OSUN GEOGRAPHICAL REVIEW

Journal of the Department of Geography,
Osun State University, State of Osun, Nigeria

Volume 4, 2021

ISSN: 2695 - 1959

Published by the
Department of Geography, Osun State University,
State of Osun, Nigeria

EDITORIAL BOARD

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OSUN GEOGRAPHICAL REVIEW
Published by the Department of Geography, Osun State University, State of Osun, Nigeria
ISSN: 2695 - 1959 Volume 4, 2021; 170 - 180

TEMPORAL ANALYSIS OF URBAN HEAT ISLAND IN IBADAN METROPOLIS

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Abstract
Considering the threat posed by the urbanization on health and wellbeing of the urban dwellers, this study analysed the temporal pattern of urban heat island (UHI) in Ibadan Metropolis. Data on minimum, maximum and mean monthly temperature were obtained from six weather stations for a period of twenty years (1999-2018). Hourly and daily data on these parameters were obtained from the online archives of ECMWF Re-Analysis (ERA Interim) and "World Weather Online" for a 40-day period to enable proper description of the diurnal characteristics of UHI intensity. On the average, a total of 40 average hourly and daily observations were collected and used to complement the data obtained from the ground stations. The entire study area was divided into 40 grid cells of 1 km × 1 km using the 'Fish-net' technique in the ArcGIS™ software. Results show that there are seasonal variations in temperature, with a higher trend during the dry season. It was also revealed that the UHI intensity was observed to be higher during night hours than afternoon hours (maximum up to 3.8°C) and strongest during the dry season. There was a strong positive relationship between the mean annual UHI intensity and years considered and this was found to be statistically significant ($r = 0.786$; t_{value} 5.09, C_v=2.12, $P \leq 0.05$) with 1999, 2013 and 2015 being the years of peak UHI values, indicating strong thermal contrast.UHI in the study area is increasing on various forms of temporal scales. UHI intensity tends to be weakest in wet season and strongest during the dry season with the average values of the magnitude of UHI slightly higher in the latter. This studytherefore recommends a massive control of migrants from the rural areas to the urban areas by improving the lots and quality of life of rural dwellers through the provision of basic social infrastructure and decentralization of nodal locations and commercial areas through the building of supermarkets, shopping malls and departmental stores in residential areas.

Keywords: Urban Heat Island (UHI), Temporal Pattern, Diurnal

Introduction

Urbanization is a process whereby an increasing proportion of the population in a country resides in cities. Approximately 48% of the world's population live in urban areas and this is projected to increase by an annual rate of 1.8% until 2030 (UN, 2004). Going by this estimate, it is suggested that the number and size of urban areas are likely to increase substantially in the future. Over the years, the meteorological and climatological consequences of urbanization have been noted in different parts of the world. This has elicited the numerous studies carried out on urban climatology in both the tropical and extra-tropical countries of the world.

In Africa, the urban areas serve as centers of economic activities, financial activities, governmental institutions and commercial activities. There is therefore no gain saying that there are considerable level of investment and developmental activities in the urban centres. The choice of this research is hinged on the fact that there have been imminent problems arising from the impact of urban centres on their local climate, especially in the tropical cities of the world. These problems might be attributed to the rapid growth of tropical cities due to the influx of rural-urban migrants, increased risk of flooding due to poor urban planning (Adelekan, 2004), replacement and continuous misuse of climate resources, the apparent indifference of policy makers to the threat of climate change with serious consequences on the climate of urban centres.

It is worthy to note that there is one peculiar phenomenon that has attracted researchers to widely observed meteorological factors between the urban and rural environment which is regarded as "The Urban Heat Island" (UHI).

UHI basically refers to a situation where the temperature of metropolitan cities are significantly higher than the surrounding rural areas with the main cause being the modification and replacement of natural land surfaces with urban structures that possess materials which are capable of storing shortwave radiation. Magee *et al.*,(1999) defined UHI as a term used to describe the effect of a city's urban development and human activities on the air temperature within and around the city.

It is obvious that the associated risk and series of environmental challenges which arise from these unabated growths can only be better imagined. They include increased noise and air pollution, unpredictable rainfall pattern, increased temperature and heat waves. Other problems like urban floods, increased heat wave, poor visibility and problems of solid waste are also common place. Of utmost importance in all of these threats to human survival are the problems arising from the modification of the local city climate. This is because the inadvertent modification of climate of cities renders considerable effect on the health, comfort, productivity and socio-economic development of the city dwellers.

A study by Tereshchenko and Filonov (2001) found negative heat island intensities in the rainy months for Guadalajara, Mexico City. Also, the seasonal profile of UHI was found to follow Oke (1987) general cross section of a typical UHI for a cross section of urban area (defined as 'cliff', 'plateau' and peak") in Unger *et al.* (2001). Cueto*et al*. (2009) identified the temporal variability of the temperature in the boundary layer of Mexicali City, B.C. and rural surroundings. Extant literatures point to the deep potential impact of urban activities on the parameters of local climate in Ibadan, Nigeria (Oguntoyinbo, 1973; Adebayo, 1985; Babatola, 2013; Anibaba et al., 2017; Anibaba et al., 2019). The climate in Ibadan has been reported to be modified by the process of urbanization (Adebayo, 1985; Babatola, 2013; Anibaba et al., 2017; Anibaba et al., 2019). Adebayo (1987) and Jauregui (1997) reported a larger heat island effect in the dry season than the wet season for Ibadan and Mexico City. This explains the larger thermal admittance in the rural environs during times of moist soils.

