AN ASSESSMENT OF `VARIABILITY OF BIOCLIMATIC CONDITIONS WITHIN KADUNA METROPOLIS, KADUNA STATE, NIGERIA

BY

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ABSTRACT

This study compared bioclimatic conditions using thermohygrometric Index (THI) between urban and rural control stations in Kaduna Metropolis, Nigeria. Temperature/Relative Humidity USB-data loggers were used for data acquisition for one month. 1hour mean thermohygrometric indices for urban core and control station were subjected to Student "t" test to determine if there is significant difference in bioclimatic conditions between the two sampled sites. The "t" test results showed a significant difference in bioclimatic conditions between the urban core and the control station at 0.05 statistical significance level. Analysis of variance (ANOVA) test was employed to test the temporal variability in bioclimatic conditions in the two sampled sites. The Analysis of variance (ANOVA) results showed a significant difference in bioclimatic conditions between different times of the day at 0.05 statistical significance level. Both very hot and hot bioclimatic conditions were predominant in the urban core with few cases of torrid condition. In the control station, hot condition is the dominant category with few instances of comfortable condition. These imply that the rural environment is relatively more livable than the urban environment in terms of bioclimatic conditions

Key words: Bioclimatic conditions, Kaduna metropolis, Thermohygrometric variability

INTRODUCTION

Urban climates all over the world are distinguished from those of less built-up areas by differences in air temperature, humidity, wind speed and direction, and amount of precipitation. These differences are attributable in large part to the altering of the natural terrain through the construction of artificial structures and surfaces. For example, tall buildings, paved streets, and parking lots affect wind flow, precipitation runoff, and the energy balance of an urban environment (Chan, 2001). These altering effects culminate to warmer urban environment than its rural surrounding (Idzikowska, 2010). Most cities are 14% higher in terms of thermohygrometric index than their counterpart rural environments (Sümer and Demir, 2002).

Most of the cities in Sub-Saharan Africa have bioclimatic conditions in terms of thermohygrometric index that is either above or below the comfort zone at most time of the day, due to high amount of insolation received, high relative humidity, and emission of pollutants

(Linden, Thorsson and Eliasson, 2008). According to Balogun, Ifeoluwa and Jimmy (2009), there seem to be a spatio-temporal variability in bioclimatic conditions. If natural factors such as

topography and elevation are considered to remain the same, differences in climatic features in urban areas can be said to result mainly from two interrelated factors: urban surface structures and anthropogenic activities. Transformation of natural surfaces into urbanized ones and anthropogenic activities in these areas mainly alter the radiation balance causing albedo differences and lowering air quality because of particles and gases released into the atmosphere. As results of these combined effects and additional heat emission of anthropogenic activities requiring combustion (for example, industry and traffic), urban environments are generally found to be warmer than its natural/rural counterparts with a varying degree (Toy and Yilmaz, 2007).

Total or partial effects of urban areas with their different aspects (for example, street canyons or urban trees) on human thermal comfort are now under the consideration of many scientists from different parts of the world. For instance, effects of street geometry on human thermal comfort were investigated by Ali-Toudert and Mayer (2007), and the result indicates a significant effect of street geometry on human thermal comfort. Effects of urban trees were researched in details by McPherson, Nowak and Rowntree (1994), and the result revealed a significant relationship between urban trees and comfort level of a city. Effects of different surfaces were studied by Yilmaz, Toy and Yilmaz (2007), total effect of urban area on bioclimatic comfort was investigated by Toy and Yilmaz. (2007).

According to Gulyas, Matzarakis and Unger (2007), the concentration of tall buildings and high population density are responsible for the rapid changes in thermal comfort in most cities of Hungary. A study carried out by Mateeva (1996) on bioclimatic diversity revealed a high spatio-temporal variability in bioclimatic conditions in Bulgaria. The result indicates areas with cold, warm and hot bioclimatic conditions. According to the research findings, these conditions vary with time and seasons. Cities in Bulgaria were found to have bioclimatic conditions that vary with the surrounding villages. Mateeva's (1996) results also show significance variability in head load in these areas.

