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Spatial variation in temperature of urban space and urban heat island differentials in Warri metropolis, Nigeria

Origho, Thaddeus
Department of Urban and Regional Planning
University of Delta Agbor, Delta State
E-mail: Thaddeus.origho@unidel.edu.ng

Ushurhre, Ochoko
Department of Environmental Management and Toxicology
Dennis Osadebe University, Asaba

Abstract

Urban Heat Island (UHI) has become one of the greatest problems associated with urban growth and industrialization. This is because of the elevated temperature associated with it. This paper examined spatial variation in temperature of urban space and magnitude of Urban Heat Island in Warri Metropolis, Nigeria. The study proceeded by stratifying the study area into four (Jakpa, Giwa-Amu, Airport Road and Okumagba Layout) and selected a peri-urban conurbation (Oha) as a control. Quasi-experimental (ex-post-facto) research design was adopted for the study. Secondary data of minimum and maximum temperature for a period of 30 (1992-2021) years was used. The study found that mean annual maximum temperature for Warri was 31 ºC compared to that of Oha (27.3 ºC). Minimum temperature for Warri was 23.2 ºC while Oha was 21 ºC. Generally, the mean temperatures for the Warri locations were higher than that of Oha. The UHI values, for Jakpa and Airport road were similar with UHI values of 1°C respectively. Giwa Amu recorded 1.1 °C, while Okumagba recorded UHI value of 1.2 °C. The ANOVA model comparing the temperature values for the study area was significant at $P<0.05$ (*F-62.7; sig-.000*). Implying that there is a significant spatial variation in temperature of Warri; and Oha was significantly cooler with a temperature of 27.1 °C. The paired sample t test comparing mean temperature in Warri and Oha was significant at $p<0.05$ (t-22.9; sig-.000). This implied that there is a significant difference between mean temperature in Warri and that of Oha. Therefore, tree planting, urban planning was among the recommendations advanced in the study.

Keyword: Urban-heat-island, urbanisation, urban-space, temperature, spatial-variation

Introduction

Urban Heat Island is a name given to the characteristic warmth of environments in cities compared to their non-urbanized surroundings (Voogt, 2004; Adachi et al., 2012; Ahmed et al., 2015). Urban heat island may be up to 10-15^{0}C under optimum conditions (Oke, 1982). For almost 200 years, climate differences between urban and rural environments have been recognized (Taha, 1997), of which temperature is the most obvious (Unger, Simeghy, and Zoboki, 2001). Of the many factors contributing to urban heat island, changes on surface physical characteristics (including geometry, thermal conductivity and wind speed) as well as the concentrated release of anthropogenic heat, are believed to be the major causes of urban heat island (Unger et al., 2001).

Heat islands develop when a large fraction of the natural land cover in an area are replaced by build surfaces that trap incoming solar radiation during the day and then re-radiate it at night (Figure 1) (Quattrochi, Luvau, Rickman and Estes, 2000; Oke, 1982). To Quattrochi et al. (2000) three types of heat islands may be identified. These are the Canopy Layer Heat Island (CLHI), Boundary Layer Heat Island (BLHI) and Surface Heat Island (SHI). The first two refer to a warming of the urban atmosphere; while the last refers to the relative warmth of urban surfaces.

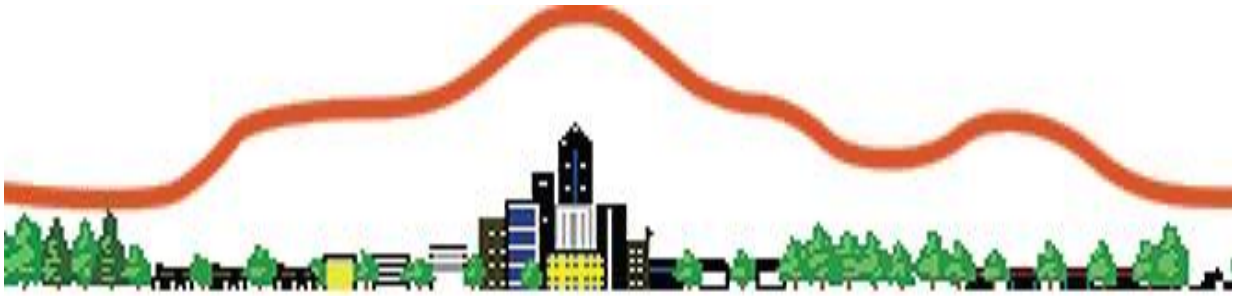

Figure 1: A diagrammatic display of urban heat island (UHI)

The Urban Canopy Layer (CLHI) is the layer of air closest to the surface in cities, extending upwards to approximately the mean building height. Above the urban canopy lies the Urban Boundary Layer (BLHI), this may be one kilometre or more in thickness by day, shrinking to hundreds of meters or less at night (Oke, 1995). It is the Boundary Layer Heat Island that forms a dome of warmer air that extends downward of the city. Winds often change the dome to a plume shape (Kalu, 1978).

