Multi-temporal change detection at a limestone mining and cement production facility in Central Nigeria

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Abstract: Limestone mining and cement production at Yandev, Nigeria commenced in 1980 without an environmental impact assessment (EIA) to ascertain the extent of impact these activities could bring to bear on the physical and living conditions of the host environment. This study was carried out to assess the impact that mining of limestone and production of cement has inflicted on the quality and density of vegetation within the study area about 32 years since production commenced. Multi-temporal satellite imageries of the study area (Landsat for 1976, 1986, 1996 and Nigeriasat-1 for 2006), ILWIS Academia 3.3 and SPSS Version 15 were used for data analyses. Landuse and landcover (LULC) change detection; land surface temperature (LST) extraction; and normalized differentials of vegetation index (NDVI) estimation were carried out. The paired t-test was used for landcover data analysis. The study discovered first, that LULC changes occurred with built-up area increasing from 0.05 km^2 in 1976 to 1.51 km^2 by 2006, thus representing the landcover category with the highest gain. Conversely, thick vegetation declined from 4.30 km^2 in 1976 to 1.51 km^2 in 2006. Thick vegetation category lost to all other landcover categories while gaining only 0.07 from water bodies. The projected LULC of the study area by 2015 reveal an expected expansion in built-up area from 1.51 km^2 in 2006 to 1.90 km^2 by 2015, whereas thick vegetation is expected to further decline from 1.51 km^2 in 2006 to 0.80 km^2 by 2015. Second, the LST have risen over the study epochs (1976, 1986 and 1996) while NDVI signifies decline in quality and health status of vegetation cover over the study period (1986, 1996 and 2006). The study concludes that there is rapid decline in density and quality of vegetation cover within the study area. Ameliorative measures are recommended to include reforestation and improvement in limestone mining methods/techniques amongst others.

Keywords: LULC, Change Detection, Change Prediction, LST, NDVI, Sustainability

1. Introduction

Landuse and landcover (LULC) changes are products or outcome of prevailing interacting natural and anthropogenic factors [1, 2] and their utilization by man in time and space [3]. LULC changes have been proven to be central to environmental processes, environmental change and environmental management through its influence on biodiversity, water budget, radiation budget, trace gas emissions, carbon cycling, livelihood [4, 5], urban and rural agricultural land loss [6, 7, 8, 9], and a wide range of socio-economic and ecological processes [10, 11], which on the aggregate affects global environmental change and the biosphere [2].

LULC change detection have become a central component in current strategies for managing natural resources and monitoring environmental changes thus, providing an accurate evaluation of the spread and health of the world's forest, grassland, water, and agricultural and land resources has become an important priority [12].

In addition, forecast analyses can be carried out to show the landcover status on a future date if current trend prevails. An understanding of the change prediction is expected to aid in developing policies that would ensure sustainable use of the environment within a given area. This has been increasingly achievable through the use of both satellite

imageries generated through remote sensing data, and Geographic Information System (GIS) tools.

This study assesses the status of vegetal cover over a period of 30 years, using remote sensing data and GIS tools. The intention is to create a baseline data for vegetation cover at the study area since no environmental impact assessment (EIA) was conducted prior to the establishment of the cement factory.

2. Study Area

The central location of Dangote Cement Plc, Yandev is at 7º 24□ 42.45□N and 8º 58□ 31.28□E, with an elevation of 532 feet above mean sea level (Fig. 1). The area is generally located within a sub-humid tropical region with mean annual temperature ranging from 23ºC to 34ºC, and is characterized by the dry season, and rainy season. The mean annual precipitation is about 1,370mm and is described by [13] as having a bimodal pattern. The average wind speed over the study area is about 1.50 m/s, while the average ambient air temperature is about 30ºC [14]. The area, according to [15], is largely covered by Cretaceous continental (to the north) and marine (to the south) sediments. The area contains limestone reserves of Cretaceous formation, in excess of 70 million tonnes [16].
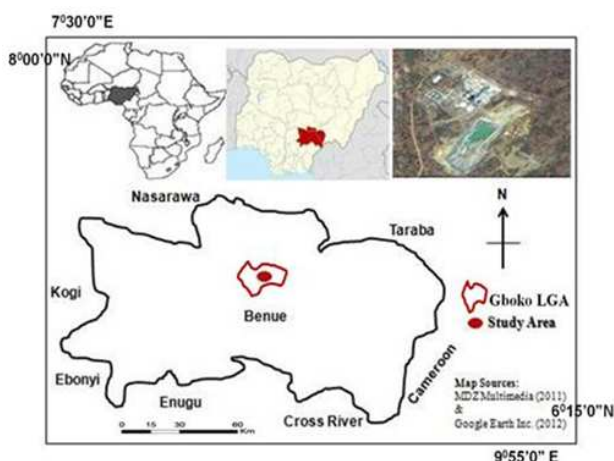

