DEVELOPING URBAN ENVIRONMENTAL CLIMATE MAP FOR SELECTED NORTHERN NIGERIAN CITIES

By

ODEKUNLE, Mary Oluwatobi

PhD/SPS/2015/696

DEPARTMENT OF GEOGRAPHY,

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

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ABSTRACT

Rapid urbanisation in developing countries is becoming issue of great concern, where high-density or mega-cities becoming the order of the day. Public concern and climate change when high-quality urban living is involved, one of the most important task is sustainable climatic spatial planning and planners and policymakers have challenges entering an era of mega-urbanisation. This study provided a social science-based approach for developing an UECM for heterogeneous cities, using three states (Kano, Kaduna and FCT) in Nigeria. Landsat 8 (OLI) images of 2018 and Landsat 4 (TM) images of 1988 covering the entire study area were collected, clipped with the shapefiles of each states and classified using the nearest neigbourhood analysis and forest classifiers to generate the LULC and LCZ maps of the study areas respectively. Vegetation indices (NDVI), built-up indices (NDBI) and land surface temperature (LST) were also calculated and daily temperature data form 1988 to 2018 (30 year period) were analysed using R software package. On the final note, a total of seven input layers were developed along with a final evaluation UCAM, together with URM, and were implemented into a system of local urban planning. The result of two classification schemes showed the morphology characteristics of rural and urban area in the three states and also detected the potential Urban Heat Island (UHI) distribution pattern across the states. The results of the accuracy assessment in each state also showed satisfying result as LCZ Kappa/overall accuracy includes 0.96/84.69%, 0.99/88.76& and 0.99/78.12% for Kaduna, FCT and Kano respectively, while the LULC Kappa/overall accuracy includes 0.81/89.85%; 0.79/89.90% and 0.86/88.57% respectively for Kaduna, FCT and Kano. The results of Pearson correlation coefficient analysed in SPSS software measures strength and direction of association that existed between the variables and indicated a perfect inverse relationship between LST and NDVI with r value of -1, while indicating a perfect relationship between LST and NDBI with r value of +1. Time plots of temperature observations showed indications of trend, seasonality and randomness in the patterns; hence decomposition of additive time series analysis were carried out and these revealed the pattern of average monthly temperature over the years under consideration (1988 – 2018). One can therefore deduce especially right from analysis of variance and standard deviation that the nature of temperature over the study period in Kaduna and FCT followed similar trend, this has been substantiated also with the time plot analysis and decomposition of additive time series analysis and eventually corroborated with seasonal index plot; in all situations, Kano was showed a different trend. In addition, the UECM of these three Nigerian States were developed for implementation at the state level. Further work at the city, district and local planning levels are needed. In practice, the findings through the URM and corresponding climatic planning recommendations that has to do with wind, vegetation, water bodies, urban morphology and topography can make available to governments and local planners with a useful reference which could guide them to better climatic spatial planning at the any level depending on the study focus.

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GLOSSARY OF ABBREVIATIONS

AMAC	Abuja Municipal Area Council
AR	Aspect Ratio
BNRCC	Building Nigeria's Response to Climate Change
BSF	Building Surface Fraction
CAM	Climate Analysis Map
DN	Digital Number
ETM	Enhanced Thematic Mapper
FCT	Federal Capital Territory
GE	Google Earth
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
ISF	Impervious Surface Fraction
KML	Keyhole Markup Language
KMZ	Keyhole Markup Language Zipped
LCZ	Local Climate Zone
LCZC	Local Climate Zone Classification
LST	Land Surface Temperature

LULC	Land Use Land Cover
LWIR	Longwave Infrared
MIR	Middle Infrared
NDBI	Normalised Difference Built-up Index
NDVI	Normalised Difference Vegetation Index
NIR	Near Infrared
NUDAPT	National Urban Database and Portal Tool
OLI	Operational Land Imager
PSF	Pervious Surface Fraction
ROI	Region of Interest
SAGA GIS	System for Automated Geoscientific Analysis
SAT	Surface Air Temperature
SVF	Sky View Factor
SWIR	Short-wave Infrared
TIR	Thermal Infrared
TM	Thematic Mapper
TMG	Tokyo Metropolitan Government
TR	terrain Roughness
UCAM	Urban Climate Analysis Map

UCM	Urban Climate Map
UCSS	Urban Climate Simulation System
UECM	Urban Environmental Climate Map
UHI	Urban Heat Island
URM	Urban Recommendation Map
UTM	Universal Transverse Mercator
WUDAPT	World Urban Database and Access Portal Tools

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The science of urban climatology and the actual practice of urban planning are two extremes of reality that has come to stay all over the world; but the effect of the reality more intense in developing countries especially such with issues of rapid urbanization, increased compact cities coupled with high population density. This has created a gap that requires the serious attention of academics, climatologists, policy makers, and urban planners in order to work towards a shared goal of creating a sustainable city through investigating urban climatic data to be analyzed, translated, and also implemented in urban planning in an effort to create future metropolises that will be sustainable with qualitative urban spaces.

There has been gradual changes to the physical urban environment, the transformation of landscape along with associated activities in the urban areas which have resulted in the modifications of the meteorology of the cities and urban climate. To this effect, United Nations (2008) brought up a worldwide vision of designing cities that are sustainable, comfortable, healthy and enjoyable. This brought about the necessity to understand and apply urban climatic information into the process of planning and designing urban cities (Mills *et al*., 2010). However, the need to transfer climatic knowledge into planning language came up with such an important link of creating an information platform that will have a nature of interdisciplinary communication and collaboration.

> *"An Urban Climatic Map (UCMap) is an information and evaluation tool for integrating urban climatic factors and town planning considerations by presenting climatic phenomena and problems in two-dimensional spatial maps. It has two major components: the urban climatic analysis map [or synthetic climate function map] (UC-AnMap) and the urban climatic planning recommendation map [UC-ReMap]" (Ng & Ren, 2015).*

Natural and anthropogenic factors have been interacting with each other since the beginning of the world and the trend will continue. The impact of this interaction will be felt both by living and non-living things all over the world. The problem of climate change is a serious and urgent one that demands a mobilization of effort across many different disciplines. Easterbrook, (2010) noted that climate change is likely to be the defining issue of the 21st century and the concentrations of greenhouse gases are rising faster than any previous period in the history of the earth, the impact of which are evident already. Easterbrook (2010) identified a triple challenge of climate change as mitigation, adaptation and education.

a. Mitigation: to avoid the worst climate change effects by rapidly transitioning the world to a low carbon economy,
b. Adaptation: to re-engineer the infrastructure of modern society so that man can survive and flourish on hotter planet and
c. Education: to improve public understanding of the inter-relationships between the planetary climate system and human activity systems and understanding of the scale and urgency of the problem

One of the elements of the physical environment is urban climate, but this element is often ignored in urban planning. Ren *et al.* (2009) noted that it is necessary to factor the climatic information holistically and strategically into the process of planning in an attempt to design a sustainable city. Nigeria as a developing nation is sensitive to the effects of climate change. Both people and the economy of the nation are particularly vulnerable to the effects of climate change. In the events when resources are affected, whole communities are in turn implicated. Building Nigeria's Response to Climate Change (2008) fact sheets identified the visible effects of Climate Change and its challenges in Nigeria both at the present and in the nearest future and suggests ways of managing and adapting to the process. Five different fact sheets were compiled as follows:

a. Repercussions for health and human settlements
b. Water resources, wetlands, and freshwater ecology
c. Energy, industry, commerce, and financial services
d. Agriculture, food security, land degradation, forestry, and biodiversity, and
e. Coastal and marine ecosystem

Liu *et al.* (2017) aimed at mitigating urban climate issues in their studies of city of Xiamen in China, their perspective was to correlate the morphology of the underlying surface and urban climate based on natural, economic and social conditions and urban development strategies in which they explored new strategies for compiling urban climate map for the coastal city. The anchor of the approach was in assessment of the differences between theoretical value of issue of urban climate calculated with morphological zoning and corresponding observed results to redefine the main objective of climate analysis. The attempt was to locate areas where inappropriate constructions occur and map the city with reference to carrying capacity of urban climate environment. The study laid foundation for generating customized strategies for urban design and also provided quantitative analysis from urban climate research.

Ren *et al.* (2012) developed Urban Climate Map System in Arnhem city of Netherlands in a GIS platform and included planning data and natural climate resources as the basic input described in the methodology of compact cities because of the urgent need for the policy makers and local planners to protect local climate and open landscape resources to create room for climate change adaptation in urban construction. The effort was geared towards synergizing the established understanding for a case at hand and also to demonstrate how useful guidance can still be made for planners and policy makers.

Ojeh *et al.* (2016) also used hourly air temperature differences between city hall taken as urban an Okoafo (rural) in Lagos, Nigeria to study rural-urban temperature differences; the study investigated urban temperature conditions in the largest city of Africa. The findings showed that maximum nocturnal UHI magnitudes can be more than 7^{o}C during dry season whereas in the rainy season wet soil in the rural environment exceeds regional wind speed as the dominant control over the magnitude of UHI. This is because the intensity of UHI can be quantified by the difference in temperature between urban and rural site but the magnitude depends on meteorological factors, pattern of land use, population density and the city's anthropogenic activities (Rinner *et al.,* 2010).

The science of climatic environment is complicated; and the application of climatic environment in planning is a great concern to researchers all over the world. Germany and Japan have taken the lead in developing various guidelines for developing urban climate maps which have been adapted by other countries of the world and refined by some to suit their different environmental conditions. The following are some of the benefits of urban climate maps:

a. Urban climate map is capable of helping both compact and non-compact cities to incorporate the effects of climate in the process of planning in a systematic way.

b. The advantage of using GIS platform to develop an UCM makes it possible for inclusion of interdisciplinary studies.

c. It also serves as a platform for useful climatic information to be made available to planners and policy makers so as to protect the local climate and open landscape resources for adaptation of climate change in urban construction.

d. It represents a visual document where climatic and planning data are used to create an information platform made available for planning uses.

e. It is also capable to provide urban climatic information platform at the municipal level.

f. It gives room for the provision of boundary condition and background understanding for additional studies detailed at micro-climatic scales for better decision in planning and future development.

1.2 Statement of the Research Problem

Physical development and constructions in urban cities really inevitable but are supposed to be guided by policies and planning whereby government and planners need to bear in mind the climatic environment so as to build a sustainable city suitable to protect climate conditions and resources in open landscape as a means for climate change adaptation to be effective in such cities. Urban design projects and buildings needs to recognize the serious impact of the small scale climate variations both at urban and regional scale, this in turn gives room for the need for architects, urban planners, climatologists and the government to work together in city development.

Bloch *et al.* (2015) acknowledged that Nigeria's urban population has expanded rapidly over the past 50 years and will continue to grow relatively fast in the coming decades. There was a 10 fold increase in the size of Nigeria's urban population between 1950 and 1990 considering data sources from the available censuses of 1952, 1963 and 1991 from about 3 million to roughly 30 million. The more urban areas develop, open land and vegetation of such areas are at the receiving end, as there will be conversion of uses and such conversion may not be environmental friendly. The expansion of urban areas has brought with it many environmental problems which include air pollution and urban heat island (UHI) among others.

The work of Onaiyi (2015) on the use of geo-spatial techniques in the production of Abuja and Minna Climate Maps in Nigeria demonstrate the significance of such visual tools for urban planning and implementation strategies for adapting and mitigating climate change in the country level. However, the inclusion of wind data and road traffic data stand as a gap that this research seek to address. Ojeh *et al.* (2016) identified road traffic to be one of the most relevant urban induced source of air pollution which urban dwellers are exposed to. The effort is put together to develop Urban Environmental Climate Map comprising two major types of maps such as Urban Climate Analysis Map and Urban Recommendation Map of the study areas. Degradation of environmental quality has been an associated problem faced by the developing countries with dramatic growth of their urban population coupled with maximum destruction of natural resources (Balogun *et al*., 2010).

Climate conditions are examples of important natural phenomena that have gone beyond an ordinary limit into a severe subject of study by various experts to mitigate, adapt or reduce its effect for a better environment and condition of living. Ren *et al.*

(2009) and Ren *et al.* (2012) acknowledged that Climatic condition from a scientific perspective, must be analyzed systematically and strategically introduced into the planning process. Globally the situation of climate change promotes interest on incremental basis between climate change effects and spatial planning in terms of climate change adaptation.

Despite the vast advantages of UCM, it is not without other numerous issues which can be taken as disadvantage on the other hand. Ren *et al.* (2012) acknowledged that the tool remain a fragile bridge responsible to cover a huge gap existing between the practical world of spatial planning and the scientific world of climate studies that will never be totally closed. Therefore, the observed gap here is linking spatial planning with the scientific climate studies which has been identified earlier to be complicated issue in development of urban cities especially taking policies and planning in developing countries like Nigeria in general and specifically, the cities of Kaduna, Abuja and Kano.

The specific research questions are as follows:

i. What are the different categories of land use and land cover types/local climate zones that are found within the study area?
ii. What are the relationship that exist between urban spatial characteristics and land surface temperature?
iii. What are the modalities of extracting recommendation tool from the developed Urban Climate Analysis Map of the study area?

1.3 Aim and Objectives of the Study

The aim of this study is to develop an urban environmental climate map as a tool for reducing the impact of climate change for selected cities in Northern Nigeria. The specific objectives towards achieving the aim are to:

i. Identify and map the various Local Climate Zones (LCZ) in the study areas
ii. Determine the effects of the urban spatial features on the Land Surface Temperature of the study areas
iii. Develop Urban Climate Analysis Map (UCAM) and Urban Recommendation Map (URM) of the study areas.

1.4 Research Hypothesis (Null Hypothesis)

1. There is no significant relationship between built-up and Land Surface Temperature
2. There is no significant relationship between vegetation and Land Surface Temperature

1.5 Justification for the Study

1.5.1 Performance improvement

Urban climate map as a worldwide research interest with over 50 cities in Europe, South America and Asia who have formulated their UCmap; the studies is important for better understanding on the UCmap trend and methodology so as to adopt its useful information and experience to design livable and better environment in the developing world (Ren *et al.*, 2009). Climate application studies undertaken from scientific discipline such as meteorology and climatology without using urban planning as a perspective create a huge gap between urban planning and climate research which must be addressed. Climate change situations are global challenges and so the interest between climate change effects and spatial planning are supposed to follow similar trend, the efforts put in place by the developed countries in addressing the challenge must be corroborated by the developing countries likewise so as to speak common language for an outstanding result globally.

1.5.2 Policy improvement

Understanding climatic data and scientific research results are big tasks to policy makers, developers and planners; therefore it became a difficult thing to integrate such into their planning processes or policy documents. On the other hand Eliasson, (2000) acknowledged that climatologists are also not familiar with the procedures involved in spatial planning and the mechanisms and therefore provision of appropriate climatic evaluation and information to meet the real needs of planners becomes difficult. This was the reason why the parties involved need to come together to bridge the communication gap so as to create a unified document valuable to all the parties. Such document is the urban environmental climate map that represents an information and evaluation tool relevant for further communication between climatologist, meteorologist, architects, planners and policy makers.

Conclusion from the study by Ren *et al.* (2012) on the Dutch city of Arnhem in Netherlands was that the gap that is existing between scientific world of climate studies and the practical spatial planning world will never be closed. This tools remain a fragile one targeted at bridging a huge gap. Ren *et al.* (2012) also described a way of bridging the gap that the challenges must be met by applying the first requisite of a common language and agreement between the relevant actors in order to analyse and address common problems without which a common solution cannot be achieved. With these in place, information from UC maps will provide knowledge in common language about climate change effects but not just an ordinary knowledge. This will now take us to the key question on “How can these solution be organized?”

1.5.3 Contribution to body of knowledge

Academics of various fields have been carrying out research on different findings in their different fields such as climatology and urban planning among others, but urban environmental climate map calls for a need for these academics/researchers to collaborate so that generating a workable tool can be possible whereby policy makers too are not left out. Hence, the need for generating urban environmental climate map along with urban recommendation map that will serve as a tool that will be used to tackle the problem of designing a sustainable city. Therefore, this research intended to bridge this gap which aim to develop an urban environmental climate map as a tool for reducing the impact of climate change for the selected cities in Northern Nigeria.

1.5.4 Areas of further research

The methodology explored in this particular Urban Environmental Climate Map is an initial work of urban climatic mapping in Nigeria and it is state based, which gives room for planners and policymakers to get useful information for their daily ongoing works. The LCZ scheme utilized the random forest classification and comparison was made with the LULC scheme that utilized the nearest neighbor classification and also accumulate climatic information to create a platform for planning use. It mostly relied on literature and theoretical understanding well practiced elsewhere. The main effort was to synergise the understanding that have been established for a case at hand and demonstrate how useful guidance can still be made for policymakers and planners.

There is a need to further refine and update the Urban Environmental Climate Map in Nigeria cities, district and at local level using the present methodology and also generalise it across the nation.

1.6 Description of Study Areas

1.6.1 Location, position and size

The locations of the study states are as follows: Kaduna State is located between latitudes 8°07'N – 11°30'N of the Equator, and Longitude 6°06'E-8°45'E of Greenwich, Kano State is also located on Latitudes 10°30'N to 12°45'N of the Equator and Longitudes 7°45'E to 9°25'E of Greenwich while Abuja is on latitudes 8°25'N – 9°20'N of the Equator; Longitude 6°45'E-7°45'E of Greenwich.

The study cities in each state include: Abuja Municipal Area Council (AMAC) in Abuja on Latitudes 8°30'N to 9° 15'N and Longitudes 7°00'E to 7°45'E; Kaduna North and Kaduna South local government areas on Latitudes 10°20'N to 10° 35'N and Longitudes 7°25'E to 7°32'E; and the six Local Government Areas within Kano metropolis which includes Fagge, Dala, Gwale, Kano Municipal, Tarauni and Nassarawa Local Government Areas on Latitudes 11°50'N to 12°05'N and Longitudes 8°25'E to 8°37'E. The total area coverage of the study area is 1,902.52KM^2, the breakdown in each state is as follows: Abuja (1,642.41km^2); Kaduna (119.51km^2) and Kano (140.6km^2) -

Kano and Kaduna are the two most populous northern states according to the 2006 population census figure and are both located at the North Central region of Nigeria. Kaduna is located at the southern part of Kano while Abuja is located at the southern part of Kaduna, apart from its unique location at the heart of the country, Nigeria.

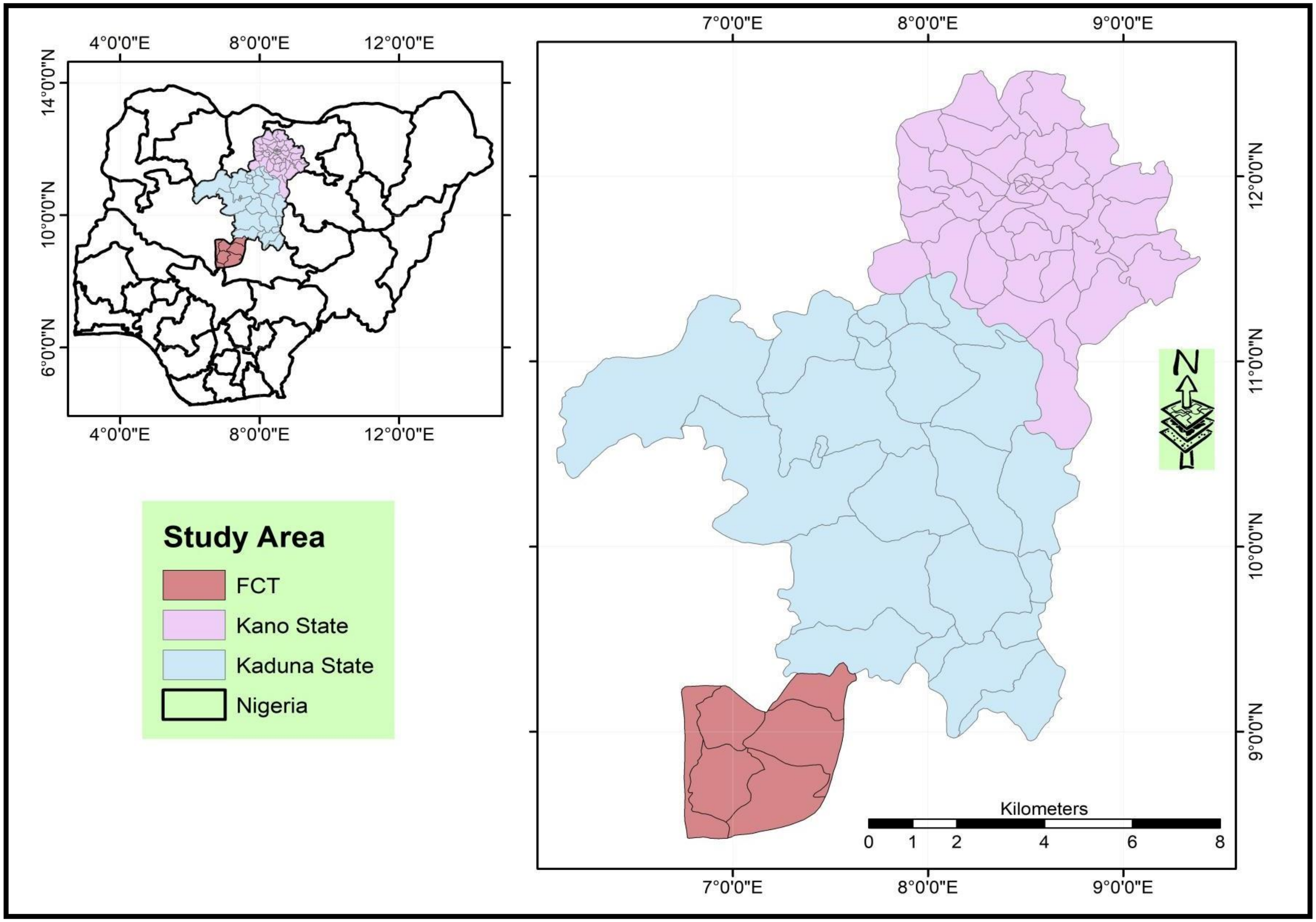

Figure 1.1 The Study Area
Source: Author, 2018

1.6.2 Climate of the study area

The Zone experience similar climatic conditions but with local variations due to relief and topographic effects which modify the thermometer and rain gauge readings within the study area. Generally, the belt is categorized under Köppen's Aw **(**Tropical wet and dry or savanna) climate. On a general note, the study area experiences two main seasons on a yearly basis; namely the wet season and the dry season. The rainy season lasts from about April to October. The area experiences a period of Harmattan between the months of December to February. The Harmattan is occasioned by Tropical Continental air mass (the North East Trade Wind) from the Sahara Desert, characterized by dry air, dust haze, intensified coldness during the morning and night hours. The mean annual rainfall is about 1,350mm in Abuja and 1223.7mm in Kaduna. The raining period lasts for about 150-190 days in the northern Guinea savanna and from 181-240 days in the southern Guinea savannah. The maximum temperature hovers between 20°C in December/January and 34°C in March/April. The mean annual rainfall recorded in FCT reflects a situation that results from the FCT's location on the windward side of the Plateau which gives rise to frequent rainfalls and a noticeable increase in the mean annual total from the south to the north (Hassan, 2008).

1.6.3 Vegetation of the study area

The study areas are located in the Guinea Savanna belt of Nigeria, the study area also lies largely on the Guinea/Sudan Savanna vegetation belt of Nigeria, characterized by woodlands and tall grasses interspersed with tall dense species. The zone is characterized by grasses such as *Pennisetum, Andropogon, Panicum, Chloris, Hyparrhenia, Paspalum* and *Melinis*. Some common trees in the belt include the false balsam Copaiba (*Daniellia oliveri*), *Isoberlinia doka, I. tomentosa*form, locust bean tree (*Parkia filicoidea*), shea butter tree (*Butyrospermum parkii*) and mangoes (*Mangifera indica*). Some parts of this area fall within the Northern Guinea Savanna which has comparatively fewer and shorter trees than in the Southern Guinea Savanna. The Northern Guinea Savanna also composed of Savanna wood lands (trees), shrubs patch land or extensive grass land. The trees lay long taproots, develop thick barks, and shed their leaves to survive long dry season or drought. Grasses developed durable roots, which remain under the ground after the tops have been burnt by fire during the dry season. After the dry season the grasses sprawl again with the onset of rain.

During the growing season, the area is characterized by a lush vegetation of tall grasses that grow and reach maturity rapidly and thus become fibrous and tough. However, the lush vegetation quickly disappears during the dry period and are often consumed by periodic Author-fires set either during farm clearance in anticipation of rainfall onset or during hunting exercises. A common adaptation of trees in this belt to the yearly Author fires is development tick barks which are resistant to fires. In addition, most of the trees and shrubs in the belt are deciduous in nature largely in bids to conserve water during the dry period.

The riparian vegetation (along stream valleys) is usually dense and made up of savannah woodlands. Ornamental vegetation is common around residential and administrative corridors. Botanical gardens have increased the greening of the metropolis. Despite these, there appears to be a general trend of decline in the natural vegetation in Kaduna and Kano on a general note.

1.6.4 Geology and topography of the study area

Six landform types can be identified in Kano as follows: dissected hilly highlands, high plains with grouped hills, pediplains, sandy plains, dune fields and alluvial channel complexes. The Kano Plains are made up of many distinct sections, prominent among which are: the Gari, the Jakara, the Chalawa, the Kamanda and the Basara Plains. Most of these pediplains has been covered by a layer of wind drift material which could be up to 2.5m thick, except in sections where the mean elevation is above 520m and the slope is greater than 2 degrees. Where the wind drift is present the pediplains slope at characteristic depositional angles ranging from zero to two degrees (e.g. Gari:0.5^0 Gaya:0.5^0 Jakara:$1.0^0$and Iggi: 1.5^0). Such plains are called drift plains here (but called “loess” or pedisediment” by some writers). A typical drift plain, such as the Kano Plain, consists of the following morphological units: an upland plain, two river terraces and wide channel beds, all sloping at angles less than 2 degrees. Others are inter-unit scarps sloping at angles steeper than 60 degrees and isolated residual hills ranging in height from 10m to 50m above the plains.

Kaduna metropolis is situated on the high plains of Hausaland which consist mainly of the Precambrian rocks of the basement complex (Geological Survey of Nigeria, 1971), mainly of older granites, schist and quartzite in different composition. The weathered profile is rich in red clay which is mined for construction purposes, while granite is also commonly quarried. Though, no large scale mining of solid minerals is known to be existing in

Kaduna urban environment. The rock is known to be stable and withstand all kinds of civil engineering construction such as dams, roads, buildings, and so on.

Hills in the FCT occur either as clusters or they form long ranges. The most prominent of these ranges are the Gawu, Gurfata, Bwari-Aso, Idon Kasssa, Wuna and the Was-Sukuku ranges. The last one is fact a complex of ridges that run across the centre of the FCT from Kwali in the west, to Wasa in the east. These ridges are composed of the Pre-Cambrain Basement Complex rock. According to Balogun (2001), two broad relief regions can be recognized in the FCT. These are the hiily and dissected terrains include BwariAso Hills, AgwaiKaru Hills, Gawu.

Most parts of the study area are underlain by Basement Complex of Precambrian age comprising of discontinuous mantle of weathered of Migmatite-Gneiss Complex, the Schist Belts and the Older Granites. The Younger Granites which are structurally and petrologically distinct from the Older Granites comprise several Jurassic magmatic ring complexes (Aizebeokhai, 2012).

1.6.5 Soils in the study area

The study area (especially Kano and Kaduna) comprises different types of soils; the interplay of geological, geomorphological and Bio-climatic factors result in the area underlain with ferruginous tropical soils containing about 30-40% clay at reasonable depth due to intensive leaching. The soil profile is less than 3m, with hard-pan which may be encountered within the profile. These soils are characteristically waterlogged when it rains and dries out with cracks during the dry season (Kofa, 1983). Some areas have permanently water logged soils called ‘Fadama’. Experts note that these ferruginous tropical soils are fragile with nutrient holding capacity not good to support intensive agriculture for long periods without application of fertilizers or manure. In recent times, soil degradation has taken the forms of erosion due to loss of vegetal cover, compaction from trampling by grazed animals, acidification/alkalinisation from synthetic fertilizers.

Two broad geological regions with each one having similar structural and lithological characteristics are recognized within the FCT. These regions comprise the Pre-Cambrian Basement Complex and sedimentary rocks, and they both have very strong influence on the morphological characteristics of the local soils.

The first region, the Basement Complex, consist of wide variety of rock type that may be classified into three. The first is commonly made up of granites gneisses. The second one consists of quartz and feldspathic quartz schists. The numerous wooded ridges are examples of areas that are composed of this category of rocks. The last group comprises of the areas that are composed of this category of rocks. The last group comprises of the more basic igneous and metamorphic rocks such as diorite, hornblende schist, biotite schists and gneisses. These underlie some of the low relief regions such as some parts of Gwagwa Plains. The deepest and least stony soils of the first geological region, area found to develop on this last group of rock types. (Balogun, 2001)

The sedimentary formations also known as the Nupe sand stones consist mostly of fine-grained sandstones, but they also have intrusions of grits and siltstone. In the past, most of the sandstone ridges of the south-west had laterite caps, but some of these have since been degraded. In addition to these two rock groups, alluvial deposits also occur. This is especially true of the Gurara flood-plain where the river flows through the Nupe-sandstone. These deposits do not, however, constitute a major soil parent material. This is because the rivers and streams are generally entrenched in their valleys, with the result that their alluvial belts are usually restricted.

1.6.6 Economic activities in the study area

The weather and climate of Kano play a great role on the agricultural practices and are favourable to large scale cultivation of cereals, groundnuts, beans and vegetables. The socioeconomic activities of people are closely linked with the seasons, with crop production dominant during the wet season and off-farm activities dominant during the dry season.

The physical location of Kaduna town as earlier seen in the physical setting implies that the state has a lot of agricultural potentials. Its location on a monotonous lowland makes mechanized farming around Kaduna metropolis increase such as. Wushishi farms, Niyya farms, Quarro, Albarka, Cloudy River, Sambawa farms among others, even though the ferruginous soils are not particularly rich, they are fragile thereby requiring the application of chemical fertilizers and organic fertilizer to increase their fertility. Livestock grazing is common in and around Kaduna metropolis. Also, there is the rearing of environmental unfriendly animals like pigs in most of the slums settlement. There is substantial flood plain agriculture along the river Kaduna. The vast land surrounding the metropolis is under intensive cultivation.

About eighty-five percent (85%) of people in the FCT are peasant farmers, but their prevailing agricultural practices are generally unsustainable (Balogun, 2001). They engaged in shifting cultivation and when the land becomes degraded they abandon the plots for further cultivations. Crops grow here include yam, rice, sorghum, guinea corn, maize, sugar cane amongst others. Livestock production is relatively common in the study area. Furthermore, because the study area is the capital city of Nigeria, a lot of construction works is noticeable in the Federal Capital Territory.

1.7 Scope and Limitation of the Study

1.7.1 Scope of the study

The focus of this study is on the development of urban environmental climate map for some Northern states of Nigeria. The states are Kaduna, Kano and Abuja (FCT); the selections of the case studies are location specific with the following indicators considered and ranked based on Local Government Areas and Area Councils: population size, total area coverage in square kilometers, population density and socio-economic activities. The study area in each state is as follows:

a. Kaduna State: in terms of population size, Igabi local government area ranked highest followed by Zaria and Kaduna South before Kaduna north with population figure of 430, 753; 406, 990; 402,731; and 364,575 respectively. But in terms of landmass, Chikun is the leading local government followed by Igabi, it is noteworthy that Zaria, Kaduna south and Kaduna north are far away with landmasses of 302km^2, 61.49km^2 and 58.02km^2 respectively. The population density eventually kicked out Igabi local government with the issue of population density due to the fact that Kaduna south and Kaduna north emerged with the highest population density of 6,549.54 persons/km^2 and 6,283.61 persons/km^2 with Zaria and Igabi having density of 1,344 persons/km^2 and 118.91 persons/km^2 respectively. Also considering the socio-economic activities of the leading local government established above, Kaduna north and Kaduna South are the local governments within Kaduna city and certify the leading core center of economic activity. Kaduna city is not limited to these two Local Government Areas On one hand, and on the other hand the provision of the local climate zone classification methodology stated on the procedure guideline that the Region of Interest (ROI) should contain the entire urbanized area with a buffer of about 20km around the area and the entire area with the buffer should not be smaller than 50km in each direction. To this effect, the study area apart from the core Local Governments mentioned earlier includes: Chikun, Kajuru, Igabi and a little extreme of Birnin Gwari Local Government Areas.

b. Kano State: Considering the major indicators above for the local government in Kano State, it was discovered that the six local governments found within Kano metropolitan areas also certify the criteria to be established as the study area in Kano state. They are Fagge, Dala, Gwale, Kano municipal, Tarauni and Nassarawa local government areas. They form a cluster city with the following population density which is a strong indication of significant attention: Fagge (11166.02persons/km^2); Dala (22,156.56persons/km^2); Gwale (21,223.43persons/km^2); Kano Muunicipal (19,087.04persons/km^2); Tarauni (6,849.15persons/km^2) and Nassarawa (19,664.06persons/km^2); all the six local governments that constitute the study area are covering a total land area of 140.6km^2.

c. Federal Capital Territory: The indicators in FCT were based on the six area councils; Abuja Municipal council (AMAC) ranked highest in terms of population size followed by Bwari and Gwagwalada respectively, but due to the size of the land masses of each area council, Abaji ranked highest with density of 644.35 persons/km^2 followed by AMAC (219.40persons/km^2) and then Bwari (147.98persons/km^2). But due to the fact that Abaji ranked low in terms of socio-economic activity and also it is located at the outskirt of the FCT, AMAC in turn certify the criteria for the core study area better than Abaji and Bwari; AMAC covers a total land area of 1,642.41km^2, but with further buffer that extend beyond AMAC into Bwari, Gwagwalada, Kwali and Kuje Area Councils. Details on the study cities can be seen on Figure 1.1.

It is certain that most of the climate influenced activities that pave way for this study are domicile in areas clustered both by people and other urban developmental activities that needed to be monitored so as to establish proper mitigation or/and adaptation strategies needed towards a sustainable city. The period of temporal range of this study is thirty years from 1988 to 2018 which was selected because it is a climatic study which cannot be studied within a short period.

1.7.1.1 *Content boundary*

This study on UECM focus on the three study areas are based on state level not city, district or local levels because emphasis was made broadly on comparing three states and recommendations were made towards breaking down the study into city, district and local levels in further studies.

1.7.2 Limitation of the study

Some of the limitations experienced during this research included the case of insecurity in the study areas which made the field work to be systematically carried out carefully to avoid hotspot zones. At the tail end of it COVID 19 also interrupted close interactions with respondents because the status of individual's health were unknown, so both the researcher, the guides and respondents were careful of the ugly fact.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Conceptual Framework

2.1.1 The concept of urban environmental climate map

The concept of urban climate map is not a new one, it has been generated by German researchers since the 1970s (Ren *et al.*, 2009). It is an information and evaluation tool suitable for integrating factors of urban climate and consideration for town planning by presenting climatic phenomena and problems in 2-D spatial map (Ren *et al.*, 2009). Ren *et al.* (2009) admitted that the climatic understanding and evaluation from urban climate map can help in grouping homogenous into bioclimatic zones with which urban recommendation map can be developed to give urban planning recommendation a strategic method to improve the urban environment from the climatic view point and also air and noise pollution could be added when necessary so that the corresponding control measures can be detected and planned for.

Takahiro *et al.* (2009) in the study of the cities of Yokohama and Sakai in Japan defined Urban Environmental Climate Map (UECM) as map consisting of Climate Analysis Map (CAM) and Recommendation Map (RM) and went further to explain the fact that CAM has the role of mapping actual climate conditions while RM involves planning recommendations that needs to fit into the actual system of planning. Ren *et al.* (2012) also define urban climate map as a climatic information and evaluation tool that helps planners to understand climatic environmental conditions and variations and create better design. It resolves scientific climatic knowledge into guidelines and planning recommendations and could be used to guide decision making and planning actions.

Takahiro and Masakazu (2002) also indicated that Urban Environmental Climate Map consists of two types of maps such as Climate Analysis Map and Recommendation Map. The Climate Analysis Map represents the existing climate map of an area on which terrain, climatope, wind and temperature are overlaid. On the other hand, Recommendation map is made to show option of counter measures of urban heat island extracted through discussion by climatologists as climate experts and the planners. For instance, they represents road plan along the wind flow, green area/tree planting along wind flow, roof planting and tree planting recommendation zone maps among others.

Takahiro *et al.* (2009) elucidated the requirements for UECM from the officials of local government involved in urban planning related occupations with their respective target departments as follows:

- Department of rivers and channels
- Department of green space
- Department of urban planning and the
- Department of environmental activity

Study from these group of author utilized a qualitative approach of data gathering using the following major questions along with other questions in each local government department covered:

- *"*What is the urban climate related work performed in your department?*"*

- “In what situations will UECM be effective? Information of what kinds should be represented on the maps?”

To each of the questions, results were gathered and summarized from which the authors extracted three requirements for UECMs as follows and quoted directly from the authors:

2.1.1.1 Requirement A

> “A UECM should represent recommendation areas for each countermeasure against urban heat island effects such as recommended areas for restoring water channels, greening recommendation area, recommended areas for using sea breezes, and recommended areas for reducing anthropogenic heat release” (Takahiro *et al*., 2009)

2.1.1.2 Requirement B

> “Another UECM, with detailed scale (about 1:2500), will also be needed for urban redevelopment”.

2.1.1.3 Requirement C

> “A human comfort element is also needed for representation on the UECM such as a psychological feeling of “Coolness” that water areas have”.

Developed nations are vast in both planning and development, but sustainable development is paramount all over the world especially in developing countries such as Nigeria, and so just as recommended by Ren *et al.* (2009), there is a need to carry out Urban Climate Map studies in the developing nations too.

2.1.2 The concept of climatope

Climatope is a German word meaning *landscape unit* from the view of climate which is based on land cover. Climatopes are areas with similar microclimatic characteristics. They differ especially in the daily temperature curve, the vertical roughness (wind field disturbances), the topographic position and exposure and above all in the type of actual land use. Another criterion for particular climatopes is the quantity of emission.

As microclimatic characteristics in built-up areas are primarily determined by the type of actual landuse and especially by the type of development, climatopes are named after the dominant type of landuse. A climatope is the basic Spatial unit of an urban climate map used for presenting areas with similar urban climatic conditions and features (Ren *et al*., 2009). Also, the concept of climatopes was analyzed and explained at the city of Stuttgart, office for environmental Protection, at the section of Urban Climatology in the following manner together with some associated climatope types in the following way:

Climatopes according to the office of Stuttgart Environmental Protection can be termed as areas with similar microclimatic characteristics. Their differences can be shown especially with respect to daily temperature curve, the vertical roughness (wind field disturbances), the topographic position and exposure and above all in the type of actual land use. Not that alone, another criterion for particular climatopes is the quantity of emissions that can be found Just as the microclimatic characteristics in built-up areas are primarily determined by the type of actual land use and most especially by the type of development, climatopes also are named after the dominant type of land uses as follows:

1. **Water body climatope**: These climatopes have a balancing thermal effect on their surroundings as a result of weakly marked daily and annual temperature curves. The air temperatures in summer in these climatopes are lower than in their surroundings at daytime and higher during the nighttime. Water body climatopes are always characterized by a high humidity and wind exposure. It is naturally related to large water bodies, while smaller water surfaces are mainly included for reasons of orientation. This indication however is not to reduce their local climatic relevance in any way.

2. **Open land climatope**: Open land climatope is characterized by extreme daily and annual temperature and humidity curves; as well as only small changes in the wind flow. This also results into an intensive production of fresh and cold air during the night hours. Especially, this is true for large meadows and also for agricultural areas and open land which is only sparsely forested.

3. **Forest climatope**: Another one is the forest climatope which is characterized by much attenuated daily and annual temperature and humidity curves. This is associated with relatively low temperatures and high humidity which are predominant around the trunks due to shadowing and evaporation during the daytime, relatively mild temperatures occur during night hours. More importantly also, the canopy of the trees act as a pollutant filter and this qualifies forest climatopes as regeneration zones for the air and people in such environment.

4. **Green space climatope**: In the right sense green spaces within towns or urban cities, such as parks, have balancing effects on their developed and often overheated surroundings because of the relative extreme daily temperature and humidity curves and this result into production of cold and fresh air in such environment. Larger green spaces act as ventilation opening; while densely forested green spaces especially within towns or cities provide shadowing effect during the day and therefore represent cool compensation areas with a high humidity in contrast to the heated surroundings always around the cities or towns.

5. **Garden town climatope**: The garden town climatope is made up of built-up areas with open development, one to three storeys, and/or numerous green spaces. All climatic elements are slightly modified compared to the open land climatope with a considerable night cooling and an only mild slowing down of regional winds in the surrounding areas.

6. **Suburban climatope**: This is determined by denser single buildings, terraced houses or perimeter development with green spaces and a maximum of three storeys or by detached buildings with green spaces and a maximum of five storeys. Cooling during the night is strongly limited and depends basically on the surroundings. Also, local winds and cold-air flows are constrained and regional winds massively slowed down in such area.

7. **Town climatope**: Another one is town climatope where multistorey closed development with just few green spaces and detached tower blocks represents it major characteristics. The heating during the day is very strong and the cooling at

night also very weak. This result into a heat island effect with a relatively low humidity compared with the surroundings areas. The air exchange is limited and the ambient air concentration of pollutants is generally high because dense and high development significantly influences the regional wind systems. Urban canyons have high pollutant concentrations and noise exposure as well as gusty wind turbulences.

8. **Town center climatope:** Inner cities are always characterized by dense and high built-up areas with only few green spaces which always lead to a strong heating during the day to the clear formation of a heat island during the night with a low average humidity in such areas. Massive development combined with a marked heat island considerably influence regional and superregional winds. The ambient air concentration of pollutants is generally high. Urban canyons have gusty wind turbulences as well as high pollutant concentrations as well as noise exposure.

9. **Business climatope**: This corresponds basically to the climatope of dense development such as heat island effect, low humidity and significant wind field disturbances. Other characteristics are extensive access roads as well as parking spaces and increased emissions. The thermal night pictures indicate an intense cooling in parts of the hall roofs especially zinc roofs, while urban canyons and parking spaces lined by buildings remain strongly heated.

10. **Industry climatope**: This climatope is similar to the town center and town climatope, but this particular climatope has large circulation areas and much higher emissions (with plants requiring permission). As the heating during the day is strong,

a clear heat island is formed at night due to the high percentage of sealed areas, even if many hall roofs cool down significantly. The air masses near the ground are also heated, dry and have a high concentration of pollutants. Massive buildings and the warming near the ground in such way considerably modify the wind field.

2.2 Theoretical Framework

2.2.1 Urbanization and climate models

Liu *et al*. (2017) acknowledged that land-use and land-cover changes have environmental significance out of which urbanization becomes an extreme case. The situation is said to be well recognized but understood in a very limited way. Urbanization form an important effect in regional and global climate and urban cities respond to climate change at time scales from seasonal to decadal, this also form good research areas. The studies further established the fact that most global climate models that are used to investigate impacts of land-use and land-cover changes on the climate do not include urban representation. Also, urban expansion effect on climate of near-by areas has not been characterized in any existing urban representations. It was in such attempt that Liu *et al.* (2017) through Geophysical Fluid Dynamics Laboratory (GFDL) is developing a high-resolution global climate model with an urban representation capable of simulating interactively both changes in urban environments and feedbacks of urban changes. Efforts were made towards urbanizing the GFDL land model LM3 and historical simulations with the urbanized GFDL LM3 are presented in order to demonstrate how growth of urban areas has affected the near-surface climate in recent decades over the continent of United States.

Argueso *et al.* (2015) investigated the combined effects of urban expansion and changes in greenhouse gas emissions on the future climate of the cities of Sydney and Australia. Regional climate model at very high resolution (2 km) was used to dynamically downscale a Global Climate Model and simulate the climate of the region for present and future climate conditions. The model was coupled with an urban canopy model in order to incorporate the interactions between urban structures and the atmosphere while preserving the physical consistency of the model. Changes in temperature and vapor pressure were examined as a means of determining changes in the population exposure to heat stress due to the combination of urban expansion and greenhouse gas. Daily maximum and minimum human heat stress were also estimated using hourly values of temperature and vapor pressure. Results indicated that new urban areas are likely to experience higher heat stress conditions at night in the future, with changes that are substantially larger than in the rural counterparts; urban structures seem to compensate the climate change effects on heat stress through vapor pressure differences in the daytime. Overall, urban areas tend to enhance the climate change signal during the cooler hours of the night by contributing to temperature increases, whereas vapor pressure deficits induced by urban surfaces dominate over temperature during the day. The major emphasis of the study include explicit representation of urban effects and to consider variables other than temperature to assess climate change impacts on urban population due to contrasting urban climate that need serious consideration.

Projections of global climate testified to the fact that both global warming and the increasing extreme weather conditions including heat waves and pluvial flooding will mount an increasing pressure on the livability of cities as evident in the work of Wouters *et* *al.* (2017). Urban Heat Island intensities are also expected to increase because of the unrestrained urban expansion, which has thrown cities into hotspots of climate change. Severe health hazards and increased energy consumption are the implications of this for many urban dwellers which also lead to damage of the infrastructures in the cities. Relative impact of urban land-use change and global climate change on the increased temperatures and extreme precipitation in cities at the second half this century were investigated. Models were simulated for recent past, a period from 2000-2010 and also for future climate projection from 2060-2070. The regional climate model accounts for urban land-use change for Belgium towards 2060 based on projections with Ruimtemodel Vlaanderen. Synergy between urban heating and global climate change was addressed further and frequency and intensity of heat waves was investigated, also atmospheric radiative transfer by greenhouse gases, changes in precipitation, the urban expansion and increased cooling demands, all were found to affect heat island intensities in Belgium. Relationship between urban heat island intensities and the frequencies of circulation weather types or the percentiles from the temporal temperature distributions were examined to account for urban climate with a broad-risk assessment approach.

Kershaw *et al.* (2010) stressed that cities are known to exert influence that are significant on their local climate and warmer generally than their surroundings. These Authors acknowledged however that climate models generally do not include a representation of urban areas, and so climate projections from models are likely to underestimate temperatures in urban areas. Calculating the urban heat island from a set of gridded temperature data was a method adopted such that UHI was calculated on monthly basis and downscaled to hourly and added to weather data generated and UHI intensity result was found to be consistent with observed data. The methodology allows the temporal downscaling of the UHI for use in building thermal simulation software.

Twenty three wards of Tokyo metropolitan area were used to generate heat balance model which were simulated by Urban Climate Simulation System (UCSS); the model composed of urban canopy model and atmospheric turbulent model taken into account for different categories of thermal environment load such as anthropogenic heat, land cover, urban morphology and building use (Ashie, 2008, 2009 cited in Ren *et al.,* 2009). In addition to these, other data were added such that the researchers in Tokyo analyzed the climatic problem from thermal aspects and Tokyo metropolitan government was able to announce a thermal environment map in 2005 (Ren *et al*., 2009).

2.3 Review of Related Studies

2.3.1 The urban data gap

The Urban data gap was well captured in the table adapted from Stewart and Oke (2009) on the problems and needs of urban data as seen by these Authors from global and regional perspectives. Details illustrated in Table 2.1

Table 2.1 Problems and Needs of Urban data

Problems and Needs	Facts
Urban Data Availability and Accessibility	Availability of few or no datasets globally on countries, most especially for rapidly growing places in economically developing regions and countries
Climate Relevant Urban Data	Existing urban databases are not consistent on temporal and spatial resolution and variables to characterize the landscape of urban areas
Data Harmonization and Standardization	Classification to represent landuse and landcover of cities and surrounding landscapes are not standard (such details as densities, heights, functions and natural coverage for distinction among others)
Modeling Needs	Global database that offers multiple properties on urban morphologies and landscapes is needed(for instance geometrics, morphologies, surface cover, thermal/physical information, just to mention few)
Application Needs	Database that should be applicable globally and transferable to each world city (for instance urban planning, transdisciplinary for scientific research, risk and disaster management, health impact analysis and response among others)

Source: (Stewart & Oke, 2009)

Majority of the world cities operate like management systems that respond by the way of mitigating the actions that cause some undesirable changes after then adapt the system to cope with some environmental hazards. Since different cities have different capacities to respond based on their differences in political cultures, economic base, socio-cultural make-up among other things, there is a need to be a common language between the cities to describe urban landscapes in global perspective. Experts of the scientific community (such as climatologists, environmental engineers, geographers, ecologists, urban planners and technologists) are looking for more standardized information/data on the urban form and function of cities so as to devise solutions to aid mitigation and adaptation to climate change (Cleugh *et al*., 2011). However, there arise the need for a consistent database on global cites at scales which are suitable for scientific inquiry and policy formulation, but such does not exist (Table 2.1).

