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Synthesized effect of Land Surface Modification and Net Radiation on the Urban Climate: A study of Lagos metropolis (Nigeria) between 1984 and 2013

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Abstract

Land use change are human modifications induced by urbanization which promotes variations in the energy and radiation balance, which in-turn has made the temperature of urban areas higher compared to the surrounding rural areas, known as Urban Heat Island (UHI). This urban phenomenon is becoming more distinct and unique in urban areas in Lagos metropolis. Geographical Information System (GIS) and statistical techniques were adopted to synthesize the effect of land surface modification and net radiation on the urban climate of Lagos metropolis between 1984 and 2013. The following factors such as urban area, Land Surface Temperature (LST), net radiation, and Normalized Difference Vegetation Index (NDVI) was derived from Landsat imagery using GIS. In Lagos metropolis, increase in the urban-rural landscape difference has led to a decreased in the urban vegetation which has increased net radiation and LST resulting from increase in urban built-up area between 1984 and 2013. The above factors were analyzed using factor analysis (statistical technique) to produce an urban climate determinant driven by the effect of: (1) the urban area and (2) land surface temperature of Lagos metropolis. Based on the above, GIS techniques was employed to map UHI areas for Lagos metropolis by delineating the urban built-up area from the rural built-up area with reference to its LST mean. Furthermore, UHI areas are on the increase as well as its spatial extent. This has triggered UHI effect in cities of Lagos metropolis between 1984 and 2013. Based on research findings, possible mitigation measures as means of controlling the menace of UHI were highlighted for Lagos metropolis.

Keywords

Land Surface Temperature (LST), Urban area, Urban Heat Island (UHI), Lagos metropolis

1. Introduction

The energy that is known as net radiation has a significant influence on thermal comfort and negative health effects on humans [1], [2]. Net radiation is a fundamental variable that determines the climate of the lower layers of the atmosphere, and is dependent on the physics and chemistry of the atmosphere as well as the presence of clouds [3],[4],[5]. Its effects depend on both the structure and composition of the atmosphere and the presence of clouds, in addition to surface characteristics such as albedo, emissivity, temperature, moisture and the thermal properties of underlying soil [6]. The net radiation balance at the earth's surface determines the amount of energy which can be transformed into the remaining components of the energy balance, i.e., the sensible, the latent, and the soil heat flux [3]. Given the importance of this magnitude and its relation to landscape change, accurate measurements of net radiation are essential in studies of global and urban climate change. Net energy at the earth's surface plays a significant role in the surface thermal conditions [7]. Over any landscape, whether modified or urbanized, the use of net radiation as a critical variable in models of surface-atmosphere exchange is routine but its measurement is not [8].

Net radiation is also important in studies of surface energy balance, where its magnitude is mainly related to sensible and latent heat flux [3]. The relationship between radiation and surface energy balance is important for understanding the urban climates (or microclimates) caused by varying surface types [9]. The spatial heterogeneity of urban landscapes leads to a non-uniform transmission and distribution of energy radiation. Because the urban area is a complex physical interface, the thermodynamic and kinetic properties of the underlying surface may be substantially changed by modifying the physical characteristics of that surface [10], [11]. These factors result in cities that have unique climatic characteristics [12]. Thus, Wypych and Bokwa [13] revealed that changes in land use in urban areas affects the amount of heat transfer (heat flux) and the amount of reflected radiation energy and radiation energy received by a surface, receiving surface water (the balance sheet water) and to human health. Land cover changes such as urban landscaping, agriculture crops or hard scapes for building and parking lots promote variations in the energy and radiation balance compared to rural or natural land cover. This change in urban surface characteristics result in increased surface runoff, reduced latent heat flux and increased sensible heat flux to the urban atmosphere, all of which affect human comfort and activity [14],[15]. In particular, urbanization is one of the most extreme ways in which humans alter the land cover and land use, as it results in dramatic differences after cities have been established. Urbanization provokes the most complete transformations of land cover, generating a complex spatial surface material mosaic that is in part driven by real estate marketing and the consequences of planning policies [16].

Due to the above listed modifications, the surface temperatures and near-surface air temperatures over urban patches are generally higher than those over rural areas, thus resulting in Urban Heat Island (UHI) [17], [18], [19]. Some factors at the meso-scale contribute to the development of UHI, whereas other UHIs are related to natural factors, such as weather and location. Other factors are related to human activity, such as urban geometry and materials, anthropogenic heat flux and deforestation [20], [21]. All of the aforementioned factors may induce varying amounts of energy in the interface between the atmosphere and the urban surface. However, one key factor central to UHI studies is the Land Surface Temperature (LST) which is the temperature measured at the earth's surface and is regarded as its skin temperature, acquired from thermal satellite sensors, which primarily measure the radiance at the top of the atmosphere in the thermal infrared [22] region. The surface temperature is of prime importance to the study of urban climatology. It modulates the air temperature of the lowest layers of the urban atmosphere, central to the energy balance of the surface, helps to determine the internal climates of buildings and affects the energy exchanges that affect the comfort of city dwellers. Urban Heat Island (UHI) is a well-documented phenomenon [9], [23] that results in a conurbation being warmer than the surrounding rural areas. It is an example of an unintentional modification of the local climate and is principally caused by altering the energy balance influenced by variations in land use, surface properties (e.g., surface roughness, albedo, emissivity) and geometry of the urban area [24],[25]. Urban Heat Island effects are becoming more and more distinct in many major cities [26]. Elevated temperatures from Urban Heat Islands, particularly during the summer, can affect a community's environment and quality of life. While some heat island impacts seem positive, such as lengthening of plant-growing season, most impacts are negative and include: (1) increased energy consumption; (2) elevated emissions of air pollutants and greenhouse gases; (3) compromised human health; and (5) impaired water quality [27].

In this study, remote sensing was used to analyze urban-rural LST difference which is defined as Surface Urban Heat Island (UHI). Also in this study, satellite derived LST was used to synthesize the effect of land surface modification and net radiation on the urban climate of Lagos metropolis. UHI phenomenon has not been extensively studied in Lagos metropolis, so this research tries to fill the gap in literature in understanding relationship between UHI and the role net radiation (surface energy balance) play in increasing thermal discomfort and heating of the urban area. Putting into consideration the urban-rural landscape changes of Lagos metropolis which connotes the temperature difference of UHI highlighted in the study area. For proper comprehension, the study is considered under the following by employing GIS and statistical techniques to: (1) mapping changes in urban-rural landscape difference; (2) mapping changes in the urban-rural temperature; (3) mapping changes in the urban-rural net radiation; (4) mapping urban-rural Normalized Difference Vegetation Index (NDVI); (5) selection of factors that determine the urban climate; and (6) effect of land surface modification and net radiation on the urban climate of Lagos metropolis.

2. Methodology

This research integrates GIS (Geographic Information System) and statistical techniques in synthesizing the effect of land surface modification and net radiation on the urban climate of Lagos metropolis. The data acquired for this study includes: (1) Landsat Thematic Mapper (TM) 5, Enhanced Thematic Mapper Plus (ETM+) 7 and Operational Land Imager (OLI) 8 imagery from USGS-Earth Explorer for 1984, 2000 and 2013 with a Path/Row number of 191/055,056 and a resolution of 30meters(Table 1). (2) Map (GIS vector shapefile format) covering the study area was obtained from Guinea Current Large Marine Ecosystem (GCLME) and Unilag Regional Centre for Environmental Management, University of Lagos, Nigeria. The study area covers Lagos metropolis also known as "Metropolitan Lagos", and officially as "Lagos Metropolitan Area". The city of Lagos lies in Southwestern Nigeria, on the Atlantic coast. The city is located within a geographical coordinates of 3° 04' to 3° 40' East longitude and 6° 23' to 6° 42' North latitude. Figure 1 shows the location of Lagos metropolis in Lagos state, Nigeria. Lagos metropolis covers 1171Km^2 area of which 221Km^2 is Lagoons and waterways [28]. In addition, (3) field survey (GPS reading and ground trotting) was conducted to get first-hand information about the land use type and urban heat island areas throughout the study area, useful to assess the dynamics of change.

In other to study the synthesized effect of land surface modification and net radiation on the urban climate of Lagos metropolis between 1984 and 2013, the following procedures was adopted to analyze data collected for this study; this includes derivation of the following parameters, which includes, namely: Urban-rural landscape difference, Land Surface Temperature (LST), net radiation, and Normalized Difference Vegetation Index (NDVI) for 1984, 2000 and 2013. To derive the urban-rural landscape difference of Lagos metropolis, the following procedures was adopted, namely: (1) Image processing, this includes the following: (a) Selection of band 4, 5 and 7 from Landsat imagery for 1984, 2000 and 2013 (Table 1), mosaicing of bands, and enhancement which involves stretching of bands and creation of composite image as well as defining a region of interest (ROI) using the GIS map of Lagos metropolis to create a subset. The images were already rectified to a common UTM co-ordinate system, which is 31N.

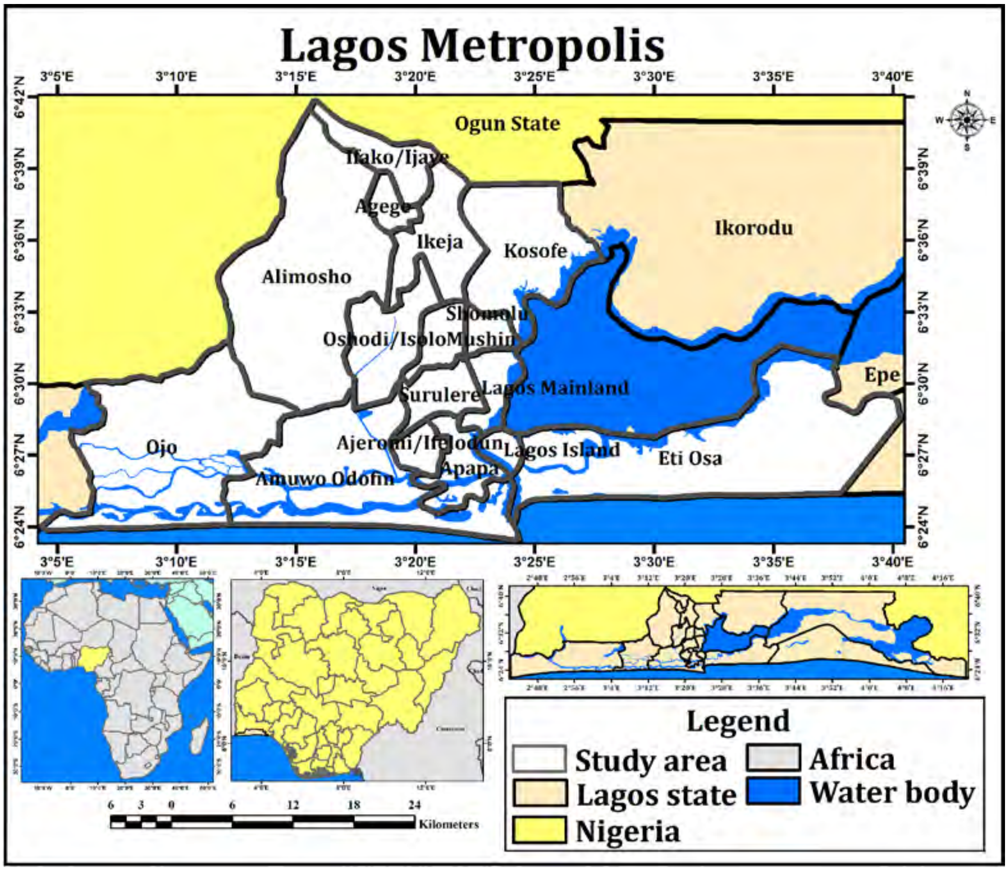

Figure 1. Location of Lagos metropolis.