Fig. 1. *Study area*

Within the study area, the most significant water bodies are two streams – 'Ahungwa' and 'Oratsor'. The Ahungwa stream is impounded for use by the various production processes at the cement factory. Similarly, the area is characteristically a flat plain without hills or rocky outcrops. The major communities within the 5-kilometre radius (comprising the area of interest to this study) falls in the *Mbaiwan, Mbatyula, Mbausu, Mbagar, Mbaataiwa* and *Mbawav* kindreds of *Mbatyu* in *Mbayion*, Gboko LGA. The most prominent communities within the study area are Tse-Kucha and Tse-Amua. The inhabitants are largely pre-occupied in subsistence agriculture and wildlife hunting.

3. Materials and Methods

3.1. LULC Change Detection

The satellite data for the study were obtained from 2 platforms: Landsat and Nigeriasat-1. Based on the *priori* knowledge of the study area for over 2 decades and following reconnaissance survey, a classification scheme was developed by modifying the scheme developed by [17]. The Level I classification themes were adapted. The classes identified include Built-up area, Vacant land, Water bodies, Thick vegetation and Light vegetation. After data training, the Maximum Likelihood Classifier algorithm was used for digital image classification exercise. Analyses involved matrix and calculation of the area in hectares of the resulting LULC types for each study year (1976, 1986, 1996 and 2006) and subsequently comparing the results. The percentage change was used to determine the trend of change over the 4 study epochs. The annual rate of change was also determined between 1976 and 2006. Also, LULC forecast was developed using the IDRISI 32 image software to reveal the projected rate and pattern of change in LULC of study area by year 2015.

3.2. LST Estimation and NDVI Extraction

The study adopted LST extraction and NDVI estimation (Fig. 2) for assessing changes in the environment and variation in thermal properties of the study area. This had been adopted by [18, 19, 20]. For LST extraction, the Landsat satellite imageries' bands 3, 4 and 6 (thermal infrared) were corrected for radiometric errors after which the digital number (DN) was converted to Radiance, then to Reflectance (surface albedo). The images utilised were for the years 1976, 1986 and 1996 as the Nigeriasat-1 platform (providing the 2006 imagery) does not provide for the thermal band with which LST can be retrieved.

The NDVI was computed for 1986, 1996 and 2006 from the band 3 and band 4 reflectance data. In this case, the 1976 Landsat platform failed to provide the band combination to allow for NDVI analysis. The effective satellite temperature (Ts) was determined for all 3 study epochs to reveal the NDVI status of the study area.

3.3. Statistical Analyses

Using the SPSS (version 16) data analysis software, a paired T-test was carried out to determine the statistical significance of LULC changes between the study epochs. The method is found suitable for carrying out statistical test for relationship between 2 or more LULC study epochs. As a parametric test, the paired t-test is considered appropriate for this analysis.
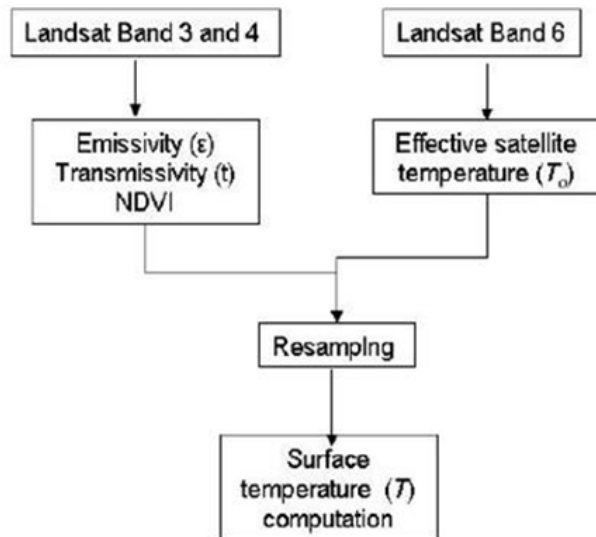
Fig. 2. *Flowchart for the computation of LST and NDVI Adapted from [21]*

