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Change Detection in Land Surface Temperature and Land Use Land Cover over Lagos Metropolis, Nigeria.

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Abstract

With more than 78% of Nigerians living in cities, urbanization has had an important impact on climatic variations. Lagos Metropolis is located in a region experiencing rapid urbanization, which has produced a remarkable Urban Heat Island (UHI) effect. This effect influences the climate and socio-economic development on a regional scale. In this study, the Land Surface Temperature (LST) and Land Use Land Cover of 1984, 2001 and 2013 were analyzed for the spatial distribution of changes in temperature and land cover using Landsat images. A quantitative approach was used to explore the relationships among land surface temperature, land cover areas and Normalized Difference Vegetation Index (NDVI). Results showed that the vegetal cover has decreased rapidly over the 30 years' period from 70.043% to 10.127%; and this changes has contributed to the variations in the microclimate and affected the UHI intensity. Furthermore, the urban and bare areas correlated positively with high land surface temperatures (r>0.8) while water body and vegetated areas correlated positively with low LST values.

Keywords: Urban heat island; Land use; Land cover; Land surface temperature; Normalized difference; Vegetation index

Introduction

Urbanization, a term which refers to the transformation of natural land surfaces to modern land use and land cover (LULC) (i.e., buildings, roads, and other impervious surfaces) causing a division in the uniformity of urban landscapes and consequentially affecting human habitability in the cities [1]. The rapid expansion and growth occurring in major cities of developing countries play effective roles in the environment, causing changes in ecological processes at local, regional and global scales. In addition, the rapid influx of people into all major cities and towns, and its accompanying consequences has led to enhanced environmental chaos [2].

Recently, remote sensing and GIS has been proven to be a very useful tool in assessing the changes in LULC [3]. Analysis of LULC and change detection mapping is of great importance to climate scientist, urban and regional planners, environmentalists and policy makers. The LULC plays a significant role in Urban Heat Island (UHI) phenomenon. The UHI phenomenon can be related to changes in surface energy budget due to the replacement of permeable and evaporating surfaces with impermeable ones [1,3-6].

Nigeria, a country regarded as the most populous in Africa has reached a state where urbanization and its related challenges have assumed large proportions. Hence there is need for immediate attention and intense monitoring. Recent observation showed that over 400,000 hectares of vegetation cover is lost annually [7]. Greater percentage of the vegetal cover is lost due to increasing infrastructural development, exploration of minerals and settlements expansion [7,8]. The degree of LULC change and pattern in urban areas of Nigeria has evidently experience rapid increasing growth [9]. Analysis of LULC performed over the Federal Capital Territory (FCT) of Nigeria showed a high level increasing trend [10]. Results from [11] showed that UHI intensity has increased significantly over Kano as a result of rapid increase in LULC.

Although, there has been a tremendous increase in researches done on land use and land cover change analysis in the last four to five decades but the level of research attention on land use and land cover change studies in Lagos Metropolis is extremely low.

Since satellite remote sensing have proven in recent time, to be a better alternative in estimating the changes in various parameters such as land surface temperature, this research aims at studying the relationship between Normalized Differential Vegetation Index (NDVI), Land use Land cover (LULC) change and Land Surface Temperature (LST) as a signal for Urban Heat Island in Lagos metropolitan area of Lagos State, Nigeria.

Study Area

Lagos is a metropolis city located within Lagos State, a state created in 1967 [12]. The urban center served as the capital of Nigeria until December 12, 1991 before it was transferred to Abuja. The city is located in south-western region of Nigeria between longitude 2.42°E and 3.42°E and latitude 6.22°N and 6.42°N. On this stretch, lies the Lagos Lagoon with long coastal sand spits or sand bars. Badagry Creek flow parallel to the coast for some distance before finding an exit through the sand bars to the sea. The southern boundary of the state is formed by the 180km long Atlantic Coastline, while its northern and eastern boundaries are shared with Ogun state and the western boundary is shared with the Republic of Benin [13]. The geographical area of Nigeria that is defined as Lagos metropolis is unique in many ways. It is currently the 5th most populated city in the World and the largest city in sub-Saharan Africa. It is composed of 20 local government areas (LGA), of which 16 form the high-density metropolitan region [10].

