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Mapping Urban Heat Island Areas in Ibadan

Feyi Oni[1], Uwadiegwu Ibeabuchi[2]*

[1,2]Department of Geography, Faculty of Social Science, University of Lagos, Lagos-Nigeria
onifeyi@gmail.com[1], *ibeabuchi09@gmail.com[2]

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Abstract

Today, across the world many urban areas are experiencing higher temperatures compared to their surrounding rural areas; this difference in temperature is known as Urban Heat Island (UHI). UHI has created temperature hotspots in our urban centers which are known as UHI areas. This study maps Urban Heat Island areas in Ibadan using remotely sensed data for 1984, 2000 and 2011. Land Surface Temperature (LST) and land use land cover (LULC) characteristics of Ibadan urban were examined. Also, Normalized Difference Vegetation Index (NDVI) was computed for the study area. Correlation analysis was performed, and the results reveals that in Ibadan urban a negative relationship exist as LST increase NDVI decrease. Furthermore, UHI areas were defined using the LULC and LST for 1984, 2000 and 2011. The result reveals that to map UHI areas, LST maximum and LULC conventionally regarded as UHI areas should be used, such as: high density residential areas, commercial/industrial area, and public/educational institution. The result presents an objective approach adopted to give us a detailed view of places that fall under UHI areas and account for their change through the study years. Based on findings, possible mitigation measures as means of controlling the menace of UHI were highlighted for the study area.

Keywords

Urban Heat Island, Land Surface Temperature, Land Use Land Cover, Normalized Difference Vegetation Index, Ibadan

1. Introduction

Man's development and construction of large cities has had a profound influence on the local climate [1]. Urbanization, the conversion of other types of land to uses associated with growth of populations and economy, is the most important type of land use and land cover change in human history [2]. Urban growth has had an increasingly significant socioeconomic and environmental impact at local, regional and global scales. In-turn, the level of pollution that is air, water and land has increased because of lack of poor environmental management. Data, given by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, reported that Nigeria's urban population was almost 3.5 million in 1950, this rose to about 78.8 million in 2010, and is expected to increase to about 217 million in 2050[3]. The estimate implies that by the year 2050, about seventy-five percent of Nigerian population will reside in urban areas [4]. The most staggering evidence of this projection can be seen in the continuous population growth of Ibadan urban. This explosive increase in the exponential form of “population growth” has caused havoc for the human life in the city environment. Doubling and tripling of urban population practically in all major cities and towns, and the consequent strain on the existing system manifest in environmental chaos [5]. In Ibadan urban, the rapid expansion of urban centres and their peripheries has led, in many cases, to a series of complex problems related to flooding, loss of agricultural land and natural vegetation, uncontrolled urban sprawl, increased traffic congestion and degradation of air and water quality which could be seen to increase due to high density and industrial area increase. This in-turn has produced Urban Heat Island effects. Ojo [6] defines Urban Heat Island as a metropolitan area within a city which is relatively warmer than its immediate environment.

Over the past few decades (from 1980 to date) Urban Heat Island has been a nightmare to government, planners, citizens and other stake holders [7]. Such that planners, government, architects, scientist, environmentalist and geographers have adhered to the mantra that urban sprawl increases pollution and housing costs, more driving time to work and shopping, stress, and the escalating consumption of scarce farmland and open space. Irrefutable evidence, however, have shown that urban planning and zoning areas creates the very nightmares which it is supposed to eliminate [7]. Christopherson [8] states that the physical characteristics of urbanized regions produce Urban Heat Island that has on the average both maximum and minimum temperature higher than nearby rural settings. Jensen [9] also states that it is well known that Urban Heat Island exists over most urban areas compared to the relatively cooler non-urban surrounding countryside. According to Cao et al. [2], this alteration will inevitably result in the redistribution of incoming solar radiation and induce the urban-rural contrast in surface radiance and air temperatures. Lockwood [10], states that the changes in the surface conditions will usually modify the local radiation and water balance and therefore change the local climate. The extent of the built environment, population size and density, anthropogenic activity, and socio-economic aspects of a city play a critical role in determining the effect of urbanization on temperature variation [11], [12]. Urban Heat Island, an anthropogenic generated phenomenon, is a distinct surface signature of human habitation. Urban Heat Island occurs when an urban center is warmer than its surrounding environment. This effect may be up to 10^{o}C warmer, although there is considerable variation due to different local environments and atmospheric conditions [13]. Heat Islands of varying extent and magnitude have been observed in most urbanized areas in the world [14]. Furthermore, Ojo [6] stressed that within a city you can have more than one heat island. While change in the energy balance of the urban area often leads to higher temperatures than surrounding rural areas [15], this contributes to the development of Urban Heat Island. In other words, heat Islands develop when a large fraction of the natural land cover in an (urban) area is replaced by built surfaces that trap incoming solar radiation during the day then re-radiate it at night [15],[16].

Due to variations in Urban Heat Island effect and its lower magnitude during the day, very limited research is available to study daily variations of urban heat in cities when the Urban Heat Island effect threatens usability of outdoor public spaces [17], [18], [19]. In response to substantial excess heat in cities, people increasingly move into air-conditioned buildings to benefit from indoor thermal comfort. Meanwhile, resultant anthropogenic heat generated from indoor air-conditioning causes an ever-increasing outdoor temperature. There are several impacts associated with Urban Heat Island, and the most recurrent are: (1) Influence on local microclimate (contributing to an increase in surface temperature, reduced relative humidity and latent heat, and intensified sensible heat); (2) Changes in the displacement of air masses, precipitation, hydrological behavior (such as displacement of water bodies) [20], [21]; (3) Thermal discomfort [22]; (4) Socio-environmental and public health impacts [15], [23]; (5) Increase in mortalities when combined with natural phenomena such as Heat Waves [24].

In this research, remote sensing technique was adopted as an indirect measurement to study and predict (Surface) Urban Heat Island areas in Ibadan urban. This method is a quantitative remote sensing study of temperature changes, a promising application, currently still limited. Also, this approach is not subjective as early believed and adopted but objective. It gives us a detailed view and places that fall under Urban Heat Island areas [7], [25]. This approach as well shows us areas that may not qualify for Urban Heat Island when subjective method was used but could be included in this objective approach. This approach has explained the fact that remote sensing is an objective method and technically quantifies Urban Heat Island, while, transverse method is a subjective approach in studying the phenomena. In addition, Urban Heat Island has created temperature hotspots in our urban centers which are known as Urban Heat Island areas. Remote sensing approach forms a suitable means to give us detailed view of areas that fall under Urban Heat Island conventionally using the LULC to assess such changes. The objectives of this research include: (1) To examine land use land cover change in Ibadan from 1984 to 2011; (2) To derive and study changes in land surface temperature in Ibadan from 1984 to 2011; and (3) To map Heat Island areas in Ibadan for 1984, 2000 and 2011. For proper comprehension, this study is divided into four sub titles, namely: (a) assessing changes in the land use land cover; (b) assessing changes in the land surface temperature; (c) assessing changes in vegetation density; and finally, (d) mapping Urban Heat Island areas in Ibadan between 1984 and 2011 using GIS techniques.

