AN ANALYSIS OF URBAN CLIMATE FIELD SITES USING LOCAL CLIMATE ZONES: THE CASE OF KADUNA METROPOLIS

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ABSTRACT

Differences in concentration of physical features made up of materials with higher thermal properties including buildings which also restrict wind flow, result in intra-urban variation of microclimatic conditions. This study used such land use/land cover characteristics in classifying the urban climate field sites of Kaduna metropolis according to local climate zones (LCZ) scheme. Data used for the classification include sky view factor obtained from sky view photographs taken with fish-eye length using BMSky view program, percentages of built surfaces, paved areas, vegetated surfaces and bare land surfaces obtained from QuickBird satellite imagery using ArcGIS 10.1. Other data are roughness height and traffic density obtained through observation and zone function obtained from land use map of the metropolis. The study identified and selected ten LCZs which include; LCZ2, LCZ3, LCZ4, LCZ5, LCZ6, LCZ7, LCZ8, LCZ9 and LCZ10 which mostly consist of higher proportions of man-made land use/land cover types such as built-up and paved surfaces and to a lesser extent vegetated and bare land surfaces. There are also varying degrees of anthropogenic activities which modify the microclimate such as traffic flow, commercial and industrial activities. The last one is LCZD which consist of natural surfaces only. The results demonstrate that LCZ system adequately suited the city. This classification is good especially for observational urban heat island (UHI) studies as the distinguishing features of the classification provide logical basis for discussing microclimatic variations. In order to produce a universal system of classification, more classification efforts are needed from tropical cities.

Key words: Classification System, Inter-zone, Local climate zones, Metadata

INTRODUCTION

Urban terrain is mostly made up of impervious materials that restrict wind flow, absorb, store and release more heat from solar radiation to warm up overlying air and limit evaporative cooling of vegetation and moist natural land cover. These coupled with anthropogenic activities that release heat such as mobile transportation and industrial activities gave rise to differences in microclimatic conditions across urban areas. Failure of some urban climate researchers to provide adequate information on such distinguishing characteristics which are the basis for differences in urban climate field sites is what compromises the quality of most research works in urban climatology (Stewart, 2010). Therefore, the issue of standardization in reporting urban climate studies became an issue of concern to researchers.

The earlier attempts made by urban climatologists to address this issue include Auer (1978) and Ellefsen (1990/1991) who produced classification schemes of cities for climate studies based on physical features. These were followed by Aguilar, Auer, Brunet, Peterson and Wieringa (2003) and Oke (2004) who produced comprehensive World Meteorological Organisation (WMO) guidelines for siting meteorological stations in cities. Oke (2004) developed a classification system known as 'urban climate zones' (UCZ), which incorporated the classifications of Auer (1978) and Ellefsen (1990/1991). This marked an important turning point in urban climate science as it ushered in a series of urban climate field sites classification schemes. These include; 'local scale climate zones' (LSCZ) with 9 classes (Krayenhoff, Stewart and Oke, 2009), 'local climate zones' (LCZ) with 19 classes (Stewart and Oke, 2009a), 'thermal climate zones' (TCZ) with 9 classes (Stewart and Oke, 2009b), 'local climate zones' with 15 classes (Stewart, 2009), 'local climate zones' with 16 classes (Stewart and Oke, 2010), 'urban zones for characterizing energy partitioning' (UZEs) (Loridan and Grimmond, 2011) and the latest one, 'local climate zones' with 17 classes (Stewart and Oke, 2012). The Stewart and Oke (2012) classification is adopted in this study.

In the same context, Oke (2006) argued that for meaningful scientific interaction between the field of urban climate and cognate fields to be achieved, there was the need for better communication. Moreover, better communication could never be achieved in the field except through proper classification of urban climate field sites based on relevant physical properties. However, Schroeder, Basara and Illston (2010) identified additional parameters that need to be considered in classifying urban climate field sites which have not been included in all the five different classification systems including the one used in this study.