Table 1. Landsat TM, ETM+ and OLI sensor and characteristics.

Sensor	Path/Row	Spectral Range (μm)	Band	Resolution (Meters)	Time Acquired	Date Acquired
TM 5- Multi Spectral	191/055,056	0.45 - 2.35	3, 4, 5 & 7	30	9:33 AM	12/18/1984
TM 5- TIRS*		10.40 - 12.50	6	120		
ETM+ 7- Multi Spectral		0.45 - 2.35	3, 4, 5 & 7	30	9:56 AM	02/06/2000
ETM+ 7-TIRS*		10.40 – 12.50	6.2	60		
OLI 8-Multi Spectral		0.53 - 2.29	3,4, 6 & 7	30	10:04 AM	03/25/2013
OLI 8-TIRS*		10.6–12.51	10	100		

* TIRS -Thermal Infrared Sensor

(b) To classify the Land use land cover (LULC), supervised classification method was used which involves the following steps: Definition of training sites with the aid of field trips conducted to train the image analysts, extraction of signatures and classification of the remotely sensed imagery using maximum likelihood classification procedure into three classes, namely: built-up area, others and water body. GIS reclassification procedure was employed to recode the imagery into correct land use classes, due to misclassification and spectral confusion errors. This was implemented using Idrisi Selva software. (2) To study the urban–rural landscape difference, the Urban Landscape Analysis Tool (ULAT) extension in ArcGIS 10 software developed by Center for Land use Education and Research (CLEAR), University of Connecticut, Department of Natural Resources and the Environment, USA was used to classified the developed areas into different densities as well as identify undeveloped lands that are likely to be degraded by close proximity to development. In classifying the urban area, the following LULC class which includes: built-up area (urban), water body and others were used as input. The ULAT output classification identifies the following seven classes which include: (a) *urban built-up area*, (b) *suburban built-up area*, (c) *rural built-up area*, (d) *urbanized open land*, (e) *captured open land*, (f) *rural open land,* and (g) *water body* which are of interest to this research in understanding urban-rural landscape difference of Lagos metropolis as well as urban-rural temperature, urban–rural net radiation and urban–rural normalized difference vegetation index for 1984, 2000 and 2013. The urban–rural landscape derived above was further divided loosely into two: (a) urban (urbanized) area which comprises of urban built-up area, urbanized open land and captured open land, and (b) rural area which comprises of rural built-up area and rural open land. (3) Urban-rural landscape change was computed such as: (i) changes in the urban-rural landscape between 1984 and 2013; and (ii) rate of change in the urban-rural landscape between 1984 to 2000 and 2000 to 2013 for Lagos metropolis.

Land Surface Temperature (LST) was derived from thermal band (6, 6.2 and 10 from TIRS in Table 1) of Landsat TM 5 in equation 1, ETM+ 7 in equation 2 and OLI 8 in equation 3 as stated below using ILWIS 3.6 software:

$$L_\lambda = offset + gain \times DN \quad (1)$$

$$L_\lambda = \frac{(L\min - L\max)}{255} \times DN + L\min \quad (2)$$

$$L_\lambda = M_L Q_{Cal} + A_L \quad (3)$$

$$T_B = \frac{K_2}{\ln\left[(K_1 / L_\lambda) + 1\right]} \quad (4)$$

Where, *offset*, *gain*, K_1 *and* K_2 = User defined parameters, L_λ = Cell value as radiance (W/m^{-2}sr^{-1}µm^{-1}), *DN*= Digital number of the thermal imagery, *Lmax* and *Lmin* = Derived temperature depending on gain status, M_L= Band-specific multiplicative rescaling factor, A_L = Band-specific additive rescaling factor, Q_{cal} = Quantized and calibrated standard product pixel values (*DN*), and T_B= Blackbody temperature. Land Surface Temperature (LST) (*K*) (degree Kelvin) was derived based on the blackbody temperature in equation 4. The conversion was carried out using equation 5 as follows:

$$T_{LST}(K) = \frac{T_B}{1 + \lambda \times T_B / \rho \times \ln \varepsilon} \quad (5)$$

Where, T_{LST}(K) = Land Surface Temperature (in degree Kelvin); λ= wave length of emitted radiance (11.5µm); $\rho = h \times C / \sigma$ = 1.438×10^{-2} (m K); σ = Stefan Boltzman constant = 1.38×10^{-23} J/K; *C*= Light velocity = 2.998×10^{-8}ms^{-1}; *h*= Planck's constant = 6.626×10^{-34}Js, and ε = Emissivity in the range between 0 and 1. According to Ramachandra et al. [29], additional correction for spectral emissivity (ε) is required to account for the non-uniform emissivity of the land surface. Spectral emissivity for all objects is very close to 1. Yet for more accurate temperature derivation emissivity of each land cover (LC) class is considered separately. Emissivity correction is carried out using surface emissivity for the specified LC derived from the methodology described in Snyder et al. [30] and Stathopoulou et al. [31]. Using equation 6 the Land Surface Temperature (LST) was converted from degree Kelvin to degree Celsius:

$$T_{LST}(^\circ C) = T_{LST}(K) - 273.16 \quad (6)$$

Where, T_{LST}(°C) = Land Surface Temperature in degree Celsius (°C) and T_{LST} (K) = Land Surface Temperature in degree Kelvin (K). The derived result was used to study the urban-rural temperature with the aid of the urban-rural landscape.

Net radiation (R_n) is the net energy amount received by a surface reduced by the energy expended by a surface [32]. Net radiation is calculated from the amount of shortwave radiation that comes with the number of long wave radiation that comes into a surface reduced by the amount of shortwave radiation coming out with the outgoing long wave radiation [32]. Equations for calculating net radiation are as follows [33], [34] using ILWIS 3.6 software:

$$R_n = R_{sin} + R_{lin} – R_{sout} – R_{lout} \quad (7)$$

$$R_n = (1 - \alpha)\, R_{sin} + \varepsilon_a a T_a^4 0.7\, (1 + 0.17N^2) – \varepsilon_s a\, T_s^4 \quad (8)$$

Where, R_n = Net radiation (W/m^{-2}); R_{sin} = Shortwave radiation incoming (W/m^{-2}) (derived from satellite); R_{sout} = Shortwave radiation out coming (W/m^{-2}), R_{lin} = Long wave radiation incoming (W/m^{-2}) [35]; R_{lout} = Long-wave radiation out coming (W/m^{-2}); α = Surface albedo (derived from satellite); T_s = Surface temperature (K) (derived from satellite); T_a = Air temperature (K) (derived from satellite); ε_s = Surface emissivity[36]; ε_a = Air emissivity (0.938 x 10^{-5} T_a^2); σ = Stefan Boltzmann constant (5.67 x 10^{-8} W/mK^4), and N = Cloud fraction (%) (= 0, for clear sky). The derived result was used to study the urban-rural net radiation with aid of the urban-rural landscape.

Normalized Difference Vegetation Index (NDVI) was computed as the ratio of the difference in reflectivity for the near-infrared band and red band to their sum [37] using ILWIS 3.6 software to study the effect of urbanization as an indicator of urban surface modification on vegetation for 1984, 2000 and 2013 in Lagos metropolis. NDVI value was transformed from -1 to 1 into an 8 bit value image known as *Scaled NDVI.* NDVI was scaled to remove negative value for easy computation and use in Microsoft excel 2010 (or any other statistical) software. *Scaled NDVI* was derived by adding one to NDVI multiplied by 100. The derived result was used to study the urban-rural NDVI with aid of the urban-rural landscape.

Curve estimation procedure was used to create and compare models for linear and nonlinear relationships between a dependent and independent variable. Statistics includes namely: regression coefficients, R^2, linear and logarithmic regression. The statistics was performed to study the relationship between: (a) NDVI and LST; and (b) NDVI and net radiation. This was implemented using SPSS 20 software.

Finally, synthesized effect of land surface modification and net radiation on the urban climate of Lagos metropolis between 1984 and 2013 was performed using factor analysis, the following parameters was selected, namely: *urbanized area, LST, NDVI and net radiation,* and applied to: (1) Identify underlying variables or factors that explain changes in the pattern of correlations in the urban climate; (2) Identify factors that explain most of the variations observed in the urban climate; and (3) Generate hypotheses regarding causal mechanism responsible for urban climate modification in the creation of Urban Heat Island (UHI) in Lagos metropolis using SPSS 20 software. Based on the selected factors using factor analysis, the effect of land surface modification and net radiation on the climate of Lagos metropolis which in-turn produces Urban Heat Island (UHI) was mapped using the urbanized area to delineate the urban built-up area from the rural built-up area with reference to its Land Surface Temperature (LST). UHI areas were selected and defined based on the mean urban LST value because it accounts for the temperature difference observed between the urban centers and their more rural surroundings. Also, changes in UHI areas were mapped using UHI spatial (area) extent to shows areas covered by UHI in 1984, 2000 and 2013. Calculate areas tool in ArcGIS spatial statistics toolbox was used to calculate UHI area and results was published as maps in ArcGIS 10 software and output tables were exported to Microsoft excel 2007 to publish values as graphs. Finally, curve estimation procedure in SPSS 20 software was used to analyze the effect of changes in urbanized area, LST, net radiation, and NDVI on the urban climate and creation of UHI in Lagos metropolis.