Few (if any) have attempted to re-examine and analyse the temporal pattern of UHI. Hence, the need for re-examination and in-depth analyses of temporal pattern of UHI in most tropical cities for update and comparison with several cities of the world are very germane. Also, the evident neglect of recent studies on the UHI effect and its temporal pattern by various researchers especially in Africa compared to a number of studies in most developed countries of the world whose effects were closely monitored (Auer, 1981; Ackerman, 1985; Bohm, 1998; Kim and Baik, 2001; Hughes, 2006)have prevented sustainable development and a workable policy to be incorporated into future urban planning. It is against this background that this study analyses the temporal pattern of UHI in Ibadan Metropolis, Nigeria. The choice of Ibadan was based on the fact that is the largest city in sub-Saharan Africa. Therefore, the study seeks to (i) examine the temporal pattern of temperature in the study area (ii) analyse the diurnal, seasonal and annual variations in the UHI Intensity.(iii) determine the trend of mean annual UHI intensity in the study area over time.

Materials and Methods

Study area

Ibadan is located within Latitude 7º 15'N and 7º 30'N of the Equator and Longitude 3º 45'E and 4º 00'E of the Greenwich Meridian. Spatially, Ibadan is located near the forest-grassland boundary of south-western Nigeria, situated at an approximate distance of 150 km from the Atlantic coast. Presently, Ibadan metropolis hosts the administrative capital of Oyo state. Out of the eleven local government areas (LGAs) that make up Ibadan region, five are generally regarded as Ibadan metropolis and they are Ibadan North, Ibadan Northwest, Ibadan Northeast, Ibadan Southeast, and Ibadan Southwest while the six Peri-urban LGAs are Egbeda, Akinyele, Ido, Ona-Ara, Oluyole, Lagelu. In view of its location, the climate of the study area is that of a tropical wet and dry climate. Largely, it is strongly influenced by the West African monsoon climate, marked by a distinct seasonal shift in the wind pattern, radiation and cloud cover due to its latitudinal location. The two most defined rainfall seasons are the dry and wet season. The period of wet season is usually between March and October when the area is under the influence of the prevailing moist, maritime southwest monsoon winds which blow inland from the Atlantic Ocean while the dry season occurs normally from November to February when the dry, dust-laden north-east trade winds blow from the Sahara desert. The mean annual rainfall of Ibadan is about 1205mm, falling in approximately 109 days. The temperature of Ibadan is characterized by constant high temperatures throughout the year with mean monthly temperature fluctuating around 26.6ºC, while the mean monthly minimum and maximum temperature is rarely below 21.4ºC. Highest temperatures usually occur around February and March which coincides with the period that mark the end of the dry season. Relative humidity is constantly high throughout the year with annual average greater than 80 percent, and the period of highest relative humidity coincide with the rainy season. The cloud cover is high with about 80 percent in the rainy season. In terms of drainage system, Rivers Ogunpa and Kudeti drain the built-up area of the city. These rivers later extend into the drainage areas of Ona and Ogbere. The eastern side of the city is drained by rivers Ogunpa and Kudeti while the western flank of the city is drained by Ona River (Adebayo, 1985).

For a long time, the city was the largest in Tropical Africa and the largest indigenous metropolitan area in sub-Saharan Africa (Adedimeji*et al*., 2008). Ibadan's population grew from an estimated figure of 170,000 in 1911 to 459,196 in 1952. By 1963, its population had reached 625,000. The 1991 census put the population of the city at about 1.45 million people. Together, the region of Ibadan has a population of over 2,550,593 persons according to the 2006 population census. The Ibadan metropolis local government areas account for 1,338,659 persons, while the six other local government areas that constitute the rest of the region account for slightly less than one-third of the population for the state (National Population Commission, 2006). The total area of developed land in Ibadan increased from 100 ha in 1830 to 12km^2 in 1931. But by the mid-twentieth century, the contiguously built-up area of Ibadan grew from 30 km^2 in 1963 to 214 km^2 in 1988 (Fabiyi, 2006). By the year 2000, it expanded covering an area of about 400 km^2. The expansion of the urban area in terms of its growth during the latter half of the 20th century (from 40 km^2 to 250 km^2 in the 1950s and 1990s respectively) reveals that there has been an underestimation of the total growth of the region, and its locational advantage made it a favorable city for educational, socio-political, commercial and industrial activities.

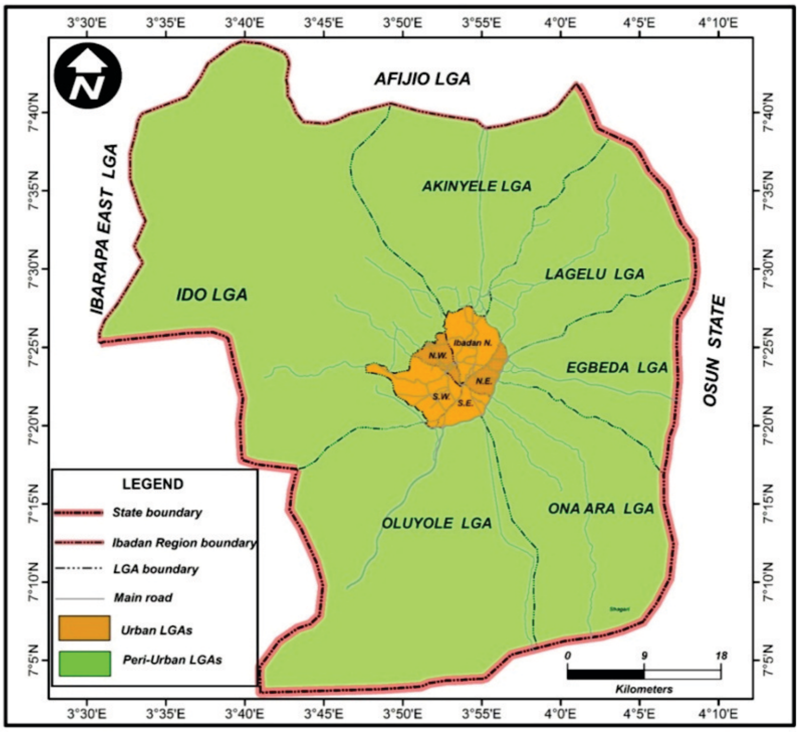

Figure 1: Map Showing the Study Area (Ibadan Metropolis and its Peri-Urban Areas)