Heat Island types vary in their spatial form (shape), temporal (related to time), characteristics and some of the underlying physical processes that contribute to their development (Voogt and Oke, 2003). Air temperatures for canopy layer heat island or boundary layer heat island are directly measured using thermometers, whereas the surface heat island is measured by remote sensors (Roth, Oke and Emery, 1989).

In Nigeria, urban growth is not a recent phenomenon. Since the emergence of ancient cities such as Benin, Kano and Zaria between the 14th and 17th century, there has been a steady evolution and multiplication of urban centres (Ojeifo & Eseigbe, 2014). The rate of multiplication however, became greater from the 1960's with more urban centres emerging. As at 1960 only four major administrative centres existed, these centres were Lagos, Ibadan, Enugu and Kaduna. By 1967, the centres rose to 13, it became 21 centres in 1987. The centres rose to 30 administrative state headquarters in 1991. Similarly, administrative changes were undertaken at the local government level resulting in the emergence of towns which are new headquarters of local government areas. Urbanization rate for Nigeria is 4.4% and about 4.6% on the average for sub-Saharan Africa, compared to 0.4% urbanization rate in Europe (Masson et al., 2020).

Studies (Blocken et al., 2013; Brazel & Balling, 2016; Bründl & Hoppe, 2020) have shown that there remain only few landscapes on the earth surfaces that still remain in their natural state. Due to anthropogenic activities, the earth's surface is being significantly altered and man's presence on the earth and his use of land has had a profound effect upon the natural environment, thus resulting into an observable pattern in the land use/land cover over time.

The most significant characteristics of man's induced changes in the urban environment area is the variation in thermal properties of the built up and surfaces, soil land impervious surfaces which result in more solar energy being stored and converted to sensible heat, and also the removal of shrubs and tree which serve as a natural cooling effects of shading and evapotranspiration (Pickett et al, 2001). This contributes to the reduction in outgoing longwave radiation by hindering the loss of sensible heat and distribution of heat (Oke, 1982; Ifatimehin, 2007). The reduced vegetation cover, increased in impervious surface area and the morphology of buildings in the urban centres, combine to lower evaporative cooling by storing heat during the day and releasing such during the night to warm the surface air. A built up of ambient land surface temperature in the urban centres of 2-3 degrees higher than the surface surrounding suburban environment are witnessed in relatively areas, greater cover of vegetation, cultivated lands and as well as greater areas of wet soils (Ifatimehin, 2007). These thermal differences are contributing to the development of a micro climate condition otherwise referred as the urban heat island.

The metropolitan city of Warri has witnessed remarkable expansion, growth and development activities such as buildings, and road construction, since its inception. This has resulted in increased land consumption and changes in land use and land cover. This modification certainly has consequences on the land surface temperature. Up till now, few detailed and comprehensive attempt (as provided by a remote sensing data and GIS) has been made to evaluate land use change and its effects on land surface temperature in a developing world city. It is therefore necessary for a study such as this to be carried out. It will avoid the associated problems of a growing and expanding city like many others in the world. The rapid population growth in Warri has brought about urban expansion resulting in the increased exploitation of natural resource and by extension, brought about a change in the surface temperature due to the input of harmful substances (CO_2 methane) and pollutants into the atmosphere, resulting to urban heat effect, increased pollution, urban warming effect, health implication and above all, an alternation of the micro climate. These effects have been identified at several times by different researchers (Ifatimehin et al., 2011; Ujoh et al., 2009) include loss of vegetation, loss of prime agricultural land, alternation of the micro climate and degradation.

Urban heat island phenomenon is one of the key subjects to be studied for the urban climate. It has been studied for a long time because its characteristics vary in the different locations, based on the magnitudes of anthropogenic activities, meteorological conditions and unique features of the cities and towns. Some studies have looked at the UHI of cities in the context of night time impacts (Chandler, 2017; Arenghi et al., 2021) others have looked at UHI at a meso scale (Best & Grimmond, 2014; Chen et al., 2020; Calheiros & Stefanakis, 2021). This study looked at UHI by using the historical data of Warri to examine the UHI differentials over the years.