The climate of Lagos is the wet equatorial type [13] with two rainfall peaks. The heaviest falling from April to July and a lesser rainy season

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in October and November. There is a relatively brief dry spell in August while the dry season is from December to March. In this study, five local governments; Alimosho, Agege, Ikeja, Oshodi/Isolo, and Ifako Ijaiye were chosen out of the Lagos metropolis as shown in Figure 1. The study area covers a total land area of 28970 hectares.

Data and Methodology

The study utilized multi-temporal satellite data acquired from Landsat^{TM} (1984), Landsat^{ETM+} (2001) and Landsat^{ETM+} (2013) as described in Table 1. The 3 images were already corrected for geometrical and radiometric errors. A suitable land surface temperature algorithm was used in estimating the LST. The classification scheme was developed using a combination of data collected from the satellite imagery. Using ArcGIS software, the maximum likelihood classifier algorithm was employed in the classification of the satellite images. Three land use classes were found occurring within the study area.

Estimation of normalized difference vegetation index (NDVI)

The NDVI is an index that provides a standardized method of comparing vegetation greenness between satellite images. It is an alternative measure of vegetation amount and condition. It can also be associated with vegetation canopy characteristics such as biomass, leaf area index and percentage of vegetation cover.

The model used in estimating NDVI is;

$$NDVI = \frac{NIR - PAR}{NIR + PAR} \quad (1)$$

This formula yields a value that ranges from -1 (usually water) to +1 (strongest vegetative

growth.)

where;

NDVI- Normalized Difference Vegetation Index

NIR- Near Infrared band imagery

PAR- Photosynthetic Active Radiation band imagery.

But in this study, the Red band imagery was used as the PAR. Thus the formula is;

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (2)$$

Land use and land cover (LULC) classification and estimation of land surface temperature (LST)

The LULC were classified based on the use of a supervised method of classification. Furthermore, for the LST estimation, the digital numbers of the thermal bands (6th band) of the satellite imagery was converted to spectral radiance using the bias and gain value. This conversion was obtained using this algorithm explained in [14];

$$C_{VR} = G\,(CV_{DN}) + B \quad (3)$$

Where;

C_{VR} – is the cell value radiance

G – is the gain value (0.05518 was used in this study)

CV_{DN} –is the digital number (DN) of the band 6 imageries

B=is the offset value (1.2378 was use in this study).

Once the DNs for the thermal bands was converted to radiance values, the brightness temperatures were estimated by using this algorithm of [14]:

$$TB(^{\circ}K) = \frac{K_2}{\ln\left(\left(\frac{K_1 \times \varepsilon}{C_{VR}}\right) + 1\right)}$$

where;

T_B – is the satellite brightness temperature in degrees Kelvin

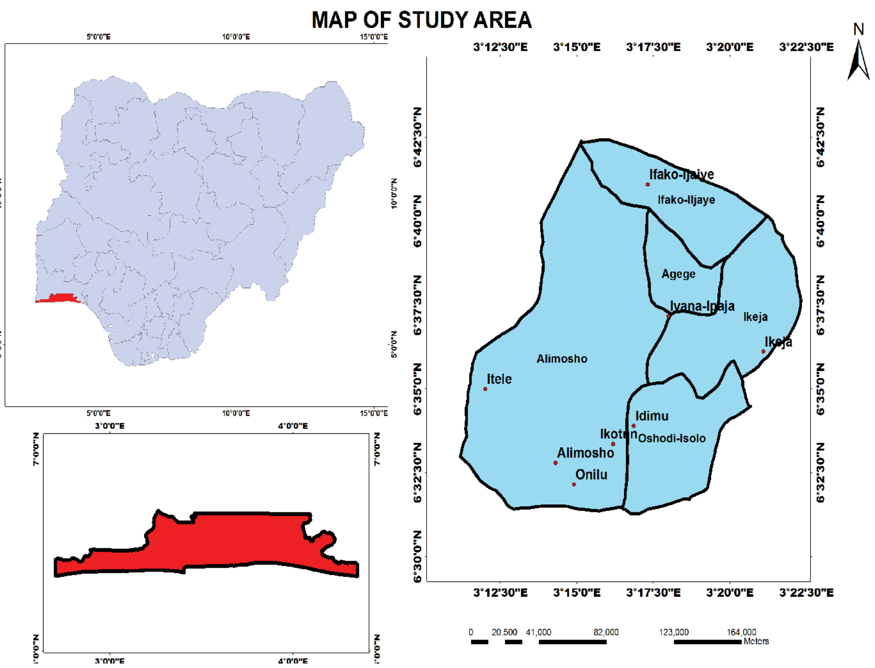

Figure 1: The study area map.

