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Geospatial Assessment of Urban Expansion and Land Surface Temperature in Akure, Nigeria

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dated : 30 June 2015

ABSTRACT

This study employs the use of geo-spatial techniques with survey to identify various transformations in land use land cover types and their corresponding land surface temperature (LST) between a 20-year time intervals in Akure, Nigeria. The analysis was done using available Landsat TM and ETM+ satellite data for 1986, 2002 and 2006. The variability of the LST has been investigated with respect to different land use / land cover types that were determined from the Visible and Near Infrared (NIR) channels. Also, the emissivity per pixel is retrieved directly from satellite data and estimated as narrow band emissivity at the satellite sensor in order to have the least error in the surface temperature estimation. The study revealed that the built up area has expanded from 17.88% of the total land area of Akure in 1986 to 27.02% in 2006 with a corresponding increase of 9.9 °C in LST, indicating an average annual increase of 0.5 oC. The vegetation cover has reduced from 47.23% to 37.79% with an increase of 2.79 °C in temperature. A very strong correlation between the LST and the NDVI has also been established. The implication of the uncontrolled unprecedented expansion in the city may exacerbate environmental and ecological problems such as the Urban Heat Island if not properly ameliorated. This study actually exploits the possibility of using Remote Sensing and Geographic information systems (GIS) in the drive towards achieving sustainable urban environment in terms of planning, policy and decision making.

1. Introduction

Massive urbanization, accompanied by rapid expansion of cities and metropolitan regions and the sprawling growth of megacities is one of the most important transformations of our planet. Much of this explosive growth has been unplanned. It is quite obvious that most cities in the developing countries have been unprepared for the expansion currently witnessed. These cities are envisaged to double their urban population in the next thirty years, and possibly triple the land area (Angel et al, 2010). Arnfield (2003) stated that the world is becoming increasingly urbanized with 45% of the population already living in the urban areas in the year 2000, with the projections as at then that half of the world will live in urban areas by 2007. More recent estimate is that by the year 2025, 60% of the world's population will live in cities. Despite the fact that urban growth is a local or regional phenomenon, it has impacts far beyond city boundaries. Over the last decades, continuous urban expansion at rates much higher than population growth has resulted in a massive urban footprint on most part of the world; fragmenting rural space, blocking ecosystem services and increasing the demand for transport and energy. Remote sensing has contributed in documenting the actual change in land use land cover on regional and global scales from the mid-1970s (Lambin et al., 2003). In this study, the relationship between land cover and surface temperature in Akure was analyzed and examined using satellite data from LandSat TM and ETM+. Band 6 of the LandSat was used for brightness temperature which intersects with land use land cover and NDVI from other bands of Landsat ETM+, with the aim of determining the variations in the thermal environment of the city over the years. This study evaluates the use of Landsat ETM+ data for indicating temperature differences in urban areas, and to analyze and compare the relationship between urban surface temperature and land cover types.

2. Study Area

Akure, the capital city of Ondo State, Nigeria is located on latitude 7.25 ^{o}N and longitude 5.20 ^{o}E (Figure 1). The rapid growth of the city, particularly within the last few decades, has made it one of the fastest growing metropolitan cities in the South Western Nigeria. Its population has more than tripled from 157 947 in 1990 to ~500 000 in 2006 [Balogun et al., 2011]. The city became an administrative and economic seat to Akure South Local Government Authority, and Ondo State with the latter's creation in 1976 from the old Western State. Since then, the city has witnessed immense growth in the size of built-up areas, number of inhabitants, transportation, and commercial activities. Within the last three decades, subsequent changes in the land-atmosphere energy balance relationships have occurred alongside traffic related air quality degradation over the city [Balogun et al., 2012]. Akure experiences warm humid tropical climate, with average rainfall of about 1500mm per annum. Monthly average temperatures range between 21.4 and 31.10C, and its mean annual relative humidity is about 77.1% (based on the 1980- 2012 datasets obtained from the Nigerian Meteorological Agency).