Balogun, Ifeoluwa and Jimmy (2009), in their study on variability of carbon monoxide and bioclimatic conditions in Akure discovered a warmer urban core compared to the rural surrounding settlements. Abdulhamed (2011) in a study on urban canopy heat island (UCHI) in Kano metropolis, found a significant difference in heat concentration among different urban climatic zones in Kano matropolis. The study attributed these variations to differences in street canyon geometry and thermal conductivity of urban structures. Similarly, Usman (2012) assessed the effects of sky view factor (SVF) on micro climate of Kaduna metropolis; the study revealed a variation in micro climate of the city which is attributed to variation in sky view factors.

Usman et al. (2016) classified urban climate field sites by local climate zones of Kaduna metroplis. Their study identified ten (10) different climatic zones with different temperature characteristics. This is an indication that different zones have different structures with different thermal characteristics. These variations could affect the bioclimatic conditions of the city, since temperature and relative humidity are major determinats of thermohygrometric index which measures the thermal comfort of a place.

The knowledge of bioclimatic condition is critical to city dwellers due to the concomitant effects of conditions below or above the comfort level. Based on the UN projection, 60% of the entire world population is expected to be in the cities by 2030, and that nearly all the population growth will be in the cities of developing countries. This population increase will result in a lot of changes, especially in the composition of the urban atmosphere, including the canopy layer urban heat island; the observed warmth of the urban core compared to its rural surroundings, bioclimatic comfort and various forms of air pollution (Balogun, Ifeoluwa and Jimmy, 2009).

Kaduna Metropolis is one of the largest cities in Nigeria, and it is experiencing a rapid population growth that may cause urban meteorological problems in the few years to come. This study therefore, deems it necessary to look at the variability in bioclimatic conditions in this area so as to make necessary recommendation to the urban planners and the generality of the urban dwellers.

THE STUDY AREA

Kaduna is the capital of Kaduna State in north-western Nigeria. The area is located between Latitudes 10° 23'-10° 43'N and Longitudes 7° 17'-7° 37'E (Figure 1) comprises of Kaduna north Local Government, Kaduna south Local Government, southern part of Igabi Local Government, and the Northern part of Chikun Local Government. Kaduna is 912 km north of the Gulf of Guinea, about 390 km from Nigeria's northern border and 180 km from Abuja, the country's capital city. It has an area of about 35 square kilometers (Oguntoyinbo, 1983).

The city has tropical continental climate type characterized by wet and dry seasons. The tropical continental is more pronounced in the dry season particularly in December and January. The dry season is from October to April and is dominated by the north-east trade wind called Harmattan which prevails between November to February. The dry season is also rainless from October to April. The wet season is dominated by the south-east winds which start between May/June to October (Ayoade, 1988). The natural vegetation of the study area is that of the Northern Guinea Savanah with grass dominating and scattered trees hardly higher than 15ft with broad leaves. Meanwhile, the seasonal character of rainfall in the study area has influenced the vegetation which turns evergreen during the wet season and pale brown in the dry season respectively (Oguntoyinbo, 1983).