4. Results and Discussions

4.1. Quantifying LULC Changes from 1976-2006

The distribution of LULC within the study area was determined through the 5 landuse classes identified. Hence, the static LULC distributions for each study year (Table 1) were derived over the four study epochs (1976, 1986, 1996 and 2006). The table reveals that as at 1976, thick vegetation constituted the largest single landuse category within the study area occupying 85.99% of the total land cover of the study area, with the built-up area being the least occurring land cover type (0.95% of total land cover area). The classified imageries are presented as maps in Fig. 3. Visual appreciation of variations of changes in land cover classes over the 4 study epochs can be clearly noticed from these maps. Summarily, the pattern of transformation from 1976 to 2006 reveals that built-up area is the category that has experienced the highest rate of expansion, whereas thick vegetation is the single most transformed and degraded landuse category within the study area.

The LULC change matrix was derived showing the gains from and losses to different land cover categories within the study area between 1976 and 2006 (Table 2). The matrix reveals that thick vegetation category lost to all other land cover categories starting with the highest loss of 1.40 km^2 to built-up area, followed by 0.78 km^2 to light vegetation, 0.43 km^2 and 0.14 km^2 to vacant land and water bodies, respectively. However, thick vegetation gained only 0.07 km^2 from water bodies. In addition to the gain from thick vegetation, built-up area also gained 0.06 km^2 from light vegetation between 1976 and 2006. Again, built-up is the category that had gained most from other landuses between 1976 and 2006, while conversely, thick vegetation represents the land cover category that had declined most over the study period.

Vectorized maps of the two key land covers (built-up and thick vegetation) for all study epochs reveal the pattern of changes occurring within these land cover types (Fig. 4 and Fig. 5). Built-up areas have consistently increased over the study period. However, while thick vegetation declined between 1976 and 1986, it increased between 1986 and 1996 while further declining again between 1996 and 2006. The increase in vegetation can be attributed to the decline and eventual halting of limestone mining and cement production in the early 1990s up until the privatization and eventual acquisition of the plant by Dangote Cement Plc at which point production commenced again.

Given the average LULC transformation between the base and terminal years of 1976 and 2006 respectively, the projected static LULC for the study area by the 2015 is derived and presented on Table 3. By the year 2015, built-up area, light vegetation and vacant land categories are expected to increase while thick vegetation and water bodies are expected to decline.

The paired T-test statistical analyses carried out on data generated from the classified satellite imageries of the study area are shown on Tables 4, 5, 6 and 7. The paired T-test is applied here to compare the mean values of 2 study epochs, and compute the difference between the two epochs for each case, then test to see if the average difference is significantly different from zero.

Table 4 shows that the year 2006 records the least values in terms of mean, standard deviation and standard error mean whereas the year 1976 reveals the highest values for all descriptive statistical parameters. The implication is a greater variation among the values of the landuse classes between the years 1976 and 2006.

The test correlation results are indicative of a strong inverse correlation (Table 5). Hence, the LULC classes that were larger in the previous study epoch declined significantly in the preceding study epoch. However, the strongest correlation is found to exist in pair 2 between the years 1986 and 1996. Also, the significance value of Pair 2 shows that there is a significant difference between the means of the two study years (1986 and 1996).

The results of the paired sample test (Table 6) show that the *p* values (sig. (2 tailed)) for all categories are greater than 0.05. It therefore, implies that there are no statistically significant differences in changes in the overall land cover between all 3 pairs of study epochs analyzed. While this does not necessarily connote total absence of changes in LULC over the study period, the test simply states that 'the changes recorded do not represent a significant proportion in statistical terms'. In other words, the aggregated changes in LULC between the study epochs are insignificant, although there are changes within individual LULC categories that can be considered to be significant.

