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URBAN HEAT ISLAND ANALYSIS USING GIS AND REMOTE SENSING IN KOSHOFE LAGOS STATE

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Abstract

Urban heat islands (UHIs) are a significant concern in urban areas, particularly in tropical regions like Lagos, Nigeria. This study employs geographic information systems (GIS) and remote sensing (rs) techniques to analyze the urban heat island effect in Koshofe, a rapidly urbanizing area in Lagos. The research aims to identify the spatial distribution, intensity, and factors influencing

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UHI in koshofe. Using Landsat 8 and sentinel-2 satellite imagery, land surface temperature (LST) was retrieved and analyzed. GIS spatial analysis and mapping techniques were applied to examine the relationship between lst, land use/land cover (LULC), population density, and urban morphology. The study also investigated the impact of urban planning strategies on UHI mitigation. Results show that Koshofe experiences significant UHI effects, with lst varying between 28°c and 38°c. Built-up areas, particularly commercial and industrial zones, exhibited higher (LST) values compared to vegetated areas. Population density and urban density were found to be positively correlated with (LST). The study identified areas with high UHI risk, including major road networks and informal settlements.

INTRODUCTION

Urbanization and climate change have increased the prevalence of urban heat islands (UHIs), posing risks to human health, energy consumption, and urban sustainability. Kosofe, a local government area in Lagos, Nigeria, experiences rapid urbanization, making it vulnerable to UHI effects. This study aims to analyze the spatial distribution, intensity, and factors influencing UHI in kosofe using gis and rs techniques.

The global population is projected to surge to 9.6 billion by 2050 (United Nations, 2012), with the bulk of this growth concentrated in urban centers of developing nations (wuyep, 2018). According to the United Nations Department of Economic and Social Affairs Population Division, approximately 66% of the world's population will reside in urban areas by 2050 (United Nations, 2013). This burgeoning population will necessitate expanded settlements, resulting in increased built-up areas (wayep, 2018).

Urbanization yields dual consequences: beneficial socio-economic outcomes for inhabitants and detrimental environmental impacts (estoque & Murayama, 2014). Unplanned urbanization leads to eradication vegetation cover, replaced by impervious surfaces, such as construction materials, transportation

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infrastructure, and urban landscapes (Fazal et al., 2011). This, in turn, disrupts insulation patterns and contributes to:

Climate change, greenhouse gas emissions, deterioration of air, soil, and water quality. Disruption of ecological cycles (Senanayake et al., 2013; estoque et al., 2017). The urban heat island (UHI) phenomenon is another major negative impact of urbanization (ranagalage et al., 2017). It was described in 1818 as a phenomenon whereby cities have higher surface and atmospheric temperatures than their surrounding areas (Adeyemi et al., 2015;

Available from: al., 2017). Urban heat island develops when a large fraction of the natural land cover in an area is replaced by built surfaces that trap incoming solar radiation during the day and then reradiate at night. The impervious surfaces of urban areas generally have higher solar radiation absorption, and a greater thermal capacity and conductivity such that heat is stored during the day and released by night. Therefore, urban areas tend to experience higher temperatures than the surrounding areas (Aderoju et al., 2013; Enete & Okwu, 2013; Molnar, 2016; Wuyep et al., 2021). This thermal difference in conjunction with waste heat released from transportation, urban houses and industrial activities contributes to the development of UHI (Tran et al., 2006). The intensity of UHI increases as the size of a city increases, due to the larger size of the built area (Rinner & Hussain,2011). Urban topography, surface roughness, the morphology of buildings, and anthropogenic activities contribute by reducing outgoing long-wave radiation, hindering sensible heat loss, distribution of heat, and generation of heat respectively (Ifatimehin, 2007). Many urban areas in Nigeria have expanded mostly on agricultural land in recent decades. The increasing population and introduction of various forms of land use planning are the major threats to the present-day environment (Vernon, 2002; Wuyep, Daloeng, Isha, and Arin, 2020). Koshofe Lagos State, the urban centre is not an exception to this observed Land Use Land Cover Change (LULC). In Koshofe Lagos State, fundamental change has occurred due to accelerated expansion since 1976. The urban growth has been accelerated and

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has caused extreme stress to the environment. It is against this background that this study seeks to assess the urban heat island of Koshofe Lagos State. Findings from this study will be of significance to governmental and non-governmental agencies in designing and implementing programs, policies projects aimed at designing proper town planning for the convenience of the inhabitants of the study area. Based on this aim, the objectives of the study are to: i) examine the different land cover in the urban Koshofe Lagos State for three decades; ii) assess the UHI; and iii) find out the temperature variations associated with different land cover types.