Local climate zones are defined as regions of relatively uniform surface-air temperature distribution across horizontal scales of 10^2 to 10^4 metres (Stewart and Oke, 2009a, 2009b). The zones are derived from divisions of the urban landscape into sub-divisions based on properties such as surface cover (built fraction, soil moisture, albedo), surface structure (sky view factor, roughness height) and cultural activity (anthropogenic heat flux) (Stewart and Oke, 2009a). In Nigeria, some of the classification systems have been adopted for observational UHI studies and were found to have excellently improved reporting of the phenomenon. For instance, UCZ system was used by Ibrahim, Nduka, Iguisi and Ati (2011), TCZ was used by Nduka and Abdulhamed (2011) and LCZ (Stewart, 2009 version) was used by Usman, Abdulhamed, Ibrahim, Iguisi, Azare and Ati (2016). This study intended to determine varieties of urban climate field sites according to LCZ classification scheme obtained in Kaduna metropolis and assess the efficacy of this classification system in describing the urban terrains of a tropical wet and dry city in a developing country.

STUDY AREA

Kaduna metropolis is located between Latitudes 10º19ʹN and 10º40ʹN and Longitude 7º15ʹE and7º35ʹE as shown in Figure 1. The metropolis is made up of two main local government areas (LGA); Kaduna North and Kaduna South and extends to parts of Igabi and Chikun LGAs. Kaduna metropolis has been ranked number 13 on the list of 100 most populous cities in West Africa (Cour and Snrec, 1998) and number 5 among Nigerian cities, behind Lagos, Kano, Ibadan and Abuja. It has human population of 1.4 million in 2009 (NPC, 2009).

