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Effects of Urban Vegetation in Mitigating Land Surface Temperature (LST) in Kaduna Metropolis, Nigeria

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Abstract

Urban vegetation plays a vital role in mitigating higher temperature through shade, evapotranspiration and high albedo. Replacement of vegetation with urban land uses results in the increase in Land Surface Temperature (LST). This study analyses the effects of urban vegetation in mitigating LST in Kaduna metropolis, Nigeria. Landsat 8 data was used to classify the area into built-up area, vegetation, bare land and water bodies using random forest supervised classification. Information on the vegetation density was obtained using Normalized Difference Vegetation Index (NDVI), while single channel algorithm was used for the retrieval of LST. The effect of vegetation on LST was quantified using correlation analysis. The results showed that built-up area was the largest land cover, occupying 157.99km^2 (46.53%), followed by vegetation with 143.34km^2 (42.22%). Bare land had 34.26km^2 (10.09%), while water bodies occupied 3.95km^2 (1.16%). The vegetation density that mitigates LST indicated by NDVI showed higher values (0.38-0.69) in the suburb with higher vegetation density, which resulted in low LST range (22^o-26^{o}C). Lower NDVI values (0.05-0.38) were recorded in the bare land and built-up area with sparse vegetation. This resulted in moderate (28^o-30^{o}C) and high (30^o-34^{o}C) LST respectively. Lowest NDVI (-0.26 – 0.05) and LST (22^{o}C – 26^{o}C) were recorded in the water bodies. There was negative correlation (-0.55) between NDVI and LST, indicating the effect of vegetation in mitigating LST. Proper urban planning is necessary by planting more trees in the metropolis as part of LST mitigation strategies.

1. Introduction

Urbanization is a leading factor responsible for land use/land cover change, where vegetation cover is replaced with buildings and impervious surfaces like concrete and asphalt, which are responsible for higher temperature in urban areas (Sadroddin et al., 2015). Reduction in vegetation cover as a result of urban expansion and increase in human activities increase Land Surface Temperature (LST) (Bokaie et al., 2016; Pal and Ziaul, 2017; Yin et al., 2020). LST changes due to alteration of urban surface albedo, roughness and heat flux exchanges (Estoque et al.,2017; Singh et al., 2017; Zhu et al., 2022). Buildings and impervious surfaces in the urban built-up areas store and emit heat resulting in the increase in sensible heat flux and decrease in the latent heat flux compare with the pervious and vegetated surfaces (Liu et al., 2012; Zhan et al., 2012; Rogan et al., 2013). High temperature causes human discomfort and increases disease and mortality (Basara et al., 2010; Sadroddin et al., 2015). For instance, in 2003, there was an increase in mortality by 7.6% in Munich, Germany as a result of heat wave (D'Ippoliti et al., 2010; Sadroddin et al., 2015). Urban vegetation has a role to play in mitigating high temperature through shading, and increasing evapotranspiration and albedo (Armson et al., 2012; Rogan et al., 2013). The spatial variation in the urban LST depends on the land cover type, with higher temperature in impervious surfaces and lowers in vegetation cover (Rogan et al., 2013). Remote Sensing is a significant tool used for the study of spatial distribution of LST and vegetation. Kaduna Metropolis is witnessing urbanization causes replacement of vegetation cover with buildings and impervious surfaces (Alamin and Dadan-Garba, 2014). This led to increase in the LST that is detrimental to human health and environment. Excessive heat exposure results in medical condition like heat cramp, heat exhaustion and heat stroke. High urban temperature can be mitigated through proper urban

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planning. This study examines the role of vegetation cover in mitigating LST in the metropolis.

