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

Aruya Emmanuel, I.
Department of Geography and Environmental Management, Ahmadu Bello University, Zaria, Nigeria.

Ariko Joseph, D.
Department of Geography and Environmental Management, Ahmadu Bello University, Zaria, Nigeria.

Ikpe Elisha
Department of Geography and Environmental Management, Ahmadu Bello University, Zaria, Nigeria.

Corresponding Author's Email: arikology@yahoo.co.uk

Abstract

The temperature in urban areas are impacted by increases in urban population and human activities which produce emissions of heat, water vapour and pollutants leading to a temperature difference between these urban areas and their rural surroundings. This temperature difference is Urban Heat Island. This study assessed the spatial variation of Urban Canopy Heat Island (UCHI) in the wet season in Benin City, Edo State, Nigeria. The Local Climate Zones (LCZs), the nature and spatial variations of the UCHI and the significance of variation of UCHI in the study area were identified and determined using geo-coordinates, elevation, satellite imageries and the eye-level photograph of sites and temperature data. Stewart and Oke (2012) system of classification was used to classify Benin City into climate field sites. DS1921G – F5 thermocron iButton data logger was used for collecting the temperature measurements from the stations. The 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 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 variation of UCHI was attributed to the availability of moisture in the wet season and increased cloud cover. The highest value of UCHI recorded in WR (2.9°C) was attributed to high vehicular movement and traffic congestion during the day, which led to increased emission of heat. The lowest UCHI recorded in WI (1.24) is because of thermal storage resulting from lack of skyscrapers, massive reduction in traffic flow, presence of cloud cover and reduction in heating and cooling demand. The study therefore recommended the use of climate-sensitive planning and design schemes, adoption of planning methods of green city, and green roof approaches.

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

1. Introduction

The climate in cities and other built up areas is altered most by the modifications 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, Gonzalez-Rouco and Valero (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. 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. 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 thermochronic i-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 study was able to establish 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 daytime and night periods, suggesting that most of the stations had high temperatures.

More recently, Usman (2016) investigated the effect of surface cover composition on spatial and temporal variations of UCHI in Kaduna metropolis, Nigeria. Results of this study using one-way ANOVA revealed significant spatial and temporal variations of UCHI in March and August and only significant spatial variation in January. In addition, the percentage of surface elements influenced the spatial variation of UCHI. Benin City and its surrounding areas have experienced changes in their morphology over the years. In Benin City, there are some areas where the buildings are tall, for example Akpakpava, G.R.A, 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 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 examines urban canopy heat island in Benin City in the wet season using the following objectives; identifying the local climate zones (LCZs) in the study area, determining the nature and spatial variations of the UCHI in the study area and determining the significance of variation of UCHI in the study area.

2. The Study Area

Benin City serves as the principal administrative and socio-economic centre for both Oredo Local Government Area and Edo State in Nigeria. Benin City is a humid tropical urban settlement, which 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°. It broadly occupies an area of approximately 112.552km.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 and John-Abebe, 2017). 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. Benin City has a total population of 1,086,882 based on the 2006 census. 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.

