Spatio-temporal variance and urban heat island in Akure, Nigeria: A time-spaced analysis Using GIS Technique

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Abstract

The threat of the increasing global temperature is now of global concern than ever before. This prompted the authors to gain insights on the Urban Heat Island (UHI) phenomenon in a medium-sized city of Akure, Nigeria. A random sampling of three hundred and twenty-five (325) structured questionnaires was administered and analyzed with the aid of the Statistical Package for Social Sciences (SPSS). Landsat satellite imagery for the years 2000; 2007; 2013 and 2018 were acquired and used for the computation of land use-land cover (LULC) and the Land Surface Temperature (LST) of the study area using ArcGIS 10.5. Between the years 2000 and 2018, built-up area increased by 8.78% at the expense of the non-built up land use. The residents were aware of UHI and climate change but characterized by superficiality. The study recommends a community awareness program on the menace of climate change and the integration of climate education into the curriculum of schools and other institutions of higher learning.

Keywords: *Urban Heat Island, Land Surface Temperature, GIS, Climate, Akure*

1. Introduction

Changes and variability in climate can no longer be a hidden fact across the Nations of the globe. The reflection of the changing climate has been said to be both anthropogenic and nature-driven (Popoola, 2019). Identifying the argument is that many anthropogenic activities such as unplanned urbanization (Coraiola, *et al*., 2011; Babatola, 2013; Lasisi, *et al*., 2017), bush burning, deforestation, and over-grazing (Wahab and Popoola, 2019; Popoola, 2019) are all drivers for the changing climate and increased global warming. For example, Coraiola, *et al*. (2011), argued that the rapid and uncontrolled urban development, the introduction of paved surfaces, reduction of green areas and heat emission by vehicles led to an increase in air temperature in urban areas, causing detrimental effects to human health and irreversible environmental problems. Babatola, (2013), went further to mention that the physical processes affecting the local climate are determined by surface conditions, location and exposure of the area and surface conditions such as heat capacity, moisture content, vegetation cover, albedo and roughness of the ground surface. Indeed, the pave ground urban areas have a much faster run-off of excessive water, which may further reduce the natural cooling due to the shorter time the water is available for evaporation (Babatola, 2013).

Iterating the changes in climatic condition, Wahab and Popoola, (2018), aver that changes and instability in climatic elements, such as precipitation, temperature, wind, and humidity are generally experienced now in urban areas of Nigeria. This was why Hartmann, *et al*., (2013), reported an increased and increasing global temperature. With Africa temperature expected to increase with 4°C (Niang, *et al*., 2014), Adhikari, *et al*., (2015) identified that the global temperature has increased by 0.72°C which is still expected to increase to between 0.3°C and 0.7°C by 2023 with an increase of 0.3–4.8°C by the end of the 21st century. Barrios, *et al*., (2010), suggested rainfall pattern influences the increasing temperature experienced in Africa. The instability in seasonal rainfall (both in length and quantity) resulted in an increased temperature and consequently urban heat island (Heaviside, *et al*., 2016). Coraiola, *et al*. (2011), buttressed that the consequence of anthropogenic changes in the cities' surface characteristics, urban areas tend to have higher air temperatures than their rural surroundings; a phenomenon known as urban heat island (UHI).

The UHI effect has received considerable attention in climate warming research and urban settlements (Kalnay and Cai, 2003). It is a phenomenon of higher atmospheric and surface temperatures occurring in urban areas than in the surrounding rural areas due to urbanization (Voogt and Oke, 2003). Urbanization, characterized by more people living in the city than in the rural area is not likely to stop, rather on the increase. Approximately 55 percent of the world's population lives in urban areas and by 2050, 68 percent of the world's population is projected to be residing in the urban area (United Nations, 2019). UHI expands when cities replace the natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat and this effect increases energy costs and will likely lead to more frequent, more severe, and longer heat waves during summer months**.** Evidences from the geological records are consistent with the mechanism which shows that adding large amounts of CO_2 to the atmosphere leads to global warming and consequently climate change (The Geological Society, 2010). Chrisitian and Ugoyibo, (2013), state that urban areas (Akure) in Nigeria will generally experience the same exposures to climate as their surrounding countryside, the urban setting- its form and socio-economic activity can alter exposures as well as impacts at the local scale. The view was that built-up areas in the cities create unique microclimate due to the replacement of natural vegetation with a hard-concrete surface which results in increasing temperature and disturbance of evaporation processes and subsequently precipitation patterns (*ibid)* and global warming.

The impacts of global warming are already apparent today in melting glaciers, increased frequency of extreme weather events such as droughts, cyclones or heavy rainfall, sea-level rise, and changes in plant growth affecting agriculture and food production (UNEP, 2011). Increased global warming due to temperature increase will result in varying damaging consequences depending on regions with increasing net annual costs (Virola, *et al*., 2008). This calls for the need to investigate or examine the impacts of urban heat island effects on future climate change. UHI contributes immensely to global warming, hence, the need to consider reducing its effects. Several factors that make people vulnerable to the effect of UHI one of these reasons is being socially marginalized. Indicators of social marginalization include living in poverty, living alone, being disconnected from social networks, and suffering from chronic physical and mental illnesses (Lindley, *et al*., 2006). People living in poverty are less able to escape the heat due to lack of financial resources to make necessary changes, such as by purchasing air conditioners or making appropriate home renovations (Harlan, 2006). Variation in air quality within cities due to several factors such as temperature, vegetation cover, wind, and anthropogenic activities also increases the vulnerability of people within. For example, air quality conditions are typically worse along busy transportation routes (Lindley, *et al*., 2006).