Urban heat island (UHI) has become one of the greatest problems associated with urbanization and industrialization of human civilization. As a result, increased in temperature associated with UHI has exacerbated threats to human health (thermal stress). Experience in many cities revealed that temperatures are larger at night than during the day, more pronounced in winter than in summer, and is most apparent when winds are weak (Zhang et al, 2004; Song and Zhing, 2003; Convertino et al., 2021; Dardir & Berardi, 2021). For example, in Beijing, the difference in mean air temperature between the city centre and surrounding fields can be as much as 4.6 K (Zhang et al, 2004; Dardir & Berardi, 2021).

Warri has become an urban centre in Delta State (Efe, 2002). The city today is under the pressure of urbanization and climatic factors, due to the presence of some oil companies. The city has undergone an uncontrolled haphazard development. The city has developed paved surfaces and buildings substituted with the natural landscape. Gloomy surfaces like parking lots, roofs and roads attract the greatest amount of heat. Large masses of reinforced concrete and steel structure buildings absorb and produce huge amount of heat, which in turn radiated to the surroundings (Efe & Ojoh, 2013).

The population density in the city has also increased because of the increasing number of migrants searching for better working opportunities, services, and facilities (Efe, 2002). Consequently, multi-storey buildings and high commercial buildings that dominated the skyline have occupied the city, and they have a dramatic effect on the microclimates of the city, by altering the wind circulation system and creating an elevated temperature characteristic otherwise known as urban heat island (Zhang & Jim, 2014).

Furthermore, human activities intensified the amount of heat due to the transportation systems, industrial plants and heating ventilation and air conditioning (HVAC) systems that are installed in building to lower the internal temperature to suit human thermal comfort inside the buildings. Heat production becomes a primary problem in the city of Warri (Efe and Ojoh, 2013). As a result, urbanization and human activities such as urbanisation, bush burning, fossil fuel emissions and use of cooking fuels are major factors in increasing the modification of the microclimate condition of the area. In the high-density areas, air temperatures, lack of greenery, low quality of albedo facades in urban spaces are quite important issues of the high temperature in Warri. There is the need to examine the characteristics of Urban Heat Island in Warri.

Aim and objectives

The aim of this study is to examine the spatial variation in temperature of urban space and urban heat island characteristics in Warri metropolis, Nigeria. The above aim sets to address the following objectives;

1. Examine the temperature characteristics in Warri
2. Compare the temperature in Warri to that of the control area (Oha).
3. Identify the Urban heat island characteristics in Warri.
4. Evaluate the spatial variation in Urban Heat Island characteristics in Warri.

Research hypothesis

Based on the objectives of the study, the following hypothesis is formulated to investigate the urban heat island characteristics in Warri.

1. There is no significant variation in temperature in Warri metropolis.
2. There is no significant difference in the temperature of Warri and that of the control environment (Oha).

Methodology

The study adopted the quasi-experimental (ex-post-facto) research design. This design and approach was adopted mainly because the study is an effort geared towards a specific existing problem which the researcher have no control over the accumulated data. Thus, the data used for this study is the historical type. In order to measure UHI intensity during a 30 years period, this study identified four locations (Jakpa, Airport Road, Giwa Amu, Okumagba Layout) within Warri Urban and a control (Oha) which is a peri urban conurbation of warri. The reason for the selection of the urban centres for to identify the spatial variation in Warri temperature. Nigerian meteorological Agency (NIMET) data was grossly inadequate for a study of this magnitude, considering the spatial spread of the stations. The researchers wanted to see the internal variation in the temperature within Warri and NIMET only has one station within Warri metropolis. Therefore, National Aeronautics and Space Administration (NASA)/CRU temperature data was used. This data set has been used by Ozabor (2018) with maximum accuracy. Therefore, 30 years data for each of the identified locations were downloaded from the websites of NASA/CRU for 1992-2021.

The results obtained were analyzed using both descriptive and inferential statistical techniques. The descriptive stats were used to determine the means of temperature and the intensities of UHI among the urban centres and the control environment. Analysis of variance (ANOVA) test was used to determine significant difference in the UHI magnitudes in the urban centres, while paired samples of test was used for comparing the temperature of Warri and Oha. The analyses were done in the environment of the IBM/SPSS version 26.