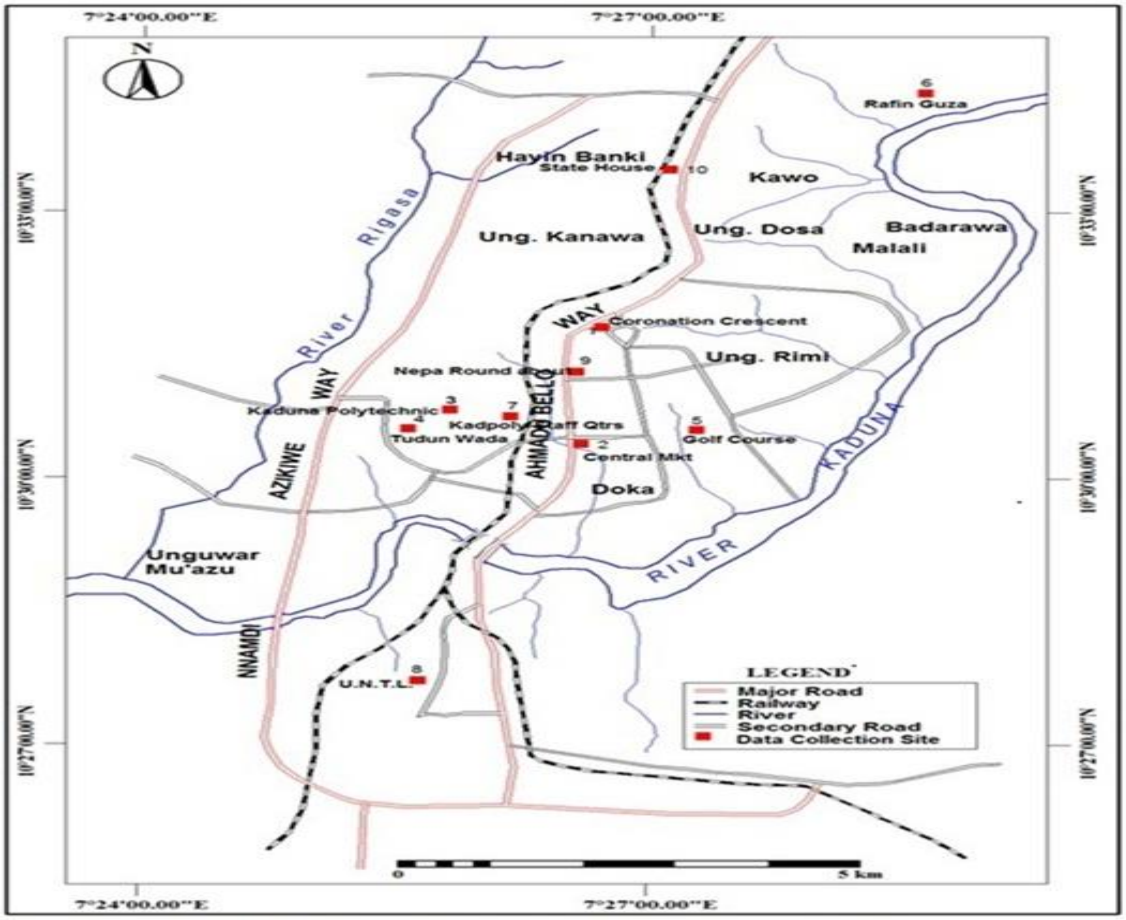


Fig. 1: Kaduna metropolis showing data collection sites (Locations of LCZs)

Kaduna metropolis has a tropical continental climate (Aw) with distinct wet (May – October) and dry (November – April) seasons, reflecting the oscillation of Intertropical Discontinuity (ITD) over the area. ITD is the point where moist tropical maritime air mass (mT) meets dry tropical continental air mass (cT). Most of the rainfall in Kaduna and the whole of West Africa is a result of generation of lines of organised convective disturbances often referred to as squall lines (Rowell and Milford, 1993). Military establishments used to be the largest single consumer of land (about 29%) followed by other institutional uses and low density housing (24.7% and 20.7%) (Lock and Partners, 1967). Now residential uses have surpassed the military uses. A lot of industrial activities are also found in Kaduna.

MATERIALS AND METHODS

The data used to classify the sites were obtained through field study conducted from 7th January to 11th February, 2015. The data include nature of traffic flow, height of buildings, width of streets, predominant function of the area (residential, commercial, industrial, educational, etc). Traffic flow was graded as heavy, medium or light. Heights of buildings (in metres) were computed using Yamashita and Sekine (1990/1991) formula:

$H = 3.0n + 2$ …………………………………………………………………… (1)

or

$H = 3.0n + 0.5$ ………………………………………………………………………. (2)

Where H is the height of building in metres and n is the number of floors. The height of one floor was assumed to be 3m and base of the building 0.5m. For buildings with gable roofs, equation (5) is used; height of roof is assumed to be 1.5m, which when added to the base height (0.5m) gives 2m. On the other hand, for buildings with flat roofs, the height of the roof is assumed to be 0m thus, only the base height (0.5m) is considered as such, equation (6) is used. The traffic flow and height of buildings (number of floors) were observed with eyes and recorded, while predominant function of sites were obtained from the land use map of the metropolis obtained from Kaduna Urban Planning and Development Authority (KUPDA). Widths of streets were recorded using the Garmin GPS receiver by walking across the street.

Sky view factor (SVF) was computed from sky view photographs taken with a digital camera (HP Photosmart-M425) fitted with a fish-eye lens (Digital King M-Power 180^{o}) mounted horizontally on a tripod 1 metre above ground level, using BMSky View program. Built fraction, vegetated, pervious and impervious surface fractions were obtained from QuickBird satellite imagery of the study area (recorded in 2012). A 500m x 500m buffer zone within each LCZ was taken from the imagery; the imagery was then classified using ArcGIS version 10.1 using supervised classification. The required areas were obtained in hectares from which the fractions were computed. Additional data such as satellite imageries and computer sketches were obtained from Google Earth and classification studies (Stewart and Oke, 2009b; Stewart and Oke, 2012).

Stewart and Oke (2012) LCZ classification scheme (see Figure 1) was adopted in this study. A datasheet for every zone was prepared based on the above mentioned parameters from which the best fit zones were selected (for a sample of such datasheets see Table 1).