Radhi, *et al*., (2013), mentioned that urban thermal behaviour and pattern in built areas if urban centres are mainly distorted by large scale urban construction and loss of wetlands and water bodies that characterizes city spaces over time. To establish the thermal behaviour in urban areas, satellite remote sensing is a valuable technique for examining the thermal environment of cities (Marina and Constantinos, 2007). Satellite images recorded in the thermal infrared part of the electromagnetic spectrum can be processed to define – at high spatial resolutions – the surface temperatures and display the surface urban heat islands (UHIs) formed within a city (Marina and Constantinos, 2007). Therefore, this study is interested in establishing the thermal pattern (urban heat island) of Akure, Nigeria of the period. Therefore, this paper appraises the effects of UHI on climate change in Akure, Nigeria. The objectives of the study are to: (a) examine the Land Use-Land Cover change for the years 2000 to 2018; (b) determine the Land Surface Temperature (LST) for the years2000-2018and (c) determine the effects of UHI in Akure. This paper started with an overview of UHI and its challenges within the global and local context. Further, the study milieu and geographical methods were discussed. The subsequent section is about results and discussion of findings. Finally, limitations of the study, policy relevant recommendations and conclusion were discussed.

2. Study setting

Akure, also known as Akure city is the capital of Ondo State. The city is made up of two local governments – North and South. Akure lies in the tropics between E 5°04'42"--E 5°29'45"/N 7°26'43"--N 7°03'50".It stands on the altitude of about 370 meters above the sea level. Akure combines two different Local Government Areas which includes Akure North and South. According to the 2006 population census, Akure North Local Government Area has a total population of 130,765 while Akure South Local Government Area has a population of 360, 268 (Ministry of Economic Planning and Budget, 2010).

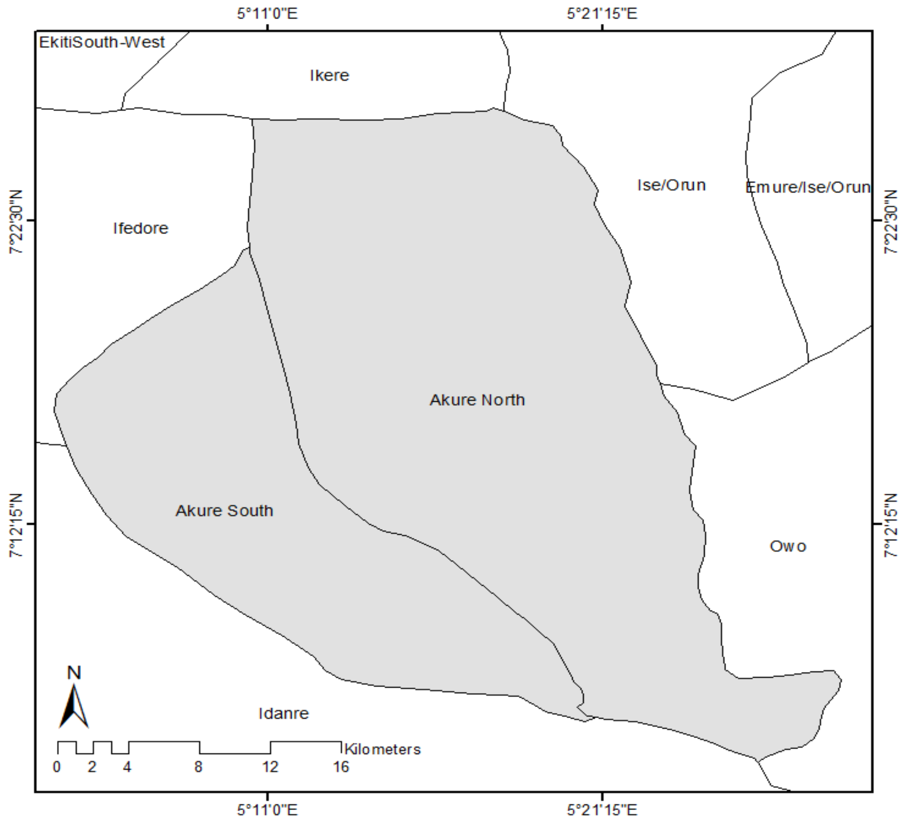

Figure 1: The Study Area

Since Akure became the capital of Ondo State in 1976, it has and continues to experience increasing in population from its hinterlands such as Ifedore and Idanre. According to Fasakin, *et al*., (2018), this phenomenon correlates with increasing urban development and morphological changes in the city. In accordance with the population census conducted in 2006, the population of Akure was approximately 360, 268 and expected to be 486, 300 by 2016 according to its growth rate of 2% (National Population Commission, 2016).

3. Methods

This study demonstrated the applicability of GIS through land use/ land cover analysis and a land surface temperature analysis for the year 2000; 2007; 2013 and 2018.The irregularity among the period of study is because of the high proportion of cloud cover on the Landsat satellite imageries. The study also evaluates the socio-economic factors of the residents in Akure, Nigeria. The following steps were considered:

3.1. Land Use Classification

Landsat Enhanced Thematic Mapper (ETM+) imageries acquired from 2000 to 2018 were obtained from the Global Visualization Viewer (USGS, 2012). ArcGIS 10.5 was engaged for the land-use supervised classification (Maximum Likelihood). A false colour composite of Band(s) 4, 3 and 2 were selected to generate training samples for the following land classes – built-up, rock outcrop and vegetation.