Results

Monthly averages of maximum and minimum temperature distribution in Warri metropolis and Oha (°C) from 1992 to 2021 is presented in Table 1. The mean annual maximum temperature for Warri was 31 ºC compared to that of the control environment which was 27.3 ºC. As for the minimum temperature, 23.2 ºC was recorded, while the control was 21 ºC. This shows that the temperature for both environments are not the same. The elevation may be traced to the urbanisation characteristics in Warri (Derome et al., 2017). The monthly patterns of Warri temperature were quite different from that of the control. In table 1, no month in the control environment could measure with that Warri; whether minimum or maximum temperature.

Table 1: Monthly averages of maximum and minimum temperature distribution in Warri metropolis and Oha (°C) from 1992 to 2021

	Months												
Warri	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
Maximum ºC	32.1	33.1	33.4	33.0	33.1	30.2	28.5	28.2	28.5	29.3	30.9	31.6	31.0
Minimum ºC	22.8	23.9	23.9	24.0	23.9	22.8	22.5	22.6	22.8	23.1	23.3	22.9	23.2
Range	9.3	9.2	9.5	9.0	9.2	7.4	6.0	5.6	5.7	6.2	7.6	8.7	7.8
Control (Oha)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
Maximum ºC	28.5	29.5	29.8	29.4	29.5	26.6	24.9	24.6	24.9	25.7	27.3	28.0	27.3
Minimum ºC	20.6	21.7	21.7	21.8	21.7	20.6	20.3	20.4	20.6	20.9	21.1	20.7	21.0
Range	7.9	7.8	8.1	7.6	7.8	6.0	4.6	4.2	4.3	4.8	6.2	7.3	6.4

Table 2 presented the mean monthly temperature for locations in Warri and Oha (control). Similarly, the UHI magnitudes are also presented in table 2. The mean temperatures for the Warri locations are quite higher than that of the control environment, although that of February was higher in the control area (28.5 °C) than that of locations in Warri. The elevation may have been caused by the build-up of the maritime airmass in the Warri area at this time of the year (which is closer to the sea) relative to that of Oha which is, further hinterland. As for the UHI values, Jakpa and Airport road were similar in the UHI values recorded (1°C). Giwa Amu recorded 1.1 °C, while Okumagba recorded UHI value of 1.2 °C and indication that Okimagba Avenue is the hottest of the places in Warri.

Table 2: Monthly mean temperature and the UHI intensities of locations in Warri and Oha (°C) from 1992 to 2021

Areas	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Mean*	*UHI Int*
Jakpa	27.5	27.8	29.2	29.1	29.4	26.5	26.3	26.6	27.8	28.0	29.0	29.5	28.1	1.0
Airport Road	27.4	27.9	29.4	28.9	29.5	26.3	26.5	26.7	27.9	28.5	29.3	29.4	28.1	1.0
Giwa Amu	27.5	28.0	29.5	29.3	29.4	26.5	26.3	26.6	27.8	28.0	29.1	30.5	28.2	1.1
Okumagba Layout	27.5	28.4	29.3	29.6	29.4	27.4	26.5	26.2	28.0	28.1	29.0	30.3	28.3	1.2
Oha	27.5	28.5	28.7	28.5	28.5	26.5	25.5	25.4	25.7	26.2	27.1	27.3	27.1	control

N: B: UHI-Int implies Urban Heat Island Intensity

Table 3A showed the variation in the temperature of Warri and the control area. The model is significant at *P*<0.05 (*F-62.7; sig-.000*). This implies that there is a significant spatial variation in temperature of Warri. Table 3B shows that Oha (control) is the coolest area with a mean temperature of 27.1 °C. Jakpa, Airport Road and Giwa Amu posted a mean temperature of 28.1 and 28.2 °C respectively. Okumagba Avenue recorded the highest temperature of 28.3 °C.

Table 3A: *Anova table showing variation in temperature in Warri metropolis and control (Oha)*

ANOVA

Temperature

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	337.486	4	84.371	62.735	.000
Within Groups	2414.060	1795	1.345		
Total	2751.546	1799			

Table 3B: Duncan table showing variation in temperature in Warri metropolis and control (Oha)

S

Duncan[a]

		Subset for alpha = 0.05		
Factors	N	1	2	3
Oha	360	27.1156		
Jakpa	360		28.0611	
Airport Road	360		28.1389	28.1389
Giwa Amu	360		28.2078	28.2078
Okumagba Layout	360			28.3078
Sig.		1.000	.109	.064

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 360.000.