STUDY AREA AND METHODOLOGY STUDY

Area Koshofe Lagos State urban area is located almost in the geographical cente of Nigeria Figure 1. Koshofe Lagos State City, the administrative capital, and the commercial nerve center of Plateau state is the most densely populated area in the state. According to the 2006 Nigerian census result, the city has a population of 836,910 people, and a projected population of about 1.1 million people with a growth rate of over 3% per annum (Olumide and Nwanret, 2014). It lies precisely within latitudes 9°45'46.82" to9°57'58.38" North of the Equator and longitudes 8°48'57.78" to 8°58'0.88" East of the Greenwich meridian. Relatively, urban Koshofe Lagos State is situated within Koshofe Lagos State North and Koshofe Lagos State south LGAs, it is bounded from the West by Bassa LGA, to the East by Koshofe Lagos State East, and to the South-East by Barkin-Ladi LGA. The urban study area is located in the extreme northern part of the state (Wuyep, 2018). The climate is influenced by its height above sea level and spatial position across the seasonal migration belt of the Inter-Tropical

Discontinuity (ITD). Koshofe Lagos State falls within the wet and dry climatic type classified bopped

(1923) as Tropical Rainy climate (Aw). Mean annual rainfall is 1260 mm, and peaks between July and August; meanwhile, the mean annual temperature is

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about 220C. From mid-November to late January, night-time temperatures drop to as low as 11°C. Hail precipitation is sometimes experienced during the rainy season because of the cooler temperatures (Adzandeh et al.,2015).



Figure 1: Lagos State showing the study area

METHODOLOGY

The study used digital data (Landsat images) acquired through remote sensing and GIS techniques.

A time series of the Landsat satellite images which include Operational Land Imager (OLI) and

Thermal Infrared Sensor (TIRS) of April 2017, Enhanced Thematic Mapper Plus (ETM+) of January 2000 and Thematic Mapper (TM) of November 1985 were obtained from the U.S. Geological Survey (USGS) and Land Viewer Earth Observatory Systems websites, which provide 30 meters resolution imagery. In addition, Google Earth images, topographical maps, land cover maps, and the shape file of the study area were also used.

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Three main parameters were considered in carrying out this study which include, Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), and Land Surface Temperature (LST). The following are the software used for analysis; ArcGIS 10.3.1 and Google Earth. Operations are shown as parallelograms and linked to input and output data layers with arrows.

ArcMap 10.3.1 was used for land use land cover classification of the study area using the selected bands of the LandSat images. The selected bands for True Colour band combination are Bands 4, 3, 2 for Landsat 8 and Bands 3, 2, 1 for Landsat 7 & 5 which was composed to identify surface features through a technique called composite banding before classifying the image. Composite banding which is a combination of visible colors represented by Red, Green and Blue (RGB) in a three-dimensional space is a technique used to display the standard color composites for a representation of features observed on earth. A supervised image classification technique was employed in carrying out the study. The procedures in analyzing and achieving these parameters are discussed below:

Calculation of Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a simple graphical 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.

The NDVI was calculated from these individual measurements as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 1$$

Where:

RED =Spectral reflectance measurements acquired in the red (visible) region NIR = Near-infrared region

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This spectral reflectance are themselves ratios of the reflected over the incoming radiation in each spectral band individually; hence they take on values between 0.0 and 1.0. By design, the NDVI itself thus varies between -1.0 and +1.0. It should be noted that NDVI is functionally, but not linearly, equivalent to the simple infrared/red ratio (NIR/VIS).

