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LAND SURFACE TEMPERATURE IN PART OF SOUTH-WEST NIGERIA (1991 - 2015)

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Abstract: The study examined the spatial and temporal variation of land surface temperatures over a typical medium-size traditional settlement in southwestern Nigeria. Data were the multi-date satellite Landsat imageries (1991, 2002 and 2015) covering the area, as well as values of ambient air temperatures that were measured at different landuse areas (industrial, commercial, residential and outskirts) and along the major road that traverse the study area using a portable handheld air weather station thermometer. Ambient temperature values were obtained between 0600 and 1900 hours of the Nigerian local standard time. Analysis of the Landsat imageries indicate that thermal reflectance (in terms of normalized difference build-up index, NDBI) has generally increased between 1991 and 2015 by about 92 %. The NDBI shows that temperature has increased over the built up regions by 49 - 52 % between 1991 and 2015. Average land surface temperature (LST) in the area also increased by about 2.2 ºC (22.8 ºC - 25 ºC) in the study period, but with higher than average increase around road junctions, industrial and commercial centres. Analysis of diurnal variation showed that daytime temperature was about 0.5 - 1.4 ºC higher in the afternoon than either the morning or evening. The study concluded that increased in anthropogenic activities, including urbanization and commercialization are main causes of temperature increase in the traditional area, and that remote sensing imageries and in situ measurements of temperature are complementary for monitoring of changes in urban climate.

Key words: landsat imageries, land surface temperature (LST), traditional urban settlement, Normalized Difference Building Index

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INTRODUCTION

Rapid urban growth is an attribute of settlements in many developing countries (UNEP, 2002; Ichimura, 2003; Yuan and Bauer, 2007; United Nation, 2010). Many cases of urban growth are often defined in terms of population increase, land expansion, unmonitored constructions and depletion of vegetation as a result of increased extent of impervious surfaces (Herman, 2008, 2009, 2010). In general, many urban areas are characterized by modified microclimates and creation of urban heat islands, such that certain areas in the urban centres contribute to elevated air temperature increase of energy demands, and elevated pollution concentrations compared to rural surrounding areas (Oke, 1982; Voogt, 2002). Atmospheric and surface temperatures within urban environments are generally warmer than their peripheries, especially in areas with poor greening. This is due to the replacement of natural green surfaces with non-evaporative and non-porous urban materials with high heat capacity and low solar reflectivity, such as concrete masses, asphalt roads and metal surfaces (Rose and Devadas, 2009; Arrau and Pena, 2010). Studies have indicated that people residing in areas with intense temperature can be subjected to adverse health issues, including heat stroke, physiologic disturbances, among others (Besancenot, 2002; Luber and McGeehan, 2008).

Urban heat island is considered as one of the major problems in the 21st century posed to human beings as a result of human civilization (Lu et al., 2009). Accurate observation of surface temperature provides much information about surface climate thereby inputting to the general database of urban heat island studies. Apart from the temperature influences, the welfare and health of inhabitants could also be affected by local heat waves. More than 800 people died during the heat wave in Chicago in 1995 (Changnon et al., 1996). The hot summer in 2003 in Europe also caused 15,000 deaths due to heat related illness in Paris (Wright et al., 2005). Urban heat island will also cause increase in air pollutants. Urban heat island also increases the energy demand used for cooling. This in turn causes extra heat to be dumped into the urban area further exacerbating the urban heat island effect (Voogt, 2004).

Studies have indicated that traditional and growing urban areas have become increasingly vulnerable to increase in temperature and urban heat island, probably due to population increase and built up areas. While, most cities today exhibit heat island effects relative to predevelopment conditions, their individual intensities depend on a number of factors: geography, topography, land use, population density, and physical layout. Available studies have shown that in situ temperature data which are generally discontinuous and remotely sensed data that are typically continuous and ensure greater land coverage can be used complementarily. The aim of this study is to assess changes in temperature along the traverse of Ile Ife, a traditional urban settlement in southwest Nigeria. Specific objectives of the research are to examine the spatio-temporal variation of land surface temperature; and evaluate the difference in the in situ values of the temperatures and the values extracted from satellite imageries over the area.