2.3.2 Local climate zone (LCZ)

Universal approach of describing and characterizing the physical nature of cities has been a thing of great concern to urban climatologist. Initially, much of the existing terminologies were not transferable across cultural and various geographical regions of the world. In an attempt to address this problem, Stewart and Oke (2012) developed the Local Climate Zone (LCZ) classification scheme in general and particularly to help standardize observation and documentation method in urban heat island studies. Properties of surface structure (such as building, tree height and density) were used to group the scheme into seventeen zones; each zone is local in scale, this indicates that it represents horizontal distance of 100s of meters to several kilometers. The scheme represents a logical starting point for WUDAPT's aim to compile consistent information of urban climate across cities globally.

Stewart and Oke (2012) refined the Urban Climate Zones (UCZ) by Oke, (2004) into LCZ in which each LCZ class can be defined quantitatively using standard set of parameters. There are two subsets of the LCZ; ten are built types while seven are land cover types as shown on Table 2.2, the extended definition of each LCZ shown on Appendix C.

Each Local Climate Zone class is made up of different values for geometric and surface cover properties as documented by Stewart and Oke (2012). The values are unit less except height of roughness elements which is measured in meters (m). Other highlighted geometric and surface cover properties include Sky View Factor (SVF), Aspect Ratio (AR), Building Surface Fraction (BSF), Impervious Surface Fraction, Pervious Surface Fraction, and terrain Roughness, the values for each in different LZC are well stated so as to guide in the classification. The definitions of each Local Climate zones is illustrated in Appendix C as adapted from Stewart and Oke (2012) while the values of geometric and surface cover properties for Local Climate Zones is also illustrated in Appendix A.

Table 2.2 Names and Designations of the LCZ Types

LCZ Built types	LCZ Land cover types
LCZ1-Compact high-rise	LCZ A-dense trees
LCZ2-Compact mid-rise	LCZ B-Scattered trees
LCZ3-Compact low-rise	LCZ C-Author/scrub
LCZ4-Open high-rise	LCZ D-Low plants
LCZ5-Open mid-rise	LCZ E-Bare rock/paved
LCZ6-Open low-rise	LCZ F-Bare soil/ sand
LCZ7-Lightweight low-rise	LCZ G-Water
LCZ8-Large low-rise	
LCZ9-Sparse low-rise	
LCZ10-Heavy industry	

Source: (Cai *et al.*, 2016)

2.3.3 Applications of local climate zone

In an attempt to face the associated problems of urban warming, mitigation and adaptation strategies are not efficient enough to tackle excessive urban heat, especially at the local scale. Wang *et al*. (2017) employed the local climate zone (LCZ) classification scheme to examine the diversity and complexity of the climate response within the city of Wuhan in China. This study suggested that zonal practice could be an efficient way to bridge the knowledge gap between climate research and urban planning. Classifying urban surfaces by LCZ are designated as urban climate landscapes, and this extends the LCZ concept to urban planning applications. Attempt was also made to explore the climatic effect of landscape patterns in this study. Comparing the thermal effects across the urban climate landscapes and also establishing the relationship between patch metrics and land surface temperature, results indicated that climate landscape layout is a considerable factor impacting local urban climate. The contrast of temperature between surrounding landscape patches contribute to the heat release. In most cases climate landscape types patch metrics also have a significant effect on thermal response. In this situation when three metrics were included as predictive variables, 53.3 percent of the heating intensity variation can be explained for the large low-rise landscape, while 57.4 percent of the cooling intensity variations can be linked to water landscape. Therefore, claims were made that land-based layout optimization strategy at local scale, which conforms to planning manner should be taken into account in terms of heat management.

2.3.4 World urban database and access portal tools (WUDAPT)

The World Urban Database and Access Portal Tools (WUDAPT) was developed in Dublin in 2012 by a team of researchers in remote sensing, GIS, urban climate, architecture and environmental science led by Gerald Mills and Jason Ching. The template of WUDAPT is based on the National Urban Database and Portal Tool (NUDAPT) developed in 2009 (Cai *et al.*, 2016) to be a universal, simple and objective method to be used as part of a global protocol to derive information about the form and function of cities. The growing need to improve the urban system and ensure the healthy development of the urban agglomeration call for methodologies which can be of global value and also give room for further improvement from time to time.

Based on this, Cai *et al.* (2016) explored the possibility of the level 0 WUDAPT method in classifying LCZs of Guangzhou and compared this methodology with that of an improved WUDAPT methodology and discovered that the extensive results can be used as input data for urban climate model simulation and climatic-spatial planning both at city and regional scale. Despite the universality of the WUDAPT method in urban studies, studies from Ren *et al.* (2016) and Cai *et al.* (2016) indicated that there are variations in the accuracy of the method due to various reasons ranging from poor data quality, urban morphological characteristics and limited information provided by the buildings and vegetation in the Landsat images. With the improved WUDAPT methodology, the overall accuracy of the method improved from 75.5 percent in the previous study to 80-84 percent in the later study due to the increase in the training samples used and specifically, the urban morphology of Greater Pearl River Delta (GPRD) is very similar and homogenous with the exception of Hong Kong and Macau (Cai *et al.*, 2016). It can be seen clearly that WUDAPT method is relatively new, and it is undergoing improvement and there is a need for standardization and validation.

Wang *et al.* (2017) explored the advantages and limitation of GIS-based and WUDAPT methods in classifying the LCZs of the city of Hong Kong in China, it was indicated from the study that Local Climate Zone has become an international standard method of exploring urban morphology and its resulting impact on local temperature. GIS-based and WUDAPT methods according to this group of Authors are the two most popular ways to classify and map Local Climate Zones. Hong Kong's high-density complex urban areas were used to examine both methods' performance and accuracy. From the result of the analysis it was found that at a city level, GIS-based method has a better accuracy rate than WUDAPT, but from the general spatial distribution patterns of different LCZ classes in the two LCZ maps (that is the one generated from GIS based method and that generated from WUDAPT method) both match with the reality of Hong Kong.

Aggregating the result from each method from 100m resolution to 1km resolution, the findings indicated that the WUDAPT method has achieved an acceptably high accuracy of urban categories. Thus, the level 0 data of WUDAPT are suitable as input data for mesoscale weather and climate modelling, such as Weather Research Forecast, at a coarse spatial resolution of 1km. Under this type of circumstances, the advantage of WUDAPT's freely accessible data, coupled with simple methodology, and more suitable accuracy for application will be helpful for researchers, especially the researchers found in developing countries and in such regions where GIS data is either not complete or not available at all.

There are also findings on suitability and limitation of both methods and these can provide a useful reference for researchers who are interested in Local Climate Zone classification and mapping work for their cities. Local planners and designers can also refer to the results of urban morphology analysis for a better understanding of urban morphological characteristics in high-density urban areas which can also serve as an input to assist their planning and design work.

In summary, the advantages of WUDAPT extracted from Wang *et al.* (2017) include the following:

1. WUDAPT level 0 method follows a specific standard and procedure for data collection and data processing;
2. Required data, software and generated results of WUDAPT are free and can be publicly accessed;
3. Anyone can refer to, share and process these results further;
4. The data generated from this process can be applied to other studies, such as weather and climate modelling, urban planning, and public health

2.3.5 Selection of city of interest using WUDAPT methodology

To start the process of gathering information globally, WUDAPT group have identified a number of cities (Table 2.3), for which they have acquired the Landsat data needed to generate Level 0 data. These are known as C40 group of cities. The spatial limits of each city were obtained from a map of the **global urban extent derived on MODIS data** (Schneider *et al*., 2009). For each city, the group have created a 10 km buffer around the urban extent and the maximum/minimum limits around this area was used to create a **Region of Interest (ROI)**. They used the ROI to extract the city area from the larger Landsat images. Users of any of the C40 group of cities will use these ROI files as the boundary for the digitization of their training areas. In the situation where the chosen cities are not part of the C40 cities shown on Table 2.4, procedures to create the ROI and getting other necessary data are outlined in WUDAPT website www.wudapt.org.

Table 2.3 C40 Group of Cities

City	N scenes	N bands	mean coverage	min coverage
Addis Ababa	5	45	100	100
Amman	5	45	100	100
Athens	4	36	100	99
Bangkok	4	36	60	42
Berlin	2	18	100	100
Buenos Aires	5	45	100	100
Cairo	4	36	100	100
Caracas	1	9	100	100
Dhaka	5	45	97	96
Hanoi	3	27	100	100
Ho Chi Minh	5	45	100	100
Houston	5	45	89	89
Istanbul	2	18	63	63
Jaipur	5	45	100	100
Jakarta	1	9	100	100
Johannesburg	6	54	83	82
Lagos	0	0	0	0
Lima	0	0	0	0
London	0	0	0	0
Los Angeles	5	45	52	51
Mexico City	8	72	71	64
Moscow	2	18	100	100
Mumbai	5	45	100	100
New Delhi	6	54	76	54
Paris	2	18	100	100
Philadelphia	5	45	98	96
Rome	3	27	95	94
Seoul	4	36	98	97
Sydney	10	90	75	57
Tokyo	5	45	67	67
Toronto	4	36	66	36

Source: WUDAPT website (www.wudapt.org) – Retrieved in 2017

2.4 Examples from Other Regions/Countries

2.4.1 Global and regional climate change

Building Nigeria's Response to Climate Change (BNRCC, 2008) stated that the global distribution of temperature increase is not uniform. Some regions experience greater change than others, especially the interior of continental regions such as the Sahel in West Africa. Takahiro *et al*. (2009) admitted that urban climate is increasingly important in designing and planning of Japanese cities because of the severity of the urban thermal environment in summer; and stakeholders cannot consider urban climate in the processes of their planning and design because urban climate systems are difficult to comprehend by the stakeholders.

2.4.2 Paris agreement/global warming limit

Paris Agreement's long-term goal of the 2015 is to limit global warming to well below 2^0C above pre-industrial levels and also to pursue efforts to limit it to 1.5^0C. However, further studies are still needed for climate mitigation and adaption efforts, to understand the regional effects between the two global warming limits. Shi *et al.* (2017) provided an assessment of temperature extremes changes over China in two different period at 1.5^0C and 2^0C warming levels. The relative periods are 1986-2005 and 1861-1900; 5th phase of the Coupled Model Inter-comparison Project (CMIP5) models were used under three RCP scenarios which include: RCP2.6, RCP4.5, and RCP8.5. Results of their findings shows an increase in mean temperature and temperature extremes over China are greater than that in global mean temperature. With respect to the period between 1986-2005, the temperature of hottest day and coldest night are projected to increase about $1/1.6^0$C and $1.1/1.8^0$C, whereas warm days and warm spell duration (WSDI) increase about 7.5/13.8 percent and 15/30 percent for the 1.5/2^{0}C global warming target, respectively. The projected increases of temperature in warmest and coldest day/night are both more than 0.5^{0}C across almost the whole China with an additional global warming of 0.5^{0}C. The projected changes in Northwest China, Northeast China and the Tibetan Plateau, are sensitive particularly to the additional 0.5^{0}C global warming. Spatial hotspot still exist as the area-averaged changes in temperature extremes are very similar for different scenarios in areas such as Northwest China and North China, apparently the increases in temperatures are larger in RCP8.5 than in RCP4.5. The study by Fu *et al.* (2017) investigated the projected changes in the annual mean surface air temperature (SAT) over China under the 1.5 and 2.0^{o}C targets, outputs from 22 models of the Coupled Model Inter-comparison Project Phase 5 were analyzed and the result of the warming showed a clear spatial distinction with northwest being stronger while southwestern China was weaker.

The scope of changes in the average SAT over China under the 1.5^{o}C target is quite narrow and has the largest probability to increase by 1.7-2.0^{o}C under the various RCP pathways, although the time of occurrence of the 1.5^{o}C target has a large spread of 40-60 years. In like manner the models consistently show that the average SAT over China would most likely increase by 2.4-2.7^{o}C under the 2.0^{o}C target. Under all RCP pathways, the SAT over the northwest part would increase by 1.9-2.1^{o}C for the 1.5^{o}C target, which is much stronger when compared with the SAT increase over the southeast part between 1.3-1.5^{o}C. The spatial pattern for the 2.0^{o}C target is also similar to 1.5^{o}C target.

2.4.3 Urban climatic map studies in the world

Literature revealed that urban climatic map studies have been taken in both large and small cities of the world with Germany and Japan as the two important leading countries (Takahiro & Masakazu, 2002; Shimoda, 2003; Takahiro *et al.*, 2009; Ren *et al.*, 2009; World Bank, 2010;, Ren *et al.*, 2012; Ren *et al.*, 2013; San José *et al.*, 2015; Zhou & Liu, 2015; Zhou *et al.*, 2015; Yang & Chen, 2016), Examples of such large cities include: Tokyo and Yokohama in Japan, Beijin in China, Sakai in Osaka, Ho Chi Minh City in Vietnam, Hesse, Berling and Frankfurt in Germany, Singapore, Salvador in Brazil, Kaolisiung in Taiwan, Lisbon in Portugal, Campina in Brazil, Birmingham and Greater Manchester in United Kingdom while urban climatic map studies in small cities includes: Sendai in Japan, Stuttgart and Freiburg in Germany, Bilbao in Spain, Gothenburg in Sweden and Arntiem in Holland. This is an indication that the tool (Urban Climate map) is not just needed by large cities but also by the small cities.

Germans synthesized all climatic and planning data from dynamic potential and thermal load aspect taking prevailing wind direction, mountain and valley winds into account, while Japanese calculated and evaluated all climatic information based on heat balance model also taking into account land and sea breezes, mountain and valley winds and air movement from parks, (Ren *et al.*, 2009).

A rise in temperature by 2-3^{0}C in Tokyo over the past century was the driving force which made the Tokyo Metropolitan Government (TMG) to commission the production of a thermal environment map in 2000 in order to get the understanding on the factors affecting Urban Heat Islands (UHIs) in the city of Tokyo. Based on this the Tokyo Metropolitan

Government formulated relevant control measures in 2005 with focus on some urban design aspects which include: greening premises, greening rooftops, greening building walls, increased rooftop reflectance, water-retentive pavement, and reductions in waste heat from buildings (Ren *et al.*, 2013). The Urban Climatic Analysis Map in Hong Kong also provided Urban Climatic Planning Recommendations to city planners based on evaluation of some available planning parameters which include density, building volume such as floor area ratio, building and site coverage, greenery, open space, air paths and breezeways and proximity to the water front.

An Urban Climatic Map (UCMap) is a suitable information and evaluation tool capable of integrating urban climatic factors and town planning considerations through presentation of urban climatic phenomena on a two dimensional spatial map in a format that is easily read by city planners. It collates meteorological planning land use, topographic, and vegetation information also analyze and evaluate spatially and quantitatively their interrelationships and effects on the urban environment (Ren *et al.,* 2013). It was also admitted that UCMap can assist policy makers and planners in the search for a suitable location for new developments; detailed recommendations of UCMap study can help in choosing the best plan out of the various proposed scenarios and to establish land use zone.

Part I of the World Bank challenge that a climate smart world require us to act now, act together and act differently (World Bank, 2010), each component of the idea is very important and should be a focus in Nigeria.

Mitigation and adaptation strategies of the effect of Urban Heat Island are not efficient enough to resolve the excessive problem of urban heat, especially at the local scale. The Local Climate Zone (LCZ) classification scheme can be employed to examine the diversity and complexity of the response of climate within a city (Wang *et al*., 2017). The study by Wang *et al.* (2017) suggested that zonal practice could be an efficient way in bridging the knowledge gap existing between climate research and urban planning in the various cities in the world. LCZ was used to classify urban surfaces designated as urban climate landscapes, and this extends the LCZ concept to urban planning applications. The city of Wuhan in China was used as a case study, and attempt was made to explore the climatic effect of landscape patterns in which thermal effects were compared across the urban climate landscapes. Quantification of the relationships between patch metrics and land surface temperature (LST) was made and the results indicate that climate landscape layout is a considerable factor impacting local urban climate. For the city of Wuhan, 500 meter is an optimal scale for exploring landscape pattern to temperature relationships. Temperature contrast between the surrounding landscape patches has a major influence on LST of the city of Wuhan in China. On a general note, fragmental landscape patches contribute to heat release. For most climate landscape types, patch metrics also have a significant effect on the thermal response.

2.4.4 Urban climate application in Nigeria

Nigeria is undergoing rapid urbanization which has led to changes in its urban climate and environment. It was established in Citiest Alliance, (2014) that Nigeria adopted a robust National Urban Development Policy and also at the same time enacted a comprehensive Urban Regional Planning since 1992 when a new planning law was put in place. To this effect, there was little achievement to show in terms of implementation; and this general apathy towards urban planning still persist in Nigeria as a country as established in the Federal Republic of Nigeria, in 2012.

The broad aim of the planning law in 1992 was to improve the planning and management of urbanization so that urban settlements would foster sustainable economic growth and improve living standards of people; more specific objectives to achieve the broad aim were also put in place. But this well-conceived planning law suffered greatly due to poor implementation.

The fourth specific objective is related to the challenges observed by the present study, the objective goes thus “to revise and implement sectoral programmes in housing, environment, employment and other fields to make them more responsive to the country’s urban problems”. There exist limited urban climatic studies on the impact of urban development intensity on local climatic conditions and the limited available are no consistent in the methodological approach. Also, Ren *et al.* (2016) noted that urban morphology data and information are not easily accessed in the public domain. Thus LCZ classification of cities using WUDAPT methodology can facilitate information extraction of cities based on free Landsat data and free SAGA-GIS software for urban study and evaluation.

2.4.5 Status of local climate zone mapping in the world

Despite the numerous advantages of mapping Local Climate Zone using WUDAPT initiative, the method still have a long way before the beauty of its capability can be revealed, the summary of the various cities are illustrated according to continent in figure

2.1. Among the countries that indicated interest, few have completed their tasks; some are still working while others have abandoned the tasks.

There are four major tasks to be covered by each city as indicated below:

1. Prepare Landsat data
2. Digitize training areas
3. Run the LCZ classification
4. Verify a completed LCZ map

Summarily, 111 cities indicated interest as gathered from WUDAPT website (www.wudapt.com) and only 22 cities have completed their task as at the time of documenting this literature while 59 cities are working on their task and 30 cities have abandoned their task. The attempt is a good one especially if the cities working can also complete their tasks. But the point here is the challenge for other cities to embrace the methodology to achieve the benefits uniformly. The status is indicated visually on figure 2.1, apart from Austrasia, African cities ranked the second lowest in adopting this methodology.

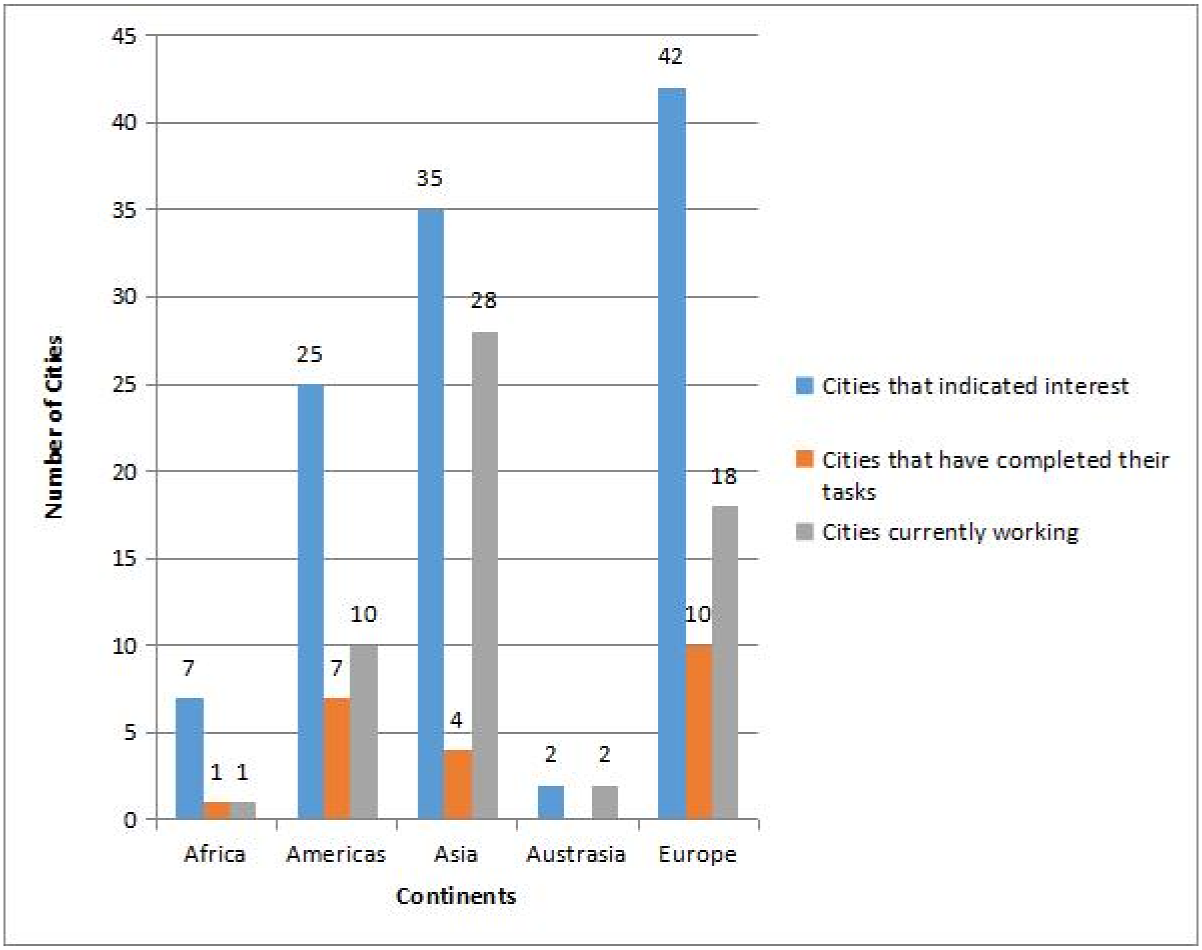

Figure 2.1 Status of Local Climate Zone Mapping in the World
Source: Author, 2018

2.5 The Overview and Key Issues of the Study

2.5.1 Urbanization as a key agenda in international development policy

UN Habitat (2020) gathered that the turn of the 21st century has made cities to become more central to global discussions around sustainable development. Decades of ambivalence from policymakers, have made urbanization a key agenda within international development policy. The unanimous adoption in 2015 Agenda for Sustainable Development of the 2030, which also includes the SDG goal 11 "Sustainable Cities and

Communities"; the goal to "make cities and human settlements inclusive, safe, resilient and sustainable," as well as the New Urban Agenda (NUA) in 2016, places urbanization firmly at the forefront of international development discussions. In fact, the recognition in this case goes beyond viewing urbanization as simply a demographic phenomenon, but rather see urbanization as a transformative process capable of galvanizing momentum for development.

Governments at national levels, local authorities, international NGOs and also the private sector now must emphasize the implementation of the New Urban Agenda in their plans, which lays out a 20-year vision for sustainable urban development, as a way forward for achieving the urban dimensions of the seventeen Sustainable Development Goals (SDGs). The significance of urban systems thinking is no longer seen as relevant only to a few globally-connected metropolitan hubs but now distributed across the full spectrum of human settlements, ranging from megacities to secondary cities and also to smaller towns that constitute the world's urban majority. The world for one decade now has become predominantly urban, the continued increase in urbanization, especially with the rapid pace in developing countries, has placed the urban space at the forefront of global policy debate. Securing sustainable future has been central in urban process with the diverse challenges such as climate change, economic growth, poverty eradication, housing, infrastructure, basic services, decent jobs, food security and public health that include the recent coronavirus pandemic currently ravaging all parts of the world today.

Quick facts along with policy points were summarized from UN Habitat (2020) as follows:

2.5.1.1 Quick facts

1. Urbanization has emerged as a key agenda in international development policy after decades of ambivalence from policymakers.
2. Emphasis was placed on effective implementation at the local level and on the role of local governments in the New Urban Agenda.
3. Highly urbanized regions are expected to have slower rates of urban growth though every region is expected to become more urbanized in the next ten years.
4. The 2030 Agenda for Sustainable Development and the New Urban Agenda were all adopted in times of profound global challenges and coronavirus pandemic has exacerbated many of them.
5. Cities have borne the brunt of COVID-19 with over 90 per cent of confirmed cases coming from urban areas.

2.5.1.2 Policy points

1. Means of achieving SDG 11 that offers a framework for unlocking the value of urbanization is the New Urban Agenda.
2. There are challenges that need to be addressed despite the fact that countries have made progress in the implementation of the New Urban Agenda and urban dimensions of the SDGs.

3. Decade of Action for accelerating sustainable solutions targeted towards eradicating poverty, reducing inequality, addressing climate change and enhancing gender equality sustainable urbanization has a key role to play.
4. Among the most cost-effective way to boost economies hit by COVID-19 while reducing emissions is sweeping investment in clean technologies such as renewable energy.
5. The opportunity for cities to build back better in the long term and build up resilience against future pandemics was provided by COVID-19.

In order to ensure the achievement of SDG 11, the Voluntary National Reviews identified four key areas that need to be improved upon by the United Nations Member States as follows:

i. Reinvigorate civil society and governance participation: Effective institutions and structures to oversee the implementation of national urban plans to be developed, strengthen stakeholder collaboration and urban governance, incorporate urban planning into local development and increase civil society participation.
ii. Financial mechanisms reinforce: This is to establish financial frameworks that attract sustainable investments, increase the productive role of cities and urban territories, promote fiscal decentralization especially in developing countries, and enhance collaborations with private sector and the international development banks to scale up urban investment in line with NUA principles.
iii. Capacity development: Enhance the human resources and capacity of policymakers and technical personnel to implement the New Urban Agenda and the urban dimension of the SDGs.

iv. Information and technology: Produce open data to monitor and better manage urban development by increasing the use of technology.

Member states are therefore required to send reports from their various countries as input to Global Sustainable Development Report 2023, a United Nation Publication on sustainable development published every four year and was launched in 2019. The publication represents 'assessment of assessments' aimed at strengthening science policy interface at the High Level Political Forum (HLPF) on sustainable development.

2.5.2 Urbanization and urban heat island

Zhang *et al.,* (2021) investigated the correlation between spatio-temporal changes of urbanization and surface urban heat island in Beijing; remote sensing data was used to retrieve the distribution of local climate zones in the years 2003, 2005, 2010 and 2017 and land surface temperature in summer from 2000 to 2017 were used to analyse the surface urban heat island (sUHI) area and change. GeoDetector statistical was used to investigate the explanatory ability of LCZs and population as the driving factors. Increasing trend was shown in the sUHI from the year 2000 which eventually decreased and a changed pattern before and after 2009 where the increase was mainly in the suburbs which was later enhanced towards the central area. The intensity of sUHI change under different LCZ conversion conditions and these showed that the LCZ conversion influences the sUHI intensity significantly. Based on population distribution data, it was revealed that the relationship between population density and sUHI gets weaker with increasing population density. GeoDetector result indicated that the LCZ is the main factor influencing the sUHI, but population density is also an important auxiliary factor. The research reveals the sUHI variation pattern in Beijing from 2000 and this particular research could help city managers plan thermally comfortable urban environments with a better understanding of the effect of urban spatial form and population density on surface urban heat islands.

The effect of remotely sensed-based LULC indices on LST was investigated by Khan *et al.* (2021), and the impact magnitude of green spaces on LST in the city built-up blocks were quantified in the city of Beijing in China. Random forest classifier algorithm was used to map LULC from the Gaofen 2 satellite and land surface temperature was retrieved from Landsat-8 ETM data through the split-window algorithm. Line transect approach was also used to extract the pixel values of the LULC types and indices where multicollinearity effect was excluded before regression analysis was carried out. There was a very strong negative relationship between the vegetation index and LST, but a positive relationship was found between built-up indices and LST in univariate analysis. The normalized difference impervious index (NDISI), dry built-up index (DBI), and bare soil index (BSI) were the preferred indices and so predicted the LST (R2 = 0.41) in the multivariate analysis. Stepwise regression analysis explained adequately the LST (R2 = 0.44) due to the combined effect of the indices. The results of the analyses indicated that the LULC indices can be used to explain the LST of LULC types with useful information for urban managers and planners for the design of smart green cities.

A close examination into different cities of the world indicated different methodologies used to create UECM but this study is examining majorly the methodologies from Germany and Japan coupled with that of Kaohsiung in Taiwan. On the other hand, the issue of expansion of urban area in the early 1980s in local government of the Kassel city in

Germany and concern about improving human thermal comfort and decreasing the air pollution were the major considerations in climatic and environmental evaluation. This created room for the first version of UCMap for the city created by a research team lead by Prof. Luts Katzscher which was followed by the second version of the map in 2003. For this reason, this German UCAn map focused on the thermal and wind aspect which was based on the evaluation of the thermal radiation and surface roughness length of developments and greenery.

In summary, a good UECM (UCAn Map and RM) cannot be completed without input from government (as policy makers) and the various stakeholders. UECM as seen from the developed world are policy driven especially from the part of the government putting the citizens into consideration. Also, a need for high resolution image and large scale maps are among the factors needed for better UECM that may become difficult in the developing nations where such data are not easily accessible. The fact that Nigeria urban population is also on the increase and the issues of urban climate changing very vast becomes a serious concern in research which must be strategically introduced into the government policy for a sustainable development to also take its effects.

Urban Environmental Climate Map for the purpose of this study can be summarily placed into three analytical levels and each level will show the relationship between the map and the various input. The first level represent the broad level where the major map (UECM) represent the independent variable and the two maps to be developed (UCAn Map and Recommendation Map) are the dependent variables such that the combination of Urban Climate Analysis map and Recommendation map is what is called Urban Environmental Climate Map.

The placement of variables move at the second level where UCAn map is taken as the independent variable, this level is the main analytical level where all variables that are imputed into the map become the dependent variables; they include: the land use and land cover map, topography map, wind data, temperature map and population density map, natural landscape and water bodies. Also at this level, when the variables are considered alone, the land use and land cover map becomes the independent variable whereby all other variables are dependent variables.

On a final note, at the third level, the output of the second level (UCAn map) represent the document that was used for planning and it represents the independent variable, planning information as taken from the various stakeholders and policy makers are the dependent variable used to create planning zone used for the recommendation map.

This study is defining Urban Environmental Climate Map (UECM) as a planning and evaluation tool that not only help planners to understand the environmental climatic conditions but also help direct policy of a particular geographic location in such a way that a balance is maintained between environmental resources and urban construction and development for sustainable city design.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Data Requirement

The following are the dataset used for the study:

1. Landsat 8 (Operational Land Imager) images of 2018
2. Landsat 4 (Thematic Mapper) images of 1988
3. Shuttle Radar Topography Mission (SRTM) – Digital Elevation Model (DEM)
4. Meteorological data (Temperature and Wind Speed data from 1988 to 2018)
5. Population Data (1991, 2006 and projected population data of 2016)

3.2 Data Collection

Data collection was done using Landsat 8 satellite data for 2018 and Landsat 4 Thematic Mapper (TM) of 1988. Landsat satellite data captures images every 16 days. A total of eight Landsat 8 satellite data scenes and eight Landsat 4 satellite data scenes covered the entire study area for the two period under study (Table 3.3). The images were chosen for the study because they include thermal information which can be used for classifying and mapping LCZs (Ren *et al* ., 2016). It is also worth to note that Local Climate Zones (LCZ) as classified by Stewart and Oke, (2012) has the advantage that looks beyond the temperature difference between urban and rural (UHI) but among LCZ with more emphases on intra-urban temperature comparison among the different urban classes.

Table 3.1 Band representation and resolution of the Landsat 8 satellite data

Band	Band Name	Wavelength (µm)	Resolution (m)
Band 1	Coastal	0.43 – 0.45	30
Band 2	Blue	0.45 – 0.51	30
Band 3	Green	0.53 – 0.59	30
Band 4	Red	0.64 – 0.67	30
Band 5	NIR	0.85 – 0.88	30
Band 6	SWIR 1	1.57 – 1.65	30
Band 7	SWIR 2	2.11 – 2.29	30
Band 8	PAN	0.50 – 0.68	15
Band 9	Cirrus	1.36 – 1.38	30
Band 10	TIRS 1	10.6 – 11.19	100 (resampled to 30)
Band 11	TIRS 2	11.5 – 12.51	100 (resampled to 30)

Source: Luca Congedo, 10th June, 2019 Semi-Automatic Classification Plugin Documentation Release 6.3.0.1. https://readthedocs.org/projects/semiautomaticclassificationmanual/downloads/pdf/latest/

Table 3.2 Band representation and resolution of the Landsat 4 satellite data

Bands	Wavelength (µm)	Resolution (meters - m)
Band 1 -Blue	**0.45 -0.52**	**30**
Band 2 -Green	**0.52 -0.60**	**30**
Band 3 -Red	**0.63 -0.69**	**30**
Band 4 -Near Infrared (NIR)	**0.76 -0.90**	**30**
Band 5 -SWIR	**1.55 -1.75**	**30**
Band 6 -Thermal Infrared	**10.40 -12.50**	**120 (resampled to 30)**
Band 7 -SWIR	2.08 -2.35	30

Source: Luca Congedo, 10th June, 2019 Semi-Automatic Classification Plugin Documentation Release 6.3.0.1. https://readthedocs.org/projects/semiautomaticclassificationmanual/downloads/pdf/latest/

Table 3.3 **Properties of Landsat Images Used**

Data	Path/Row	Sensor	Bands	Resolution (m)	Date Obtained
Landsat 4	189/051	TM	7	VNIR =30	1/7/1988
Landsat 8	189/051	OLI	11	TIR = 120	1/16/2018
Landsat 4	189/052	TM	7	VNIR = 30	1/6/1988
Landsat 8	189/052	OLI	11	TIR = 100	2018-16-2018
Landsat 4	189/053	TM	7	PAN = 15	1/7/1988
Landsat 8	189/053	OLI	11		1/16/2018
Landsat 4	189/054	TM	7		1/7/1988
Landsat 8	189/054	OLI	11		1/16/2018
Landsat 4	188/051	TM	7		1/31/1988
Landsat 8	188/051	OLI	11		1/16/2018
Landsat 4	188/052	TM	7		1/31/1988
Landsat 8	188/052	OLI	11		1/25/2018
Landsat 4	188/053	TM	7		1/31/1988
Landsat 8	188/053	OLI	11		1/25/2018
Landsat 4	188/054	TM	7		1/31/1988
Landsat 8	188/054	OLI	11		1/25/2018

Source: Author (2017)

USGS earth explorer site was used to collect data for Landsat 4 level one images of 1988 and Landsat 8 level one images of 2018 in each case. With reduced cloud cover of less than 10% at the initial stage some Landsat scenes were downloaded but others were accessible with a slight increase of the cloud cover all in Tiff format. After collecting the data, all of the band data were assessed for quality, cloud cover, aerosol content, and pixel quality; among others and were found satisfactory for proceeding with the research work. Landsat 8 band representation and resolution are outlined on Table 3.1, Landsat 4 band representation and resolution are outlined on Table 3.2 while the exact Landsat scenes used for this study are listed in Table 3.3 while information on urban morphology which include the building and land cover were derived from Google Earth Pro.

3.2.1 Procedure guidelines for creating region of interest

The first procedure was to create the Region of Interest (ROI) which corresponds to the study cities in each state. This has to be done because three study cities were not part of C40 group of cities, and so the step-by-step procedures has to be strictly adhered to in order to create the ROI before downloading the required Landsat scenes.There are conditions for selecting the ROI as created in Google Earth Pro software, the conditions are as follows:

a. The guideline about the ROI covering the entire urbanized area was considered and also the buffer area and the required dimension of the ROI was also followed. Boarders and label layer in GE pro were also switched on in the process to serve as a guide in the choice.

Ruler tool was used to guide in the ROI dimension, Figure 3.1 and the style of the polygon changed to transparent and the colour changed to outlined; the polygon is a rectangular shape but do not need to be exact. Yellow line on Figure 3.1 indicating the length as measured in GE Pro, red line indicating the actual Rectangle with the name under My Places**, F**igure 3.2 shows the prepared ROI in the three study areas. The prepared ROI were used for digitizing the training areas used for the LCZ classification.

b. The ROI was saved as a KMZ file by right clicking on it, Save Place As option in the dialogue box.

Shuttle Radar Topography Mission (SRTM) images were downloaded for the study area from USGS earth explorer site and the cloud cover was reduced to less than 10 percent just like the Landsat data download, all data also downloaded in Tiff format. Population data was downloaded through web of National Bureau of statistics and National population Commission of Nigeria the downloaded population data covered The population of the local government areas (LGAs) and states of Nigeria according to results of census of 1991 (26th November, 1991) and 2006 (21st March, 2016) and population projections of 21st March, 2016. Meteorological data (temperature and wind speed) were obtained from the NASA Langley Research Center (LaRC) Power Project funded through the NASA Earth Science/Applied Science Program. Meteorological data sources from NASA Langley Research Center are natively produced on global 1° by 1° latitude/longitude grid and also remapped to 0.5° by 0.5° latitude/longitude grid through bilinear replication or interpolation. After processing the data was archived and also made available through power service suit.

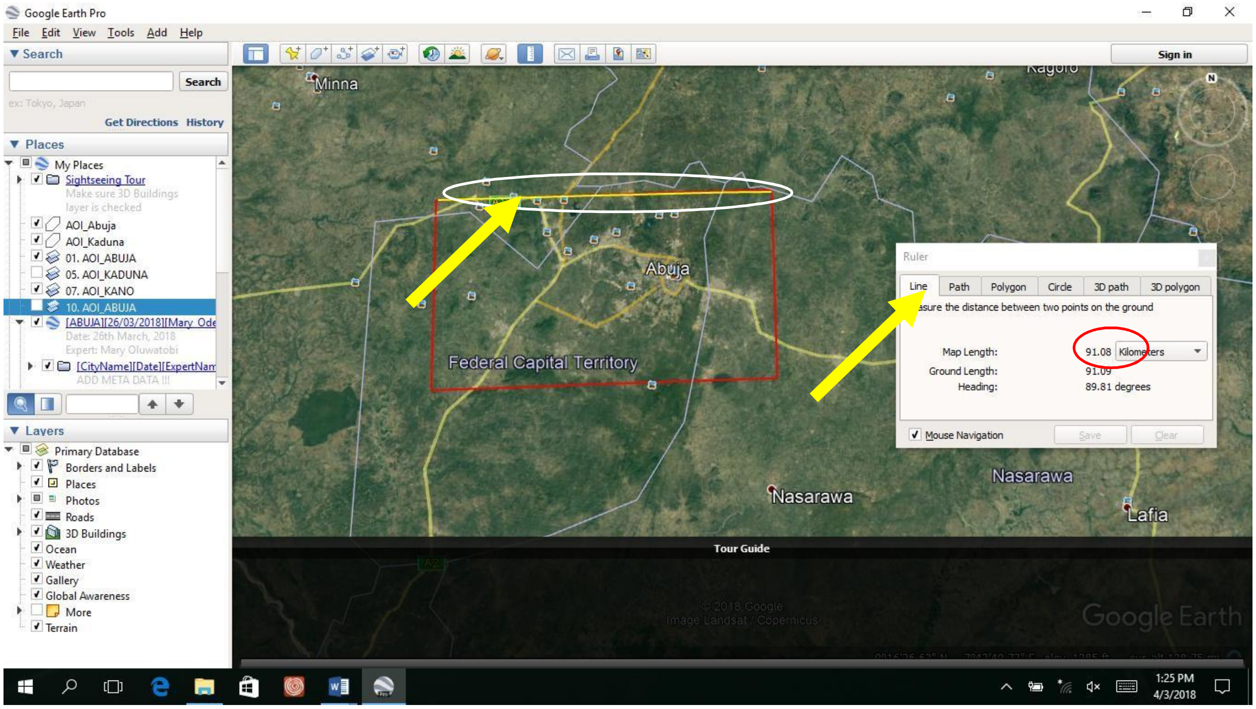

Figure 3.1 **Abuja Region of Interest Indication the ROI Standard**

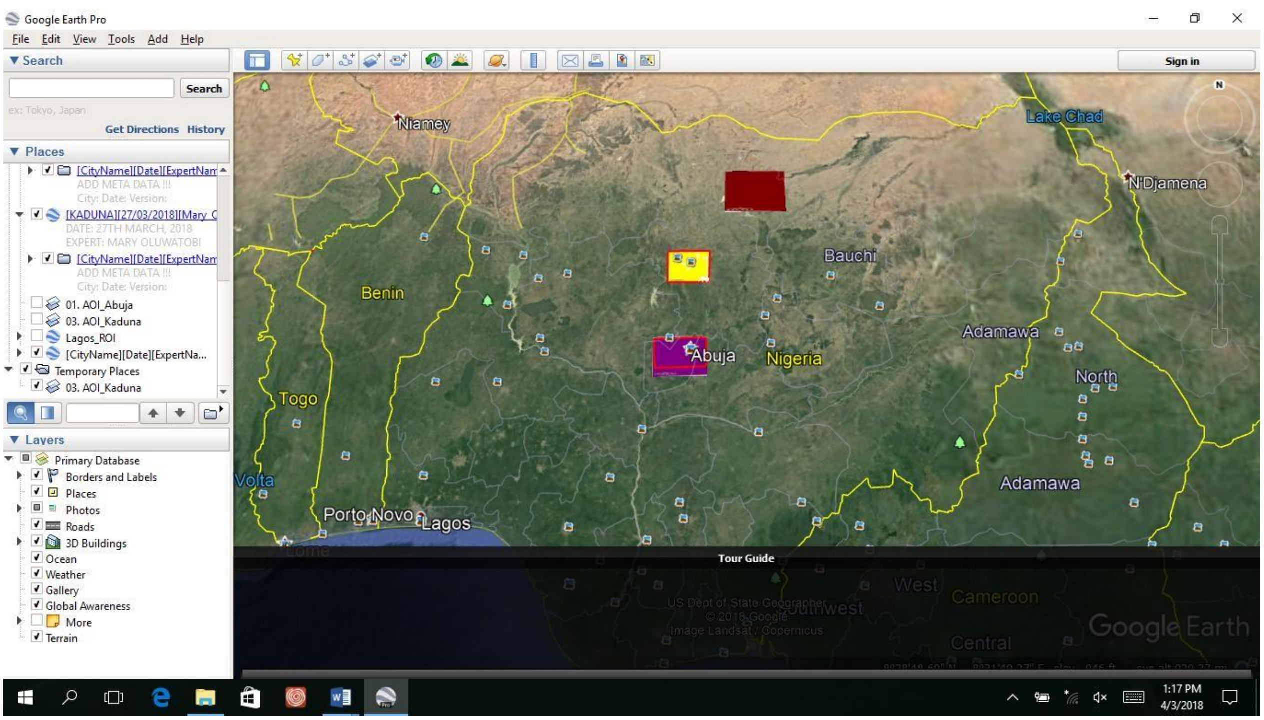

Figure 3.2 The Prepared Regions of interest (ROI) in Google Earth Pro

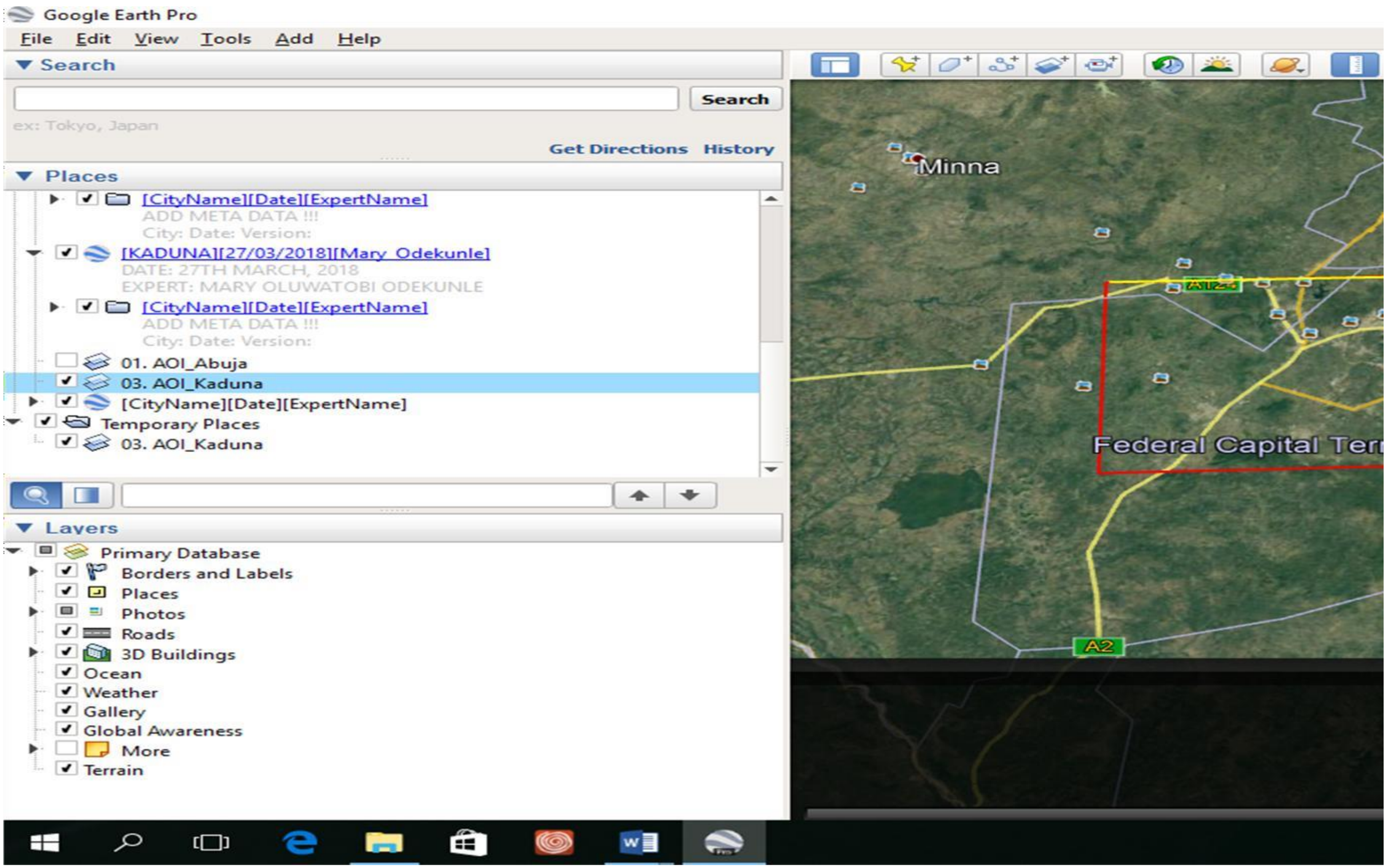

Figure 3.3 Kaduna City Prepared Using the City Folder Template

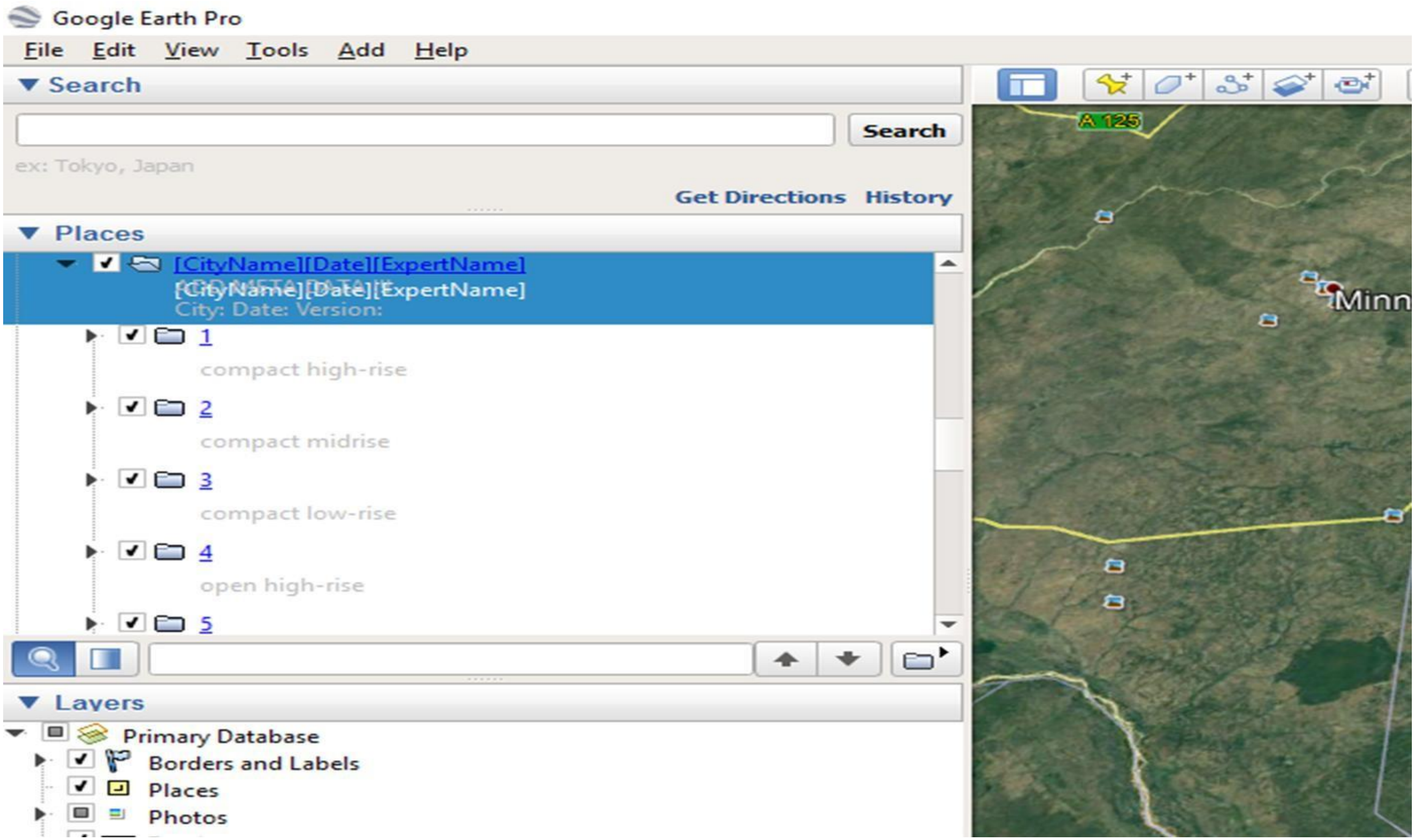

Figure 3.4 LCZ Types Indicated Under My Places Ready for LCZ Digitization

3.3 Identification and Mapping the Local Climate Zones (LCZ) in the Study Areas

3.3.1 Importing the ROI into SAGA GIS and Projecting the ROI to (UTM)

Objective one involves identification and mapping the various LCZ in the study areas which requires satellite image of the study area, the training data used for classification and the software. After successful creation of the (Region of Interest) ROI, figure 3.3 and downloading the required Landsat scenes for the study, the next step was to import the ROI into SAGA GIS and project the ROI to Universal Transverse Mercator (UTM), the projection of Landsat data because the downloaded Landsat data scenes were all level 1 GeoTIFF Landsat data; meaning that they have been geo-referenced. This operations were performed using SAGA GIS. Another important data used in this study also downloaded from WUDAPT website as stated earlier in section 3.2 was the city template folder also explained further in the section 3.4.3. The file containing the format for the city name called the city template file for consistency in city name format and another file for the colour scheme also called cmap were downloaded. The cmap contain such important function of making the colours in each LCZ classes in different classification to be consistent Figure 3.5.