Meanwhile before running or calculating the NDVI, the DN values was converted to TOA reflectance. The OLI/TIRS, ETM+ and TM band data was converted to TOA planetary reflectance using reflectance rescaling coefficients provided in the product metadata file (MTL file). The following equation was used to convert DN values to TOA reflectance:

$$\rho\lambda' = M_p\, Q_{cal} + A_p \ldots\ldots\ldots\

Where:

$P\lambda$ = TOA planetary reflectance ϑ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).

ϑ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90° - \vartheta_{SE}$

Deriving Land Surface Temperature (LST)

Surface Temperature is one of the significant variables that have been measured by remote sensing satellites. Remote sensing of temperature uses the amount of radiation reflected or emitted in the thermal infrared portion of the electromagnetic spectrum (EMS). The thermal infrared range of the EMS is generally considered to be between 3 and 14µm (Tsai and Hamblin, 2017). Different LST retrieval methods have been developed according to different data sources. In this study the mono- window algorithm was used, this algorithm for obtaining LST, help in avoiding the dependence on radio sounding in the radiative transfer equation RTE method but also doing atmospheric correction.

Conversion of DN to TOA Spectral Radiance

OLI/TIRS and ETM+ band data of Landsat 8 and 7 was converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file using the formula:

$$L_\lambda = M_L Q_{cal} + A_L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 4$$

Where:

L_λ = TOA spectral radiance (Watts/ (m2 * srad * µm))

ML = Band-specific multiplicative rescaling factor from the metadata (RADIANCE MULT_BAND_x, where x is the band number)

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AL = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Qcal = Quantized and calibrated standard product pixel values (DN)

While TM band data of Landsat 5 was converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file using the formula:

$$L_\lambda = G \times DN + B \quad \text{... equation 5}$$

Where:

L_λ = spectral radiance

G =Gain value for a specific band

DN =Quantized and calibrated standard product pixel values

B =Bias value for a specific band

Conversion to spectral radiance is necessary to correct atmospheric effect on the reflectance value; absorption and scattering create an overall effect of "haziness" which reduces the contrast in the image. Scattering also creates the "adjacency effect" in which the radiance recorded for a given pixel partly incorporates the scattered radiance from neighboring pixels.

Conversion to At-Satellite Brightness Temperature

The brightness temperature (or T_B) is the fundamental parameter measured by passive microwave radiometers. The brightness temperatures, measured at different microwave frequencies, are used at Remote Sensing Systems to derive wind, vapor, cloud, rain, and SST products.

OLI/TIRS, ETM+ and TM band data was converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata file using the Formula:

$$Ts = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} - CF \quad \text{... equation 6}$$

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Where:

Ts = At-satellite brightness temperature (K)

L_λ = TOA spectral radiance (Watts/ (m2 * srad * μm))

K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the band number, 10 or 11)

K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the band number, 10 or 11)

CF =Conversion Factor to Degree Celsius (272.15)

Calculation of Land Surface Emissivity (LSE)

Land surface emissivity (LSE) is the average emissivity of an element of the surface of the Earth calculated from measured radiance and Land Surface Temperature (LST). This was calculated using the formula:

$$(\varepsilon) = 1.0094 + 0.047 \times In\,(NDVI) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad equation\ 7$$

Where:

ε = Land Surface Emissivity ln = Log

NDVI = Normalized Difference Vegetation Index

Computation of the Land Surface Temperature (LST)

Land surface temperature is how hot the "surface" of the Earth would feel to the touch in a particular location. From a satellite's point of view, the "surface" is whatever it sees when it looks through the atmosphere to the ground. It could be snow and ice, the grass on a lawn, the roof of a building, or the leaves

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in the canopy of a forest. Land Surface temperature was calculated using the formula: Where:

$$T = Ts\left\{1 + \left[\lambda x \left(\frac{Ts}{\rho}\right)\right] \ln \varepsilon\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation 8}$$

T = Land Surface Temperature

Ts = At-Satellite Brightness Temperature λ =wavelength of the emitted radiance = 11.5µm (Markham and Baker, 1985);

ρ = hc/σ = 1.438 x 10^2 mK; σ =Stefan Boltzmann constant (5.67 x 10^-8Wm^-2K^4), h = Planck's constant (6.626 x10^-34Js) and c =2.998 x 10^8 m/s.