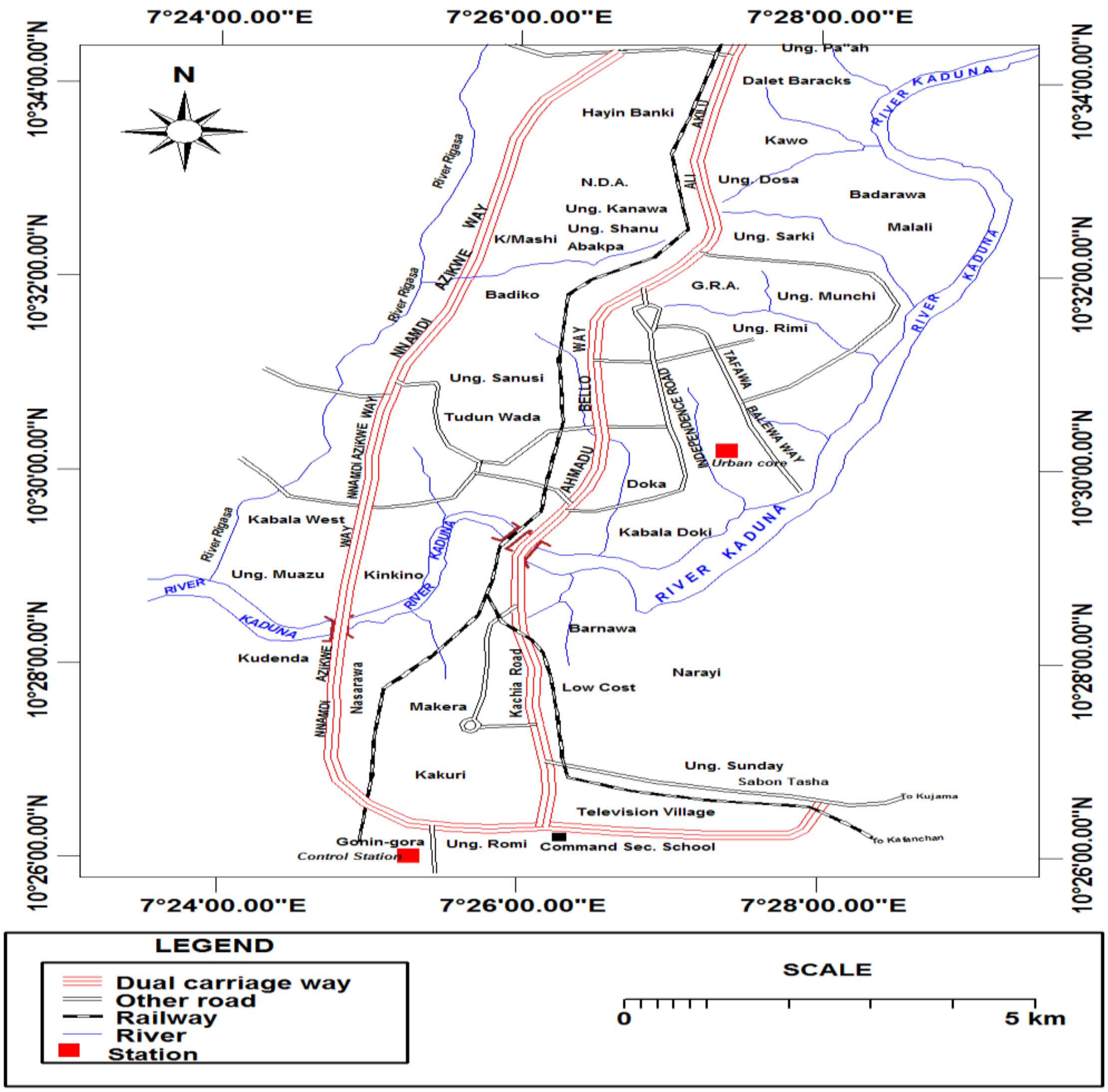

Figure 1: Map of Kaduna Metropolis
Source: Kaduna State Environmental Protection Authority

MATERIALS AND METHODS

This study was based on urban-rural comparison approach. The sites selections for this study were based on Local Climatic Zones (LCZ) categorization by Steward and Oke (2009) and are in accordance with World Meteorological Organization standard. The sites that best represent the Local Climatic Zones (LCZ) category for urban core and a control station were selected.

The bioclimatic data required are temperature and relative humidity and were measured and recorded by digital USB-Temperature/Relative humidity data loggers which were mounted in the urban core and Rural control stations, for a period of one month (from 12th of June, to 9th of July, 2017). A total of 8064 temperature and relative humidity values were measured and recorded, which were downloaded from the data loggers to the computer. The 8064 data were summarized into 672 mean hourly values for further analysis. The bioclimatic conditions were categorized based on Thermohygrometric index (THI). The Thermohygrometric indices (THI) were determine as given below:

$$THI = T- (0.55-0.0055RH)(T-14.5)$$

Where:

THI= Themohygrometric index

RH= Relative Humidity

T= Temperature.

0.55, 0.0055 and 14.5 are constants.