Data type	Production date	Scale	Source
Landsat 1984^{TM}	18/12/1984	30 m	USGS
Landsat 2001^{ETM+}	09/12/2001	30 m	USGS
Landsat 2013^{ETM+}	18/12/2013	30 m	USGS

Table 1: Description of data used.

K_1 = 666.09 – is the constant used for this study

K_2 = 1282.71- is the constant used for this study

ε=0.92 – is the emissivity value used for correction which is appropriate for less

Vegetated areas

C_{VR} – is the cell value inform of imageries obtained after converting the DN_s to

radiance.

Furthermore, the Land Surface Temperatures (LST) was estimated with the use of an emissivity corrected Land Surface Temperature's algorithm [14];

$$S_t(^\circ K) = \frac{T_B}{1 + \left(\frac{\lambda \times T_B}{\rho}\right)\ln \varepsilon} \quad (5)$$

where;

S_t - is the emissivity corrected Land Surface Temperature in degrees Kelvin

T_B – is the satellite Brightness Temperature in degrees Kelvin retrieved previously

λ=11.5 μm

$$\rho = \frac{h \times c}{\delta} = 1.438 \times 10^{-2}\ \text{mk} = 1.438 \times 10^{-8}\ \mu\text{mk}$$

h - is Planck's constant=6.626×10^{-34} J/s

c - is Velocity of light=2.998×10^{8} m/s

δ - is Boltzman's constant=1.38×10^{-23}J/k

After the emissivity corrected Land Surface Temperatures were estimated in degrees Kelvin, the temperature values were then converted to degrees Celsius by simply subtracting 273.15. That is;

S_t(°C)=S_t(°K) -273.15

Results and Discussion

Analysis of spatial pattern of NDVI

Spatial variation of NDVI is not only subject to the influence of vegetation amount, but also to topography, slope, solar radiation availability, and other factors [15]. NDVI is commonly used as a measure of land surface greenness based on the assumption that NDVI value is positively proportional to the amount of green vegetation in an image pixel area [15]. Theoretically, NDVI values are represented as a ratio ranging in value from -1 to 1 but in practice, extreme negative values represent water, values around zero represent bare soil and values close to one represent dense green vegetation. The spatial distribution of NDVI over Lagos metropolis for the period of 1984, 2001 and 2013 is shown in Figure 2. Visual inspection ascertained the differences of each NDVI. The highest degree of difference was observed in 2013, with the majority of NDVI values appearing to be below 0. The dominance of negative NDVI values may be attributed to increasing urbanization leading to more built-up areas and bare-surfaces. The observed negative value is because the reflectance value in the red band is higher than reflectance value in Near Infra-red band. Also, recent decrease in surface water as a result of dry weather were essential to the low values of the NDVI in 2013 because the index decreases as foliage (vegetation) comes under water stress [16]. Comparing the NDVIs of 1984 and 2001, changes were identified. In 1984, majority of the region under study exhibited positive values of NDVI except the core central part of Ikeja local government area indicating expanse of wide coverage of healthy vegetated surface. The observed features in 1984 had been reduced when considering the subsequent years.

Analysis of land use and land cover (LULC)

The Red Green Blue (RGB) composition created by the NDVI was useful for identifying land cover types and enable in selecting training areas for the supervised maximum likelihood classification. Each composed image was ordered into 3 area classes: built-up areas, vegetation and bare lands. Using the matricial algorithm, we could edit the urban and bare areas of high spectral confusion according to the information obtained by the photo-interpreter. The results of the classifications of land cover are found in Figure 3. The classification and quantification of the images of the study area (which covers a total land area of 28970 hectares) was necessary in the detection of changes in the various LULC observed within the study area and over the study period. Thus, the static LULC distributions for each study year (Table 2) were derived over the three study years (1984, 2001 and 2013). The table reveals that as at 1984, vegetation occupies the largest area with 70.043% (representing 20291.457 hectares) of the total study area, while built-up area covered 27.428% (representing 7945.892 hectares) and unused lands occupied the least area 2.529% (representing 732.651 hectares). Statistics for the year 2001 indicates that there is a significant gain in the built-up area as it increased from 27.428% in 1984 to 38.276% (representing 11088.557hectares) in 2001. Vegetation as a land cover type experienced significant loss between 1984 and 2001, while all other land use experienced significant gain. This changes are not ordinarily encountered and can be explained by the fact that Lagos state, remaining the economic nerve centre of Nigeria until December 12, 1991 was the Federal Capital of Nigeria, development until the era (when the state became the capital territory) was stunted such that most of the lands was used by the locals for agriculture. Within the period of 2001 and 2013, built-up area as a land cover category has over 100% increase (from 38.276% representing 11088.557 hectares of land to 79.561% representing 23048.822 hectares of land) and all other land cover type reduced drastically (Figure 4). This shows that there is increased demand or pressure on land by the sprawled population due to increased rural- urban and urban-urban migration and Lagos state being the financial hub of the country Nigeria.