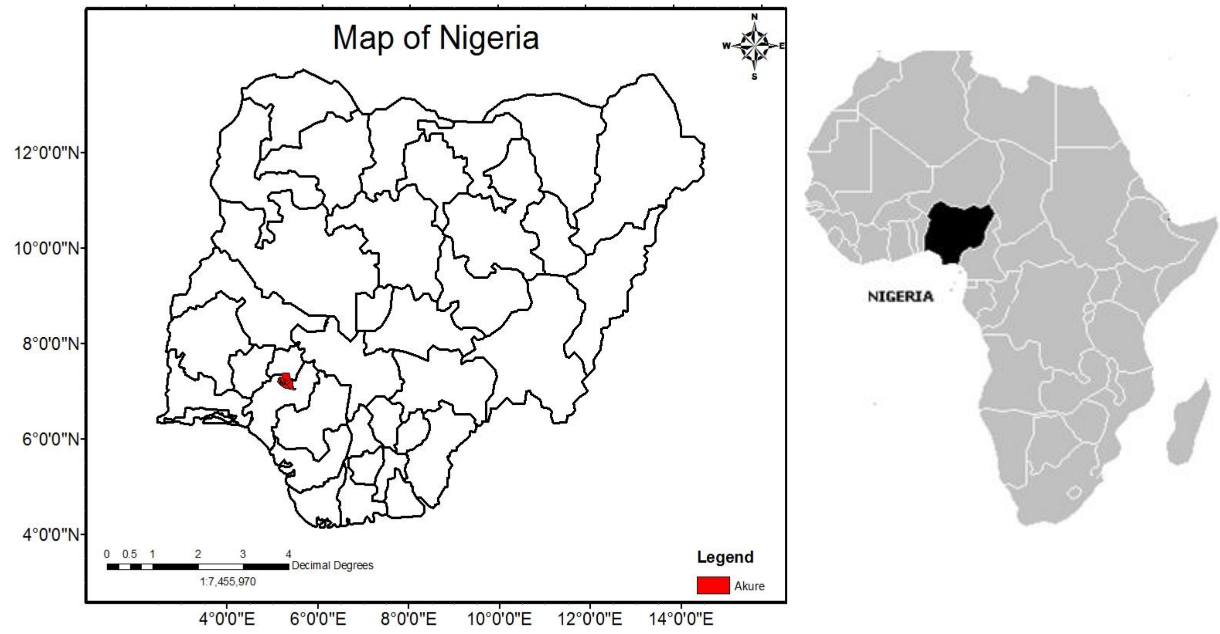


Figure.1: Flowchart of estimating surface temperature adopted from Wuber, 2003

3. Data and Methodology

3.1 Data

The digital data used in this study were collected by Landsat TM and ETM+, their spectral and spatial characteristics as well as acquisition dates are shown in Table 1 below: In addition to this, boundary maps for national, state and local governments within the study area were obtained from the National Space Research and Development Agency (NASRDA), Abuja.

Table 1: Satellite imageries used in this study and the source

Sensor	Date of acquisition	Number of reflective bands	Number of thermal bands	Resolution of reflective band	Resolution of thermal band	Source
TM	17-12-1986	6	1	30m	120m	GLCF
ETM +	03-01-2002	6	1	30m	60m	GLCF
ETM +	30-11-2006	6	1	30m	60m	GLCF

3.2 Derivation of Land Surface Temperature (LST)

This study employs the Radiative transfer method in estimating LST from the thermal infra-red band of the Landsat TM and ETM+ imageries.