STUDY AREA

GEOGRAPHICAL LOCATION, POPULATION AND LANDUSE

The study area is Ile-Ife, a university town in Osun State in the Southwest Nigeria (figure 1). Ile Ife is located within Latitude 7° 24' to 7° 33' North of the equator and Longitude 4° 27' to 4° 36' East of the Greenwich meridian. The total land area is about 218 kilometres square (NPC, 2006). Ile Ife is semi urban city (Obioh et al., 2005). Its population is estimated at about 600, 000 in 2016 (Popoola, 2017), an increase from the National Population Commission figure of 355,813 in 2006 (NPC, 2006). Ile-Ife is an ancient city which has witnessed immense growth in size of built-up areas, number of immigrants, transportation, and commercial activities with the pattern of land distribution shows that about 25.81% is used for residential Built-up purposes, while the remaining portions are shared for industrial 1.20%, commercial 0.79%, vegetation 61.16%, water body 0.15% and educational purposes 5.63%. Bare soil or unused or vacant land is 6.47% (Arodudu, 2008).

The centrally located Ife-Ibadan road, Ife-Ilesha and Ife - Ondo roads remains the most important centre of commercial activities in the town. The road also forms a node for a number of roads linking other nearby settlement. Tall buildings and tarred surfaces are found within the environment. The residential zone extends into the commercial zones and is densely populated around these main roads. The study area is undergoing rapid urbanization which is affecting the drainage system through unplanned development.

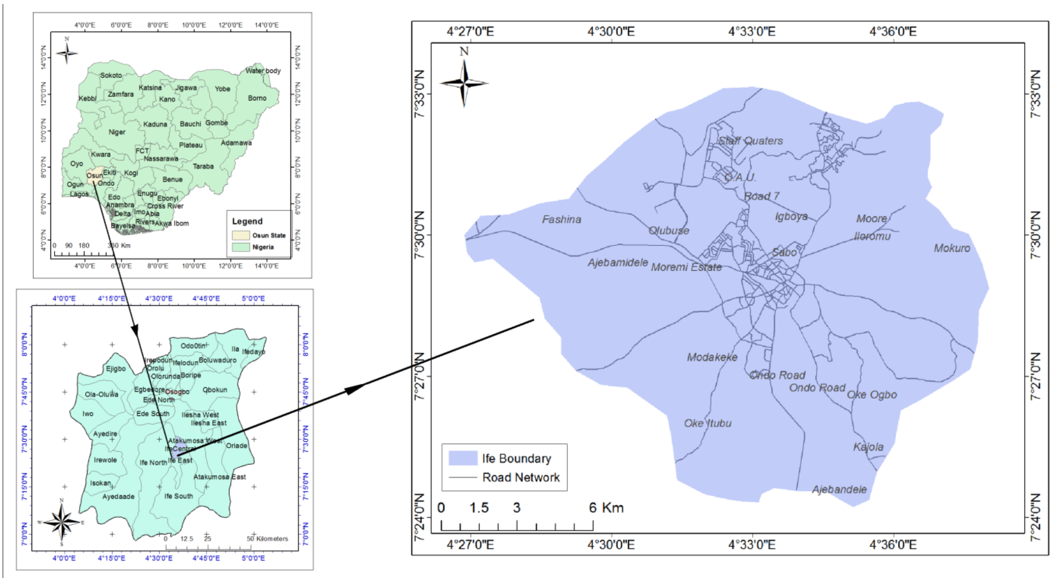

Figure 1. The study area, Ile-Ife in Osun State, southwest Nigeria

CLIMATE AND LANDUSE/COVER

Ile Ife is located within the rainforest ecological belt or tropical wet and dry climate (Eludoyin et al, 2014). The climate is is influenced by the monsoons originating from the South Atlantic Ocean, which is brought into the area by the maritime air mass. It is characterized by small (1-2 ºC) temperature range of 26 °C - 28 °C, average rainfall of 1250 mm per annum, and 75% mean relative humidity range. The pattern of rainfall is characterized by the double maxima regime, the two period of maxima rainfall being June/July and September/October. The vegetation is primarily of lowland rainforest and derived savanna. In most areas the natural vegetation has been replaced by secondary forest, perennial or annual crops (Mengistu and Salami, 2007), and many of the farm areas have become built up areas (Iyanda, 2017).