Analysis of land surface temperature

The spatial distribution of surface temperature over Lagos metropolis is shown in Figure 5. The LST ranged from 21°C in 1984 to 35°C in 2013. The estimate from the satellite images and ground observation exhibit high level of correlation (r ~ 0.89), hence depicts significant level of accuracy and relationship between both platforms. The observed slight difference might be caused by radiometric error of the satellite platform. In 1984, it is evident that the temperature is

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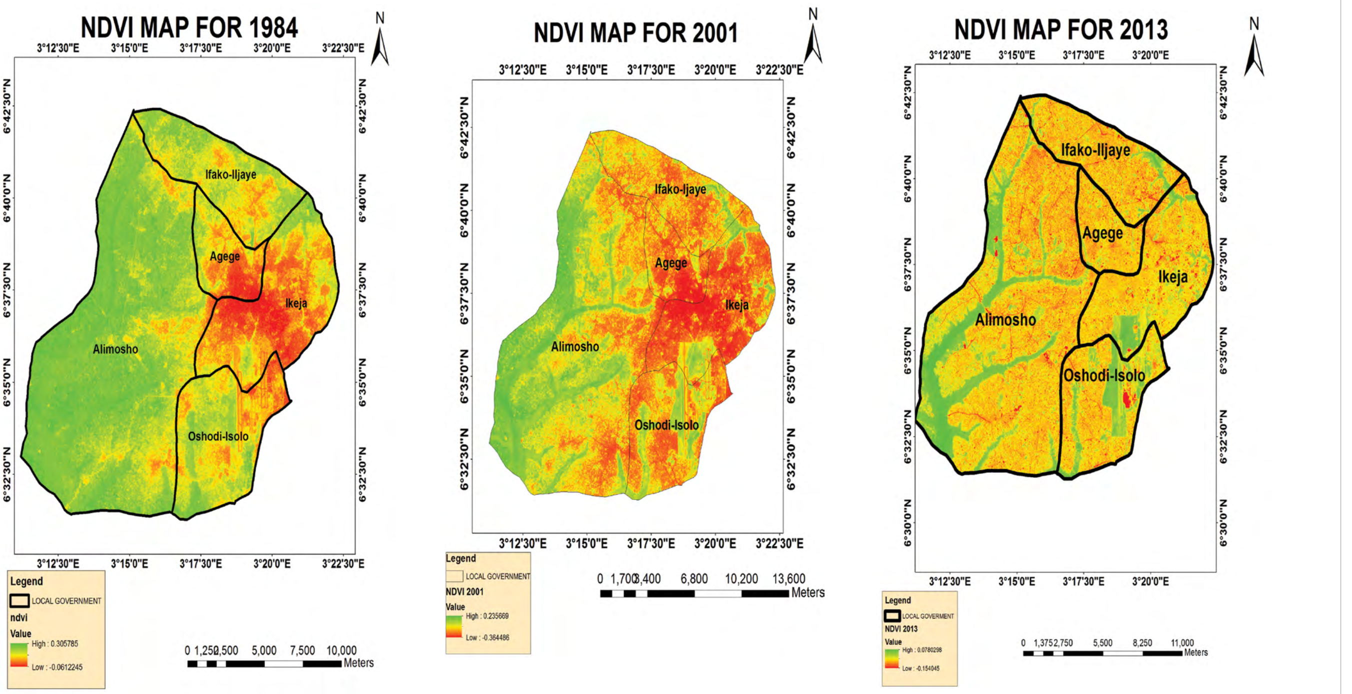

Figure 2: Spatial distribution of Normalized Difference Vegetation Index (NDVI).

