symmetrical tails that fall off in a convex fashion on either side (Figure 2). In a normal distribution, the standard deviation (SD) measures the characteristic dispersion of values away from the mean (Wojtek, 2007). Therefore, values that were within plus or minus SD from the mean are areas where change is not expected to take place (Eastman, 2009). This implies that any values beyond the SD values mentioned above are considered as change in the difference image. In this study, +/- SD was adopted.

Global Journal of Human Social Science (B) Volume XIII Issue VII Version I

Year 2013

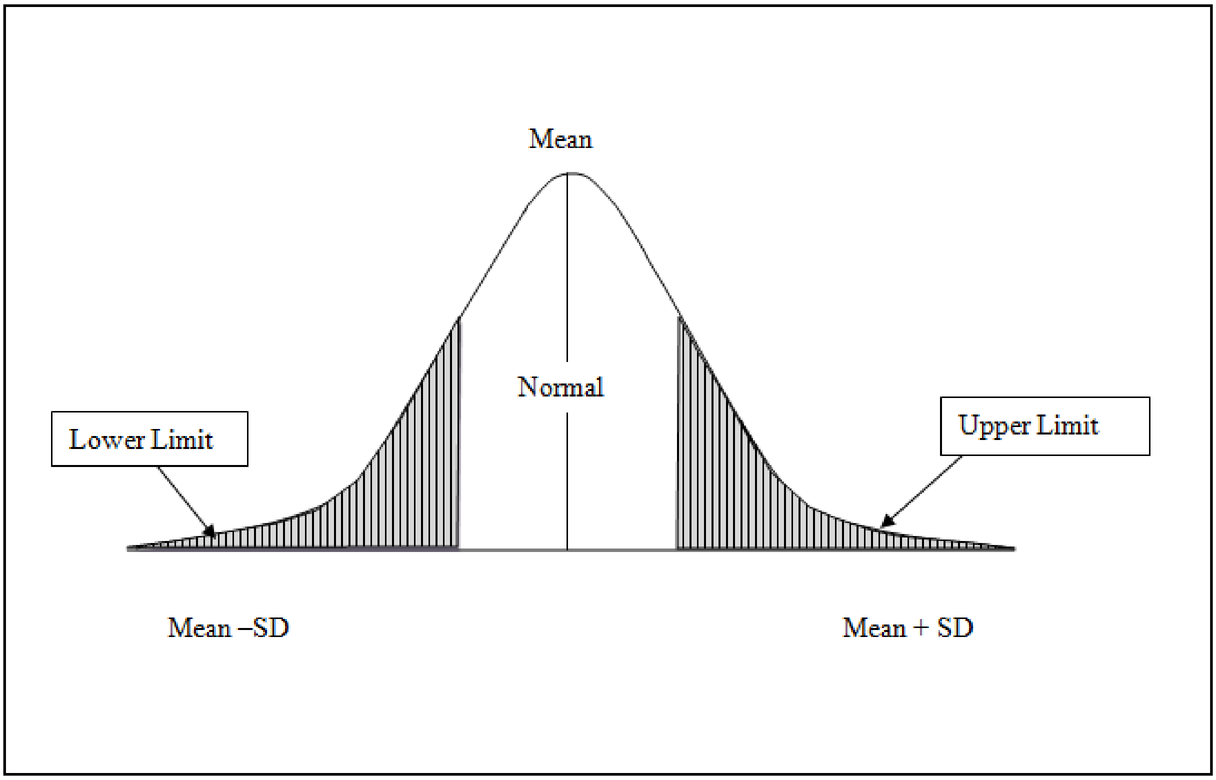

Figure 2 : Illustration of the Thresholds used in the Analysis

Correlation between changes in NDVI, PVI, TSVI, WDVI and GVI images over the period under study and rainfall variability within the same period was carried out in order to determine the relationship between vegetation indices and rainfall in the area (Bonan et al. 2002; Anyamba and Tucker, 2005). The rainfall data were those of Nguru located at Latitude 12052/ N and Longitude 10027/ E which was collected from Nigerian Meteorological Agency (NIMET). The Nguru weather station is located 28 km southeast of the study area. The rainfall data were monthly rainfall records but were added up to obtain annual total for each of the five years.