2. Method

2.1. Study Area

The study area is located between Latitudes 10°25' and 10°72' North of the Equator, and Longitudes 7°25' and 7°75' East of the Greenwich Meridian (Figure 1). The metropolis occupies almost 260 km^2, and it is made up of Kaduna North and South local government areas, and parts of Igabi and Chikun local government areas. It is the capital city, economic, and financial centre of Kaduna State (Aliyu and Suleiman, 2006). It is drained by River Kaduna and its tributaries, which takes its source from Sherri Hill in Plateau State (Folorunsho, 2004; Folorunsho et al., 2012). The climate of the area is tropical continental with distinct rainy and dry season. The rainy season is shorter and lasts from April to October, while the dry season starts from November to March (Orogade et al., 2016). The annual rainfall values range between 1500mm and 2000mm (Alamin and Dadan-Garba, 2014). The temperature is high throughout the year, with a mean annual temperature between 26^{o}C and 34^{o}C (Bununu *et al.,* 2015). The natural vegetation of the area is Sudan savannah which is characterised by grasses and scattered trees (Amadi et al., 2014). The tree species found include *Azadirachta indica*, *Mangifera indica, Eucalytptus* sp, *Tamarindus indica,* and *Parkia biglobosa* (Ogunkalu et al., 2017).

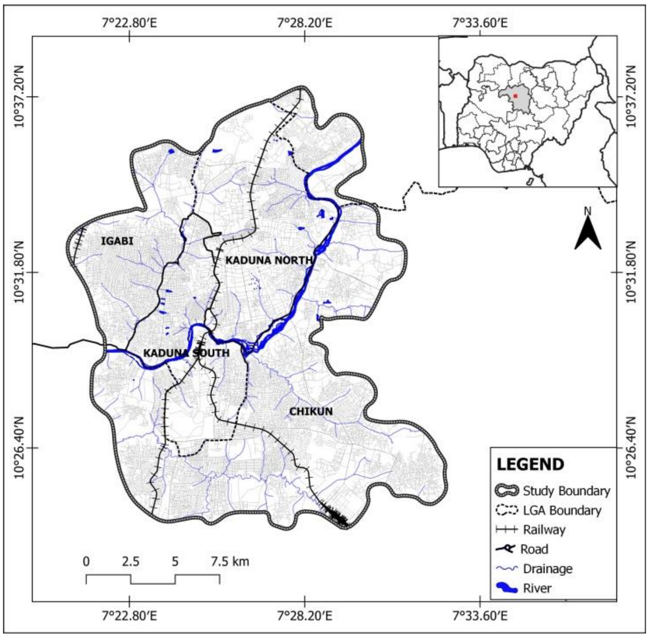

Figure 1. The Study area

2.2. Material and Methods

In this research, we used Landsat 8 Operational Land Imager and Thermal Infrared Sensors (OLI/TIRS) obtained on 8th November, 2021. It was downloaded freely from the United States Geological Survey's website. The data was used for land use/land cover classification, extraction of vegetation density and retrieval of Land Surface Temperature (LST),

Random Forest (RF) supervised machine learning algorithm was used for image classification to classify the study area into built-up area, bare land, vegetation, and water bodies.

Normalized Difference Vegetation Index (NDVI) was used to quantify the vegetation greenness and density. It is the ratio between the red and near infrared band, with values range between −1.0 and +1.0. It was calculated using the following algorithm:

$$NDVI = NIR - Red/\ NIR + Red \qquad (1)$$

Where

NIR is the near infrared band of the image

Red is the red band of the image

Single channel algorithm was used to retrieve the LST from thermal band 10 of the imagery. Finally, the effect of vegetation on LST was quantified by correlation analysis. The satellite imagery was processed using Semi-Automatic Classification Plugin (SCP) for QGIS.

3. Results

The classified imagery (Figure 2) displayed the four major land cover classes, namely built-up area, bare land, vegetation, and water bodies. Built-up area was the largest land cover class, occupying 157.99km^2 (46.53%). It covered most of the centre of the metropolis and extended to the northern and southern parts. Vegetation was the second-largest land cover with an area of 143.34km^2 (42.22%). It was sparse in the built-up area and bare land, and dense mostly around the built-up area. Bare land covered 34.26km^2 (10.09%) found mostly within the vegetation area. Water bodies were the smallest land cover class that occupied 3.95km^2 (1.16%). It was found mostly in River Kaduna and its tributaries that nearly divide the metropolis into two.