Data Collection and Analysis

Weather data and remote sensing images for Ibadan were obtained for this study. Weather data obtained were from both the conventional and point locations (satellite extract). The ground-based weather station consists of the meteorological and agricultural stations which are the Geospatial Unit of the International Institute of Tropical Agriculture (IITA), Institute of Agricultural Research and Training weather unit (IARandT), Cocoa Research Institute of Nigeria (CRIN), Forestry Research Institute of Nigeria (FRIN) and Ibadan Airport (through Nigeria Meteorological Station (NIMET). Data on maximum, minimum and mean monthly temperature were obtained from these stations over a period of twenty years (1999-2018). Hourly and daily data on these parameters were obtained from satellite-based sources which are websites of "Era-Interim" (http://www.ecmwf.int/en/ research/ climate-reanalysis/era-interim) and "World Weather Online" for a 40-day period to enable proper description of the diurnal characteristics of UHI intensity. The choice of a 40-day period is because the historical weather data available in these websites are only limited to a three-month period (October-December, 2017). The data bank may lose its integrity when it lasts beyond this period due to large volume of data generated from the satellite hourly. On the average, a total of 40 average hourly and daily observations were collected and used to complement the data obtained from the ground stations.

In addition to the climatic data sourced from the ground weather stations, satellite data were also obtained to ensure adequate spatial coverage of the study area.In achieving this, the dataset were first of all downscaled to the study area. The entire area was divided into 40 grid cells (or pixels) of 1 km × 1 km. Using the 'Fish-net' technique in the ArcGIS™ software, point locations were randomly selected and the weather data for each point were extracted so as to get a good representation of the terrains therein. Going by the conclusions by Mohan *et al.* (2012) who used 32km × 32km grids in their analysis, these are expected to provide accurate measurements of UHI intensity and provide a basis for comparison with in situ measurements which can be used to detect major hotspots and for assessing hotspots for other sites and times when in situ measurements are inadequately available. Overall, twenty-four (24) sites were chosen throughout the city which include the six conventional ground station (WS) and eighteen points of satellite data extract. Figure 2 shows the location of the sampled sites on the map of Ibadan. The data extracted were analysed using Statistical Package for the Social Sciences (SPSS) and other statistical tools. Other secondary data sources used in this research include Administrative and Road network maps of the study area and review of the existing literatures.

The study of UHI conventionally requires an elimination of the effects of large-scale changes and hence an isolation of local effects (Kim and Baik, 2001). A technique most commonly used to detect the influence of urbanization on the climate of urban centres is to consider a difference in temperature between representative urban and rural station, commonly referred to as "Index of UHI Intensity" (Yague*et al.* 1991; Jauregui*et al.*, 1992; Karaca*et al.* 1995). The intensity is a measure of the magnitude or strength of the heat island (Voogt, 2004).

For this study, a rural reference station (Cocoa Research Institute of Nigeria) was chosen and the difference in temperature between the rural site and urban stations (average temperature) were used as a surrogate measure of the UHI intensity in Ibadan. The choice of the reference station is based on the fact that only the green areas in the city were observed to have the lowest temperatures. The only station that closely approximates this feature is the weather station in Idi-Ayunre. The station was therefore considered as a baseline to assess UHIs at other stations. To study the distribution of UHI over the entire monitoring network grid, the diurnal UHI cycle were constructed for the tri-hourly period of the GMT. These hours were chosen based on approximate time of occurrence of minimum and maximum temperatures at all the stations and transitory conditions between morning-afternoon and evening-night respectively.

Figure 2: Locations of Satellite Data Extract and Weather Stations across the Study Area

S/N	Station Name	Type	Latitude	Longitude	Elevation (m)
1	NIMET	Synoptic Station	7^0 26' 45.0"	3^0 53' 26.0"	197m
2	CRIN	Agro-climatological Station	7^0 14' 58.0"	3^0 50' 56.2"	130m
3	IAR and T	Agro-climatological Station	7^0 22' 46.2"	3^0 50' 37.7"	146m
4	IITA	Agro-climatological Station	7^0 29' 48.0"	3^0 54' 12.4"	211m
5	FRIN	Agro-climatological Station	7^0 23' 30.9"	3^0 51' 47.7"	187m
6	NIHORT	Agro-climatological Station	7^0 24' 21.6"	3^0 51' 03.0"	200m

Based on statistical analysis, the trend in the time series was evaluated by fitting a regression curve to the time series using the least square method. This is used to determine the general trend of the heat island intensity over time. A test is further carried out to determine the statistical significance of this trend of UHI intensity using correlation analysis.

Results and Discussion

Temporal pattern of temperature

Figure 3 shows the seasonal pattern of minimum, maximum and mean temperature based on the average values obtained in all locations. It was observed that mean temperatures increased from the end of October, attaining a peak just before the onset of the rainy season in March. Temperature values at the end of March are relatively high due to fairly uniform cloudy conditions in the sky. In the middle of the raining season, particularly around the time of the "little dry season" at the end of July to early August, the temperature over the city is less intense as they vary between 21°C to 28°C. This is possibly due to the heavy cloud cover at this particular time of the year. Also, due to the heavy cloudy conditions, temperatures are generally low and there is no marked difference between the temperature values between the Peri-urban and urban centre. Towards the end of July and early August, the temperature distribution begins to rise following a general pattern which however rose sharply in September until it attains a peak in March.