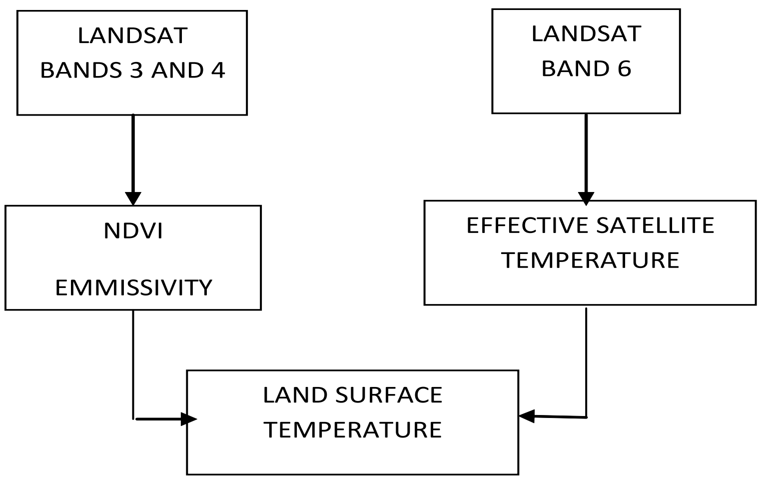


Fig.2: Flowchart of estimating surface temperature

The radiometrically corrected Landsat TM and ETM band 3, 4 and the thermal infra-red (TIR) data (band 6) was used for this purpose. The following equations were adopted sequentially.

Extraction of digital number (DN) from the TIR image and conversion of DN to spectral radiance using,

$$L\lambda = 0.0370588 \times DN + 3.2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Lλ is the spectral radiance

The effective satellite temperature (TEs) is calculated using,

$$TEs = (K2)/\ln\{(K1/L\lambda)+1\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where K2 and K1 are constants and the values are

	Landsat TM	Landsat ETM	
K1	607.76	666.09	mWcm^2
K2	1260.56	1282.71	K

3.3 Derivation of the Derivation of normalized difference vegetation index (NDVI)

In this present study NDVI is used to examine the relationship between LST and greenness. The NDVI were calculated as the ratio between measured reflectance in the red and near infrared (NIR) spectral bands of the images using the following formula:

$$NDVI = (R\ band\ 4 - R\ band\ 3)/(R\ band\ 4 - R\ band\ 3) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

R band 4 and R band 3 are the land surface reflectance in the near infra-red and the visible bands respectively; We later derive the emissivity (ε) from the NDVI using the following;

$$\text{Emissivity } (\varepsilon) = 1.094 + 0.047 \times \ln(NDVI) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

And thereafter compute the surface temperature (Ts) using;

$$Ts = (TEs)/\{1 + [\lambda \times (TEs/\rho)] \ln \varepsilon\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where λ is the wavelength of the emitted radiance = 11.5μm (Markham and Baker, 1985); and $\rho = hc/\sigma = 1.438 \times 10^2$ mK; σ =Stefan Boltzmann constant ($5.67 \times 10^{-8} Wm^{-2}K^{4}$), h = Planck's constant (6.626×10^{-34}Js) and c =2.998×10^8 m/s.

3. Results and Discussion

3.1 Landuse Landcover Change Detection

The classification of the images of the study area at different epochs was necessary in the detection of changes which has occurred in the various land use within the study area over the study period. Land use changes arising from urbanization, agriculture, recreation and deforestation are some of the contributing factors to land cover changes in Akure. The urban expansion witnessed in Akure is characterized by uncontrolled growth of urban development coupled with lack of appropriate land use planning and the measures for sustainable development.
The changes in the LULC are described in terms of number of pixels for each classification category. The number of pixels for the different classes and years are clearly represented in figure 3. Statistics show that as at 1986, Bare-surface and Vegetation constitutes the largest LULC categories in Akure. They collectively occupy an area of 3835.62 km2, representing 86.22% of the total land cover of the study area. The settlement lands are the least land cover type. It occupied an area of 617.315 km2 which represents 13.78% of the total land cover of the study area. Observations from year 2002 show a significant increase in the built environment/ settlement from 617.315 km2 in 1986 to 786.087 km2 in 2002 which implies an increase from 13.78% to17.34%. Whereas, vegetation land decreases from 58.80% to 54.03% while bare-surface increased from 27.42% to 28.63%. Also between 2002 and 2006, settlements has the highest rate of expansion from 786.087 km2 (17.34%) to 932.957 km2 (20.80%) while there were loss of vegetation and bare surface.