2. Study Area

Ibadan is the capital and most populous city in Oyo State. It is located in Southwestern Nigeria, 128 km inland Northeast of Lagos and 345 km Southwest of Abuja, the federal capital and is a prominent transit point between the coastal region and the areas to the North [26]. Ibadan is located between Longitude 591714.71 meters Easting to 605334.71 meters Easting (3°50'East to 3°58' East) and Latitude 822840.25 meters Northing to 808260.11 meters Northing (7° 26'North to 7° 19'North). Figure 1 shows the location of Ibadan urban indicating Oyo State and Nigeria for details.

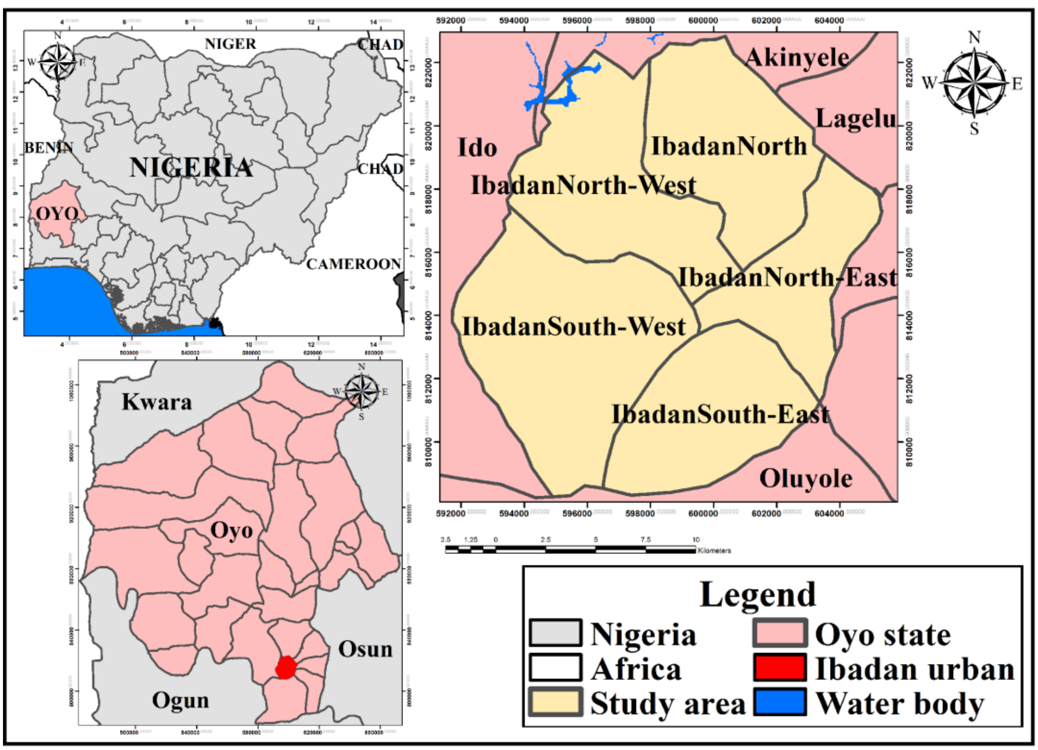

Figure 1. Ibadan urban geographical location with inset maps of Nigeria and Oyo State for details.

It borders Olouyole and Ona Ara Local Government Area (LGA) to the South, Akinyele LGA to the North, Ido LGA to the East, and Egbeda and Lagelu LGA to the West (Figure 1). Furthermore, Ibadan is the third-largest city by population after Lagos and kano. The population of Ibadan is 1,326,506 residents according to 2006 Census result [27] and estimated to be 3, 649,000 residents in 2021. Ibadan (also known as *Ibadan urban*) is divided into five LGAs [26] covering 135.96km² and it includes: Ibadan North, Ibadan Northeast, Ibadan Northwest, Ibadan Southwest, and Ibadan Southeast. Presently, Ibadan is a metropolitan area consisting of five LGA and six surrounding (semi-urban) LGA mentioned above and officially extent to cover an area of 3080 km².

3. Methodology

The methodology adopted for this research includes:

3.1 Data collection

The data collected for this study is classified into primary and secondary data. Primary data includes: Field survey (GPS reading and ground trotting) conducted to help understand and get first-hand information about the land use and Urban Heat Island areas throughout the study area which is useful to assess the dynamics of change. Secondary data used for this study includes: (a) Landsat-5 Thematic Mapper (TM) and 7 Enhanced Thematic Mapper Plus (ETM+) Imagery. This was acquired from United State Geological Survey (USGS)-Earth Explorer (website) for 1984, 2000 and 2011 with a path/row of 191/55. The image and spectral characteristics are presented in Table 1; (b) Administrative map of Ibadan and Nigeria in GIS vector format (ESRI shapefile). This was acquired from the Department of Geography, University of Lagos, Akoka, Nigeria; (c) Mean temperature data for Ibadan. This was obtained from NIMET (Nigerian Meteorological Agency) station in Oshodi, Lagos (Nigeria) for 1984, 2000 and 2011; (d) High resolution satellite imagery. This was acquired for 1984, 2000 and 2011 from Google Earth Pro 7.3 edition 2017 with a resolution between 15 meters to 15 centimeters; and (e) Review of existing literatures.

Table 1. Landsat-5 TM and 7 ETM + imagery acquired and characteristics.

Satellite	**Sensor**	**Spectral Range**(μm)	**Band**	**Scene Size**(Km^2)	**Pixel Resolution**(meters)
L 5	TM multi-spectral	0.45 - 2.35	1, 2, 3, 4, 5, 7	185 x 185	30
L 5	TM TIRS *	10.40 - 12.50	6		120
L 7	ETM+ multi-spectral	0.450 - 2.35	1, 2, 3, 4, 5, 7		30
L 7	ETM+ TIRS *	10.40 – 12.50	6.1, 6.2		60
L 7	Panchromatic	0.52-0.90	8		15

L- Landsat*;* * TIRS -Thermal Infrared Sensor

3.2 Method adopted for Land Use Land Cover classification

Landsat imagery for 1984, 2000 and 2011 were used to create a Land Use Land Cover (LULC) map by selecting band 4, 5 and 7 (Table 1). Image mosaicking was not performed because one image scene was used (path/row-191/55), while, procedures performed includes: enhancement and creation of composite image used for training sites. The images were already rectified to a common UTM coordinate system, i.e., 31N. The LULC was classified using supervised classification method, the following steps were adopted which includes: definition of training sites, extraction of signatures and classification of the remotely sensed imagery using maximum likelihood classification procedure into ten classes, namely: *High- and low-density residential area, bare ground/open space, agricultural land, other built-up area, public/educational institution, commercial/Industrial* *service, forest land, wetland* and *water body*. The above procedure was implemented in Idrisi Andes software. The accuracy of LULC maps was compared with Google Earth Pro imagery and estimated to be 80.40%, 85.10% and 99.70% accurate for 1984, 2000 and 2011 from Crosstabs procedure in IBM SPSS Modeler 17 software.

