DIURNAL VARIATION OF URBAN CANOPY HEAT ISLAND IN THE WET SEASON IN BENIN CITY, EDO STATE, NIGERIA

[1]Aruya Emmanuel Iruobe; [2]Matthew Habila Ibahim and [3]Victor Odoh

[1]Department of Geography and Environmental Management, Ahmadu Bello University, Zaria, Nigeria.
[2&3]Department of Geography, Nigerian Defence Academy, Ribadu Cantonment, Kaduna, Nigeria.

Corresponding Author's E-mail: [1]aaruyaemmanuel@yahoo.com
[2]ma2whabila@gmail.com

ABSTRACT

This study assessed the diurnal variation of Urban Canopy Heat Island (UCHI) in the wet season in Benin City, Edo State, Nigeria. Stewart and Oke (2012) system of classification was used to classify Benin City into ten climate field sites. DS1921G – F5 Thermochroni Button data logger was used to collect the temperature measurements from the stations. Data entry, coding, cleaning and test for normality was made following standardized procedures. Quantitative statistical methods was employed to analyze the information collected from the field. Result of the analysis showed that the highest temperature in the wet season was 27.40°C, while the lowest was 24.5°C.The highest UCHI values were 2.9°C, 2.59°C and 2.47°C while the lowest values of UCHI were 1.24°C, 1.38°C and 1.68°C. Maximum UCHI were recorded at 15:00 hours with an UCHI value of 7.13°C and6.48°while the lowest UCHI value recorded in this season was at 05:00 hours with a diurnal UCHI value of -0.64°C. The study therefore recommended the use of climate-sensitive planning and design schemes such as inclusion of building codes, adoption of planning methods of green city, and green roof approaches.

Key Words: *Heat, Planning, Spatial, Temperature, Urban*

INTRODUCTION

The climate in cities and other built up areas is altered mostly by the modification humans make to the surface of the earth during urbanization. City surfaces are typically rougher and often drier as naturally vegetated surfaces are replaced by buildings and paved streets. Buildings along streets form urban street canyons that cause the urban surface to take on a distinctly three-dimensional character. These changes affect the absorption of solar radiation, evaporation rates, storage of heat, the turbulence and wind pattern of cities and the surface temperature (Voogt, 2004).

Montavez *et al.,* (2008) defined Urban Heat Island (UHI) as the temperature differences between the urban area and its rural surroundings, always assuming that the records should be similar if there were no urbanizations. Usually these differences show that cities are warmer than the surrounding rural areas. In most developed countries where the divide between compact urban areas and sparsely populated peripheries is comparatively clear and abrupt, the temperature difference between the air in the urban area and air in the rural reference area outside the settlement is significant and comprises of intensities greater than 4°C (Stewart and Oke, 2012).

UHI is categorized into three main types based on scale and method of measurement (Oke, 2012). First, surface urban heat island (SUHI), which refers to higher temperature of urban surfaces. This is determined by measuring the thermal infrared radiation emitted and reflected by the surfaces. It is normally done using satellite remote sensing and Geographic Information System (GIS) techniques. Second, urban canopy heat island (UCHI), which refers to higher temperatures obtained within urban canopy layer. Urban canopy layer is the layer of air between the ground and treetops or roofs of buildings, where most of human activities take place. Third, urban boundary layer heat island (UBLHI), which refers to higher air temperatures within urban boundary layer. This layer is located above the urban canopy layer and its characteristics are affected by the presence of the urban canopy layer (Voogt, 2004). UCHI is the type of UHI that this study is designed to investigate. This is because UCHI investigates ambient air temperature which directly influences human comfort.

Several studies have been carried out in Nigeria to investigate the relative warmth of cities by measuring air temperature (also known as ambient temperature). Nduka (2011) used Thermochroni-Button data-loggers to assess the urban canopy heat island variation and land use/land cover in Onitsha metropolis in the hot and dry season. The studyestablished a significant variation in both the spatial and temporal distribution of UCHI in the metropolis. Abdulhameed (2011) measured temperature data in Kano using an automatic temperature data logger and determined the UCHI from the data collected. The different sample stations were determined using the canyon zoning system known as the Urban Climate Zone (UCZ). The UCHI Characteristics shows a generally warm profile during the day time and night periods, suggesting that most of the stations had high temperatures. Usman (2016) investigated the effect of surface cover composition on spatial and temporal variations of UCHI in Kaduna metropolis, Nigeria. The results of this study using one-way ANOVA revealed a significant spatial and temporal variations of UCHI in March and August and only significant spatial variation in January.