The region of interest was imported into SAGA GIS and projected into the same projection with the Landsat dataset; then, the projected ROI imported into GE pro for digitization of the training areas. The prepared training dataset, the ROI and the Landsat dataset were further imported into SAGA GIS to generate the Local Climate Zone Classification (LCZC).

3.3.2 Preparation of the study cities in google earth pro

This particular study is classifying the cities that are not part of C40 cities therefore this preparation run through from the beginning to the end. The first thing was to download the zipped city template folder; unzip the folder and work on its other components such as: city name, date, expert name and other important information that were required. The following are the constituents of the city template folder:

Four sub-folders such as classification folder, feature folder, ROI folder and training folder. These folders were used to store the various geo-processing that was carried out.

Two other files such as city name Meta data and the cmap file which contain the colours for each of the LCZ class were also downloaded.

The feature folder contains the relevant feature data (cropped Landsat data for the city). The template folder were saved to a specified location on the hard disk. In the next process, file was selected from the Google Earth Pro main menu through open icon and city template folder was loaded which first appeared under temporary places as **[City_Name][Date][Expert_Name]** as shown in Figure 3.4. provided it is a C40 city this will appear with the name of the city under my places. Since the cities are not part of C40 cities, a folder was created for each city on Google earth pro under temporary places where the different components were changed to suit each city under study such as Abuja, Kaduna and Kano. The date was also changed and the expert's name inserted. Other important details were also used to replace the metadata such as details of each city, email of the expert, remarks and other important information; most of the information here are optional. The folder was the slided into my places before further processes can take place.

Finally, the folder was saved to My Places under a new file name by right clicking on it and selecting “Save Place As” name given to it (Otherwise all edits will be lost). A small arrowhead was attached to the city template folder, by clicking on it all the sub-folders labelled according to LCZ types 1 to 10 representing the urban types and 101 to 107 that correspond to LCZs A to G representing the natural classes are seen (Figure 3.4). For instance LCZ 1 is Compact High-rise and LCZ 101 is the Dense Trees. The sub-folders were used to store the digitized training areas for available LCZ type; the colour scheme and LCZ types were shown clearly on Figure 3.5. Details of the different LCZ can be seen clearly from the previous section on Table 2.2. The LULC maps covered six classification scheme such as built up areas, forest, vegetation, agricultural land bare surface and water body; while LCZ map covered seventeen land cover classes known as Local Climate Zones which divides land cover types into two broad groups such as built type and land cover types. LCZ classification was not carried out for 1988 because the methodology flow of classifying image using the LCZ is based on training datasets acquired on Google map but historical images of 1988 is not available on Google earth. LCZ classification was not carried out for 1988 because the methodology flow of classifying image using the LCZ is based on training datasets acquired on Google map but historical images of 1988 is not available on Google earth.

3.3.3 Digitizing the training areas

This section involves the procedures involved on how LCZ polygons were digitized using Google Earth Pro and all the good practice guidelines used for digitization were adhered to in order to become familiar with the basic ideas to complete the task and also for a good classification thereafter. The colour scheme in Figure 3.5 is known as cmap in the template folder which represents the legend of LCZ map, it is uniform in all WUDAPT methodology flow also downloaded from WUDAPT website. Names and designation of each LCZ type has been given on Table 2.2 while the abridged definitions for the LCZs has also been given on appendix C while the actual and uniform colours used for each LCZ types were indicated on the colour scheme; this made comparison much easier.

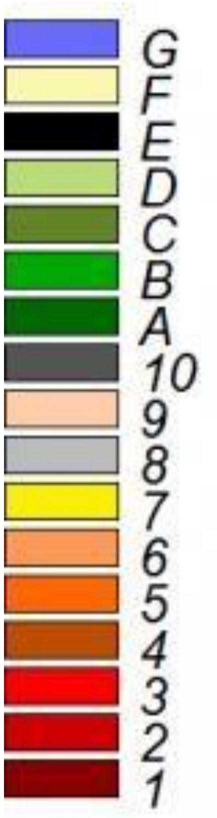

Figure 3.5 LCZ Color Scheme (Source: www.wudapt.org/wudapt)

The LCZ map legend shows 1 to 10 representing LCZ 1 to LCZ 10 such are the built LCZ types whereas LCZ A to G represents the other land cover LCZ types as indicated previously on Table 2.2. The colours have been chosen for uniformity in all studies that consider LCZ classification and it gives room for easy comparative analysis to be carried out across different cities/countries and regions of the world, the colour schemes are indicated on Figure 3.5.

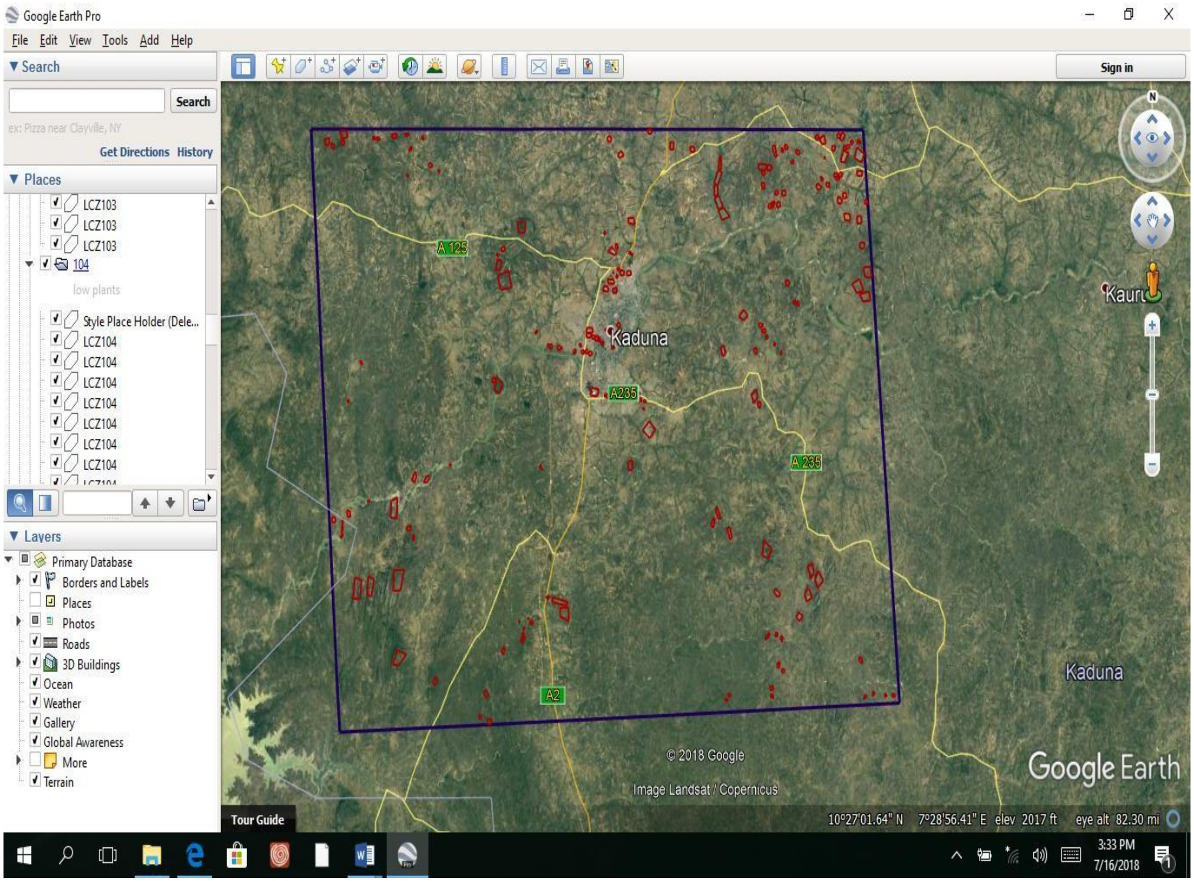

Figure 3.6 Sample of Kaduna Digitized Training Areas

3.3.4 Saving the training areas

There are basically three final steps in this process:

i. The training data were saved as a kmz file, all style placeholders were deleted before saving the work (also delete the LCZ classes that are not existing in the study area).

ii. All what has been done represent a version of LCZ training areas of the city classified, other versions of the training areas can be considered once the accuracy of the classification is not satisfactory enough, was finalized as soon as good accuracy is achieved. The digitized training area for Kaduna is seen on Figure 3.6 as a case study for others.

iii. The classification was then performed based on the training data and the Landsat satellite data which has been downloaded. The classification was an iterative process, likely, after the first round one may find out that some areas were misclassified, in such situations more training data were added and saved as new version of the training data while same procedure were followed to classify again. This was repeated again and again until the images are well classified the methodology flow is shown on Figure 3.7.

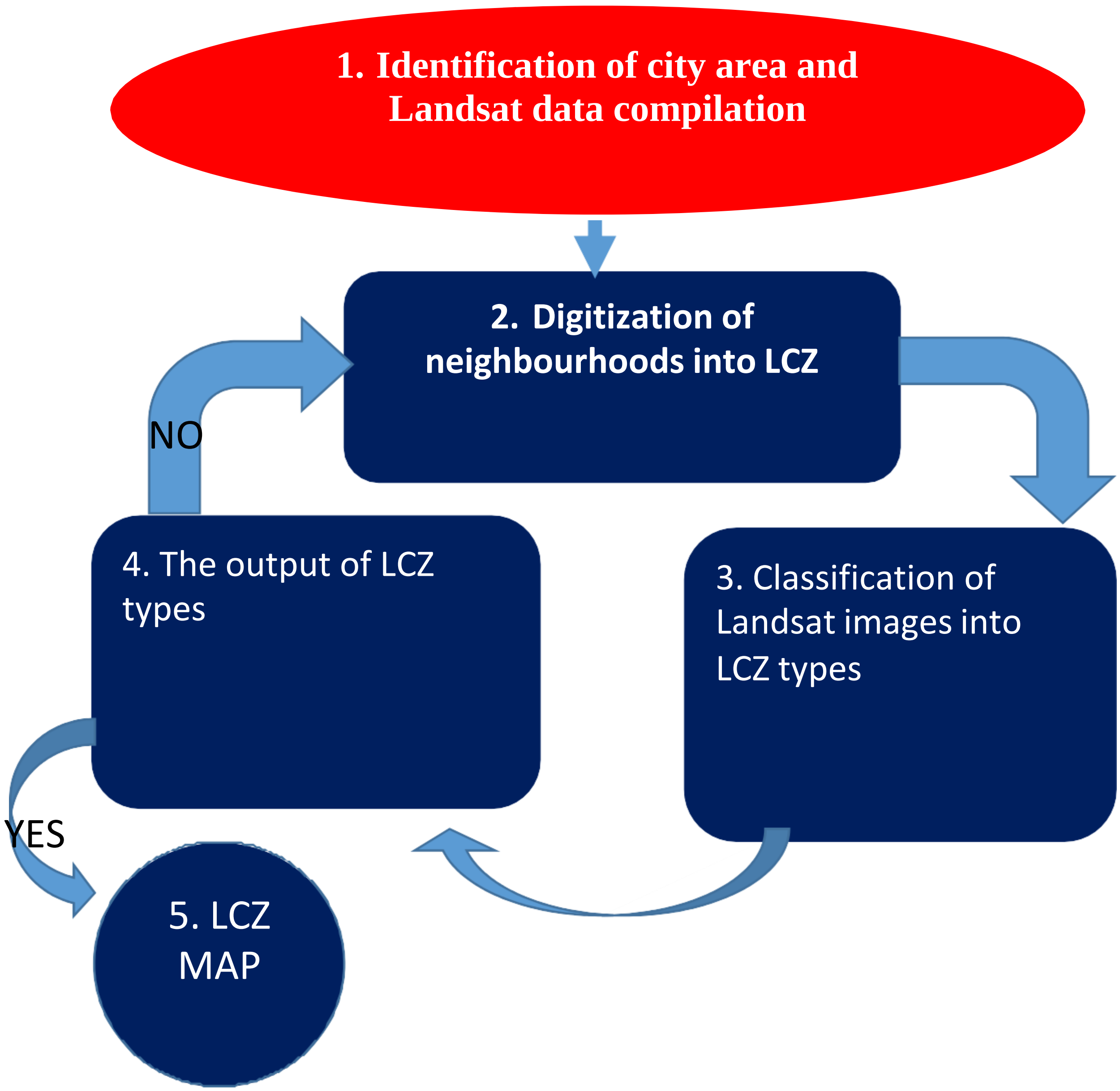

Figure 3.7 **Refined Flow Chart for WUDAPT Level 0 Method used for generating LCZ Classification**
Source: (Gerald Mills) www.wudapt.org/wudapt

3.3.5 Generation of LCZ classification

The following steps were used to generate the LCZ classification using the SAGA GIS software:

a. SAGA GIS software was loaded by clicking on the **saga_gui.exe** file.

b. The template folder was opened and the files that contain the features for classification loaded using the procedure: File => Grid => load => navigate to feature folder and select all.

c. Then, run the **Local Climate Zone Classification (LCZC):** Geoprocessing => Imagery => Classification.

d. Defining the parameters used for classification: the following procedure was used for classifying the Local Climate Zone Classification:

i. Grid System of the features (only available) was selected in SAGA GIS

ii. Feature grids these are the Landsat data were added at the right side of the dialogue box.

iii. KMZ file generated from the previous process as Training Areas was also selected.

iv. The Class Definition File defines the color-map for the output of the workflow named cmap_WUDAPT_2015.txt or equivalent and is in the City template folder. Otherwise, it can be downloaded separately from WUDAPT website in case it is not in the folder. This was also added

v. The LCZ classification (LCZC) was saved whereby the path to save the classification output as KMZ was specified, so as to evaluate it further in Google Earth again.

e. After the classifications have been generated, the project was saved since the classification has only been saved as a KMZ file and not in SAGA format. This was done by simply saving the project.

f. Finally, the newly created KMZ file was opened in Google Earth and validation of the accuracy of the classification was carried out. In situations where large areas of the urban landscape were incorrectly classified, further training areas were added in Google Earth and the classification repeated until a satisfactory result was achieved as stated in the previous section.

3.3.6 Validation of LCZ classification

Once classification exercise is complete, it is important to assess the accuracy of the results obtained from the classification. This will give room for a degree of confidence to be attached to the acquired results and also serve as an indicator to the fact that the analytical objectives have been truly achieved. Confusion matrix is analysis that usually summarizes the results of an accuracy assessment in rows and columns. An assessment that always compares the classified LCZ classes with the reference data to reveal the level of similarity and differences.

Before proceeding with digitization of the validation samples in Google Earth Pro, a ground truth was first carried out where actual field samples were observed and noted along with the geographical coordinates of the different LCZ types across the study area; sampled points can be seen in Appendix C. This was done randomly to cover the entire study area after which the field points were typed in Microsoft Excel and imported into

Google Earth Pro were further samples were digitized. To be more objective, samples of the LCZ in each case have been set at 0.5% of the number of each LCZ developed earlier. The entire sample points were taken back to Microsoft Excel for further preparation and added to the classified raster in ArcGIS exported using Global Mapper to preserve the classified colour scheme and LCZ classes.

The XY data were displayed and spatial analysis function, statistical tool, data management tool and conversion tools in ArcGIS were used to generate the confusion matrix table known as pivot table in ArcGIS which was taken to Microsoft Excel where the accuracy assessment was carried out. The confusion matrix table lists the number of classified pixels and reference pixels both correctly and incorrectly classified. The reference data were in rows while the classified data were in columns. The methodology flow is illustrated in Figure 3.8.

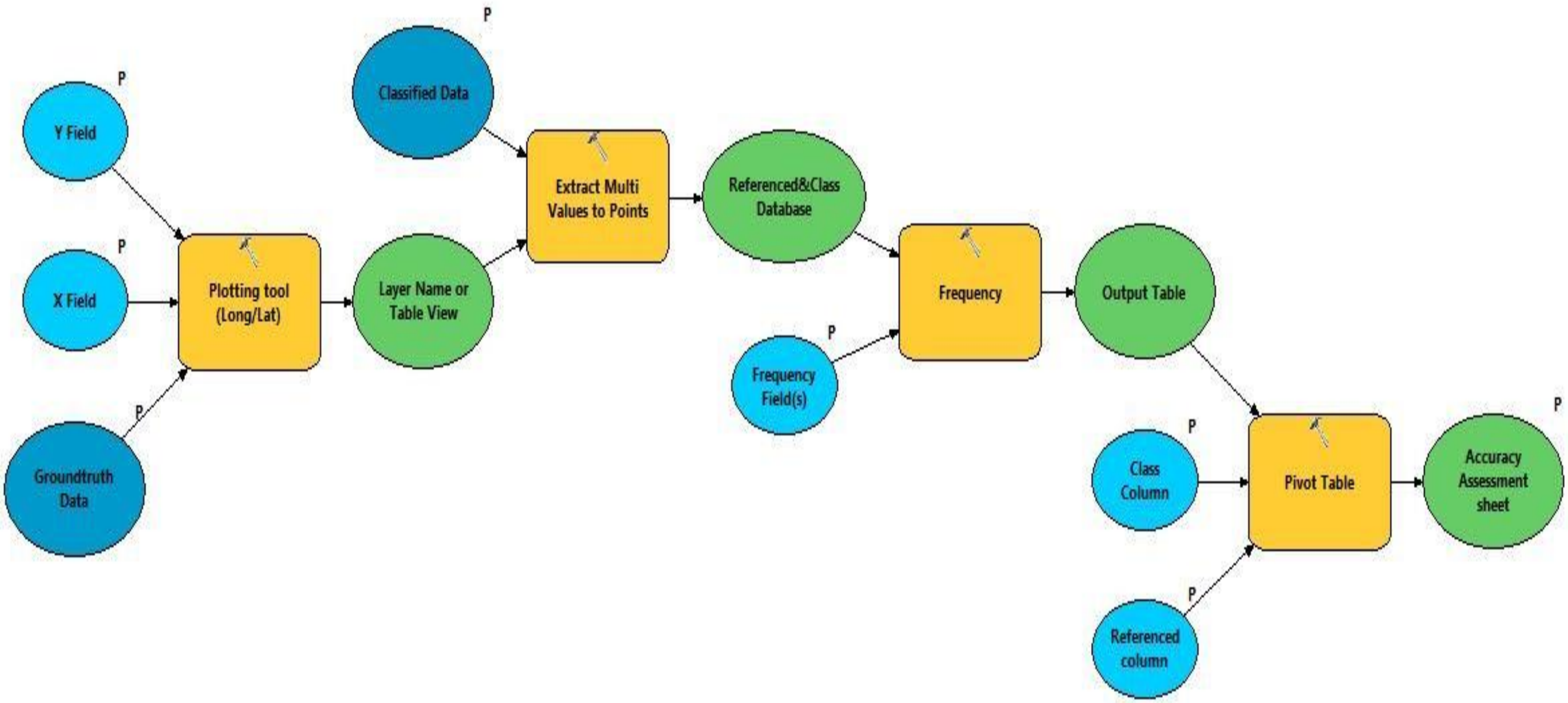

Figure 3.8 Accuracy Assessment Methodology Flow
Source: Author, (2019)

The major details extracted to validate the classification from the confusion matrix include:

1. Total reference points (Ground truth pixels)
2. Total classified points (Testing pixels)
3. Total correct reference pixels indicated with $\mathbf{P_o}$ (Summation of the diagonal where features classified as LCZ3 remain LCZ3 in the digitized reference, LCZ4 remain LCZ4, LCZA remain LCZA among others
4. Summation of the products of 1 and 2 in each LCZ indicated with $\mathbf{P_c}$
5. Kappa coefficient defined in terms of the elements of the confusion matrix; represented by xij, total number of test pixels (Observations) represented in the confusion matrix is P,

   All the details are represented in chapter four on Table 4.1, Table 4.2 and Table 4.3

3.4 Effects of the Urban Spatial Features on the Land Surface Temperature of the Study Areas

3.4.1 *N*ormalized difference vegetation index (NDVI)

Normalised Difference Vegetation Index (NDVI) is an index describing vegetation by showing the difference between near-infrared, which is strongly reflected by vegetation and red light which is absorbed by vegetation. The NDVI map was created in ArcGIS 10.2 environment using the satellite Image. Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) absorbs more visible light (red). This was why NDVI map was chosen for this study because it uses NIR and Red channels to measure healthy vegetation and identify the locations of green spaces in the study areas.

The formula for calculating NDVI is:

$$NDVI = \frac{NIR-Red}{NIR+Red} \qquad (3.1)$$

Where NIR (Near Infrared band) represent band 5 in Landsat 8 OLI image and the Red band is band 4 of the same image.

3.4.2 Normalized difference built-up index (NDBI)

The Normalized Difference Built-up Index (NDBI) provides indices to strengthen building information and extraction of built-up from urban areas. It represents the reflectivity of urban building and it is higher in the Middle Infrared (MIR) band than the Near Infrared band. The following formula was used in calculating the NDBI, equation 3.2:

$$NDBI = \frac{SWIR-NIR}{SWIR+NIR} \quad (3.2)$$

Where:

SWIR represents the Short wave Infrared band of the satellite image

NIR represents the Near Infrared band of the satellite image.

3.4.3 Generation of the thermal map of the study area

Thermal map of the study areas was generated in ArcGIS 10.2 software. This map is necessary for identifying the heat distribution of the study areas. The thermal map was generated using the thermal bands of Landsat 8 Operational Land Imager (OLI) of the study areas and the land surface temperature (LST) of the study areas was calculated. The first step to be taken was to convert the Digital Numbers (DN) on the imageries to Radiance and the calculated radiance value was used to generate the Satellite Brightness Temperature that gives the temperature on the satellite whereas the needed Land Surface Temperature was derived with the values of the calculated Satellite Brightness Temperature to generate the thermal maps of the study area.

The procedure include conversion of the Digital Numbers (DN) on the imageries to Radiance values using the formula in equation 3.3

$$L_\lambda = M_L Q_{cal} + A_L \quad (3.3)$$

Where:

L_λ = Top of the Atmosphere (TOA) Spectral Radiance (Watts/ (m2 * srad *))

M_L = Band-specific multiplicative recalling factors from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L = Band-specific additive recalling factors from the metadata

Q_{cal} = Quantized and calibrated standard product pixelvalues (DN)

The Radiance calculated above was then used to generate the Satellite Brightness Temperature using the formula in equation 3.4

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L\lambda}+1\right)} \qquad (3.4)$$

Where:

T = At-Satellite brightness temperature (K)

K_1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the band number, 10)

K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the band number, 10)

But this gives the temperature on the satellite whereas land surface temperature needed was derived in the next step calculated using the formula in equation v:

Land Surface Temperature = BT/1 + w * (BT/p) * ln (e)) (3.5)

Where:

BT = At Satellite Temperature

w = wavelength of emitted radiance (11.5µm)

p = h * c/s (1.438 * 10^-2 m K)

h = Planck's constant (6.626 * 10^-34 Js)

s = Boltzmann constant (1.38 * 10^-23 J/K)

c = Velocity of light (2.998 * 10^8 m/s

With these processes, the thermal map (LST) of the study areas was generated so as to know the Heat Distributions of the study areas. The results of the NDVI, NDBI and LST were generated both in maps and tables and their values copied from ArcGIS to Microsoft Excel for further preparation in excel and copied to Statistical Package for

Social Sciences (SPSS) software package for further analysis to address the hypothesis 1 and 2 and also to achieve the second objective; further details can be seen in chapter four.

The Normalized Difference Vegetation Index (NDVI) is a commonly used measurement but standardized permitting the researchers to come up with image showing relative biomass (greenness). This index takes the advantage of the distinction of the features of 2 bands of multi spectral formation datasets. The chlorophyll pigment absorption within the red band coupled with the high reflectivity of plant materials within the near-infrared (NIR) band. An NDVI is commonly used globally to study drought occurrence, monitor and judge agricultural production, and map desert encroachment. Popularly, NDVI is used for worldwide vegetation monitoring as a result of it helps complete ever-changing illumination conditions, surface slope, aspect, and other factors.

The differential reflection within the red and infrared (IR) bands permits the observer to monitor the density and intensity of green vegetation growth applying the spectral reflectivity of radiation. Green leaves normally show higher reflection within the near-infrared wavelength band than in visible wavelength bands. When leaves are water-stressed, diseased, or dead, they become yellow and reflect considerably less within the near-infrared range. On the other hand, clouds, water, and snow show higher reflection within the visible range than within the near-infrared range which also indicates low NDVI values, whereas the distinction is nearly zero for rock and exposed soil. The NDVI method creates a single-band datasets that in the main represents greenery variations. The negative values represent clouds, water, and snow, and values close to zero represent rock and exposed soil.

For the purpose of this research, NDVI interpretation by NASA (Figure 3.3) and Sara Antognelli (Figure 3.4) were adapted and modified into four landuse classes; the tables show the interpretation of the different values of vegetation indices.

Table 3.4 NDVI Interpretation

NDVI Value	Interpretation
0.0 – 0.1	Bare soil
0.1 – 0.2	Almost absent canopy cover
0.2 – 0.3	Very low canopy cover
0.3 – 0.4	Low canopy cover, low vigour or very low canopy cover, high vigour
0.4 – 0.5	Mid-low canopy cover, low vigour or low canopy
0.5 – 0.6	Average canopy cover, low vigour of mid-low canopy cover, high vigour
0.6 – 0.7	Mid-high canopy cover, low vigour or average
0.7 – 0.8	High canopy cover, high vigour
0.8 – 0.9	Very high canopy cover, very high vigour
0.9 – 1.0	Total canopy cover, very high vigour

Source: Sara Antognelli, https://www.agricolus.com/en/indici-vegetazione-ndvi-ndmi-istruzioni-luso/

Table 3.5 NDVI Interpretation by NASA

Value	Interpretation
0.1 and below	correspond to barren areas of rock, sand, or snow
0.2 to 0.3	represent shrub and grassland
0.6 to 0.8	temperate and tropical rainforests

Source: https://earthobservatory.nasa.gov/features/MeasuringVegetation

3.5 Developing Urban Climate Analysis Map and Urban Recommendation Map

Table 3.7 Selected Parameters and their Impacts on the Urban Environment

Physical Urban Environment	Selected Factors for Analysis	Impact on Urban Environment
Thermal Environment	Topography	Negative effect on Thermal Load
	Population Density	Positive effect on Thermal Load
	Land Use (built up areas)	Positive effect on Thermal Load
	UHI Intensity	Positive effect on Thermal Load
	Natural Landscape (greenery, open space, forest)	Negative effect on Thermal Load
Wind Environment	Water System (Sea, river, lake, pond)	Negative effect on Thermal Load
	Prevailing wind direction	Wind Information
	Local wind circulation (Land and sea breezes)	Wind Information

Source: Ng and Ren (2015)

3.5.1 Procedures and data collection

This study was carried out using a Geographic Information System (GIS) as the platform of the data. This is because GIS platforms ensures that city planners can assess and use the data eventually, since GIS has been used as working tool of the city planners; the flow of the work was summarized in Figure 3.9. The required data which include meteorological data, landuse data, population data and climate data collected on the first note from various sources. The data were then collated and input layers were developed based on data analysis and evaluation. The impact of the selected parameters on physical environment were taken into account when the development of the layers were conducted Table 3.7. And so, these input layers were synergized and merged in order to develop the Urban Climate Analysis Map (UCAM) for the study areas.

The map was made up of various climatopes that spatially stand for thermal conditions coupled with the wind environment. Based on the understanding of UCAM, areas of problems and sensitive areas were identified and due to that, a number of general urban climatic planning recommendations summarized into the Urban Recommendation Map (URM). Urban Environmental Climate Map (UECM) involves both the Urban Climate Analysis Map (UCAM) and Urban Recommendation Map (URM).

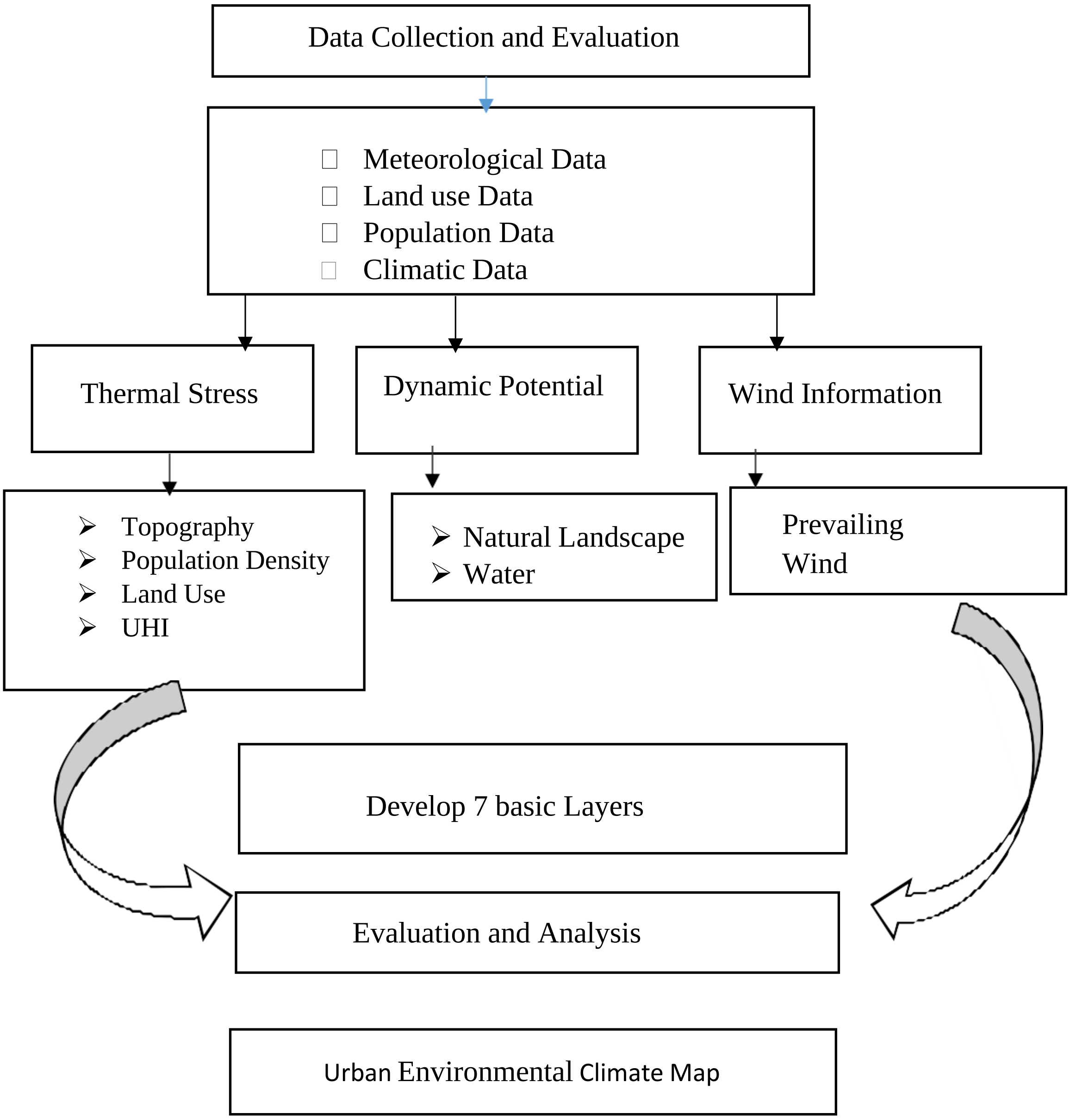

Figure 3.9 Main Procedures of the Urban Environmental Climate Map Study

Source: Author, 2021

4

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Identification and Mapping the Local Climate Zones (LCZ)

4.1.1 Local climate zones of Kaduna state

The LCZ map of Kaduna State is seen on Figure 4.1 while the Land use land cover (LULC) map of the state is seen on Figure 4.3 and Figure 4.4 for the years 1988 and 2018 respectively. The maps show the morphology characteristics of rural and urban area and also detect the potential Urban Heat Island (UHI) distribution pattern of the entire Kaduna State. Also for the 2018, it can be seen that only five built LCZ types were classified for Kaduna city covering just 4.46 percentage of the entire state while the entire land cover types of the LCZ were covered with LCZ A – dense trees (otherwise denoted as LCZ 101) covered 33.48 percentage of the entire state; and by low plants (LCZ D or LCZ 104) 23.04 percentage; bare rock/pave (LCZ E or LCZ 105) covered 24.56 percentage and others in their different area coverage as indicated on Figure 4.2., the major variation in coverage of the different LCZ type is also presented on Figure 4.2 that shows the coverage in hectares across the study area.

The entire municipal area are mainly classified as compact low-rise (LCZ 3), Open Low-rise (LCZ 6) and Lightweight Low-rise (LCZ 7) representing 0.08 percentage, 1.73 percentage and 0.48 percentage.

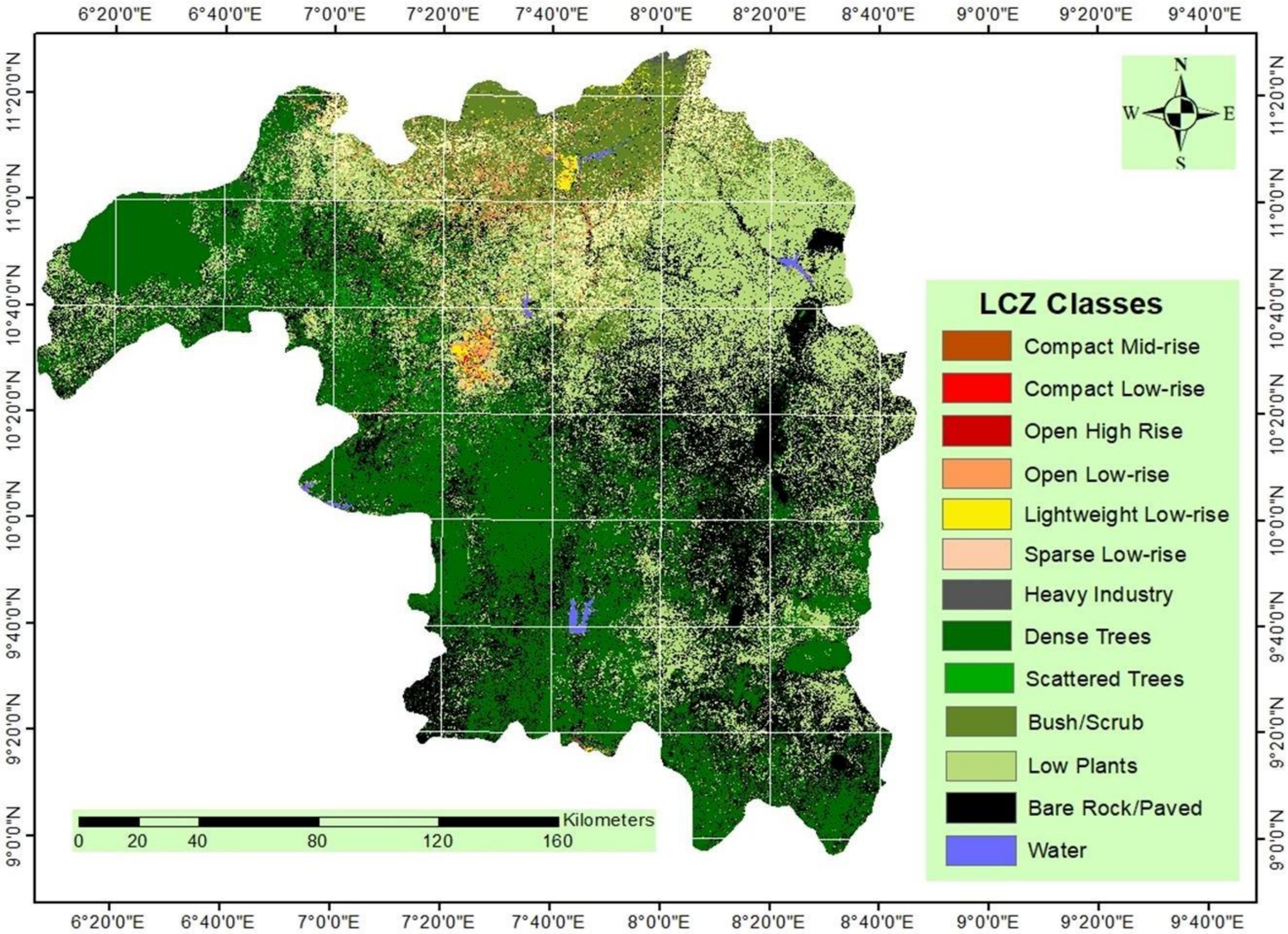

Figure 4.1 Local Climate Zones of Kaduna for 2018

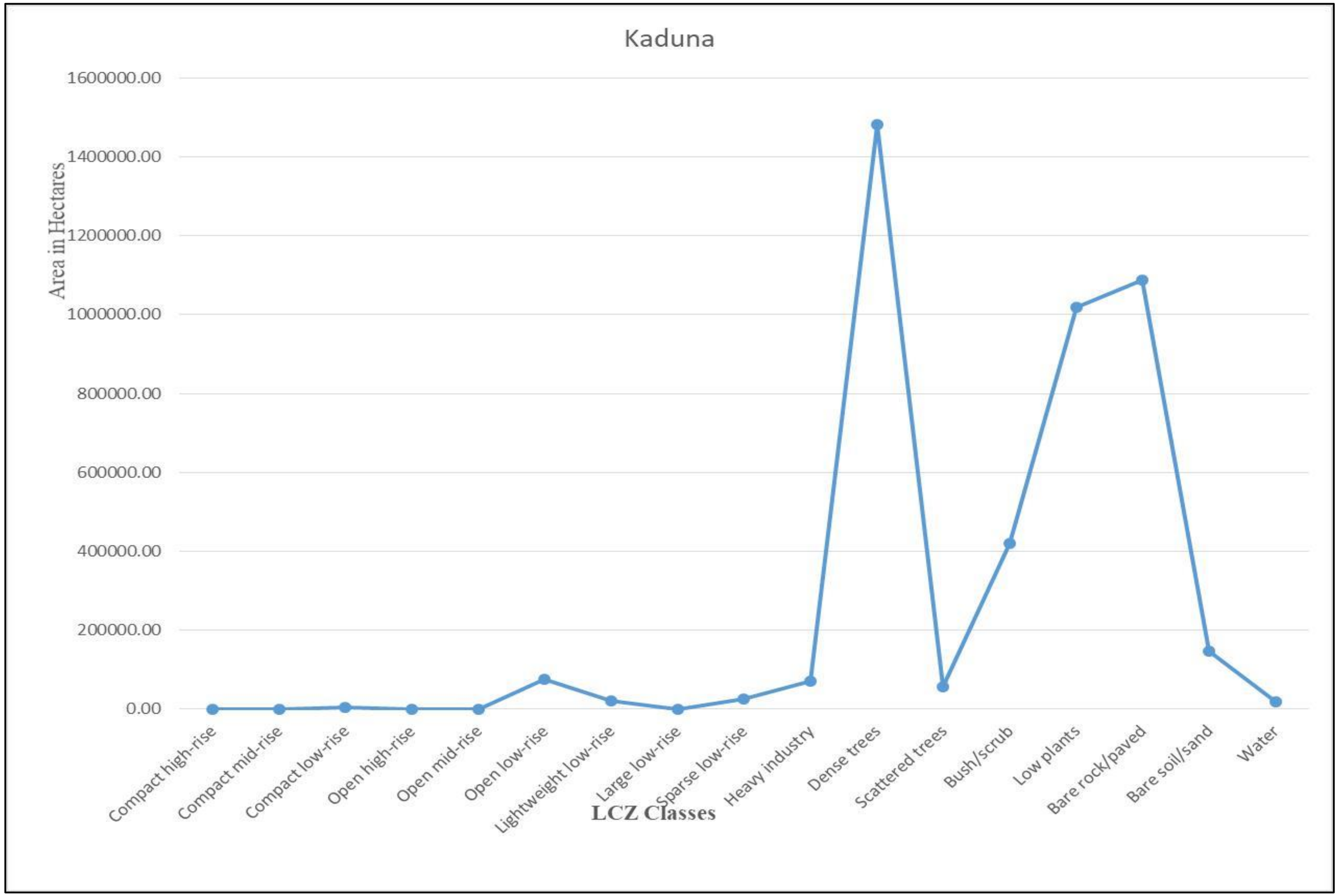

Figure 4.2 Local Climate Zone Classification of Kaduna for 2018

respectively. Rural areas area classified as Sparsely Built (LCZ 9) 0.59 percentage while other areas classified as Heavy Industries (LCZ 10) covered 1.57 percentage of the entire built up areas. The LCZ classification is illustrated using Figure 4.2 and the table showing the area statistics of the local climate zones in Kaduna is in Appendix I.

On the other hand, the LULC classification was carried out for 1988 and 2018, an interval of 30 years as indicated on Figure 4.3 and Figure 4.4. The LULC area statistics on Table in Appendix H also showed the different land cover in hectares along with the percentage coverage for each land cover classes in both years. Built-up which is the main target of this research increased from 11.84 percentage in 1988 to 20.80 percentage in 2018, while Agricultural land also showed an increasing trend from 26.70 percentage in 1988 to 35.58 percentage in 2018. Forest and vegetation cover showed a decreasing trend from 25.16 percentage in 1988 to 14.85 percentage in 2018 and 26.5 percentage in 1988 to 20.09 percentage in 2018 respectively. The LULC in Kaduna State and the magnitude of change between the two periods are illustrated on Figure 4.5a and Figure 4.5b.