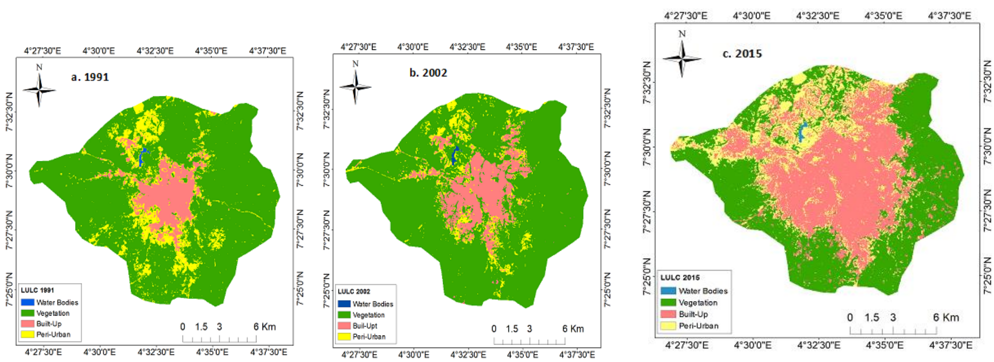

Figure 2. Land cover changes over Ile-Ife, Nigeria in 1991, 2002 and 2015

Land cover classes (water body, vegetation, built-up and peri-urban) around the study area have changed between 1991 and 2015. While areas covered by vegetation have decreased by about 32.7 %, the built-up area has increased by about 28.9 %; area classified as peri-urban and water body have slightly increased by 0.01 % and 4.1 %, respectively (figure 2, a, b, c). The spatial distribution of the built-up areas showed that the areas expand from the core (centre of the study area) towards the surrounding regions between 1991 and 2015. About 38 % of the vegetation has been converted to either the built-up area or peri-urban area within the period of study.

METHODS

DATA

Data used were values of ambient air temperatures of some selected geo-referenced points within the study area, measured with a portable handheld air weather station thermometer through traverse surveys method. Ambient air temperature values were recorded 100 m interval at road junctions and near major industrial, residential and commercial activities, along the main roads (Ibadan road-Mayfair, Mayfair-OAUTHC, Lagere-Ondo road) that traverse Ile-Ife, and air temperature values were measured before noon (0600-0800 Nigeria local standard time, LST), at noon (1100-1300 LST) and after noon (1700-1900 LST) hours. The time range of three hours for each period was to allow the period of moving from one sampling point to the other. The measurements were carried out, concurrently, with the help of field assistants at the different observation points. With the assistants, measurements were obtained between 20th and 22nd of December, 2015. Coordinates are obtained with Global Positioning System (GPS, ±10 m accuracy).

In addition, freely available multi-date satellite Landsat imageries (Landsat TM of 1991, Landsat ETM+ of 2002 and Landsat OLI of 2015) of the area were downloaded from the archive of the United States Geological Survey (USGS). Landsat-5 Thematic Mapper (TM) image (acquired by the USGS on 5th January 1991), Landsat-7 Enhance Thematic Mapper (ETM+) (acquired on December 12th 2002) and Landsat-8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) (acquired on January 5th 2015) are part of the few sensors whose imageries are free for users, especially in developing countries where students and researchers rarely find sponsorship. Table 1 shows the attributes of the Landsat imageries used for this study.

Table 1. Some characteristics of the Landsat imageries used in this study

Satellite/Space craft ID	Sensor ID	Path/row	Date of Acquisition	Spatial Resolution/ Grid Cell Size (m)	Sun Elevation (Degree)
Landsat-5	Thematic Mapper	190/055	1991-01-05	30	43.74
Landsat-7	Enhance Thematic Mapper Plus	190/055	2002-12-12	30	48.66
Landsat-8	Thermal Infrared Sensor	190/055	2015-01-15	30	56.45

ANALYSIS

The imageries were geo-processed, separately and re-georeferenced for local referencing of the features using ArcGIS 6.3 software to correct for radiometric and geometric errors. Subsequently, the Normalized Difference Built-up Index (NDBI, one of the widely used indices to extract the built-up land from the urban area; (Lu et al., 2009) and Land Surface Temperature (LST) over the study area were determined. The NDBI index was developed by Zha et al., (2003), to analyze increments of reflectance on TM 5 and ETM+ 7 bands 4 and 5 while band 6 and band 5 of reflectance on OLI/TIRS 8 for images of urbanized and barren land areas. NDBI in this study was were derived using equation (1)

NDBI**Error! Reference source not found.** (1)

This index was created on the assumption that the reflectivity of urban buildings in the shortwave is higher than in the near infrared (Lu et al., 2009). The processes were performed for the years of 1991, 2002 and 2015. Land Surface Temperature was thereafter determined using the mono-window algorithm (Zhang et al., 2009), following equations 2 a-e.