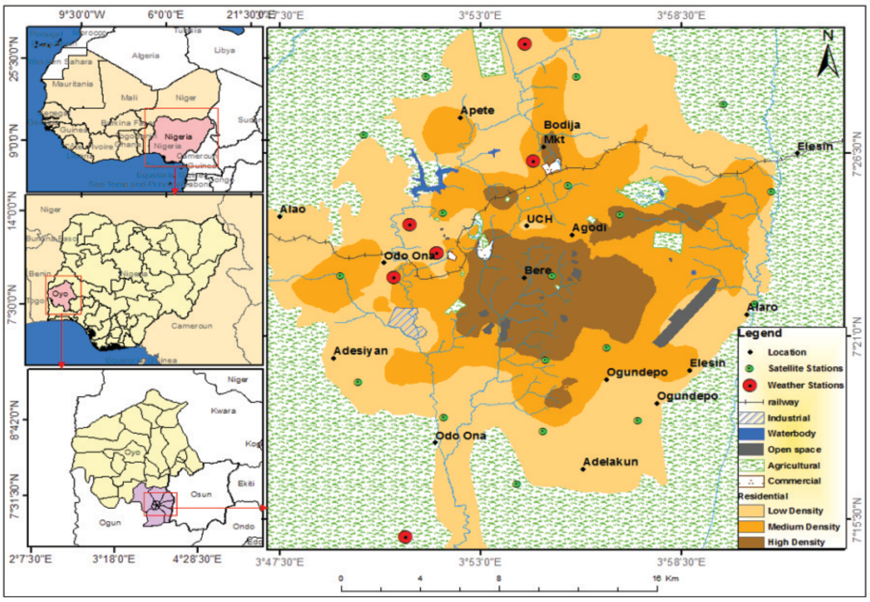

Figure 2: Locations of Satellite Data Extract and Weather Stations across the Study Area

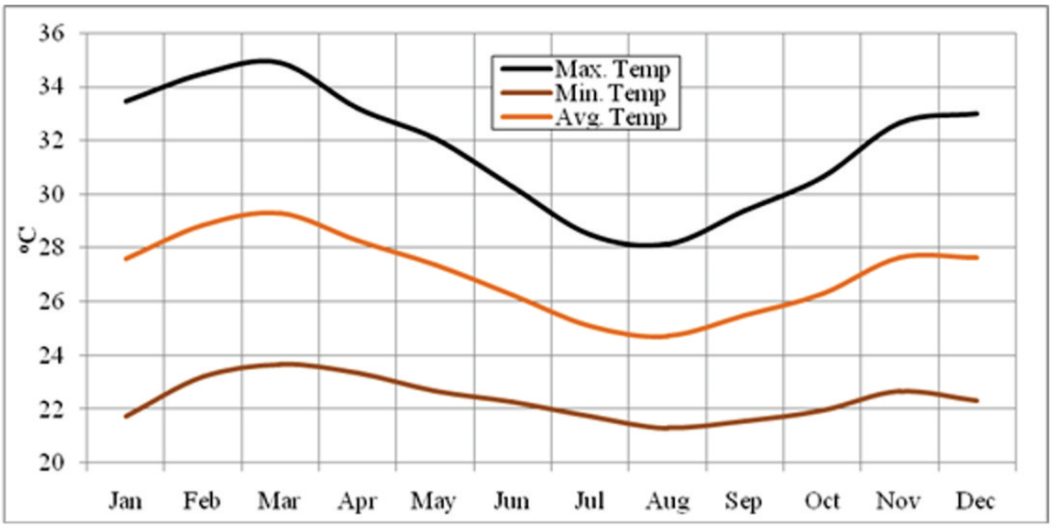

Figure 3: Pattern of Minimum, Maximum and Mean Temperature for all the Stations (1999-2018)

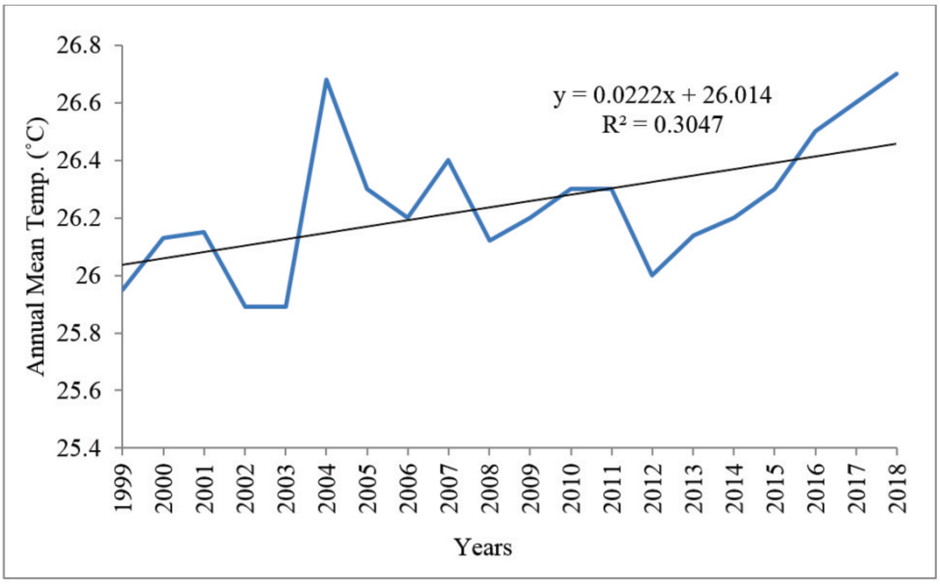

Figure 4: Annual Mean Temperature for Ibadan (average observations from all stations)

The annual mean temperature for Ibadan based on the records of average of all daily temperature reading for all the stations in Ibadan is 26.5ºC with 0.7ºC decadal increase in temperature over the last twenty years (Figure 4). The highest annual mean temperature of 26.7ºC was recorded in the year 1998 and 2012, while the lowest annual mean temperature of 25.9ºC was recorded in 1993, 1996 and 1997 indicating that those years were relatively cooler than other years. The maximum value of 26.7ºC was recorded in 1998 and 2012 indicating that those two years were relatively warmer. It was also revealed that there was a steady rise and fall in the average temperature values between the years 1998 to 2006. However, these fluctuations gave way to a continuous rise in mean annual temperature until it attained a peak in 2012. These findings indicate that the temperature of Ibadan has increased in the last six years and this can be attributed to the rise in population of the urban area, climate change phenomenon, change in land use and increasing automobiles in the cities (Balogun et al., 2012; Anibaba et al., 2017; Adeyeri et al., 2017; Anibaba et al., 2019;Popoola et al., 2020). Rising population consequently result in series of land use dynamics which renders a corresponding effect on average temperature and precipitation of the urban area (Balogun et al., 2012; Olusola et al., 2017; Eresanya et al., 2019).