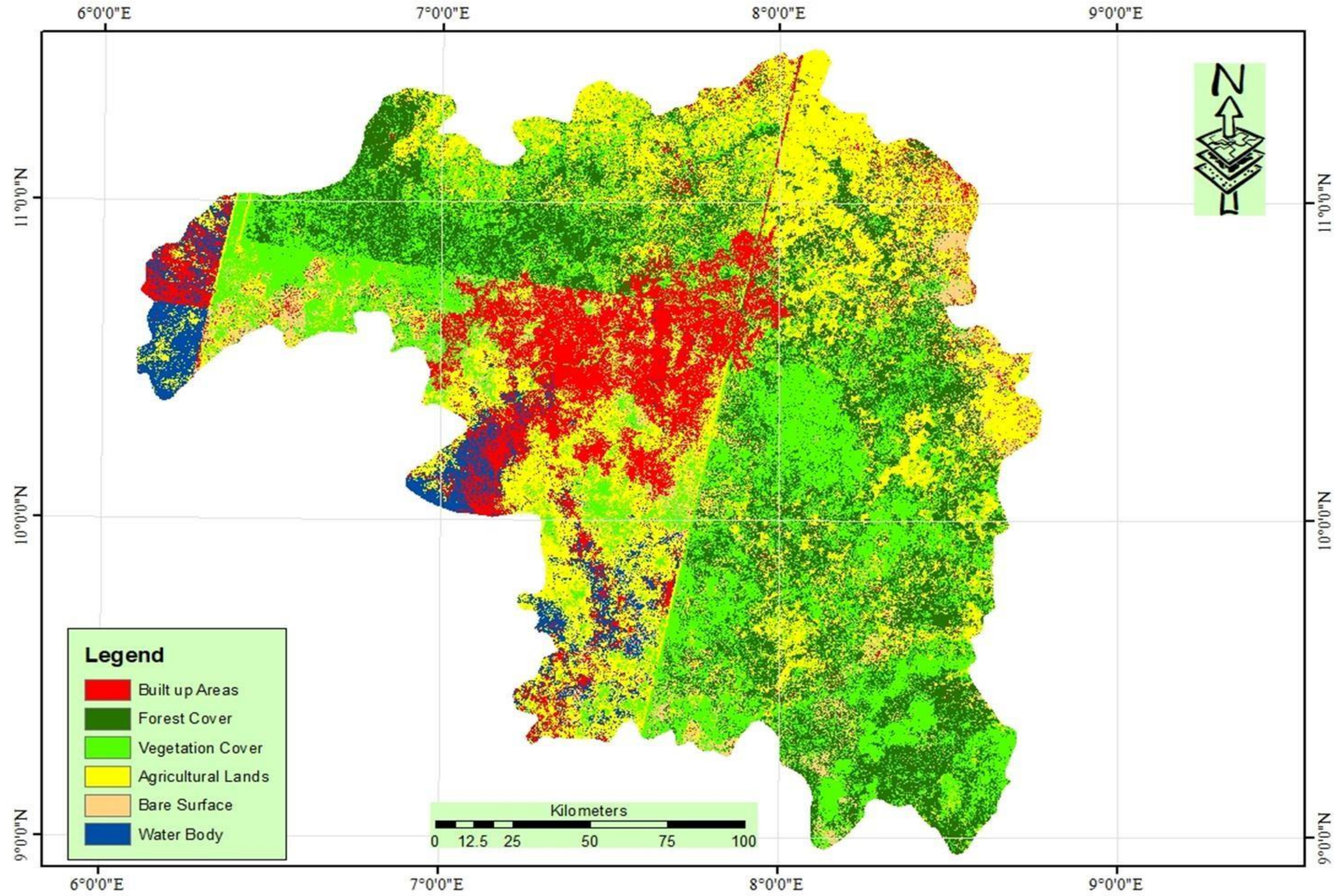

Figure 4.3 LULC of Kaduna for 1988

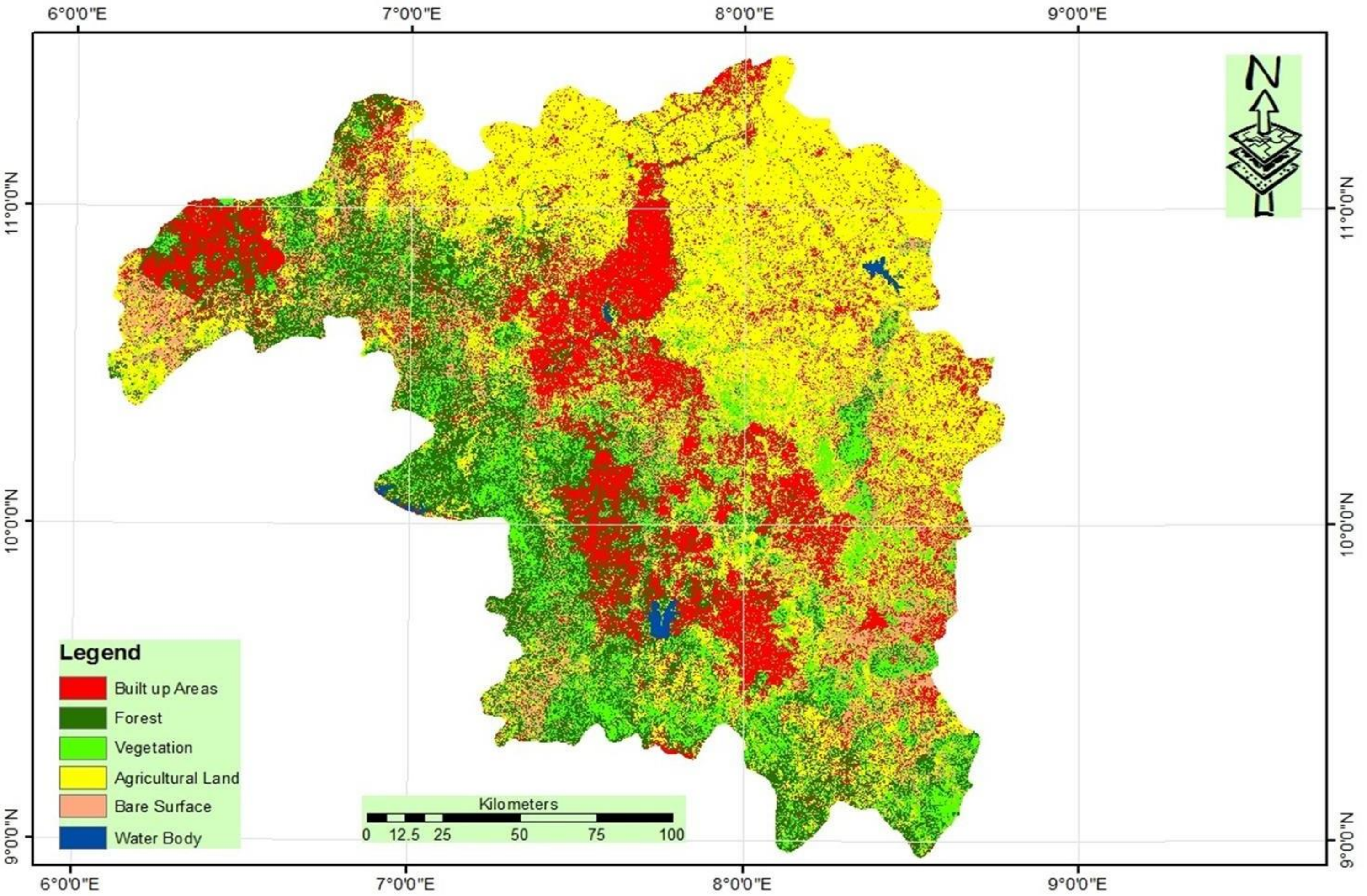

Figure 4.4 LULC of Kaduna for 2018

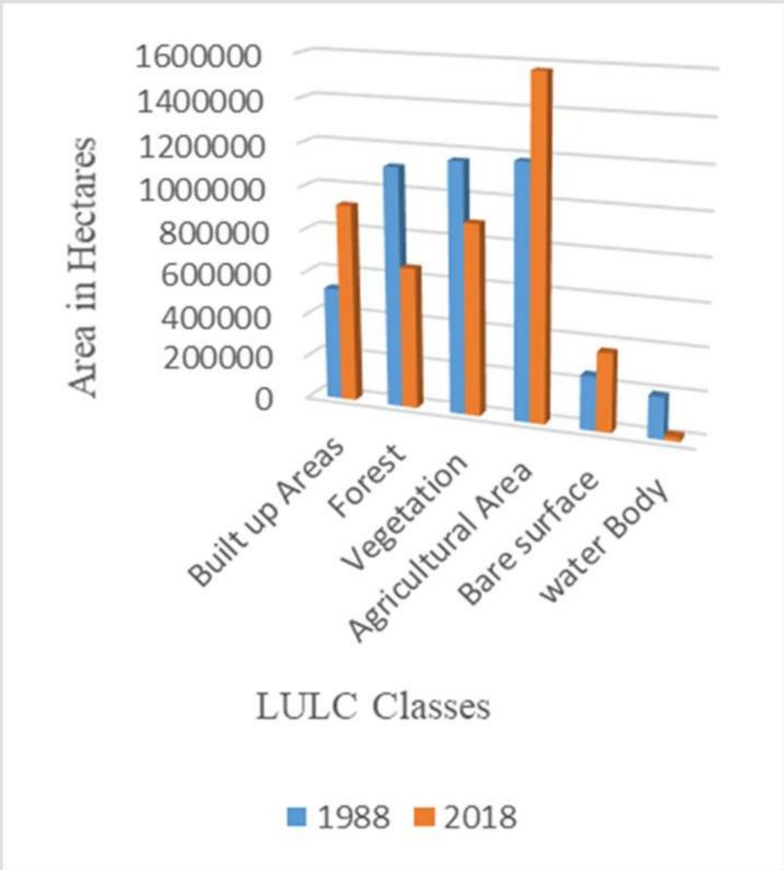

Figure 4.5a: LULC Classes in Kaduna

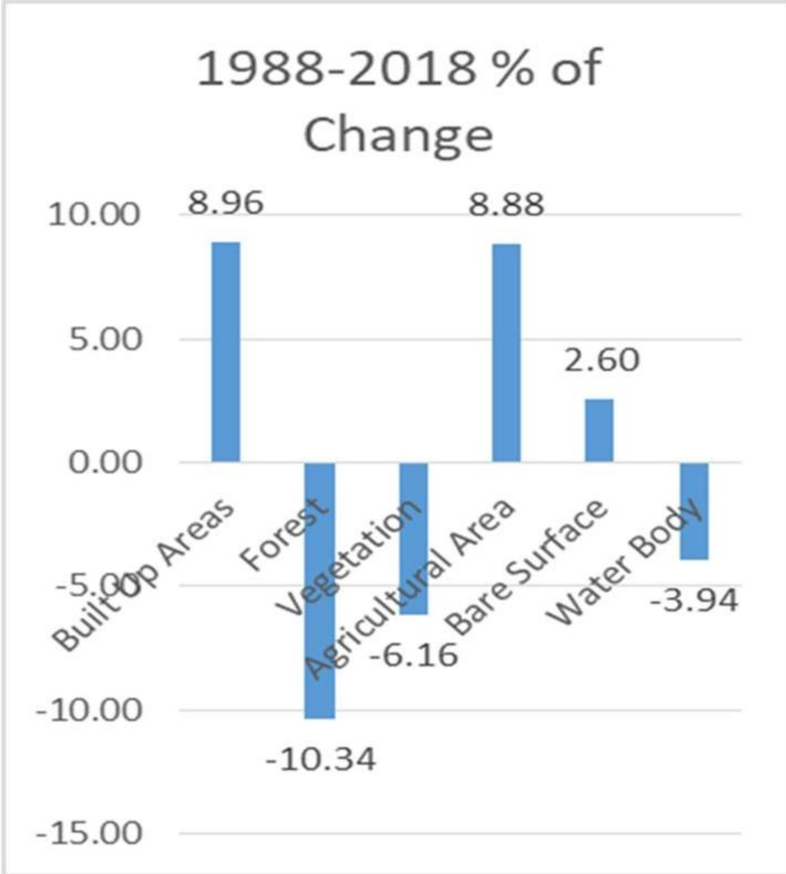

Figure 4.5b: LULC Percentage Change (1988 & 2018)

4.1.2 Local climate zones of the Federal Capital Territory (FCT)

The LCZ map of FCT is also seen on Figure 4.6 while the Land use land cover (LULC) map of the state is seen on Figure 4.8 and Figure 4.9 for the years 1988 and 2018 respectively. The maps show the morphology characteristics of rural and urban area and also detect the potential Urban Heat Island (UHI) distribution pattern of the Federal Capital Territory. The LULC maps covered six classification scheme just like Kaduna State such as built up areas, forest, vegetation, agricultural land bare surface and water body; while LCZ map covered seventeen land cover classes known as Local Climate Zones which divides land cover types into two broad groups such as built type and land cover types. In the case of the FCT, seven built LCZ types were classified covering a total of 11.23 percentage of the entire state while only one land cover types of the LCZ was not covered. LCZ 103 (LCZ C) has the highest coverage with 30.8 percentage, followed by scattered trees (LCZ 102) with 27.28 percentage coverage and then low plants (LCZ D or LCZ 104) 20.23 percentage all others in their different area coverage are indicated on the area statistic Table in appendix section.

The LCZ classified as built types were illustrated in Figure 4.7 and appendix K, very few built up areas were classified as compact high rise (LCZ 2) covering just 0.01 percentage, while 3.41 percentage were classified as compact low rise (LCZ 3), open high rise (LCZ 4) – 0.17 percentage; open low rise (LCZ 6) – 0.11 percentage; lightweight low rise (LCZ 7) – 1.71 percentage and industry (LCZ 10) – 5.07 percentage.

Just like the case in Kaduna, LULC classification was also carried out for 1988 and 2018 in FCT also with interval of 30 years as indicated on the maps on Figure 4.8 and Figure 4.9. The LULC area statistics on Table in appendix section also showed the different land cover in hectares along with the percentage coverage for each land cover classes in both years for FCT. Built-up which is the main target of this research increased from 11.29 percentage in 1988 to 22.60 in 2018, and also forest from 17.49 percentage in 1988 to 23.63 percentage in 2018. Vegetation cover and agricultural land showed a decreasing trend from 22.52 percentage in 1988 to 17.64 percentage in 2018 and 40.11 percentage in 1988 to 31.32 percentage in 2018 respectively, while water body remain almost constant. The LULC in FCT and the magnitude of change between the two period (1988 and 2018) are illustrated on Figure 4.10a and Figure 10b.

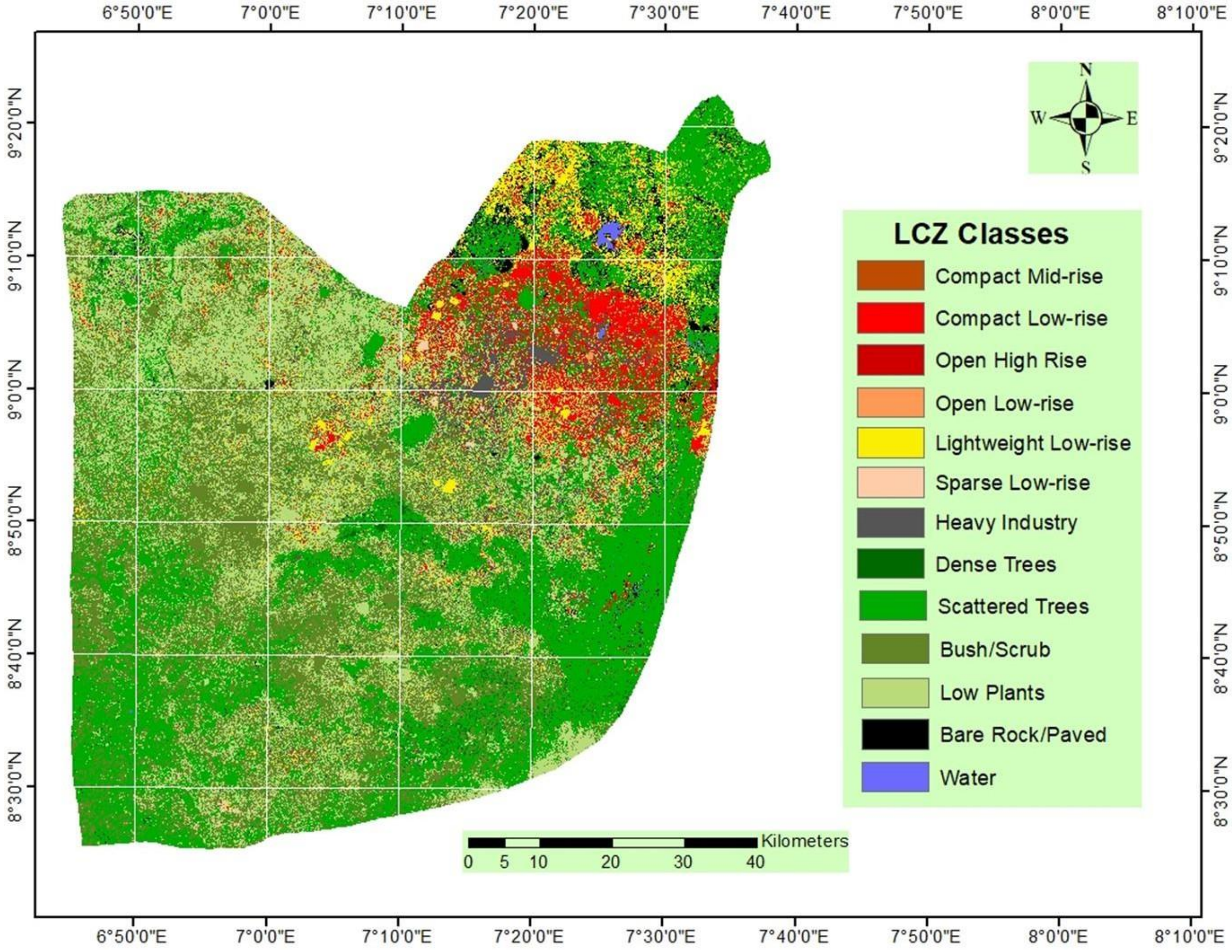

Figure 4.6 Local Climate Zone of FCT for 2018

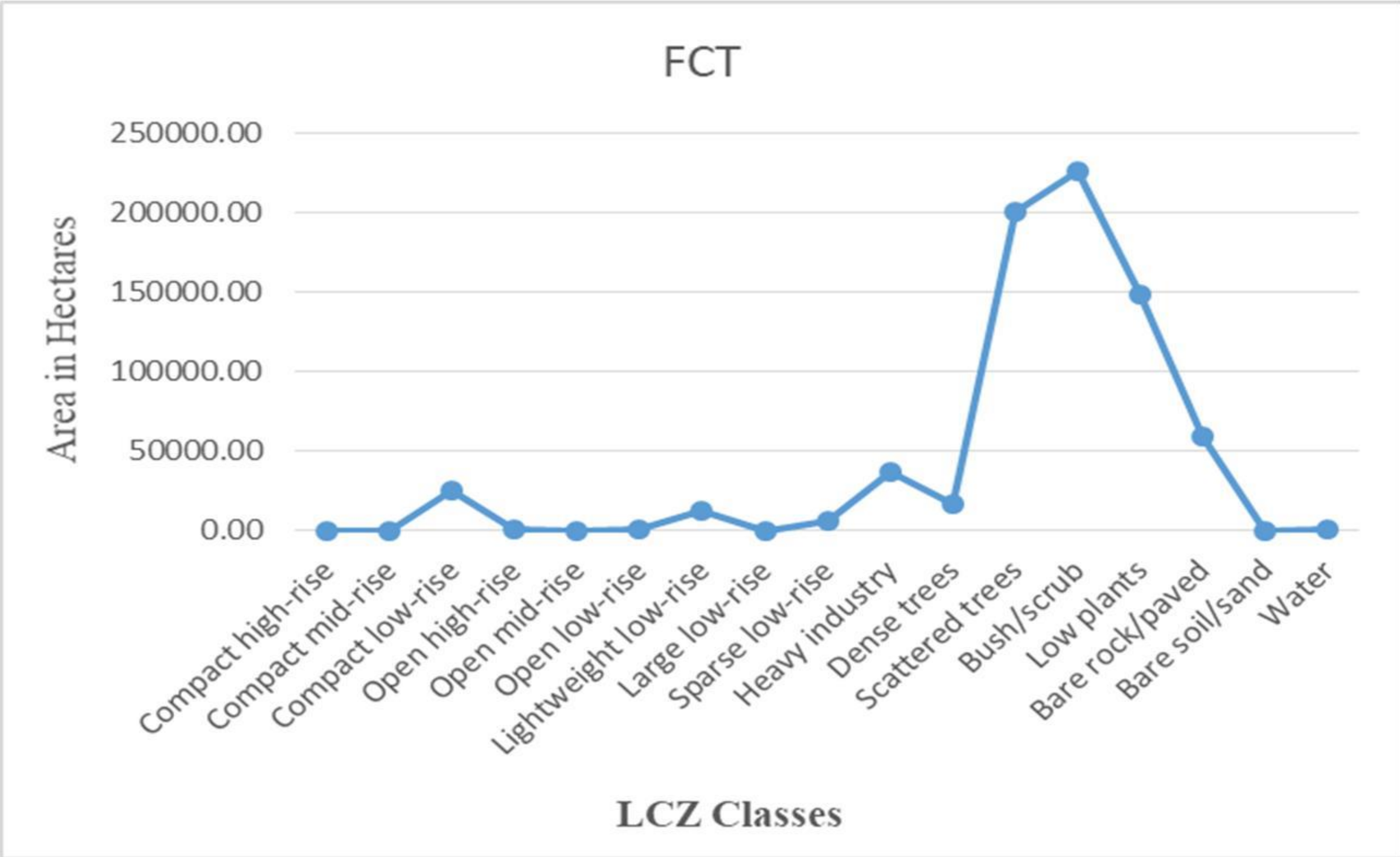

Figure 4.7 Local Climate Zone Classification of FCT for 2018

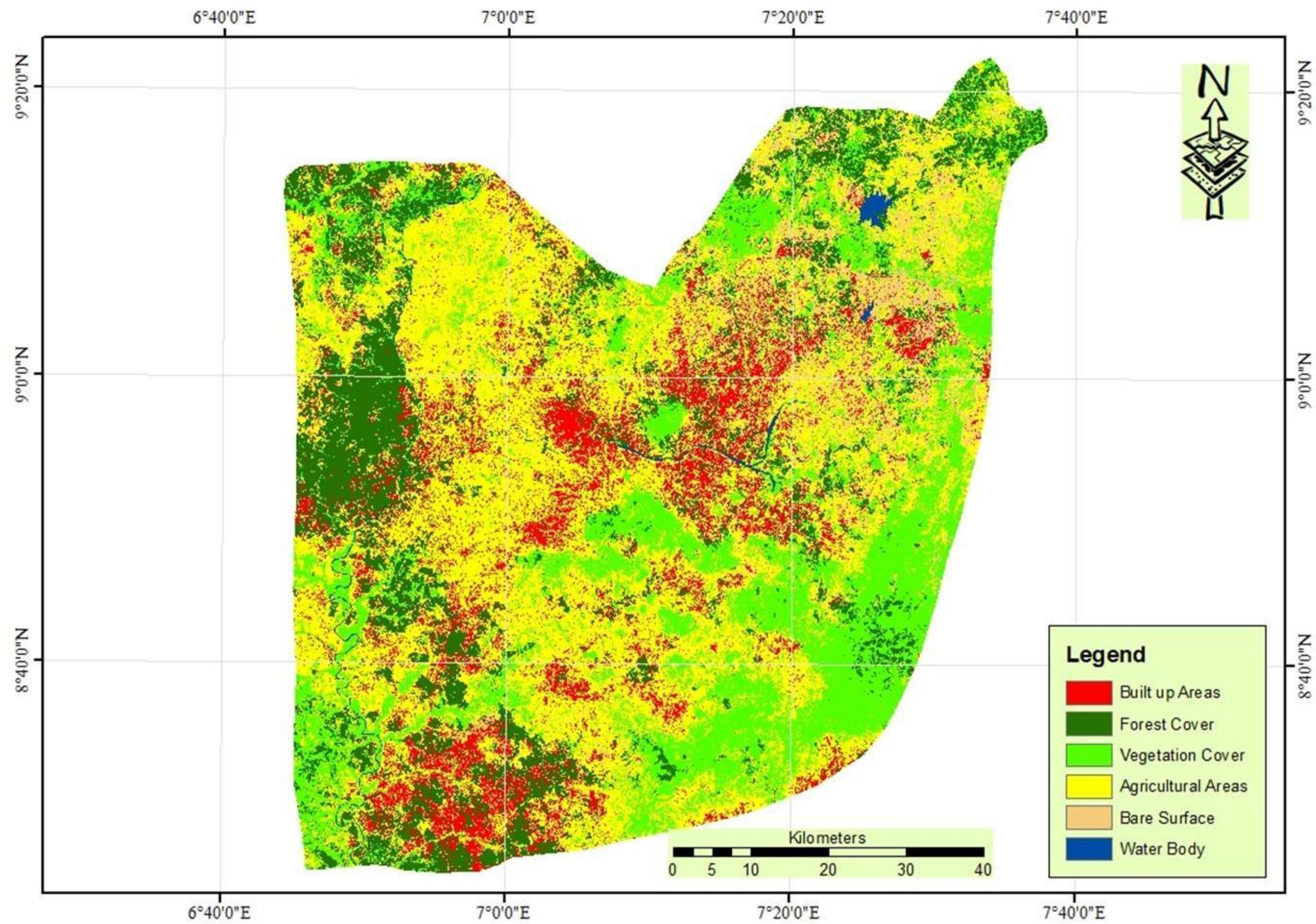

Figure 4.8 LULC of FCT for 1988

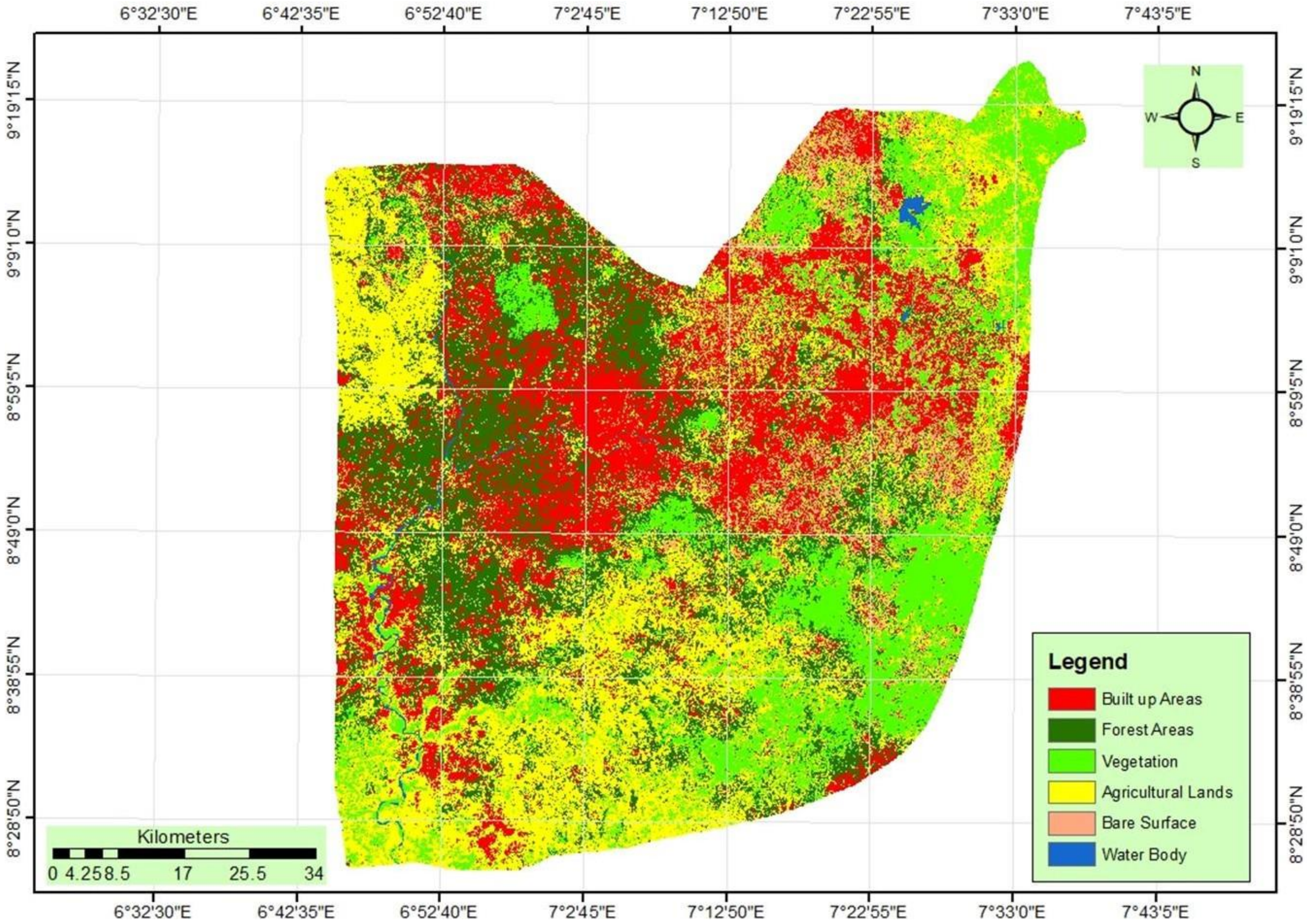

Figure 4.9 LULC of FCT for 2018

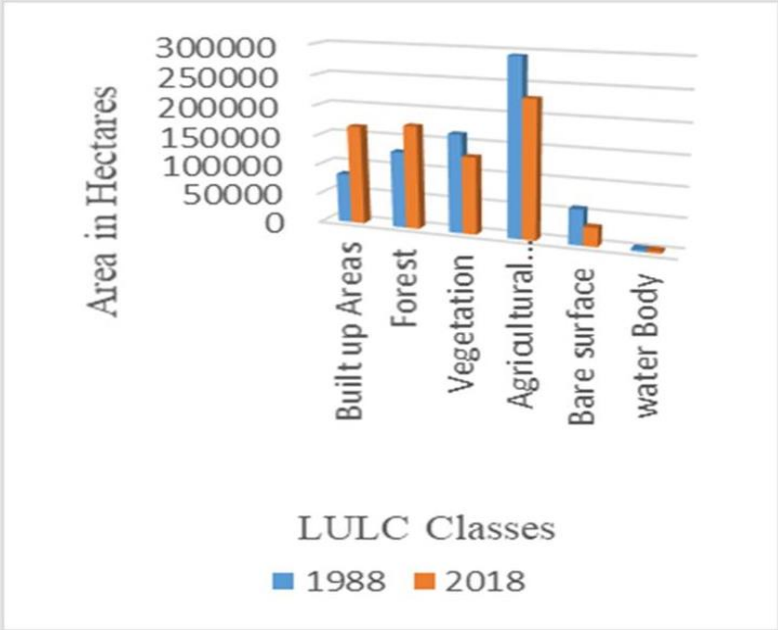

Figure 10a LULC Classes in FCT

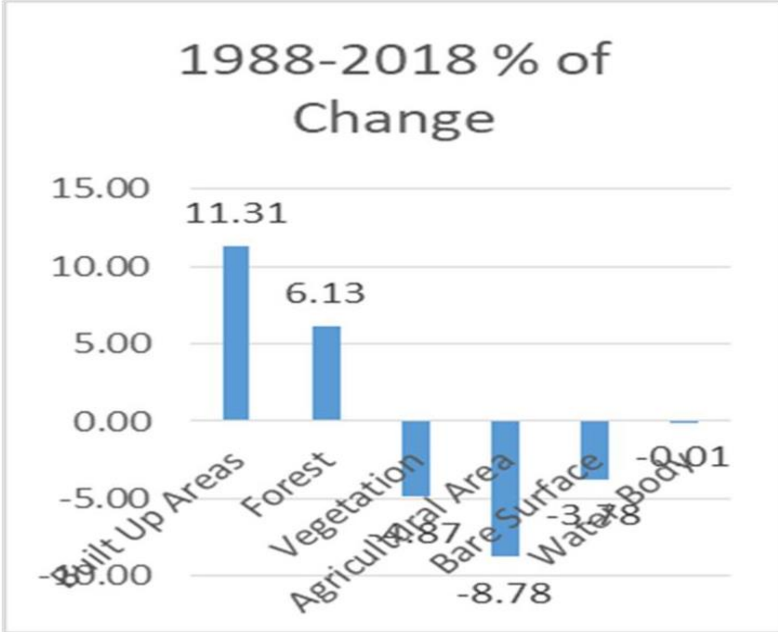

Figure 10b LULC Percentage Change (1988 & 2018)

4.1.3 Local climate zones of Kano state

The Land use land cover (LULC) map of Kano state on Figure 4.13 and Figure 4.14 for the years 1988 and 2018 respectively while the LCZ map of Kano as indicated on Figure 4.11. The three maps showed the morphology characteristics of rural and urban area in Kano state and also detected the potential Urban Heat Island (UHI) distribution pattern of the state. The LULC maps covered six classification scheme just like other states such as built up areas, forest, vegetation, agricultural land bare surface and water body; while LCZ map covered seventeen land cover classes known as Local Climate Zones which divides land cover types into two broad groups such as built type and land cover types. In the case of Kano, only four built LCZ types were classified covering a total of 5.04 percentage of the entire Kano state and five land cover types of the LCZ were covered representing the remaining 96.94 percentage of the entire State (Figure 4.11)

The LCZ classified as built type was illustrated in Figure 4.12 apart from the breakdown on statistical on appendix M. The classified built up involves compact low-rise (LCZ 3) 0.1 percentage, lightweight low-rise (LCZ 7) covering 1.83 percentage, sparse low-rise (LCZ 9) 0.71 percentage and industry (LCZ 10) 2.40 percentage respectively.

Just like the case in Kaduna, LULC classification was also carried out for 1988 and 2018 in Kano State also with interval of 30 years as indicated on the maps on Figure 4.13 and Figure 4.14. The LULC area statistics table in Appendix J also showed the different land cover in hectares along with the percentage coverage for each land cover classes in both years for Kano State. Built-up which is the main target of this research increased from 9.56 percentage in 1988 to 20.79 in 2018, forest decreased from 7.79

percentage in 1988 to 4.91 percentage in 2018.. Vegetation cover from 31.41 percentage in 1988 to 15.67 percentage in 2018; agricultural land also showed a decreasing trend from 37.55 percentage in 1988 to 44.41 percentage in 2018. Water and bare surface also showed a slight increase in the two study period as indicated on the table in the appendix J. The LULC in Kano State and the magnitude of change between the two periods were illustrated on Figure 4.15a and Figure 4.15b.

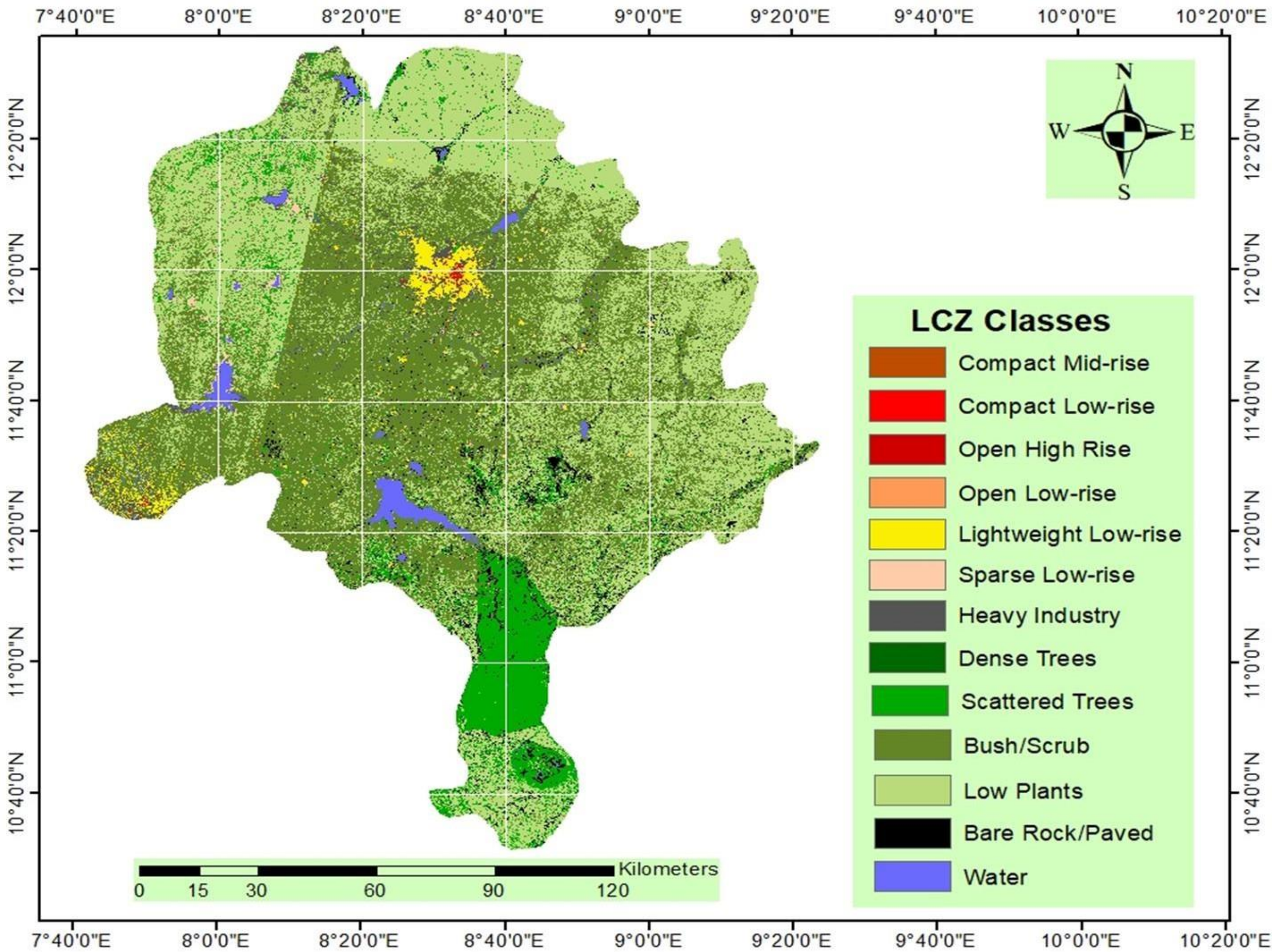

Figure 4.11 Local Climate Zones of Kano for 2018

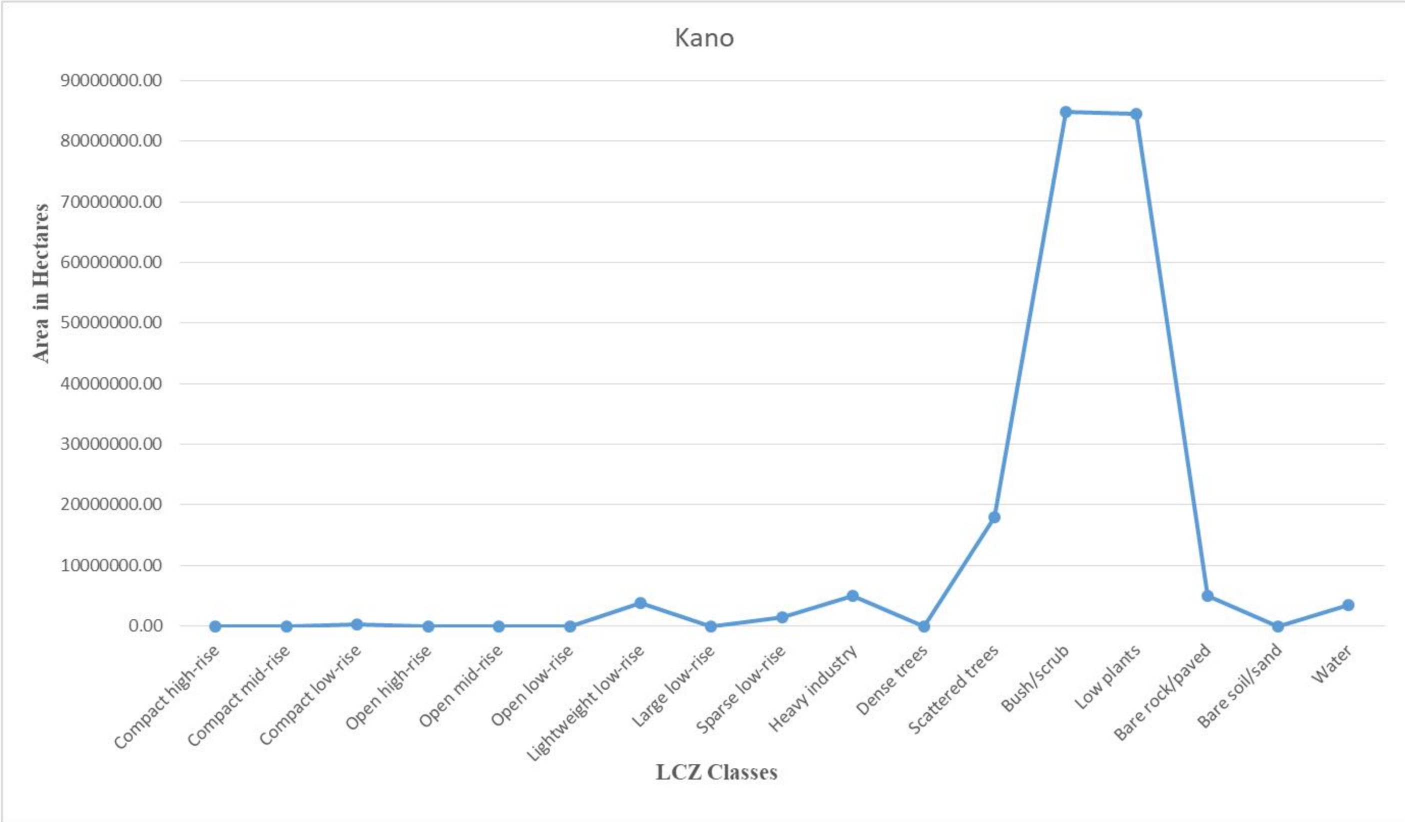

Figure 4.12 Local Climate Zone Classification of Kano for 2018

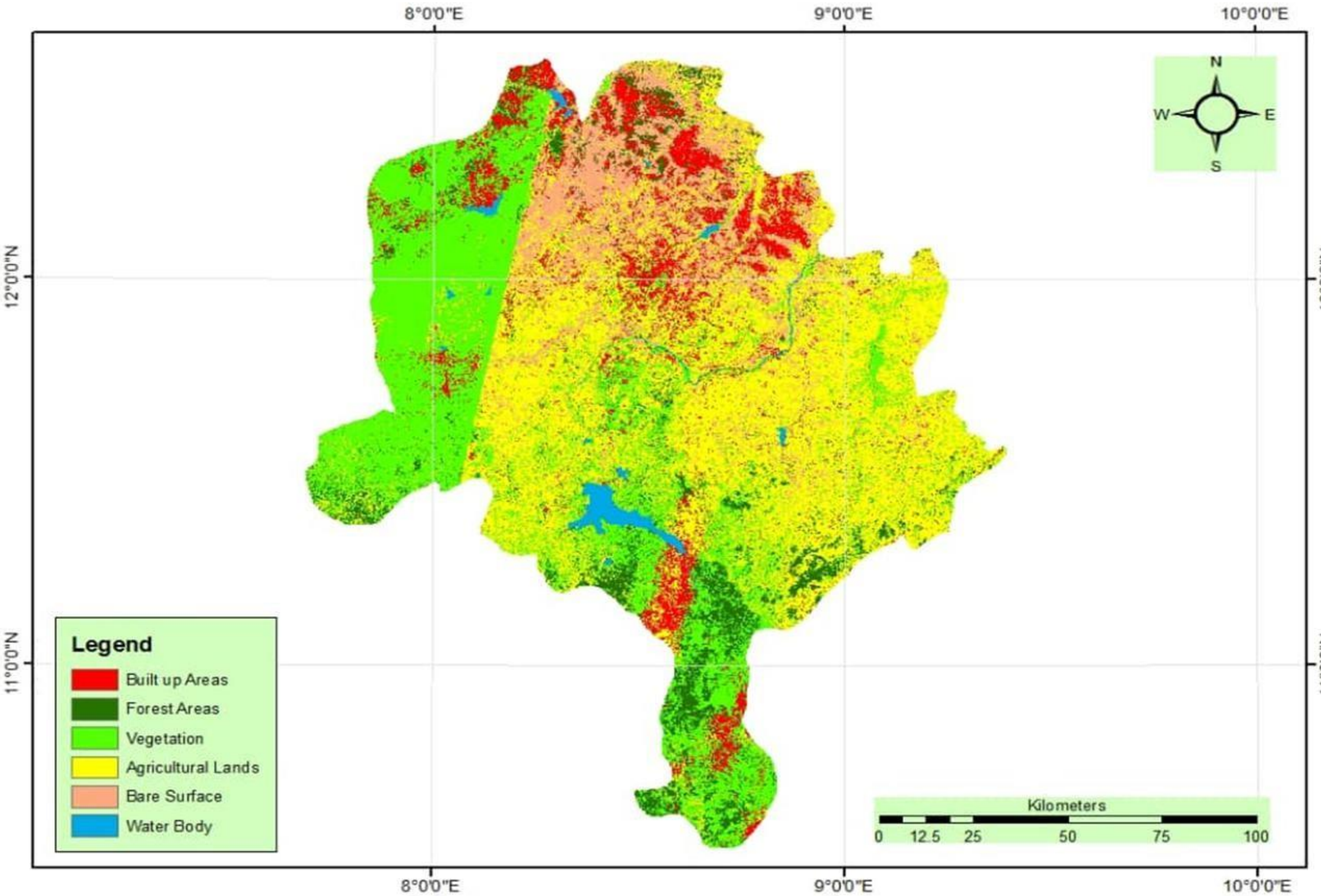

Figure 4.13 LULC of Kano for 1988

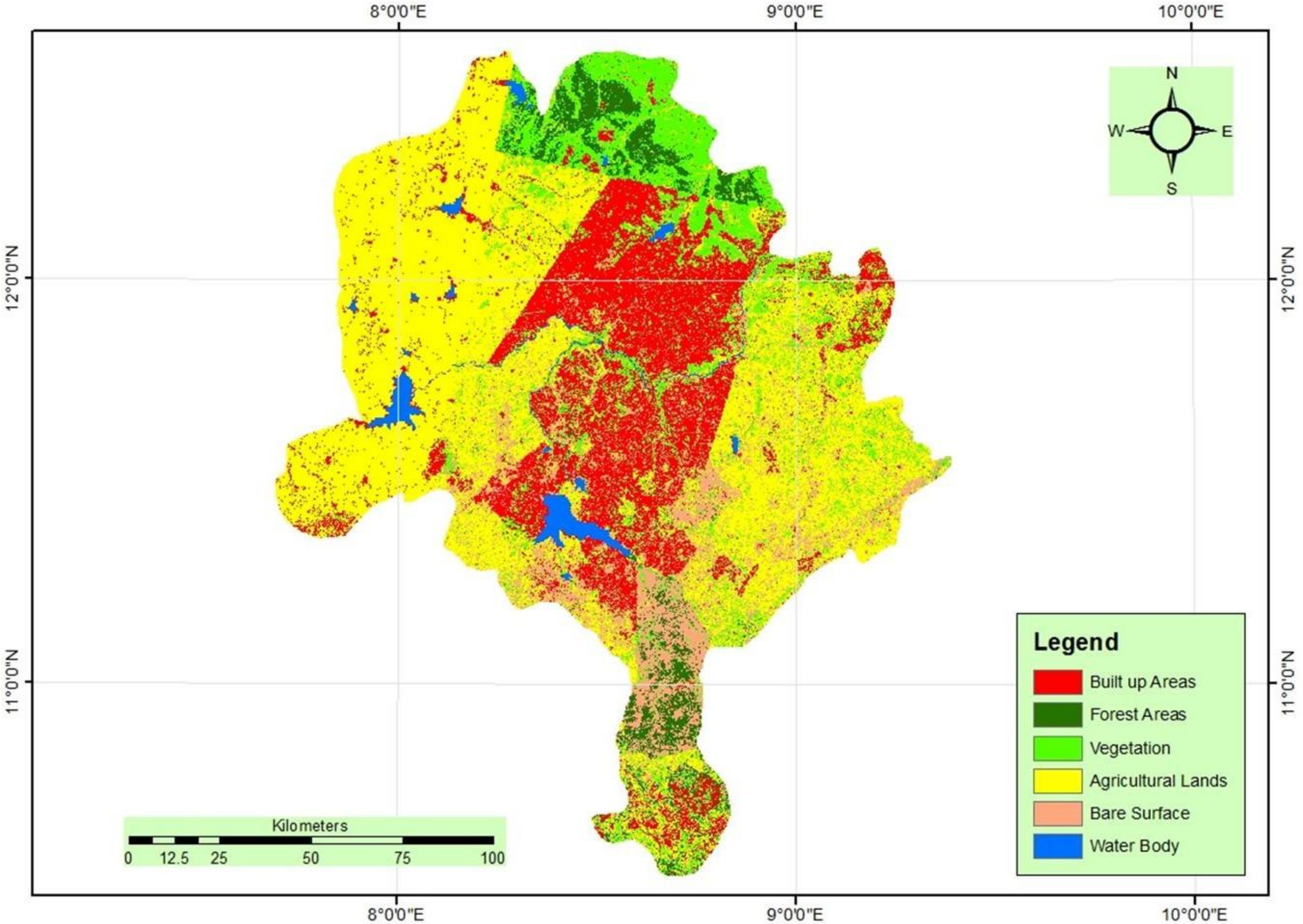

Figure 4.14 LULC of Kano for 2018

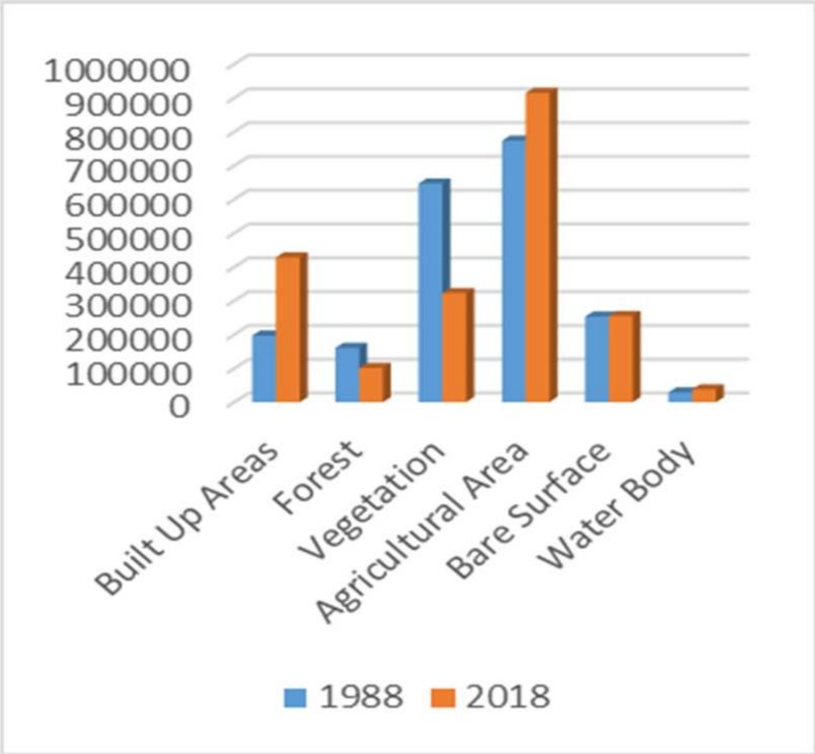

Figure 4.15a LULC Classes in Kano

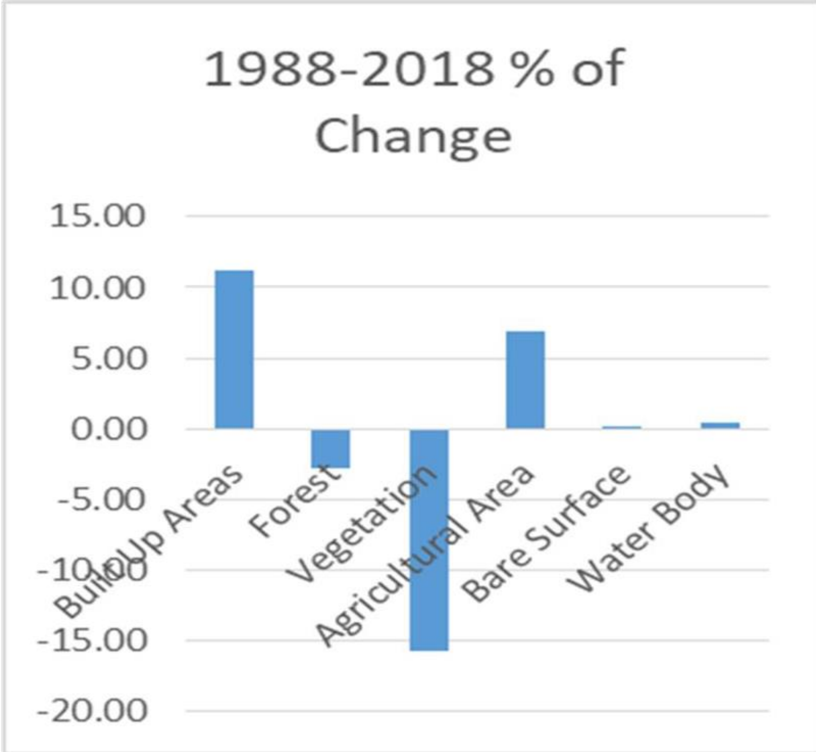

Figure 4.15b LULC Percentage Change (1988 and 2018)

4.1.4 Accuracy assessment of LCZ classification

The overall accuracy was 84.69 percentage and Kappa Coefficient was 0.964 for Kaduna as seen on Table 4.1. The overall accuracy was 88.76 percentage and Kappa Coefficient is 0.995 for FCT, (Table 4.2) whereas the overall accuracy for Kano LCZ classification was 78.12 percentage and Kappa coefficient was 0.996 as reflected in Table 4.3 respectively. The result of the accuracy assessment for the cities of Kaduna and FCT demonstrated a better and satisfying result for the LCZ classification but Kano overall accuracy too is also within acceptable limit. It can be concluded that the WUDAPT level 0 method is credible and effective for conducting LCZ classification for Nigerian cities especially those that share similar urban morphological characteristics like those of Kaduna and FCT as can be seen clearly as compared to Kano.