Benin City and its surrounding areas has experienced changes in its morphology over the years. In Benin City, there are some areas where the buildings are tall, for example Akpakpava, Government Reserved Area (GRA), Airport road, Mission road and Sapele road. There are also some areas in Akpakpava, Igun Street, Igbesonwa and Sakpoban road where the buildings are tightly spaced; the distance separating these houses ranges from 1m - 10mm in the traditional areas and 30m - 50m in the planned areas. The height of these structures and the way they are spaced cause a reduction of turbulence that in turn keep air trapped within buildings. Benin City has also experienced dramatic changes in building patterns, moving from single-storey buildings to multiple-storey buildings, zinc to aluminum roofing sheets and louvers to sliding windows that trap solar radiation during the day and emit heat in the night. These have markedly altered the surface properties of the area and hence modified the energy and water balance of the area, which result in increased temperature of the urban canopy of Benin City. Commercial activities in Benin City also add human metabolic heat into the atmosphere, these includes the various markets where you have high concentration of people. Others are increase in the numbers of buildings, structure and warm air from air conditioners that adds warmth to the surroundings, which pollute and radiate heat into the surrounding landscape and also turning of landscape into townscape also altered the natural environment. These have markedly altered the surface properties of the area and hence have modified the energy and water balance of the area, and resulted in increased temperature of the urban canopy of Benin City (Omogbai, 1985 and Efe, 2006).

The continuous growth of population and urbanization in Benin City has left in its wake emerging development of infrastructures and housing patterns which have given the urban fabric of the city a new look. These infrastructures and housing patterns have led to the development of Local Climate Zones (LCZs) in conformity with the delineations outlined in Stewart and Oke (2012) which have an impact on the socio-economic and thermal comfort of the inhabitants. These impacts can no longer be neglected. Therefore, this study as well examined the spatial variation of urban canopy heat island in Benin City in the wet season using the following objectives;

I. Identify the local climate zones (LCZs) in the study area
ii. Determine the nature and spatial variations of UCHI in the wet season
iii. Assess the diurnal variation of UCHI in the wet season in the study area

THE STUDY AREA

Benin City comprises three Local Government Areas namely Egor, Ikpoba Okha and Oredo. It is located within Latitudes 6°20´55″N to 6°58´39″N and Longitudes 5°35´18″E to 5°41´18″E. It broadly occupies an area of approximately 112.552km (Efe, 2006. This extensive coverage suggests spatial variability of weather and climatic elements (Figure 1).The study area has a tropical climate characterized by two distinct seasons, the wet and dry seasons. The wet season covers the months of March to October with an annual rainfall amount usually up to 2000 mm and a mean temperature of approximately 27°C (Odekunle, 2004). The month of March is the warmest in the study area due to increasing cloudiness during the transition from the dry season to the wet season, while July is one of the months of peak rainfall since rainfall is bimodal with September being the second month of peak rainfall (Atedhor &John-Abebe, 2017).