Diurnal Variation of the UHI in Ibadan

Results presented in Figure 5 indicate the presence of a heat island in Ibadan which has been observed and recent data confirmed the tendencies found in previous research (Oguntoyinbo, 1973; Adebayo, 1985, 1987) where temperature recordings taken in the urban centre were higher than those observed in the surrounding Peri-urban sites. The means UHI intensity in the study area were found to be positive. This indicates that the air temperature at the urban sites were higher than those at the Peri-urban sites most of the time. Figure 5 illustrates the diurnal variation in UHI values and it was revealed that during the night time (1800-0600 GMT), the mean UHI varies between 1.5-3.7ºC while diurnal UHI (0600-1800 GMT) varies between 1.4-2ºC. The highest UHI intensity of 3.8ºC occurred at 3:00am (0300 GMT), while the weakest UHI intensity occurred at 1500 GMT. Furthermore, the UHI is seen to dissipate rapidly within 1-3 hours in late midnight just before sunrise as evident in rapid dip in the UHI intensity curve just after 0300GMT. The result also indicates that the highest UHI intensity occurred during the night time and the dawn just immediately before sunrise, while the lowest mean UHI intensity occurred during the day time. Thus, night hours showed significant UHI intensity than daytime hours. This report corroborates the works ofAdebayo (1987), Balogun et al. (2012), Adeyeri et al. (2017), Anibaba et al. (2019), Eresanya et al. (2019) and Popoola et al. (2020) where significant UHI values were observed during the night hours and early-hour transition.

In addition, a much significant night time UHI was equally observed in the study of Popoola et al., (2020). This result can be explained by a large proportion of open spaces exposed to the sun and the intense concentration of human activities in the urban centres which results in a prominence of night time UHI. Besides, the cooling rates are influenced by surface thermal properties and surface geometry (Oke*et al*., 1991). During the day, urban surfaces trap more incoming solar radiation than surfaces in rural areas. Then they re-radiate it at night than surfaces in rural areas. The ability of heat release by long-wave radiation in urban areas is low due to decreased sky view which results in heat storage in building structures (Rizwan*et al.*, 2008).

Seasonal and annual variation of the UHI

The air temperature difference between the urban and rural stations also showed seasonal variations. Figures 6 and 7 show the temporal variation of pockets of UHI intensity in Ibadan. The intensity of the 'heat island' was found to increase from the rural area to the urban centre. The result indicates that the strongest UHI intensity occurred during the dry season (November-February) and declined during the rainy season (March-October). Furthermore, there is also an increase in the dry season's heat island intensity compared with the wet season. The highest UHI intensity (4.8-5.0ºC) were found at the city centre of Beere, Agodi and Dugbe area of the city during the dry season, while the lowest UHI intensity occurred at the fringes/suburbs in both the dry and rainy season. The values of UHI range from a mean of 0.2ºC to 4.5ºC and 0.4ºC to 5.0ºC during the wet and the dry seasons respectively. It is obvious from the result that the average values of UHI intensity in the dry season are slightly higher than that of the wet season. Also, the highest UHI values observed in the dry season are in agreement with Balogun*et al.* (2009b) that reported UHI at 1500 in October and November and higher UHI values in January and February in Akure City, Nigeria. The findings also confirm the work of Jauregui*et al* (1992) which revealed that UHI intensity is largest during the dry season in Mexico City, Mexico. The major factor responsible for the seasonal variations in UHI intensity is probably the differences in weather conditions (Montavez*et al.*, 2000; Unger *et al*., 2001; Kim and Baik, 2001; Zhang *et al.*, 2009; Adeyeri et al., 2017 and Popoola et al., 2020). In both seasons, the major UHI zones consists of the high density residential areas and the commercial centres of Beere, Dugbe, Inanlena and Oke Ado area of the city. In addition, the heat island zones were observed in the zone corresponding to the downwind direction of the prevailing winds.

Most prominent amongst the explanations advanced for the seasonal variations in UHI intensity especially for temperate cities of the world is the length of daylight during the summer time. Many cities with four distinct seasons are in the mid-latitudes, which have variable day lengths between the seasons. Longer daylight in summer implies that the UHI effect would be worse in summer, as there would be more time for the different surfaces to absorb short-wave radiation from the sun. For most tropical cities with pattern of UHI intensities similar to those of the temperate regions, increased daily insolation leads to large thermal contrasts owing to the heat absorbed for warming the soil, vegetation and albedo. These factors coupled with the physical structure of the city and materials or fabrics of buildings especially of most tropical cities largely explain the strong positive value of UHI during the dry season. Aside from these factors, increased cloud cover and a higher air humidity act to depress the UHI effect during the rainy season (Jonsson, 2004).