IV. Results and Discussions

The result of NDVI differencing between 1972 and 1986 shown in Table 2 reveals that the areas without vegetation in 1972 have witnessed an increase (regeneration) in area of vegetation cover by 1720.59 hectares while areas with vegetation have experienced decrease (degradation) in vegetation cover by 1705.40 hectares. This means that the areas with vegetation in 1972 have increase than decrease between the two periods with a difference of 15.19 hectares. Areas that did not witness any change in vegetation cover (No change) represent 7190.69 hectares.

Table 2 : Vegetation change detection of the study area between 1972 and 1986

Vegetation Index	Area measured in Hectare			
	No change (0)	Decrease (1)	Increase (2)	Difference
NDVI	7190.69	1705.40	1720.59	15.19
GVI	7278.57	1662.66	1675.43	12.77
PVI_3	8100.81	1241.93	1273.93	32
$TSAVI_2$	7316.10	1667.31	1633.27	-34.04
WDVI	9780.46	317.35	518.87	201.52

All the other vegetation indices studied, show increase in vegetation cover than decrease between the year 1972 and 1986, even though there was slight decrease in rainfall from 247.6 to 240.5 mm between 1972 and 1986 respectively (Figure 3). Only TSAVI showed a result that closely reflects the status of vegetation cover in the period. This is base on the premise that rainfall is a determinant of vegetation development in the area (Anyamba and Tucker, 2005; Fabricante et al. 2009). NDVI shows the highest increase than decrease in area of vegetation compared with all the other vegetation indices followed by GVI with an increase in area of vegetation cover amounting to 1675.43 hectares and decrease to 1662.66 hectares.

PVI shows an increase in vegetation by 1273.93 hectares and decrease by 1241.93 hectares while WDVI shows the lowest increase in terms of vegetation cover

(518.87 hectares) and a decrease of 317.35 hectares. TSAVI shows an increase of 1633.27 and a decrease of 1667.31 hectares in area of vegetation cover. Though the difference in the changes witnessed between increase in vegetation and decrease in vegetation was not so pronounced, but the increase in vegetation cover might be attributed to slight increase in rainfall in the years preceding 1986 and probably as a result of abandonment of farmlands by the migration of people out of the area due to frequent droughts witnessed in the period (1972 and 1986).

The correlation between rainfall and the vegetation indices is presented in Table 3. The results show that there is significant relationship between rainfall and NDVI at the 95 percent (p=0.05) level of significance while the other vegetation indices show no significant relationships in the period spanning 1972 and 2007 in the area. Although most of the results of the Pearson Correlation show no significant relationship existing between vegetation indices and rainfall, there is a strong negative linear relationship existing between the variables.