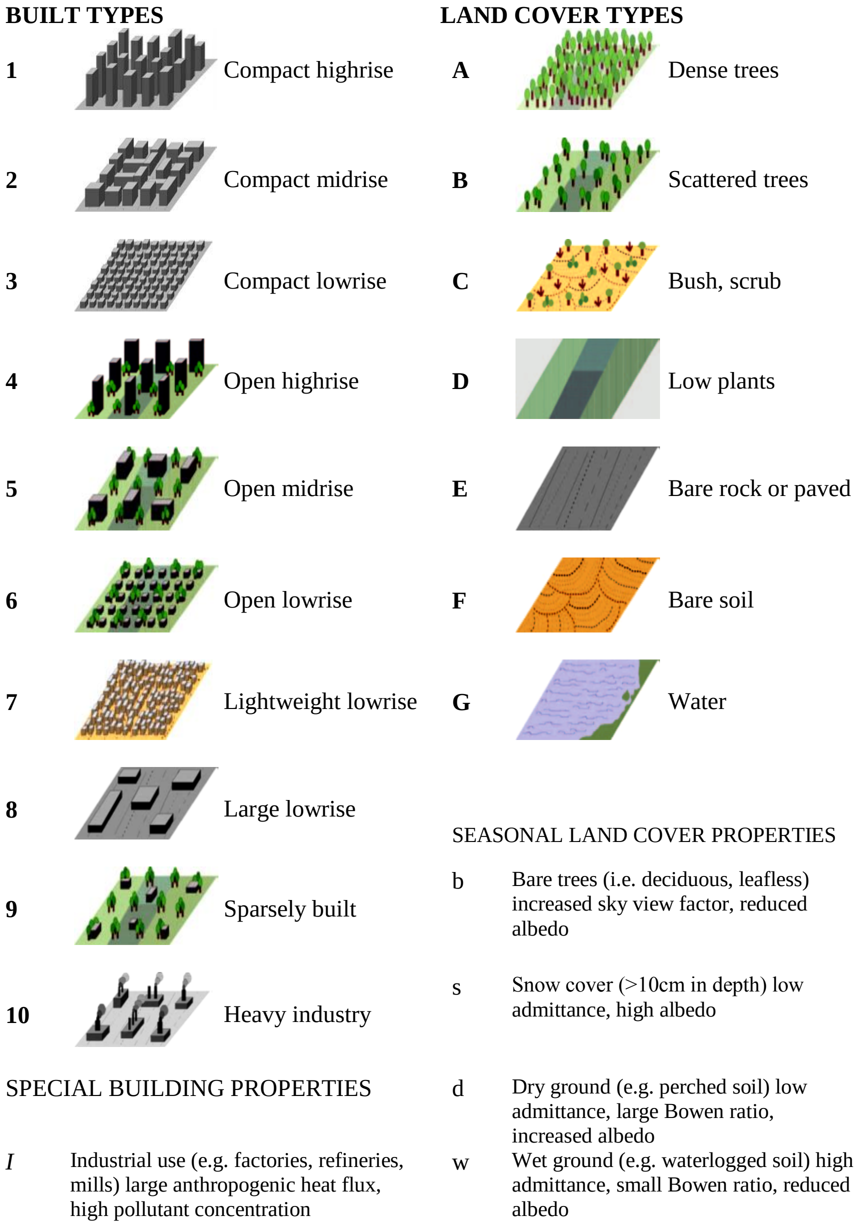
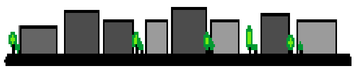
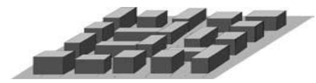
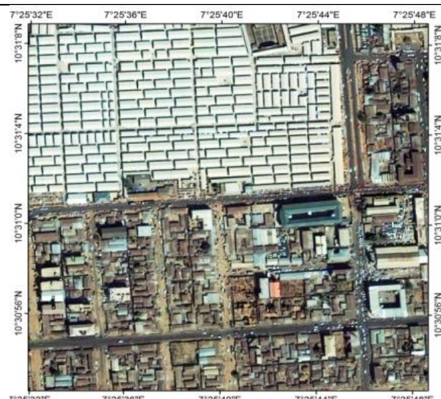
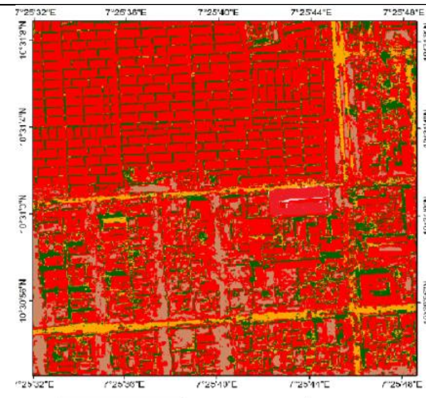