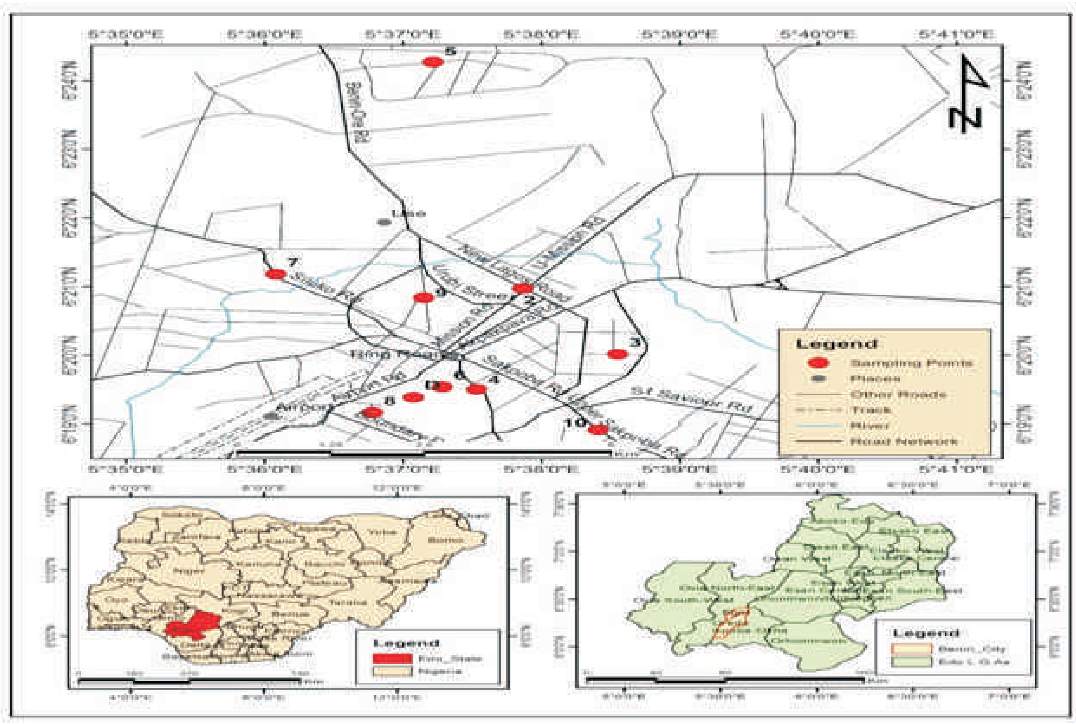


Figure 1: The Study Area showing Selected Sites
Source: Adapted and modified from Benin City Map (2011)

As observed during the assessment of the urban troposphere using sensitive rain gauges of the American origin, the rainfall amount, its intensity, duration as well as its distribution throughout the city are determined by the prevailing maritime winds, changing clouds, temperatures, and circulating pressures.

Based on the 2006 national census, Benin City has a total population of 1,086,882 (NPC, 2009). The City has a radial network of roads which converge in the city centre. Economic activities are dominantly commercial and are largely concentrated in the city centre. These commercial activities generate huge waste that sometimes constitutes a nuisance due to poor refuse evacuation. The high vehicular traffic coupled with pockets of industrial activities remains sources of effluents and favours development of UCHI.

METHODOLOGY

Metadata was used in preparing datasheets for all the probable zones. Each datasheet was then compared with the general properties of the site it represents in the LCZ classification datasheets of Stewart and Oke (2012). Then the best match or best fit for each site was identified (a site whose metadata are fairly aligned with those in the data sheets containing the general properties) and selected. In addition to the identification of the LCZ, a temperature recording site was also located in each LCZ.

The data used for this study include geo-coordinates, elevation, satellite imageries, and the eye-level photograph of sites and temperature data. Both the geo-coordinate and elevation data of selected sites were captured using a hand-held Garmin GPS receiver. Other data collected that were relevant to this research include the nature of traffic flow, the height of buildings, the width of streets, the predominant function of the area (residential, commercial, industrial, educational, among others.). These data were used to select local climate field sites based on Stewart and Oke (2012) LCZ classification method. Traffic flow was graded as heavy, medium or light (Table 1 and Figure 1).

Table 1: Selected Sites, their Corresponding LCZ Designations and code for Temperature Recording Station in each LCZ

Site	Name	LCZ	Designation	Station code	Traffic
1	New Benin	LCZ 2	Compact midrise	NB	Heavy
2	Textile Mill Road	LCZ 3	Compact low-rise	TM	Moderate
3	Permanent Secretariat	LCZ 4	Open high-rise	PS	Moderate
4	Faculty of Social Science	LCZ 5	Open midrise	FS	Low
5	G.R.A Benin	LCZ 6	Open low-rise	GR	Low
6	NIFOR	LCZ D	Low plants	NI	Low
7	Welu, Igor Axis	LCZ 7	Lightweight low-rise	WI	Low
8	Kada Plaza	LCZ 8	Large low-rise	KP	Heavy
9	Wire Road	LCZ 9	Sparsely built	WR	Low
10	Nigerian Brewery	LCZ 10	Heavy industry	BR	Moderate