3.2. Land Surface Temperature

The thermal band (6) was used in the estimation of the surface temperature. To estimate the LST from the pre-processed Landsat images, the temperature data stored as DN values in the thermal band 6_2 (high gain band) for ETM+ were initially converted to spectral radiance values using the following standard LMin and LMax spectral radiance scaling factors equation.

$$\text{Radiance} = \frac{\text{LMax}_\lambda - \text{LMin}_\lambda}{\text{QCalMax} - \text{QCalMin}} * \text{QCal} - \text{QCalMin} + \text{LMin}_\lambda$$

Where:

QCal = digital number

LMinλ = spectral radiance scales to QCalMin

LMAXλ = spectral radiance scales to QCalMax

QCalMin = minimum quantized calibrated pixel value (usually = 1)

QCalMax = maximum quantized calibrated pixel value (usually = 255)

The scene calibration data are available on the metadata file of each Landsat scene. Having computed the spectral radiance values for each of the Landsat scenes, they were subsequently converted to temperature values (Kelvin) using the inverse of the Planck function shown below.

$$T = \frac{K2}{\ln\left[\frac{K1 * \varepsilon}{Radiance} + 1\right]}$$

Where:

T = Effective at-satellite temperature in Kelvin

K2= Calibration constant 2 (see Table 1)

K1= Calibration constant 1 (see Table 1)

ε = Emissivity (typically 0.95)

Radiance = Spectral radiance.

Table 1: Thermal Band Constants

Satellite	K1	K2
Landsat 7	666.09	1282.71

Source: https://www.usgs.gov/land-resources/nli/landsat

In respect to the socio-economic survey aspect of this paper, the sample population must be properly defined. The research population of the research is the whole of Akure. Akure was first divided into three different zones according to the city morphology. The zones are: Core, Transition and Periphery. This approach is similar to the classification of Akinbamijo and Fasakin, (2006); Olujimi and Bellow (2009). One district each was randomly selected from each zone. The total number of houses in each district was identified to be approximately 4251. This was achieved by digitizing the structures within the captured and geo-referenced Google earth image of 2019 in ArcGIS 10.5. Questionnaires were randomly administered to people in the randomly selected houses in each selected district. The agreed sample size is 7.64%, which is an adequate representative of the study area after putting into consideration the homogeneity among households in the study area.

Table 2: Sample size

District	**No of Houses**	**No of respondent (*7.64% sample size*)**
Araromi	1088	100
Oke-Ogba	2513	125
Wesco Estate	650	100
Total	**4251**	**325**

4. Results and discussion of findings

4.1. Climate Change and Urban Heat Island

The relationship between climate change and the urban heat island was considered relevant to this study (Rinner and Hussain, 2011; Efe and Eyefia, 2014). The reason is that studies (Sachindra, *et al*., 2016; Koomen and Diogo, 2017; Yang et al., 2017) have established that there is a relationship between climate change and urban heat island effect. Koomen and Diogo, (2017), mentioned that climate change and urban development will exacerbate current urban heat island effects. Thus, the study examines urban awareness of climate change. From the responses recorded (Table 3), all the respondents were all affirmative about their awareness of climate change. This evidence points at the same response in (Pandve, *et al*., 2011; Shahid and Piracha, 2016) that iterates that urban climate awareness is on the increase. Indeed, the synopsis of findings as presented in Pandve, *et al.* (2011), shows that the general population in the urban area is in the study were aware of global climate change and the roles of human activities in climate change. Although the sources of awareness about the climate change knowledge was said to be from non-scientific materials. The experience is somewhat similar in Nigeria (BNRCC, 2011; Odjugo, 2013; Ojomo et al., 2015).

According to Odjugo, (2013), while the urban awareness of climate change may be high, the knowledge of the climate change effect outside their immediate environment might be minimal. In the findings of Ojomo, *et al*. (2015) the knowledge of climate change effect is limited irrespective of the awareness of the cause and impact of climate change. The findings and further investigation suggested that Akure respondents understanding of climate change was superficial. The respondents were also asked about the indicator that makes them notice climate change. This is because none of the respondent has knowledge of UHI and afforestation. The latter is highly possible in urban areas where little or no consideration is given for the development of green infrastructure. Indeed, the perceptive knowledge of climate change was mainly based on rainfall and temperature weather elements.

From the sample, 28.30% of the respondents stated that they noticed climatic variation through temperature increase while 71.70% noticed climatic variation through variation in rainfall pattern (Table 3).The study argues that the limited knowledge of temperature change might account for the limited knowledge of UHI. Girdhar, (2013), reported that temperature variability and discrepancy is the result of the UHI bizarre. It was argued that the UHI-temperature effect is often more noticeable in the urbanized environment that than their adjoining peri-urban and rural areas (Girdhar, 2013).

The study observed more temperature changes in the transition zone of Oke-Ogba compared to the urban core area of Araromi. The reason for this can be traced to increasing sub-urbanization and peri-urban development (Olujimi and Gbadamosi, 2007; Tofowomo, 2008; Basorun and Daramola, 2015; Lasisi, *et al*., 2017). In Akure, Olujimi and Gbadamosi (2007) recorded that often, big projects such as educational institutions, housing, scheme and industrial establishments are located at the periphery of the towns and cities without recourse to the master plan. The study reported the extensive conversion of agricultural land into other land-uses, development of squatter settlements and overstretching of existing infrastructure among others. Explaining the driver for transition and periphery growth, Tofowomo, (2008), allude to the notion that the increasing suburbanization of the population. The study mentioned that the growth of the suburbs has come about because people have fled the social problems of the core region of Akure. Core city problems may have led people to leave and seek solace in socially controlled suburbs. This resulted in the urban built-up area increase, and decline in bare or undeveloped land. Although, Ramakreshnan, *et al*., (2019), mentioned that the UHI-temperature knowledge is limited due to variable lack of awareness and knowledge towards UHI amongst the stakeholders. It was addressed in their writings that UHI is poorly addressed, communicated and integrated into local urban policies (ibid) thus the weak knowledge.