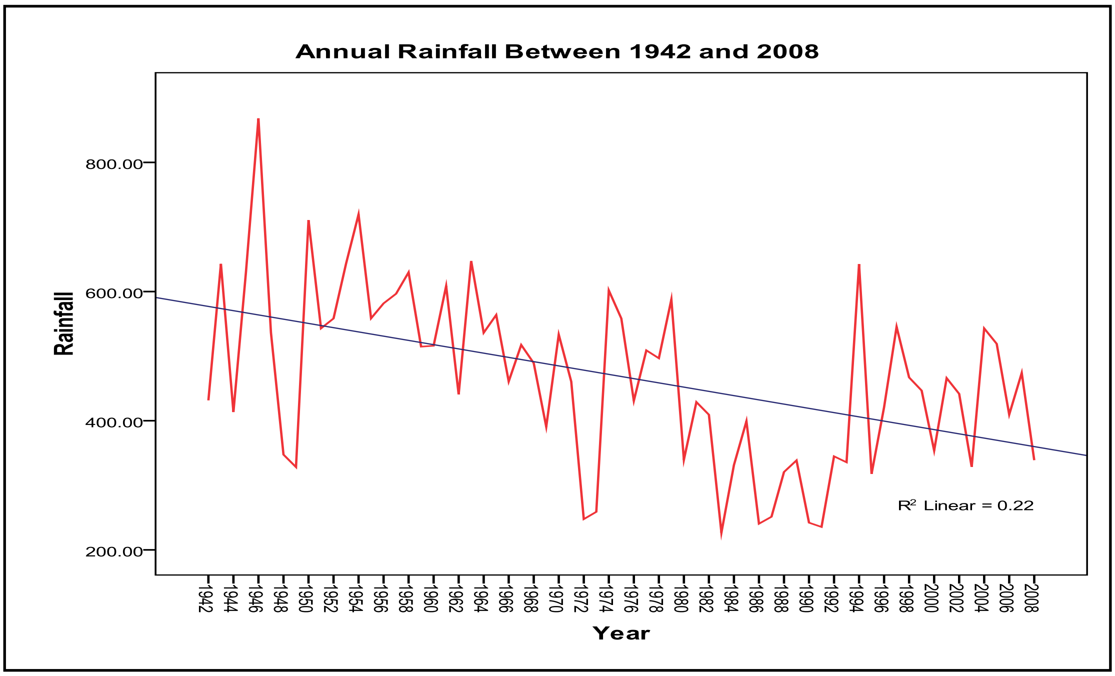

Figure 3 : Rainfall of the study area between 1942 and 2008

NDVI, GVI and TSAVI are the ones with strong negative correlations - r = -0.92, -0.75 and -0.77 - with rainfall while PVI and WDVI have weak linear relationship with rainfall. (r = 0.15 and 0.29). This means that there was decrease in vegetation cover in the area in spite of increase in rainfall between 1972 and 2007. It thus appears that other factors other than rainfall might have influenced the development of vegetation cover in the area.

Table 3 : Relationship Rainfall and Vegetation Indices

Vegetation Index	NDVI	GVI	PVI	TSAVI	WDVI	Rainfall
NDVI	1					
GVI	0.565	1				
	0.217					
PVI	-0.509	-0.003	1			
	0.245	0.499				
TSAVI	0.552	0.994**	0.093	1		
	0.224	0.003	0.454			
WDVI	-0.223	0.299	-0.361	0.210	1	
	0.388	0.351	0.320	0.395		
Rainfall	-0.919*	-0.752	0.155	-0.770	0.288	1
	0.040	0.124	0.423	0.115	0.356	

*. Correlation is significant at the 0.05 level (1-tailed).
**. Correlation is significant at the 0.01 level (1-tailed).

The result from the image differencing of the study area between 1986 and 2000 with respect to the vegetation indices show that NDVI, TSAVI and WDVI indicated greater degradation in vegetation cover than regeneration between 1986 and 2000 while GVI and PVI show more increase than decrease in vegetation cover (Table 4). The rainfall record shows that there was more rainfall in 2000 (353.8 mm) than in 1986 (240.5 mm). Thus, if rainfall had been the major determinant of vegetation development in the area (Anyamba and Tucker, 2005) then the change detection result should have shown greater increase than decrease in vegetation cover. However, reverse was the case as most of the vegetation indices gave a contrary result. This result therefore supports the earlier assertion that other factors especially human activities might have played a major role in the development of vegetation in the area within that period.

Table 4 : Vegetation Cover change in the study area between 1986 and 2000

Vegetation Index	Area measured in Hectare			
	No change (0)	Decrease (1)	Increase (2)	Difference
NDVI	7581.05	1549.61	1486.01	-63.6
GVI	7297.58	1654.80	1664.30	9.5
PVI_3	5265.09	2652.16	2699.43	47.27
$TSAVI_2$	7237.15	1721.40	1658.13	-63.27
WDVI	9750.09	450.96	415.63	-35.33

The result of vegetation change detection between 2000 and 2005 is presented in Table 5. The values for NDVI indicate greater increase in area of vegetation degraded (1451.73 hectares) than in area of vegetation restoration or increase (1423.63 hectares) in spite of the increase in rainfall by up to 47.6 percent in 2005. GVI and TSAVI on the other hand indicated greater increase (regeneration) in area of vegetation cover (1338.91 and 1151.12 hectares) than decrease (degradation) in vegetation cover (1151.99 and 1147.63 hectares respectively).