Fig. 1: Local Climate Zone Types
Source: Stewart and Oke (2012)

Table 1: Sample Data Sheet for Compact Midrise.

<table>
<tr><td colspan="3">Zone Name: Compact midrise</td><td colspan="2">Landscape series: Built</td><td>Code: LCZ2</td></tr>
<tr><td colspan="6">Definition: Flat, compact skyline; of mid-rise buildings 3 to 10 stories tall, different height. Most of the buildings are large and dense, attached or close-set, and heterogeneous in character. Narrow streets or alleyways separate the buildings. Sky view from street "canyons" significantly reduced. Heavy, solid construction materials; thick roofs/walls (stone, concrete, brick, tile). Paved streets (asphalt or concrete). Significant proportion of impervious surface cover and scarce tree or vegetative cover. High-moderate space cooling demand. High traffic flow.</td></tr>
<tr><td colspan="6">Function: High-density; commercial (retail, hotels, offices); light industrial (wholesaling, manufacturing).</td></tr>
<tr><td colspan="6">Location: City centre.</td></tr>
<tr><td colspan="6">Computer Sketch</td></tr>
<tr><td colspan="3">Side View</td><td colspan="3">Oblique View</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="6">Photographs</td></tr>
<tr><td colspan="3">Eye Level</td><td colspan="2">Sky View</td><td>Aerial (Google Earth)</td></tr>
<tr><td colspan="3"> </td><td colspan="2"></td><td></td></tr>
<tr><td colspan="6">QuickBird imagery – 500m x 500m buffer zone</td></tr>
<tr><td colspan="3">Before classification</td><td colspan="3">After classification</td></tr>
<tr><td colspan="3">
</td><td colspan="3"></td></tr>
<tr><td colspan="6">Zone Properties</td></tr>
<tr><td>SVF[1]</td><td>% built[2]</td><td>ZH[3]</td><td>Albedo[4]</td><td>μ[5]</td><td>Q_F[6]</td></tr>
<tr><td>0.30 - 0.60</td><td>>85</td><td>10– 15</td><td>0.10 – 0.20</td><td>1,500 - 2,200</td><td><75</td></tr>
<tr><td colspan="6">1. Mean sky view factor from ground level. Varies with height and density of buildings, trees.
2. Proportion of zone surface covered by impervious materials (buildings, roads, pavement).
3. Average height of main roughness elements (trees, buildings, crops). 4. Weighted average reflectivity of zone surface. 5. Thermal admittance varies with surface type, wetness and materials. 6. Local scale mean annual anthropogenic heat flux from combustion processes and space heating/cooling.</td></tr>
</table>

Source: Author's field work, 2015, Google Earth and QuickBird and computer sketches adapted from Stewart and Oke (2012),

RESULTS AND DISCUSSION

Results of the LCZ classification are summarised and presented in Table 2. From this table, the identified zones are; BCZ2, BCZ3, BCZ4, BCZ5, BCZ6, BCZ7, BCZ8, BCZ9, BCZ10 (in the built series) and NCZ4 (in the natural series). In general, the Kaduna field sites appear to be well represented by LCZ except the BCZ1. In most cases, metadata for each site are to a greater extent comparable with the general zone properties. The zones clearly portray the nature of urban terrains of Kaduna metropolis as differences in built form are captured by the zones. High, medium and low building density classes are identified from the urban sites.