Table 3: Anthropogenic Activities, Climate Change and Urban Heat Island

Awareness of Climate Change				Indicator for Climate Change			
Location	**Response**	**No.**	**%**	**Location**	**Weather Elements**	**No.**	**%**
Araromi	*Yes*	100	100	**Araromi**	*Temperature*	26	26.0
	No.	0	0		*Rainfall*	74	74.0
Oke-Ogba	*Yes*	125	125	**Oke-Ogba**	*Temperature*	36	28.8
	No	0	0		*Rainfall*	89	71.2
WESCO	*Yes*	100	100	**WESCO**	*Temperature*	30	30.0
	No.	0	0		*Rainfall*	70	70.0
Awareness of Urban Heat Island				Practice of Afforestation			
Araromi	*Yes*	0	0	**Araromi**	*Yes*	0	0
	No.	100	100		*No.*	100	100
Oke-Ogba	*Yes*	0	0	**Oke-Ogba**	*Yes*	0	0
	No.	125	100		*No.*	125	100
WESCO	*Yes*	0	0	**WESCO**	*Yes*	0	0
	No.	100	100		*No.*	100	100

The income level in Akure is below average as demonstrated in the findings. A significant (31 percent) number of respondents earn below ₦18,000, 34.46 percent earn between ₦18000 and ₦25000, between ₦25000 and ₦40000 (20 percent), 9.54% earn between ₦40000 and ₦60000 while 5.24% earn above ₦60000 (Figure 2). The analysis also shows that 65.46% of the respondent earn below the set minimum wage of ₦30000. This portrays a convoluted situation whereby the populations are not economically buoyant enough to purchase an air-conditioning system while measures for natural cooling such as greenery are not encouraged. With the international poverty line set at 1.90USD per day (Ferreira *et al*., 2015) the income distribution of the study shows that 31 percent of the sampled respondents can be classified as poor (1 USD to ₦389.77). Why this study was unable to completely expatiate on income-afforestation nexus, studies (Rozelle, *et al.,* 2000; Rauf, *et al.,* 2019) have related that fulewood consumption and land cover loss is related to household income and dependence on fuel energy. The role of afforestation a poverty easing mechanism and livelihood strategy in Pakistan was argued by Rauf, *et al*., (2019).

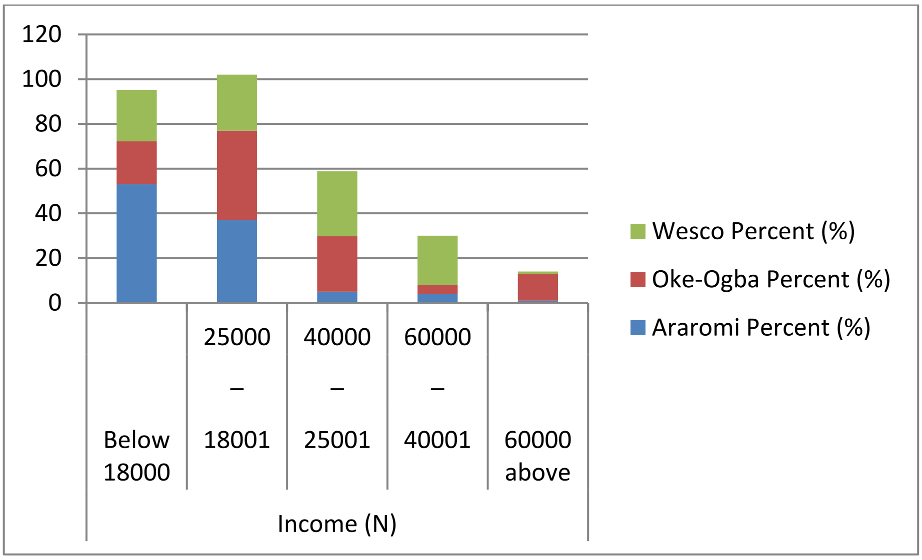

Figure 2: Income Distribution of Respondents

4.2. Land Cover and Surface Temperature Analysis

The study shows a continuous decrease in the spatial extent of vegetated land with direct increase in built-up areas. For example, the spatial extent of the built-up area tripled from 4094 hectares to 12779 hectares between the years 2000 and 2018. This exemplifies a gradual and trend-like replacement of vegetated land with built-up areas. This phenomenon is characterized by urbanization – an influx of people from the hinterlands to the city. As the population increases the demand for shelter and land infrastructures in Akure also increase as suggested in earlier studies (Fasakin, *et al.,* 2018). Similarly, in a study conducted by Eke, *et al*., (2017), they discovered that despite population and built-up areas are increasing in a similar direction, the rate of increase in built-up areas is significantly higher. Besides, the population increased at a lower rate than the rate of urban expansion. This implies that outward growth in Akure has contributed to the ecological and micro-climatic changes and disparities in Akure as observed in other studies (Hu and Jia, 2010; Singh, *et al.,* 2017).