The result of the producer and user's accuracy for the cities of Kaduna, FCT and Kano have relatively good accuracy for all the cities as shown in Table 4.1, Table 4.2 and Table 4.3. The confusion matrix also indicate that lightweight low-rise and sparse low-rise have the same accuracy for producer and user while open low-rise, scattered trees, bush, bare rock/paved and bare soil have higher users accuracy which was taken to be most adopted accuracy (John *et al.*, 2005). On the other hand the error matrix for FCT indicate that heavy industry, dense trees, low plants and water have higher users accuracy while the accuracy of compact low-rise, open high-rise, lightweight low-rise, scattered trees and low plants are also remarkably satisfactory. Dense trees and bare soil/sand show zero accuracy for Kaduna, the possible reason may be that limited information was provided by the training data which makes it difficult for the classification to be established in the Landsat image; image with better resolution can be the proactive way out to such cases. The case of Kano was not showing a different trend because both producer and user's accuracy showed satisfying results within acceptable limit.

Table 4.1 Kaduna LCZ Confusion Matrix (2018)

LCZ	**3**	**6**	**7**	**9**	**10**	**101**	**102**	**103**	**104**	**105**	**106**	**107**	Total Reference Points	Users Accuracy
3	6	1	0	0	0	0	0	0	0	0	0	0	7	85.71
6	0	8	0	0	0	0	0	0	0	0	0	0	8	100.00
7	0	0	20	0	0	0	0	0	0	1	0	0	21	95.24
9	0	0	0	23	0	0	0	0	0	0	0	0	23	100.00
10	0	0	0	0	20	0	1	0	1	0	7	0	29	68.97
101	0	0	0	0	0	0	11	0	0	0	0	0	11	0.00
102	0	0	0	0	0	0	34	1	1	0	1	1	38	89.47
103	0	0	0	0	0	0	0	22	1	0	0	0	23	95.65
104	0	0	1	0	0	0	1	1	19	1	0	0	23	82.61
105	0	0	0	0	0	0	0	1	0	16	0	0	17	94.12
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
107	0	0	0	0	0	0	0	0	0	0	0	9	9	100.00
Total Classified Points	6	9	21	23	20	0	47	25	22	18	8	10	209	
Producers Accuracy	100.00	88.89	95.24	100.00	100.00	0.00	72.34	88.00	86.36	88.89	0.00	90.00		
Po	177													
Pc	4927													
Kappa	0.9643													
Overall Accuracy	84.689													

Source: Author (2018)

Table 4.2 Federal Capital Territory LCZ Confusion Matrix (2018)

LCZ	3	4	7	9	10	101	102	104	105	107	Total Reference Points	Users Accuracy
3	244	4	0	0	8	0	8	0	0	4	268	91.04
4	0	60	0	0	8	0	0	0	0	0	68	88.24
7	16	0	160	4	0	0	0	0	0	4	184	86.96
9	0	0	4	80	0	0	0	0	0	16	100	80.00
10	0	0	0	4	112	0	0	12	0	0	128	87.50
101	0	0	0	0	0	68	0	0	0	4	72	94.44
102	0	0	4	0	0	36	144	0	0	0	184	78.26
104	0	0	0	0	4	0	4	184	4	0	196	93.88
105	0	0	0	0	0	4	0	8	184	0	196	93.88
107	0	0	0	0	0	0	0	0	0	28	28	100.00
Total Classified Points	260	64	168	88	132	108	156	204	188	56	1424	
Producers Accuracy	93.85	93.75	95.24	90.91	84.85	62.96	92.31	90.20	97.87	50.00		
Po	1264											
Pc	245520											
Kappa	0.99486											
Overall Accuracy	88.764											

Source: Author (2018)

Table 4.3 Kano LCZ Confusion Matrix (2018)

LCZ	3	7	9	10	102	103	104	105	107	Total Reference Points	Users Accuracy
3	251	0	0	7	0	5	0	0	6	269	93.31
7	5	145	0	3	0	0	0	0	3	156	92.95
9	0	4	87	0	0	0	0	0	14	105	82.86
10	0	0	5	127	0	0	15	0	0	147	86.39
102	0	0	0	0	74	0	0	2	0	76	97.37
103	0	2	2	0	25	138	0	0	0	167	82.63
104	0	0	0	2	1	3	190	6	0	202	94.06
105	0	0	0	0	2	1	6	181	0	190	95.26
107	0	0	0	0	0	0	0	0	36	36	100.00
Total Classified Points	256	151	94	139	102	147	211	189	59	1348	
Producers Accuracy	98.05	96.03	92.55	91.37	72.55	93.88	90.05	95.77	61.02		
Po	1053										
Pc	235680										
Kappa	0.995536										
Overall Accuracy	78.11573										

Source: Author (2018)

4.1.5 Accuracy assessment results of LULC classification

Summer and Nordman (2008) acknowledged that accuracy assessment allows users to understand the reliability of a map through assigning a measure of validity to the map product in which the mapped classes capture conditions on the ground, this will enable potential users to determine how suitable a particular map is for any particular application.

The overall accuracy for Kaduna city was 88.07 percentage and 89.85 percentage for the years 1988 and 2018 respectively and the Kappa coefficient for the two period was 0.81 as indicated on Table 4.4., on the other hand Table 4.5 shows the overall accuracy for FCT which was 83.03 percentage and 89.90 percentage for the years 1988 and 2018 respectively and Kappa coefficient was 0.78 and 0.79 respectively for both years whereby for Kano study area, the overall accuracy for 1988 and 2018 are 82.83 percentage and 88.57 percentage and Kappa coefficient stand at 0.79 and 0.86 respectively, Table 4.6. The result of the LULC accuracy assessment for the three study cities (Kaduna, FCT and Kano) showed a satisfying result for LULC classification for Nigeria cities.

Table 4.4 Comparison of Classification Accuracy LULC Imagery in Kaduna

Class Name	1988		**2018**	
	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Built-up	87.16	85.87	89.87	88.79
Forest	88.62	89.90	92.21	90.20
Vegetation	89.07	88.70	93.72	91.04
Agricultural land	91.72	91.36	93.14	91.72
Bare surface	91.87	90.81	92.73	89.53
Water body	95.64	92.39	94.80	90.56
Overall Classification Accuracy (%)	**88.07**		**89.85**	
Overall Kappa	**0.81**		**0.81**	

Source: Author (2018)

Table 4.5 Comparison of Classification Accuracy LULC Imagery in FCT

Class Name	1988		2018	
	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Built-up	88.29	86.53	91.25	89.87
Forest	89.94	87.89	93.10	90.07
Vegetation	87.08	88.70	91.83	88.85
Agricultural land	87.48	81.1	95.68	90.86
Bare surface	88.56	95.2	92.68	86.96
Water body	90.04	90.39	90.40	89.56
Overall Classification Accuracy (%)	**83.03**		**89.90**	
Overall Kappa	**0.78**		**0.79**	

Source: Author (2018)

Table 4.6 Comparison of Classification Accuracy LULC Imagery in Kano

Class Name	1988		2018	
	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Built-up	87.50	80.33	84.22	79.54
Forest	85.45	83.93	83.67	80.29
Vegetation	84.52	81.63	87.04	83.50
Agricultural land	88.64	82.25	85.71	82.37
Bare surface	85.96	84.48	86.64	83.44
Water body	70.97	68.75	75.75	73.63
Overall Classification Accuracy (%)	**82.83**		**88.57**	
Overall Kappa	**0.79**		**0.86**	

Source: Author (2018)

The Relationship between LST, NDVI and NDBI in the Study Areas

4.2.1 Land surface temperature of Kaduna in 1988 and 2018

Land Surface Temperature (LST) map of Kaduna was presented on Figure 4.16 and Figure 4.17 for both 1988 and 2018 respectively. The LST ranges between 10.5134^{o}C and 62.837^{o}C in 1988 and 17.6719^{o}C and 59.5596^{o}C in 2018 in the entire state of Kaduna. The trend of the values of LST computed for the entire state in the two years also indicated on Figure 4.18 shows an increase in the minimum value of LST between 1988 and 2018 and a decrease in the maximum value of LST between the two periods. This result may be misleading because it contradict with the fact that an increase in population coupled with the development of towns and cities also serve as an important factor in the climate change. But this can be further substantiated with further research into the core urban instead of combining urban with rural at the same time.

On the other hand, Figures 4.19 to 4.22 also displayed the NDVI and NDBI of the entire Kaduna state for the two study periods while Tables 4.7 and 4.8 showed the correlation matrix between LST, NDVI and NDBI. The minimum and maximum values of the indices were compared to LST in the two study periods. This was carried out in order to analyze the relationship between the indices (NDVI and NDBI) and temperature in the study area using the Pearson moment correlation coefficient (r). SPSS package was used to run the correlation analysis and the results showed a perfect relationship between temperature and NDVI with r value of -1 and also a perfect relationship between temperature and NDBI with r value of +1. But in the case of NDVI, there was an inverse relationship, which indicated that as the values of LST was increasing the values of NDVI was decreasing and

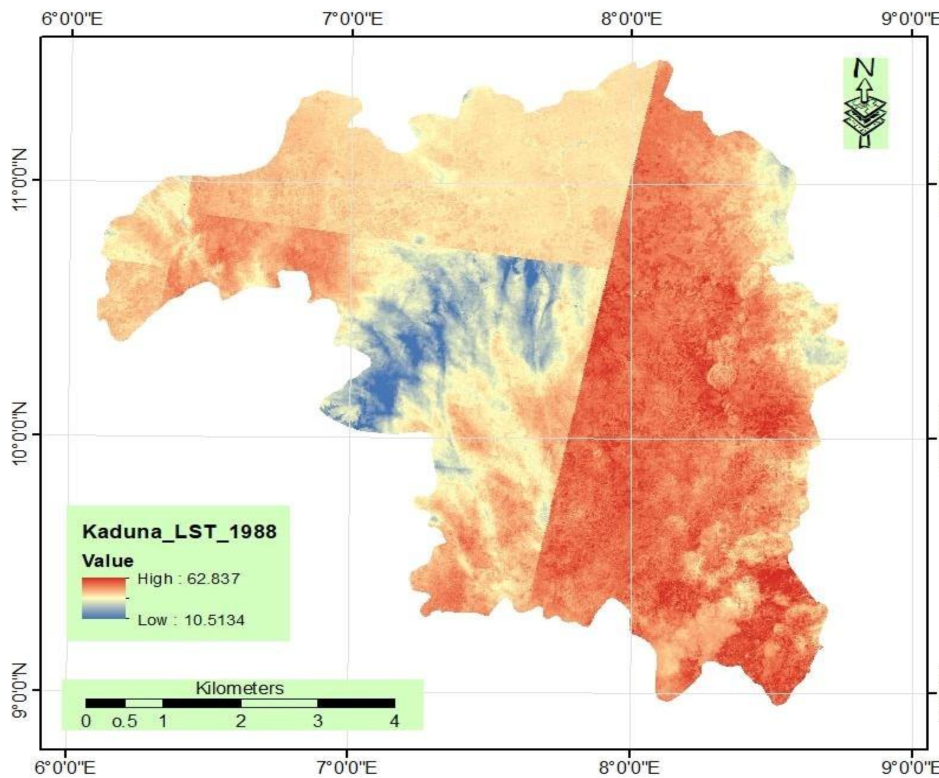

Figure 4.16: Kaduna State Land Surface Temperature Map in 1988

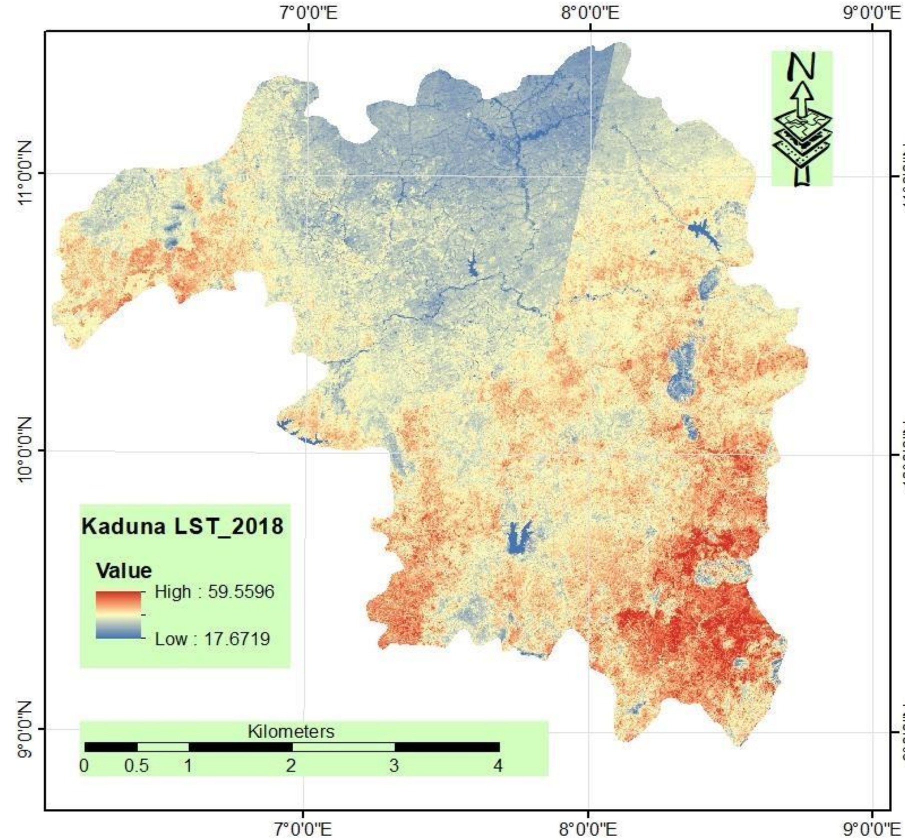

Figure 4.17: Kaduna State Land Surface Temperature Map in 2018

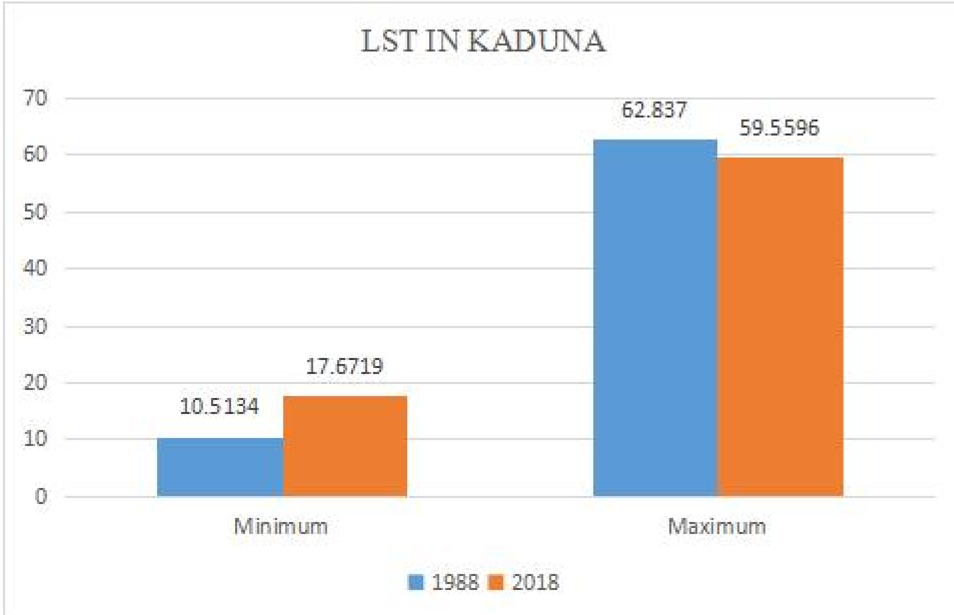

Figure 4.18: Land Surface Temperature in Kaduna

vice versa. On the contrary, the relationship between LST and NDBI with r value of +1 signifies that as the value of LST was increasing, the value of NDBI was also increasing and vice versa. This indicated that higher temperature is also synonymous to decrease in vegetation cover and increase in impervious surfaces as can be found in cities due to built-up areas and other developments in the environment.

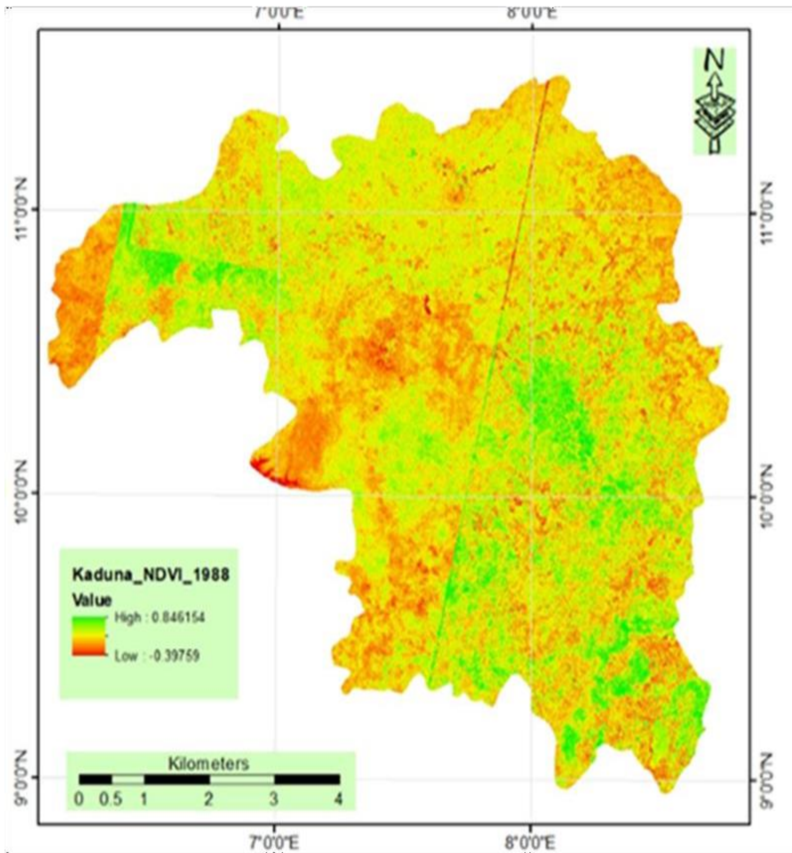

Figure 4.19 Kaduna NDVI Map 1988

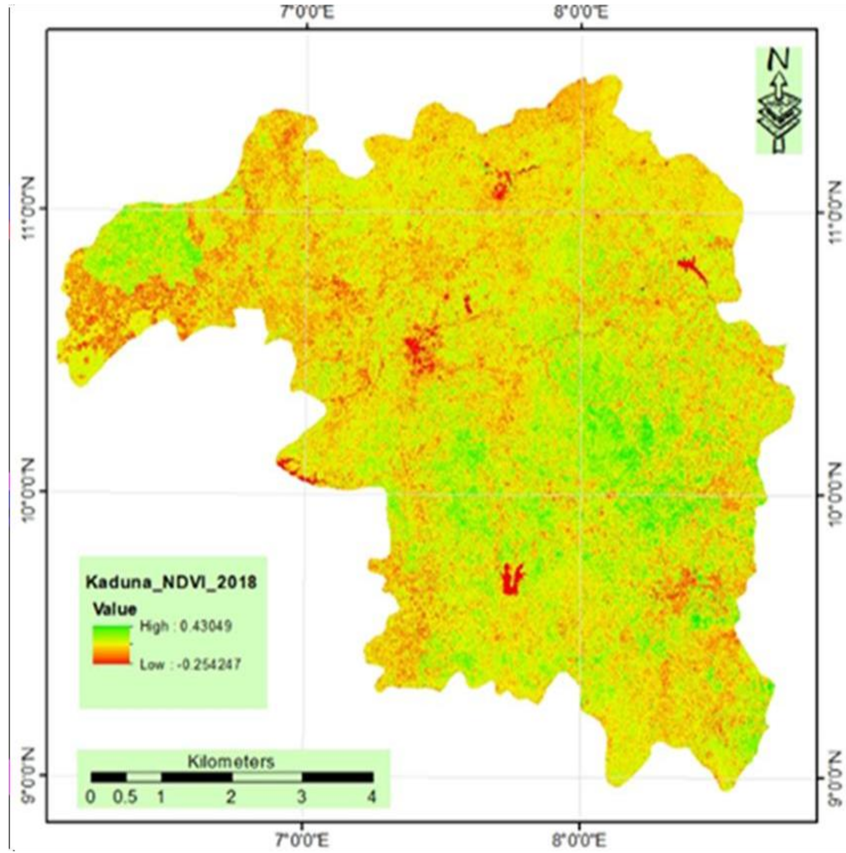

Figure 4.20 Kaduna NDVI Map 2018

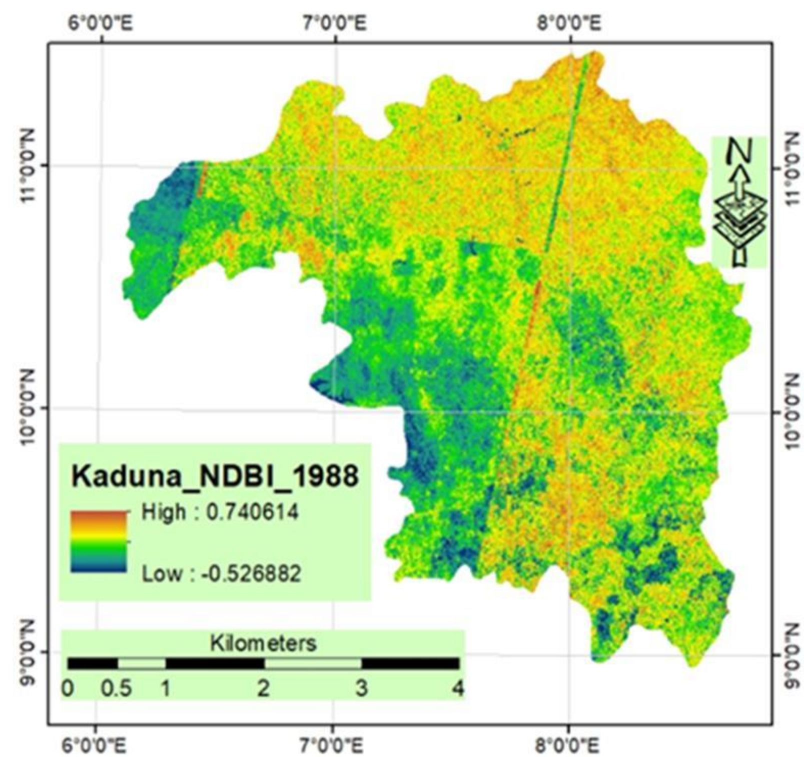

Figure 4.21 Kaduna NDBI Map 1988

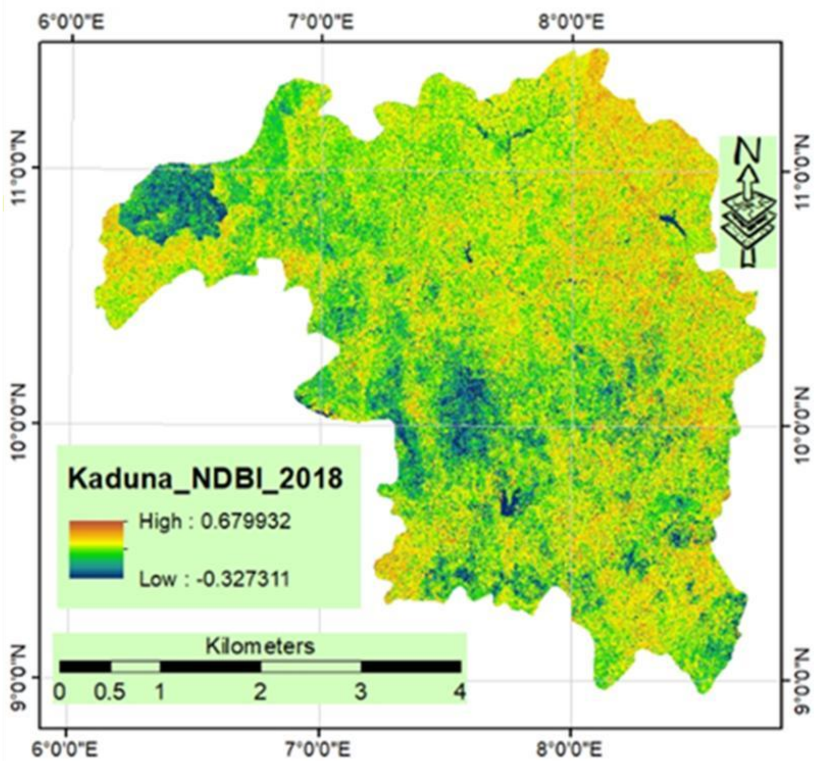

Figure 4.22 Kaduna NDBI Map 2018

Table 4.7 Correlation Matrix of Values of the Indices and LST in Kaduna (1988)

		LST	NDVI	NDBI
LST	Pearson Correlation	1	-1.000**	1.000**
	Sig. (2-tailed)		.	.
	N	2	2	2
NDVI	Pearson Correlation	-1.000**	1	-1.000**
	Sig. (2-tailed)	.		.
	N	2	2	2
NDBI	Pearson Correlation	1.000**	-1.000**	1
	Sig. (2-tailed)	.	.	
	N	2	2	2

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author (2018)

Table 4.8 Correlation Matrix of Values of the Indices and LST in Kaduna (2018)

		LST	NDVI	NDBI
LST	Pearson Correlation	1	-1.000**	1.000**
	Sig. (2-tailed)		.	.
	N	2	2	2
NDVI	Pearson Correlation	-1.000**	1	-1.000**
	Sig. (2-tailed)	.		.
	N	2	2	2
NDBI	Pearson Correlation	1.000**	-1.000**	1
	Sig. (2-tailed)	.	.	
	N	2	2	2

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author (2018)

4.2.2 Land surface temperature of FCT in 1988 and 2018

Land Surface Temperature (LST) map of FCT was presented on Figure 4.23 and Figure 4.24 for both 1988 and 2018 respectively. The LST ranges between 20.8596^{o}C and 60.999^{o}C in 1988 and 22.4221^{o}C and 54.7713^{o}C in 2018. The trend of the values of LST computed for the entire FCT in the two years also indicated on Figure 4.25 showed an increase in the minimum value of LST between 1988 and 2018 and a decrease in the maximum value of LST between the two periods just like Kaduna state. Similar case can be reported here in such a way that the study when narrowed down to the city level will show remarkable and reasonable variation in the micro climate so as to have clear differences between the two study periods.

Figures 4.26 to 4.29 also displayed the NDVI and NDBI of the entire FCT for the two study periods while tables 4.9 and 4.10 showed the correlation matrix between LST, NDVI and NDBI. The minimum and maximum values of the indices were compared to LST in the two study periods. This was carried also out in order to analyze the relationship between the indices (NDVI and NDBI) and temperature in the study area using the Pearson moment correlation coefficient (r). SPSS package was used to run the correlation analysis and the results showed a perfect relationship between temperature and NDVI with r value of -1 and also a perfect relationship between temperature and NDBI with r value of +1. But in the case of NDVI, there was an inverse relationship indicated by r value of -1, which also indicated that as the values of LST was increasing the values of NDVI was decreasing and vice versa. On the contrary, the relationship between LST and NDBI with r value of +1 signifies that as the value of LST was

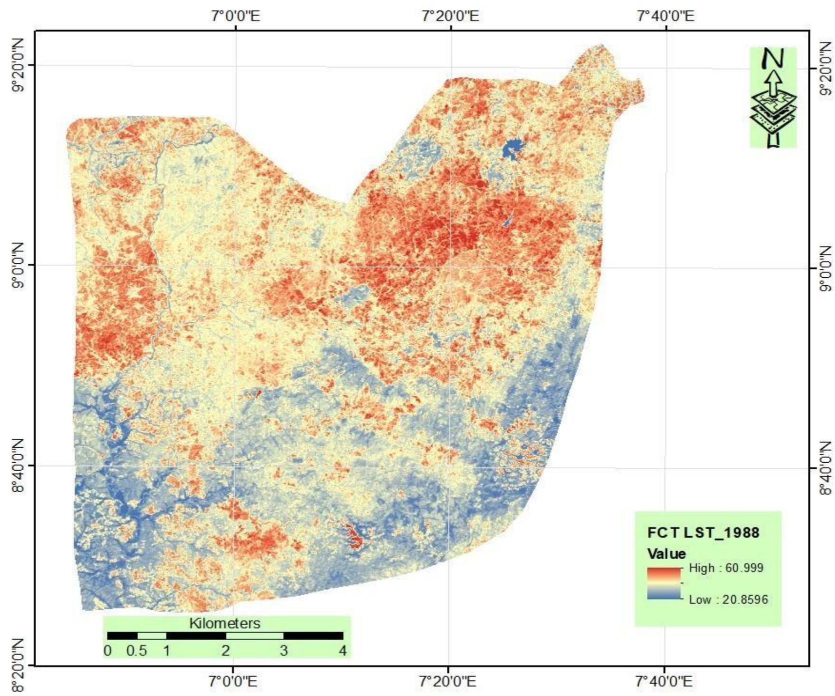

Figure 4.23 FCT Land Surface Temperature Map in 1988

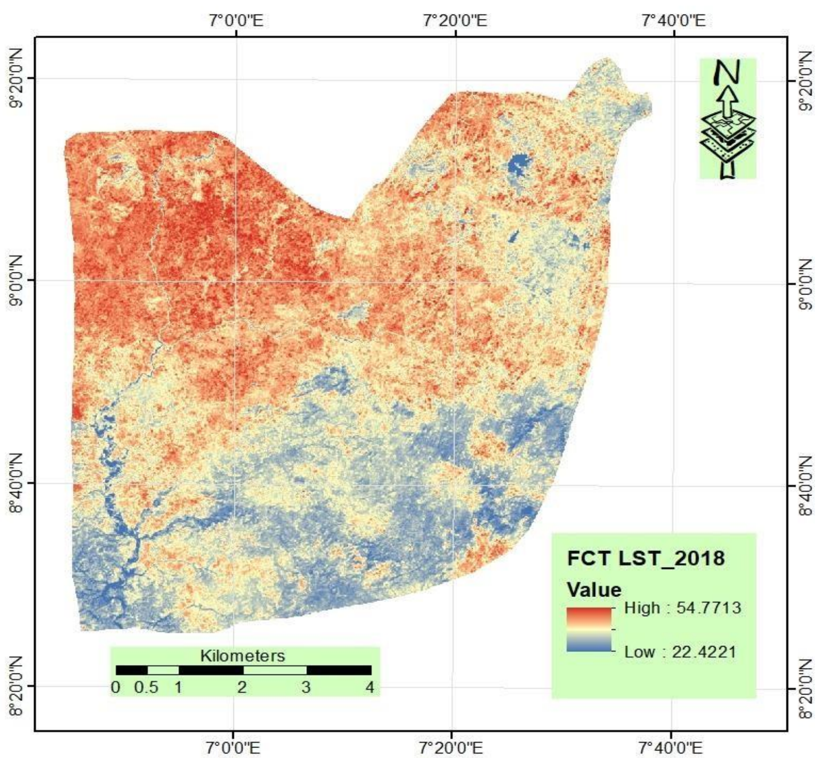

Figure 4.24 FCT Land Surface Temperature Map in 2018

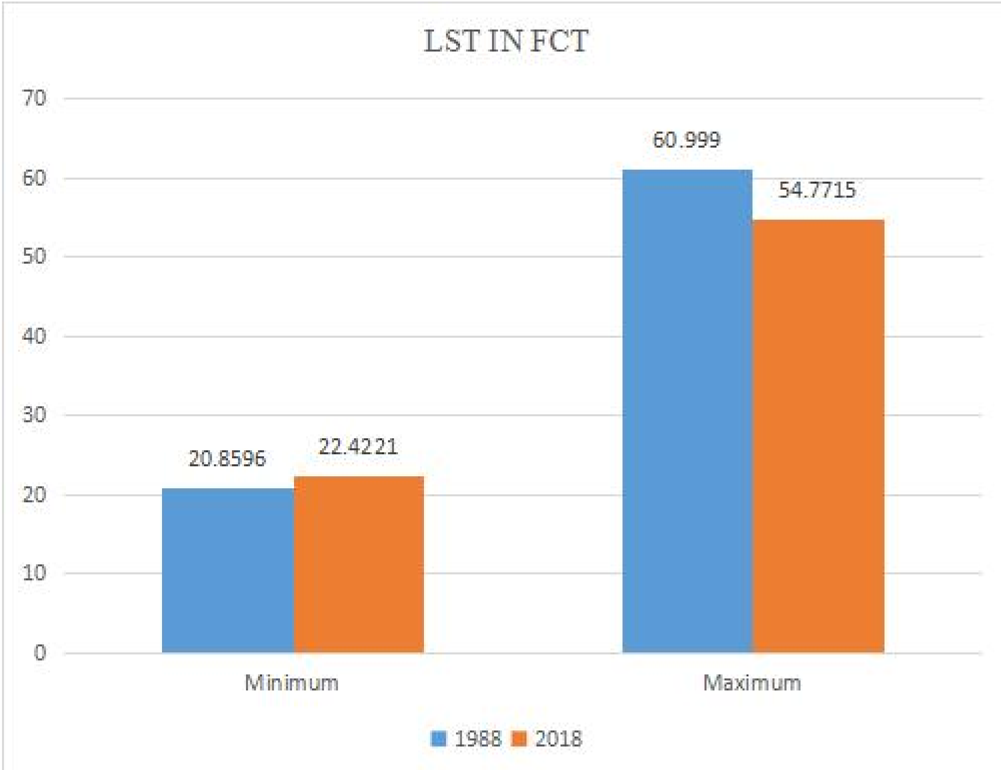

Figure 4.25 Land Surface Temperature in FCT

increasing, the value of NDBI was also increasing and vice versa. This indicated that higher temperature was also synonymous to decrease in vegetation cover and increase in impervious surfaces as can be found in cities due to built-up areas and other developments in the environment.

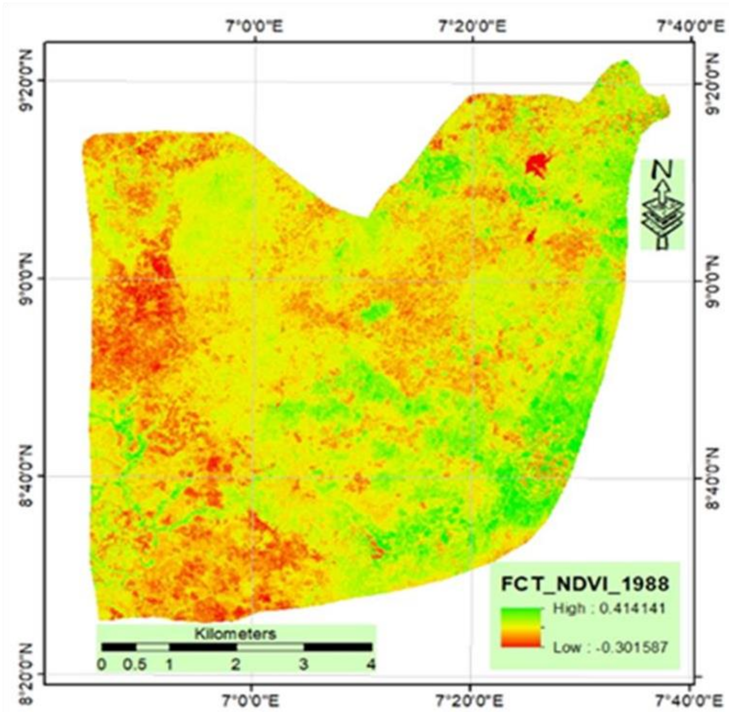

Figure 4.26 FCT NDVI Map 1988

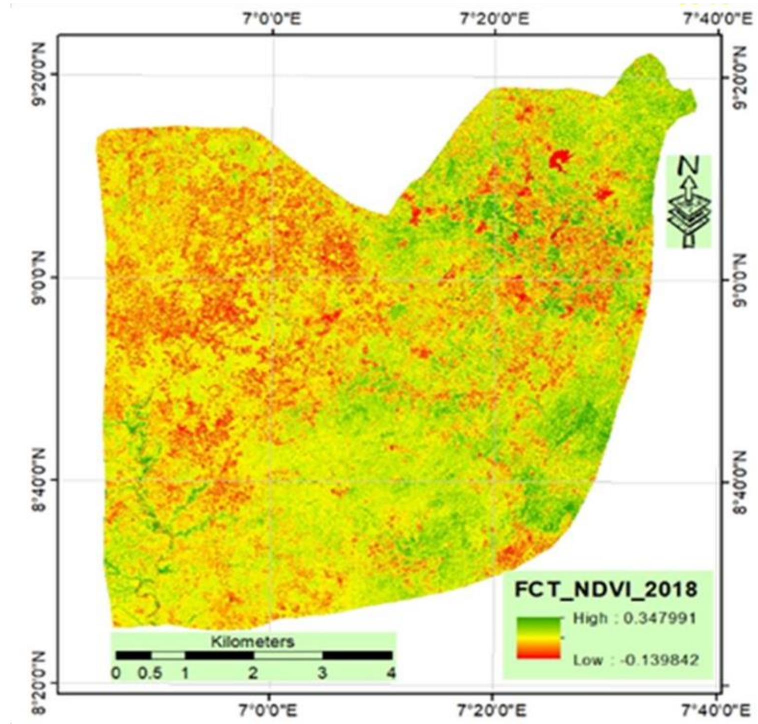

Figure 4.27 FCT NDVI Map 2018

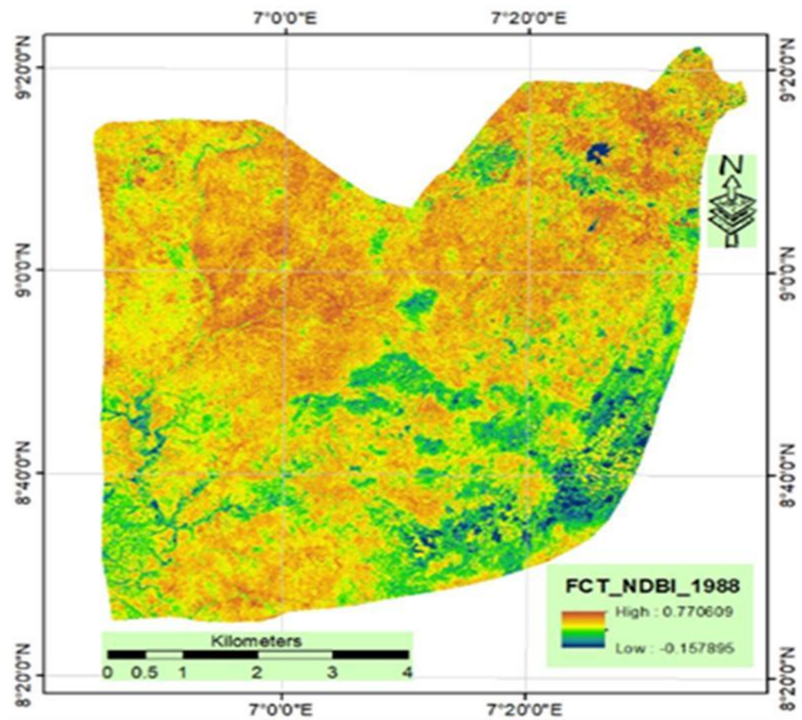

Figure 4.28 FCT NDBI Map 1988

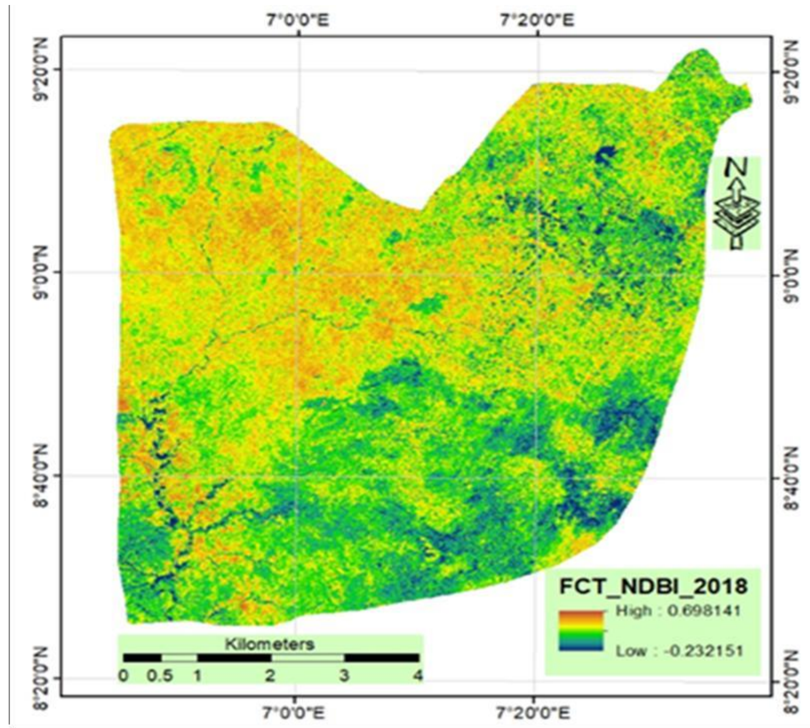

Figure 4.29 FCT NDBI Map 2018

Table 4.9 Correlation Matrix of Values of the Indices and LST in FCT (1988)

		LST	NDVI	N
LST	Pearson Correlation	1	-1.000**	
	Sig. (2-tailed)		.	
	N	2	2	
NDVI	Pearson Correlation	-1.000**	1	-
	Sig. (2-tailed)	.		
	N	2	2	
NDBI	Pearson Correlation	1.000**	-1.000**	
	Sig. (2-tailed)	.	.	
	N	2	2	

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author (2018)

Table 4.10 Correlation Matrix of values of the indices and LST in FCT (2018)

		LST	NDVI	NDBI
LST	Pearson Correlation	1	-1.000**	1.000**
	Sig. (2-tailed)		.	.
	N	2	2	2
NDVI	Pearson Correlation	-1.000**	1	-1.000**
	Sig. (2-tailed)	.		.
	N	2	2	2
NDBI	Pearson Correlation	1.000**	-1.000**	1
	Sig. (2-tailed)	.	.	
	N	2	2	2

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author (2018)

4.2.3 Land surface temperature of Kano in 1988 and 2018

Land Surface Temperature (LST) map of Kano was presented on Figure 4.30 and Figure 4.31 for both 1988 and 2018 respectively. The LST ranges between 10.6143^{o}C and 47.8791^{o}C in 1988 and 10.1004^{o}C and 39.6016^{o}C in 2018. The trend of the values of LST computed for the entire state in the two years also indicated on Figure 4.32 showed a slight decrease in the minimum value of LST between 1988 and 2018 and a decrease in the maximum value of LST between the two periods. This result was not too far from that of Kaduna and FCT and so similar situation accounted for the reason.