$$LST = \frac{BT}{1+w} \times \frac{BT}{p} \times In(e) \quad (2a)$$

$$p = h \times \frac{c}{s}\left(1.438 \times 10^{-2} mK\right) \quad (2b)$$

$$e = 0.004Pv + 0.986 \quad (2c)$$

$$Pv = \left(\frac{NDBI - NDBI_{\min}}{NDBI_{\max} - NDBI_{\min}}\right)^2 \quad (2d)$$

$$NDBI = \left(\frac{MIR - NIR}{MIR + NIR}\right) \quad (2e)$$

Where
BT = At-sensor brightness temperature
w = wavelength of emitted radiance
h = Plank's constant $\left(6.626 \times 10^{-34} Js\right)$
s = Boltzmann constant $(1.38 \times 10^{-23} J/K)$
c = velocity of light $(2.998 \times 10^{8} m/s)$
e = LSE
In = Natural Logarithm
L_λ = Spectral Radiance at the Sensor's Aperture [W/(m^{2}sr μm)]
Pv = Proportion of Vegetation
MIR = Mid Infra-Red Band
NIR = Near Infra-Red Band
$NDBI_{min}$ = Minimum value of NDBI
$NDBI_{max}$ = Maximum value of NDBI

RESULTS

DIURNAL VARIATIONS LST VALUES

The temporal variation of temperature values at different road junction of the land use/cover, along the major road indicate that LST values at 0600 and 1900 hours varied over time and space (table 2).

Table 2. Mean, variation and range of ambient surface temperatures along major roads in Ile-Ife, Southwest Nigeria (in December 2015)

Road	Morning 0600-0800 hr	Afternoon 1100-1300 hr	Evening 1700-1900 hr
	Mean ± SD (ºC) (Min- Max)	Mean ± SD (ºC) (Min-Max)	Mean ± SD (ºC) (Min-Max)
Ibadan - Mayfair	29.1 ± 0.4 (28.5 - 29.8)	44.9 ± 0.9 (43.1 - 45.8)	34.4 ± 0.3 (34.0-35.1)
Mayfair - OAUTHC	29.6 ± 0.5 (28.7 - 30.6)	46.6 ± 0.8 (45.6 - 47.3)	36.0 ± 0.9 (34.2-36.8)
Lagere - Ita Osa	28.7 ± 0.9 (26.9 - 29.9)	44.3 ± 1.7 (41.4 - 46.5)	35.3 ± 0.6 (34.2-36.0)
Overall average	*29.1±0.6 (26.9-30.6)*	*45.21±1.1 (43.1-47.3)*	*35.2±0.6 (34.0-36.8)*

At 0600-0800 hr, Mayfair-OAUTHC recorded the 29.6 ºC, and by 1100 - 1300 hr, this increased to an average of up to 46.6 ºC, and later 36 ºC at 1700-1900 hrs. Temperature also varies at different land use/cover in the study area with motor parks exhibiting higher temperature values than the other landuses, especially in the morning (figure 3). Temperatures were also higher at traffic-busy junctions (such as opposite the Teaching Hospital, and commercial areas, Sabo and Lagere, than the residential areas (Ita-Osa) at all the periods investigated. in the three periods.

CHANGE IN LST BETWEEN 1991 AND 2015

Average LST values were 22.8 °C, 23 °C, and 25.8 in 1991, 2002 and 2015, respectively (figure 4). Average temperature was highest at the peri-urban in 1991 (25.9 ºC), and at the built-up area in 2002 (28.7 ºC) and 2015 (27.8 ºC). The vegetal surfaces and water bodies recorded the least values of temperature in the three years. The spatial variations of LST within the study area indicate temperature increase from the nucleus of the town towards the outskirts over the period of the study. Hotspots, indicating the thermal urban heat surface occurred at the core of the settlement, and more hotspots developed with the increase in years (i.e. more hotspots occurred in 2015 and 2002 than in 1991).