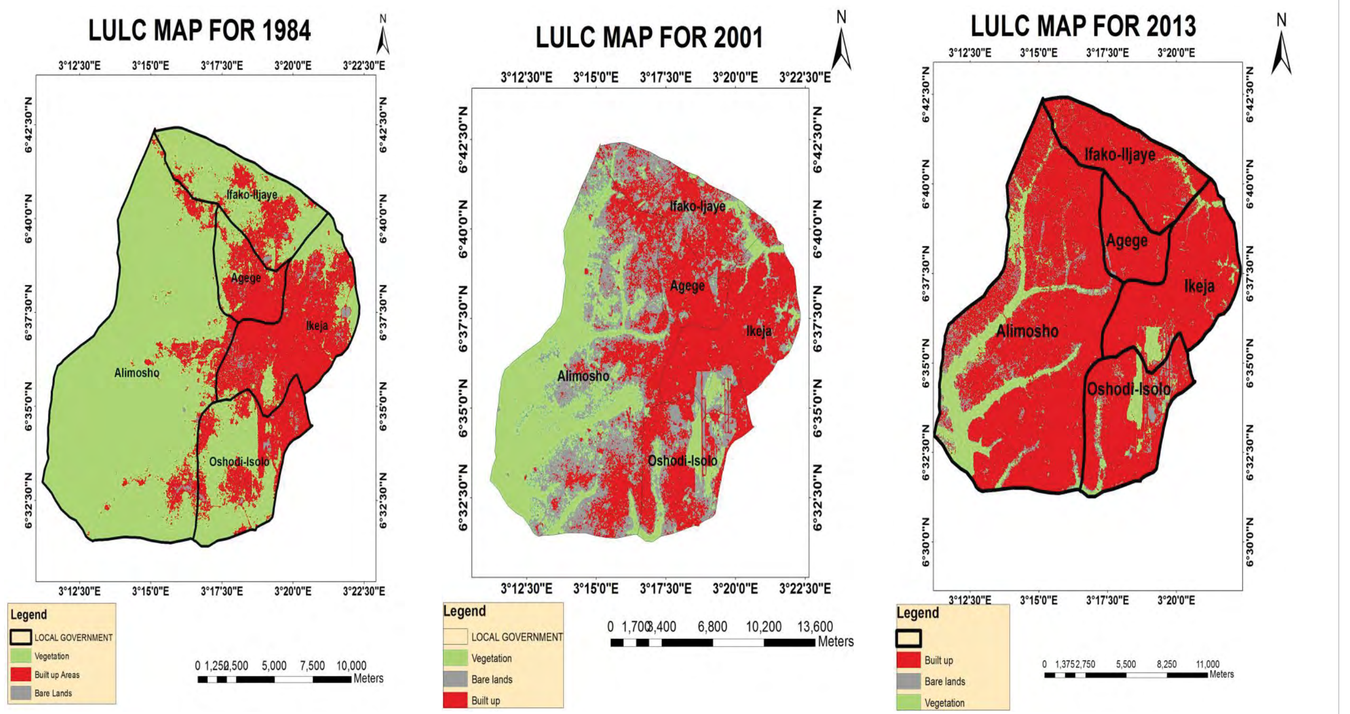

Figure 3: Spatial distribution of Land Use and Land Cover (LULC).