Table 4: Land Cover and Surface Temperature Analysis

Land Area for Classes of Land for Years 2000-2018								
LU/LC	*Year 2000*		*Year 2007*		*Year 2013*		*Year 2018*	
	Area(Ha.)	**(%)**	**Area**(Ha.)	**(%)**	**Area**(Ha.)	**%**	**Area**(Ha.)	**%**
Built-Up	4094	4.14	7189	7.26	10373	10.49	12779	12.92
Vegetation	78147	79.01	60241	60.91	79832	80.71	77584	78.44
Rock Outcrop/ Bare Ground	16668	16.85	31179	31.83	8704	8.8	8546	8.64
Total	**98909**	**100**	**98909**	**100**	**98909**	**100**	**98909**	**100**
	Land Surface Temperature							
	Year		*Max Temp. (^{0}c)*		*Min Temp. (^{0}c)*		*Diff*	
	2000		36.82		22.53		14.29	
	2007		60.22		19.36		40.86	
	2013		51.57		30.71		20.86	
	2018		59.43		24.00		35.43	

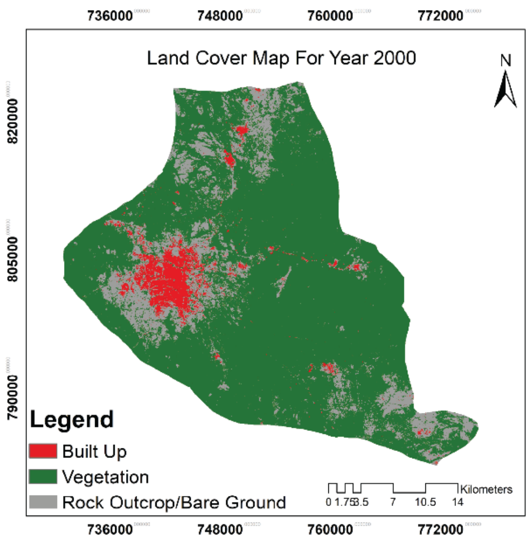

Fig. 3. LULC Map for Year 2000

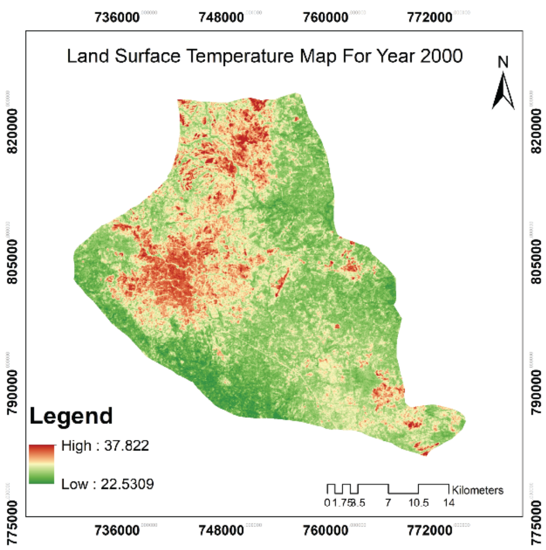

Fig. 4. LST Map for Year 2000

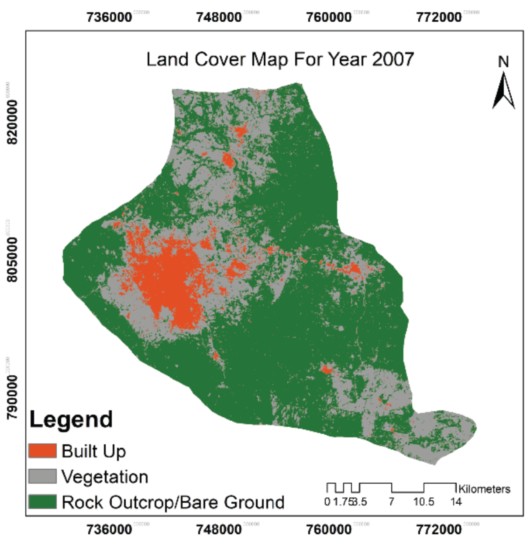

Fig. 5. LULC Map for Year 2007

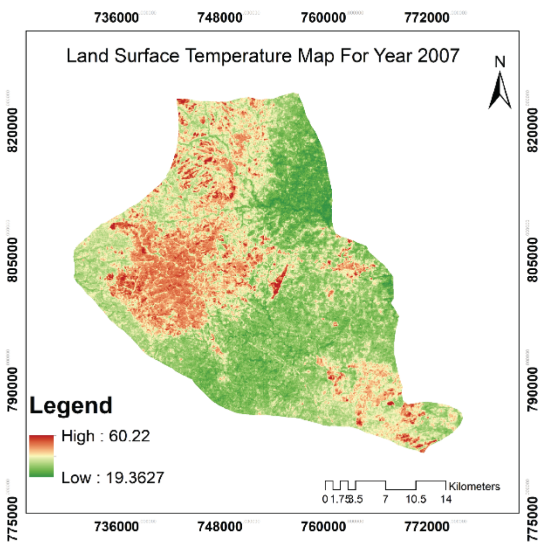

Fig. 6. LST Map for Year 2007

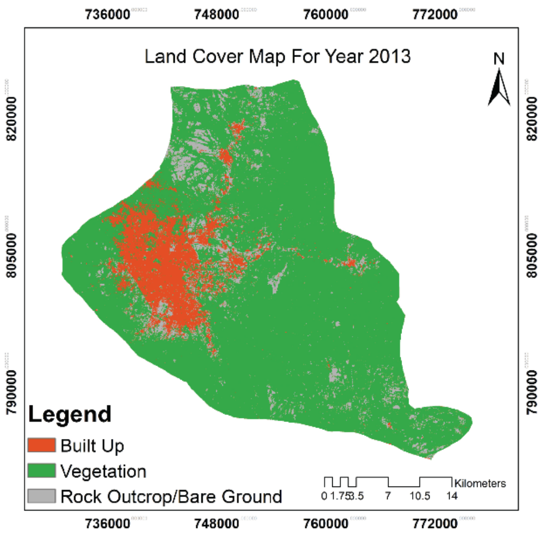

Fig. 7. LULC Map for Year 2013

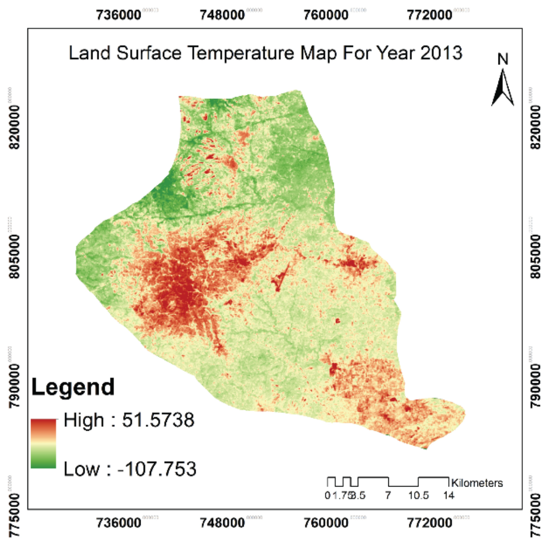

Fig. 8. LST Map for Year 2013

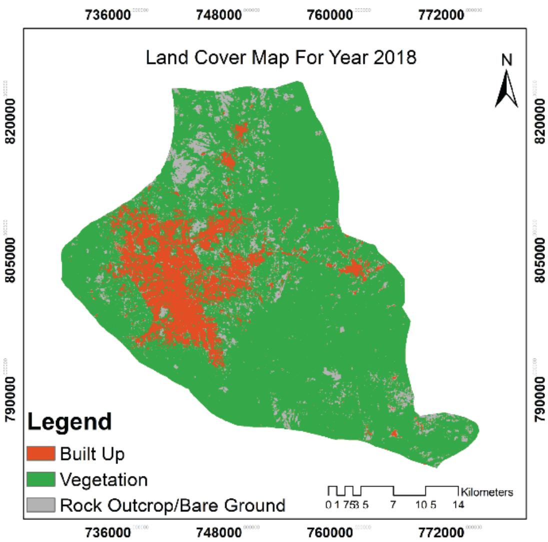

Fig. 9. LULC Map for Year 2018

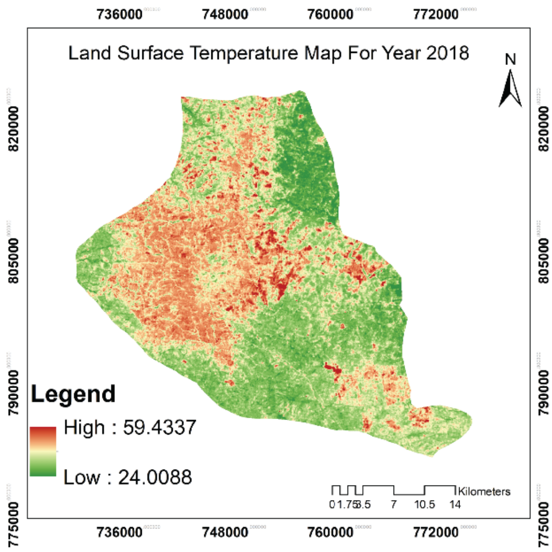

Fig. 10. LST Map for Year 2018

As shown in the figures above, it can be noted that the expanse of land area with the highest temperature happens to be the area of land classified as built-up and rock-outcrop/bare ground land cover type. The average difference in maximum and minimum temperatures between the years 2000 and 2018 is 27.86 degrees. Furthermore, a positive Pearson-correlation of 0.7 ($p = 0.3$) was observed between built-up and maximum temperatures using R statistical package, however not statistically significant. This is likely because of the paucity of satellite image samples of four years used for the study.

5. Limitations, recommendations and policy guidelines