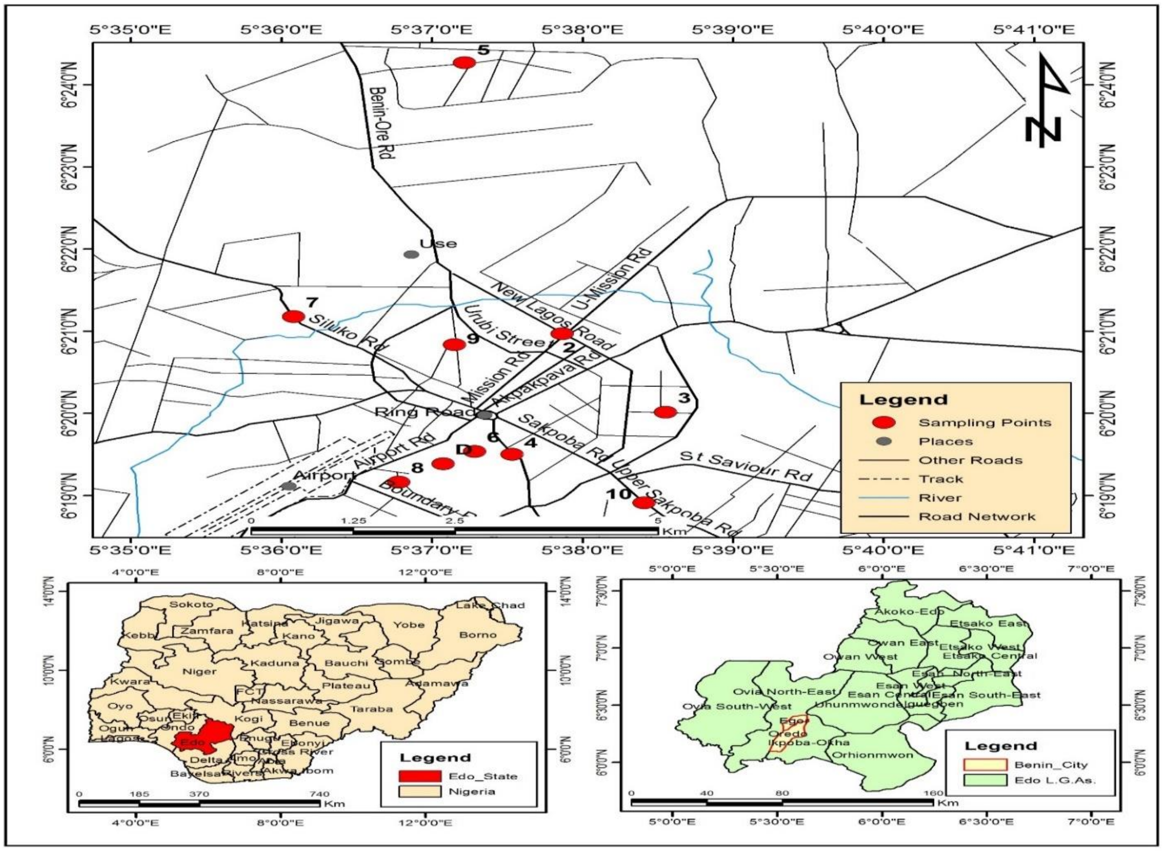

Figure 1: The Study Area showing Selected Sites
Source: Adapted and modified from Benin City Map 2011

3. Materials and Methods

The name LCZ is appropriate because the classes are *local* in scale, *climatic* in nature, and *zonal* in representation (Stewart and Oke, 2012). LCZ can therefore be defined as regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale (Stewart and Oke, 2012). Each LCZ has a characteristic screen height temperature regime that is most apparent over dry surfaces, on calm, clear nights, and in areas of simple relief. These temperature regimes persist year-round and are associated with the homogeneous environments or ecosystems of cities (e.g., parks, commercial cores), natural biomes (e.g., forests, deserts), and agricultural lands (e.g., orchards, cropped fields). Each LCZ is individually named and ordered by one (or more) distinguishing surface property, which in most cases is the height/packing of roughness objects or the dominant land cover. The physical properties of all zones are measurable and nonspecific as to place or time (Figure 2)

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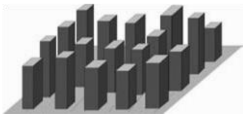
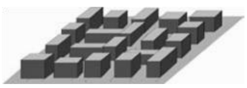
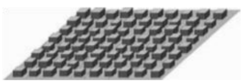
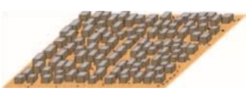
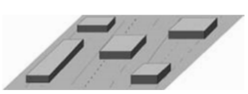
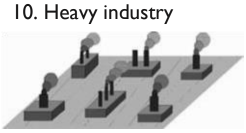
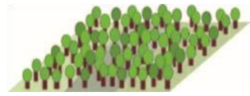
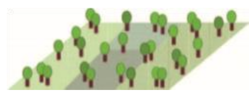
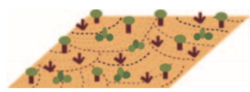
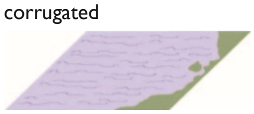
Built types	Definition
1. Compact high-rise 	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.
2. Compact midrise 	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.
3. Compact low-rise 	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.
4. Open high-rise 	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.
5. Open midrise 	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.
6. Open low-rise 	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.
7. Lightweight low-rise 	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction Materials (e.g., wood, thatch, corrugated metal).
8. Large low-rise 	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.
9. Sparsely built 	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).
10. Heavy industry 	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.