3.3 Method of deriving Land Surface Temperature

Landsat thermal imagery (band 6 and 6.2) (Table 1) for 1984, 2000 and 2011 was processed to extract Land Surface Temperature (LST) using Idrisi Andes software image calculator. Digital number (*DN*) values of Landsat ETM+ 7 was converted to spectral radiance value using published post-launch gains, which was calculated using the following equation:

$$L_\lambda = \frac{(L\min - L\max)}{255} \times DN + L\min \quad (1)$$

For Landsat TM 5, radiance was computed through the following equation:

$$L_\lambda = offset + gain \times DN \quad (2)$$

In the next step, the spectral radiance is converted to Brightness temperature (T_B) at satellite sensor using the following equation:

$$T_B = \frac{K_2}{\ln[(K_1 / L_\lambda) + 1]} \quad (3)$$

Where, *offset*, *gain*, K_1 *and* K_2 = User defined parameters but K_1= W/m^{-2}sr^{-1}µm^{-1} and K_2 = Kelvin (K); 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; and T_B=Brightness temperature (K). From equation 4, correction for emissivity was carried-out and the conversion was done as follows:

$$T_{LST}(K) = \frac{T_B}{1 + \lambda \times T_B / \rho \times \ln \varepsilon} \quad (4)$$

Where, T_{LST} (K) = Land Surface Temperature (Kelvin); λ= Wave length of emitted radiance (µm); ρ=h × (c/σ) = 1.438×10^{-2} (m K); σ = 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; T_B=Brightness temperature (K); and ε = Emissivity in the range between 0 and 1.Emissivity (ε) [28] was computed as:

$$\varepsilon = \textstyle\int_v \varepsilon_v + (1 - \int_v)\, \varepsilon_s \quad (5)$$

Where, ε= Composite emissivity, ε_v = Vegetation emissivity, ε_s= Soil emissivity, and $\int_v$ = Fractional vegetation cover. Fractional vegetation cover was computed using the following equation [29] and expressed as:

$$f_v = 1 - \left(\frac{NDVI - NDVI_{Min}}{NDVI_{Max} - NDVI_{Min}} \right)^\alpha \quad (6)$$

Where, *NDVI*= Normalized Difference Vegetation Index (see equation 8 for derivation details); $NDVI_{Max}$ = *NDVI* for complete vegetation cover; $NDVI_{Min}$ = *NDVI* for bare soil; α = Coefficient function of leaf orientation distribution within the canopy, where erectophile to planophile canopies have values between 0.6 and 1.25. A value of 0.6 was used in this current investigation. The fractional vegetation cover was compared with limited ground observations and the results were consistent. Emissivity was estimated using the derived fractional vegetation cover and specified emissivity of soil and vegetation. Using equation 7, LST was converted from Kelvin to Degree Celsius (°C) and expressed as:

$$T_{LST}(°C) = T_{LST}(K) - 273.16 \tag{7}$$

Where, T_{LST} (°C) = Land Surface Temperature (Degree Celsius) and T_{LST} (K) = Land Surface Temperature (Kelvin).

3.4 Method of deriving Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (*NDVI*) is a simple numerical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not [30]. *NDVI* for 1984, 2000 and 2011 was calculated using Idrisi Andes image calculator as:

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \tag{8}$$

Where, $\rho_{nir:}$ = Spectral reflectance measurements acquired in the near-infrared regions and ρ_{red}= Spectral reflectance measurements acquired in the red regions, respectively. *NDVI* value is transformed from -1 to 1 into an 8 bit value image. The scale value was used in statistical analysis using correlation model. *NDVI* value was scaled to remove negative value for easy computation using IBM SPSS Modeler 17 software [7]. Scaled NDVI [7] was computed using Idrisi Andes image calculator as:

$$\text{Scaled NDVI} = (\text{NDVI - 1}) \times 100 \tag{9}$$

3.5 Statistical Model adopted

3.5.1 Pearson Correlation Coefficient

Pearson Correlation Coefficient was used to determine relationship between LST and *NDVI* in Ibadan for 1984, 2000 and 2011. Correlation statistics is expressed as:

$$r = \frac{N\sum XY - \left(\sum X\right)\left(\sum Y\right)}{\sqrt{N\sum X^2 \;\; - \left(\sum X\right)^2 N\sum Y^2 \left(\sum Y\right)^2}} \tag{10}$$

Where, r = Correlation coefficient, N = Total number of sample or parameters, X = Independent variable, Y = Dependent variable, and Σ= Summation function. The model was computed in IBM SPSS Modeler 17 software using Bivariate Correlation.

3.5.2 Root Mean Square Error

Root Mean Square Error (RMSE) method was used to validate temperature derived from Landsat imagery for 1984, 2000 and 2011. The validation consists of comparing LST to observed temperature, with respect to their mean, and RMSE. RMSE is expressed as:

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{a_i - b_i}{N}} \tag{11}$$

Where, a = Temperature derived (from LST) and b =Temperature observed (from NIMET station) and N= Total number of sampled stations. T-test statistics was used to conclude whether the two datasets are significantly different from one another or not for 1984, 2000 and 2011. The above procedure was executed in Microsoft Excel 2010 software formulas and functions.

3.6 Mapping Urban Heat Island areas

Land use land cover (LULC) was used as a criteria to define areas conventionally regarded as Urban Heat Island areas, namely as: *High density residential areas, commercial/industrial areas, and public/educational institution*, sometimes *low density residential areas* depending on the level of the density. Areas conventionally not regarded as Urban Heat Island areas are *forest land, wetland, water body, and agricultural land* [7], [25]. Using the LULC and LST (maximum) as criteria, Urban Heat Island areas for Ibadan were defined for 1984, 2000 and 2011. The above procedure was implemented in ArcGIS 10 software.

4. Results and Discussion

For proper comprehension, the results is divided into the following areas which include: (i) assessing changes in the land use land cover; (ii) assessing changes in the land surface temperature; (iii) assessing changes in the vegetation density; and finally, (iv) mapping Urban Heat Island areas in Ibadan between 1984 and 2011.

4.1 Assessing changes in the Land Use Land Cover of Ibadan between 1984 and 2011

Land use land cover (LULC) for 1984, 2000 and 2011 is shown in Figures 2 for Ibadan derived from Landsat TM 5 and ETM+ 7 imagery. Table 2 shows the distribution in LULC in Ibadan for 1984, 2000 and 2011. The LULC pattern in Ibadan shows that agricultural land increased from 1.79Km^2 in 1984 to 5.10Km^2 in 2000 and then, decreased to 4.05Km^2 in 2011. While, commercial/industrial services decreased from 15.59 to 7.88Km^2 from 1984 to 2000, then increased to 8.19Km^2 in 2011. Forest land reduced from 1.29 to 0.01Km^2 from 1984 to 2000 and increased to 0.11Km^2 in 2011. Low density residential areas increased from 46.42 to 39.58Km^2 and then decrease to 23.80Km^2 for 1984, 2000 and 2011. High density residential areas increased from 7.34 to 21.57Km^2 and then to 27.23Km^2 in 1984, 2000 and 2011. Bare ground/open space increased from 1.26 to 1.28Km^2 and then to 3.29Km^2 for 1984, 2000 and 2011. Public/educational institution increased from 28.65 to 34.44 Km^2 and then to 40.27Km^2 in 1984, 2000 and 2011. These changes as shown in Figure 2 and simplified by Table 2 imply that built-up area has increased at the expense of forest land, agricultural land and water body in 2000 and 2011. From the above result in Figure 2 in compliment to other studies reveals that continued growth in Ibadan population has resulted in drastic changes in the LULC pattern of the area over the past few decades [31], [32], [33]. This change has enhanced the incident radiation absorbed, capacity of heat retained and heat conducted in the region [34], which in-turns increase the radiating surface temperature of the area [35].