This study attempted to explore the spatio-temporal analysis of UHI and LST in Akure. However, limited by several factors. The choice of Landsat imagery was limited to four different years because of the high level of cloud cover in the south-western region of the country, cloud-free images were only available during the dry season. This invariable masked the effect of seasonality in the study. Nevertheless, according to past studies, the hottest period in Akure is the dry season because of little volume of rainfall.

Findings from the study revealed that climate change is prevalent in the study area. Even though there is awareness of climate change in the study area, it is not backed up with knowledge of UHI. This necessitates a public awareness program in which the causes and effects of climate change as well as measure to be taken to ameliorate its effects. This awareness could be done through television programs, mass media, distribution of pamphlets. Schools and other institutions of higher learning should be encouraged to include the teaching of subjects relating to climate change in their curriculum such as Climate Education for Sustainable Development (CESD). The focus of education should be on climate change effect awareness and the need for transition and urban afforestation.

One of the major causes of urban heat island is the removal of natural ground cover and deforestation. It is therefore suggested that afforestation programs should be carried out by the government and individuals should be encouraged to partake in this programme. The models could be fashioned towards *n* numbers of tree replacement for every *n* number of trees fell. Passive cooling of a structure with a green roof alleviates heating and cooling demands. Furthermore, aside from the aesthetics, green roofs can filter pollutants in the air, especially in the filtering of greenhouse gases which cause global warming from the atmosphere.

Therefore, it recommended that, green walls and other available heat preventing wall finish materials should be encouraged in the study area. Town Planners who are concerned with the development control in the environment should ensure that buildings and other developments in the environment are well controlled and regulated as urbanization is on the increase in Akure.