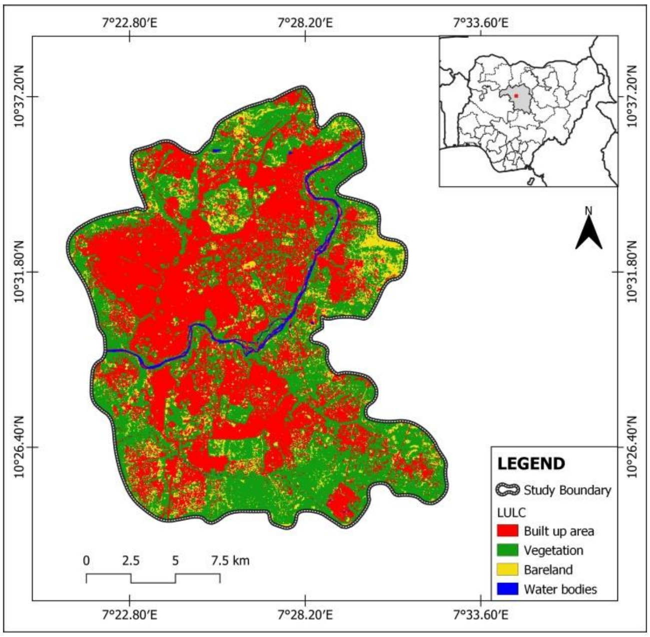

Figure 2. Land use/land cover

The vegetation density displayed by the NDVI values ranges from −0.26 to 0.69 (Figure 3). The lowest values range from -0.26 – 0.05 were found in the water bodies. Average NDVI values between 0.05 – 0.38 were found in the built-up area and bare land, while the highest values from 0.38 – 0.69 in the vegetation.

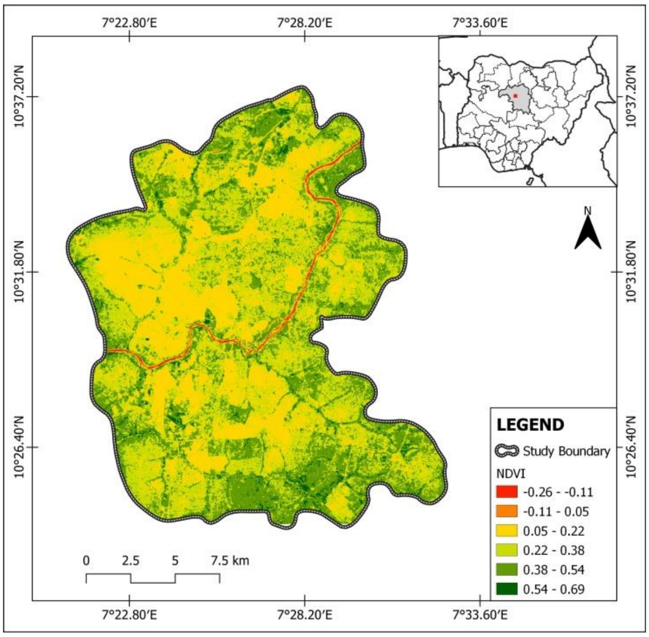

Figure 3. Normalized Difference Vegetation Index

The LST retrieved from the image showed spatial variability, with 22°C as the lower value and 34°C as the highest (Figure 4). Lowest temperature range (22-26°C) was recorded in the water bodies. Vegetation exhibited a low range of between 26 to 28°C. Higher temperature range (28-32°C) was found in the bare land and built-up area. Hotspots of LST (32-34°C) were found in the built-up areas in different locations of the metropolis. The relationship between LST and NDVI showed a moderate negative correlation (-0.55).