ε = Land Surface Emissivity

RESULTS AND DISCUSSION

Land Cover Distribution for 1985, 2000, 2017

The Red, Green, and Blue (RGB) composition created through composite banding was useful for identifying land cover types and allowed for easy selection of training areas for the supervised maximum likelihood classification. Each composed image was ordered into four area classes: builtup areas, water, vegetation, and bare surfaces.

From the result shown in Figure 2, the land cover type that dominated the urban Koshofe Lagos State area in 1985 was bare-surface, which is about 60.893% of the total land area followed by vegetation at 30.236%, built-up 8.835% and water having the least with 0.036% of the land area. The reason for this distribution can be largely attributed to the season. The image was acquired during the dry season precisely on 03 March, 1985. At this period, it is believed that there is little or less vegetation as a result of low rainfall in the area, the dry vegetation exposes the soil and the rock outcrops at this period are seen clearly as most trees have shaded their leaves, this account for the high percentage of bare-surface (60.893%), this also couple with the fact that the study area has not experience much development which put the built-up

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class at 8.835% with much concentration at the city centre (Terminus Area). The urban Koshofe Lagos State the study area, has less water body due to the low rainfall at this period (dry season), it accounts for a very small percentage of water cover (0.036%) and are only confined to the water body like dam and ponds. The percentage of vegetation in the area is less despite less development because of little or no water for vegetation growth and cover, this result in weak and scanty vegetation in the area as shown by the NDVI in Figure 5a.

The result of the analysis of 2000 on the classified image (Figure 5b) shows that vegetation occupies the largest area with 69.9 percent followed by bare-surface which is about 16.9 percent of the total area, built-up area and water bodies occupies 12.4 percent and about 1 percent respectively. The Landsat 7 ETM+ Image of 2000 was acquired in wet season precisely 11 August, this explains the reason for vegetation cover occupying the largest proportion of the total land area. With the high volume of rainfall usually experience at this month, it gives rise to a healthy and thick vegetation in the metropolis. Figure 5b show water bodies scattered and spread almost all over the classified image with about 0.845%, this can still be attributed to the rainy season. Bare-surface have 16.864% which is largely rock-outcrop because the open soils have been covered by vegetation and the built- up area which have about 12.436% (Figure 3) can be said that the urban Koshofe Lagos State was just starting its high rate of urbanization with concentration at the city centre in the northern part of the map and the Bukuru axis in the South.

For 2017, built-up area occupies the largest proportion of the land area with about 80.553% (Figure 4), bare-surface occupies 18.218% while vegetation and water occupy 1.092% and 0.137% respectively. Figure 4 show that built-up area to have the highest percentage of the total area. This suggests that by this year Koshofe Lagos State metropolis have undergone serious development in terms of infrastructures like buildings and roads which have almost the same reflectance. It is also observed in Figure 5c that the built-up area is spread over the entire metropolis with a high density in the CBD (Terminus Area) and

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Bukuru in the southern part of the map. Despite the fact that the Landsat OLI/TIRS of 2017 was acquired in the wet season, 30 May, 2017, the vegetation and water bodies have less percentages. This is due to urbanization that have led to deforestation and clearance of vegetation for different structures in the metropolis. The available vegetation in the metropolis is confined to the rocky and hilly part of the metropolis and places that urban agriculture and irrigation is being practiced.

From the result, it was observed that the identified land cover types in the metropolitan area have changed from 1985 to 2017 and with variation in dominant land cover type depending on the season. Built-up area continues to increase while vegetation and bare-surfaces reduced drastically, this is attributed to urban growth of the metropolis. This result is generally in line with the study carried out by Omran (2012) in the Ismailia Governorate, Egypt, Bernard & Raymond (2012) in São Koshofe Lagos Stateé dos Campos, Brazil from 1986-2010 respectively that the decrease in natural land simultaneously increase in developed land in the study areas is attributed to urban growth and development.