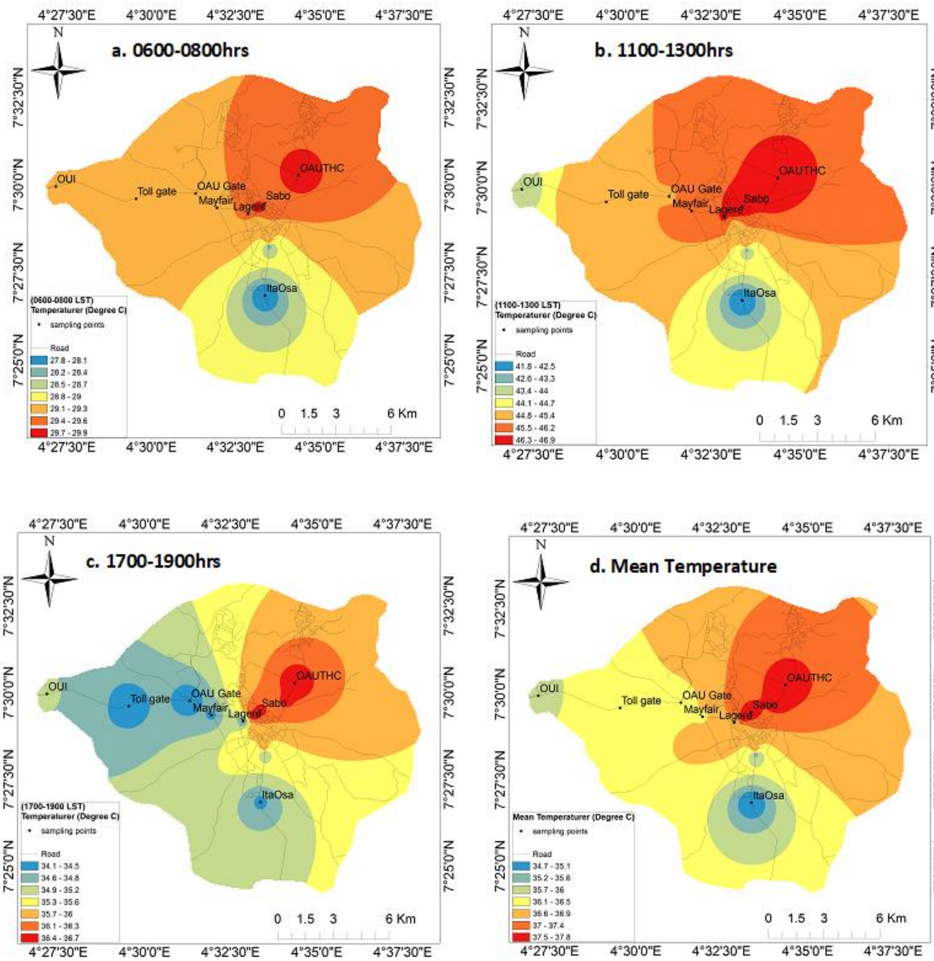

Figure 3. Temporal variations of ambient temperature on a typical day in December 2015

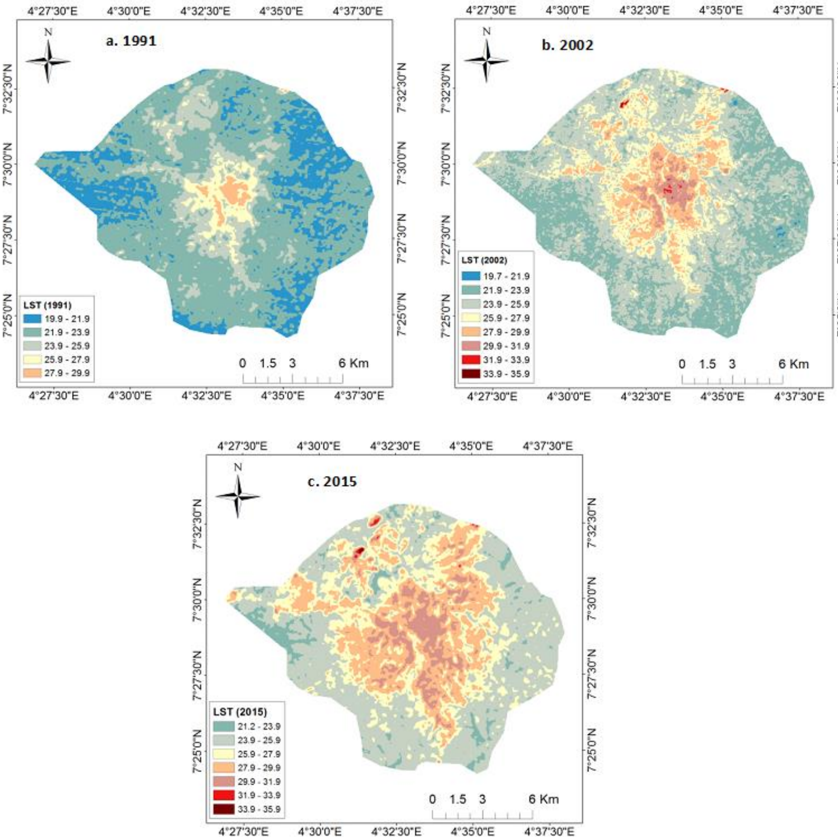

Figure 4. Temporal and spatial variations in land surface temperature (°C) over the study area in 1991, 2002 and 2015