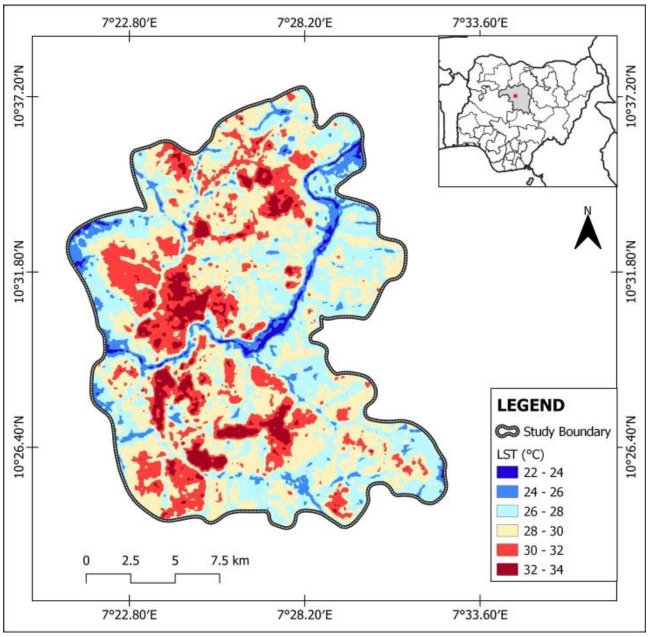

Figure 4. Land surface temperature

4. Discussion

The land use/land cover indicated built-up area, bare land, vegetation, and water bodies. The built-up area was the dominant land cover because of urban expansion, where other land cover classes were converted to urban land uses. Urban expansion is caused by increase in population as a result of rural-urban migration and high birth rate. Currently, more than half of the world population is currently living in the urban areas (United Nations, 2011; Uysal and Polat, 2015). The centre of the metropolis is the Central Business District (CBD), which is the commercial and administrative hub that consists of markets and offices. The northern part was dominated by low and high density residential areas, while the southern part comprises of industrial and residential areas. The low NDVI values in the built-up area showed low vegetation density because of the replacement of trees with buildings and impervious surfaces. Reduction in vegetation exposed the buildings and pavements to sunlight, increasing the amount of energy absorbed and radiated in the air. This is because of the decrease in shed and evapotranspiration. Moreover, release of heat from anthropogenic activities contributed to the higher LST.

The bare land showed the pervious areas of exposed soil and impervious rock surfaces found in undeveloped lands that were not put to urban uses. The bare land had scattered trees with grasses and shrubs that dried up because of the dry season and exposed the land. This led to the low NDVI values recorded. Moreover, the exposure of the bare land to solar radiation resulted in the high temperature because of reduction in shade and evapotranspiration. Furthermore, the impervious nature of the rock surfaces and the properties of the soil like the color contributed to the higher LST.

The vegetation showed the assemblage of plants in the area found along the streets, in the residential and commercial areas, and other green areas. The replacement of vegetation cover with buildings and other impervious surfaces led to the sparse vegetation at the centre of the metropolis. Dense vegetation found around the built-up area indicated the suburb area with higher NDVI values. The surface temperature in the vegetated areas was low because of the abundant shade and evapotranspiration that mitigate LST.

River Kaduna and its tributaries that mainly drained the metropolis showed a very low NDVI values indicating the absence of vegetation in the water bodies. The lower LST exhibited by water was as a result of evaporation that takes heat from water. Moreover, water heats slower than land. Finally, the negative correlation between NDVI and LST demonstrated the effect of vegetation in mitigating LST. Therefore, the increase in vegetation density leads to decrease in LST as a result of increase in shade and evapotranspiration.

5. Conclusion

Remote sensing is an essential tool for studying land use/land cover change and LST spatial variability. The role of urban vegetation in mitigating LST in Kaduna metropolis, Nigeria was analysed. Landsat 8 data was used to classify the area into built-up area, bare land, vegetation and water bodies using random forest algorithm. Moreover, vegetation density and LST were derived from the imagery using NDVI and single channel algorithm respectively. The effect of vegetation on LST was quantified by correlation analysis. The results revealed that built-up area was the largest land cover followed by vegetation, bare land and water bodies. Highest NDVI values and lower LST were found in vegetation. In contrast, lower NDVI values with higher LST were recorded in built-up area and bare land. Lowest NDVI and LST were found in the water bodies. Increase in vegetation density, resulted in decrease in LST. Proper urban planning is required for sustainable development.

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