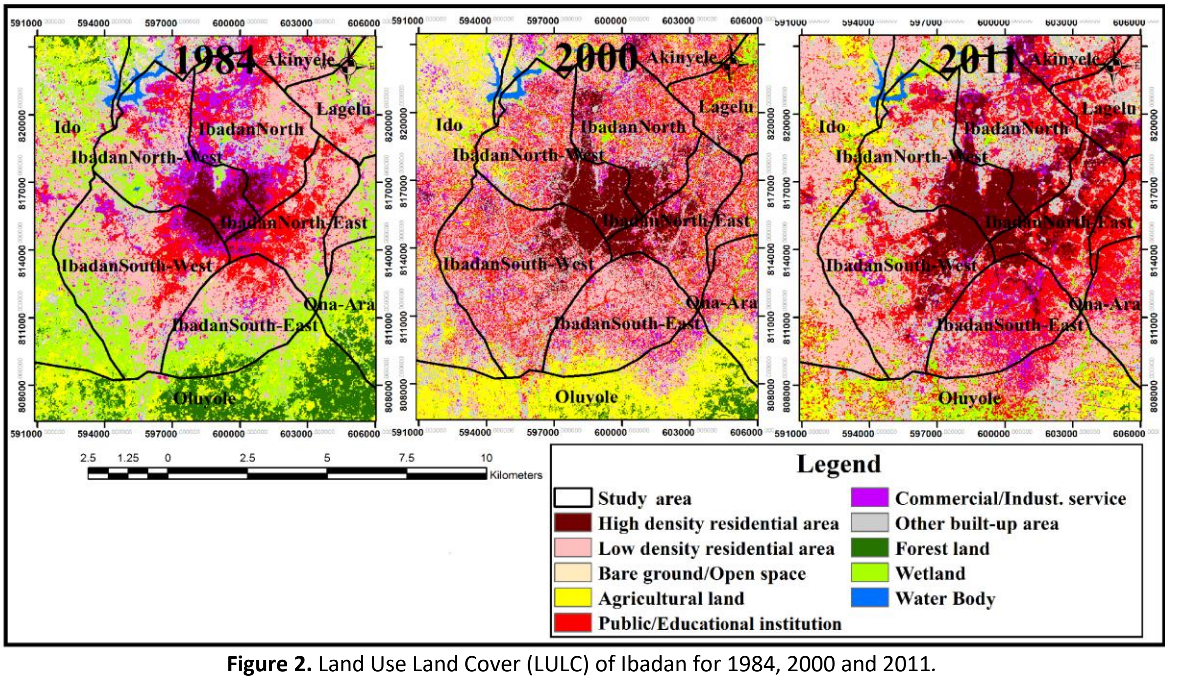

Figure 2. Land Use Land Cover (LULC) of Ibadan for 1984, 2000 and 2011.

Table 2. Land use land cover distribution (Km²) in Ibadan for 1984, 2000 and 2011.

Land Use Land Cover Class	1984	2000	2011	Land Use Land Cover Class	1984	2000	2011
High density residential area	7.34	21.57	27.23	Commercial/Industrial service	15.60	7.88	8.19
Low density residential area	46.41	39.58	23.80	Other built-up area	13.77	22.07	24.45
Bare ground/Open space	1.26	1.28	3.29	Forest land	1.30	0.01	0.11
Agricultural land	1.80	5.10	4.05	Wetland	19.03	3.43	4.14
Public/Educational institution	28.65	34.44	40.27	Water body	0.80	0.60	0.43

4.2 Assessing changes in the Land Surface Temperature of Ibadan between 1984 and 2011

Land Surface Temperature (LST) was computed using thermal band from Landsat imagery for 1984, 2000 and 2011. Land Surface Temperature for Ibadan is shown in Figure 3. Land Surface Temperature for the Local Government Areas (LGAs) is tabulated in Table 3. Ibadan Northeast, Northwest, North, and Southeast in 1984 have mean LST values between 25.88°C to 26.12°C and Ibadan Southeast have low mean LST of 24.75°C. For 2000, Ibadan Northeast, Northwest, and Southwest have high mean LST values between 27.91°C to 28.22°C alongside Ibadan North and Southeast with a high mean LST value of 28.23°C and 27.99°C. In 2011, Ibadan Northeast, Northwest and North have high mean LST values between 28.73°C to 28.07°C alongside Ibadan Southeast and Southwest with a high mean LST value between 26.87°C to 26.69°C.

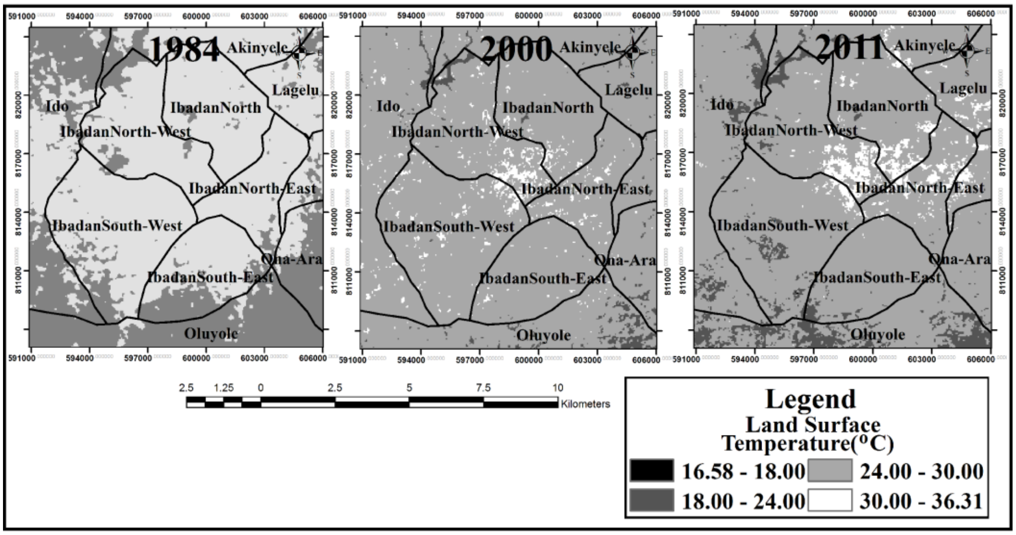

Figure 3. Land Surface Temperature (LST) of Ibadan for 1984, 2000 and 2011.