Land surface temperature also increased temporally in the study area from 1991 to 2015 with a maximum LST value of 29.0 °C at 1991, 31.7 °C and 30.7 °C for 2002 and 2015. It is projected that by 2026 and 2038 the maximum LST will have a maximum temperature of 32.5 °C and 34.9 °C (table 3). The spatial distribution of LST indicate that by 2026 the LST is expected to be concentrated at the commercial area around the north east of the study area while by 2038 it is expected to have increase and concentrated at the north west an industrial area where smelting industry is located.

Table 3. Mean, standard deviation and range of ambient air temperature values at different land use/cover in the study cover

Land use/cover	Morning 0600-0800 Nigerian local standard time (NLST)	Afternoon 1100-1300 Nigerian local standard time (NLST)	Evening 1700-1900 Nigerian local standard time (NLST)
	Mean ± SD (°C) (Min- Max)	Mean ± SD (°C) (Min- Max)	Mean ± SD (°C) (Min- Max)
Residential	28.7 ± 0.4 (28.5 - 29.8)	44.0 ± 0.9 (43.1 - 45.8)	35.4 ± 0.3 (34.0-35.1)
Motor Park	29.6 ± 0.5 (28.7 - 30.6)	46.8 ± 0.8 (45.6 - 47.3)	36.5 ± 0.9 (34.2-36.8)
Industrial	28.7 ± 0.9 (26.9 - 29.9)	43.9 ± 1.7 (41.4 - 46.5)	34.7 ± 0.6 (34.2-36.0)
Road Junction	29.3±0.6 (28.0-30.1)	45.2±1.1 (43.4-46.5)	35.0±0.6 (34.1-36.0)
Commercial	29.5±0.5 (29.0-29.9)	46.4±0.1 (46.3-46.5)	35.8±0.2 (35.6-35.9)

CHANGE IN NDBI VALUES BETWEEN 1991 AND 2015

The Normalised Difference Built-up Index (NDBI) - that was used to examine the land use / cover change that can be attributed to construction or concretisation of surfaces in the study area – indicated that mean NDBI values increased both temporally and spatially within the study period (figure 5). Mean NDBI values varied from 0.04 (0.07) in year 1991, through 0.09 (0.1) in 2002 to ─0.07 (0.07) in year 2015, and the temporal spread exhibit a polynomial relationship over the study period. The polynomial relationship indicates that the average NDBI values increased in 2002 from 1991, but declined from 2002 till 2015.