3. Results and Discussion

The results of this research was analyzed for proper comprehension as follows: (1) mapping changes in urban-rural landscape, (2) mapping changes in the urban-rural temperature, (3) mapping changes in the urban-rural net radiation, (4) mapping urban-rural Normalized Difference Vegetation Index (NDVI), (5) selection of factors that determine the urban climate, and (6) effect of land surface modification and net radiation on the urban climate of Lagos metropolis.

3.1. Mapping changes in Urban-rural Landscape of Lagos metropolis

Based on the adopted urban-rural landscape classification scheme, Figure 2 shows changes in the urban area of Lagos metropolis for the period of 1984, 2000 and 2013 respectively. The urban-rural landscape map of Lagos metropolis uses the urbanized area to evaluate the impact of development on the open land around the city as presented in Figure 2.

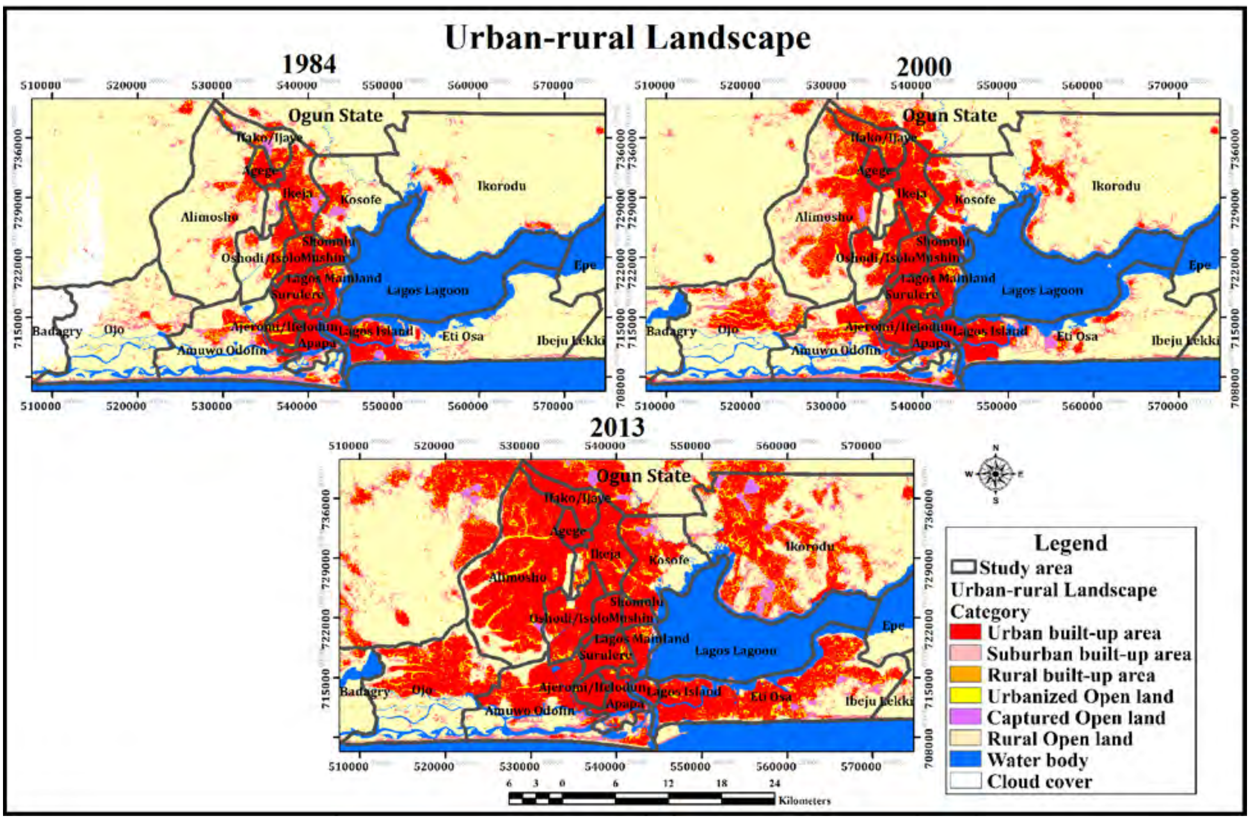

Figure 2. Urban-rural landscape of Lagos metropolis for 1984, 2000 and 2013.

Table 2a tabulates changes in the urban-rural landscape between 1984 and 2013 for Lagos metropolis. Based on Table 2a, urban built-up area constitutes 242.41Km^2 of the study area in 1984, 296.46Km^2 in 2000 and 563.28Km^2 in 2013. Suburban built-up area constitutes 68.14Km^2 of the study area in 1984, 69.37Km^2 in 2000 and 58.74Km^2 in 2013. Rural built-up area constitutes 8.14Km^2 of the study area in 1984, 4.95Km^2 in 2000 and 3.31Km^2 in 2013. Urbanized open land constitutes 169.07Km^2 of the study area in 1984, 158.04Km^2 in 2000 and 151.74 Km^2 in 2013. Captured open land constitutes 13.64Km^2 of the study area in 1984, 12.62Km^2 in 2000 and 14.31Km^2 in 2013. Water body constitutes 111.54Km^2 of the study area in 1984, 98.34Km^2 in 2000 and 85.26Km^2 in 2013. Urbanized area witness a rapid increase in 1984 by 493.26Km^2, 536.49Km^2 in 2000 and 788.07 Km^2 in 2013. While a rapid reduction was observed in rural area by 362.88Km^2 in 1984, 356.98Km^2 in 2000 and 118.50 Km^2 in 2013. The rate of change in the urban-rural landscape is presented in Table 2b; this reveals that rapid increase is witnessed in urban built-up area over the years from 54.05Km^2 between 1984 and 2000 to 270.02Km^2 between 2000 and 2013. While, a drastic reduction was observed in rural open land from -1.01Km^2 to -233.64Km^2 from 1984 to 2000 and 2000 to 2013. Also, an increase was observed in urbanized open land from -11.03Km^2 to -3.10Km^2, rural built-up area from -3.19Km^2 to 1.56Km^2, captured open land from -1.01Km^2 to 4.87Km^2 and water body from -13.2Km^2 to -13.08Km^2 from 1984 to 2000 and 2000 to 2013. It is noted that cities and their surrounding regions tend to experience intensive LUCC (land use/cover change) due to faster urban sprawl, more population, and intense human activities [38]. This is the case of Lagos metropolis between 1984 and 2013 with rapid increase in urban built-up area and reduction in urbanized open land and rural built-up areas (Figure 2). The result in Figure 2 reveals that Lagos metropolis is highly urbanized which could be assessed using the impact of the urban built-up area on the available surrounding open lands. Thus, landscape dynamics involving LULC changes have contributed to the increase in land surface temperature (LST) [39], [40]. Climatic differences, especially the temperature difference between urban and rural areas, always appear and keep increasing with urban sprawl and human aggregation [41].

Table 2. (a) Changes in the urban-rural landscape for Lagos metropolis between 1984 and 2013; and (b) Urban-rural landscape rate of change (ΔT_1-T_2) for Lagos metropolis between 1984 to 2000 and 2000 to 2013.

	(a)Urban-rural landscape change (Km^2)			**(b) Urban-rural landscape rate of change (Km^2)**	
Category	**1984**	**2000**	**2013**	**1984-2000**	**2000-2013**
No Data	24.14	0.00	0.00	-24.14	0.00
Urban built-up area	242.41	296.46	563.28	54.05	270.02
Suburban built-up area	68.14	69.37	58.74	1.23	-7.43
Rural built-up area	8.14	4.95	3.31	-3.19	1.56
Urbanized open land	169.07	158.04	151.74	-11.03	-3.10
Captured open land	13.64	12.62	14.31	-1.01	4.88
Rural open land	354.74	352.03	115.19	-2.72	-233.64
Water body	111.54	98.34	85.26	-13.20	-13.08

3.2. Mapping changes in the Urban-rural Temperature of Lagos metropolis

Land Surface Temperature (LST) for Lagos metropolis was derived from Landsat- TM 5, ETM+ 7 and OLI 8 thermal band for 1984, 2000 and 2013 as shown in Figure 3. In Lagos metropolis, LST minimum was observed to be 17.90°C, 21.25°C and 20.63°C for 1984, 2000 and 2013. LST maximum was observed to be 27.90°C, 35.80°C and 33.59°C for 1984, 2000 and 2013. While LST mean was observed to be 23.05°C, 25.99°C and 26.66°C for 1984, 2000 and 2013. Table 3 presents the urban-rural Land Surface Temperature (LST) of Lagos metropolis in 1984, 2000 and 2013. Based on the urban-rural Land Surface Temperature (LST) in Table 3, LST for the urban built-up area have a minimum of 20.20°C and a maximum of 27.90°C in 1984 with a mean of 24.76°C and a minimum of 22.67°C and a maximum of 35.80°C in 2000 with a mean of 27.99°C and a minimum of 21.46°C and a maximum of 33.60°C and a mean of 28.59°C in 2013. Suburban built-up area LST recorded a minimum of 19.30°C and a maximum of 27.30°C in 1984 with a mean of 23.61°C to 22.39°C minimum and 31.13°C maximum in 2000 with a mean of 27.08°C, and 20.79°C minimum and 32.61°C maximum with a mean of 25.37°C in 2013.

Rural built-up area LST recorded a minimum of 20.20°C and a maximum of 26.80°C in 1984 with a mean of 22.93°C and 22.10°C minimum and 30.07°C maximum in 2000 with a mean of 26.91°C, and 20.79°C minimum and 26.77°C maximum with a mean of 23.15°C in 2013. Urbanized open land LST recorded a minimum of 18.60°C and a maximum of 27.10°C in 1984 with a mean of 23.43°C, minimum of 22.10°C and 32.71°C maximum in 2000 with a mean of 26.66°C and 20.70°C minimum and 32.48°C maximum with a mean of 25.24°C in 2013. Captured open land LST recorded a minimum of 19.70°C and a maximum of 26.80°C in 1984 with a mean of 23.07°C, minimum of 23.23°C and 30.60°C maximum in 2000 with a mean of 25.87°C, and 20.70°C minimum and 30.14°C maximum with a mean of 24.20°C in 2013. Rural open land LST recorded a minimum of 17.90°C and a maximum of 26.80°C in 1984 with a mean of 22.02°C, minimum of 22.10°C and 30.87°C maximum in 2000 with a mean of 24.67°C, and 20.63°C minimum and 30.33°C maximum with a mean of 23.32°C in 2013. Water body LST recorded a minimum of 18.80°C and a maximum of 25.50°C in 1984 with a mean of 22.16°C, minimum of 21.25°C and 27.38°C maximum in 2000 with a mean of 22.91°C and 20.78°C minimum and 29.27°C maximum with a mean of 22.33°C in 2013.