Table 1. Distribution of LULC in study area (1976-2006)

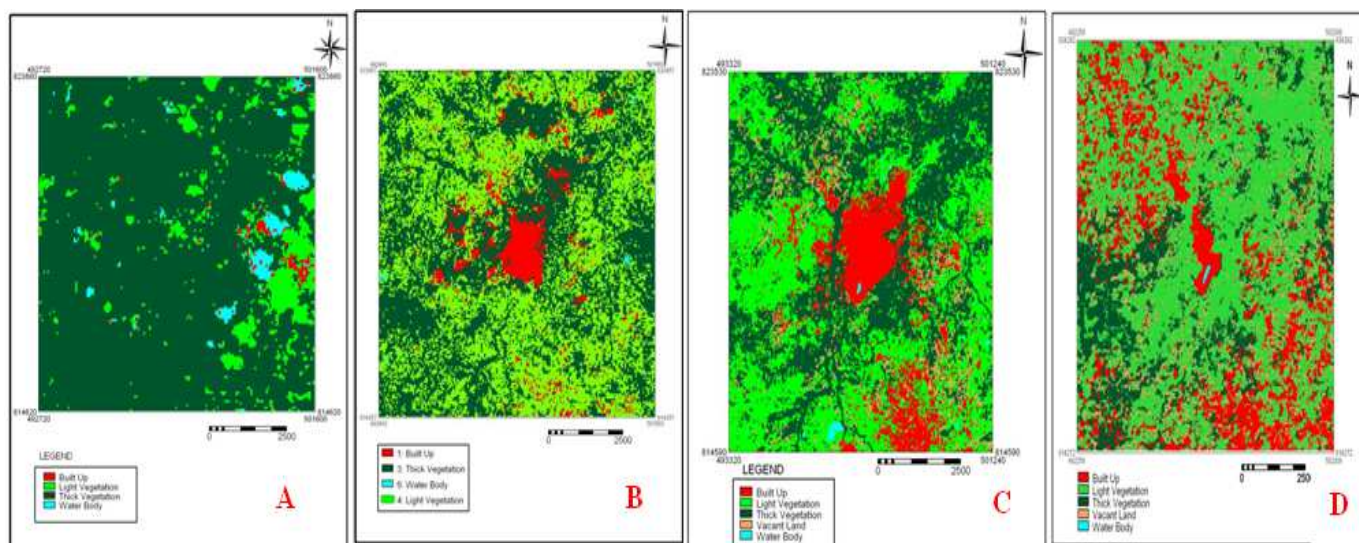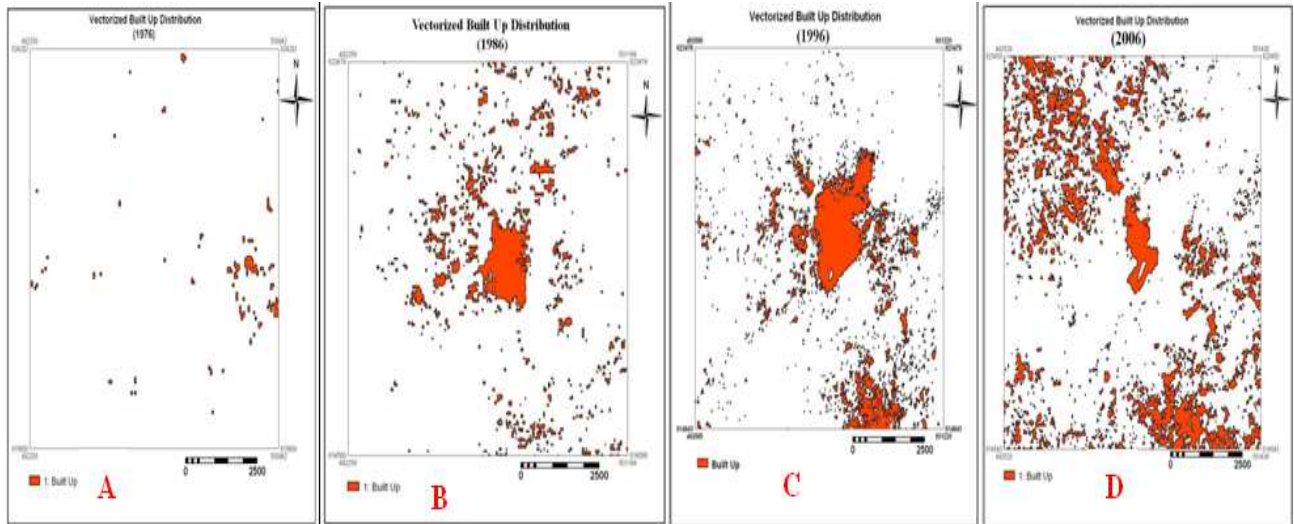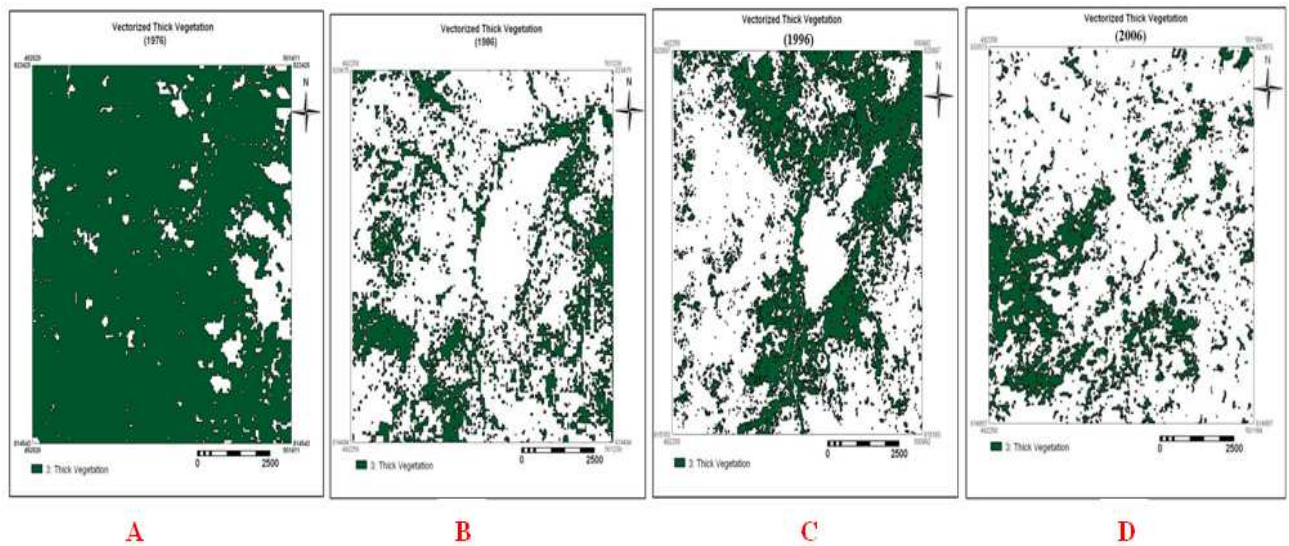| Code	LULC Categories	1976		1986		1996		2006	
		Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)	Area (Km²)	Area (%)
BUA	Built-up Area	0.05	0.95	0.31	6.15	0.56	11.19	1.51	30.12
VAC	Vacant Land	0.00	0.00	0.00	0.00	0.24	5.58	0.57	11.38
WAB	Water Bodies	0.10	1.95	0.01	0.19	0.02	0.39	0.03	0.52
TVEG	Thick Vegetation	4.30	85.99	1.38	27.51	1.77	35.33	1.51	30.12
LVEG	Light Vegetation	0.55	11.12	3.30	66.15	2.37	47.51	1.33	26.61
TOTAL		**5.0**	**100**	**5.0**	**100**	**5.0**	**100**	**5.0**	**100**