On the other hand, Figures 4.33 to 4.36 also displayed the NDVI and NDBI of the entire Kano state for the two study periods while Tables 4.11 and 4.12 also showed the correlation matrix between LST, NDVI and NDBI for Kano State. The minimum and maximum values of the indices were compared to LST in the two study periods. This was carried out so as to analyze the relationship between the indices (NDVI and NDBI) and temperature in the study area using the Pearson moment correlation coefficient (r). The results of the correlation analysis shows a perfect relationship between temperature and NDVI with r value of -1 and also a perfect relationship between temperature and NDBI with r value of +1. But in the case of NDVI, there was an inverse relationship, which indicated that as the values of LST was increasing the values of NDVI was decreasing and vice versa. On the contrary, the relationship between LST and NDBI with r value of +1 signifies that as the value of LST was increasing, the value of NDBI was also increasing and vice versa. This indicated that higher temperature was also

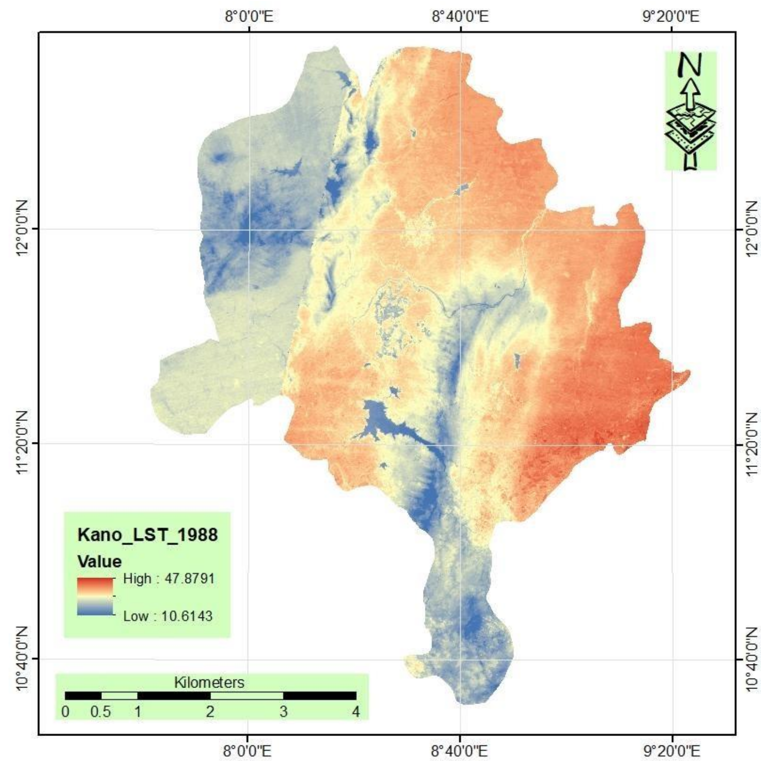

Figure 4.30 Kano State Land Surface Temperature Map in 1988

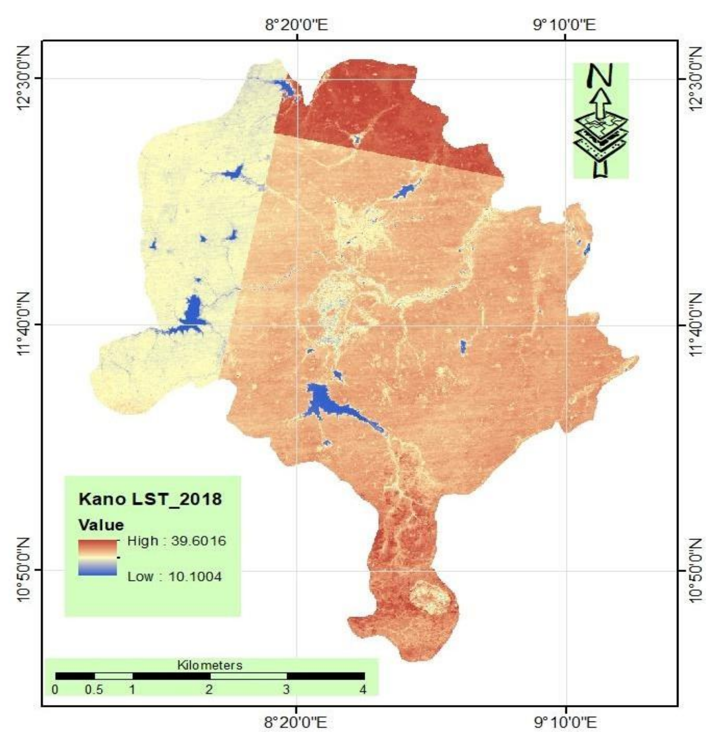

Figure 4.31 Kano State Land Surface Temperature Map in 2018

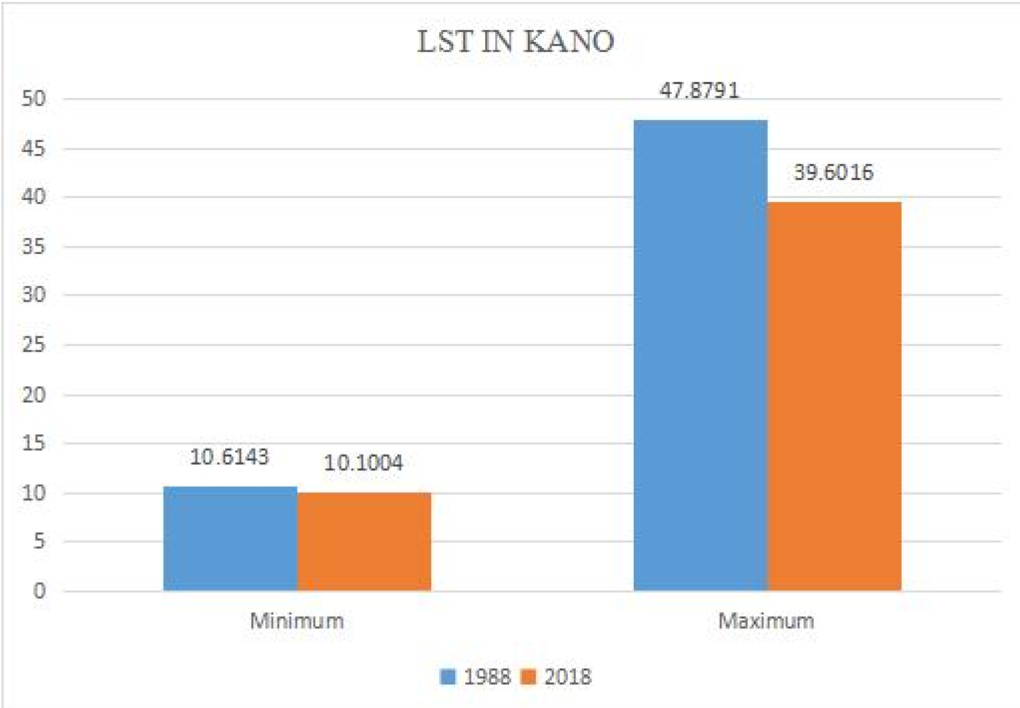

Figure 4.32 Land Surface Temperature in Kano

synonymous to decrease in vegetation cover and increase in impervious surfaces as can be found in cities due to built-up areas and other developments in the environment, the result was also similar to that of the two other states.

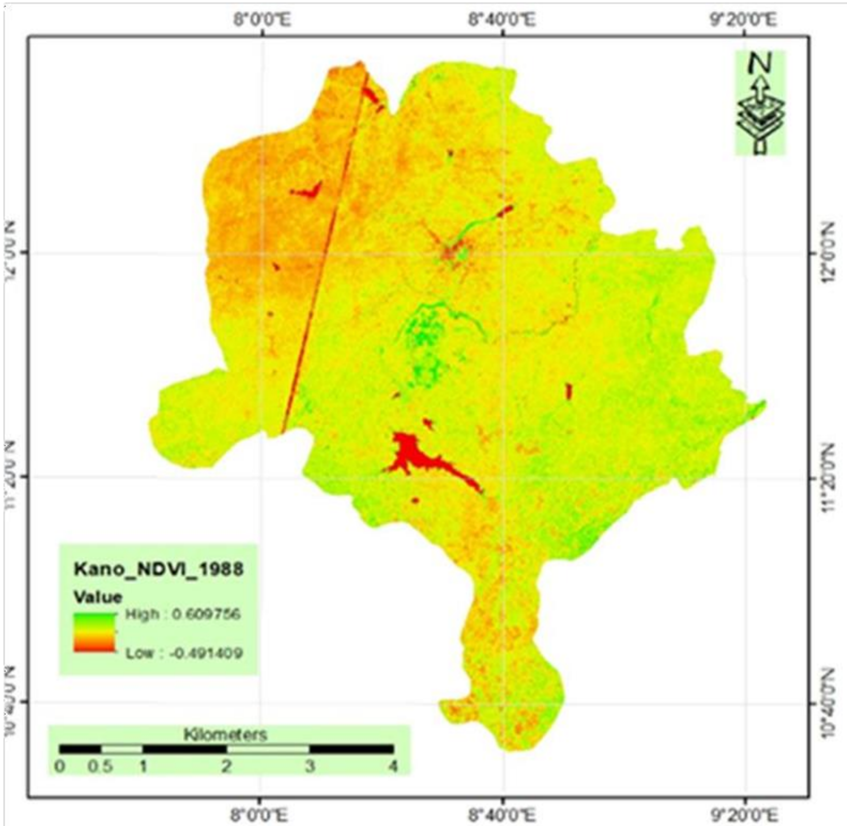

Figure 4.33 Kano NDVI Map 1988

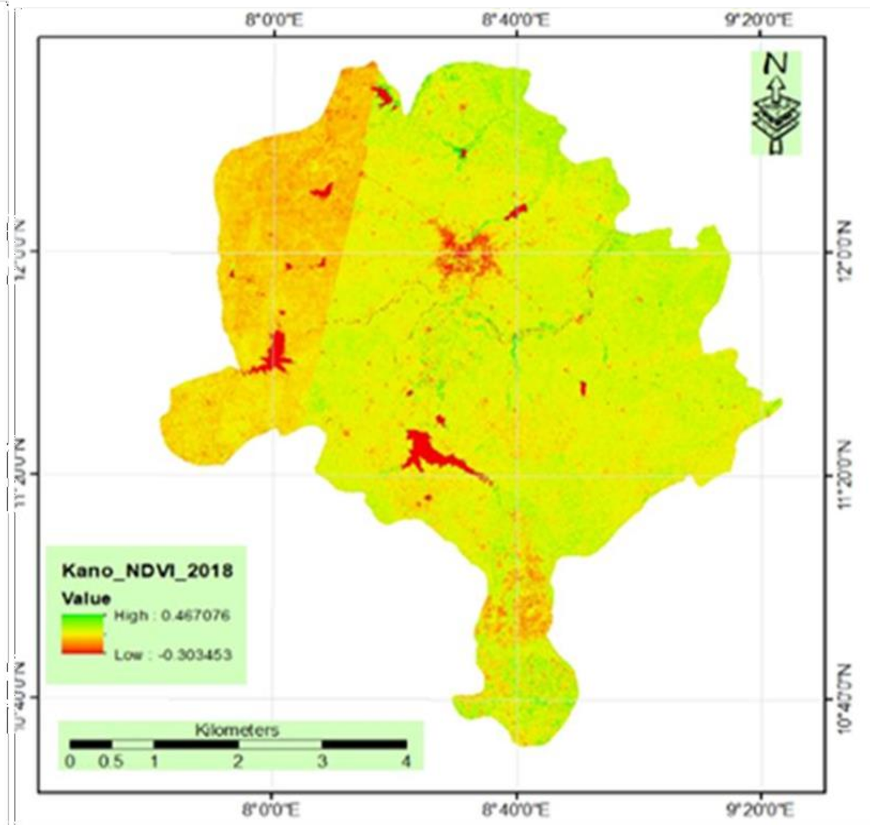

Figure 4.34 Kano NDVI Map 2018

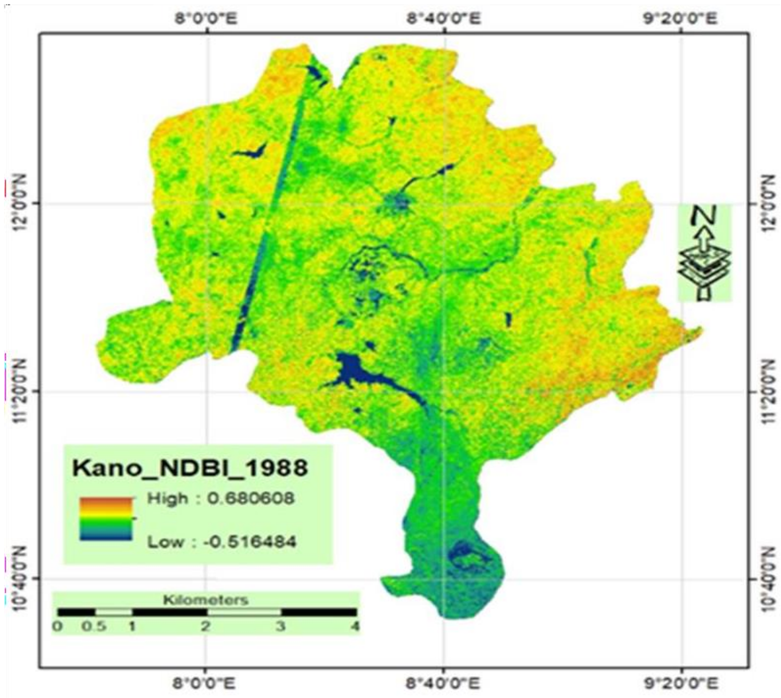

Figure 4.35 Kano NDBI Map 1988

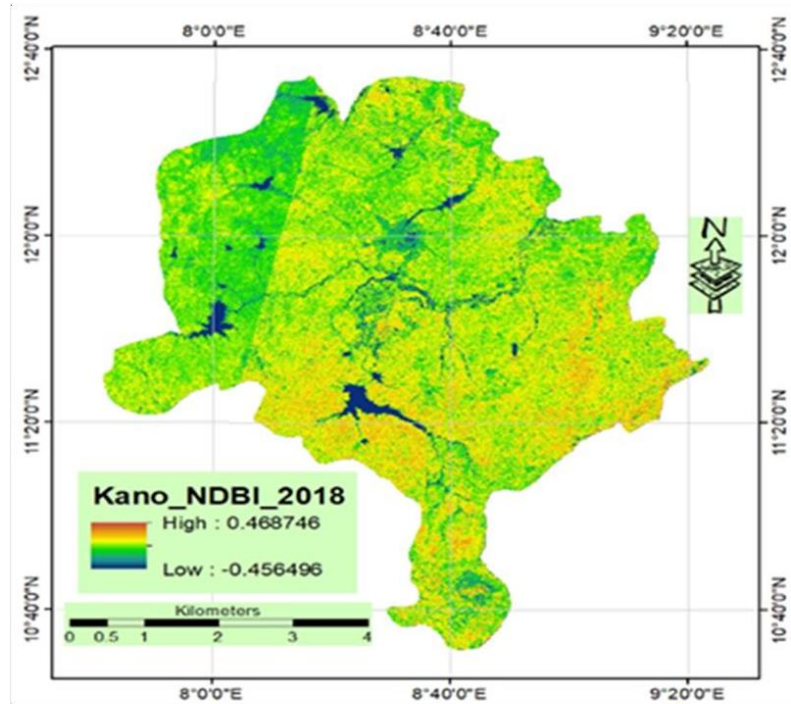

Figure 4.36 Kano NDBI Map 2018

Table 4.11 Correlation Matrix of Values of the Indices and LST in Kano (1988)

		LST	NDVI	NDBI
LST	Pearson Correlation	1	-1.000**	1.000**
	Sig. (2-tailed)		.	.
	N	2	2	2
NDVI	Pearson Correlation	-1.000**	1	-1.000**
	Sig. (2-tailed)	.		.
	N	2	2	2
NDBI	Pearson Correlation	1.000**	-1.000**	1
	Sig. (2-tailed)	.	.	
	N	2	2	2

Source: Author (2018)

Table 4.12 Correlation Matrix of Values of the Indices and LST in Kano (2018)

		LST	NDVI	NDBI
LST	Pearson Correlation	1	-1.000**	1.000**
	Sig. (2-tailed)		.	.
	N	2	2	2
NDVI	Pearson Correlation	-1.000**	1	-1.000**
	Sig. (2-tailed)	.		.
	N	2	2	2
NDBI	Pearson Correlation	1.000**	-1.000**	1
	Sig. (2-tailed)	.	.	
	N	2	2	2

Source: Author (2018)

4.2.4 The relationship between LST, NDVI and NDBI

The analysis carried out using Pearson Correlation analysis to find out the relationship between the variables (LST, NDVI and NDBI) measures strength and direction of association that existed between the variables. The results showed similar trend in the three study locations because their exist perfect relationship between LST and the two indices measured in the study area but the relationship between LST and NDVI was inverse indicated by the value of r that was -1, meaning as the values of LST was increasing, that of NDVI was decreasing. On the other hand, correlating LST and NDBI in the study locations also gave a perfect relationship in the three study locations with the value of r that was +1 which was also an indication that as the value of LST was increasing, that of NDBI was also increasing (a perfect positive relationship). Tables 4.7 to 4.12.

4.2.5 Temperature analysis

Temperature data recorded in Kaduna, Kano and FCT for thirty-one years (1988 to 2018) was summarized in Table 4.13 as analyzed using R software package, it revealed that the average temperature from FCT was 26.58 and highest among the list. However, the standard deviation from the average temperature from Kano was the highest, which indicated the erratic nature of temperature records in Kano as compared to Kaduna and FCT.

Table 4.13 Summary Statistics of Temperature in Kano, Kaduna and FCT

Town	Mean	Variance	Standard deviation
Kano	24.76	9.11	3.02
Kaduna	25.20	3.11	1.76
FCT	26.58	2.81	1.68

Source: Author, 2021

4.2.5.1 Time plots of temperature observations

In a similar view, Figures 4.37, 4.38 and 4.39 are time plots of temperature observations from Kano, Kaduna and FCT; from the three time plots, there were indications of trend, seasonality and randomness in the patterns. Hence, decomposition time series analysis was suggested and carried out in R software which captured the trend, seasonality and randomness in time series.

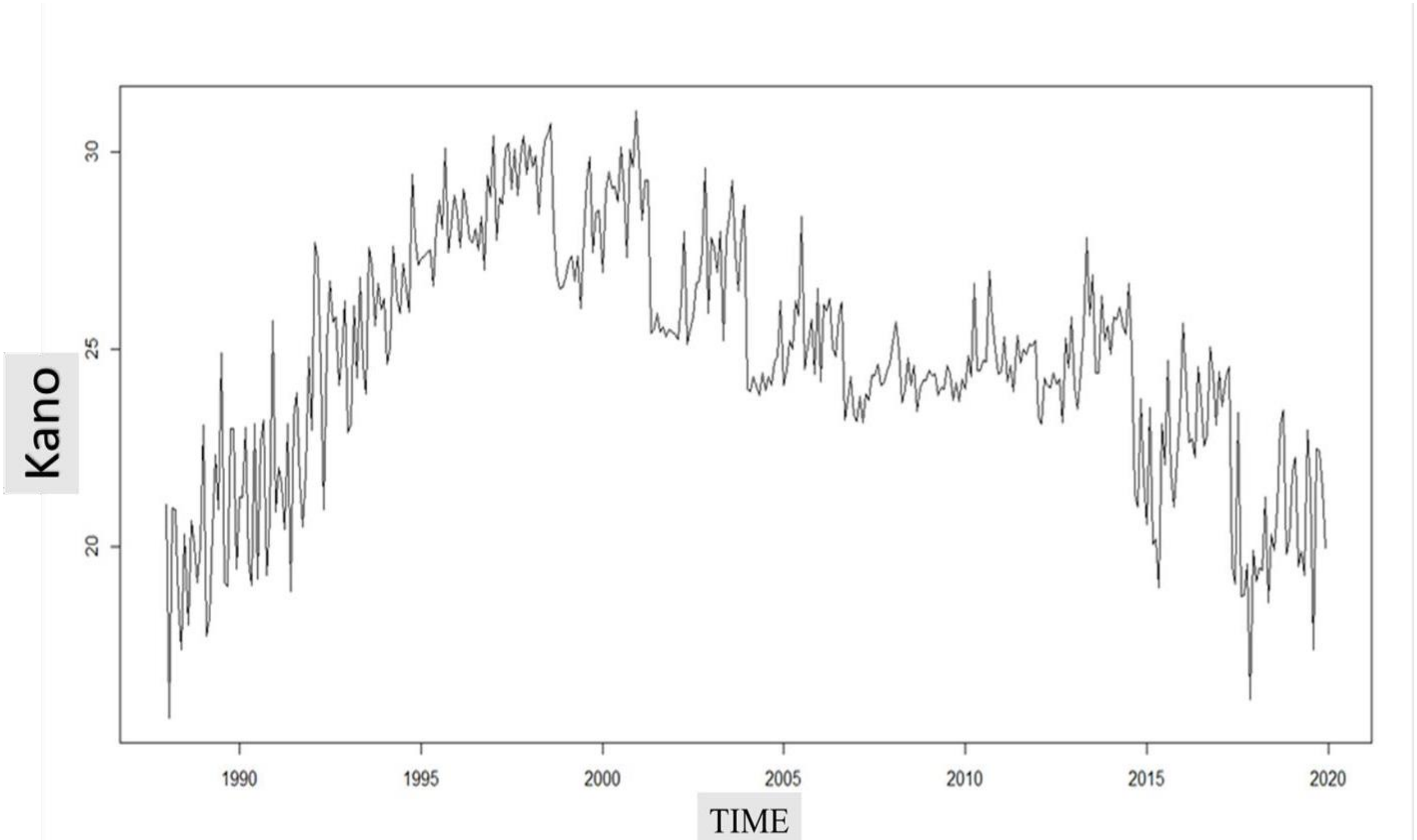

Figure 4.37 Time Plot of Temperature Observations in Kano

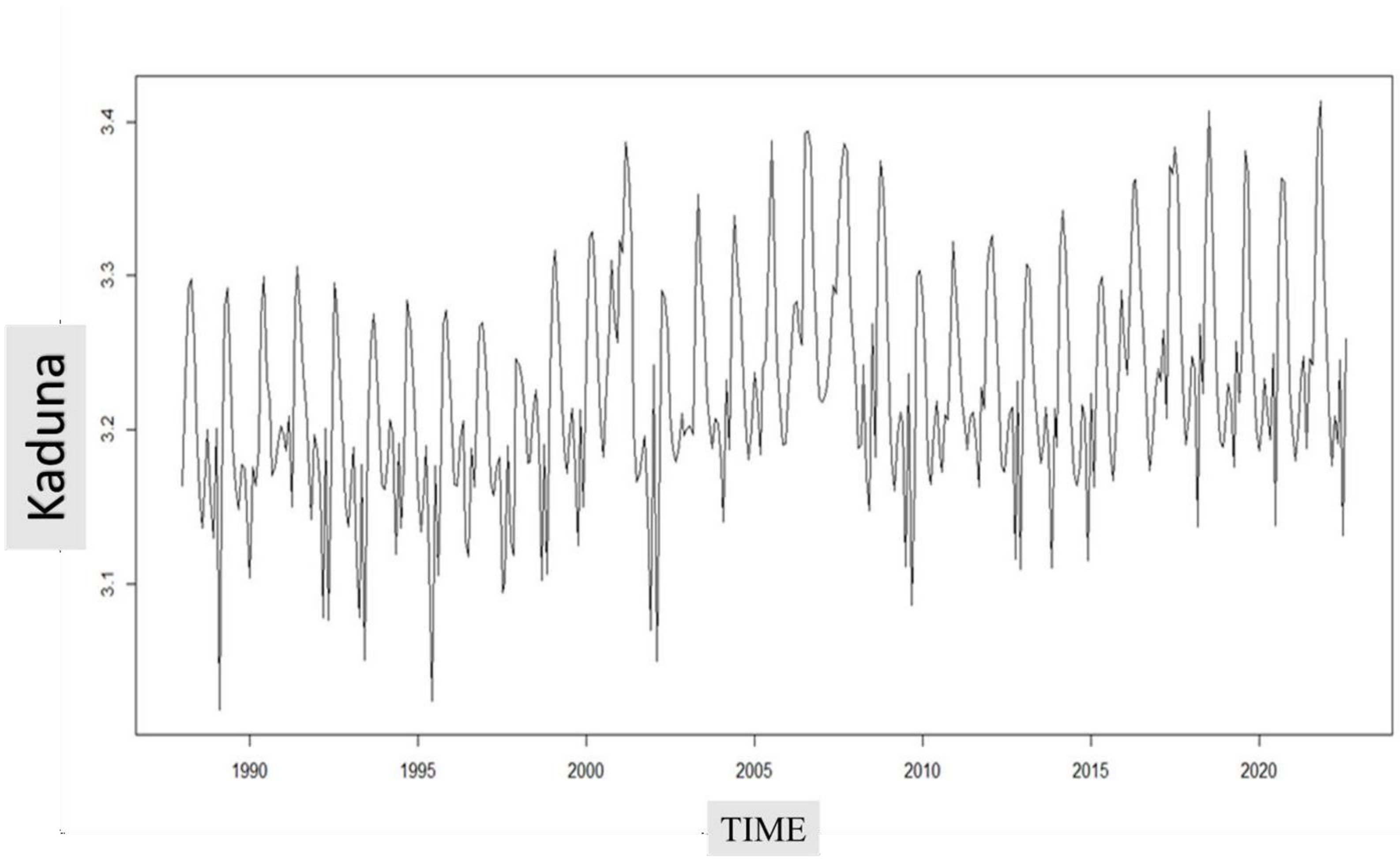

Figure 4.38 Time Plot of Temperature Observations in Kaduna

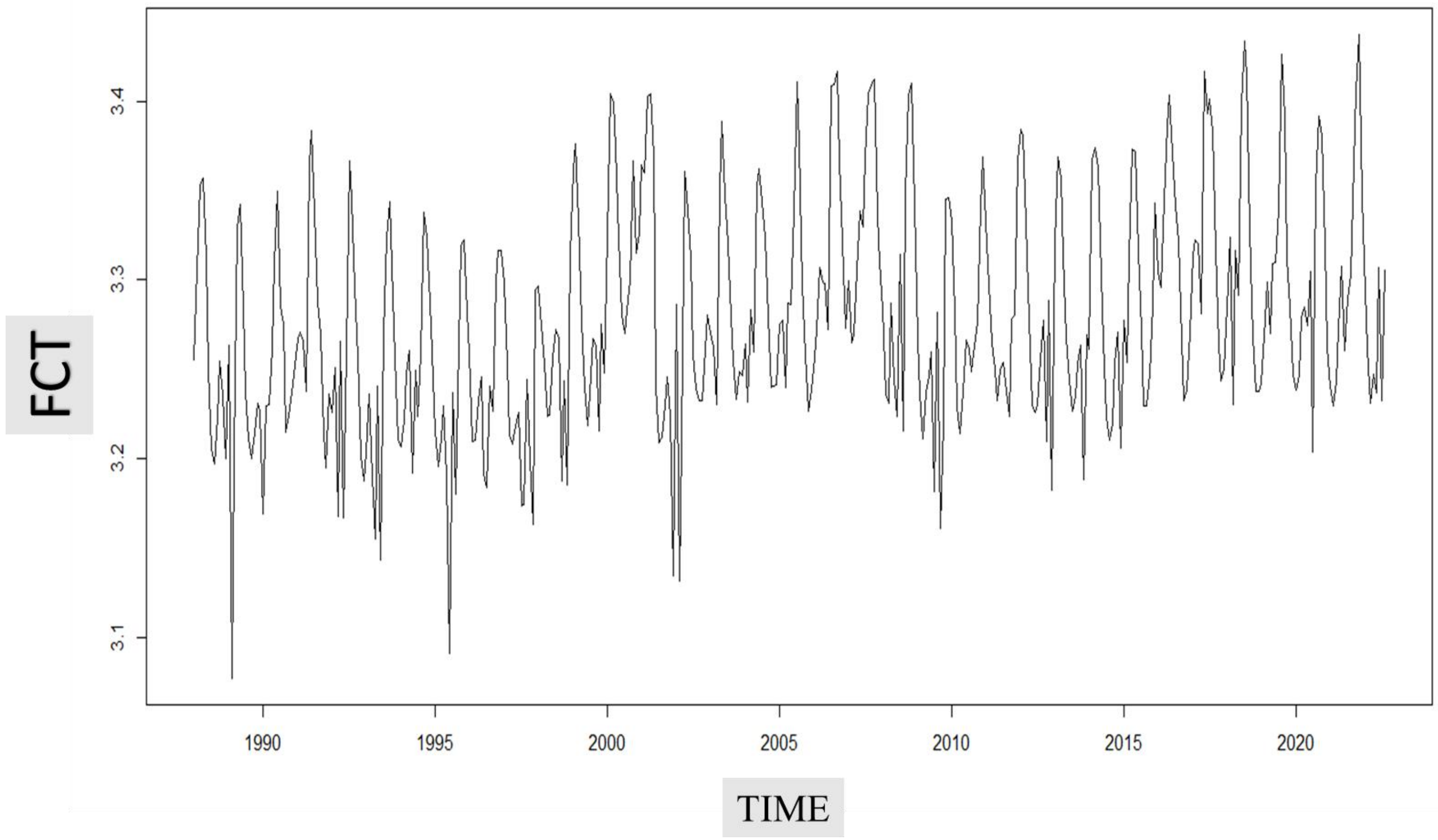

Figure 4.39 Time Plot of Temperature Observations in FCT

4.2.5.2 Decomposition of additive time series of temperature analysis

The decomposition of additive time series analysis was carried out in R software as indicated on Figures 4.40, 4.41, and 4.42 as the decomposition of additive time series plot which showed the time plot, the trend, the seasonal and random plots of the temperature time series between 1988 to 2018 for Kano, Kaduna and FCT respectively. The decomposition of additive time series revealed the pattern of average monthly temperature over the years under consideration.

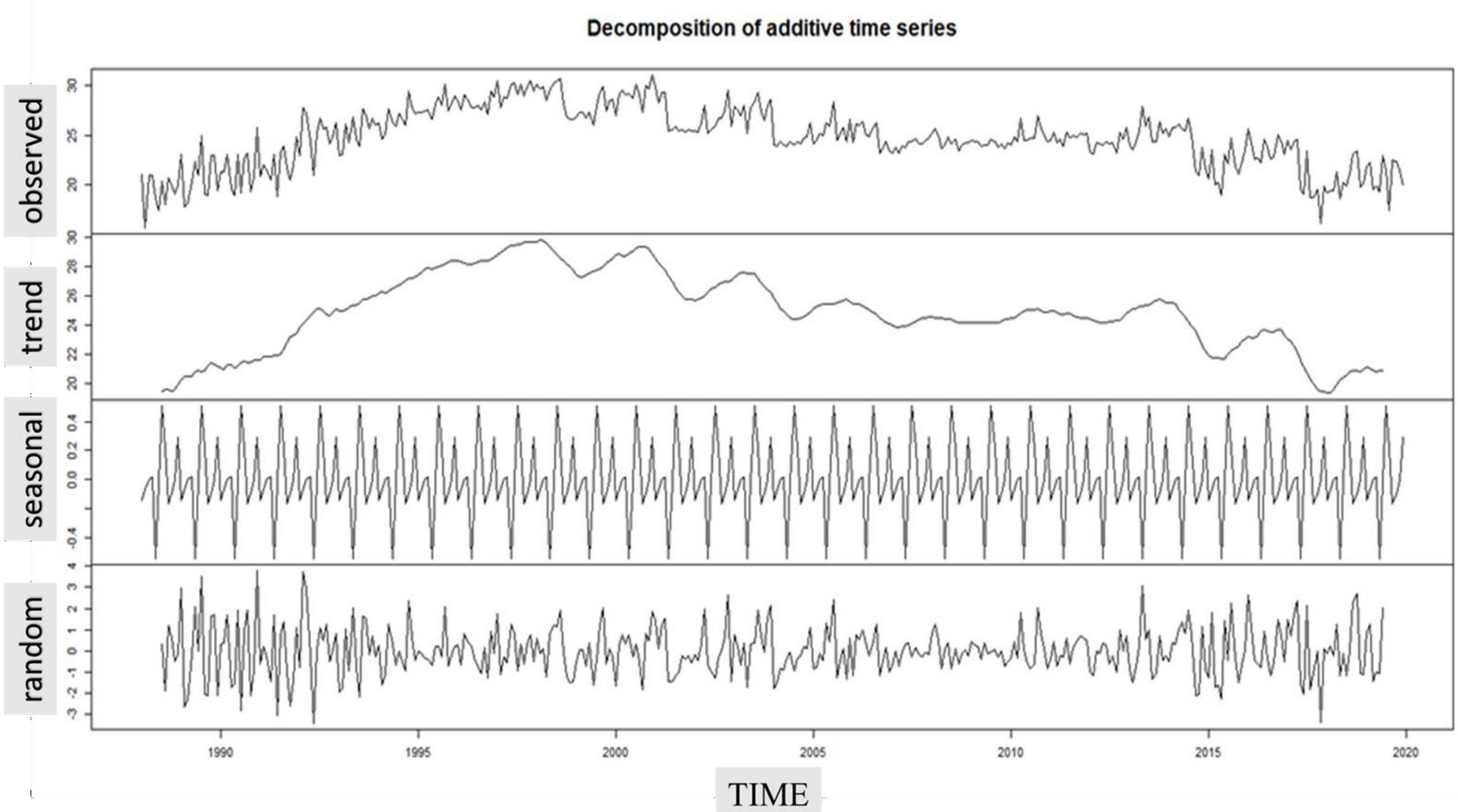

Figure 4.40 Decomposition Additive Time Series Plot in Kano

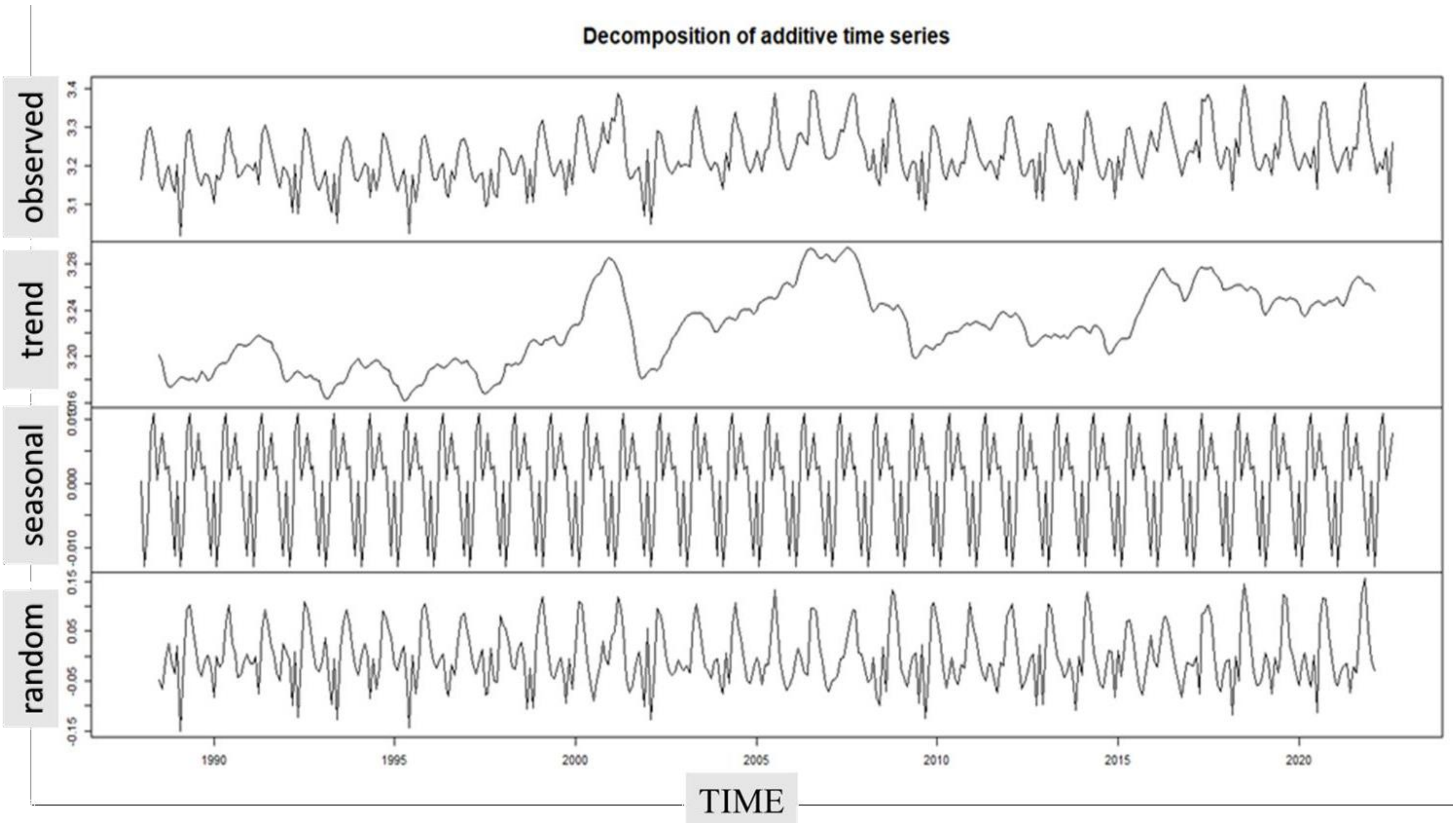

Figure 4.41 Decomposition Additive Time Series Plot in Kaduna

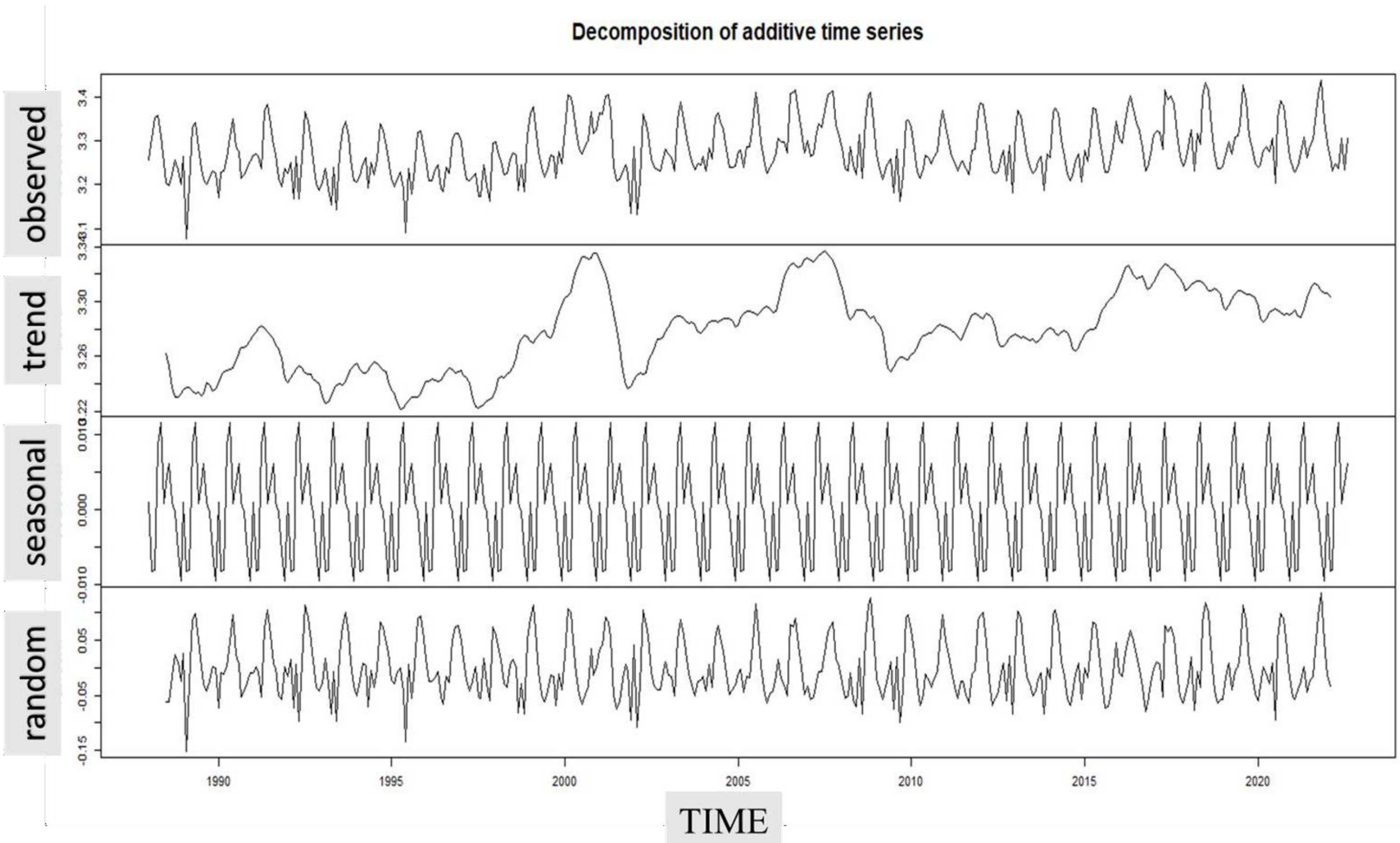

Figure 4.42 Decomposition Additive Time Series Plot in FCT

4.2.5.3 Temperature seasonal indices for Kano, Kaduna and FCT

Based on the table 4.14 Kano experienced a rise in temperature around July, August and December. Kaduna and FCT experience are similar in pattern. The temperature rose from April and sustained through to September. Figure 4.40, 4.41 and 4.42 indicated a peak in temperature in Kano in July while lowest temperature was recorded in May. Kaduna and FCT showed almost similar trend with a peak in May while the lowest temperature recorded in Kaduna was in February and FCT experienced lowest temperature between February and March illustrated on Figures 4.43, 4.44 and 4.45.

One can therefore deduce especially right from analysis of variance and standard deviation that the nature of temperature over the study period in Kaduna and FCT followed similar trend, this has been substantiated also with the time plot analysis and decomposition of additive time series analysis and eventually corroborated with seasonal index plot. In all situations, Kano was showing a different trend as seen also on Table 4.14

Table 4.14 The Seasonal Indices for Kano, Kaduna and FCT.

Month	Kano	Kaduna	FCT
January	-0.1422	-0.0239	0.0008
February	-0.0740	-0.3257	-0.2123
March	-0.0064	-0.1800	-0.2181
April	0.0280	0.1822	0.2149
May	-0.5433	0.2762	0.3111
June	-0.0228	0.0225	0.0285
July	0.5102	0.1266	0.1085
August	0.2186	0.2111	0.1731
September	-0.1680	0.0646	0.0265
October	-0.0914	0.0706	-0.0137
November	-0.0057	-0.1281	-0.1544
December	0.2914	-0.2961	-0.2647

Source: Author, 2021

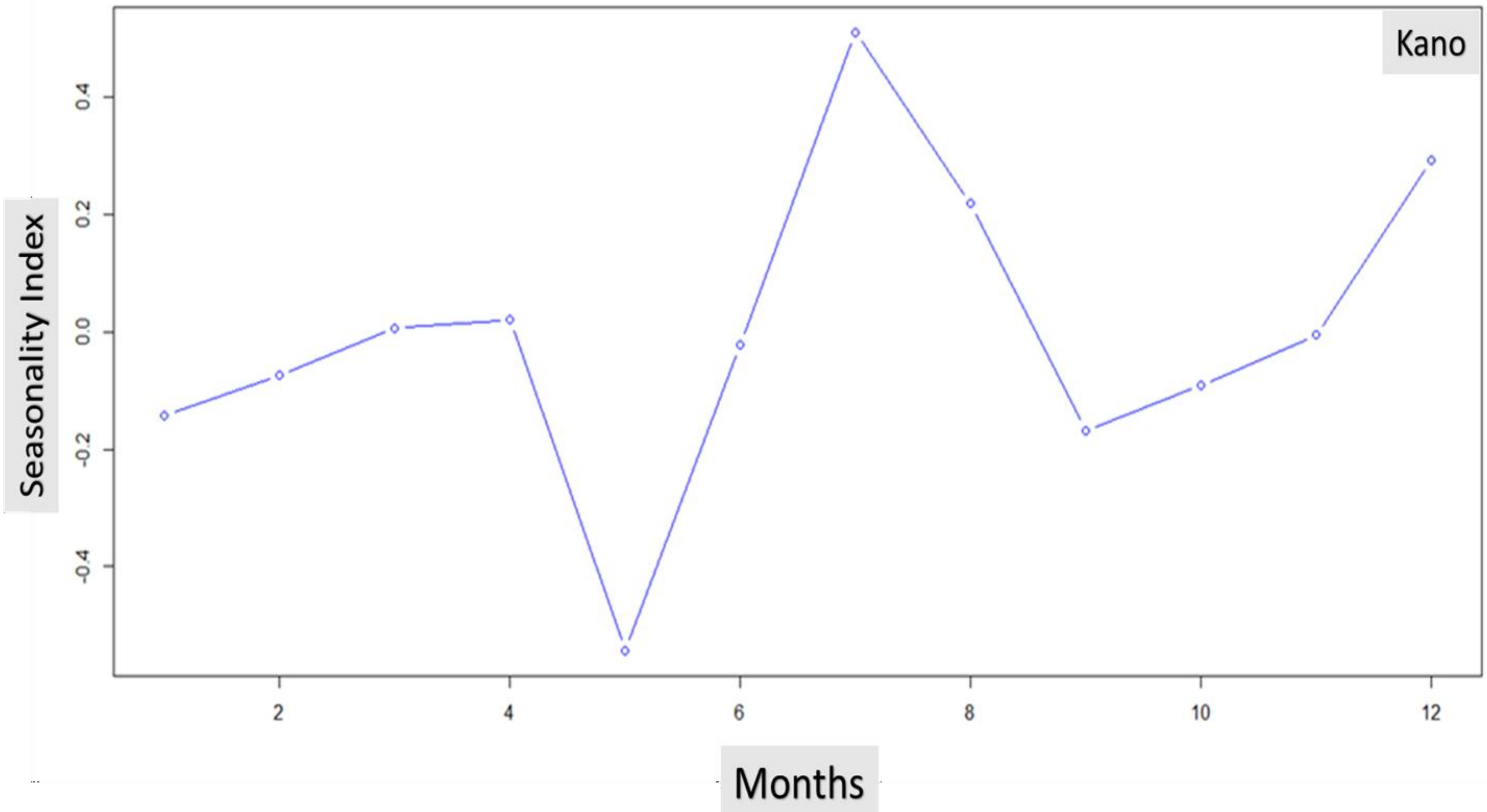

Figure 4.43 Seasonal Index Plot in Kano

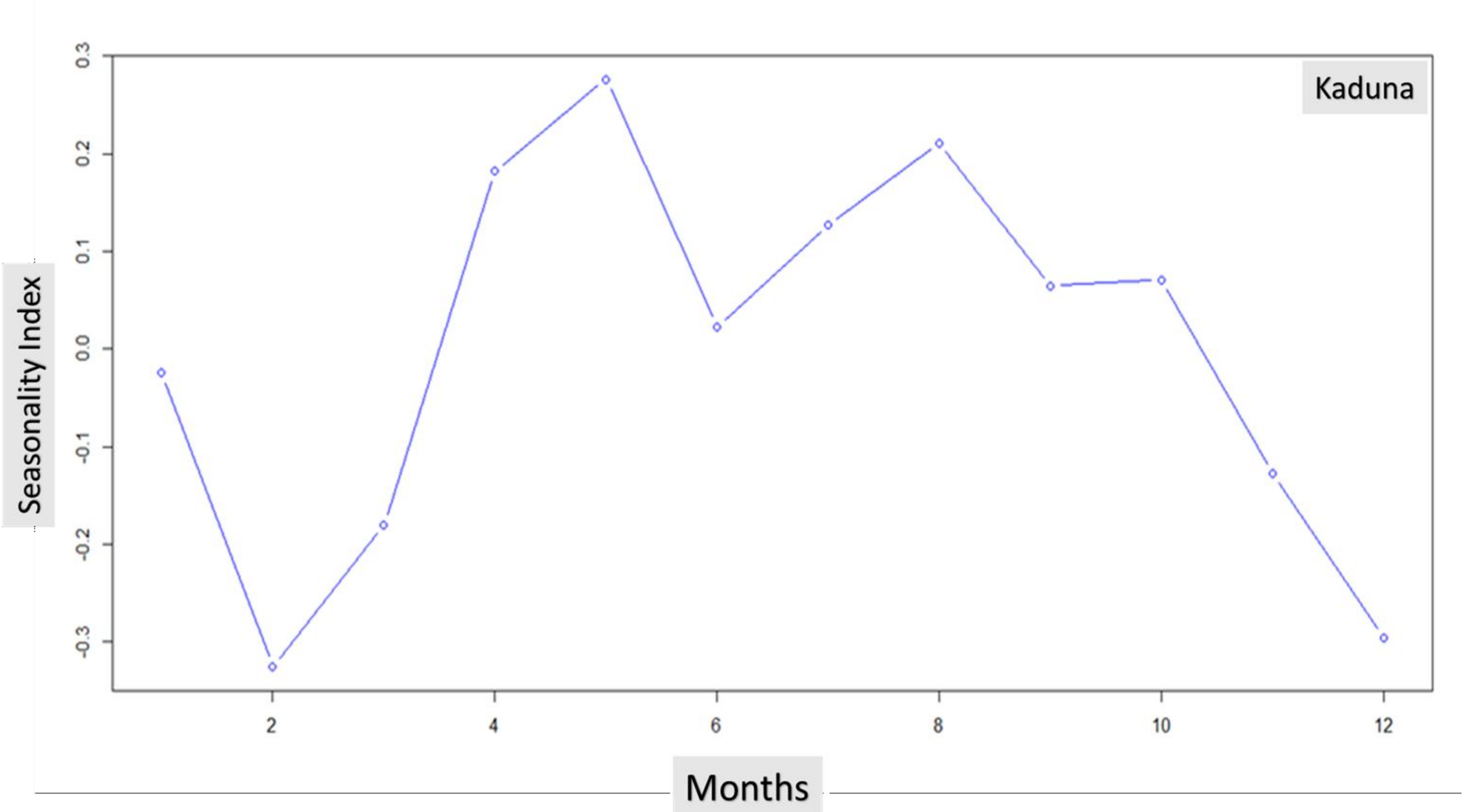

Figure 4.44 Seasonal Index Plot Kaduna

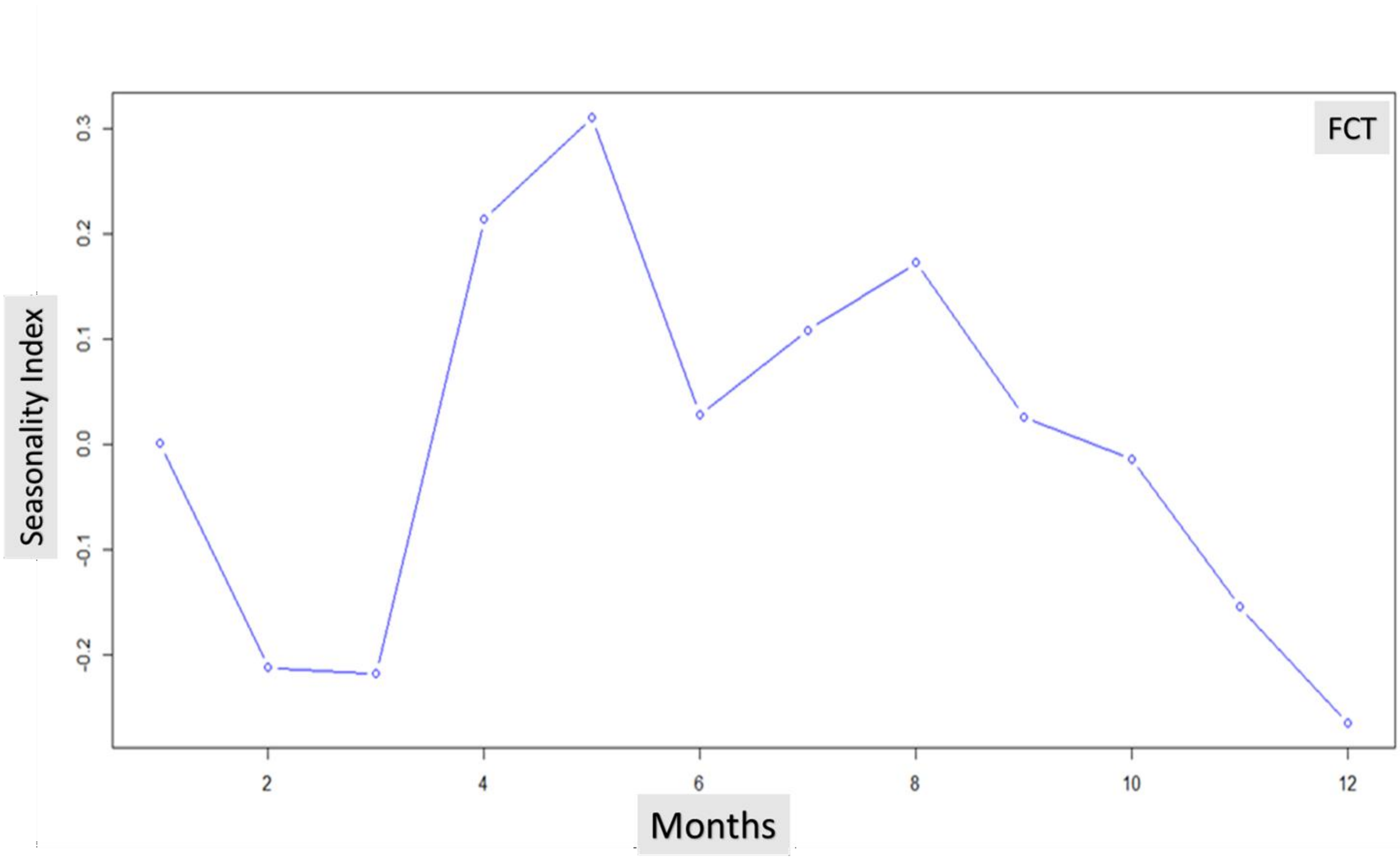

Figure 4.45 Seasonal Index Plot in FCT

4.3 The Urban Climate Analysis Map (UCAM)

The UCAM system in this study consisted of seven layers of input data generally grouped into two aspects such as thermal load aspects and the dynamic potential aspect. Thermal load aspects involves: Topography, Population density, LULC, UHI, Natural Landscape (Vegetation) whereby the dynamic potential aspect involves water body and wind information; it was unified and rasterized into grid cells of 500m × 500m. This provided for a simple area-based spatial understanding to the city planners who would make planning decisions later at the district and neighbourhood levels.