Also, the study proposes a more robust sample space. This will allow for improved investigation of UHI dynamics of Akure and similar growing cities.

6. Conclusion

The severity of the UHI threat to human health is considerable and is likely to intensify as the climate continues to change, therefore calls for urgent attention. In addition to global warming, physical factors of urban settlements, such as the mineralization of surfaces, low vegetation cover, and the production of waste heat contribute to UHI. It is imperative to address these issues to prepare cities for a warmer climate.

Information on land surface temperature is an adequate method to describe the formation and expansion of UHI which invariably affects the climatic condition of any place. Satellite data provides an efficient and cheap way of estimating the land surface temperature of an area, on a spatial-temporal basis. The formation of urban heat island is inevitable, most especially, because concentration of people will continue to expand. This will result in the continuous removal of natural cover with replacement by manmade materials. Thus, actions should be taken to reduce the effects.

7. References

Adhikari, U., Nejadhashemi, A. and Herman, M. (2015). Climate change and Eastern Africa: A review of impact on major crops. *Food and Energy Security*, 4(2), pp. 110–132

Akinbamijo, O. and Fasakin, J. (2006). Spatial Disparities in residential Housing Health- An Application of Models to Akure. *Soc. Sci*., 1, pp. 158 – 163.

Babatola, E. (2013). Urban influence on relative-humidity and its corresponding effects on rainfall, a case study of Ibadan, Nigeria. *Mediterranean Journal of Social Sciences*, *4*(4), pp. 343-353

Barrios, S., Bertinelli, L. and Strobl, E. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *Rev. Econ. Stat,* 92(2), pp. 350-366.

Basorun, J. and Daramola, J. (2015). Peri-Urban Development Planning of Igusin Community in Akure Region, Nigeria. *International Journal of Contemporary Applied Sciences*, 2(1), pp. 15-23

BNRCC — Building Nigeria's Response to Climate Change. (2011). National adaptation strategy and plan of action on climate change for Nigeria (NASPA-CCN). Prepared for the Federal Ministry of Environment Special Climate Change Unit. Available at: http://csdevnet.org/wpcontent/uploads/NATIONAL-ADAPTATION-STRATEGY-AND-PLAN-OF-ACTION.pdf [Accessed 13 May 2020]

Christian, E. and Ugoyibo, O. (2013). Mapping Enugu City's Urban Heat Island. *International Journal of Environmental Protection and Policy.* 1(4), pp. 50-58.

Coraiola, G., Targino, A., Krecl, P. and Chernev, L. (2011). Spatio-Temporal Distribution of the Urban Heat Island in a Tropical City during Winter Time. Available at: http://www.congremet.prmarg.org/upload/coraiolaguilherme.pdf [Accessed 13 May 13, 2020]

Eke, E., Oyinloye, M and Olamiju, I. (2017). Analysis of Urban Expansion for The Akure, Ondo State, Nigeria. *International Letters of Social and Humanistic Sciences*. 75, pp 41 - 55

Efe, S. and Eyefia, O. (2014) Urban Warming in Benin City, Nigeria. *Atmospheric and Climate Sciences*, 4, pp. 241-252. http://dx.doi.org/10.4236/acs.2014.42027

Fasakin, J., Basorun, J., Bello, M., Enisan, O., Ojo, B., and Popoola, O. (2018). Effect of Land Pricing on Residential Density Patter in Akure Nigeria. *Advances in Social Sciences Research Journal,* 5(1), pp. 31-43

Ferreira, F., Jolliffe, D.M. and Prydz, P., (2015). The international poverty line has just been raised to $1.90 a day, but global poverty is basically unchanged. *How is that even possible*. World Bank.

Girdhar, M. (2013). Awareness Campaign- Urban Heat Islands (part 1). Available at: https://www.behance.net/gallery/6658691/Awareness-Campaign-Urban-Heat-Islands-(part-1) [Accessed 13 April 2020]

Hartmann, D., Tank, A., Rusticucci, M., Alexander, L., Brönnimann, S., Charabi, Y., Dentener, F., Dlugokencky, E., Easterling, D., Kaplan, A., Soden, B., Thorne, P., Wild, M. and Zhai, P. (2013). Observations: atmosphere and surface. Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Vol. 9781107057999, pp. 159-254). Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.008

Heaviside, C., Vardoulakis, S. and Cai, X. (2016). Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. *Environmental health*, *15*(1), pp. S27.

Kalnay, E. and Cai, M. (2003). Impact of urbanization and land-use change on climate. *Nature*, *423*(6939), pp. 528-531.

Koomen, E. and Diogo, V., (2017). Assessing potential future urban heat island patterns following climate scenarios, socio-economic developments and spatial planning strategies. *Mitigation and adaptation strategies for global change*, *22*(2), pp. 287-306.

LandSat. (2019). Thermal Band Constants. Available at: *http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter11/chapter11.html*.

Lasisi, M., Popoola, A., Adediji, A., Adedeji, O. and Babalola, K. (2017). City Expansion and Agricultural Land Loss within the Peri-Urban Area of Osun State, Nigeria. *Ghana Journal of Geography*, 9(3), pp. 132–163.

Lindley, S., Handley, J., Theuray, N., Peet, E. and McEvoy, D. (2006). Adaptation strategies for climate change in the urban environment: assessing climate change related risk in UK urban areas. *Journal of Risk Research*, *9*(5), pp. 543-568.

Marina, S., & Constantinos, C. (2007, April). Study of the urban heat island of Athens, Greece during daytime and night-time. In *2007 Urban Remote Sensing Joint Event* (pp. 1-7). IEEE.