Table 5 : Vegetation change detection of the study area between 2000 and 2005

Vegetation Index	Area measured in Hectare			
	No change (0)	Decrease (1)	Increase (2)	Difference
NDVI	7741.31	1451.73	1423.63	-28.1
GVI	8124.77	1152.99	1338.91	185.92
PVI_3	6847.59	1891.49	1877.60	-13.89
$TSAVI_2$	8317.93	1147.63	1151.12	3.49
WDVI	9500.89	788.61	327.17	-461.44

Therefore, GVI and TSAVI show greater relationships with rainfall in the area during the period between 2000 and 2005 compared with the other indices. The relationships might also be as a result of the reflectance interaction with the soil background during the period. In line with above result of the NDVI, PVI and WDVI show higher degradation in vegetation cover (1891.49 and 788.61 hectares respectively) than regeneration (1877.60 and 327.17 hectares respectively).

Table 6 shows the results of vegetation cover change between 2005 and 2007. Three of the vegetation indices: NDV, PVI and TSAVI indicated greater degradation in area of vegetation cover than regeneration. The sizes of the degradation areas for the three indices are 1474.72, 1603.79 and 1634.33 hectares respectively, while the area sizes of vegetation cover regeneration are 1449.38, 1575.36 and 1597.94 hectares respectively.

The other two indices i.e. GVI and WDVI show increase in area of vegetation cover. The area sizes of the regenerated areas cover 1619.71 and 1597.94 hectares compared with areas of degradation which are 1532.23 and 1585.67 hectares respectively. In year 2007, there was a decrease in rainfall by about 8.7 percent from that of 2005. The decrease in rainfall would normally be expected to affect vegetation development. However, the magnitude of decrease does not appear large enough to have brought about the observed change. The human use of the environment remains a strong factor in the whole process vegetation dynamics in the study area.

Table 6 : Vegetation change detection of the study area between 2005 and 2007

Vegetation Index	Area measured in Hectare			
	No change (0)	Decrease (1)	Increase (2)	Difference
NDVI	7692.58	1474.72	1449.38	-25.34
GVI	7464.74	1532.23	1619.71	87.48
PVI_3	7437.53	1603.79	1575.36	-28.43
$TSAVI_2$	7452.80	1634.33	1529.55	-104.78
WDVI	7433.06	1585.67	1597.94	12.27

The image differencing change detection shows variations in the biomass content of the area when compared with rainfall data in the periods under review. Thus the results show that rainfall is not the only determinant of vegetation development in the area as was seen from the pattern of vegetation dynamics earlier presented. Fragmentations of the landscape was seen all over the areas which suggests that human activities have to be taken seriously if any conservation project is to succeed in the area. Giving the importance of trees in maintaing balance in the ecological systems,

Global Journal of Human Social Science (B) Volume XIII Issue VII Version I Year 2013

more efforts is required in establishing and properly managing parks and forest reserves in the area. This is in order to fight the encroaching desert and mitigate the impact of climate change. Trees are also known to sequester CO2 in the atmosphere therefore their establishment will also mean reducing the effcts of global warming. UNDP, (2009) suggested that about 20 percent of an area is required to be conserved in order to maintain and improve the ecological and social welbeing of a region.

V. Conclusion

The results on vegetation change detection using vegetation indices (VIs) show limited relationships between vegetation indices and rainfall in the study area, whereas studies on the relationships between rainfall and vegetation change at regional scale show that there is high correlation existing between them (Anyamba and Tucker, 2005; Fabricante et al. 2009). This therefore shows that anthropogenic rather than natural factors (e.g. rainfall) have more influence on the vegetation of the area at a local scale. In other words, the human activities in the area are responsible for the degradation of the environment. This therefore calls for concerted efforts in educating the dwellers of such fragile ecosystem on the consequences of devegetation on their environment. The regression differencing method of change detection proved to be good in discriminating changes in vegetation cover (trees, shrubs and grasses). The advantage of this method of change detection is that it can be used to detect "hot spots" where vegetation cover degradation is actively taking place so as to arrest the trend before it goes out of hand. This will help in the achievement of sustainable plan and in management of the dwindling ecological resources especially in arid environment.

VI. Acknowledgement

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