Fig. 3. LULC maps of study area in (a) 1976; (b) 1986; (c) 1996; and (d) 2006

Plate 1. Degradation at Limestone quarry site; a dead bird (see red arrow) in its habitat about 600 metres from factory site.

Table 2. *Landuse transformation for base (1976) and terminal (2006) years*

LULC Classes (Km²)	1976					2006
	Built-up Area	Vacant Land	Water Bodies	Thick Vegetation	Light Vegetation	
Built-up Area	0.05			1.40	0.06	1.51
Vacant Land		0.00	0.14	0.43		0.57
Water Bodies			0.10	0.14		0.03
Thick Vegetation			0.07	4.30		1.51
Light Vegetation				0.78	0.55	1.33

Note: Figures in bold (diagonally) represent area under that particular landuse in 1976, while figures in the same column represent the shift in area to other landuses. Similarly, figures in the same row are increase in area captured from the landuses

Fig. 4. *Vectorised Built-up area category maps of study area in (a) 1976; (b) 1986; (c) 1996; and (d) 2006*

Fig. 5. *Vectorised Vegetation category maps of study area in (a) 1976; (b) 1986; (c) 1996; and (d) 2006*

Table 3. *Projection of LULC Transformation at Study Area by 2015*

LULC Category	1976		2006		2015	
	Km²	%	Km²	%	Km²	%
Built-up Area	0.05	0.95	1.46	30.12	1.90	37.96
Vacant Land	0.00	0.00	0.57	11.38	0.74	14.82
Water Bodies	0.10	1.95	0.03	0.52	0.01	0.02
Thick Vegetation	4.30	85.99	1.51	30.18	0.67	13.46
Light Vegetation	0.55	11.12	1.33	26.61	1.56	31.28

Table 4. *Paired sample statistics*

Pairs		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Year1976	1.0000	5	1.85775	.83081
	Year1986	1.0000	5	1.40451	.62812
Pair 2	Year1986	1.0000	5	1.40451	.62812
	Year1996	.9920	5	1.02483	.45832
Pair 3	Year1996	.9920	5	1.02483	.45832
	Year2006	.9900	5	.66227	.29618

Table 5. *Paired sample correlations*

Paired Categories		N	Correlation	Sig.
Pair 1	Year1976 & Year1986	5	.265	.667
Pair 2	Year1986 & Year1996	5	.951	.013
Pair 3	Year1996 & Year2006	5	.699	.189

Table 6. *Paired sample test*

Paired Categories	Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 Year1976 - Year1986	.00000	2.01026	.89902	-2.49607	2.49607	.000	4	1.000
Pair 2 Year1986 - Year1996	.00800	.53312	.23842	-.65396	.66996	.034	4	.975
Pair 3 Year1996 - Year2006	.00200	.73496	.32869	-.91058	.91458	.006	4	.995

4.2. LST Estimation and NDVI Extraction

Remote sensing of heat islands has traditionally used the NDVI as the indicator of vegetation abundance to estimate the LST–vegetation relationship [22] since it is a good indicator of the energy balance at the surface because it is one of the key parameters in the physics of land-surface processes. It combines the results of surface-atmosphere interactions and energy fluxes between the atmosphere and the ground. As far as this study infers, LST and NDVI are interpreted as indicators critical to understanding the status of vegetation cover within the spatio-temporal area of interest. As a main indicator of the surface energy balance of the earth, LST is used as input data for a wide range of environmental applications including mineral resources [23]. For this study, the relevance of LST is in the determination of spatio-temporal changes occurring within the study area, as a function of declining vegetation content and quality.

The LST maps extracted from the Landsat images of the study area are provided in Fig. 6. These maps depict surface temperature fluxes within the study area which is generally increasing over the years as water bodies and vegetation (especially thick vegetation) continues to decline. For the year 2006, the Nigeriasat-1 imagery used for the study lacks Band 6 with which thermal analyses are conducted. Thus, LST analysis for the year 2006 was not conducted for this study. In 1976, the least temperatures were recorded for water (18^0C) while the highest temperature values were recorded for bare surfaces (40^0C). The minimum temperatures for 1986 and 1996 remained 18^0C while the maximum temperatures for 1986 and 1996 increased to 42^0C and 44^0C, respectively from 40^0C in 1976. The LST maps also indicate a general decline in the surface area of land cover categories (such as water bodies and thick vegetation) that exhibit low temperature.

The applicability of NDVI (vegetation indices) in LST estimation in this study is considered relevant to the extent and under the pretext that the amount of vegetation present is a critical factor, and NDVI can be used to infer general vegetation conditions which in turn can serve as an inferential basis for moisture content levels. Several similar works included the combination of LST and NDVI by scatterplot results in a triangular shape [24, 25]; the slope of the LST–NDVI curve in relation to soil moisture conditions [24, 26], and the evapo-transpiration of land surface [27].