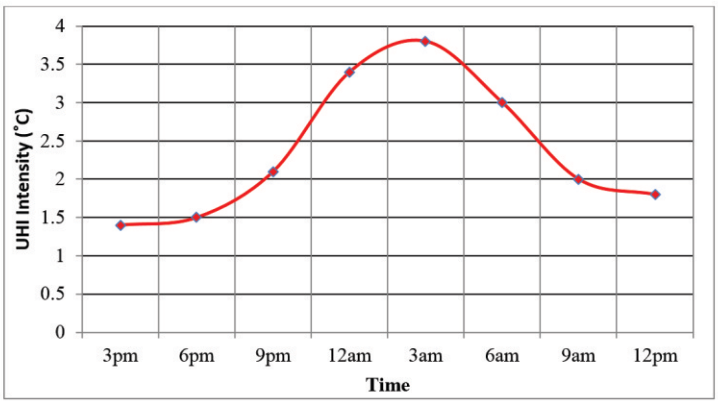

Figure 5: Tri-Hourly Mean UHI Intensity for Ibadan
(Average of 40-day observations between October and December, 2017)

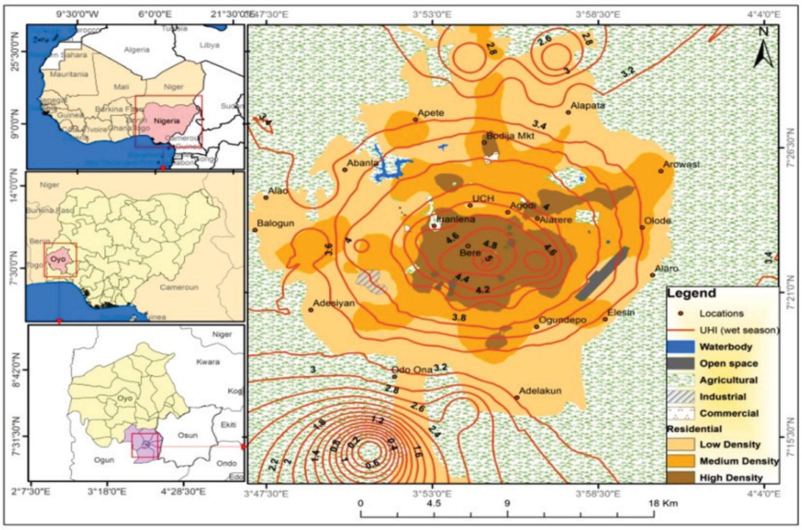

Figure 6: Spatial Distribution of UHI Intensity during the Wet Season (April-July)

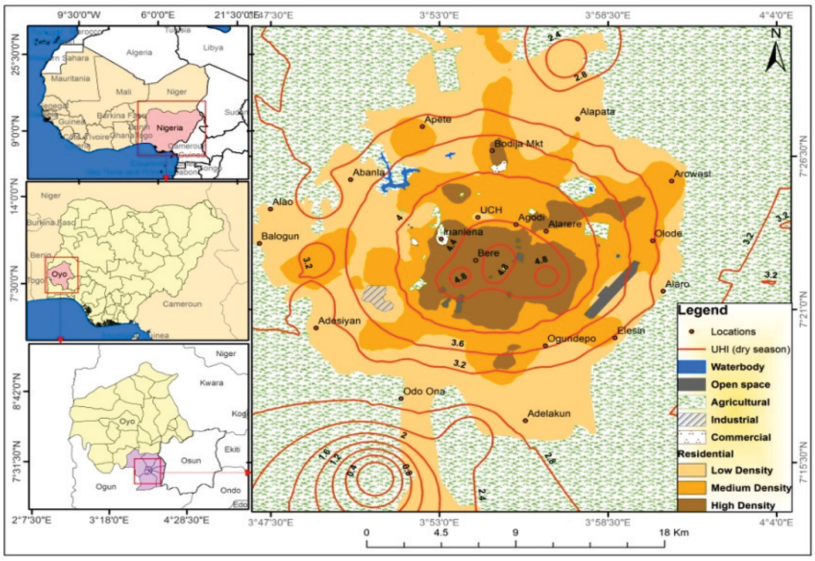

Figure 7: Spatial Distribution of UHI Intensity during the Dry Season (Nov-Feb)

Trend analysis of annual mean uhi intensity in the study area

Figure 8 illustrates the time series of the mean annual UHI Intensity (i.e. mean values of daily UHI intensities from two urban stations - 'IAR&T' and 'IITA'). It was revealed that the annual mean UHI intensity is on the increase within the study area, although, some years tend to record a decline. The mean annual UHI ranges from 3.5ºC in 1999 to a peak value of 4.4ºC in 2013 and 2015. It is obvious that the period 1999 to the early 2006 were significantly less warm than the latter decade spanning from 2010 through 2016. This shows that there was much contrast between the temperature of the urban centres and peri-urban areas in the latter period. The decline in the early 2006 and later rise after 2010 supports the work of Zhang *et al.* (2009) who reported a general rise of 0.1ºC for the UHI intensity between the period 1970s to early 1990's but concluded that the rise has not been constant in time. This implies that the annual UHI intensity have been rising, attaining a peak for certain period but at other times remained steady or declined.

A plausible explanation for this scenario in Ibadan could be due to the increasing rate of urban expansion fast spreading to the peri-urban areas of the city. In this situation, most of the agricultural or forest land is cleared for urbanization and the new areas assume the characteristics of an urban centre. Hence, a steady rise in the temperature of the urban environment. This therefore increases the temperature differences between the urban and rural location which results in the upward trend of the mean annual heat island intensity. Over the last thirty (30) years, UHI of approx. 3ºC was reported for Tucson, Arizona (Comrie, 2000). While a general rise of 1.0°C of UHI was reported by Magee *et al.,* (1999). The general rise was attributed to increased urban expansion and population of the two cities.

The regression equation derived from the trend line in Figure 8 showed an increase in the rate of UHI intensity. The average annual rate of increase for the mean annual UHI intensity is 3.5%.

To further determine the statistical significance of the trend of UHI intensity in the study area, the data were subjected to correlation analysis and the result shows a coefficient (r = 0.786; t_{value} 5.09, C_v2.12, $P \leq 0.05$). This implies that there is a strong positive relationship between the mean annual UHI intensity and the number of years. In a nutshell, this connotes that UHI intensities have significantly increased with time in the study area.

Conclusion

Modification of the land surface characteristics promotes the development of UHI phenomenon at the urban boundary and urban canopy layers. This study has analysed the temporal pattern of UHI in Ibadan Metropolis. The result of the analysis has shown to have increase in temperature whose pattern exhibits seasonal characteristics. It was particularly observed that the pattern of temperature showed a much higher trend in the dry season than the rainy season.