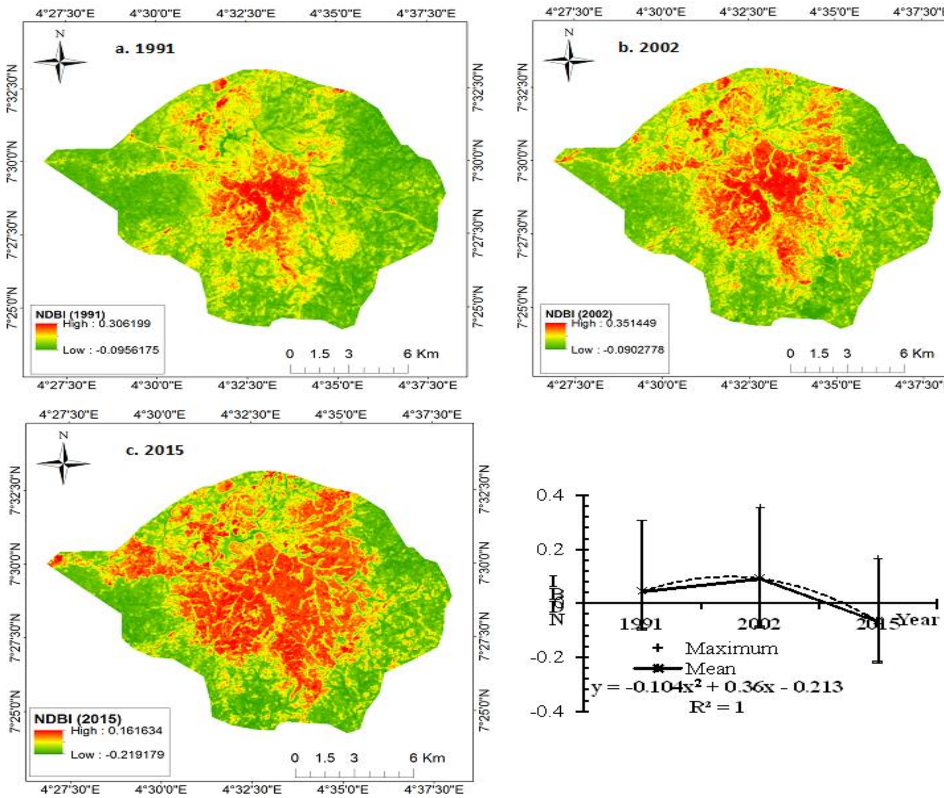

Figure 5. Spatio-temporal variations in the NDBI values around Ile-Ife in 1991, 2002 and 2015

The spatial distribution of the NDBI values showed that they increase from the central part of the study area towards the outskirts. A statistical comparison of the total area coverage (in ha) of built-up areas and corresponding NDBI values in the studied period indicate that about 85% of the change in the built up area was explained by the NDBI values in equation (3)

$$y = -45919x + 5736.9 \quad (R^2 = 0.85) \qquad (3)$$

y = built-up area (ha)
x = NDBI values (no unit)

Comparing the spatial and temporal land surface temperature which is a determinant of surface urban heat island and the in-situ air temperature measured a determinant of canopy urban heat island at various land use/cover of the study area. Table 4 indicates that the average temperature varies at different land use/cover, and that the values derived from the Landsat data were less than that from the in situ recording by about 5 – 8 °C. The graphical representations of both data also reveal variation in the spatial distribution of the heat islands (figure 6). Whereas the imagery indicates higher temperature values at the northwest region of the study, the study area indicates that the northeast exhibited higher temperature than the surrounding.

Table 4. Comparison of the temporal variation of surface-based LST (derived from Landsat 8) and ground based LST (based on ambient temperature values) over Ile-Ife in 2015

Land use/cover	Ground-based LST	Surface-based LST
Residential	36.1	29.9
Motor Park	37.6	29.4
Industrial	35.8	29.6
Road Junction	36.5	28.4
Commercial	37.1	30.1

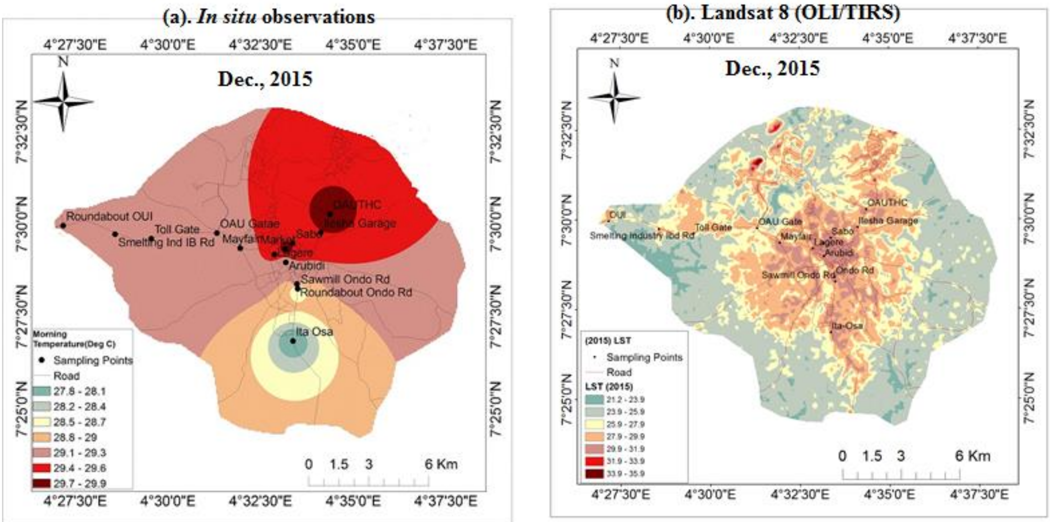

Figure 6. Comparison of the spatio-temporal distribution of land surface temperature from in situ observations and Landsat (OLI/TIRS) imagery in December, 2015

DISCUSSION

Land surface temperatures obtained at the commercial areas and junctions of major roads in this study were higher than those of the outskirts. This result is expected as such has been observed in many region with similar characteristics. For example Aboyeji (2015) noted that road junction in a study of Ilorin, Nigeria often exhibit higher concentration of carbon-oxide gases due to the emission from transport facilities. In addition, Aknbode et al., (2008) attributed temperature increase at commercial centres at a medium size administrative city of Akure, Ondo State, also in the southwest Nigeria to increased human activities in the area. Commercial cities in many African countries are often characterized with higher (than the surrounding areas) population movements, vehicular movements and relatively higher number of buildings (often used for offices, shops and residential purposes). The commercial areas in the study area are also characterized by buildings whose thermal properties are also capable of increasing the temperature of the area. The result of the remote sensing analysis of the Landsat imageries examined in this study indicate that thermal reflectance (in terms of normalized difference building index) has generally increased between 1991 and 2015 by about 92 %.