Table 4 show the spatial distribution of LST for the LULC of Ibadan in 1984, 2000 and 2011. High density residential area have a minimum LST of 25.10°C, 28.90°C maximum and mean of 27.85°C for 1984, and for 2000, 24.91°C minimum, 36.31°C maximum with a mean of 29.26°C and for 2011, 24.91°C minimum, 31.66°C maximum and 29.36°C mean. Low density residential area LST have 22.40°C minimum, 28.90°C maximum with a mean of 25.47°C for 1984, while for 2000, 16.58°C minimum, 32.44°C maximum with a mean of 27.88°C and for 2011, 18.06°C minimum, 30.87°C maximum with a mean of 26.50°C. Bare ground/open space LST have 21.60°C minimum, 28.90°C maximum with a mean of 24.42°C for 1984, while for 2000, 21.82°C minimum, 32.44°C maximum with a mean of 27.69°C and for 2011, 15.39°C minimum, 32.18°C maximum with a mean of 26.60°C. Commercial/industrial service LST have 22.90°C minimum, 28.90°C maximum with a mean of 26.41°C for 1984 and for 2000, 17.47°C minimum, 32.71°C maximum with a mean of 28.34°C, while in 2011, 13.57°C minimum, 37.57°C maximum with a mean of 27.66°C. Agricultural land LST have 21.60°C minimum, 26.30°C maximum with a mean of 22.91°C for 1984 and for 2000, 21.54°C minimum, 31.13°C maximum with a mean of 25.84°C, while in 2011, 21.54°C minimum, 28.46°C maximum with a mean of 24.38°C. Public/educational institution LST have 23.30°C minimum, 29.30°C maximum with a mean of 26.63°C for 1984 and for 2000, 22.10°C minimum, 32.44°C maximum with a mean of 27.77°C and for 2011, 18.94°C minimum, 31.40°C maximum and 27.50°C mean. Other built-up areas LST have 22.00°C minimum, 28.00°C maximum with a mean of 24.75°C for 1984, while for 2000, 21.82°C minimum, 32.44°C maximum with a mean of 27.75°C and for 2011, 22.39°C minimum, 30.87°C maximum with a mean of 26.66°C. Forest land LST have 21.60°C minimum, 26.30°C maximum with a mean of 22.31°C for 1984, while for 2000, 22.10°C minimum, 28.19°C maximum with a mean of 23.95°C and for 2011, 21.82°C minimum, 25.46°C maximum with a mean of 23.16°C. Wetland LST have 22.00°C minimum, 26.80°C maximum with a mean of 23.90°C for 1984, while for 2000, 21.25°C minimum, 30.87°C maximum with a mean of 25.94°C and for 2011, 20.39°C minimum, 29.27°C maximum with a mean of 24.41°C. Water body LST have 22.00°C minimum, 25.50°C maximum with a mean of 22.46°C for 1984 and for 2000, 21.25°C minimum, 30.60°C maximum with a mean of 23.38°C, and for 2011, 21.10°C minimum, 24.63°C maximum and 22.84°C mean.

It is evident from Figure 3 that the LST varies from one place to another within the metropolitan area, and some areas reflect high temperatures between 1984 and 2011. The rising temperatures of some regions are mainly caused by the thermal property of building materials, dark surfaces with low albedo and urban geometry [36], anthropogenic heat production [37], and finally, the geographic location of the urbanized area [38]. The dip and spike in surface temperatures over water bodies show how water can maintain a fairly constant temperature, due to its high heat capacity [39]. While, forest land have the lowest LST followed by agricultural land because of its high albedo. The highest LST is observed in high density residential area, commercial/industrial service and public/educational institutions because its surface property is impervious with low albedo which store and emit more heat. The above result in consensus with the growing body of literatures have revealed that LULC is directly associated with increase in (urban) LST and is a significant indicator and factor of available Urban Heat Island formation [37, 40, 41, 42].

Finally, model validation was performed using the Root Mean Square Error (RMSE) method. This test is based on the observed temperature compared with derived LST. The computed value of RMSE is 6.89 (6 degree of freedom at α=0.05) which implies that the result is acceptable and statistically significant. The RMSE model quantitatively assess the capability of LST model in predicting different changes in temperature when compared with the temperature observed (from NIMET station in Oshodi) for 1984, 2000 and 2011.

Table 3. Land Surface Temperature (°C) of the Local Government Areas in Ibadan for 1984, 2000 and 2011

Local Government Area(LGA)	1984			2000			2011		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Ibadan Northeast	22.00	28.90	25.88	21.82	36.31	27.91	21.53	32.18	28.07
Ibadan Northwest	22.00	29.30	26.12	22.67	32.44	28.53	23.52	31.66	28.73
Ibadan North	22.00	28.90	25.77	21.24	32.18	28.23	22.10	31.66	27.53
Ibadan Southeast	21.60	28.00	24.75	23.79	31.40	27.99	22.10	30.60	26.87
Ibadan southwest	22.00	28.90	25.41	16.58	32.71	28.22	13.39	31.40	26.69

Table 4. Land Surface Temperature (°C) of the land use land cover for 1984, 2000 and 2011 in Ibadan.

Land Use Land Cover Class	1984			2000			2011		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
High density residential area	25.10	28.90	27.85	24.91	36.31	29.26	24.91	31.66	29.36
Low density residential area	22.40	28.90	25.47	16.58	32.44	27.88	18.06	30.87	26.50
Bare ground/Open space	21.60	28.90	24.42	21.82	32.44	27.69	15.39	32.18	26.60
Agricultural land	21.60	26.30	22.91	21.54	31.13	25.84	21.54	28.46	24.38
Public/Educational institution	23.30	29.30	26.63	22.10	32.44	27.77	18.94	31.40	27.50
Commercial/ Industrial service	22.90	28.90	26.41	17.47	32.71	28.34	13.57	37.57	27.66
Other built-up area	22.00	28.00	24.75	21.82	32.44	27.75	22.39	30.87	26.66
Forest land	21.60	26.30	22.31	22.10	28.19	23.95	21.82	25.46	23.16
Wetland	22.00	26.80	23.90	21.25	30.87	25.94	20.39	29.27	24.41
Water body	22.00	25.50	22.46	21.25	30.60	23.38	22.10	24.63	22.84

4.3 Assessing changes in the Vegetation Density of Ibadan between 1984 and 2011

Vegetation density was computed using Normalized Difference Vegetation Index (NDVI) derived using near-infrared and red bands from Landsat imagery for 1984, 2000 and 2011. The NDVI value ranges between 1 to -1, the value of 1(high) represents pixels covered by substantial proportion of healthy vegetation while the value of -1 (low) represents pixels covered by non-vegetated surface including water, man-made features, and bare soil, dead or stressed vegetation. Normalized Difference Vegetation Index for Ibadan is shown in Figure 4.