Source: Field Work (2019)

DS1921G – F5 ThermochroniButton data loggers were used for collecting the temperature data simultaneously from the ten (10)stations that were set up within the study area. The sites for temperature measurement were selected according to Stewart and Oke (2012) local climate zones (LCZ) system of classification. Only nine of the sites outlined in Stewart and Oke (2012) were identified in the study area as built up while NIFOR served as the control site. The ThermochroniButton is a 17.25mm diameter by 6mm thick instrument. The data loggers were programmed to record air temperature at 30 minutes interval throughout the study period. According to Balogun, Ahmed, and Zachariah (2011), the calibration of the iButtonswill make it effective for the area under study. This study covers the period of1st to 31st June 2019 (Wet Season).

Data Analysis

Quantitative statistical methods wereemployed to analyze the information collected from the field. Firstly, average temperature value for every hour of the study period was calculated from the recorded temperature data of each site. It is from this hourly temperature data that UCHI was computed. In this study UCHI was determined as follows:

UCHI = $T_{LCZn-LCZD}$ (Stewart and Oke, 2012)

Where:

T = temperature of a sample station,

LCZ = local climate zone, n = built type zone from 1 to 10, D = land cover type zone (low plants)

Secondly, mean UCHI for each LCZ type was calculated.

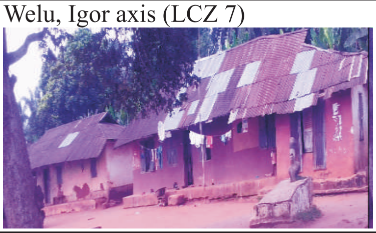
Results and Discussion

Identification of LCZs

The identification of each LCZ was defined based on Stewart and Oke (2012) and the best fit urban fabric was selected to match each LCZ(Table 2)

Table 2: Identification of LCZs

Eye-Level Picture	Coordinates	Site Satellite Imagery
New Benin Market Area (LCZ 2)	6°20´58″N - 5°37´52″E	
	6°21´32″N - 5°36´54″E	
Permanent Secretariat (LCZ 4) 	6°24´16″N - 5°37´13″E	
Faculty of social science (LCZ 5) 	6°19´30″N - 5°37´32″E	
GRA, Benin (LCZ 6)	6°19´32″N - 5°37´17″E	

Eye-Level Picture	Coordinates	Site Satellite Imagery
Welu, Igor axis (LCZ 7) 	6°21´32″N - 5°36´58″E	
Kada Plaza (LCZ 8) 	6°19´32″N - 5°37´31″E	
Wire road area (LCZ 9) 	6°20´50″N - 5°37´9″E	
Nigeria Brewery Benin (LCZ 10) 	6°20´48″N - 5°39´54″E	
NIFOR (LCZ D) 	6°33´27″N - 5°37´27″E	

Source: Field Work (2019) and Google Earth Imagery

Spatial Air Temperature Variation

The variation of near-surface air temperature of the study area was collected for the season under study. The mean monthly temperature for the wet season (June) was calculated from the daily temperature recorded for each station and presented in Figure 2. WR has the highest temperature of 27.40°C, followed by FS, GR, and KP with 27.07°C, 26.94°C and 26.57°C respectively. On the other hand, the lowest temperature of 24.54°C was recorded in NI while the mean temperature range for the wet season was 3.76°C.