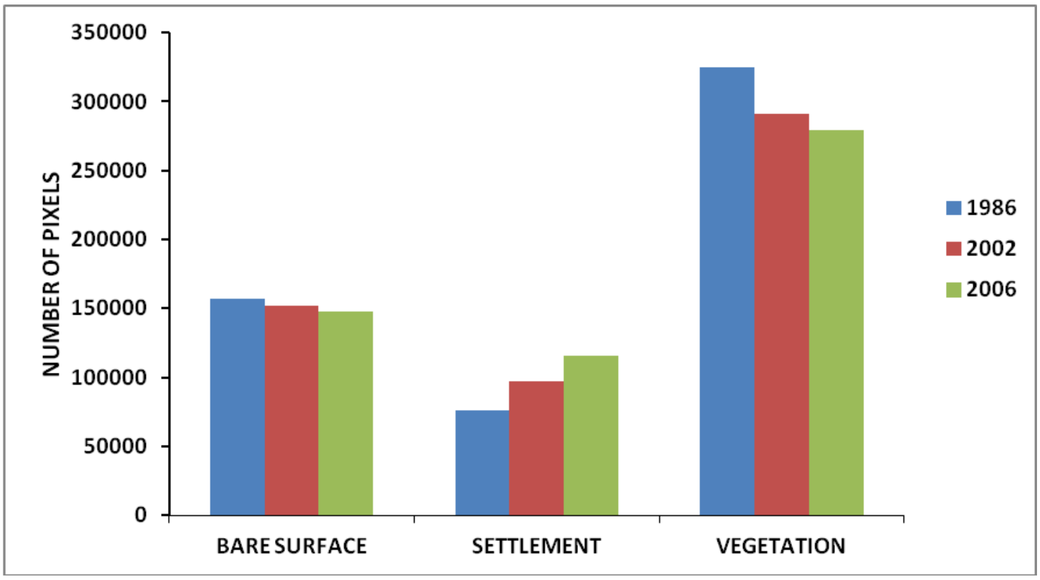
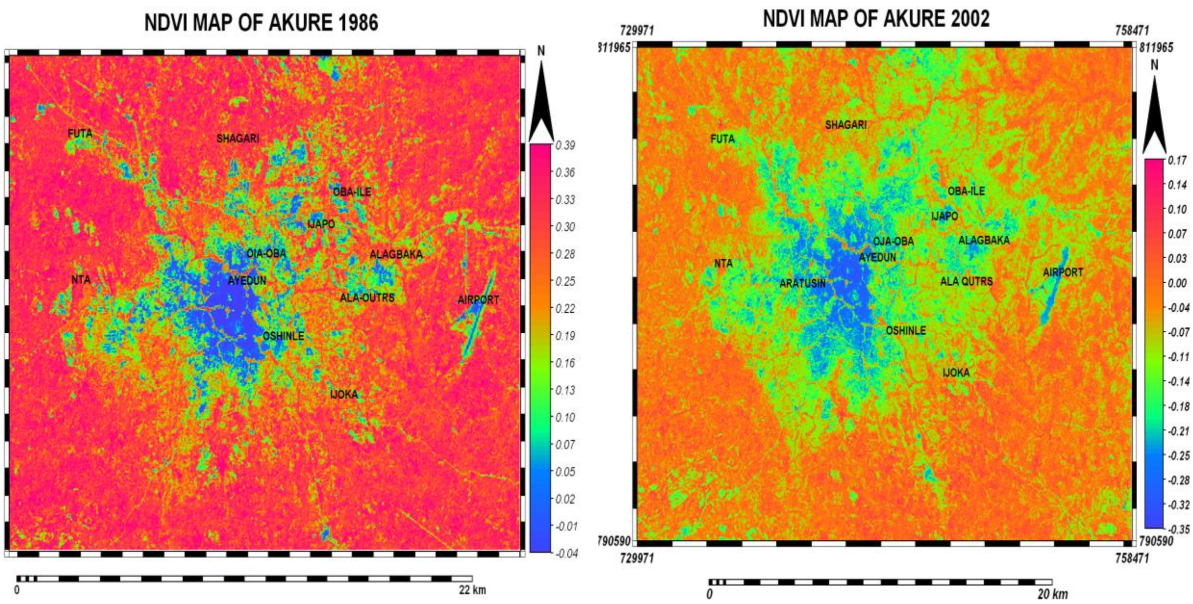


Figure. 3: Pixel information of the different LULC of Akure.