However, most of the site metadata obtained were not adequately aligned with those in the datasheets. This could be attributable to differences in physical planning and development patterns between the cities from where the metadata used in producing the original classification were obtained and what is obtained in the study area. Thus, in most cases only best-fit zones were selected based on the authors' skilled judgement and knowledge of the field sites rather than automated matching.

These results are important as they illustrate how surface characteristics which are functions of physical planning and development patterns can be used to classify urban climate field sites. Each of the parameters used in this classification has a profound effect on the microclimate of its surrounding area. For instance, sky view factor (SVF), which is the proportion of sky visible to an observer from a location at street level; controls the amount of long wave radiation (sensible heat) that escapes back to space from urban surfaces. The lower the SVF value the more amount of heat trapped and vice versa as observed by Usman (2012) in Kaduna and Balogun, Balogun and Adeyewa (2012). Furthermore, built-up and paved fractions also influence the microclimate of cities. The higher the built-up density and fraction of paved surfaces, the higher will be the amount of heat energy absorbed from solar radiation. This is because building and paving materials (mostly asphalt and cement concrete) have higher thermal capacities which enable them to absorb, transmit and store higher amount of heat energy during the day. This stored heat energy is released especially at night to heat the ambient air (Yan, Fan, Guo and Dong, 2014).

Table 2: Classification of Kaduna urban climate field sites by local climate zones

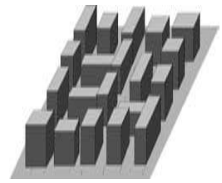
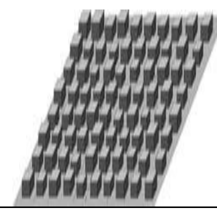
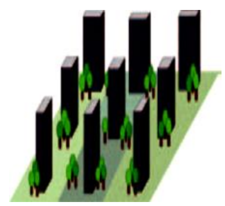
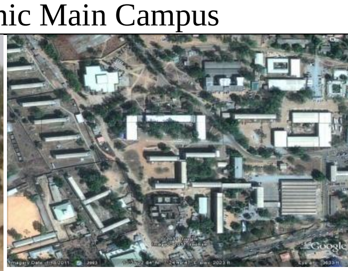
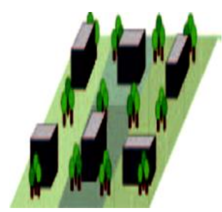
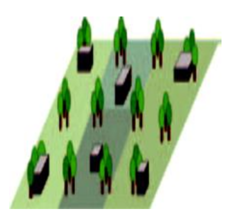
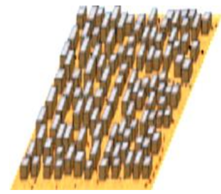
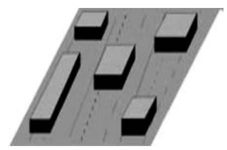
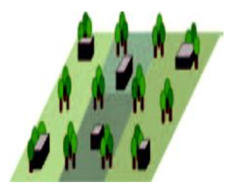
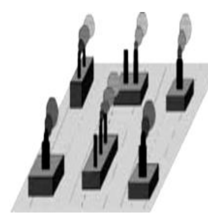
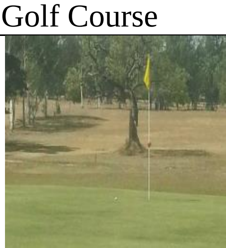
Site photographs Eye Level	High Angle	**Site Metadata**	**Local Climate Zone Classification**
Lagos Round About Area		Urban	LCZ2
		Part of the CBD. Buildings 3-5 stories, mostly large and dense. Heavy, solid construction materials. Narrow inner streets. Heavy traffic flow. Scarce vegetation. SVF=0.61. built fraction >85%	
Tudun Wada		Urban	LCZ3
		Residential area - inner city. Buildings bungalows, semi detached and densely packed. Light traffic. Scarce vegetation. SVF=0.81. Built fraction >85%	
NEPA Round about Area		Urban	LCZ4
		Busy central area along the commercial axis. Buildings 5-10 stories, dense, solid construction materials. Abundant unpaved surface cover. Moderate traffic density. Abundant vegetation. SVF=0.65. built fraction>70%	
Kaduna Polytechnic Main Campus		Urban	LCZ5
		Main campus of Kaduna Polytechnic. Buildings 2-4 stories, of different sizes, distribution and height. Heavy construction materials. Low traffic flow. Abundant vegetation SVF=0.71. Built fraction >30%	
Coronation crescent		Urban	LCZ6
		Coronation crescent/GRA. 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. SVF=0.83. Built fraction >25%	