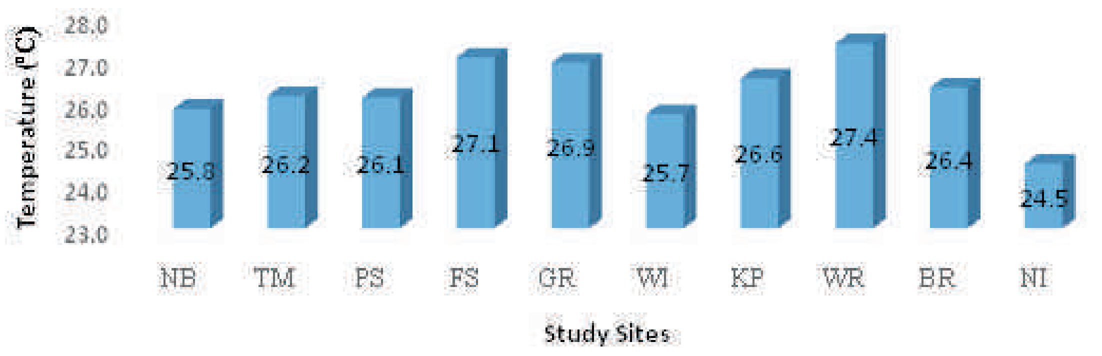


Figure 2: Mean Spatial Air Temperature Variation for June (Wet Season)
Source: Author's Analysis (2019)

The high temperature at WRis due to the surface characteristics of the site. The low temperature across the sitesis slightly due to the availability of moisture which reduces the latent heat of vaporization, land and sea breeze developing across the study area and cloud cover which tends to reduce the amount of solar radiation that reaches the earth surface. The highest mean value recorded during the wet season of 27.40°C is slightly higher than what was obtained in Kaduna (26.93°C) by Usman (2016) within the same season. However, it is lower than the temperature value obtained in Kano (30.47°C) by Abdulhamed, Nduka, Sawa, and Usman (2015) within the same period.

Spatial Variation of UCHI

To assess the nature and spatial pattern of UCHI in the study area, the spatial variation of UCHI was calculated from the near-surface temperature using the formula;

$$UCHI = T_{LCZn-LCZD}$$

Where:

T = temperature of a sample station, LCZ = local climate zone

n = built type zone from 2 to 10, D = land cover type zone (low plants)

The spatial variation of UCHI in the wet season was calculated from the mean hourly temperature of the wet season. The resultant mean UCHI is presented in Figure 3

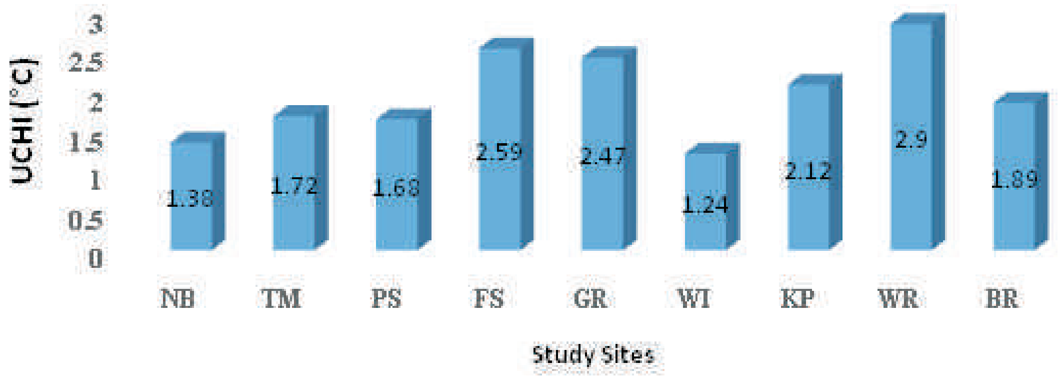


Figure 3: UCHI Variation in the Wet season

Source: Author's Analysis (2019)

Figure 3 shows that the highest UCHI values were recorded at WR, FS, and GR with 2.9°C, 2.59°C and 2.47°C respectively while the lowest values of UCHI were recorded at WI (1.24°C), NB (1.38°C) and PS (1.68°C). The highest value of UCHI recorded in WR (2.9°C) can be closely attributed to high vehicular movement and traffic congestion during the day which leads to increased emission of heat by trapping heat generated from fumes within a small air plume thereby increasing ambient air temperature and thus leading to increase in UCHI.

On the other hand, WI has the lowest UCHI in the wet season with 1.24°C. The reason for this, in addition to thermal storage resulting from lack of skyscrapers, is the massive reduction in traffic flow, cloud cover, and reduction in heating and cooling demand.