The selected parameters that have different impacts on the urban environment; topography, natural landscape and water body have negative effects on thermal load whereas Population density, LULC and UHI have Positive effects on thermal load. Wind environment and water system (general water body) have negative effect on dynamic potential.

The seven input layers were synthesized based on the urban climatic evaluation of the data. Many climatopes were involved in the maps and different types of land uses have been differentiated from one another for better understanding and planning; these includes built up areas, agricultural lands, vegetation, both were also further classified in the LCZ classification, water body was also not left out. The different climates are also affected by constituent parameters of urban morphology, population density, topography, vegetation, and water body among others.

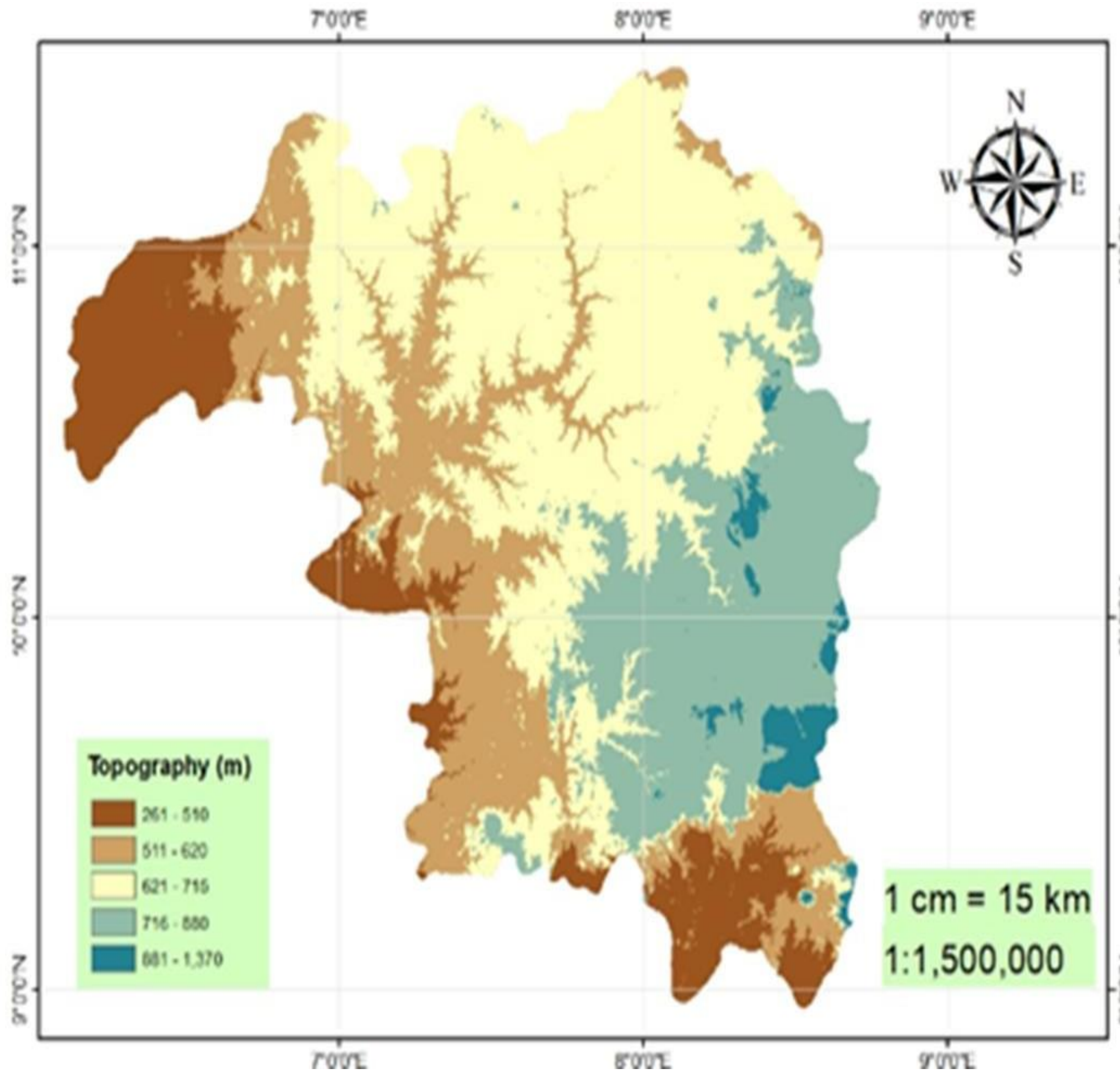

Figure 4.46 Topographic map of Kaduna

4.3.1 The thermal load aspect: topography

There is always temperature variation between places on different altitude, environmental lapse rate is the rate in which air temperature decreases as the altitude increases. This layer therefore represented the topographic height in meters according to SRTM data obtained from National Space Research and Development Agency (NASRDA) where the topography maps of Kaduna, Kano and FCT were clipped and classified into five classes each based on their different heights. Due to the possible temperature variations and thermal stress contributions in the different study areas, the five classes identified vary in each case, Kaduna included: 261m–510m, 511m–620m, 621m-715m, 716m-880m and 881m-1,370

(Figure 4.46). FCT topography included: 47m–190m, 191m–310m, 311m-450m, 451m-600m and 601m-935 (Figure 4.47) and Kano topography included: 385m–470m, 471m–545m, 546m-650m, 651m-795m and 796m-1,234 (Figure 4.48).

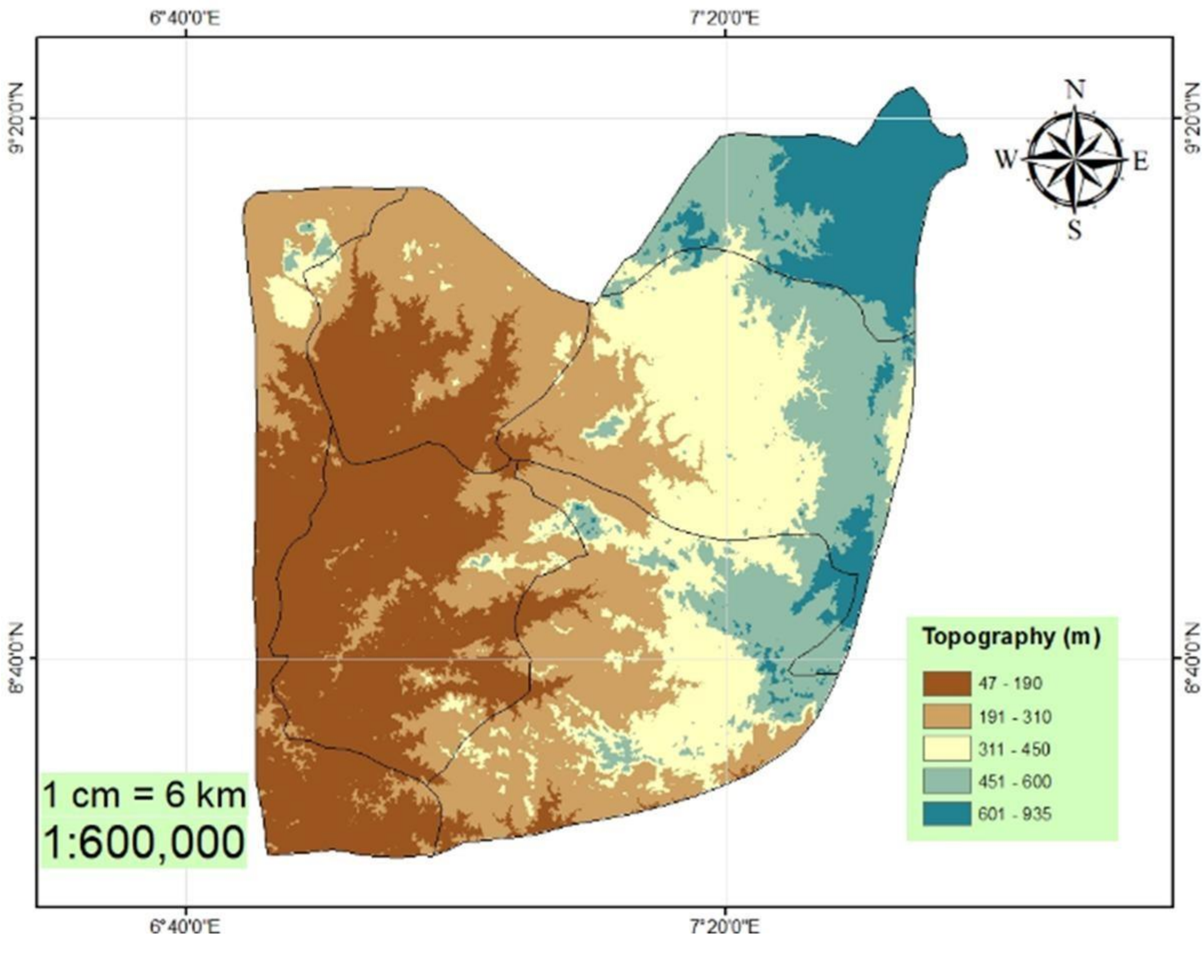

Figure 4.47 Topographic map of FCT

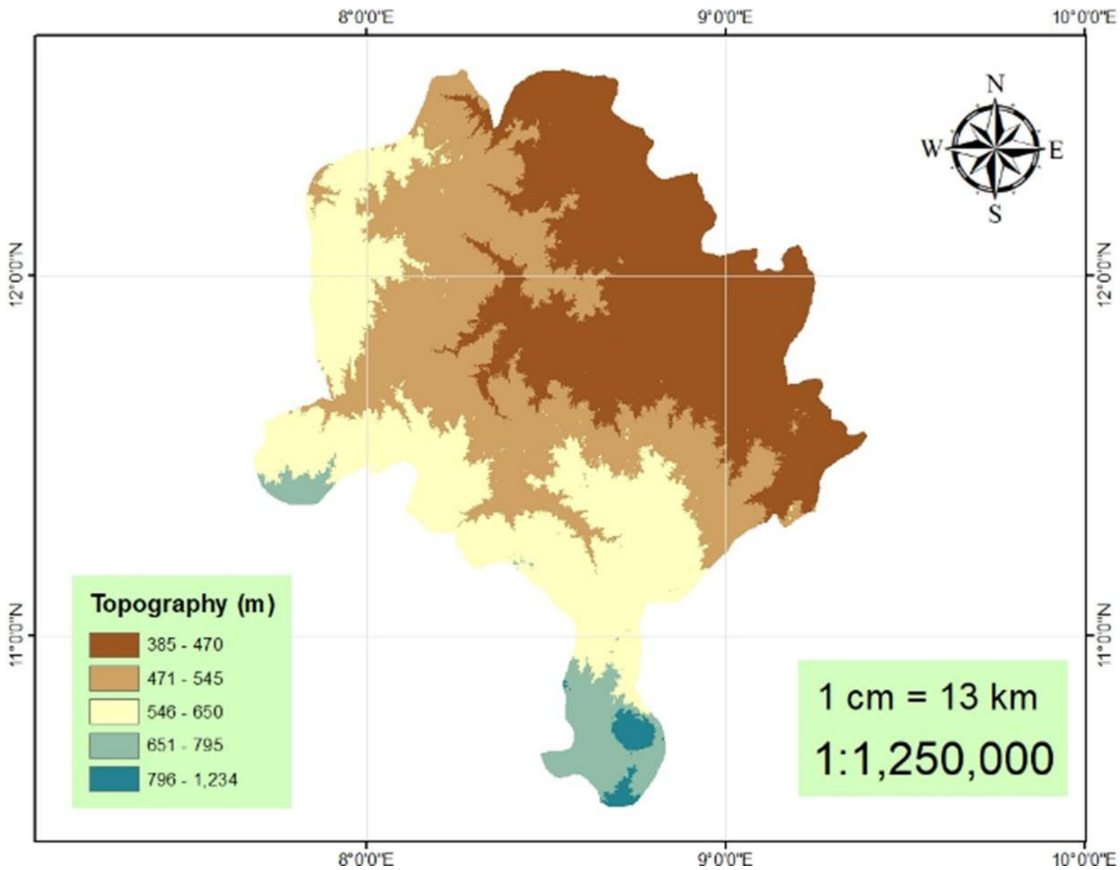

Figure 4.48 Topographic map of Kano

4.3.2 The thermal load aspect: population density

Population density is also known to contribute to the intensity of anthropogenic activities and is known to correlate with the urban thermal environment according to (Oke, 1973, 1987). High population density also gives room for building density and volume which has to increase to accommodate the population. In totality, urban area with a higher density of buildings has poorer urban ventilation conditions and stronger Urban Heat Island effects (Givoni, 1998; Hui, 2001).

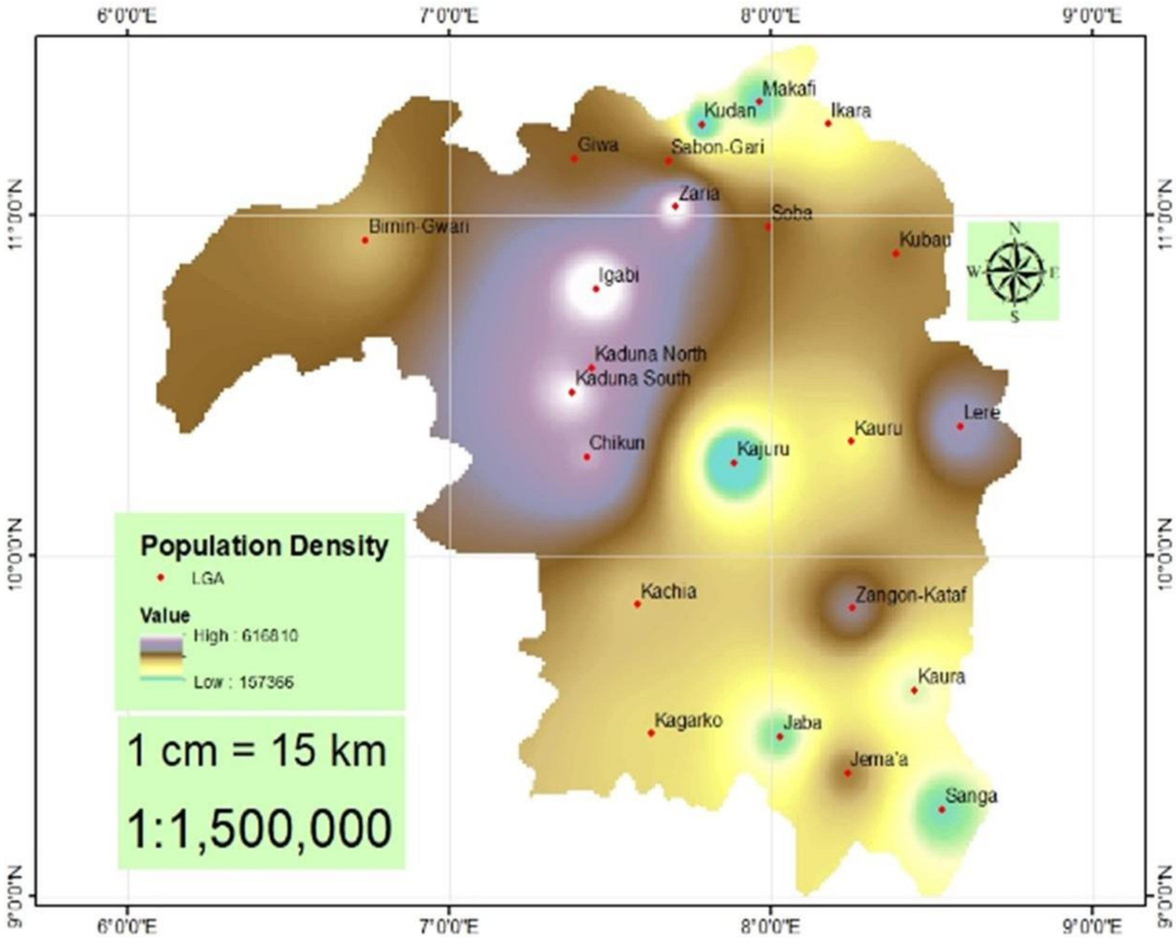

Figure 4.49 Population Density Map of Kaduna

Population density also contributes to the understanding of thermal loads in an Urban Climate Analysis Map. The layers in Figure 4.49; Figure 4.50 and Figure 4.51 represented the population density maps of Kaduna, FCT and Kano respectively. Based on the data obtained from the National Bureau of Statistics where the population figures of 2006 were projected to 2018, it was revealed that places of high population densities include Zaria, Igabi, Kaduna North, Kaduna South and Chikun, whereas low population density places include Kudan, Makafi, Kajuru, Jaba and Sanga. On the other hand Birnin Gwari, Giwa and Kubau are found between these two extremes representing medium populated density areas all in Kaduna State study area, (Figure 4.49). Considering FCT on Figure 4.50, AMAC majorly represented high population density area followed by Bwari and Gwagwalada whereas Kuje, Kwali and Abaji area councils represented low population density areas. Highly population density areas in Kano state as seen on Figure 4.51 include Ungogo, Dala, Gwale, Fagge, Kumbotso and

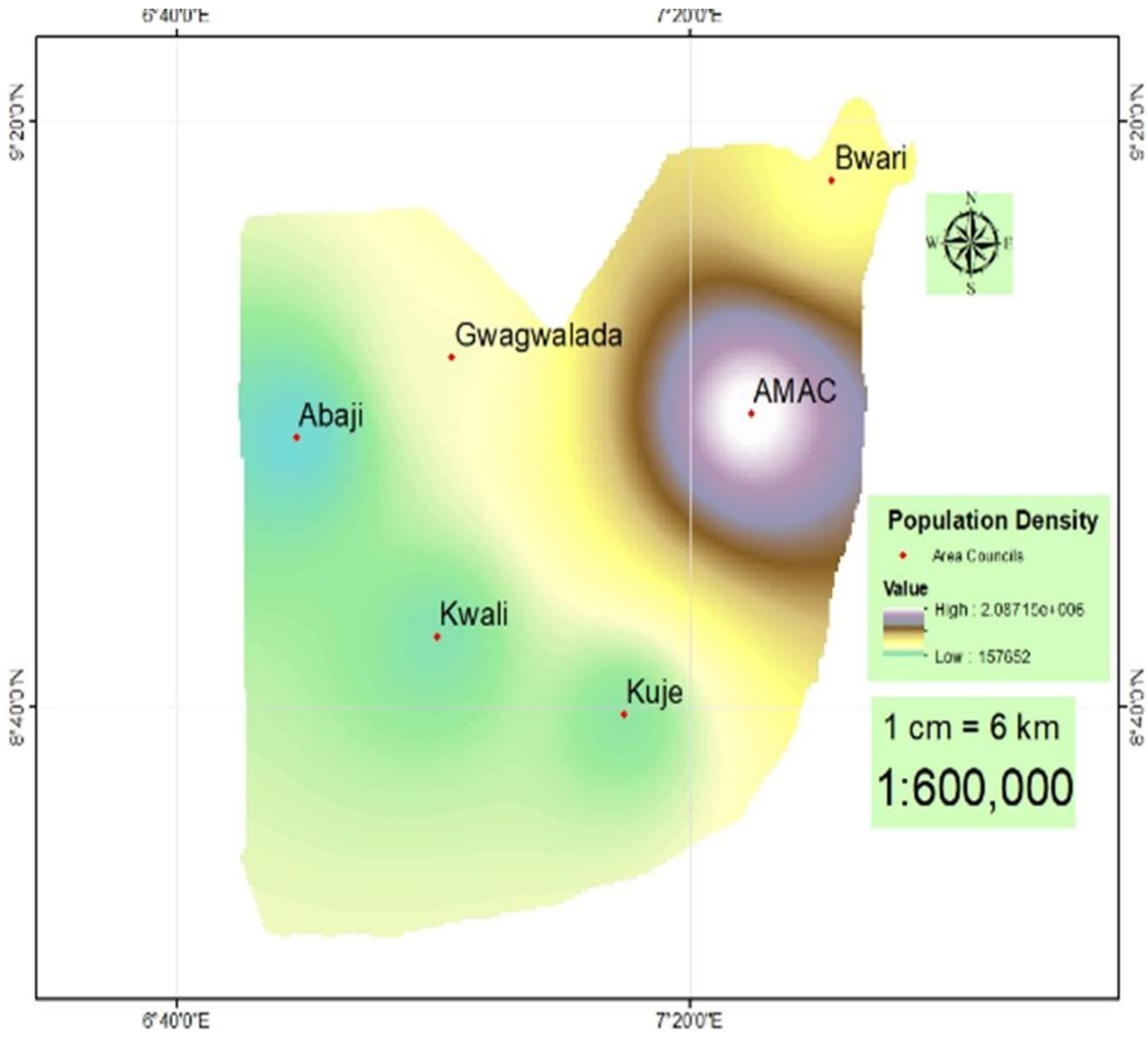

Figure 4.50 Population Density Map of FCT

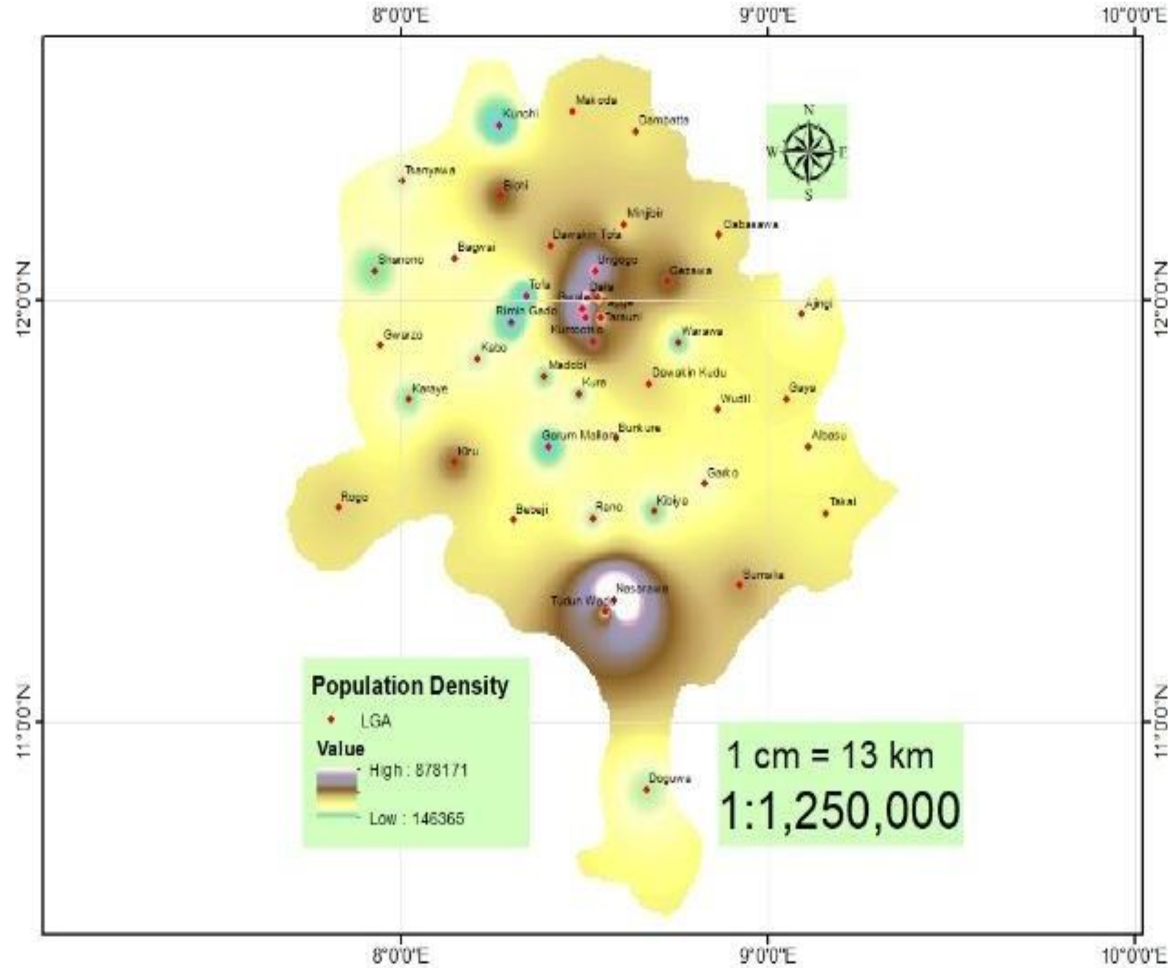

Figure 4.51 Population Density Map of Kano

Nassarawa. On the other hand low population density areas in Kano included Kunchi, Shanono, Tofa, Rimin Gado, Warawa, Kibiya and Garun Mallam, other local government areas in Kano state are medium populated areas.

4.3.3 The thermal load aspect: land use land cover

Land use is another important layer that influence urban thermal environment; it determines a wide range of urban parameters, such as urban density, building form, energy consumption, anthropogenic heat release, and behaviours of transport. Landsat images of the study areas were classified to acquire the land use land cover maps using six different classes such as built up areas, forest areas, vegetation, agricultural land, bare surface and water body, multi-temporal images of 1988 and 2018 images were used in each case coupled with Local Climate Zone Classification of 2018 was also carried out so as to have better details of urban fabric. The LCZ classification scheme has better details of urban fabric and also distinguish between different vegetation types. Details of the land use can be seen on Figure 4.1, Figure 4.2 and Figure 4.3 for Kaduna state; Figure 4.6, Figure 4.7 and Figure 4.8 covers FCT while Figure 4.11, Figure 4.12 and Figure 4.13 covers Kano respectively

Table 4.15 Comparison of the Percentage Areas of LULC Among Cities

LULC	KADUNA (%)	FCT (%)	KANO (%)
Built Up Areas	20.8	22.6	20.79
Forest	14.83	23.62	4.91
Vegetation	20.09	17.64	15.67
Agricultural Area	35.58	31.32	44.41
Bare Surface	8.25	4.28	12.37
Water Body	0.45	0.53	1.85
Total	100	100	100

Source: Author (2018)

4.3.4 The thermal load aspect: urban heat island

One of the most familiar effects of urban heat island is when the temperatures of the central urban locations are several degrees higher than those of nearby rural areas of similar elevation; this effect has been the subject of numerous studies in recent decades and is exhibited by many major cities around the world (Streutker, 2001). Oke (2004) define the phenomenon as a metropolitan area that is having a significantly higher temperature than its surrounding rural areas, that can be more significant in situation when wind or air ventilation is weak. Looking into the LULC and LCZ classification of the study areas from Tables 4.15 the percentage of places classified as built up areas are generally low as compared to vegetation cover and other land use types. Majorly LCZ classification which shows better details for built up areas, larger part of the classified built types are urban areas in each case. As indicated on Table 4.15, 20.8 percentage of the total land area was classified as built up in Kaduna, 22.60 percentage and 20.79 percentage for FCT and Kano respectively. This was also substantiated with the result of the correlation of the LST and NDBI on Tables 4.7 to Table 4.12 where the result of Pearson correlation coefficient of 1 shows a perfect correlation between land surface temperature and built ups.

Table 4.16 Comparison of the Percentage Areas of LCZ Among Cities

LCZ	LCZ DESCRIPTION	KADUNA **(%)**	FCT **(%)**	KANO **(%)**
1	Compact high-rise	0	0	0
2	Compact mid-rise	0	0.01	0
3	Compact low-rise	0.08	3.41	0.1
4	Open high-rise	0	0.17	0
5	Open mid-rise	0	0	0
6	Open low-rise	1.73	0.11	0
7	Light weight low-rise	0.48	1.71	1.83
8	Large low-rise	0.48	1.71	1.83
9	Sparse low-rise	0.59	0.76	0.71
10	Heavy Industry	1.57	5.07	2.4
101	Dense Tress	33.48	2.21	0
102	Scattered Trees	1.29	27.28	8.72
103	Bush	9.48	30.8	41.12
104	Low Plant	23.04	20.23	40.97

Source: Author (2018)

Table 4.17 Comparison of Extracted Area Statistics of LULC

LULC	KADUNA **(%)**	FCT **(%)**	KANO **(%)**
Forest	14.83	20.62	4.91
Vegetation	20.09	17.64	15.67
Agricultural Area	35.58	31.32	44.41
Total	70.5	72.58	64.99

Source: Author (2018)

4.3.5 The thermal load aspect: vegetation cover as natural landscape

Natural vegetation of various kind has cooling effects that is always beneficial to the environment and can lower thermal load. The result of the classification as extracted from both LULC and LCZ (Table 4.15 and Table 4.16) where 70.5%, 72.58% and 64.99% were classified as vegetation cover in the LULC classification for Kaduna, FCT and Kano respectively. Values recorded by the LCZ classification were also higher for vegetation type of land cover, the values are 67.29%, 80.52% and 90.81% for the study areas respectively. This can also be substantiated by the correlation of LST and NDVI with r value of -1 indicating an inverse relationship between vegetation and Land surface temperature and the trend is similar in the three study areas.

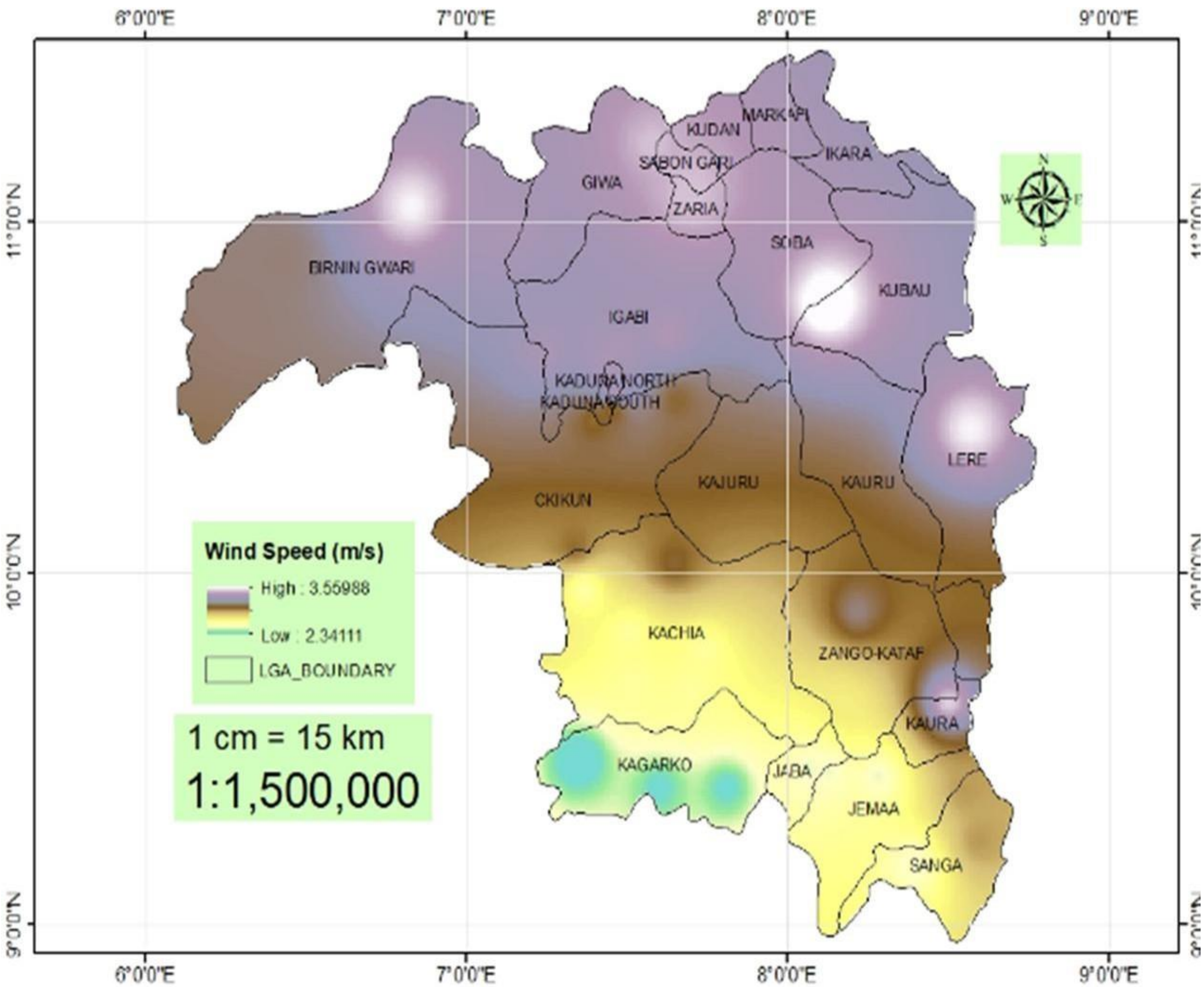

Figure 4.52 Wind Speed Map of Kaduna

4.3.6 The dynamic potential aspect: water system

The classification of the layer was based on the effects of the general water bodies termed as 'water body' in the LULC classification and simply 'water' in LCZ classification. This is basically because of the scale of the maps; the different types of water bodies can be differentiated in large scale maps.

4.3.7 The dynamic potential aspect: wind information

The three study states are located inland, therefore for their Urban Climate Maps, only prevailing wind information was important in urban settlement design. Great potentials was embedded in it in terms of improvement of the thermal environment and solving problems that are related to air pollution. Thus, wind speed was considered in this study, Figure 4.52; 4.53 and 4.54 shows the wind speed in meters per second (m/s) across the three study states; likewise areas of higher and lower wind speed were clearly indicated on the maps and also regions between the two extremes were not left out.

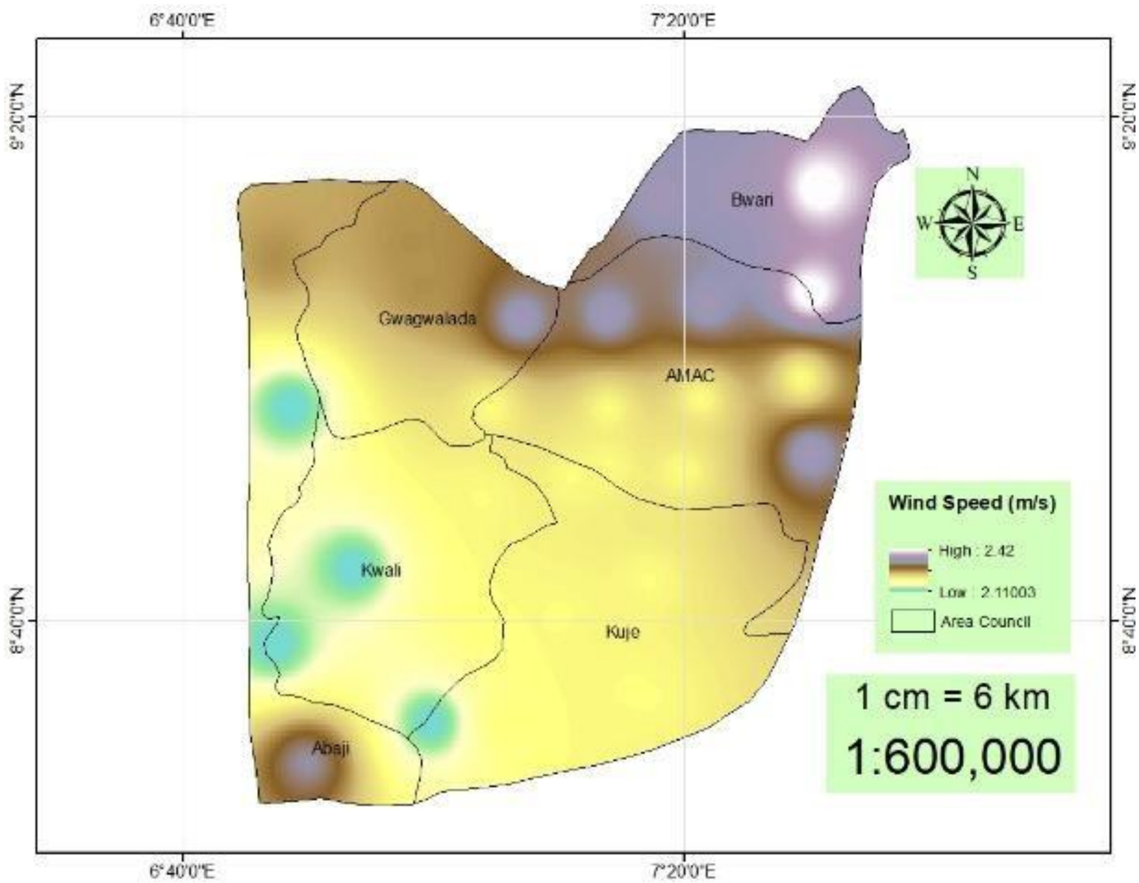

Figure 4.53 Wind Speed Map of FCT

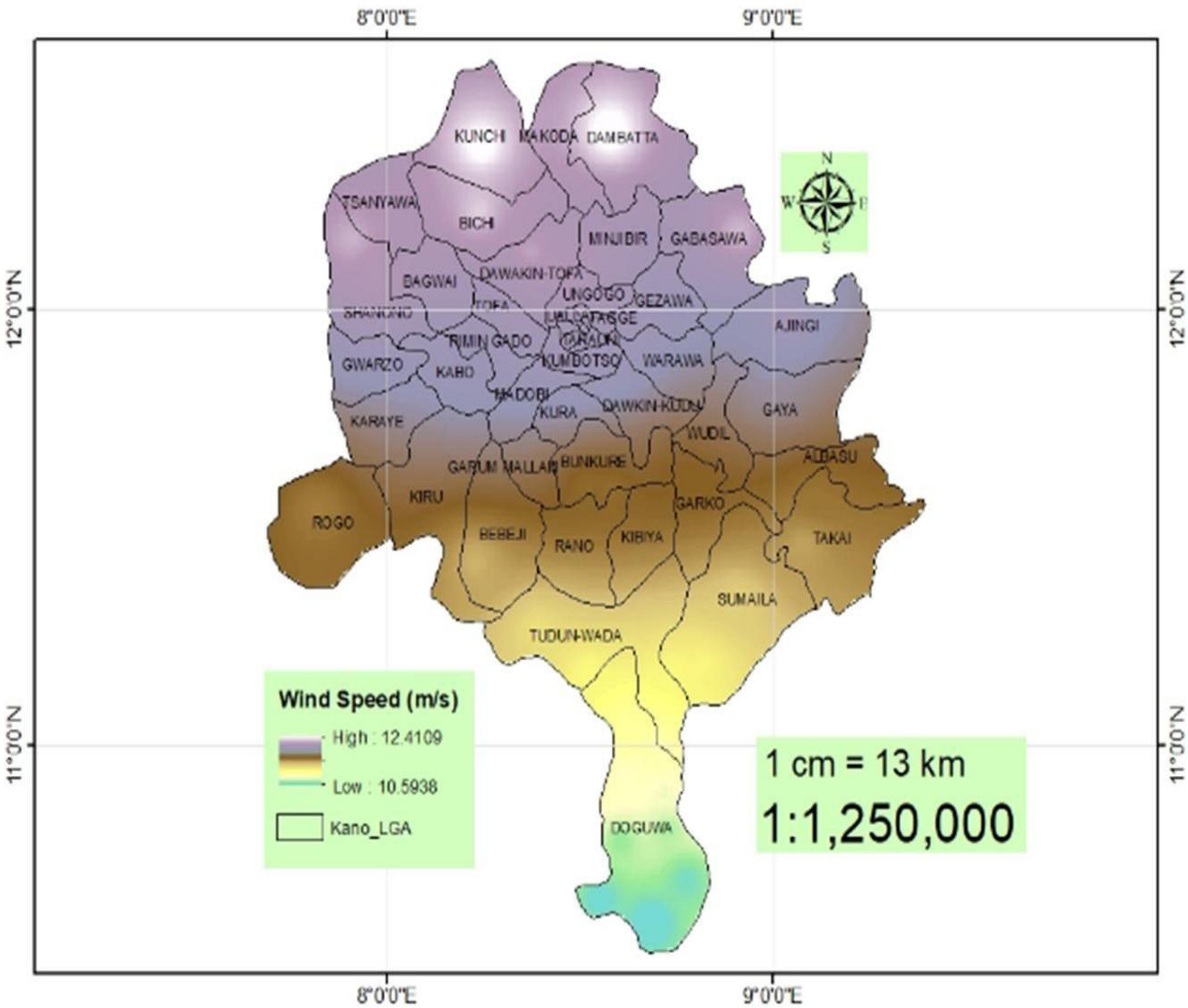

Figure 4.54 Wind Speed Map of Kano

4.4 The Urban Recommendation Map (URM)

Considering the need of the planners, three levels of planning actions were developed in the Urban Recommendation Maps and looked upon generally across the study areas. Local government areas/area councils were used to consider these as indicated in Figures 4.55, 4.56 and 4.57. The possible effective measures of control for each area were also elaborated and summarized based on aspects of greenery, shading, cool albedo, and anthropogenic heat release and air exchange Table 4.18.

Table 4.18 Action Plan and Menu of Effective Control Measures in Kaduna, FCT and Kano

Level of Action Plan	Urban Climatic Environmental Characteristics	LGAs/Area Councils	Greenery	Shading	Cool Albedo	Anthropogenic Heat Release	Air Exchange
Action Plan Necessary	High to very high thermal stress and low dynamic potential, high anthropogenic heat release, various commercial activities and low greenery coverage	Kaduna North & South	A	A	C	B	B
		Zaria	A	C	C	B	B
		Kano city LGAs	A	A	C	B	B
		AMAC	A	C	C	B	B
Some Actions Required	High to medium thermal stress and low to medium dynamic potentials, medium, anthropogenic heat release, some commercial activities and low greenery coverage	Chikun	A	C	C	D	C
		Birnin Gwari	A	C	C	D	C
		Bichi	A	C	C	D	C
		Minjibir	A	C	C	D	C
		Bwari & Gwagwalada	A	C	C	B	C
Preserve and Enhance	Medium to low thermal stress and medium to high dynamic potential, low anthropogenic heat release, some commercial activities, medium to high greenery coverage	Kaura	C	C	C	D	A
		Kajuru	C	C	C	D	A
		Rano	C	C	C	D	A
		Danbatta	E	C	C	D	E
		Kwali & Kuje	C	C	C	D	A

KEY: A – Strongly recommend to improve the existing condition; **B** - Strongly recommend to mitigate the existing condition
C - Recommend to improve the existing condition; **D** - Recommend to mitigate the existing condition;
E – Maintain or Protect the existing condition
Source: Author

To serve as help to planners and policy makers Alcoforado (2006) and Alcoforado *et al*., (2009) established that climatic knowledge from urban areas must be translated into actionable planning language with regards to policy. For this purpose, after developing UCAM a few high thermal load problem areas and sensitive urban climatic areas in Kaduna, FCT and Kano were identified; these places needed attention and mitigation measures broken into the three major levels as follows:

4.4.1 Level 1

Places in Kaduna state that falls under the first level include: Kaduna North, Kaduna South, Igabi and Zaria, only AMAC in FCT and the core city of Kano which include: Dala, Fagge, Nassarawa, Tarauni, Kumbotso, Gwale and Ungogo have very high thermal load and low dynamic potential. These means these areas have intense anthropogenic heat release and the air ventilation is limited. These areas requires specific planning action such as increasing greenery coverage so as to increase the dynamic potential and reduce the anthropogenic heat release.

4.4.2 Level 2

At this level, areas require some mitigation planning measures, the areas include Birnin Gwari, Giwa, Sabon Gari, Chikun, Kachia, Zango-Kataf (Kaduna State) among others. Gwagwalada and Bwari in FCT and Rogo, Kiru, Sumaila, Bichi, Minjibir, Dawakin-kudu in Kano State. These areas are characterized mainly with high to medium thermal stress but high dynamic potential. Anthropogenic heat release in these areas also must be reduced and provision of greenery must be encouraged.