Table 2 (continuation)

Site photographs Eye Level / High Angle	Zone Properties and Site Metadata	Local Climate Zone Classification
Rafin Guza	Built	LCZ7
 	Residential and commercial – suburb (Rafin Guza). Buildings semi-detached packed and separated by narrow unpaved streets. Light traffic. Vegetation scarce. SVF=0.91. Built fraction >75%	
State House Area, Kawo	Built	LCZ8
 	Government offices, Kawo. Buildings large, detached and separated by open spaces. Moderate-high traffic flow. Abundant vegetation. SVF=0.78. Built fraction <25%	
Kaduna Polytechnic Staff Quarters	Built	LCZ9
 	Residential- Kaduna Polytechnic staff houses. Buildings small, separated by courtyards. Surface mostly pervious. Low traffic flow. Abundant vegetation. SVF=0.84. Built fraction <25%	
Kakuri Industrial Area	Built	BCZ10
 	Kakuri Industrial area – refinery and petrochemical plant, breweries, light arms factory, textile mills. Heavy and lightweight materials. Abundant natural surface cover. Low traffic flow. SVF=0.80. Built fraction >60%	
Golf Course	Natural	LCZD
 	Kaduna Golf Course. Uncultivated fields within the city. Low uniform grass cover-bare soil. Very few buildings. Few scattered trees. No traffic flow. SVF=0.99. Built fraction <1%	

Source: Author's field work, 2015 and computer sketches from Stewart and Oke (2012

In the same context, buildings also restrict wind flow in cities, this leads to accumulation of warm air at street level as a result of limited heat transfer through turbulent flow (Yuan, Ng and Chen, 2012). Street orientation, width and pattern also affect the microclimate of urban areas. Wide streets with a regular pattern and oriented along the direction of prevailing wind allow a faster flow of air thus, transport of heat away from densely built-up areas, a process known as urban ventilation (Santamouris, Papanikolaou, Koronakis, Livda and Asimakopoulos, 1999; Shishegar, 2013). Function of respective urban segments and traffic flow density are also important in microclimatic modification of cities. For instance, industrial activities and mobile transportation are characterised by release of waste heat thus, industrial areas and areas of high traffic density in cities tend to have higher near-surface air temperatures (Taha, 1997).

However, vegetated surfaces tend to have lower ambient air temperatures and higher relative humidity. This is because vegetation (especially trees) cools its surroundings through shading effect and transpiration process (Buyadi, Mohd and Misni, 2015; Yan and Dong, 2015). When water evaporates from tree leaves, it takes away with it an additional heat energy known as latent heat of vaporisation which would have remained in the vicinity as sensible heat.

CONCLUSION

This classification was used for observational urban heat island study, the result of which reveals that it is a robust indicator of urbanisation-induced microclimatic modification. Even though currently there is no universal urban classification system for urban climate field sites in place, but LCZ is indispensable. This is because significant inter-zone temperature differences were observed. The classification brings out differences in built forms and planning patterns that are seldom rivalled by any other method. It makes everything logical and cross-study differences especially in UHI phenomenon and replication of studies much easier. In order to move closer to producing a universal classification system, it is recommended that urban climatologists from tropical and developing countries vigorously embark on classification campaign. This is in order to investigate the peculiarities of the background climate and the effect of urban planning and development patterns on the microclimate of urban areas in such environments.

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