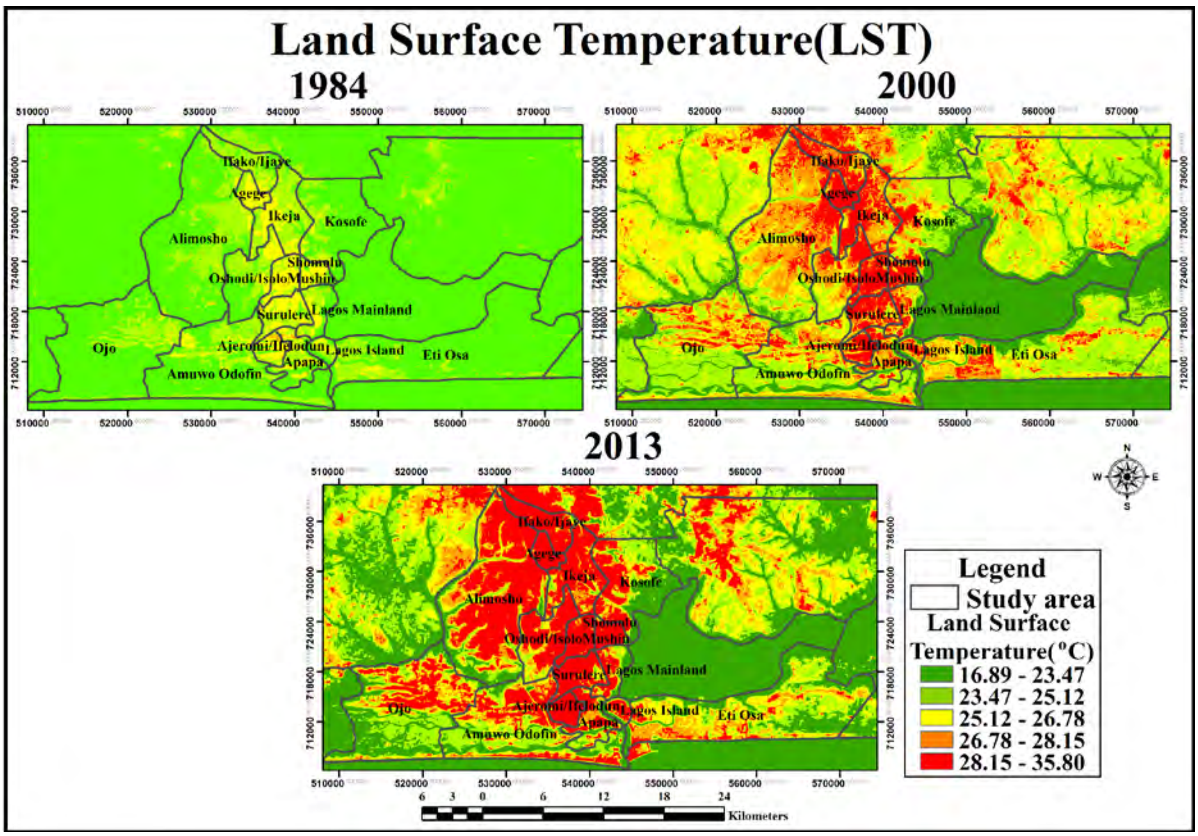

Figure 3. Land Surface Temperature (LST) of Lagos metropolis for 1984, 2000 and 2013.

Landscape dynamics involving LULC changes have contributed to increase in land surface temperature (LST). The different land use types indicate variability with different land surface temperatures [39], [40]. The dip and spike in surface temperatures over water bodies shows how water can maintains a fairly constant temperature, due to its high heat capacity [27]. It is evident from Table 3 that rural open land had showed a considerably low temperature in 1984, 2000 and 2013 when compared to urbanized and captured open lands. The result reveals that the leading cause of UHI is the modification of the land surface by urban development such as increase in urban built-up area. Land surface temperature (LST) varies from one place to another within the metropolitan area and some areas reflect high temperatures such as urban built-up area. The rising temperatures of urban built-up area are mainly caused by the thermal property of building materials, dark surfaces with low albedo and urban geometry [42], anthropogenic heat production, and finally, the geographic location of the urbanized area [43]. These are the major factors contributing to Urban Heat Island formation in Lagos metropolis.

Table 3. Urban-rural Land Surface Temperature (LST) (°C) of Lagos metropolis in 1984, 2000 and 2013.

Category	1984			2000			2013		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Urban built-up area	20.20	27.90	24.76	22.67	35.80	27.99	21.46	33.60	28.59
Suburban built-up area	19.30	27.30	23.61	22.39	31.13	27.08	20.79	32.61	25.37
Rural built-up area	20.20	26.80	22.93	22.10	30.07	26.91	20.79	26.77	23.15
Urbanized open land	18.60	27.10	23.43	22.10	32.71	26.66	20.70	32.48	25.24
Captured open land	19.70	26.80	23.07	23.23	30.60	25.87	20.70	30.14	24.20
Rural open land	17.90	26.80	22.02	22.10	30.87	24.67	20.63	30.33	23.32
Water body	18.80	25.50	22.16	21.25	27.38	22.91	20.78	29.27	22.33

3.3. Mapping changes in the Urban-rural Net Radiation of Lagos metropolis

Net radiation for Lagos metropolis was derived from Landsat- TM 5, ETM+ 7 and OLI 8 thermal band for 1984, 2000 and 2013 as shown in Figure 4. In Lagos metropolis for 1984, net radiation was found to be 272.04W/m^{-2}, 746.66W/m^{-2} and 449.43W/m^{-2} minimum, maximum and mean. In 2000, net radiation was found to be 189.23W/m^{-2}, 755.36W/m^{-2} and 376.80W/m^{-2} minimum, maximum and mean. While in 2013, net radiation was found to be 81.82W/m^{-2}, 596.28W/m^{-2} and 253.48W/m^{-2} minimum, maximum and mean. Table 4 presents the urban-rural net radiation of Lagos metropolis in 1984, 2000 and 2013. Based on Table 4, in 1984 urban built-up area net radiation was observed to be 316.84W/m^{-2} minimum and 746.66W/m^{-2} maximum with a mean of 512.50W/m^{-2}. Suburban built-up area net radiation was observed to be 333.22 W/m^{-2} minimum and 705.19W/m^{-2} maximum with a mean of 475.09W/m^{-2} in 1984. Rural built-up area net radiation was observed to be 330.74W/m^{-2} minimum and 649.40W/m^{-2} maximum with a mean of 449.80W/m^{-2} in 1984. Urbanized open land net radiation was observed to be 299.41W/m^{-2} minimum and 727.74W/m^{-2} maximum with a mean of 465.49 W/m^{-2} in 1984. Captured open land net radiation was observed to be 360.35W/m^{-2} minimum and 700.47W/m^{-2} maximum with a mean of 453.84W/m^{-2} in 1984. Rural open land net radiation was observed to be 272.04W/m^{-2} minimum and 713.73W/m^{-2} maximum with a mean of 413.90W/m^{-2} in 1984. Water body net radiation was observed to be 281.08W/m^{-2} minimum and 650.34W/m^{-2} maximum with a mean of 398.93W/m^{-2} in 1984. For net radiation in 2000, urban built-up area was observed to be 230.14W/m^{-2} minimum and 736.22W/m^{-2} maximum with a mean of 434.82W/m^{-2}. Suburban built-up area net radiation was observed to be 233.27W/m^{-2} minimum and 679.54W/m^{-2} maximum with a mean of 403.94W/m^{-2} in 2000. Rural built-up area net radiation was observed to be 235.08W/m^{-2} minimum and 638.03W/m^{-2} maximum with a mean of 394.14W/m^{-2} in 2000. Urbanized open land net radiation was observed to be 245.81W/m^{-2} minimum and 715.00 W/m^{-2} maximum with a mean of 402.09W/m^{-2} in 2000. Captured open land net radiation was observed to be 252.70W/m^{-2} minimum and 669.05W/m^{-2} maximum with a mean of 385.89W/m^{-2} in 2000. Rural open land net radiation was observed to be 212.25W/m^{-2} minimum and 755.36W/m^{-2} maximum with a mean of 340.21W/m^{-2} in 2000. Water body net radiation was observed to be 189.23W/m^{-2} minimum and 577.35W/m^{-2} maximum with a mean of 270.95W/m^{-2} in 2000. Also, for net radiation in 2013, urban built-up area was observed to be 97.16W/m^{-2} minimum and 596.28W/m^{-2} maximum with a mean of

299.02W/m^{-2}. Suburban built-up area net radiation was observed to be 90.68W/m^{-2} minimum and 507.11W/m^{-2} maximum with a mean of 231.42W/m^{-2} in 2013. Rural built-up area net radiation was observed to be 97.55W/m^{-2} minimum and 363.30W/m^{-2} maximum with a mean of 173.53W/m^{-2} in 2013. Urbanized open land net radiation was observed to be 99.27 W/m^{-2} minimum and 518.87W/m^{-2} maximum with a mean of 229.10W/m^{-2} in 2013. Captured open land net radiation was observed to be 123.52W/m^{-2} minimum and 418.07W/m^{-2} maximum with a mean of 201.23W/m^{-2} in 2013. Rural open land net radiation was observed to be 98.73W/m^{-2} minimum and 407.90W/m^{-2} maximum with a mean value of 179.90W/m^{-2} in 2013. Water body net radiation was observed to be 81.82W/m^{-2} minimum and 450.93W/m^{-2} maximum with a mean of 122.75W/m^{-2} in 2013.