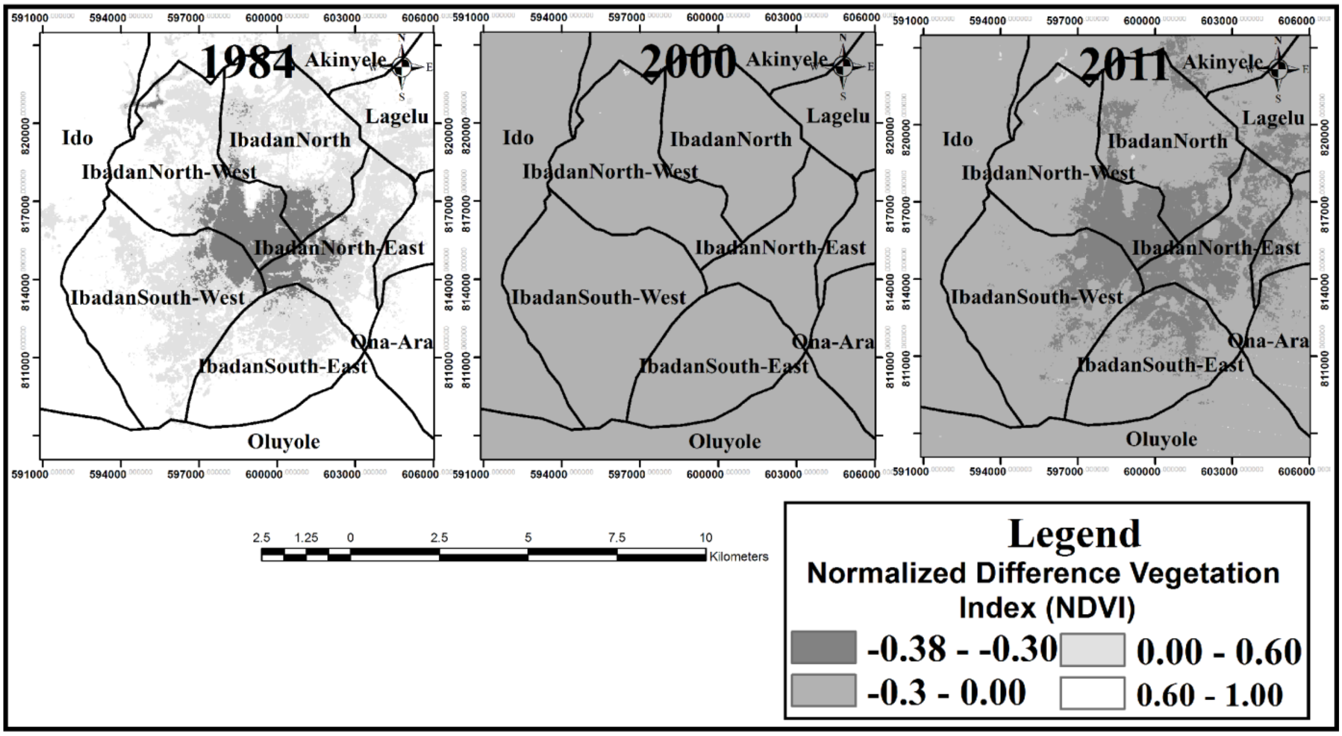

Figure 4. Normalized Difference Vegetation Index (NDVI) of Ibadan for 1984, 2000 and 2011.

Table 5 shows the spatial distribution of NDVI for the LULC of Ibadan for 1984, 2000 and 2011. As presented in Table 5 between 1984 and 2011, forest land have the highest NDVI, while, commercial/industrial service have the lowest. High and low density residential area have low NDVI due to urban development which has converted the natural vegetation into impervious surface which is non-evaporating and non-transpiring such as metal, asphalt and concrete. In 1984, NDVI range between -0.06-0.34 indicates the presence of non-vegetation to a not very green area with the presence of very few healthy vegetation. NDVI in 2000 and 2011 between -0.22-0.04 is characterised by a drastic reduction in healthy vegetation which is replaced by non-vegetated surface including water, man-made features, bare soil, and dead or stressed vegetation.

The relationship between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) was investigated for the LULC through correlation analysis as presented in Figure 5 between 1984 and 2011. Based on Figure 5, it was observed that LST correlate negatively with NDVI between 1984 and 2011 for Ibadan urban. The correlation can be visualized by plotting the mean LST against NDVI as shown in Figure 5 with R^2= 0.56 in 1984, 0.30 in 2000 and 0.56 in 2011 for Ibadan urban. The negative correlation between LST and NDVI implies that the lower vegetation (albedo) a land cover has, the higher the LST. Thus, the correlation between LST and NDVI reveals that changes in land cover have an indirect impact on LST.

Table 5. Normalized Difference Vegetation Index of the land use land covers between 1984 and 2011 for Ibadan.

Land Use Land Cover Class	1984			2000			2011		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
High density residential area	-0.06	0.12	-0.02	-0.38	-0.15	-0.32	-0.37	-0.19	-0.32
Low density residential area	-0.03	0.29	0.11	-0.36	-0.02	-0.24	-0.32	1.00	-0.21
Bare ground/Open space	-0.03	0.30	0.17	-0.37	-0.04	-0.21	-0.32	0.02	-0.20
Agricultural land	0.09	0.34	0.23	-0.34	0.01	-0.17	-0.30	1.00	-0.11
Public/Educational institution	-0.05	0.26	0.03	-0.36	-0.02	-0.24	-0.38	1.00	-0.25
Commercial/ Industrial service	-0.06	0.25	0.05	-0.36	-0.05	-0.25	-0.36	1.00	-0.27
Other built-up area	-0.03	0.27	0.13	-0.38	-0.03	-0.24	-0.34	1.00	-0.21
Forested land	0.04	0.29	0.23	-0.23	0.01	-0.11	-0.26	0.06	-0.06
Wetland	0.01	0.30	0.19	-0.33	0.04	-0.16	-0.30	1.00	-0.12
Water body	-0.02	0.26	0.06	-0.36	0.02	-0.27	-0.32	0.01	-0.24

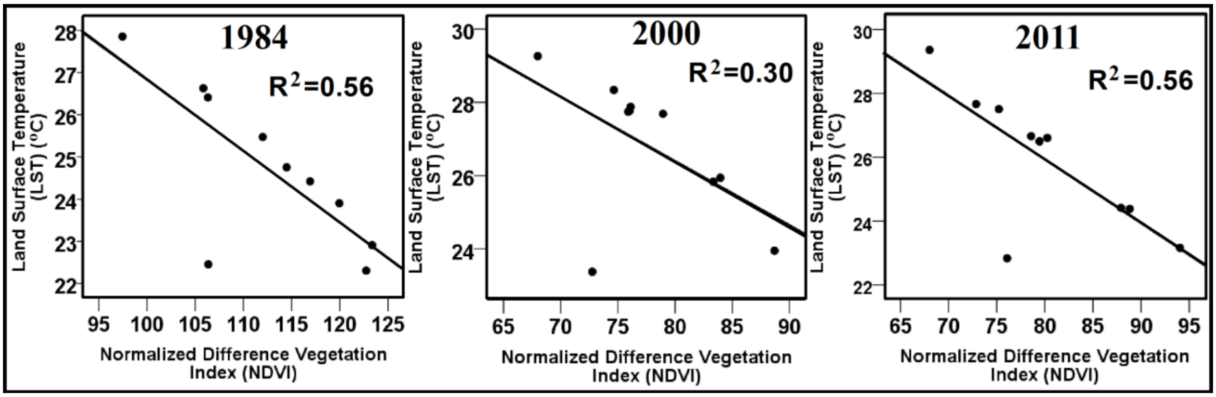

Figure 5. Relationship between Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) in 1984, 2000 and 2011 for Ibadan.

4.4 Mapping Urban Heat Island Areas in Ibadan between 1984 and 2011

Urban Heat Island areas were mapped from thermal band from Landsat imagery for Ibadan as presented in Figure 6 for 1984, 2000 and 2011. Using the LULC and its LST (maximum) as criteria as presented in Table 4, Urban Heat Island areas for Ibadan was defined as 26.00°C in 1984, 26.00°C in 2000 and 28.00°C for 2011. In Ibadan, high and low residential density areas, public/educational institutions and commercial/industrial services meet the criteria of Urban Heat Island areas between 1984 and 2011.

However, based on the above, with major comparison from previous studies available, Urban Heat Island can be studied as: (1) Point location or weather station [43]; (2) Selected studies using transect research or automobile data collection [44, 45, 46, 47]; (3) Weekday–weekend differences [48]; and (4) Selected areas assumed to be Urban Heat Island areas studied without bias [7], for example, areas with high population density, high traffic, commercial and industrial areas where pollution concentration is high.