Land cover types	Definition
A. Dense trees 	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
B. Scattered trees 	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
C. Bush, scrub 	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
D. Low plants 	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
E. Bare rock or paved 	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
F. Bare soil or sand 	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
G. Water 	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.

VARIABLE LAND COVER PROPERTIES

Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.

b. bare trees	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
d. dry ground	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Figure 2: Abridged definitions for local climate zones
Source: Stewart and Oke, 2012

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 (Stewart and Oke, 2012). Both the geo-coordinate and elevation data were recorded 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, etc.). 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 thermocron iButton 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 thermochron iButton 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 iButtons will make it effective for the area under study. This study covers the period of 1st to 31st June 2018 (Wet Season).

3.1 Data analysis

Quantitative and qualitative statistical methods was employed 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:

$UCHI = T_{LCZn - LCZD}$

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.Thirdly, from the above mean, student t-test was used to test for spatial variation of UCHI among the LCZ

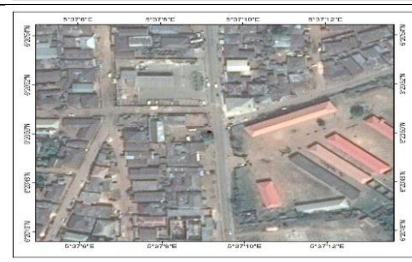
4. Results and Discussion

4.1 Characteristics of LCZs

The characteristics 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: Characterization of LCZs

Eye-Level Picture	**Coordinates**	**Site Satellite Imagery**
New Benin Market Area (LCZ 2) 	6°20′58″N - 5°37′52″E	
Textile Mill Road (LCZ 3) 	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	

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

4.2 Nature and Spatial Pattern of UCHI in the Study Area

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 3. The WR has the highest temperature of 27.40°C (Figure 3), 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.

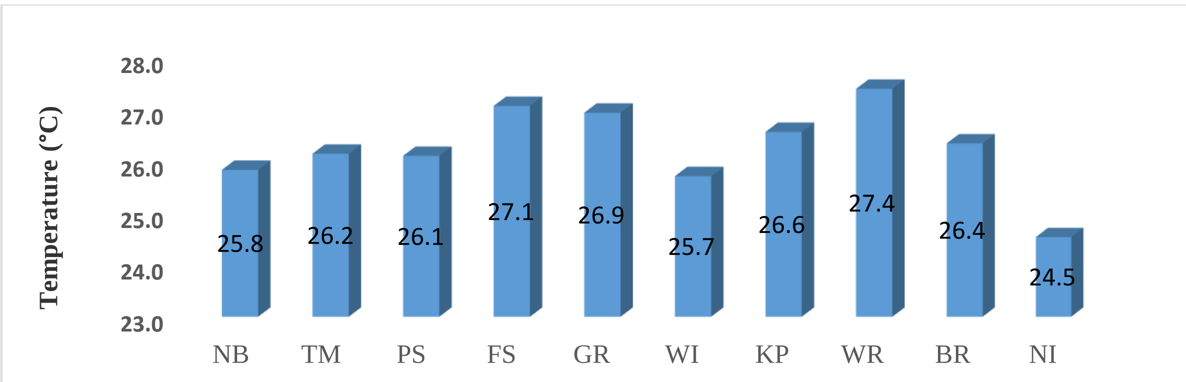


Figure 3: Mean Spatial Air Temperature Variation for June (Wet Season)
Source: Author's Analysis (2019)