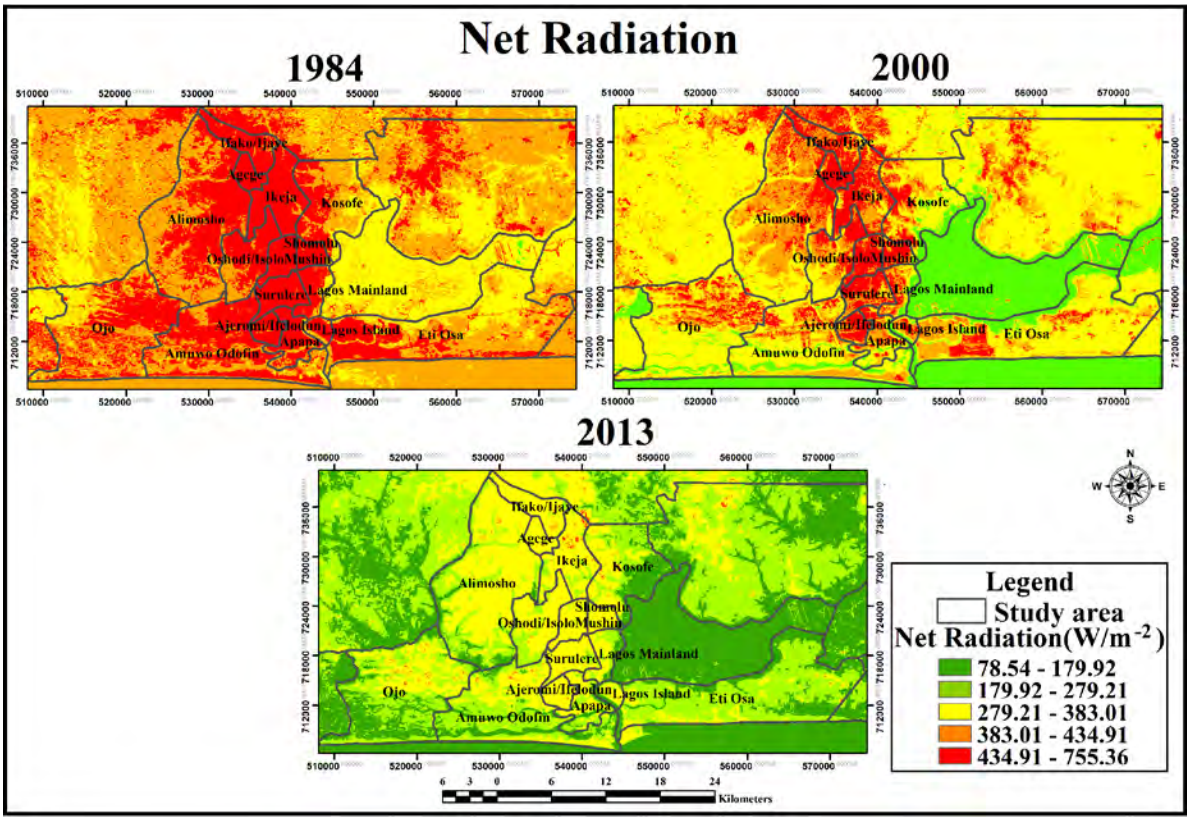

Figure 4. Net radiation of Lagos metropolis for 1984, 2000 and 2013.

Land cover changes such as urban landscaping, agriculture crops or hard scapes for building and parking lots promote variations in energy and radiation balance [14], [15]. The spatial distribution of net radiation at the time of acquisition in 1984/2/18 (at 9:33AM), 2000/02/06 (at 9:56AM) and 2013/03/25 (at 10:04AM) shows that the city is characterized by high net radiation and its highest value is located at the warmest part of the city or central part of Lagos metropolis spreading north, east and west to Ifako/Ijaye (impinging gradually upward to Ogun state), Eti Osa, Alimosho and Ojo LGA. The highest net radiation value observed corresponds to the hotter surfaces which comprises of urban (urbanized) areas in Lagos metropolis. The result is a complex interaction of net radiation spatially distributed, while the available energy for sensible heat flux and the local wind field drives the vertical fluxes. The urban areas have higher surface temperatures with low vegetation (albedo) and net radiation of 62.70W/m^{-2} higher than the rural areas in 1984, 40.68W/m^{-2} in 2000 and 125.49 W/m^{-2} in 2013. The spatial and temporal distribution of net radiation over time between 1984 and 2013 shows fluctuations in value stored in Lagos metropolis due to changes in vegetation. In urban areas, the low vegetation observed accompanied by high net radiation reflects the low surface albedo of Lagos metropolis (Table 5). Brazel and Quatrocchi [44] confirm this fact that the albedo is typically less in urban areas than in the surrounding landscape. Furthermore, Brazel and Quatrocchi [44] stress that the low albedo is due to the dark surface materials making up the urban mosaic and also, due to the effects of trapping shortwave radiation by the vertical walls and the urban canyon-like morphology. Urban built-up areas tend to have less evapotranspiration relative to rural built-up areas with natural landscape, because cities retain little moisture and are better absorber than the rural areas. This reduced moisture in urban built-up areas leads to dry, impervious urban infrastructures reaching very high surface temperature, which contribute to higher air temperature.

Table 4. Urban-rural net radiation (W/m^{-2}) of Lagos metropolis in 1984, 2000 and 2013.

Category	1984			2000			2013		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Urban built-up area	316.84	746.66	512.50	230.14	736.22	434.82	97.16	596.28	299.02
Suburban built-up area	333.22	705.19	475.09	233.27	679.54	403.94	90.68	507.11	231.42
Rural built-up area	330.74	649.40	449.80	235.08	638.03	394.14	97.55	363.30	173.53
Urbanized open land	299.41	727.74	465.49	245.81	715.00	402.09	99.27	518.87	229.10
Captured open land	360.35	700.47	453.84	252.70	669.05	385.89	123.52	418.07	201.23
Rural open land	272.04	713.73	413.90	212.25	755.36	340.21	98.73	407.90	179.90
Water body	281.08	650.34	398.93	189.23	577.35	270.95	81.82	450.93	122.75

3.4. Mapping changes in the Urban-rural Normalized Difference Vegetation Index (NDVI) of Lagos metropolis

Normalized Difference Vegetation Index (NDVI) for Lagos metropolis was derived from Landsat- TM 5, ETM+ 7 and OLI 8 using near-infrared and red bands for 1984, 2000 and 2013 as shown in Figure 5. In Lagos metropolis, NDVI ranged between -0.16 minimum to 0.73 maximum with a mean of 0.18 in 1984 to -0.44 minimum to -0.09 maximum with a mean of -0.27 in 2000 and -0.10 minimum to 0.48 maximum with a mean of 0.15 in 2013. Table 5 presents the urban-rural Normalized Difference Vegetation Index (NDVI) of Lagos metropolis in 1984, 2000 and 2013. Based on Table 5, in 1984 the NDVI of the urban built-up area was found to have a minimum of -0.39 and a maximum of 0.45 with a mean of -0.05. Suburban built-up area NDVI was found to have a minimum of -0.42 and a maximum of 0.53 with a mean of 0.02 in 1984. Rural built-up area NDVI was found to have a minimum of -0.34 and a maximum of 0.58 with a mean of 0.22 in 1984. Urbanized open land was found to have a minimum of -0.42 and a maximum of 0.63 with a mean of 0.21 in 1984. Captured open land NDVI was found to have a minimum of -0.26 and a maximum of 0.50 with a mean of 0.25 in 1984. Rural open land NDVI was found to have a minimum of-0.40 and a maximum of 0.73 with a mean of 0.39 in 1984. Water body NDVI was found to have a minimum of -0.62 and a maximum of 0.54 with a mean of -0.12 in 1984. While in 2000, urban built-up area NDVI was found to have a minimum of -0.41 and a maximum of -0.18 with a mean of -0.32. Suburban built-up area NDVI was found to have a minimum of -0.42 and a maximum value of -0.18 with a mean of -0.29 in 2000. Rural built-up area NDVI was found to have a minimum of -0.42 and a maximum of -0.16 with a mean of -0.26 in 2000. Urbanized open land NDVI was found to have a minimum of -0.39 and a maximum of -0.14 with a mean of -0.27 in 2000. Captured open land NDVI was found to have a minimum of -0.36 and a maximum of-0.14 with a mean of -0.24 in 2000. Rural open land NDVI has a minimum of -0.40 and a maximum of -0.01 with a mean of -0.21 in 2000. Water body NDVI has a minimum of-0.44 and a maximum of -0.20 with a mean of -0.36 in 2000. Furthermore, in 2013 the urban built-up area NDVI was found to have a minimum of -0.06

and a maximum of 0.43 with a mean of 0.12. Suburban built up area NDVI was found to have a minimum of -0.09 and a maximum of 0.43 with a mean of 0.17 in 2013. Rural built-up area NDVI was found to have a minimum of -0.06 and a maximum of 0.39 with a mean of 0.18 in 2013. Urbanized open land NDVI was found to have a minimum of -0.06 and a maximum of –0.46 with a mean of -0.25 in 2013. Captured open land NDVI was found to have a minimum of -0.07 and a maximum of 0.45 with a mean of 0.30 in 2013. Rural open land NDVI was found to have a minimum of -0.04 and a maximum of 0.47 with a mean of 0.31 in 2013. Water body NDVI was found to have a minimum of -0.10 and a maximum of 0.38 with a mean of -0.02 in 2013.

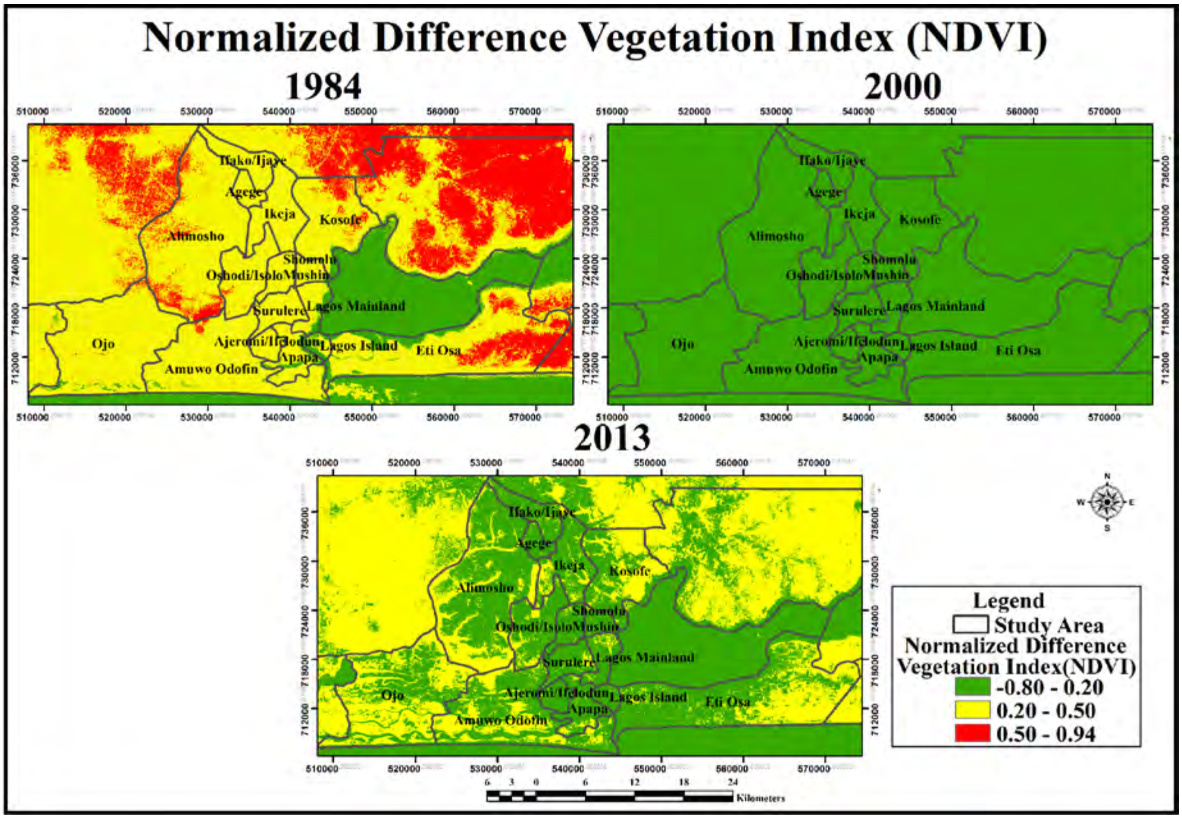

Figure 5. Normalized Difference Vegetation Index (NDVI) of Lagos metropolis for 1984, 2000 and 2013.