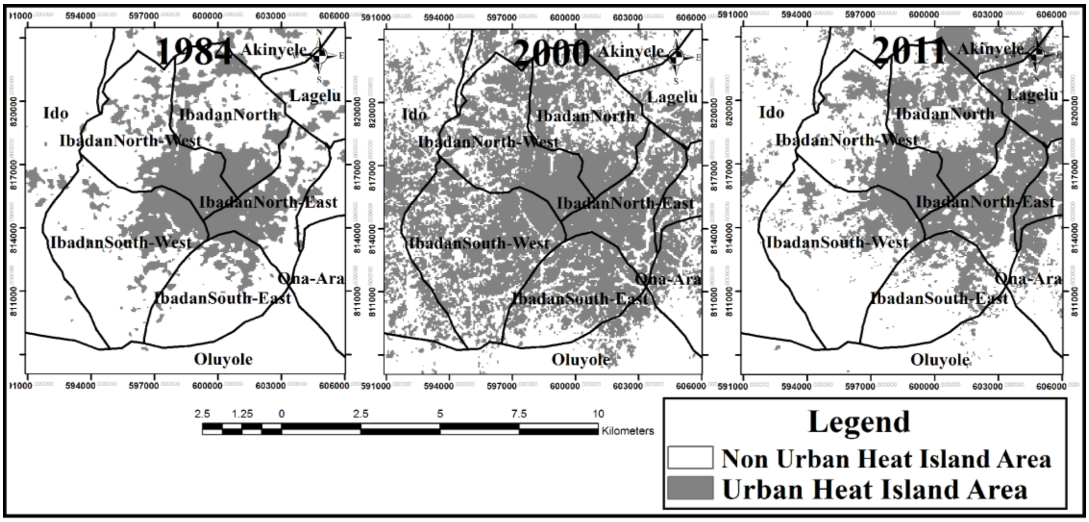

Figure 6. Urban Heat Island areas in Ibadan for 1984, 2000 and 2011.

5. Conclusion

From the research human factors and urbanization has been one of the major causes of Urban Heat Island in Ibadan. Using GIS and remote sensing approach allows for overlay and extraction of factors which aids in identification and location of Heat Island areas. A conceptual background of causes, problems and future consequences of Urban Heat Island areas were x-rayed in cognizance to the peculiarity of the urban centers as regards her climate traits or indifferences. GIS techniques were used to extract present temperature which gives us a picture of what the future changes in temperature and heat island areas will look like. With temperature increase in Urban Heat Island areas, there is need to introduce measures that would reduce the heat island effects of thermal discomfort in Ibadan. According to Ibeabuchi and Oni [25], the following measures should be adopted in mitigating Urban Heat Island which includes: (1) increasing the surface albedo and introducing structures using building materials that would lead to cool rooftops. (2) Introducing more vegetation covers in Urban Heat Island areas like Old Quarter Area, Alaafar Road, Ode Aje Road, Odo Oje Oloolu Road, Ibadan Oyo Road by Oke Aremo Street, and Yemetu Street. In particular: (a) Increase urban vegetation, e.g., trees, rooftop gardens, public parks like Mokola hills, will increase the cooling effects through evapotranspiration within and around the city; (b) Trees should be planted strategically to shade the AC condenser units, windows, and roofing; (c) Trees should be planted to shade pedestrians in major and minor roads like Lagos Ojo Expressway and Orita Apeni Bere Road. (3)Introducing measures that would increase wind circulation along major roads like Ibadan Oyo Road and Basorun Roads area in the study area. In particular, it is significant to note that: (a) Increased wind circulation patterns will diffuse heat from Urban Heat Island areas;(b) Large cities that plan "street canyons" to coincide with wind patterns will reduce the effect of thermal discomfort from Urban Heat Island; and (c) While, narrow roads may be preferable to increase density, wider street canyons are preferable towards heat reduction.

References

[1]. R.G. Barry, and R.J. Chorley, *Atmosphere, weather and climate*, *6th* ed. London, U.K. and New York, NY, USA: Routledge, 1992.

[2]. L. Cao, P. Li., L. Zhang, and T.C. State, "Remote sensing image-based analysis of the relationship between Urban Heat Island and vegetation fraction," in *XXIst ISPRS Congr., Techn. Comm. VII*, J. Chen, J. Jiang, and J. Van Genderen, Eds. Beijing, China, Jul. 2008, pp. 1379 -1384.

[3]. United Nations Department of Economic and Social Affairs/Population Division, "*World urbanization prospects: The 2003 revision*," United Nations Digital Library, 2003. [Online]. Available: https://digitallibrary.un.org/record/639679?ln=en [Accessed: Dec. 2, 2022].

[4]. O.O. Akiyode, "Urban environmental security in developing economy mega-city: A case study of Lagos, Nigeria," *J. Sustain. Develop. Afric*a, vol. 12, no. 5, Fall 2010.

[5]. A. Rahman, and M. Netzband, "An assessment of urban environmental issues using remote sensing and GIS techniques: An integrated approach. A case study: Delhi, India," in *Proc. Urban population-environment dynamics in the developing world: Case studies and lessons learned*, A. De Sherbiniin, A. Rahman, A. Barbieri, J.C. Fotso, and Y. Zhu, Eds. 2009, pp. 182- 211.

[6]. O. Ojo, *The climates of West Africa*. London, U.K.: Heinemann Educational Books, 1982.

[7]. U. Ibeabuchi, "A study of Urban Heat Island areas in Lagos metropolitan area, Abeokuta and Ibadan urban using satellite imagery," M. Sc. thesis, Dept. of Geo., Univ. of Lagos, Lagos, Nigeria, 2010.

[8]. R.W. Christopherson, *Geosystems: An introduction to physical geography*, *5th* ed. Indiana, IN, USA: Prentice hall, 2003.

[9]. J.R. Jensen, *Remote sensing of the environment: An earth resources*, *2nd* ed. New Jersey, NJ, USA: Pearson Prentice hall, 2007.

[10]. J.G. Lockwood, *World climatology: An environmental approach*. London, U.K.: Edward Arnold, 1974.

[11]. X.L. Chen, H.M. Zhao, P.X. Li, and Z.Y. Yin," Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes," *Rem. Sens. Environ.*, vol. 104, issu. 2, pp.133-146, Sept. 2006.

[12]. T.R. Oke, *Boundary layer climates*, *2nd* ed. London, U.K. and New York, NY, USA: Routledge, 1987.

[13]. B.Y. Tam, W.A. Gough, and T. Mohsin, "The impact of urbanization and the urban heat island effect on day to day temperature variation," *Urban Climate*, vol. 12, pp. 1-10, Jun. 2015.

[14]. H.E. Landsberg, The urban climate. New York, NY, USA: Academic Press, 1981.

[15]. T.R. Oke, "The energetic basis of urban heat island," Quart*. J. Roy. Meteorol. Soc.*, vol. 108, issu. 455, pp. 1-24, Jan. 1982.

[16]. D. Quattrochi, J. Luvall, D. Rickman, M. Estes, C. Laymon, and B. Howell," A decision support information for urban landscape management using Thermal infrared data," *Photo. Eng. Rem. Sens.*, vol. 66, no. 10, pp. 1195-1207, Oct. 2000.

[17]. M. Nikolopoulou, "Urban open spaces and adaptation to climate change," In *Applied urban ecology: A global framework*, M. Richter, and U. Weiland, Eds., U.K.: Blackwell Publishing, 2011, pp. 106–122.[Online]. https://doi.org/10.1002/9781444345025.ch9

[18]. M. Santamouris, C. Cartalis, and A. Synnefa, "Local urban warming, possible impacts and resilience plan to climate change for the historical center of Athens, Greece," *Sustain. Cities Soc*., vol. 19, pp. 281–291, Dec. 2015.

[19]. E. Sharifi, A. Sivam, and J. Boland, "Resilience to heat in public space: A case study of Adelaide, South Australia," *J. Environ. Plan. Manage.*, vol. 59, issu. 10, pp. 1833–1854, 2016.