3.2 Change Detection in Vegetation Density (NDVI)

Normalized Difference Vegetation index (NDVI) is a measure of the vegetation density of an area and tends to reduce with increase in the alteration of natural surfaces and replacing them with impervious surfaces. It is observed that lower NDVI corresponds to the developed settlements while high NDVI values corresponds to the less developed natural surfaces as presented in the figure 4 (a, b and c) below. 1986 has the highest NDVI value while 2006 has the lowest which indicates that the NDVI decreases with the urban expansion.



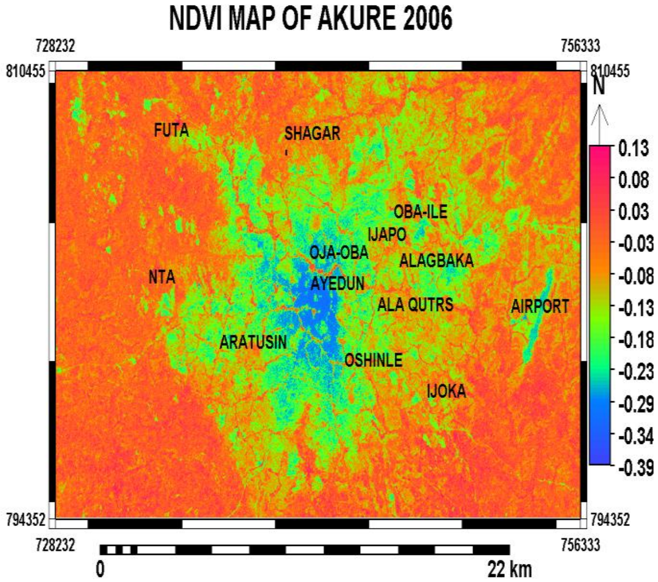


Figure .4 (a, b and c): NDVI Maps of Akure in 1986, 2002, and 2006 respectively

3.3 Land Surface Temperature (LST) and Emissivity Distributions

The result of the LST estimated using the radiative transfer method presented in table 2 shows that the land surface temperature in the study area increases with the increasing rate of urbanization in the city.

Table.2: Temperature variation associated with different LULC types.

LULC TYPE	1986	2002	2006	MEAN
Settlement	28.52	37.32	38.42	34.75
Bare ground	24.87	30.92	30.88	28.89
Vegetation	23.66	24.60	25.23	24.49

The table shows that LST over Akure has increased from 28.52°C in 1986 to 38.42°C in 2006 which constitutes an increase of 9.9°C within 20 years resulting into an average annual increase of 0.49°C. The rapid increase in the values of LST over the years of study can be attributed to the rapid increase in urbanization the city has witnessed. The population of the city has increased from 120,531 in 1980 to 486,569 in 2006 and this has lead to terrible depletion of considerable amount of natural surfaces and replacing them with impervious surfaces such as roads, pavements and other materials with the capability of retaining heat and thereby causing serious environmental stress which in-turn affect our urban micro-climate.

3.3 Relationship between Vegetation Density (NDVI) and LST

Figures 5 a, b and c shows a very strong negative correlation between LST NDVI. This indicates that features in pixels with high NDVI values have low surface temperature values and those in regions with low NDVI values have high surface temperature values. Regions with low NDVI values have less vegetation density as a result of urban development and regions with high NDVI values have very thick vegetation density. The very strong correlation between surface temperatures with NDVI observed, suggests the potential of using linear regression to predict surface temperature if NDVI values are known. It is seen that the NDVI values decreases from 1986 to 2006 due to urban expansion which has led to massive reduction in the green vegetation.