Table 5. Urban-rural Normalized Difference Vegetation Index (NDVI) of Lagos metropolis in 1984, 2000 and 2013.

Category	1984			2000			2013		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Urban built-up area	-0.39	0.46	-0.01	-0.41	-0.18	-0.32	-0.06	0.43	0.12
Suburban built-up area	-0.42	0.54	0.16	-0.43	-0.18	-0.29	-0.09	0.43	0.18
Rural built-up area	-0.35	0.59	0.23	-0.43	-0.16	-0.26	-0.06	0.39	0.18
Urbanized open land	-0.43	0.63	0.22	-0.39	-0.14	-0.27	-0.07	0.46	0.25
Captured open land	-0.27	0.51	0.25	-0.35	-0.14	-0.25	0.07	0.46	0.30
Rural open land	-0.40	0.73	0.40	-0.41	-0.09	-0.21	-0.05	0.48	0.31
Water body	-0.63	0.55	-0.12	-0.44	-0.20	-0.37	-0.11	0.38	-0.02

The spatial and temporal distribution of NDVI indicates the presence of surface modification as observed for 1984, 2000 and 2013 over the different urban-rural landscape, the urban built-up areas have a relatively low NDVI value, this indicates the presence of non-vegetation which ranges between 0.00 to 0.19 (Kamal et al. [45] affirms a range of NDVI < 0.2) compared to other land use classes such as captured open land and rural open land with low positive NDVI values ranging between 0.30 to 0.50 (Kamal et al. [45] affirms a range of low vegetation between 0.2 < NDVI < 0.4 to high vegetation, NDVI > 0.4), this indicates the presence of healthy vegetation. For the year 2000, all landscape has a very low NDVI value indicating the presence of a very low dense unhealthy, stressed and sparse vegetation and non-vegetation.

In this study, relationship was found to exist between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) as shown in Figure 6. The relationship between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) was investigated for the urban landscape using linear and logarithmic regression. Relationship was plotted on a scatter plot and the result indicates that a negative relationship exist with R^2 = 0.974 and 0.976 for a linear and logarithmic regression in 1984; 0.910 and 0.920 for a linear and logarithmic regression in 2000, and 0.474 and 0.460 for a linear and logarithmic regression in 2013 (Figure 6). From the analysis, Normalized Difference Vegetation Index (NDVI) was found to be a good indicator of changes in Land Surface Temperature (LST). This implies that the lower vegetation (albedo) a land cover has the higher the land surface temperature it produces as observed in Lagos metropolis. Also, the more the urban surface is modified with loss from vegetation the higher the LST. As cities develop, more vegetation is lost, and more surfaces are paved or covered with buildings such changes in ground cover results in less shade and moisture to keep urban areas cool. Built-up areas evaporate less water, which contributes to elevated surface and air temperatures [27]. Furthermore, the result reveals that logarithmic regression gives a better view and representation of the phenomena in question in Figure 6; logarithmic regression was picked because it gives a better fit, stronger R^2 value and a true sense to the validity of assumptions made.

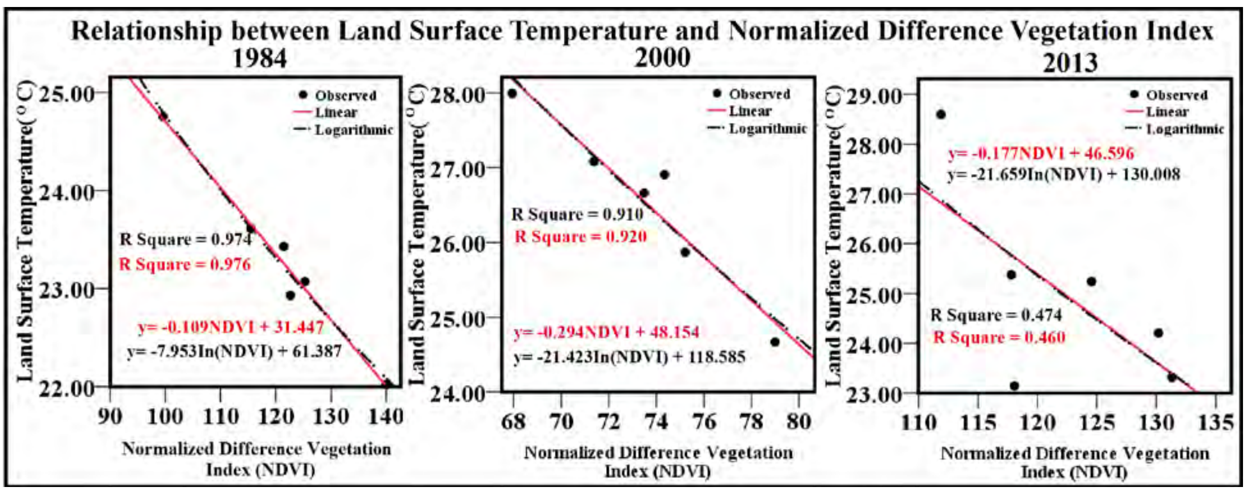

Figure 6. Relationship between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) for 1984, 2000 and 2013.

Also, in this study, relationship was found to exist between net radiation and Normalized Difference Vegetation Index (NDVI) as shown in Figure 7. The relationship between net radiation and Normalized Difference Vegetation Index (NDVI) was investigated for the urban landscape using linear and logarithmic regression. Relationship was plotted on a scatter plot and the result indicates that a negative relationship exist with R^2 = 0.982 and 0.975 for a linear and logarithmic regression in 1984; 0.937 and 0.927 for a linear and logarithmic regression in 2000; and 0.436 and 0.448 for a linear and logarithmic regression in 2013

(Figure 7). Normalized Difference Vegetation Index (NDVI) has been found to be a good indicator of changes in net radiation. This implies that the lower vegetation (albedo) a land cover has the higher the net radiation as documented by Brazel and Quatrocchi [44]. Furthermore, this reveals that the more the urban surface is modified with loss from vegetation the higher the net energy (net radiation) it stores. The result reveals that logarithmic regression was found to give a better view and representation of the phenomena in question in Figure 7; logarithmic regression was picked because it gives a better fit, stronger R^2 value and a true sense to the validity of assumptions made.

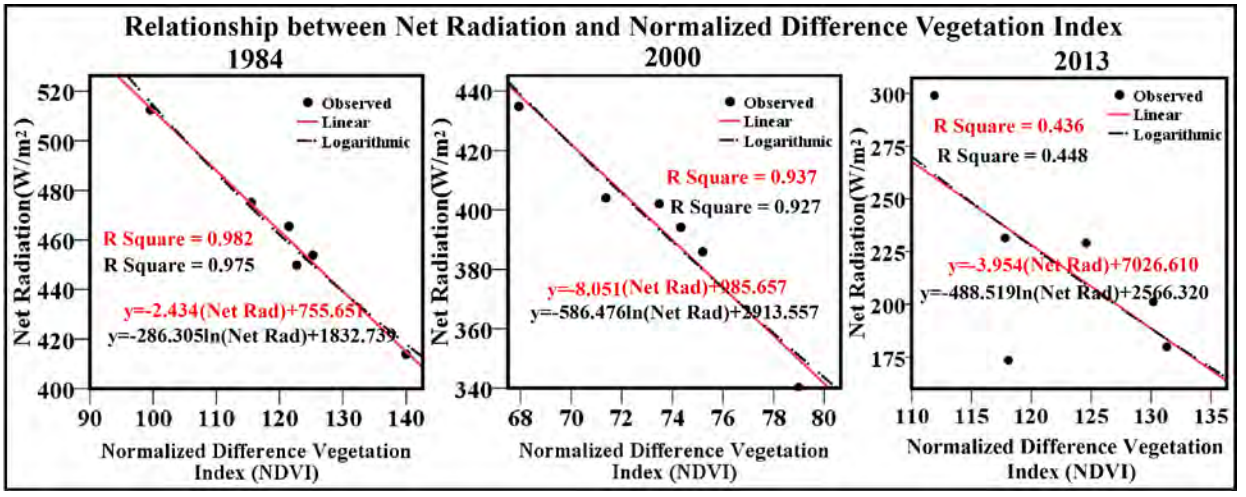

Figure 7. Relationship between net radiation and Normalized Difference Vegetation Index (NDVI) for 1984, 2000 and 2013.

3.5. Selection of factors that determine the urban climate of Lagos metropolis

In selecting synthesized factors of urban climate modification, factor analysis was used to generate causal mechanism responsible for urban climate modification and creation of UHI in Lagos metropolis. Using the correlation matrix in Table 6, a positive sign indicates an increase in relationship while a negative sign indicates a decrease in relationship. Net radiation negatively correlates with LST, NDVI and urbanized area, with the highest impact felt from NDVI. LST negatively correlates with net radiation, NDVI, and positively with urbanized area, with the highest impact felt from the urbanized area. NDVI negatively correlates with net radiation, LST and positively with urbanized area, with the highest impact felt from the urbanized area. Urbanized area negatively correlates with net radiation, positively correlates with LST, and NDVI, with the highest impact felt from LST.

Table 6. Correlation matrix[a]

Component	Net radiation	LST	NDVI	Urbanized area
Net radiation	1.00	-0.19	-0.26	-0.99
LST	-0.19	1.00	-0.89	0.28
NDVI	-0.26	-0.89	1.00	0.18
Urbanized area	-0.99	0.28	0.18	1.00

a. This matrix is not positive definite.