The NDBI shows that temperature has increased over certain areas (especially Built up, Peri-Urban, Vegetation and Water bodies) at Ile-Ife by about 49-52% in the 34 years range examined. Increase temperature is often attributed to increased population activities, urbanization and climate vulnerability (Voogt and Oke, 2003). Although the specific cause of the increased temperature was not focused in this study, it is known that population and population activities, impervious surfaces and temperature activities have increased in the town within the study period (Oyinloye and Adesina, 2011; Oloukoi et al., 2014). Existing studies of the climate has also reported an increase in the maximum temperature by about 5-10 ^{o}C (Voogt, 2002; Voogt and Oke, 2003). Diurnal variation in this study showed that daytime temperature was about 0.5 - 1.4 ^{o}C higher in the afternoon than either the morning or evening.

In general, the difference between the lowest temperature and highest temperature, 29.3 ^{o}C, 35.9 ^{o}C and 35.5 ^{o}C, from the remote sensing images for the periods of 1991, 2002 and 2015, and for 2015 (from the ground based results) indicates that 37.8 ^{o}C. The variation indicates that the UHI in the study area compares well with those of bigger cities in Nigeria (e.g. Ibadan 3-5 ^{o}C, Adebayo, 1990); Benin City 3-4 ^{o}C (Omogbai, 1985) and Akure: 3-5 ^{o}C (Akinbode et al., 2008). The regression based prediction indicates that hotspots of high temperature will increase towards either parts of the town including a junction of a tertiary hospital in the town (OAUTHC).

The spread of hotspots for temperature increase appears to be explained by the multiple-nuclei model of city arrangement hypothesized by Hoyt (1933). Hoyt (1933) hypothesized an explanation of city development in which a place is characterized by more than one nucleus for development. In Ile-Ife there seem to be a more than one nucleus focus, which may also be linked with or developed from the pre-colonial communal governance method in the region. Ile-Ife, the traditionally acclaimed origins of the Yorubas was sub-grouped into subsections (Akodi) of communities which were under a royal head (Ooni). This arrangement, with the location of the Obafemi Awolowo University at core extreme and the teaching hospital at the other; with the communally valued commercial centres, has translated to multi-nuclei arrangement. The multiple nuclei arrangement is similar to the distribution of temperature hotspots in the area.

Furthermore, the result of the comparison of the ground based temperature with the remote sensing based analysis shows that spatially, the remote sensing based temperature LST thermal urban heat surface is observed to be concentrated at the north east of the study while the ground based temperature hotspot is observed to be concentrated at the north west of the study. Lastly the study, from the results of the comparison of the LSTs showed that the values derived from the imagery do not replace that of the in-situ observations. Whereas the analysis of the imagery reveals the surface urban heat islands (SUHI), which are often most intense during the day when urban materials receive the most solar radiation, and are not heavily influenced by the anthropogenic heat sources such as transportation vehicles or heating and cooling units (Shahmohamadi et al., 2011), the atmospheric urban heat islands (AUHI) reveals the elevation in near-surface air temperature of an urban area over that of nearby rural areas, and are often not more intense at night due to a gradual release of heat from urban surfaces and water bodies (Voogt and Oke, 2003). The difference in their values could also be explained by the effect of difference that can be associated with anthropogenic sources, and vegetation. Vegetation are known to reflect about part of the incoming short-wave radiation (visible light or short- wavelengths) and provides less radiant energy to me detected by image sensors (Xian and Crane, 2006; Hoffmann and Sgrò, 2011).

CONCLUSIONS

The study concluded that Land surface temperature increased by 2.2 ^{o}C between 1991 and 2015 in the study area, and that the temperature increases can be attributed to urbanization. It also showed that LST values from satellite imagery and in situ measurements are provide complementary results, and do not duplicate the other. The study recommends urban greening to reduce the impact of future temperature increase in the area. This study is typical of urban cities in Nigeria, and developing countries, where it can be replicated.

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