[20]. T.R. Oke, G. Mills, A. Christen, and J.A. Voogt, *Urban climate*. Cambridge, U.K.: Cambridge University Press, 2017.

[21]. M.A.B. Romero, *Architecture of the place. A bioclimatic vision of sustainability in Brasilia*. Sao Paulo, Brazil: Nova Editorial Technique, 2011.

[22]. A. Qaid, H.B. Lamit, D.R. Ossen, and R.N.R. Shahminan, "Urban heat island and thermal comfort conditions at micro-climate scale in a Tropical planned city," *Energy Build*., vol. 133, pp. 577–595, Dec. 2016.

[23]. I.D. Stewart, and T.R. Oke, "Local climate zones for urban temperature studies," *Bull. Ame. Meteorol. Soc*., vol. 93, issu. 12, pp. 1879–1900, Dec. 2012.

[24]. D. Li, and E. Bou-Zeid, "Synergistic interactions between urban heat islands and heat waves: The impact in cities is larger than the sum of its parts," *J. Appl. Meteorol. Climatol*, vol. 52, issu. 9, pp. 2051–2064, Sep. 2013.

[25]. U. Ibeabuchi, and F. Oni, "An assessment of urban heat islands within Abeokuta area, South-western Nigeria," *Lagos J. Geo. Issu.*, vol. 1, issu. 1, pp. 25-42, 2013.

[26]. O.G. Ogunremi, Ed. *Ibadan: A historical, cultural and socio-economic study of an Africa city*. Lagos, Nigeria: Oluyole Club, 2000.

[27]. Federal Republic of Nigeria Official Gazette, "Legal notice on publication of 2006 census final results," Federal Government Printer, Abuja, Nigeria, FGP16/22009/10,000 (OL02), Feb. 2, 2009.

[28]. J.A. Sobrino, N. Raissouni, and Z-Li, "A comparative study of land surface emissivity retrieval from NOAA data," *Rem. Sens. Environ.*, vol. 75, issu. 2, pp. 256– 266, Feb. 2001.

[29]. B.J. Choudhury, N.U. Ahmed, S.B. Idso, R.J Reginato, and C.S.T. Daughtry, "Relations between evaporation coefficients and vegetation indices studied by model simulation," *Rem. Sens. Environ.*, vol. 50, issu. 1, pp. 1–17, Oct. 1994.

[30]. J.W. Rouse Jr., R. Haas, J. Schell, and D. Deering, "Monitoring vegetation systems in the great plains with erts," in *3rd Earth Res.Technol. Satell. Symp.*, Greenbelt, WA, USA, Dec. 10-14, 1973, pp. 301-317.

[31]. Y-C. Weng, "Spatiotemporal changes of landscape pattern in response to urbanization," *Land. Urban Plan.*, vol. 81, issu. 4, pp. 341-353, Jul. 2007.

[32]. N. Turkoglu, "Analysis of urban effects on soil temperature in Ankara," *Environ. Monitor. Assess.*, vol. 169, pp. 439-450, Oct. 2010.

[33]. H.M. Mosammam, J.T. Nia, H. Khani, A. Teymouri, and M. Kazemi, "Monitoring land use change and measuring urban sprawl based on its spatial forms: The case of Qom city," *The Egypt. J. Rem. Sens. Spac. Sci.*, vol. 20, issu. 1, pp. 103-116, Jun. 2017.

[34]. Q. Weng, D. Lub, and J. Schubring, "Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies," *Rem. Sens. Environ.*, vol. 89, issu. 4, pp. 467-483, Feb. 2004.

[35]. S. Khandelwal, R. Goyal, and A. Mathew, "Assessment of land surface temperature variation due to change in elevation of area surrounding Jaipur, India," *The Egypt. J. Rem. Sens. Spac. Sci.*, vol. 21, issu. 1, pp. 87-94, Apr. 2018.

[36]. W.D. Solecki, C. Rosenzweig, L. Parshall, G. Pope, M. Clark, J. Cox and M. Wiencke, "Mitigation of the Heat Island effect in urban New Jersey," *Glob. Environ. Chan. Part B: Environ. Haz.*, vol. 6, issu. 1, pp. 39-49, Jul. 2005.

[37]. Z. Wang, W. Xing, Y. Huang, and T. Xie, "Studying the urban heat island using a local climate zone scheme," *Pol. J. Environ. Stud.*, vol. 25, no. 6, pp. 2609-2616, Jun. 2016.

[38]. S. Ma, A. Pitman, M. Hart, J.P. Evans, N. Haghdadi, and I. MacGill, "The impact of an urban canopy and anthropogenic heat fluxes on Sydney's climate," *Int. J. Climatol.*, vol. 37, issu. S1, pp.255-270, Feb. 2017.

[39]. United State Environmental Protection Agency, "Urban heat island basics," *Reducing urban heat islands: Compendium of strategies*, 2008. [Online]. Available: https://www.epa.gov/heat-islands/heat-island-compendium [Accessed: Dec. 2, 2022].

[40]. J.M. Ali, S.H. Marsh, and M.J. Smith, "Modelling the spatiotemporal change of canopy urban heat islands," *Build. Environ.*, vol. 107, pp. 64-78, Oct. 2016.

[41]. K. Liu, H. Su, X. Li, W. Wang, L. Yang, and H. Liang, "Quantifying spatial-temporal pattern of urban heat island in Beijing: An improved assessment using land surface temperature (LST) time series observations from LANDSAT, MODIS, and Chinese new satellite GaoFen-1," *IEEE J. Select. Top. Appl. Earth Observ. Rem. Sens.*, vol. 9, no. 5, pp. 2028-2042, May 2016.

[42]. D.X. Tran, F. Pla, P. Latorre-Carmona, S.W. Myint, M. caetano, and H.V. Kieu, "Characterizing the relationship between land use land cover change and land surface temperature," *ISPRS J. Photo. Rem. Sens.*, vol. 124, pp. 119-132, Feb. 2017.

[43]. A.M. Rizwan, Y.C.L. Dennis, and C. Liu, "A review on the generation, determination and mitigation of urban heat island," *J. Environ. Sci.*, vol. 20, issu. 1, pp. 120–128, Jan. 2008.

[44]. S. Yamashita, K. Sekine, M. Shoda, K. Yamashita, and Y. Hara, "On relationships between heat island and sky view factor in the cities of Tama river basin, Japan," *Atmos. Environ. (1967)*, vol. 20, issu. 4, pp. 681–686, 1986.

[45]. K.C. Goh, and C.H. Chang, "The relationship between height to width ratios and the heat island intensity at 22:00h for Singapore," *Int. J. Climatol.*, vol. 19, issu. 9, pp. 1011–1023, Jun. 1999.

[46]. S. Kumar, T. Prasad, N.V. Sashidharan, and S.K. Nair, "Heat island intensities over Brihan Mumbai on a cold winter and hot summer night," *Maus.*, vol. 52, no. 4, pp. 703–708, Oct. 2001.

[47]. J. Unger, Z. Sümeghy, and J. Zoboki, "Temperature cross-section features in urban area," *Atmos. Res.*, vol. 58, issu. 2, pp. 117–127, Jul. 2001.

[48]. P.I. Figuerola, and N.A. Mazzeo, "Urban–rural temperature differences in Buenos Aires," *Int. J. Climatol.*, vol. 18, issu. 15, pp. 1709–1723, Dec. 1998.