This index has been used in many bioclimatic investigations (Matzarakis and Mayer, 1991; Toy and Yilmaz, 2007; Balogun, Ifeoluwa and Jimmy, 2009). Simple line graphs were used to present the Bioclimatic conditions temporal variability in the urban core and the control station. The comfort categories of thermohygrometric Index which include : Hyper-glacial (<-40°C), Glacial (-39.9 to -20°C), Extremely cold (-19.9 to -10°C), Very cold (-9.9 to -1.8°C), Cold (-1.7 to 12.9°C), Cool (13 to 14.9 °C), Comfortable (15 to19.9°C), Hot (20 to26.4°C), Very hot (26.5 to 29.9°C), and Torrid (>30°C) were used to categorize the Bioclimatic conditions in both the urban core and the control station. Thus, Student't-test' was used to test if there is any significant difference in the mean thermohygrometric index between the urban core and the rural control station, at 0.05 significance level

RESULTS AND DISCUSSION

Variability of Thermohygrometric Index in the Urban Core.

Figure 2 shows trends of thermohygrometric index in the urban core from 12th of June to 9th of July, 2017.

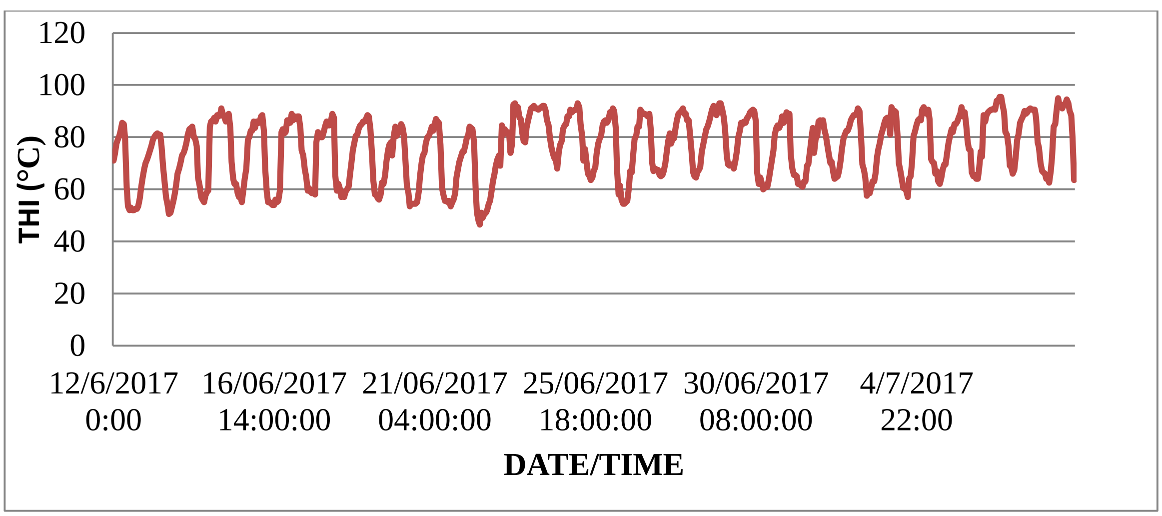

Figure 2: Thermohygrometric Index Trend in the Urban Core

From Figure 2, it is observed that there is fluctuation in Thermohygrometric Index in the urban core. The index values recorded were around 28°C to 30°C during the day time (between 11:00 to 18:00) throughout the sampling period, but lower values were recorded in the night. The highest value recorded (31.17°C) was in the afternoon (14:00), while the lowest value (20.45°C) was recorded early in the morning (05:00). This is a clear indication that even though other factors affect this index, the intensity of the solar radiation is one of the major determinants of this index in the study area. For most time of the day, the index in the urban core falls between 25°C to 30°C. This indicates a small range which is a typical characteristic of a city that has a windless environment that has been affected due to the effect of street canyons (Ali-Toudert and Mayer, 2007). This implies that the street geometry of an urban area has great effect on the urban meteorology, and affects the thermal character of the urban environment. This is not too different from the result of Toy and Yilmaz (2007).