Based on the Eigen values in Table 7, the PCA explains that 52.65% of the variance within the study area could be explained by component 1, component 2 explains 47.34% of the variance while 0.00% of the variance could be explained by component 3 and 0.00% of the variance could explained by component 4. Since, component 1 is higher than component 2, 3 and 4, and component 2 is higher than component 3 and 4, the following selected factors such as: net radiation, LST, urbanized area and NDVI are factors that account for modification of the urban climate, and most of the variance within the study area can be explained by Column 1 and 2 (Component 1 and 2).

Table 7. Total variance explained

Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings	
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance
1	2.106	52.65	52.65	2.10	52.65	52.65	2.10	52.62
2	1.894	47.34	100	1.89	47.34	100	1.895	47.37
3	0.00	0.00	100					
4	0.00	0.00	100					

Extraction method: Principal Component Analysis.

Furthermore, applying Principal Component Analysis (PCA) extraction method as presented in Table 8, the result reveals that two components were selected which represents urban climate determinants. Selected factors are factors within the component with positive values. Component one correlates with LST, NDVI and highly correlates with the urbanized area. Component one reflects the effect of the urbanized area, LST and NDVI, because the urbanized area is highly correlated, the urbanized area was picked because it is a better representative and it is less correlated with LST and NDVI. This could be called the *effect of the urban area*. While component two is highly correlated with LST and correlates less with net radiation and urbanized area, LST was picked because it is a better representative. This could be called *the effect of land surface temperature*, also known as the *temperature of the urban surface*. Based on the selected components, heat island areas were selected to show the effect of land surface modification and net radiation on the climate of Lagos metropolis. Based on the above, the causal mechanism responsible for urban climate modification and creation of UHI in Lagos metropolis was synthesized using factors such as net radiation, LST, NDVI and urbanized area in this study for Lagos metropolis.

Table 8. Component matrix[a]

	Component	
	1	2
Net radiation	-0.99	0.11
LST	0.30	0.95
NDVI	0.15	-0.98
Urbanized area	1.00	-0.02

Extraction method: Principal Component Analysis [a]; a. components extracted.

For Table 9, applying Principal Component Analysis (PCA), two components were extracted and rotated using Varimax with Kaiser Normalization rotation method, known to represents urban climate determinants, driven by the effect of: (1) *urban area* and (2) *land surface temperature (LST) of Lagos metropolis*.

Table 9. Rotated component matrix[a]

	Component	
	1	**2**
Net radiation	-0.99	0.04
LST	0.23	0.97
NDVI	0.22	-0.97
Urbanized area	0.99	0.04

Extraction method: Principal Component Analysis; Rotation method: Varimax with Kaiser Normalization [a];
a. Rotation converged in 3 iterations

For component one, the urbanized area represent the urban area, NDVI represents the surface albedo and LST represents surface temperature due to changes in surface albedo and urban area. The effective surface area of the urbanized area is much larger than that of a rural area of equivalent size. The canyon-like topographic effect of the urban areas lowers the overall albedo (NDVI) of the entire urban area independent of the individual albedo of the surface materials. The urban area dominates the skyline and has a dramatic effect on the microclimate of Lagos metropolis which in-turn affects the surface temperature (LST). Urbanized area has a considerable impact on the climate of its immediate surrounding areas (known as Urban Heat Island). Some of these effects are the creation of heat sources and the dramatic changes observed in airflow and wind speed in cities of Lagos metropolis. The formation of UHI can be ascribed to increase in urban area which represents the urban fabric which possesses a much higher conductive capacity and greater ability to absorb and store day-time solar radiation and increase temperature heat effect of Lagos metropolis which in turn affect the microclimate. To affirm to the above, Bernard et al. [46] states that rapid urbanization leads to considerable changes in the climates of urban areas…in which the (surface) temperature in typical urban areas is higher compared to their adjacent rural environment. For component two, Land Surface Temperature (LST) was found to have a significant effect, and depends inversely on the thermal admittance of the urbanized area which represents the city growth, buildings and paved surfaces which replaces the natural landscape and leads to increase in ambient temperature while the urbanized area possess a greater ability to exchange heat by radiative and turbulent transfer through net radiation balance. Net radiation and urbanized area have less significant effect as urban climate determinants that affect the amount of heat transfer and heat reflected and radiation energy received by the urban surface which in-turn affects the surface temperature. This is influenced by the effects of the urban area and structures such changes could create urban climatic effects, which could be known as Urban Heat Islands effect. The formation of Urban Heat Island can be ascribed to the increase of temperature with effect from net radiation through absorption and trapping of solar radiation in urbanized area (urban fabrics). To affirm to the above, studies have shown that the expansion of urban areas is considered a significant factor for the change in…land surface temperature [47] [48].

However, four interactions were observed to produce the following effects as presented in Table 10: (1) Component one increases in all respects, this reflects that the effect of the urban area increases in all respects. Changes over time in the urban area, surface albedo and temperature heat effect all increases in all respects with profound effect felt from the urban area which modifies the urban climate. (2) Component one increases as component two increases in all respects. This implies that as component one, the effect of the urban area increase component two the temperature of the urban surface also increases. Changes over time in the urban area, surface albedo, net radiation all increases in all respects with profound effect felt from the urban area and Land Surface Temperature (LST), this modifies the urban climate. (3) Component two decreases as component one increases in all respects. Component two, the temperature of the urban surface decreases as component one which reflects the effect of the urban area increases. A decreased change over time in the effect of Land Surface Temperature (LST), urban area, and net radiation all decrease in all respects with profound effect felt from the urban area, Land Surface Temperature (LST) and surface albedo in component one, this modifies the urban climate. (4) Component two increases in all respects. Component two which reflects the temperature of the urban surface increases in all respects. Changes over time in Land Surface Temperature (LST), surface albedo and net radiation increases in all respects with profound effect felt from Land Surface Temperature (LST), this modifies the urban climate.

Table 10. Component transformation matrix

Component	1	2
1	0.99	0.07
2	-0.07	0.99

Extraction method: Principal Component Analysis; Rotation method: Varimax with Kaiser Normalization.

Finally in Table 11, factor 1 and 2 is inactive for 1984 to modify the urban climate, factor 2 (LST) is active (responsible) in 2000 to modify the urban climate and both factor 1 and 2 (i.e., urban area and LST) is active in 2013 to modify the urban climate of Lagos metropolis.

Table 11. Factors scores

	Factor 1	Factor 2
1984	-0.57	-1.01
2000	-0.59	0.99
2013	1.15	0.01

3.6. Effect of land surface modifications and net radiation on the urban climate of Lagos metropolis

Day-time Surface Urban Heat Island (UHI) was mapped from Land Surface Temperature (LST) using Landsat TM 5, ETM+ 7 and OLI 8 thermal band for 1984, 2000 and 2013 as shown in Figure 8a. Based on the selected components in Table 9, UHI areas were selected using LST and urban built-up area delineated from urbanized area. So, based on the mean LST of urban built-up area, UHI areas was defined as 24.76°C in 1984, 27.99°C in 2000, and 28.59°C in 2013. Urban Heat Island areas was selected to show the effect of LST and urbanized area on the urban climate which confirms the assertion that urbanization can have significant effects on the local weather and climate [25] with increased temperature in cities, termed Urban Heat Island (UHI). Figure 8a shows Surface Urban Heat Island (UHI) areas of Lagos metropolis for 1984, 2000 and 2013 respectively.

Figure 8b shows spatial extent of Surface Urban Heat Island and Non-surface Urban Heat Island areas in Lagos metropolis for 1984, 2000 and 2013. Based on Figure 8b, Surface Urban Heat Island (UHI) spatial extent was computed and defined as 147.06Km^2, 200.25Km^2 and 332.36Km^2 in 1984, 2000 and 2013. Non-surface Urban Heat Island spatial extent was computed and defined as 844.91Km^2, 791.72Km^2 and 659.61Km^2 in 1984, 2000 and 2013 respectively as presented in Figure 8b. This increase in Urban Heat Island areas has triggered Urban Heat Island effect within the urban areas of Lagos metropolis. Thus, within Urban Heat Island areas, a minimum of 24.90°C, 27.70°C maximum, 25.39°C mean in 1984; while in 2000, a minimum of 28.19°C, 35.80°C maximum, 28.71°C mean; and a minimum of 28.59^{o}C, 33.60°C maximum and 29.93°C mean in 2013 was observed.