The NDVI for the study year 1976 could not be extracted from the Landsat imagery used for this study as the imagery lacks the appropriate band combinations to extract NDVI. Hence, the NDVI analyses for the study commenced with the 1986 imagery, following with the 1996 to the 2006 imageries. These are shown on the re-sampled (NDVI) maps in Fig. 7.

Generally, healthy vegetation absorbs much of the visible light that falls on it, and reflects a relatively larger portion of the near-infrared light. For unhealthy or sparse vegetation, much of the visible light is reflected while less of the near-infrared light is reflected. Bare soils on the other hand reflect moderately in both the red and infrared portions of the electromagnetic spectrum [28, 29]. The study focused on the satellite bands that are most sensitive to vegetation information (near-infrared and red) in order to derive the NDVI information for the study area. The NDVI maps indicate a consistently and successively smaller difference between the near-infrared and the red reflectance, hence implying lesser vegetation index over the study years from 1986 - 1996, and 1996 – 2006.
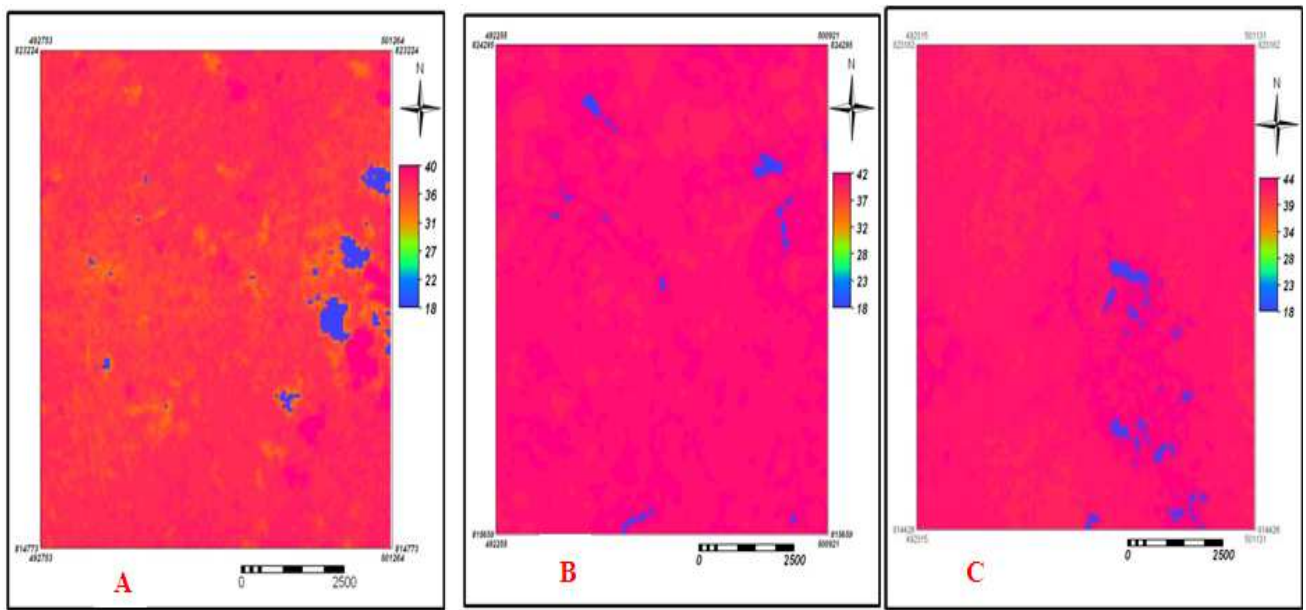
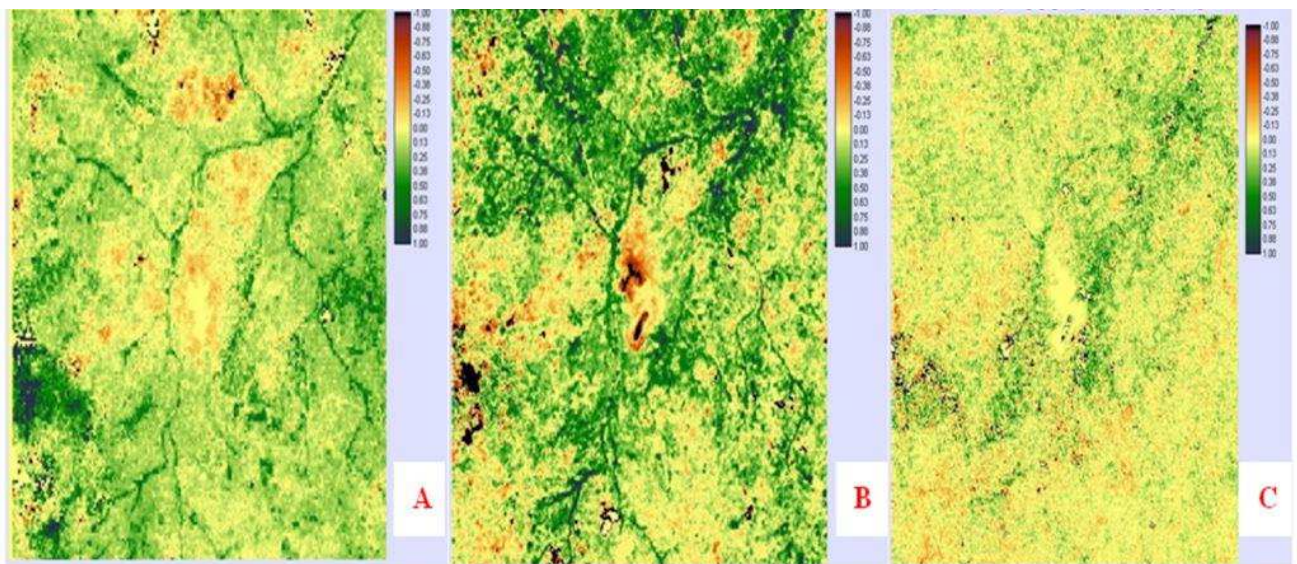***Fig. 6.*** *LST maps of study area for (a) 1976; (b) 1986; and (c) 1996*