The study also established that the UHI intensity was a positive one with values ranging from 1.5-3.7°C during night hours and diurnal UHI of 1.4-2.0°C between the urban and Peri-urban sites. UHI Intensity tends to be weakest in wet season and strongest during the dry season with the average values of the magnitude of UHI slightly higher in the latter. The study established that mean annual UHI was at its highest in 2013 and 2015 while 1999 and 2006 had the lowest value. The annual UHI Intensity was observed to have followed a periodic pattern with the last eight years being the warmest. A correlation analysis conducted to test the statistical significance of the observed mean annual UHI intensity over time was found to be statistically significant.

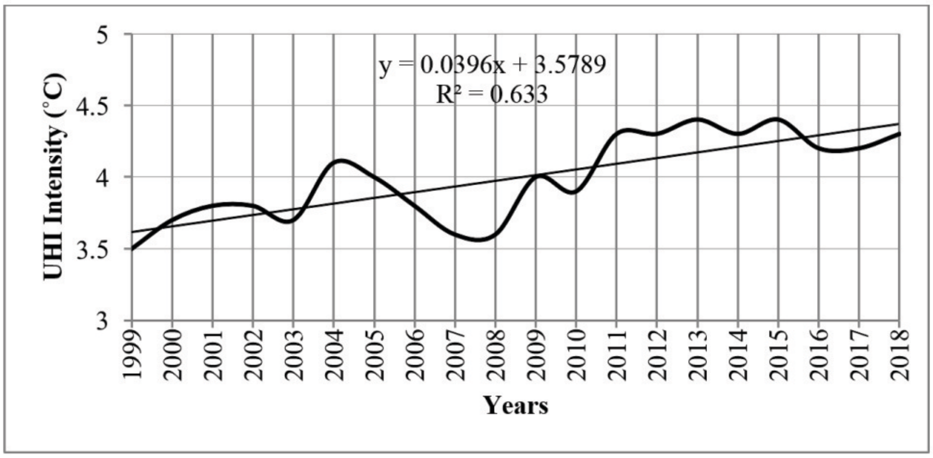

Figure8: Annual Mean UHI Intensity (Average of Daily UHI Intensity from IAR&T and IITA)

Table 2: Correlation Analysis of Annual Mean UHI Intensity over Time in Ibadan

		Annual UHI Intensity	Time (in Years)
Annual UHI Intensity	Pearson Correlation	1	.786
	Sig. (2-tailed)		.000
	N	18	18
Time (in Years)	Pearson Correlation	.786	1
	Sig. (2-tailed)	.000	
	N	18	18

**Correlation is significant at the 0.05 level (2-tailed).

Based on the findings of this study and as a result of the problem identified, there is the need to improve the condition of urban and rural atmosphere so as to ensure a pleasant and healthy environment for urban dwellers. In view of this, following recommendations are suggested to all urban planners in order to provide conditions near to rural or natural climate as there will continue to be city growth and urban expansion. Decentralization of nodal locations and commercial areas through the building of supermarkets, shopping malls and departmental stores in residential areas should be encouraged. There should be massive control of migrants from the rural areas to the urban areas by improving the lots and quality of life of rural dwellers through the provision of basic social infrastructure. The impact of both indoor and outdoor microclimates of both traditional and modern houses should be compared for the purpose of future design of buildings suitable for the tropical regions. There is the need to set up more weather-monitoring stations and the installation of highly sensitive equipment for monitoring the climatic elements at regular intervals. There should be total prohibition of burning of refuse and wastes in towns and cities. The landfill method or burying of solid wastes is a more reasonable alternative.

References

Ackerman, B. (1985). Temporal March of the Chicago Heat Island. Journal of Climatology and Applied Meteorology24, 547-554.

Adebayo, Y. R. (1985). The Microclimate Characteristics within the Urban Canopy of Ibadan.Ph.D.Thesis in Climatology. Department of Geography, University of Ibadan, Ibadan.

Adebayo, Y. R.(1987). Land Use Approach to the Spatial Analysis of the Urban 'Heat Island' in Ibadan, Nigeria. Weather42(9), 273-280.

Adedimeji, A. A., Heard, N. J., Odutolu, O.,Omololu, F. O. (2008). Social Factors, Social Support and Condom use Behaviour among Young Urban Slum Inhabitants in Southwest Nigeria.East African Journal of Public Health5 (3), 215-222.

Adelekan, I. O. (2004).Vulnerability of Poor Urban Coastal Communities to Climate Change in Lagos, Nigeria. Proceedings of the 5th Urban Research Symposium, (URS`95), Lagos, Nigeria, 1-18.

Adeyeri, O. E., Akinsanola, A. A., & Ishola, K. A. (2017). Investigating surface urban heat island characteristics over Abuja, Nigeria: Relationship between land surface temperature and multiple vegetation indices. *Remote Sensing Applications: Society and Environment*, *7*, 57–68. https://doi.org/10.1016/j.rsase.2017.06.005

Anibaba, B.W., Durowoju, O. S., & Adedeji, O. I. (2019). Assessing the Significance of Meteorological Parameters to the Magnitude of Urban Heat Island (UHI). *Analele Universităţii Din Oradea, Seria Geografie*, *29*(2), 30–39. https://doi.org/10.30892/auog.292103-798

Anibaba, B Wasiu, Durowoju, O. S., & Adedeji, O. I. (2017). Spatial Characteristics of Urban Heat Island Intensity across Different Land Use Types in Ibadan Metropolis , Nigeria. *African Journal of Sustainable Development (AJSD)*, *7*(3), 37–62.

Auer, A. H., (1981). Urban Boundary-Layer. In:S. A. Changnon (ed.) "METROMEX: A Review and Summary",. AMS Meteorology Monograph. 18, 41-62.

Babatola, E. B. (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), 343-352.