Ministry of Economic Planning and Budget (2010) .Fact and Figures on Ondo State.Ondo State Government: Akure.

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014). In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Odjugo, P.(2013). Analysis of climate change awareness in Nigeria. *Scientific Research and Essays*, *8*(26), pp.1203-1211.

Ojomo, E., Elliott, M., Amjad, U. and Bartram, J., (2015). Climate change preparedness: A knowledge and attitudes study in southern Nigeria. *Environments*, *2*(4), pp.435-448.

Olujimi, J. and Bello, M (2009). Effects of Infrastructural Facilities on The Rental Values of Residential Property. *Journal of Social Sciences* 5(4): 332-342.

Olujimi, J. and Gbadamosi, K. (2007). Urbanisation of Peri-Urban Settlements: A Case Study of Aba-Oyo in Akure, Nigeria. *The Social Sciences*, *2*(1), pp. 60-69.

Pandve, H., Chawla, P., Fernandez, K., Singru, S., Khismatrao, D. and Pawar, S. (2011). Assessment of awareness regarding climate change in an urban community. *Indian journal of occupational and environmental medicine*, *15*(3), pp. 109–112

Popoola, A. (2019). Climate Variability and Urban Agricultural Activities in Ibadan, Nigeria. A.K. Rathoure and P.B. Chauhan (eds) *Current State and Future Impacts of Climate Change on Biodiversity*, A volume in the Advances in Environmental Engineering and Green Technologies (AEEGT) Book Series (pp.11-30). IGI Global: USA. eISSN: 2326-9170

Radhi, H., Fikry, F. and Sharples, S. (2013). Impacts of urbanisation on the thermal behaviour of new built up environments: A scoping study of the urban heat island in Bahrain. *Landscape and Urban Planning*, *113*, pp. 47-61.

Ramakreshnan, L., Aghamohammadi, N., Fong, C., Ghaffarianhoseini, A., Wong, L., Noor, R., Hanif, N., Aziz, W., Sulaiman, N. and Hassan, N., (2019). A qualitative exploration on the awareness and knowledge of stakeholders towards Urban Heat Island phenomenon in Greater Kuala Lumpur: Critical insights for urban policy implications. *Habitat International*, *86*, pp. 28-37.

Rauf, T., Khan, N., Shah, S., Zada, M., Malik, S., Yukun, C. and Sadique, A. (2019). Poverty and Prosperity: Impact on Livelihood Assets of Billion Trees Afforestation Program in Khyber Pakhtunkhwa (KPK), Pakistan. *Forests*, *10*(10), pp. 916-927.

Rinner, C. and Hussain, M. (2011). Toronto's urban heat island—Exploring the relationship between land use and surface temperature. *Remote Sensing*, *3*(6), pp. 1251-1265.

Rozelle, S., Huang, J., Husain, S. and Zazueta, A. (2000). China: From Afforestation to Poverty Alleviation and Natural Forest Management. Evaluation Country Case Study Series. The World Bank, Washington, D.C.

Sachindra, D., Ng, A., Muthukumaran, S. and Perera, B. (2016). Impact of climate change on urban heat island effect and extreme temperatures: a case-study. *Quarterly Journal of the Royal Meteorological Society*, *142*(694), pp. 172-186.

Shahid, Z. and Piracha, A., (2016). Awareness of climate change impacts and adaptation at local level in Punjab, Pakistan. In *Balanced Urban Development: Options and Strategies for Liveable Cities* (pp. 409-428). Springer, Cham.

Singh, P. Kikon, N. and Verma, P (2017). Impact of landuse change and urbanization on urban heat island in Lucknow city, Central India. A remote sensing-based estimate. *Sustainable Cities and Society*, *32,* pp. 100 - 114

Tofowomo, A. (2008). The planning implications of Urban Sprawl in Akure. In 44th ISOCARP Congress, Dalian, China, 19-23 September 2008

Virola, R., Domingo, E., Talento, R., Amoranto, G. andLopez-Dee, E. (2008). Gearing a National Statistical System Towards the Measurement of the Impact of Climate Change: The Case of the Philippines. In *Conference on climate change and official statistics. Norway* (pp. 14-16).

The Geological Society (2010).Climate change: An Evidence from the geological record. London.

UNEP (2011).Climate Change Starters Guidebook. Paris: United Nations Educational, Scientific and Cultural Organization.

United Nations (2019).World Urbanisation Prospects.United Nations Office, New York.

Voogt, J. and Oke, T. (2003). Thermal remote sensing of urban climates. *Remote sensing of environment*, *86*(3), pp. 370-384.

Wahab, B. and Popoola, A. (2018). Climate-Induced Problems and Adaptation Strategies of Urban Farmers in Ibadan. *Ethiopian Journal of Environmental Studies and Management*, 11(1), pp. 31-42.

Wahab, B. and Popoola, A. (2019). Urban Farmers' Perceptions of and Adaptation Strategies to Climate Variability in Ibadan, Nigeria. In Cobbinah, P. and Addaney, M. (eds.), *The Geography of Climate Change Adaptation in Urban Africa*. pp.123- 154. Palgrave Macmillan, Cham: Switzerland.

Hu, Y. and Jia, G. (2010). Influence of Land use Change on Urban Heat Island Derived from Multi-sensor data. *Int. J. Climatol.* pp. 1382 - 1395

Yang, Q., Huang, X. and Li, J., (2017). Assessing the relationship between surface urban heat islands and landscape patterns across climatic zones in China. *Scientific reports*, *7*(1), pp. 1-11.