The result shows slight variability in thermohygrometric Index in the urban core. This may be due to the effects of Greenhouse gases that keep the atmosphere below their concentration zone warmer. Though greenhouse gases are the major cause of global warming, the uniqueness of Urban climate have been attributed to the effect of street canyon geometry that have resulted to a scenario of Urban Canopy Heat Island (UCHI) in most densely populated cities with high raise buildings, impervious surface among others (Idzikowska, 2010). Therefore, the causes of this slightly thermohygrometric Index differential in the urban core of Kaduna Metropolis may not be far away from what Idzikowska attributed to the causes of the warmer nature of most cities in Rome.

Variability in Mean Thermohygrometric Index at the Control Station

Figure 3 shows the Thermohygrometric Index trend in the control station, from 12th of June to 9th of July, 2017.

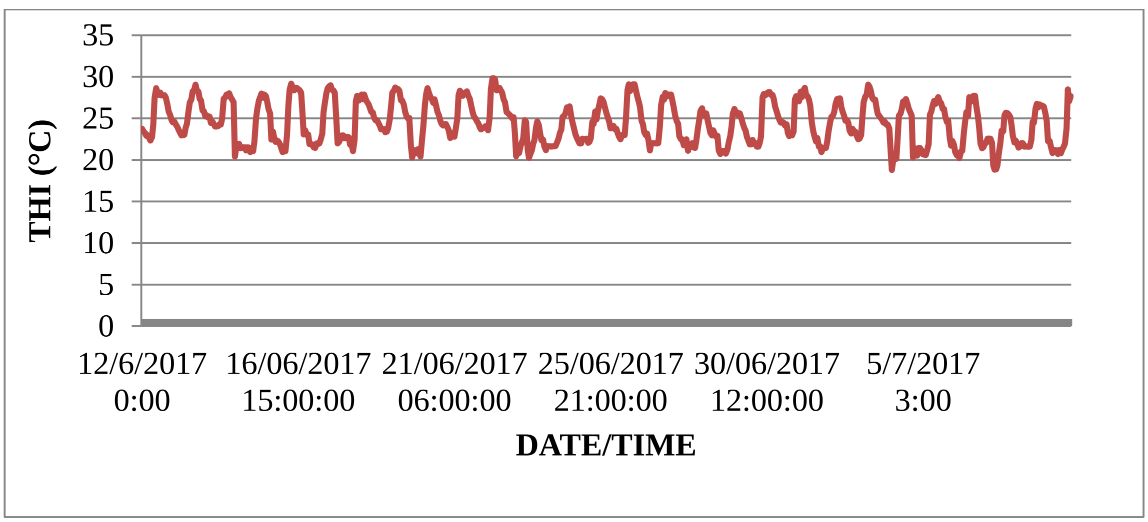

Figure 3: Thermohygrometric Index Trend in the Control Station

Like the Urban core, the thermohygrometric Index in the control station fluctuates. From Figure 3, it is observed that the trend of thermohygrometric Index in the Control station rises in the afternoon but drops at night. From the graph, it can be deduced that the highest mean thermohyrometric Index recorded was around 30°C, and the lowest was around 19°C. The highest value was recorded in the afternoon, while the lowest value was recorded in the night. This implies that the day time is characterized by conditions that are uncomfortable.

From Table 1, it is observed that only hot, very hot and torrid conditions were recorded from 12th of June to 9th of July, 2017 in the urban core. From the table, it can be observed that 42.86% of the days recorded an average bioclimatic conditions that fall under the very hot category, 46.43% of the days had conditions that fall under a hot category, while the remaining 10.71% of the day were the torrid days. All the days have mean Bioclimatic conditions that exceed 19.9°C which is the limit of the comfort, beyond which thermal stress is experienced.