The low temperature across the study sites in the wet season (June) is 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 temperature range on the other hand is due to surface cover morphology that leads to variation in emissivity capacity in the urban area, increased human activities, and emissivity from increased traffic and vehicular activities. 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 values obtained in Kano (30.47°C) by Abdulhamed, Nduka, Sawa, and Usman, 2015 within the same period. Besides, the mean temperature range of 3.76°C is higher than values obtained in the dry season (2.95°C) but lower than that obtained in Kano (6°C) by Abdulhamed *et al.*, 2015, Yola (6°C) by Adebayo and Zemba (2003). This variation is traceable to differences in air temperature at this period of the year.

4.3 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 4

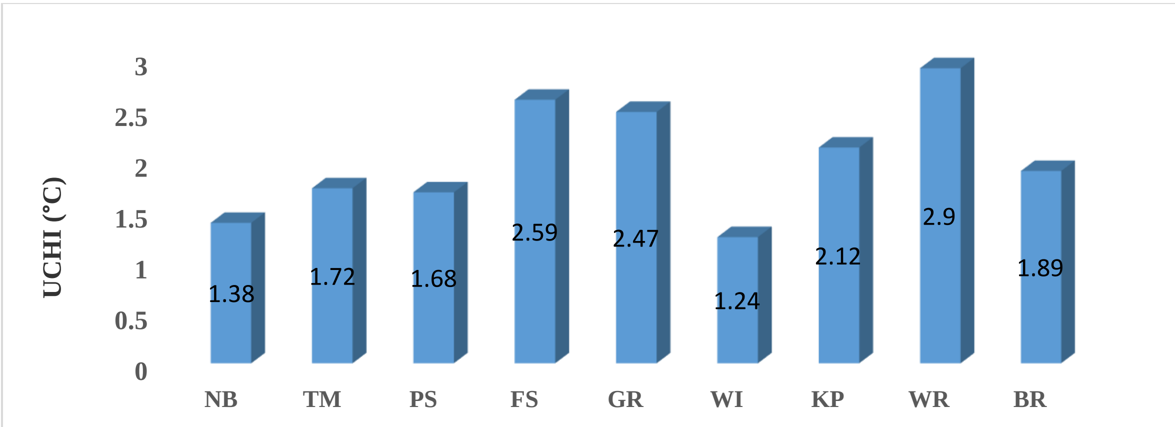


Figure 4: UCHI Variation in the Wet season
Source: Author's Analysis (2019)

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). Possible explanations for this are the already established availability of moisture in the wet season and increased cloud cover. 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. On the other hand, WI is 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
.

4.4 Test of Significant Variation of UCHI in the Wet Season

The resultant mean UCHI for the wet season was subjected to statistical procedures to test for the significance of spatial variation of UCHI in the wet season. ANOVA was used to test whether the result was statistically significant. The results are presented in Table 3.

Table 3: ANOVA Result for Spatial Variation of Mean UCHI in the Wet Season

		Sum of Squares	Df	Mean Square	F	Sig
0.05 Level of Significance	Between Groups	61.293	8	7.662	2.610	.010
	Within Groups	607.749	207	2.936		
	Total	669.042	215			

Source: Author's Analysis (2019)

The calculated F-value of 2.610 has a significance value of 0.010 at 0.05 (95%) level of significance (Table 3). Since the calculated P-value is less than 0.05, it indicates that the variation of mean UCHI in the wet season in the study area is significant. Therefore, we can safely conclude that there is a significant difference among UCHI intensities in the various LCZ within the study area.

5. 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 a significant variation in the distribution of temperature within the urban canopy of Benin City. This accounted for 2.9°C temperature variation from high-density residential and industrial areas to the control site in Benin City during the wet season, which indicated urban warming over its control station. 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.

6. RECOMMENDATIONS

i. There should be regulations made 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. This is because results from this study indicated the importance of vegetation in mitigating UCHI development

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