Fig. 7. *NDVI maps of study area for (a) 1986; (b) 1996; and (c) 2006*

5. Conclusion

The alteration of land cover and ambient air temperature hold significant possibility of impacting the micro-climate within the study area. These developments can hardly be completely excused from the mining and production activities at the factory, given the results obtained from this study. The need for consistency in similar investigations in the future at the study area is indeed, debatable.

It is hoped that the analyses carried out would assist in providing baseline information for environmental monitoring and assessment efforts with respect to spatio-temporal patterns and dimensions of LULC changes, LST and NDVI within the study area. Although redemptive measures are suggested to narrow the vulnerability/exposure of the host environment, it is however, important to also acknowledge the truism that in real-life situations a host of other factors also come into play in actually scaling vulnerability including biological susceptibility, socio-economic status, cultural competence, and the physical environment. It is therefore, probably most suitable to recommend that other spheres of the host environment be investigated, particularly in a world where multi-disciplinary solutions are promising leads to the myriads of problems arising from the increasingly dynamic and changing climate and shifting socio-economic patterns, all of which are driven by population expansion. Additionally, sound knowledge of the status of our natural resources base is indeed critical for managing present

consumption patterns and most importantly for ensuring sustainability for future applications. Because of the uncertainty of predicting environmental change and human decisions, the need for sound empirical decisions (such as is being offered in this study) on which to base environmental planning and management policies becomes more critical than ever.

In conclusion, short term measures are therefore, suggested to improve the existing situation at the study area. First, deliberate reforestation efforts should be adopted using tree species with high pollution tolerance index such as *Azadirachta indica, Albizzia lebbek, Aegle marmelos, Annona squamosa, Bambusa bambos, Butea frondosa, Cassia fistula, Cordia myxa, Delonix regia, Ficus religiosa,* etc. Second, consistent inquiry into the status of the study area is suggested as necessary for sustainable resources exploitation at the study area. Third, Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) should be installed at the Dangote Cement kilns to reduce in very drastic proportions the amount of plume emissions with poisonous gases such as NOx during production which it is believed also affects tree health. These short term measures should address the declining vegetal cover index, improve NDVI and also stall the deteriorating LST observed within the study area. Longer term measures could then be initiated beginning with detailed studies towards developing an environmental management plan for the area.

Acknowledgements

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