Diurnal Variation of UCHI in the Wet season

Mean diurnal UCHI variation in wet season (June) was calculated from mean hourly UCHI values. In order to investigate the diurnal variation of UCHI, four hours were chosen which are 05:00, 12:00, 15.00 and 20:00 hours. These hours represent, early morning (05:00 hours) when there is net radiative energy loss to an unobstructed sky and less polluted atmosphere prior to sunrise (Balogun, Balogun and Adeyewa, 2012), noon (12:00 hours) which represents full sunlight, afternoon (15:00 hours), which represents a period of peak absorption of solar radiation by surfaces and night-time (20:00 hours) about two hours after sunset which represents the period of active release of heat by urban surfaces. From Figure 4, it can be clearly seen that the highest diurnal UCHI recorded in the wet season was 7.13°C.

Figure 4: Diurnal UCHI Variation for Wet season
Source: Author's Analysis (2019)

The highest UCHI value was recorded in 15:00 hours at WR (7.13°C) and WI (6.48°C), fairly higher UCHI were recorded at midday with FS (5.80°C) and GR (5.08°C) while the lowest UCHI value recorded in this season was at 05:00 hours with a diurnal UCHI value of -0.64°C at WI. It is worthy of note that two points fell below the zero mark (negative values), indicating that these points are less than the control site, a situation called cool island (Stewart and Oke, 2012).

Also as indicated by Figure 4, between 20:00 hours and 05:00 hours, UCHI ranges from -0.64°C to 1.65°C in all study sites except WR, thereby giving an UCHI range of 2.29°C among most stations while between 12:00 and 15:00, UCHI range between 1.88°C to 7.13°C giving an UCHI range of 5.25°C. The diurnal range for this season is 7.77°C. The highest diurnal UCHI of 7.13°C recorded in the wet season is lower than what was obtained in Kano (9.78°C) (Abdulhamed *et al.,* 2015) but higher than what was recorded in Kaduna (3.32°C) (Usman, 2016) and Enugu (3.5°C) (Enete and Alabi, 2012) during the same season.

Also the minimum UCHI intensity of -0.64°C recorded in this study is lower than what was obtained in Enugu, Kano and Kaduna with 3.2°C, 1.75°C and 0.3°C (Enete and Alabi, 2012), (Abdulhamed *et al.,* 2015) and (Usman, 2016) respectively. However unlike what was obtainable in Kaduna (Usman, 2016) and Enugu (Enete and Alabi, 2012) where UCHI intensities were highest at nocturnal hours, this study reveals that UCHI intensities are highest during the day, therefore agreeing with the work of Abdulhamed*, et al.,* 2015 in Kano and Balogun, Balogun and Adeyewa, 2012 in Akure.

The high intensity of UCHI recorded is partly due to the nature of the surface materials, especially its permeability which allows it retain water after the rain, thereby reducing the amount of ambient heat through evaporative cooling. On the other hand the extremely low UCHI intensity (Cool Island) recorded at WI at both 20:00 hours and 05:00 hours local time is as a result of wetness of surface, green house effects (which causes micro climate modification), low thermal storage resulting from lack of tall skyscrapers that would have restricted thermal radiation, reduced turbulent exchanges and others.

CONCLUSION

The study confirms the existence of urban heat island in Benin City, and thus has a strong implication on the bio-climatological aspect of the urban environment and physiological comfort of the urban inhabitants. The study also showed that there is variation in the distribution of temperature within the urban canopy of Benin City. The variation in UCHI in the study area was attributed to the characteristics of surface cover and anthropogenic factors since the higher the impervious surfaces, the higher the spatial variation of UCHI intensities. The temporal variation of UCHI among the LCZs shows that UCHI values were higher during the night than at day. The study therefore recommends the following:

i. The government should enact regulations on the adoption of climate sensitive planning and design schemes.
ii. There should be the adoption of planning methods of green city, green roof approach as this will help to regulate urban climate.
iii. Building codes should be formulated which should provide standards for construction and discourage the use of dark coloured roofs, wall paints and pavements. This is because dark surfaces are good absorbers of heat thus, increase UCHI intensity

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