Table 1: Daily Categorization of the Mean Bioclimatic Conditions in the Urban Core from 12th June to 9th July 2017

Day	THI Value (°C)	Category
1	26.93	Very hot
2	27.68	Very hot
3	28.45	Very hot
4	24.09	Hot
5	25.29	Hot
6	31.02	Torrid
7	25.64	Hot
8	24.40	Hot
9	25.38	Very hot
10	26.47	Very hot
11	26.38	Hot
12	25.30	Hot
13	27.87	Very hot
14	28.19	Very hot
15	30.72	Torrid
16	27.81	Very hot
17	25.32	Hot
18	24.52	Hot
19	26.01	Hot
20	30.02	Torrid
21	26.42	Very hot
22	28.95	Very hot
23	23.03	Hot
24	27.08	Very hot
25	26.92	Very hot
26	23.57	Hot
27	25.81	Hot
28	26.02	Hot

Source: Field Data Analysis (2017)

From Table 2, it is observed that hot bioclimatic condition was the predominant category recorded in the control station. However, there was a day with comfortable bioclimatic conditions in the control station. There was equally one day with mean bioclimatic conditions that fall within the range of very hot category. A torrid condition was not recorded throughout the study period. This result differs from what was obtained from the urban core, which most of the days had bioclimatic conditions that are very hot and torrid. This may be due to less anthropogenic activities that generate heat in this area.

Table 2: Daily Categorization of Bioclimatic Conditions in the Control Station from 12th June to 9th July, 2017

Day	THI Value (°C)	Category
1	23.75	Hot
2	24.29	Hot
3	25.21	Hot
4	21.51	Hot
5	22.22	Hot
6	21.55	Hot
7	22.81	Hot
8	24.11	Hot
9	21.20	Hot
10	23.62	Hot
11	23.90	Hot
12	20.84	Hot
13	21.63	Hot
14	22.60	Hot
15	28.46	Very hot
16	24.05	Hot
17	21.55	Hot
18	20.75	Hot
19	22.81	Hot
20	27.31	Hot
21	23.43	Hot
22	25.18	Hot
23	20.15	Hot
24	25.46	Hot
25	23.24	Hot
26	19.38	Comfortable
27	22.41	Hot
28	23.85	Hot

Source: Field Data Analysis (2017)

Variability in Thermohygrometric Index between the Urban Core and the Control Station

Table 3 presents the T-test results for the variability in thermohygrometric index between the urban core and the Control station.

Table 3: t-Test Result for Variability in THI between Urban Core and Control Station

Location	N	Mean	S.D	Mean dif.	t-value	Df	Sig. level
Urban core	659	26.98	2.33	2.51	18.87	1316	0.05
Control station	659	24.47	2.50	2.51			

The result in Table 3 shows a significant difference in thermohygrometric Index between the urban core and the Control station at 0.05 significance level. This difference may be attributed largely to the differences in artificial structures such as tall buildings, pavements, impervious surfaces, which alter the natural terrain in the urban core. Chan (2001) attributed the spatial differential of meteorological characteristic of the urban centers to the differences in artificial structures. The cause of this spatial difference in thermohygrometric Index between the urban core of Kaduna metropolis and the Control station which was cited at the countryside may not be different from the former. From this result, it can be deduced that anthropogenic activities have resulted to a significant increase in thermohygrometric Index in the major cities of the world.

CONCLUSION

From the results of this study, it can be concluded that there is significance different in bioclimatic conditions between the urban core and the control station. Bioclimatic conditions in urban areas can widely be affected by the different features of urban areas, where very different Bioclimatic conditions are prevalent from their rural counterparts, thereby having negative impacts on the livability of the urban dwellers.

From the findings of the study, there are bioclimatic conditions problems in the urban core. In an attempt to proffer solutions to the problems, the following recommendations are made:

i. Urban planners and other relevant agencies should employ policies that will encourage decongestion of the congested parts of major cities. This will allow free movement of air, and reduce the effects of heat stress.
ii. There is a need for policies and laws that will encourage green areas in urban centers through re-forestation. This will help in absorbing the carbon, and cause heat reduction via two mechanisms: by shading surface and adding moisture to atmosphere through evapotranspiration.
iii. The results and findings of this research and others should not be considered as mere academics exercise, but should be used when designing new cities and in the revalidation of the old ones.
iv. More studies can still be carried out in this area, such as assessing the seasonal Bioclimatic conditions. Also, differences between more land uses can be assessed.

v. There is a need to assess urban dwellers' level of awareness of bioclimatic conditions and its implication in everyday live. This will assist immensely in planning for awareness and sensitization campaigns.

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