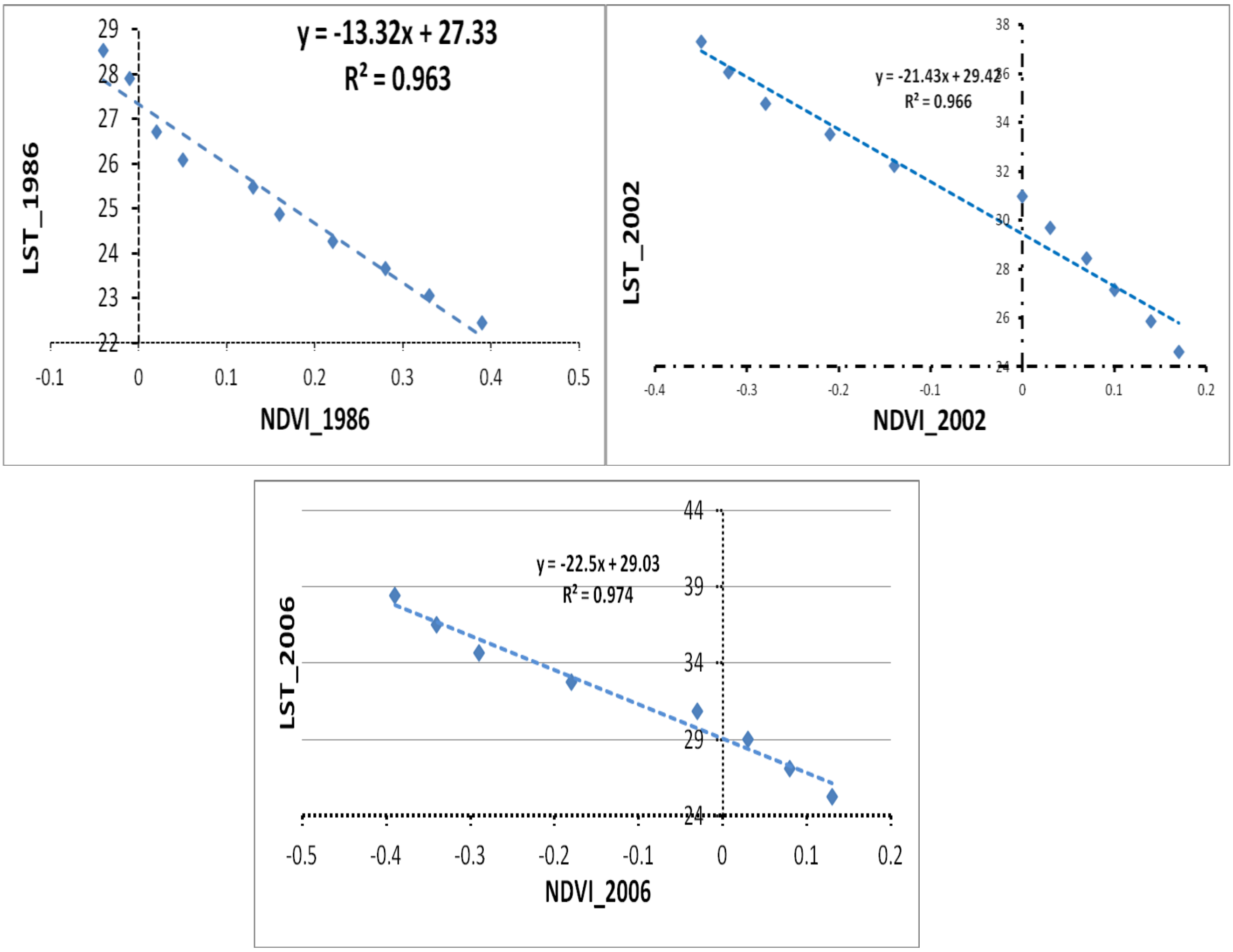


Figure .5 (a, b and c): Relationship between NDVI and LST for 1986, 2002 and 2006 respectively

4. Conclusion

This study exploits the possibility of using Remote Sensing and Geographic information systems in the drive towards sustainable environmental development with particular interest in urban expansion, vegetation loss and consequential thermal alterations. This study has shown the land use land cover dynamics of Akure at different epochs with the corresponding variation in the thermal environment as influenced by the LULCC. It went further to establish the relationship between land cover and land surface temperature in the city. The study actually evaluates the use of remote sensing data for indicating urban surface temperature differences in urban areas with respect to land cover types. It has shown that the surface temperature of the urban environment of Akure has been increasing due to anthropogenic influence on the land use & land Cover.

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