Table 4A showed the variation in the temperature of Warri area. The model is significant at *P*<0.05 (*F-2.9; sig-.032*). This implies that there is a significant spatial variation in temperature of Warri. Table 4B shows that Jakpa is the coolest area with a mean temperature of 28.06 °C. Airport Road is 28.1C and Giwa Amu posted a mean temperature of 28.2 °C respectively. Okumagba Avenue recorded the highest temperature of 28.3 °C.

Table 4A: ANOVA table showing variation in temperature in Warri metropolis

ANOVA

Temperature

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.851	3	3.950	2.936	.032
Within Groups	1931.988	1436	1.345		
Total	1943.838	1439			

Table 4B: Duncan table showing variation in temperature in Warri metropolis

Temperature

Duncan[a]

		Subset for alpha = 0.05	
Factors	N	1	2
Jakpa	360	28.0611	
Airport Road	360	28.1389	28.1389
Giwa Amu	360	28.2078	28.2078
Okumagba Layout	360		28.3078
Sig.		.109	.064

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 360.000.

Table 5 shows the paired sample of the test comparing mean temperature in Warri and that of the control area. The model is significant at $p<0.05$ (t-22.9; sig-.000). This imply that there is a significant difference between mean temperature in Warri and that of the control environment.

Paired samples test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Warri - Oha	1.06889	.88524	.04666	.97713	1.16064	22.910	359	.000

Discussion

Monthly averages of maximum and minimum temperature distribution in Warri metropolis and Oha (°C) showed mean annual maximum temperature of 31 ºC compared to that of the control environment which was 27.3 ºC. As for the minimum temperature, 23.2 ºC was recorded, while the control was 21 ºC. This reinforces the fact that the rural and peri-urban environments are coolers than the urban build up environments (Flato et al., 2014; Malys et al., 2016). According to Manteghi et al. (2015), the rural environment has the advantage of free flow of wind, a mass of vegetal cover (which also help to sink carbon) a relatively less population and anthropogenic activities which makes its temperature always lower than the urban environment. The monthly patterns of Warri temperature were quite different from that of the control. Also, the mean monthly temperature for locations in Warri and Oha were different, with the values in Warri slightly higher than that of Oha. UHI magnitudes for Jakpa and Airport road were similar with and inflated temperature of 1°C. Giwa Amu recorded 1.1 °C, while Okumagba recorded UHI value of 1.2 °C these variations in UHI are products of dense populations, energy demands and the absence of vegetations (Zhao et al., 2016; Zhang et al., 2019).

Recommendations

The following are recommendations, strategies and policy implications presented as precautionary measures for mitigating and improving on the present status of urban heat island differentials in Warri metropolis. This is presented in order to safeguard human health and improve on the environment for the sustenance of man. It should be noted that the area of expansion of Warri metropolis is now over 100sqkm, with an ever-increasing population. There is the need to control urban sprawl and land use change. Small towns near Warri metropolis should be developed to absorb the excess population of the Warri; thus, reducing continuous pressure on Warri metropolis. Secondly, development and legislative measures should be adopted as to regulate growth in Warri metropolis by urban planners, town administrators, ministries and parastatals.

Street trees should be planted as cooling and carbon sink options rather than planting open-surface trees. Weather stations should be scattered around the metropolis to monitor temperature and other weather parameters. This will enable meteorologists forecast temperature elevation and predict consequent effects on the microclimate.

Conclusion

Warri metropolis has experienced accelerated growth in its urban space from about 83.15km^2 in 1987 to 236.76km^2 today. This urban growth has led to the unregulated development of marginal areas which has affected with the land cover/land use and by extension increased the total impervious lands and is causing urban heat island. Thus, the high rate of depletion of the vegetal resources at the expense of non-evaporative land uses such as concrete, asphalt and other impervious materials are seriously responsible for the rise in the land surface temperature in Warri metropolis. The heat experience in the built-up areas is more than the surrounding (Oha).

This study concludes from findings that warming during the period under study resulted from the conversion of water bodies, natural vegetation to bare surfaces and dense forest to open forest. These were done to satisfy the demand created by population rise. This suggests that land surface temperature will yet increase, with devastating impacts on the inhabitants of the metropolis. There is therefore the need to protect the environment through sustainable resource utilization and prudent land management.

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