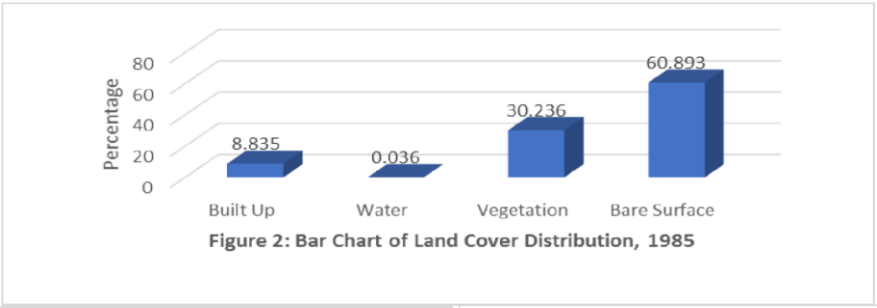

Figure 2: Bar Chart of Land Cover Distribution, 1985

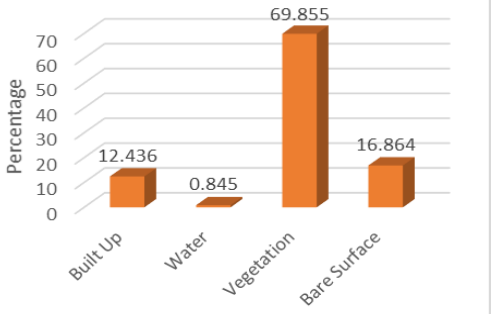

Figure 3: Bar chart of Land Cover Distribution, 2000

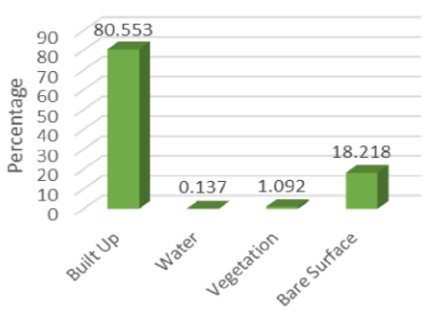

Figure 4: Bar Chart of Land Cover Distribution, 2017

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CONCLUSION AND RECOMMENDATIONS

This study aimed to assess the urban heat island response to urban expansion in Koshofe Lagos State metropolis using remote sensing and GIS techniques. Findings in 1985 indicate that the dominant land use is bare-surface, vegetation occupied the largest area in 2000 while in 2017, the built-up area occupied the largest proportion of the land area. Temperature comparison of the different land cover shows great difference between them, built- area has the highest temperature closely followed by the bare surfaces while water bodies and vegetation have the least. In addition, land surface temperatures were analyzed and it was found that the highest temperatures were not always in the center of the city, but also in the outskirts, especially the areas with high anthropogenic activities as revealed in 2017.

It has also been shown that satellite thermal data can indeed be used to characterize both the magnitude and spatial extent of an urban heat island, land use/land cover, this information can also be directly derived from remotely sensed data, which provides a powerful way to monitor urban environment and human activities. This can effectively replace the traditional analogue system of urban studies.

It is recommended that measures and strategies of curbing UHI in the metropolis includes; increasing vegetation cover, creation of green roofs, creation of high albedo pavements, pervious pavements creation, shade trees, awareness should be created to the local population regarding effects of excessive heat on human health coupled with information on simple measures to prevent excessive heat stress, enhances preparedness. Such measures can reduce sensitivity to heat exposure at the individual and community level. Simple heat warning advices from 'avoid drinking alcohol to' wear a hat can be very effective, all relevant stakeholders like Ministry of Environment, Koshofe Lagos State Metropolitan Development Board, public health services, meteorological services, and medical institutions have a role to play in reducing UHI in the metropolis. These stakeholders should meet regularly to assess how

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the changing climate could directly affect their constituents and to provide input on what is needed.

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