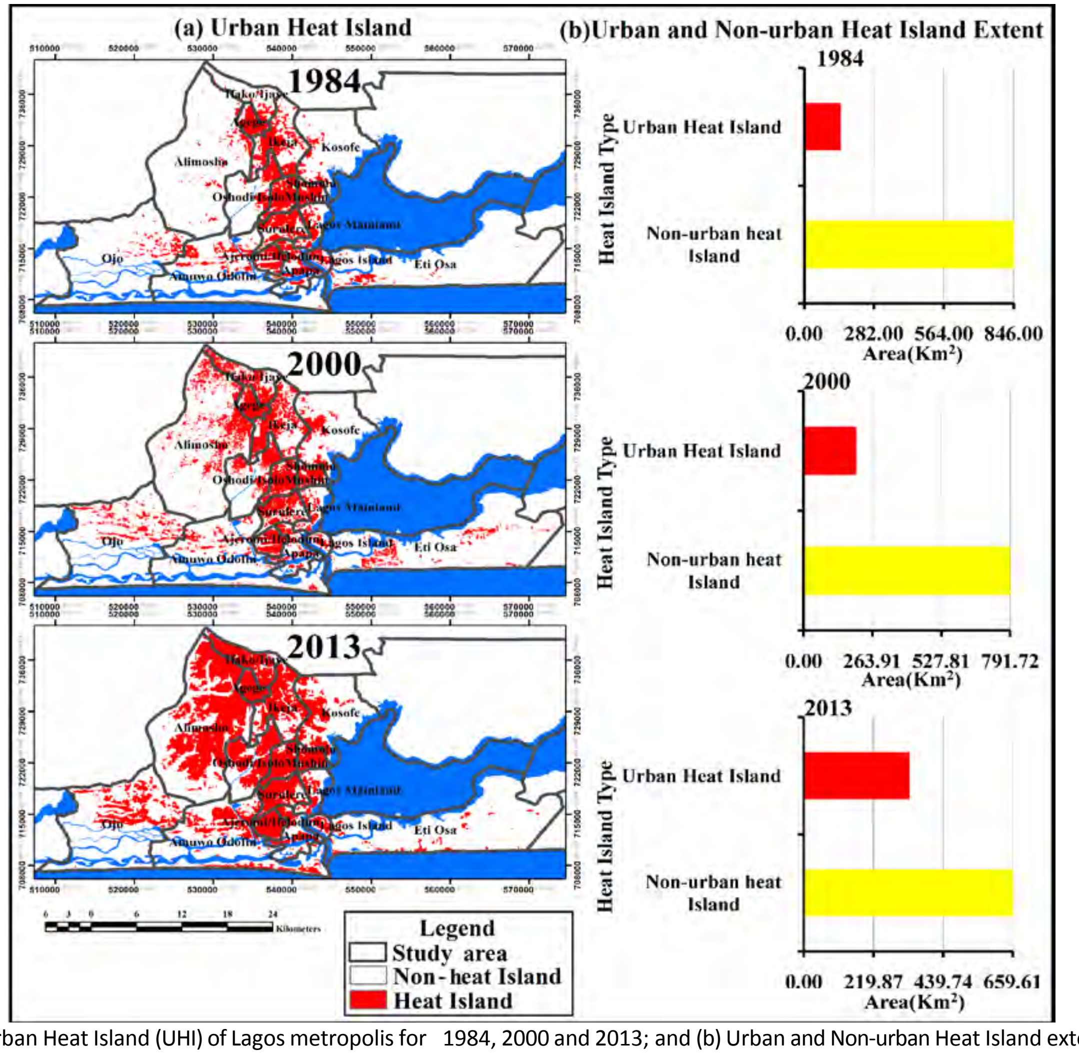

Figure 8. (a) Urban Heat Island (UHI) of Lagos metropolis for 1984, 2000 and 2013; and (b) Urban and Non-urban Heat Island extent in Lagos metropolis for 1984, 2000 and 2013.

Further studies show the synthesized effect of land surface modification and net radiation on the climate of Lagos metropolis which in-turn produces UHI, a linear and logarithmic relationship was investigated between UHI and net radiation, LST, urbanized area, and NDVI using a scatter plot as presented in Figure 9. In Figure 9a, positive relationship exist between UHI and net radiation with R^2 = 0.719 for a linear regression and 0.733 for logarithmic regression in 1984; 0.854 for linear regression and 0.728 for logarithmic regression in 2000; and 0.924 for linear regression and 0.783 for logarithmic regression in 2013. For Figure 9b, positive relationship exist between UHI and LST with R^2= 0.600 for linear regression and 0.622 for logarithmic regression in 1984; 0.576 for linear regression and 0.565 for logarithmic regression in 2000 and; 0.969 for linear regression and 0.957 for logarithmic regression in 2013. For Figure 9c, positive relationship exist between UHI and the urbanized area with R^2= 0.008 for linear regression and 0.030 for logarithmic regression in 1984; 0.001 for linear regression in 2000 and negative relationship exist with R^2 = 0.038 for logarithmic regression in 2000; and positive relationship exist with R^2 = 0.783 for linear regression and 0.427 for logarithmic regression in 2013. For Figure 9d, negative relationship exist between UHI and NDVI with R^2= 0.675 for linear regression and 0.701 for logarithmic regression in 1984; 0.222 for linear regression and 0.226 for logarithmic regression in 2000 and; 0.513 for linear regression and 0.527 for logarithmic regression in 2013.

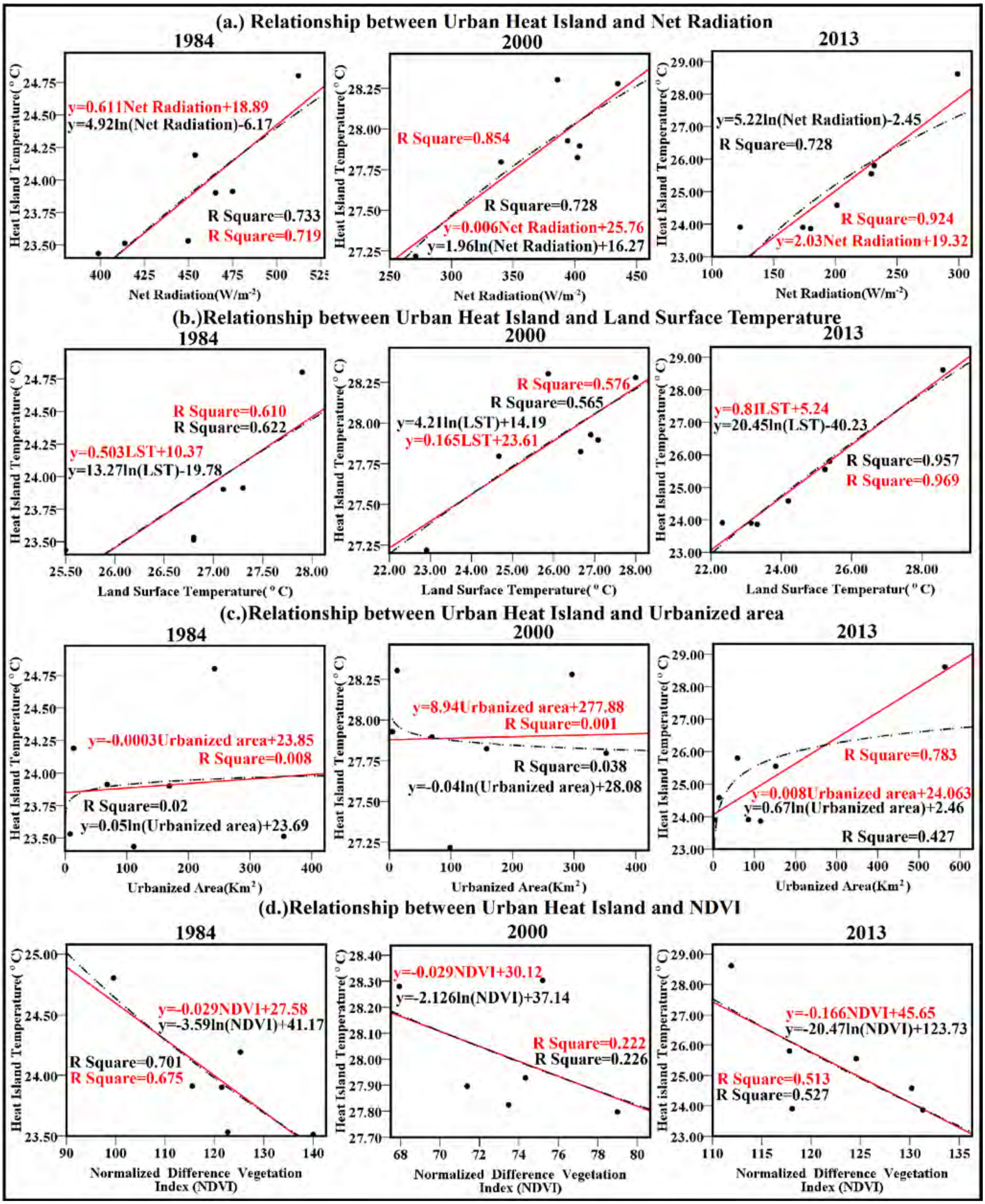

Figure 9. (a) Relationship between Urban Heat Island and net radiation; (b) Relationship between Urban Heat Island and LST; (c) Relationship between Urban Heat Island and urbanized area; and (d) Relationship between Urban Heat Island and NDVI.

During the day, generally, the derived net radiation is larger at the start of the day, net radiation relates positively strong with UHI (Figure 9a), LST relates positively strong with UHI (Figure 9b), urbanized area relates positively with a fairly strong relationship with UHI excluding 2000 for logarithmic regression (Figure 9c), and NDVI relates negatively strong with UHI in both linear and logarithmic regression (Figure 9d). Furthermore, from the result logarithmic regression was picked and found to give a better view and representation of the phenomena in question than a linear regression. The factors presented in Figure 9 tends to support the fact that urban climate could be modified by these factors due to difference in vegetation cover and urbanness of the urban area compared to the rural area which are largely responsible for daytime heat island as well as UHI effect across Lagos metropolis. The relationship reveals the contributing effect of the above mentioned factors on the climate of Lagos metropolis. These factors can categorically be divided into three: (1) net radiation, (2) indicators of urban surface modifications using Normalized Difference Vegetation Index (NDVI) and urbanized area, and (3) Land Surface Temperature (LST). These factors combine in a coherent form to modify the urban climate which is the driving force behind UHI studies in Lagos metropolis. Finally, changes in these factors have increased and produced the observed UHI effect experienced in cities around Lagos metropolis.

4. Conclusion and Recommendations

From this study, changes in the urban landscape have modified the urban surface leaving little or no vegetation as assessed using normalized difference vegetation index (NDVI), this in-turn have influenced net radiation which has elevated land surface temperature (LST), this was found to be the causes of Urban Heat Island in Lagos metropolis during the study period of twenty nine years between 1984 and 2013. In this study, statistics and GIS techniques were used to extract factors, identify the underlying mechanism responsible and account for changes that take place in the urban climate. Factors extracted include: urban area, LST, net radiation, and NDVI derived from Landsat TM 5, ETM+ 7 and OLI 8 satellite imagery for 1984, 2000 and 2013. These factors aids in studying the causes of Urban Heat Island (UHI) as well as map UHI areas in cognizance to the peculiarity of the urban centers as regards her climate traits or indifferences. With temperature increase in Urban Heat Island areas, there is need to introduce measures that would reduce the heat island effects of thermal discomfort [49] in Lagos metropolis. According to Ibeabuchi and Oni [49], measures adopted in mitigating Urban Heat Island include: (1) Those that would increase albedo in urban areas. Such measures include introducing structures using building material that would lead to cool rooftops; (2) Introducing more vegetation covers in urban heat island areas (between Ifako/Ijaye, Oshodi/Isolo down to Lagos Island axis). This could be achieved through: (a) Increase in urban vegetation e.g., trees, rooftop gardens, public parks, this will have a cooling effect on the urban area through evapotranspiration. (b) Trees should be planted strategically to shade the AC condenser units, windows, and roofing. (c) Trees should be planted to shade pedestrians; and (3) Introducing measures that would increase wind circulation (along Ifako/Ijaye, Oshodi/Isolo down to Lagos Island axis). In particular, it is significant to note that: (a) Increased wind circulation pattern diffuses heat from UHI areas; (b) Large cities that plan “street canyons” to coincide with the wind patterns will result in reduction of thermal discomfort from UHI; and (c) While narrow roads may be preferable to increase density, wider street canyons are preferable towards heat reduction.

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