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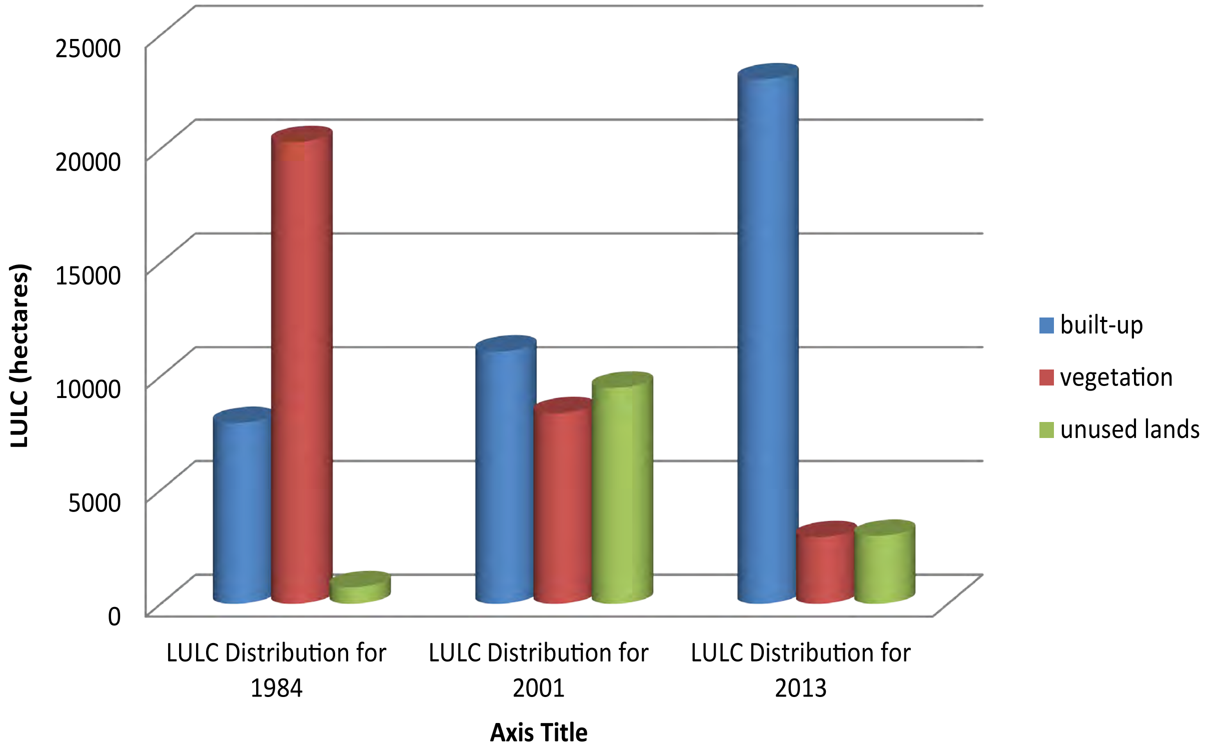

Figure 4: Land Use and Land Cover category.