Balogun, A. A., Balogun, I. A., Alefisan, A. E., Abatan, A.A. (2009). Observed Characteristics of the Urban Heat Island during the Harmattan and Monsoon in Akure. A Paper Presented at the Eighth Symposium on the Urban Environment, 10th January – 15th January.

Balogun, I. A., Balogun, A. A., & Adeyewa, Z. D. (2012). Observed urban heat island characteristics in Akure, Nigeria. *African Journal of Environmental Science and Technology*, *6*(January), 1–8. https://doi.org/10.5897/AJEST11.084

Bohm, R. (1998). Urban Bias in Temperature Time Series: A Case Study for the City of Vienna, Austria. Climatic Change38, 113–128.

Comrie, A. C. (2000). Mapping A Wind–Modified Urban Heat Island in Tucson, Arizona (with Comments on Integrating Research and Undergraduate Learning). Bulletin of the American Meteorological Society 81(10), 2417-2431.

Cueto, G.O.R., Martinez, A. T., Morales, G. B. (2009). Urbanization Effects upon the Air Temperature in Mexicali, B.C. Mexico, Atmosfera 22(4). DOI: 10.1007/s00704-005-0181-9

Eresanya, E. O., Daramola, M. T., Durowoju, O. S., & Awoyele, P. (2019). Investigation of the changing patterns of the land use land cover over Osogbo and its environs. *Royal Society Open Science*, *6*(12). https://doi.org/10.1098/rsos.191021

Fabiyi, O. O. (2006). Urban Land Use Change Analysis of a Traditional City from Remote Sensing Data: The case of Ibadan Metropolitan Area, Nigeria. Humanity and Social Sciences Journal 1(1), 42-64.

Hughes, K. (2006). The Impact of Urban Areas on Climate in the UK: A Spatial and Temporal Analysis, with an Emphasis on Temperature and Precipitation Effects. Earth & Environment 2, 54-83.

Jauregui, E. (1997). Heat Island Development in Mexico City. Atmospheric Environment 31, 3821– 3831.

Jauregui, E. Godinez L., Cruz, F. (1992). Aspects of Heat-Island Development in Guadalajara, Mexico. Atmospheric Environment, 26B(3), 391-396.

Jonsson, P. 2004. Vegetation as an Urban Climate Control in the Subtropical City of Gaborone, Botswana.*International Journal of Climatology.*24(10). 1307-1322. DOI: 10.1002/joc.1064.

Karaca, M., Tayanc, M., Toros, H. (1995). Effects of Urbanization on Climate of Istanbul and Ankara. Atmospheric Environment29, 3411-3421

Kim, Y., Baik, J. (2001). Maximum Urban Heat Island Intensity in Seoul. Journal of Applied Meteorology 41, 651 – 659.

Magee, N., Curtis, J., Wendler, G. (1999). The Urban Heat Island Effect at Fairbanks, Alaska. Journal of Theoretical and Applied Climatology 64, 39-47.

Mohan, M., Kikegawa, Y., Gurjar, B. R.,Bhati, S., Kandya, A., Ogawa, K. (2012). Urban Heat Island Assessment for a Tropical Urban Airshed in India. Atmospheric and Climate Sciences 2, 127-138.

Montavez, J. P., Rodriguez, A., Jimenez, J. I. (2000). A Study of the Urban Heat Island of Granada. International Journal of Climatology20, 899-911.

Oguntoyinbo, J. S. (1973). Temperature and Humidity Traverses in Ibadan. Paper Presented at the 17th Annual Conference of the Nig. Geog. Assoc., University of Lagos.

Oke, T. R.(1987). Boundary Layer Climates.2nd (ed.) Routledge, 435p.

Oke. T. R., Johnson, G., Steyn, D., Watson, I. (1991). Simulation of Surface Urban Heat Island under 'Ideal' Conditions. Part 2: Diagnosis of Causation. Boundary-Layer Meteorology 56, 339-358.

Olusola, A. O., Durowoju, O. S., & Adedeji, O. (2017). Interactions between topography , soil moisture and solar radiation : A model approach. *Uniosun Journal of Sciences*, *2*(1), 66–73.

Popoola, O., Durojaye, P., Bayode, T., Popoola, A., & Olanibi, J. (2020). Spatio-temporal variance and urban heat island in Akure , Nigeria : A time-spaced analysis Using GIS Technique. *South African Journal of Geomatics*, *9*(2), 365–378.

Rizwan, A. M., Dennis, L. Y. C., Liu, C. (2008). A Review on the Generation, Determination and Mitigation of Urban Heat Island. *Journal of Environmental Sciences.* Elsevier 20(1), 120-128. https://doi.org/10.1016/S1001-0742(08)60019-4.

Tereshchenko, I. E., Filonov, A. E. (2001). Air Temperature Fluctuations in Guadalajara, Mexico, from 1926 to 1994 in Relation to Urban Growth. International Journal of Climatology 21(4), 483-494. DOI: 10.1002/joc.602

Unger, J., Sümeghy, Z., Gulyás, Á, Bottyan, Z., Mucsi, L. (2001). Land-Use and Meteorological Aspects of the Urban Heat Island. Meteorological Applications 8, 189-194.

United Nations (2004). World Urbanization Prospects: The 2003 Revision. New York: United Nations.

Voogt, J. A. (2004). Urban Heat Islands: Hotter Cities. Retrieved February 22, 2005. From http://www.actionbioscience.org/environment/voogt.html

Yague, C., Zurita, E., Mart ı nez, A. 1991. Statistical Analysis of the Madrid Urban Heat Island. Atmospheric Environment 25B, 327–332.

Zhang, C. L., Chen, F., Miao, S. G., Liu, Q. C., Xia, X. A., Xuan, C. Y. (2009).Impacts of Urban Expansion and Future Green Planting on Summer Precipitation in the Beijing Metropolitan Area. *Journal of Geophysical Research*114, D02116.doi:10.1029/2008JD010328.