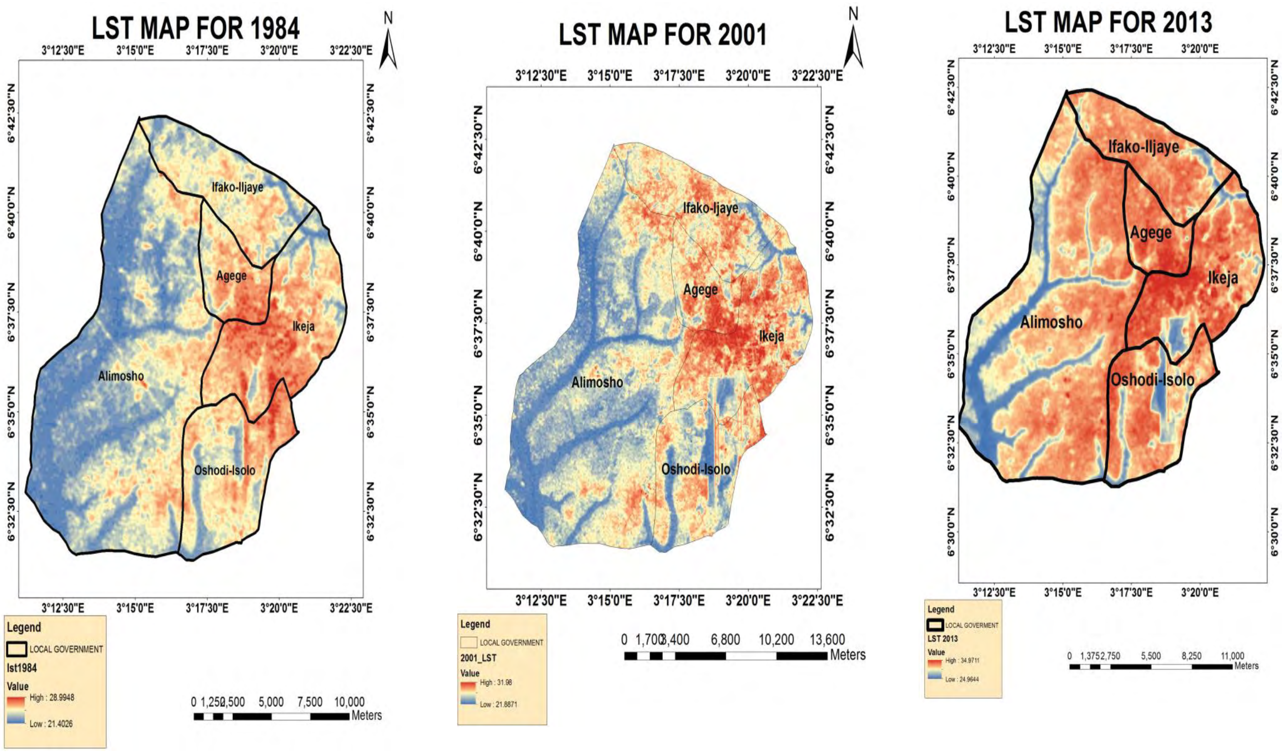

Figure 5: Spatial distribution of Land Surface Temperature (LST).

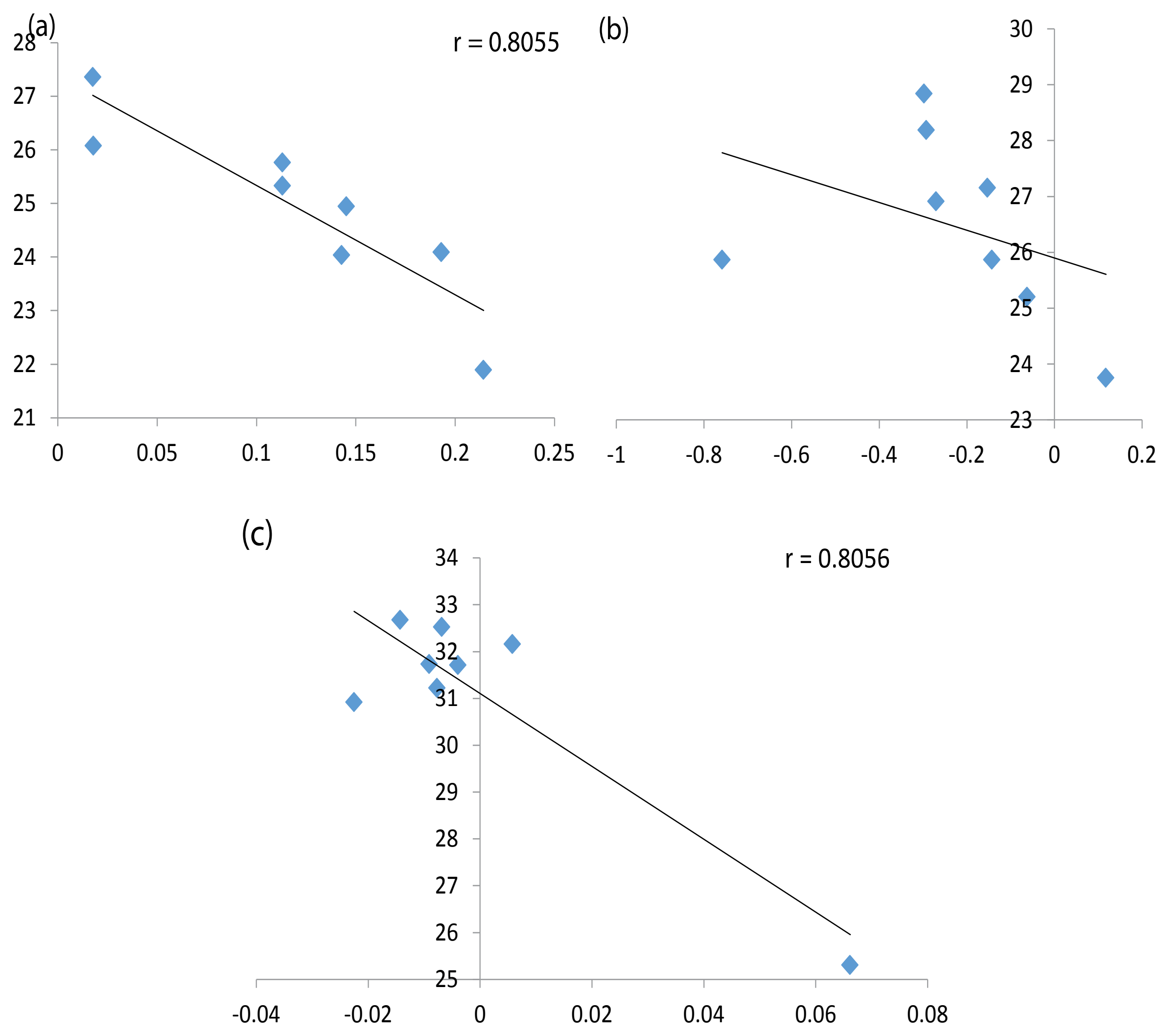

Figure 6: Regression analysis between the LST and LULC over Lagos Metropolis for (a) 1984 (b) 2001 (c) 2013.

Years	1984			2001			2013		
LULC	nPix	Area (hec)	Area (%)	nPix	Area (hec)	Area (%)	nPix	Area (hec)	Area (%)
Unused Lands	7900	732.651	2.529	102448	9500.132	32.793	32215	2987.386	10.312
Vegetation	218820	20291.457	70.043	90380	8381.021	28.930	31638	2933.792	10.127
Built-Up Areas	85686	7945.892	27.428	119578	11088.557	38.276	248553	23048.822	79.561
Total	312406	28970	100	312406	28970	100	312406	28970	100

Table 2: Land Use and Land Cover distribution.

		1984		2001		2013	
	Location	LST	UHI	LST	UHI	LST	UHI
Rural	Itele	21.89	4.18	23.75	4.44	25.3	6.86
	Alimosho	24.03	2.04	25.21	2.99	30.92	1.24
	Onilu	24.09	1.99	25.87	2.32	31.22	0.94
	Ikotun	24.94	1.13	25.87	2.32	31.73	0.43
	Idimu	25.76	0.32	26.91	1.28	32.68	-0.52
	Iyana Ipaja	27.36	-1.28	28.84	-0.65	32.52	-0.36
	Ifako Ijaiye	25.33	0.75	27.16	1.03	31.71	0.45
Urban	Ikeja	26.08		28.19		32.16	

Table 3: Urban heat island intensity.

far higher in the urban center of Ikeja local government area of Lagos State when compared to the sub-urban (rural) local government area of Alimosho, Ifako Ijaye and Oshodi indicating the presence of Urban Heat Island (UHI) with obvious intensity. This observed UHI witnessed an increasing trend over the 30 years' period as a result of increasing population, anthropogenic activities, and alteration of land cover (Table 3). It is clear that for all the years that built-up area exhibits the highest land surface temperature. The recent increase in non-evaporating and non-transpiring surfaces such as stone, metal and concrete maybe attributed to the observed increase.

Relationship between NDVI, LULC and LST

In a way to assess the relationship between NDVI, LULC and LST, a regression analysis was used to present the relationships quantitatively (Figure 6). Analysis based on linear regression showed that the correlation coefficient (r) ranges from 0.8, 0.14 and 0.8 in the year 1984, 2001 and 2013 respectively. This observed relationship depicts that there is a strong positive relationship between NDVI, LULC and LST. From the analysis, it was observed that the vegetation covers had shown a considerably low radiant temperature in all the years considered, because dense vegetation can reduce amount of heat stored in the soil and surface structures through transpiration. The cultivated land with its sparse vegetation (crops) and exposed bared soil showed a significant increase in temperature. In effect, surface soil water and vegetation contributed to the broad variation in the surface radiant temperatures of both vegetation cover and cultivated land. Hence, it is worthy to note that the Land Use change has contributed to the observed UHI intensity over the study areas mainly through the processes of urban sprawl, degradation of cropland and healthy vegetation.

Conclusion

In this paper, qualitative and quantitative analyses have been used to study the relationship between LULC and LST as an indicator for Urban Heat Island (UHI) over selected five local government areas in Lagos Metropolis of Lagos State, Nigeria. Several conclusions were made: (1) distribution of heat island has been expanded rapidly over the study area; (2) Land cover has decreased rapidly over the 30 years; (3) land cover patterns and changes contributed to the variations in the microclimate and affected the UHI intensity primarily through suburban sprawl, soil impaction and deforestation (4) there is a strong positive relationship between LULC and LST, the correlation coefficient (r) in different times were larger than 0.8 except in the year 2001.

The results also showed that although remote sensing images were ideal for analyzing UHIs, the main difficulty was in selecting images with similar conditions of cloud cover, humidity and geometric acquisition. This fact enhances the necessity of more studies to find corrections for these effects. Future studies need to focus on adapting the temperature retrieval methods for the new Landsat 8 TIR sensor. This sensor will have a spatial fidelity of 100 m and is going to be resampled and registered to the Operational Land Imager (OLI), which is a push-broom multispectral sensor that produces 30 m pixels in the final products.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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