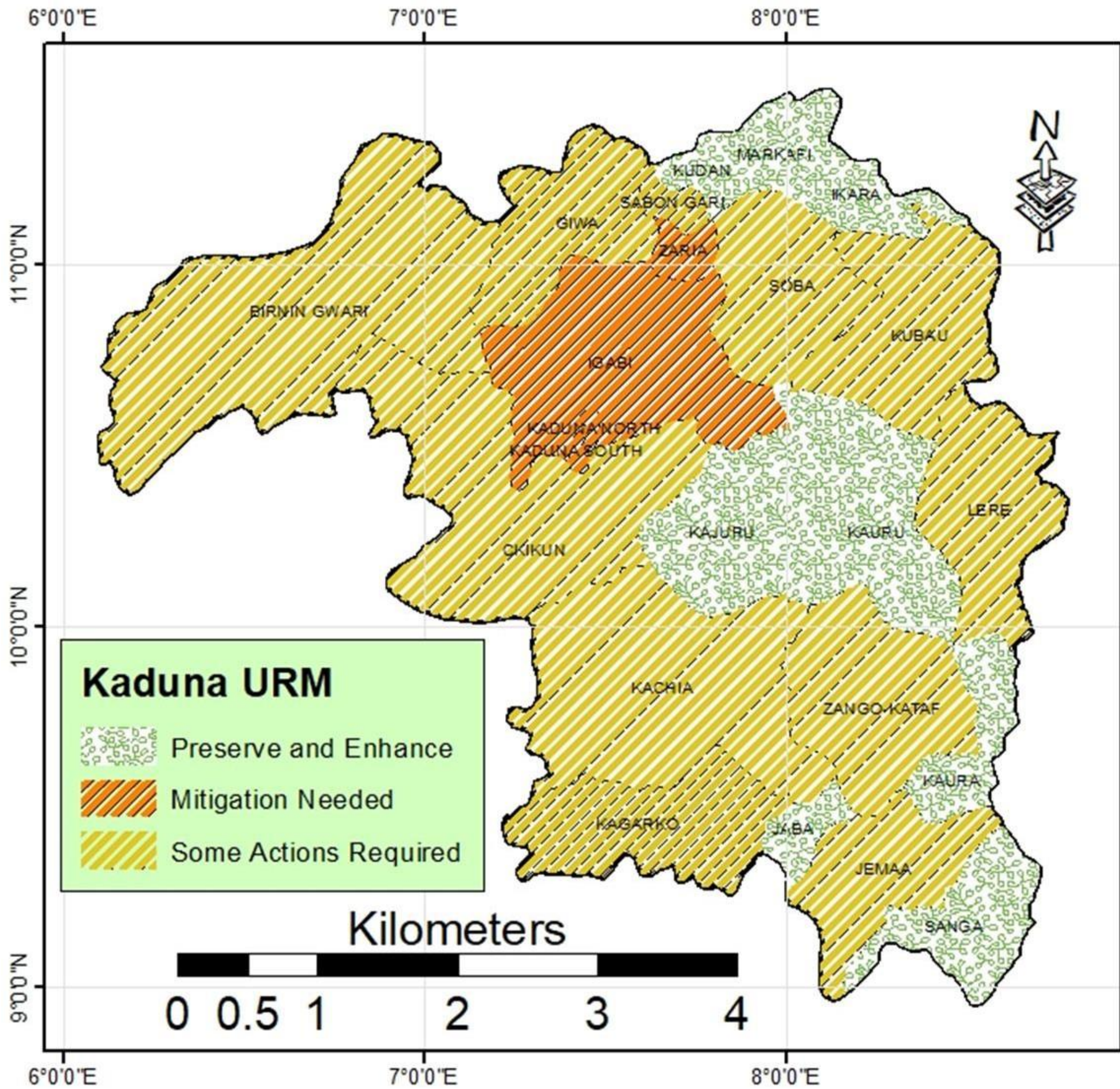

Figure 4.55 Kaduna Urban Recommendation Map

4.4.3 Level 3

Areas with low thermal stress and high dynamic potentials are found mainly in the rural areas Kajuru, Kauru, Sanga, Jaba, Kudn and Makarfi in Kaduna State, Kwali, kuje and Abaji in FCT and vast rural areas in Kano state such as Ajingi, Gaya, Garko, Tudun

Wada, Gwarzo, Shanono, Bagwai among others. The current condition in these rural areas should be preserved and the provision of surfaces of low albedo was also encouraged. Availability of air ventilation was higher in these areas and exchange of air with the surrounding urban areas was highly encouraged.

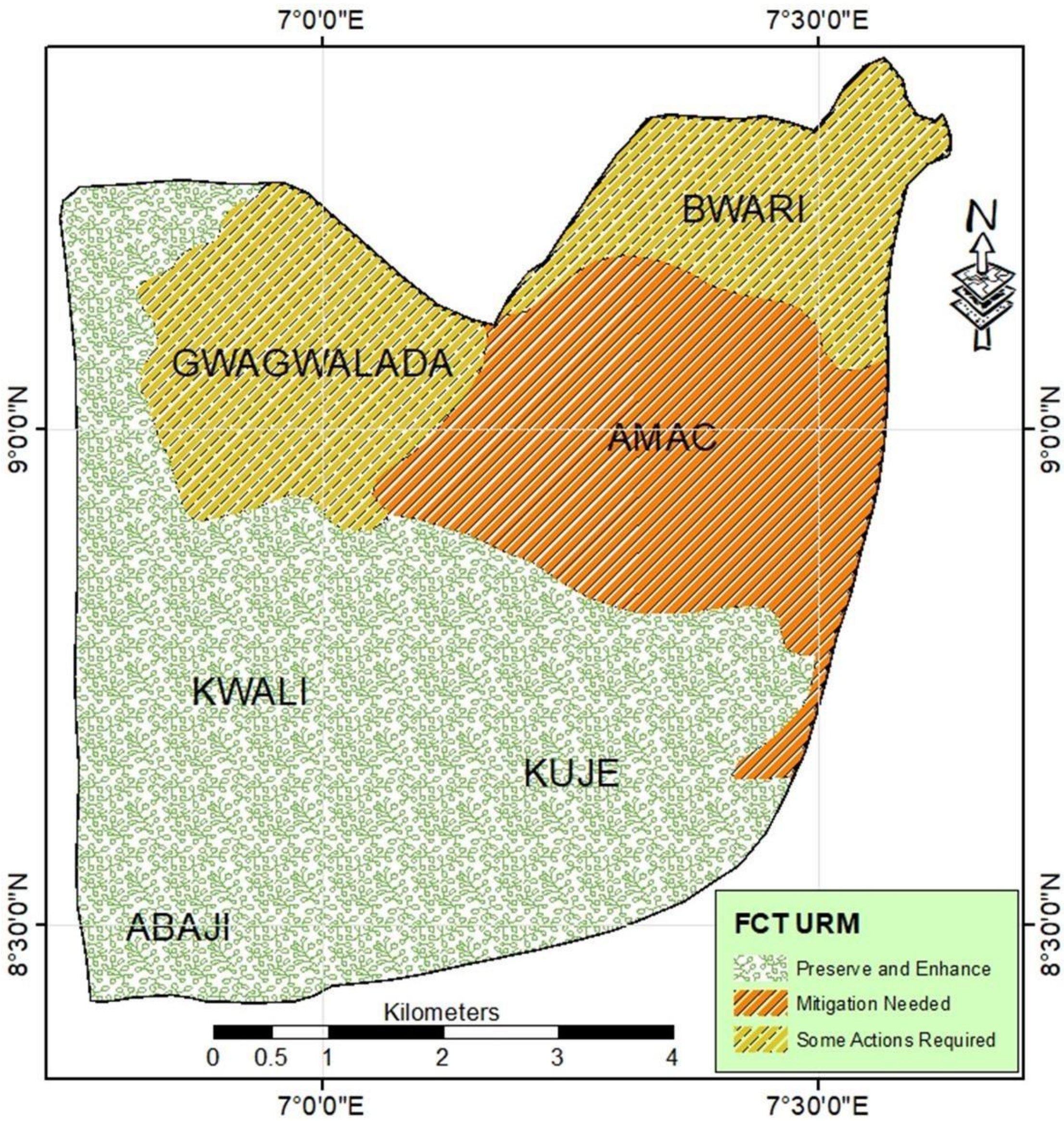

Figure 4.56 FCT Urban Recommendation Map

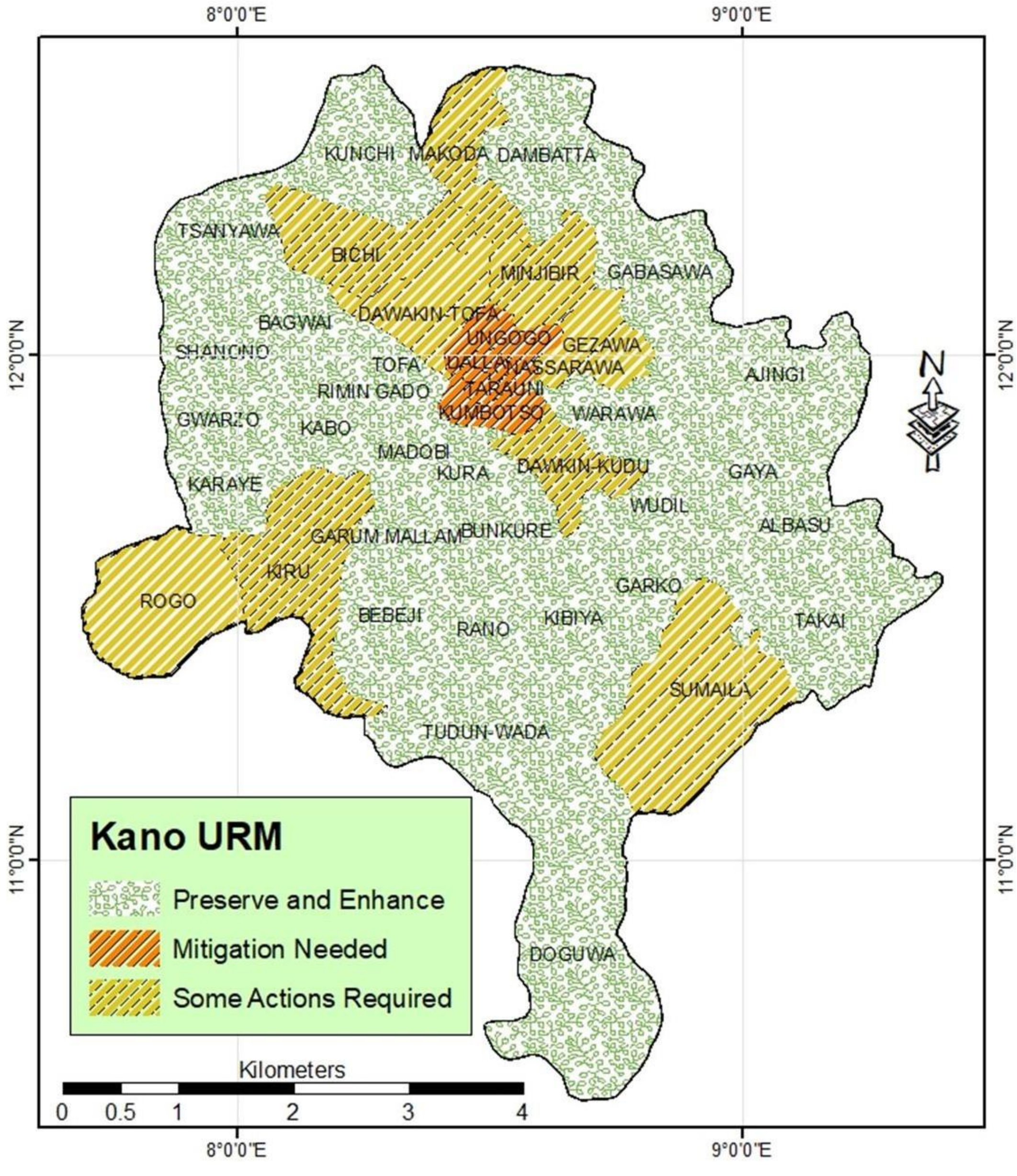

Figure 4.57 Kano Urban Recommendation Map

Further recommendation details for planners includes the following:

4.4.4 Consideration of wind in urban climate based planning

It is very paramount to consider and improve urban ventilation in very dense urban built up areas in tropical cities especially during dry season, similar situation was considered in hot humid cities during summer months (Cheng 2006 and Lin, 2009). The surrounding vegetated city slopes that are capable to provide fresh cool air to other areas are easily blocked by development of buildings, consequently further planned actions are to be considered as touching wind environment and recommended for core urban areas in Kaduna, FCT and Kano states. There are quite few areas especially in the FCT with better dynamic potentials, such areas are the green areas spread within FCT city, same goes with Kaduna especially areas across river Kaduna but the situation with core city of Kano is not good in such situation. The cooling effects from such areas should be carefully considered; the impact of developing new areas on the surrounding vegetated land ought to be minimized if not eliminated to a great extent.

4.4.5 Consideration of water bodies in urban climate based planning

Further consideration and planning action regarding water body is highly recommended in urban design and so water front sites are areas that are important to allow cool air from th water body to penetrate to the city. The cooling effects from water bodies could be from pond, river, lake among others that should be put into planning and development.

4.4.6 Consideration of greenery in urban climate based planning

Chen and Wong, (2009) stressed that cities are put into better positive ecological impact when well vegetated and such vegetated areas of the cities always have better mitigation of UHI effects by acting as oases. Consequently, further consideration and planned action regarding greenery are recommended for core cities of Kaduna, FCT and Kano and those local government areas and area councils on level two of the action plan. Green grasses should be considered along streets and driveways in the core cities instead of the usual concrete lawns found in most Nigeria cities. Road verge containing grasses, plants and trees should also be adopted in strategic areas in the cities as these green spaces will go a long way in mitigating anthropogenic heat release and air pollution naturally.

4.6 Discussion of Results

It is worth to note that Ferreira and Duarte, (2018) in their work on urban form representation of heterogeneous city of Belo Horizonte in Brazil for application in urban climate studies applied three methods and eventually came up with the calculation of the complete aspect ratio method as their best method (a quantitative approach) which can be used to represent the city in surface energy balance simulations and also as an input parameter in weather simulation.

On the contrary, this present study prefers to adopt a modified LCZ classification scheme in which there may be a need to redefine, re illustrate and adjust the properties of the LCZ classes in such a way that the objective of WUDAPT will still be valid and the outcome can also be compared with homogeneous cities to a greater extent. This will be possible coupled with sub classes as raised in the work of Stewart and Oke (2012) where users are at liberty to create new sub-classes for sites that deviate from the standard set of classes. These sub classes represent combination of built types, land cover types and properties as the case may be. The notation for new sub-classes as suggested is LCZXai where “X” represents the higher parent class, “a” represents the lower parent class and “i” represents variable or ephemeral land cover property. It was also noted for the classified compact low-rise (LCZ 3) and open low-rise (LCZ 6) in the study area that some of the land cover are not paved in all cases but the provisions of the sub-classes are enough to modify the cases here while the characteristics of the new classes can be redefined. Beside LCZ1 to LCZ6, other built type LCZ for heterogeneous cities also call for some modifications in definition and surface properties, but the colour scheme for the visual presentation can vary but not to be altered or removed and this will also serve as an opportunity and a bases for comparison to a greater extent with homogeneous cities of the world.

Some major parameters of great importance and good research focus areas in urban climate studies are the values of geometric and surface cover properties for the Local Climate Zones presented in Appendix A such as the sky view factor (SVF), aspect ratio, building surface fraction (BSF), Impervious Surface Fraction, Pervious Surface Fraction, Height of Roughness Element, and Terrain Roughness Class. The relevance of these parameters as can be extracted from this study cannot be limited to this study but serve as an open doors to many other studies substantiated through various studies especially with lots of case studies from Colombo, Sri Lanka and other cities in the world carried out by group of authors such as Perera and Emmanuel (2016), Bechtel *et al.* (2015), Perera *et al.* (2012), Perera and Langapodi (2013).

The LCZ classification for both states indicates an existence of a significant mix in the urban fabric of the cities but mostly observed from FCT where most built-up LCZ have sub-categories. The result of the ground truth indicated few or no compact high-rise (LCZ 1) but vast open high-rise (LCZ 4) around the Central Business District (CBD) combined with sub-categories of compact and open low-rise (LCZ 3 and 6) denoted by LCZ 4_{36}. The vast areas classified as compact low-rise (LCZ 3) also have sub-category of Lightweight low-rise (LCZ 7) in most cases also denoted by LCZ 3_7 with the exception of Gwarinpa Estate which perfectly fit into compact low-rise (LCZ 3) but with different building structures ranging from masfa to single phases, corner shops and bonny BB which were all well-structured.

Other areas worth to mention involves Utako classified as compact low-rise (LCZ 3) also mix with compact mid-rise (LCZ 2) denoted by LCZ 3_2. Wuse and Garki also follow the same manner as LCZ 3_2 though classified as LCZ 3 and Yanyan and Lugbe village classified as Lightweight low-rise (LCZ 7) but made up of unorganized built up settings having vast of the characteristics of sparse low-rise (LCZ 9) denoted by LCZ 7_9.

Kaduna city fabric was majorly compact low-rise (LCZ 3) and Lightweight low-rise (LCZ 7), the only area in Kaduna city where high-rise buildings were found was along constitution road and it was very difficult to classify because there are mixture of high, medium and low-rise buildings in an unorganized manner. The sub-classes here could be said to be mixture of compact low-rise building as the major class with compact and open mid-rise buildings as the sub classes LCZ 3_{25}. this can be substantiated by the works of Odekunle *et al.* (2019) in the core cities of Kaduna and FCT where it was established that similar studies could be carried out in Nigerian heterogeneous cities through the methods of sub-classification of the LCZs in the different cities.

Areas around Race Course road, Coronation Crescent, Unguwan Sarki and the environs form another cluster of mix buildings but with abundant trees and pervious land cover, sharing the characteristics of both compact low-rise and sparse low-rise buildings (LCZ 3 and LCZ 9); classified as Lightweight low-rise (LCZ 7) as the major class with LCZ 3 and LCZ 9 as the sub classes denoted by LCZ 7_{39}.

In the case of the city of Kano, major built up included light weight low-rise (LCZ 7) followed by sparse low-rise (LCZ 9), and compact low-rise (LCZ 3).

4.6.1 Sub-categories of the LCZ classes in the study areas

There are mixed LCZ classification in different parts of the study areas, the following referents the summary of the sub-categories:

1. Compact Low-rise with Compact High-rise as the sub class - LCZ 3_2
2. Compact Low-rise with Lightweight low-rise as the sub class - CLCZ 3_7
3. Open High-rise with two sub classes: Compact Low-rise and Open Low-rise - LCZ 4_{36}
4. Lightweight Low-rise with Sparse Low-rise as the sub class LCZ 7_9
5. Compact Low-rise with two sub classes: Compact High-rise and Open High-rise - LCZ3_{25}
6. Lightweight Low-rise with two sub classes: Compact Low-rise with and Sparse Low-rise - LCZ 7_{39}

The methodology put forward in this study on one hand was to bring out the details of urban fabrics in form of Local Climate Zones to map regions of uniform surface air temperature distribution at horizontal scale of 10^2 to 10^4 meters the method developed by Stewart and Oke in the year 2012. The LCZ map combined with LST, NDVI and NDBI maps were used to determine the effects of the urban spatial features across the study area.

The hypotheses set aside for this purpose were two, the first null hypothesis stated that "there was no significant relationship between built-up and LST" was rejected because there was significant relationship between the two variables because it has been established in the study area that increased in built up areas have also resulted into an increase in NDBI values which invariably was having a positive correlation with LST in both cities substantiated with perfect relationship in both cases and this could be corroborated by the study carried out by Yue *et al.*, (2007) in the city of Shangai that indicated that LST, NDVI and Shanon Diversity Index provided an effective tool in evaluating the environmental influences of zoning in ecosystems within urban areas. Not that alone, Li and Liu (2008) also indicated a strong linear relationship between LST and NDBI and suggest that urban areas account for most of the variations in LST dynamics in the study carried out in Changsha-Zhuzhou-Xiangtan metropolitan area.

On the other hand the second hypothesis that stated that “there was no significant relationship between vegetation and LST” was also rejected because there existed a negative perfect correlation between NDVI and LST and the result was statistically significant at 0.01 significant level, which indicated also that an inverse relationship existed between the two variables involved. Positive NDVI values was synonymous to lower LST value and negative NDVI values signifies higher LST value as extracted from the various maps.

Similar results obtained after analyzing the different variables in the study area indicated that since an increase in built up was the reason for an increase in NDBI values and this invariably was having a positive correlation with the Land Surface Temperature, a perfect relationship for that matter, this was a strong point that needed to be considered both in terms of research and also for planning purposes. On the other hand, the perfect negative correlation that also existed in the case of the LST and NDVI signifies the fact that the Land Surface Temperature could be controlled with planning towards planting more vegetation, since higher NDVI values represents present of healthy vegetation, and as could be deduced from correlating LST and NDVI, the higher the vegetation and healthier, the lower the Land Surface Temperature (perfect negative correlation).

The results for relationship between LST, NDBI and NDVI suggested that perfect relationships existed between the built up types indicated on the LCZ map as LCZ 1 to LCZ10 and the other land cover types most especially vegetation indicated by cover types (LCZA to LCZG) but with more emphasis on LCZ A to LCZ D that represented vegetation cover as correlated with the distribution of temperature in the study cities. This could be further substantiated with the various maps such as the LCZ map, NDVI map and NDBI map. Also corroborated by the work of Macarof and Statescu (2017) on the study of Comparison of NDBI and NDVI as indicators of Surface Urban Heath Effect in Landsat 8 imagery in Iasi where it was acknowledged that there was a strong linear relationship between LST and NDBI and it was suggested that NDBI was accurate indicator of surface UHI effect and could also be used as a complementary metric to the traditionally applied NDVI.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There was vast rapid urbanization across developing countries of the world and Nigeria was not an exception, villages are developing into towns and towns into cities and mega-cities. The reality of facing climate change and the concern of the public about high quality urban living in the era of this mega urbanization is one of the most important task and challenges for urban planners and policy makers which is sustainable climatic planning. However, urban climate and environment are easily neglected when new town plan or construction work are undertaken due to lack of climatic knowledge and comprehensible climatic environmental evaluation, so this called for the application of urban climate science to urban development in developing countries and the need for this study that covered a remarkable gap in literature especially in the study areas.

This study provided a GIS-based method for developing a UCAM for Kaduna, FCT and Kano; seven input layers were developed and evaluated in UCAM along with URM, these maps were also implemented into a local planning system for better understanding of the planners and policy makers. The advantages of this method is such that the UCAM is flexible, and the selected climatic data, environmental and planning information collated and evaluated with the same grid size embedded into GIS. This made the work sustainable because it can be updated and managed easily for planning purposes. The climatic information from the UCAM and the evaluation was also translated into planning-based language which also formed the measures of effective control and planning strategies on the general ground and could be referred to in the master plan of the states.

Knowledge sharing and exchange across fields of discipline is of paramount importance especially in a situation that applies to climate that transcends boundaries. This study scholarly contributes to the development of the urban climate mapping for high and low density cities based on environmental planning information and selected basic climatic data with joint efforts from climatologist and planners. the findings of the UCAM and the recommendations of URM concerning wind, greenery and water bodies among others was suitable to provide local planners and policy makers with useful guide which could be used as reference for better climatic spatial planning at the state level.

5.2 Recommendations

In light of the above conclusion, the following recommendations were considered as appropriate:

i. There is a need for the major stake holders such as climatologists, planners, architects and government to form an important entity that can always be consulted whenever there is a need for development in Nigerian cities.

ii. There is also a need to encourage such studies like this and the major findings are supposed to be driven into actions in different parts of the country

iii. This study was limited to larger area (the entire states) and was more general than specific, there is a need for more specific study (at city, district and local level) that will utilize higher resolution images and also at a neighbourhood scale where important climatic features will be considered for planning purposes

iv. Totally, Urban Recommendation Map (URM) elaborated through Figures 4.55, 4.56 and 4.57; also substantiated by table 4.20 along with other detail explanation of other important elements formed a major recommendation of this research. There is also an important need for the level of details to be considered in larger scale such as district level in each case.

v. Seminars and campaign programs should be set up to sensitize the populace and policy makers on the dangers of development without following the right channel.

5.3 Contribution to Knowledge

The result of the study reveals satisfying accuracy assessment of both the local climate zone (LCZ) and landuse and land cover (LULC) in the three study areas. Kappa/overall accuracy in Kaduna State was 0.96/84.69 for LCZ; FCT was 0.96/88.76 while that of kano was 0.99/78.12 respectively. While the LULC accuracy assessment in the study area between 1988 and 2018 was 0.81/88.07 and 0.81/89.85 in Kaduna; FCT was 0.78/83.03 and 0.79/89.90 and Kano was 0.79/82.83 and 0.86/88.57. Time plots of temperature observations from 1988 to 2018 also showed indications of trend, seasonality and randomness in pattern. Hence, Urban recommendation map zoned the study areas into three according to the required action plan such as zones where action plans are necessary, some action required and zones to be preserved and enhanced.

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APPENDICES

Appendix A. Values of Geometric and Surface Cover Properties for Local Climate Zones

S/N	Local Climate Zones	Sky View Factor[a]	Aspect Ratio[b]	Building Surface Fraction[c]	Impervious Surface Fraction[d]	Pervious Surface Fraction[e]	Height of Roughness Element[f]	Terrain Roughness Class[g]
1.	LCZ1-Compact high-rise	0.2-0.4	>2	40-60	40-60	<10	>25	8
2.	LCZ2-Compact mid-rise	0.3-0.6	0.75-2	40-70	30-50	<20	10-25	6-7
3.	LCZ3-Compact low-rise	0.2-0.6	0.75-1.5	40-70	20-50	<30	3-10	6
4.	LCZ4-Open high-rise	0.5- 0.7	0.75-1.25	20-40	30-40	30-40	>25	7-8
5.	LCZ5-Open mid-rise	0.5-0.8	0.3-0.75	20-40	30-50	20-40	10-25	5-6
6.	LCZ6-Open low-rise	0.6-0.9	0.3-0.75	20-40	20-50	30-60	3-10	5-6
7.	LCZ7-Lightweight low-rise	0.2-0.5	1-2	60-90	<20	<30	2-4	4-5
8.	LCZ8-Large low-rise	>0.7	0.1-0.3	30-50	40-50	<20	3-10	5
9.	LCZ9-Sparse low-rise	>0.8	0.1-0.25	10-20	<20	60-80	3-10	5-6
10.	LCZ10-Heavy industry	0.6-0.9	0.2-0.5	20=30	20-40	40-50	5-15	5-6
11.	LCZ A-dense trees	<0.4	>1	<10	<10	>90	3-30	8
12.	LCZ B-Scattered trees	0.5-0.8	0.25-0.75	<10	<10	>90	3-15	5-6
13.	LCZ C-Author/scrub	0.7-0.9	0.25-1.0	<10	<10	>90	<2	4-5
14.	LCZ D-Low plants	>0.9	<0.1	<10	<10	>90	<1	3-4
15.	LCZ E-Bare rock/paved	>0.9	<0.1	<10	>90	<10	<0.25	1-2
16.	LCZ F-Bare soil/ sand	>0.9	<0.1	<10	<10	>90	<0.25	1-2
17.	LCZ G-Water	>0.9	<0.1	<10	<10	>90	-	1

Source: Stewart and Oke (2012)

a Ratio of the amount of sky hemisphere visible from ground level to that of an unobstructed hemisphere

b Mean height-to-width ratio of street canyons (LCZs 1–7), building spacing (LCZs 8–10), and tree spacing (LCZs A–G)
c Ratio of building plan area to total plan area (%)
d Ratio of impervious plan area (paved, rock) to total plan area (%)
e Ratio of pervious plan area (bare soil, vegetation, water) to total plan area (%)
f Geometric average of building heights (LCZs 1–10) and tree/plant heights (LCZs A–F) (m)
g Classification of effective terrain roughness (*z*0) for city and country landscapes.

Appendix B Status of Local Climate Zone Mapping in the World

S/N	Continent	Cities that indicated interest	Cities that have completed their tasks	Cities currently working
1	Africa	07	01	01
2	Americas (North, Central and South)	25	07	10
3	Asia	35	04	28
4	Austrasia	02		02
5	Europe	42	10	18

Appendix C Abridged Definitions for Local Climate Zones

S/NO	LOCAL CLIMATE ZONES	DEFINITIONS
1.	LCZ1-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.	LCZ2-Compact mid-rise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.
3.	LCZ3-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.	LCZ4-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.	LCZ5-Open mid-rise	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.	LCZ6-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.	LCZ7-Lightweight low-rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (such as wood, thatch, corrugated metal).
8.	LCZ8-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.	LCZ9-Sparse low-rise	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).
10.	LCZ10-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.
11.	LCZ 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.
12.	LCZ 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.
13.	LCZ C-Author/scrub	Open arrangement of Authores, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
14.	LCZ D-Low plants	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
15.	LCZ E-Bare rock/paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
16.	LCZ F-Bare soil/ sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
17.	LCZ G-Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.

Source: Adapted from Stewart and Oke (2012)

Appendix D: Field Samples used for Accuracy Assessment

Abuja Sampled Points

S/N	Latitude	Longitude	LCZ
1	8.95407	7.37626	3
2	8.95177	7.38014	3
3	8.95293	7.37465	3
4	8.95562	7.37504	3
5	8.95280	7.37672	3
6	8.95719	7.36560	3
7	8.96346	7.38168	3
8	8.96447	7.38518	3
9	8.96860	7.38278	3
10	8.96621	7.38522	3
11	8.96382	7.38713	3
12	8.97382	7.34840	3
13	8.97641	7.34854	3
14	8.97426	7.34630	3
15	8.97397	7.34952	3
16	8.98411	7.36071	3
17	8.98451	7.36298	3
18	8.98960	7.36255	3
19	8.98448	7.36057	3
20	8.98591	7.36368	3
21	8.98931	7.36787	3
22	8.99573	7.36828	3
23	8.99404	7.37111	3
24	9.03341	7.49011	3
25	9.03585	7.49051	3
26	9.03701	7.48792	3
27	9.03283	7.48756	3
28	9.03518	7.49613	3
29	9.10792	7.40221	3
30	9.11097	7.40298	3
31	9.11122	7.40043	3
32	9.10563	7.40184	3
33	9.10852	7.40681	3

34	9.11132	7.40120	3
35	9.95219	7.37933	3
36	9.95555	7.37639	3
37	8.95621	7.36890	3
38	8.95790	7.36726	3
39	9.06924	7.43026	3
40	9.06752	7.42538	3
41	9.08198	7.46876	3
42	9.08396	7.46900	3
43	9.08463	7.47013	3
44	9.08139	7.47124	3
45	9.07939	7.46700	3
46	9.07655	7.46700	3
47	9.07553	7.46175	3
48	9.07662	7.47077	3
49	9.08797	7.47736	3
50	9.07546	7.48033	3
51	9.08123	7.50087	3
52	9.07564	7.50007	3
53	9.07574	7.49751	3
54	9.08774	7.41063	3
55	9.08790	7.41508	3
56	9.09334	7.41361	3
57	9.09487	7.40475	3
58	9.10083	7.40120	3
59	9.10596	7.40157	3
60	9.11178	7.40275	3
61	9.11702	7.41005	3
62	9.11825	7.39856	3
63	9.11483	7.41932	3
64	9.06415	7.45146	3
65	9.06452	7.45033	3
66	9.07389	7.45137	3
67	9.21568	7.40666	3
68	9.054862	7.48583	4
69	9.054179	7.48476	4
70	9.054455	7.485562	4
71	9.051745	7.487028	4
72	9.049469	7.48584	4
73	9.04885	7.484399	4
74	9.048373	7.485287	4

75	9.064071	7.484334	4
76	9.063274	7.484734	4
77	9.066009	7.486781	4
78	9.065858	7.487273	4
79	9.059622	7.489788	4
80	9.060345	7.489522	4
81	9.055904	7.492202	4
82	9.056705	7.492668	4
83	9.055635	7.492041	4
84	9.16869	7.38767	7
85	9.16728	7.38047	7
86	9.16350	7.38031	7
87	9.16339	7.39071	7
88	8.95615	7.07011	7
89	8.95182	7.06829	7
90	8.96959	7.37433	7
91	8.97045	7.37152	7
92	8.96766	7.37679	7
93	8.97251	7.37743	7
94	8.96652	7.37648	7
95	8.97074	7.37428	7
96	8.82789	7.26060	7
97	8.82861	7.25729	7
98	8.82529	7.25856	7
99	8.82950	7.27275	7
100	8.82659	7.27712	7
101	9.11577	7.23622	7
102	9.11320	7.23341	7
103	9.11148	7.23692	7
104	9.10972	7.23256	7
105	9.11065	7.23674	7
106	9.10506	7.21568	7
107	9.10324	7.21350	7
108	9.09919	7.21469	7
109	8.96639	7.37311	7
110	8.96760	7.37846	7
111	8.97350	7.37409	7
112	8.96114	7.06426	7
113	8.95932	7.06908	7
114	8.95595	7.06811	7
115	8.94979	7.07901	7

116	8.94616	7.08766	7
117	8.94144	7.09601	7
118	8.93802	7.10112	7
119	8.93706	7.09587	7
120	9.21827	7.41220	7
121	9.22036	7.41329	7
122	9.27834	7.38280	7
123	9.27542	7.38266	7
124	9.28167	7.48750	7
125	9.28060	7.38956	7
126	9.02151	7.54541	9
127	9.01883	7.54666	9
128	8.97655	7.26827	9
129	8.97489	7.27068	9
130	8.97791	7.27200	9
131	8.96048	7.12796	9
132	8.989753	7.20848	9
133	8.986238	7.211352	9
134	8.985812	7.207284	9
135	8.981514	7.208283	9
136	8.980227	7.209462	9
137	9.038682	7.175443	9
138	9.035595	7.174518	9
139	9.037549	7.17769	9
140	9.034519	7.174914	9
141	9.037377	7.173014	9
142	9.034387	7.175347	9
143	9.07436	7.363352	9
144	9.07249	7.36552	9
145	9.07193	7.363317	9
146	8.94087	7.434252	9
147	8.938219	7.436277	9
148	9.03884	7.45656	10
149	9.03859	7.45330	10
150	9.03558	7.45410	10
151	9.03357	7.40461	10
152	9.08442	7.47038	10
153	9.03359	7.40010	10
154	9.02935	7.40029	10
155	9.03345	7.40179	10
156	9.83416	7.39706	10

157	9.63206	7.40740	10
158	8.99400	7.27984	10
159	8.99046	7.27540	10
160	9.00430	7.26639	10
161	8.99500	7.25190	10
162	9.01262	7.27573	10
163	9.06448	7.45202	10
164	9.036984	7.355398	10
165	9.048099	7.34544	10
166	9.05089	7.336537	10
167	9.040354	7.357769	10
168	9.045665	7.349948	10
169	9.036082	7.357071	10
170	9.001964	7.276722	10
171	8.991287	7.282787	10
172	9.003376	7.264973	10
173	9.001697	7.278095	10
174	8.992867	7.264572	10
175	8.988473	7.253029	10
176	8.991896	7.274088	10
177	9.006983	7.276772	10
178	9.032805	7.405019	10
179	9.028662	7.407879	10
180	9.029705	7.399862	10
181	9.032621	7.386504	10
182	9.036543	7.384655	10
183	9.07977	7.51489	101
184	9.07886	7.51742	101
185	9.07597	7.51965	101
186	9.07614	7.51587	101
187	9.07401	7.52034	101
188	9.07125	7.51878	101
189	9.06882	7.51493	101
190	9.06395	7.51038	101
191	9.06052	7.51099	101
192	9.06262	7.51290	101
193	9.28047	7.48081	101
194	9.19469	7.54685	101
195	9.19417	7.54440	101
196	9.19400	7.54255	101
197	9.20399	7.55059	101

198	9.21195	7.54594	101
199	9.21298	7.54264	101
200	9.22553	7.54301	101
201	0.21824	7.43407	101
202	9.207918	7.118882	101
203	8.812335	7.598524	101
204	8.812425	7.606077	101
205	8.804553	7.608777	101
206	8.79936	7.598412	101
207	8.799672	7.607337	101
208	8.806613	7.620832	101
209	8.799412	7.622307	101
210	8.798085	7.583204	101
211	8.96520	7.19459	102
212	8.95984	7.20072	102
213	8.95300	7.18853	102
214	8.95119	7.19825	102
215	8.94600	7.19910	102
216	8.94983	7.16182	102
217	8.94780	7.17136	102
218	8.94010	7.17152	102
219	9.10930	7.39377	102
220	9.10673	7.39433	102
221	9.10727	7.39214	102
222	9.09843	7.39433	102
223	9.09532	7.39483	102
224	9.09216	7.39563	102
225	9.09359	7.39769	102
226	9.10139	7.34200	102
227	9.10076	7.34536	102
228	9.09735	7.34863	102
229	9.09651	7.35071	102
230	9.12402	7.32336	102
231	9.10946	7.33462	102
232	9.07046	7.49636	102
233	9.07059	7.49724	102
234	9.06969	7.49918	102
235	9.06900	7.49943	102
236	9.07043	7.50051	102
237	9.07256	7.50196	102
238	9.08375	7.50741	102

239	8.95166	7.07410	102
240	8.95210	7.07599	102
241	9.09455	7.40025	102
242	9.08559	7.40499	102
243	9.10931	7.39452	102
244	8.815364	7.453914	102
245	8.821927	7.457077	102
246	8.822863	7.467069	102
247	8.81995	7.475322	102
248	8.82461	7.538854	102
249	8.817257	7.533406	102
250	8.86524	7.11693	104
251	8.85944	7.12355	104
252	8.85094	7.11765	104
253	8.85537	7.10887	104
254	8.89437	7.32494	104
255	8.89272	7.32761	104
256	8.89311	7.32418	104
257	8.89594	7.32599	104
258	8.89247	7.32790	104
259	8.91306	7.32250	104
260	8.91158	7.32213	104
261	8.91155	7.32341	104
262	8.91126	7.32116	104
263	8.91597	7.31245	104
264	8.91403	7.31255	104
265	8.91273	7.31137	104
266	8.91219	7.31257	104
267	8.91249	7.30878	104
268	8.91494	7.31046	104
269	8.82687	7.06747	104
270	8.82438	7.07211	104
271	8.82103	7.07969	104
272	8.81978	7.08513	104
273	8.81821	7.07985	104
274	8.81509	7.07983	104
275	8.81717	7.08466	104
276	8.81524	7.08554	104
277	8.81896	7.08264	104
278	8.81229	7.13435	104
279	8.81420	7.13025	104

280	8.89052	7.32371	104
281	8.88939	7.32329	104
282	8.88832	7.32378	104
283	8.89202	7.32056	104
284	8.88908	7.32268	104
285	8.89263	7.32505	104
286	8.88842	7.32717	104
287	8.90159	7.31205	104
288	8.90429	7.33241	104
289	8.90058	7.33611	104
290	8.89629	7.11058	104
291	8.90855	7.10968	104
292	8.91270	7.09369	104
293	8.90322	7.08613	104
294	8.88337	7.14916	104
295	8.87580	7.16195	104
296	8.87070	7.18570	104
297	8.91484	7.16060	104
298	8.88179	7.11473	104
299	8.89539	7.10997	104
300	8.89062	7.08529	104
301	9.12965	7.23448	105
302	9.13161	7.23101	105
303	9.15738	7.30021	105
304	9.16267	7.30287	105
305	9.16672	7.23340	105
306	9.16423	7.23404	105
307	9.17038	7.23149	105
308	9.17514	7.23302	105
309	9.20713	7.40221	105
310	9.20842	7.40154	105
311	9.22161	7.42205	105
312	9.21926	7.42102	105
313	9.22312	7.41992	105
314	9.27466	7.39647	105
315	9.27433	7.39842	105
316	9.27832	7.39901	105
317	9.23702	7.55555	105
318	9.081191	7.535635	105
319	9.079316	7.553132	105
320	9.089038	7.580368	105

321	9.080252	7.534878	105
322	9.161671	7.303982	105
323	9.165745	7.304607	105
324	9.159602	7.287937	105
325	9.07057	7.41996	107
326	9.07390	7.41984	107
327	9.06736	7.41965	107
328	9.06861	7.41339	107
329	9.07313	7.42489	107
330	9.07119	7.41905	107
331	9.18676	7.41635	107
332	9.19552	7.41584	107
333	9.20534	7.42534	107
334	9.20760	7.43320	107
335	9.19931	7.43529	107
336	9.18517	7.42938	107
337	8.93606	7.09367	107
338	8.91140	7.07106	107

Appendix E: Kaduna Sampled Points

S/N	Latitude	Longitude	LCZ
1	10.51924	7.42774	3
2	10.51813	7.42796	3
3	10.51443	7.44273	3
4	10.5168	7.44478	3
5	10.5146	7.44353	3
6	10.51334	7.44549	3
7	10.5619	7.42679	6
8	10.56424	7.42368	6
9	10.57058	7.43544	6
10	10.57257	7.42889	6
11	10.60604	7.43375	6
12	10.60261	7.43748	6
13	10.60687	7.44059	6
14	10.61029	7.44032	6
15	10.51775	7.42545	6
16	10.51928	7.39965	7
17	10.51787	7.39984	7
18	10.51821	7.40276	7
19	10.51569	7.40532	7
20	10.51199	7.40492	7
21	10.51637	7.40965	7
22	10.54202	7.37455	7
23	10.54228	7.37973	7
24	10.53862	7.37955	7
25	10.53644	7.3738	7
26	10.53605	7.36855	7
27	10.53305	7.37001	7
28	10.53146	7.37338	7
29	10.49427	7.40453	7
30	10.49187	7.40681	7
31	10.49406	7.39546	7
32	10.32924	7.40503	7
33	10.52738	7.40661	7
34	10.52958	7.40116	7
35	10.53262	7.40833	7
36	10.52988	7.39973	7
37	10.69737	7.50815	9

38	10.69581	7.50984	9
39	10.69468	7.5153	9
40	10.69249	7.51327	9
41	10.69004	7.51285	9
42	10.69356	7.50454	9
43	10.64298	7.47404	9
44	10.64044	7.47388	9
45	10.64036	7.47658	9
46	10.64564	7.47362	9
47	10.31541	7.38589	9
48	10.31735	7.38116	9
49	10.31561	7.37935	9
50	10.31777	7.38121	9
51	10.62311	7.463533	9
52	10.62014	7.463868	9
53	10.61704	7.461389	9
54	10.31137	7.383853	9
55	10.31366	7.387568	9
56	10.31602	7.390636	9
57	10.63355	7.474311	9
58	10.63447	7.47112	9
59	10.63527	7.464932	9
60	10.22804	7.34974	10
61	10.22917	7.35618	10
62	10.22303	7.34828	10
63	10.2256	7.36925	10
64	10.21522	7.36472	10
65	10.4461	7.41009	10
66	10.45154	7.41077	10
67	10.45385	7.40878	10
68	10.45451	7.4172	10
69	10.46515	7.38933	10
70	10.47111	7.39101	10
71	10.46723	7.39217	10
72	10.5002	7.42709	10
73	10.49942	7.42916	10
74	10.45092	7.41082	10
75	10.44643	7.411187	10
76	10.44675	7.416951	10
77	10.45627	7.407175	10
78	10.469	7.389895	10

79	10.46562	7.391465	10
80	10.119	7.57321	102
81	10.11099	7.56565	102
82	10.11132	7.57246	102
83	10.12041	7.58577	102
84	10.12578	7.59521	102
85	10.18547	7.54891	102
86	10.18265	7.56358	102
87	10.17014	7.53097	102
88	10.13585	7.48303	102
89	10.14289	7.42752	102
90	10.15195	7.41727	102
91	10.16161	7.42868	102
92	10.1473	7.45712	102
93	10.58816	7.27032	102
94	10.5771	7.26875	102
95	10.56381	7.25691	102
96	10.56344	7.28375	102
97	10.57599	7.27958	102
98	10.5891	7.29647	102
99	10.59873	7.28753	102
100	10.61817	7.32006	102
101	10.61056	7.32318	102
102	10.62788	7.30358	102
103	10.63371	7.3017	102
104	10.63553	7.29884	102
105	10.56388	7.5803	102
106	10.56172	7.5821	102
107	10.57116	7.58028	102
108	10.41376	7.77056	102
109	10.41288	7.77141	102
110	10.41233	7.77242	102
111	10.41728	7.77166	102
112	10.41092	7.77144	102
113	10.41322	7.76895	102
114	10.16773	7.568203	102
115	10.16745	7.572373	102
116	10.16151	7.572539	102
117	10.15932	7.574775	102
118	10.15926	7.620104	102
119	10.15686	7.622619	102

120	10.15408	7.617634	102
121	10.15373	7.62186	102
122	10.15803	7.618929	102
123	10.14964	7.425013	102
124	10.14453	7.427125	102
125	10.14463	7.427391	102
126	10.14083	7.408538	102
127	10.10956	7.36688	103
128	10.11032	7.37371	103
129	10.11558	7.36587	103
130	10.12431	7.37024	103
131	10.11025	7.35914	103
132	10.11691	7.34838	103
133	10.13578	7.36115	103
134	10.14046	7.3716	103
135	10.14053	7.34623	103
136	10.28804	7.36664	103
137	10.29213	7.73755	103
138	10.28859	7.35444	103
139	10.1091	7.359693	103
140	10.10522	7.357969	103
141	10.10762	7.360485	103
142	10.1204	7.375204	103
143	10.1166	7.375435	103
144	10.11802	7.370602	103
145	10.12846	7.370717	103
146	10.12696	7.375243	103
147	10.13234	7.361168	103
148	10.09999	7.354264	103
149	10.09999	7.354264	103
150	10.1321	7.335012	103
151	10.12189	7.345509	103
152	10.66105	7.47866	104
153	10.21234	7.34277	104
154	10.21245	7.34008	104
155	10.21345	7.3452	104
156	10.21548	7.33545	104
157	10.21752	7.34237	104
158	10.21532	7.34617	104
159	10.2169	7.33474	104
160	10.21324	7.3327	104

161	10.20949	7.34349	104
162	10.20886	7.34695	104
163	10.23089	7.34847	104
164	10.73229	7.652306	104
165	10.73128	7.650525	104
166	10.73317	7.652405	104
167	10.73103	7.654287	104
168	10.21531	7.335655	104
169	10.21226	7.336208	104
170	10.71802	7.16681	104
171	10.71994	7.165601	104
172	10.71483	7.172985	104
173	10.71995	7.172992	104
174	10.71391	7.170394	104
175	10.17291	7.17048	105
176	10.19351	7.21589	105
177	10.19358	7.21678	105
178	10.16972	7.28568	105
179	10.17418	7.28291	105
180	10.17813	7.29178	105
181	10.16489	7.28554	105
182	10.15545	7.2874	105
183	10.15191	7.28511	105
184	10.15196	7.28753	105
185	10.44648	7.64278	105
186	10.44393	7.64089	105
187	10.43805	7.6479	105
188	10.44304	7.64717	105
189	10.228	7.127853	105
190	10.16077	7.290591	105
191	10.15252	7.284953	105
192	10.17315	7.286816	105
193	10.17955	7.291724	105
194	10.17212	7.169855	105
195	10.17183	7.170753	105
196	10.17642	7.174801	105
197	10.72763	7.42601	106
198	10.72446	7.43214	106
199	10.72094	7.13215	106
200	10.69742	7.44189	106
201	10.69336	7.44462	106

202	10.6719	7.44594	106
203	10.66535	7.45746	106
204	10.66193	7.46232	106
205	10.64193	7.53796	107
206	10.64491	7.60203	107
207	10.65103	7.59034	107
208	10.66127	7.59108	107
209	10.67795	7.58246	107
210	10.69637	7.58776	107
211	10.68	7.58291	107
212	10.63023	7.62412	107
213	10.65899	7.58838	107
214	10.69098	7.58751	107

Appendix F: Urban Characteristics and Parameters (Urban form and function)

Characteristic	Parameters
Cover	Vegetation, building, impervious surface cover
Material	Wall type, roof type, window type, road materials, window fraction on the wall, colour/albedo
Geometry	Building height, width of streets, contiguous or isolated buildings, roof geometry
Function	Building use, irrigation, road type, temperature setting, occupancy, air conditioning, shutters or shading, window opening, building age, building renovation post 1990.

Source: WUDAPT website (www.wudapt.org)

Appendix G: Indices and LST used for the SPSS Analysis

Kaduna 1988		
Index	**Minimum**	**Maximum**
NDVI	-0.39759	0.846154
NDBI	-0.526882	0.740614
MNDBI	-0.483871	0.74744
	Kaduna 2018	
NDVI	-0.254247	0.43049
NDBI	-0.327311	0.679932
MNDBI	-0.332339	0.742859

FCT 1988		
Index	**Minimum**	**Maximum**
NDVI	-0.301587	0.414141
NDBI	-0.157895	0.770609
MNDBI	-0.928571	0.540785
	FCT 2018	
NDVI	-0.139842	0.347981
NDBI	-0.232151	0.698141
MNDBI	-0.272684	0.736993

Kano 1988		
Index	**Minimum**	**Maximum**
NDVI	-0.491409	0.609756
NDBI	-0.516484	0.680608
MNDBI	-0.883495	0.482558
	Kano 2018	
NDVI	-0.303453	0.467076
NDBI	-0.456496	0.468746
MNDBI	-0.470271	0.717067

LST

Year	**Minimum**	**Maximum**	**Place**
1988	10.5134	62.837	Kaduna
2018	17.6719	59.5596	

1988	20.8596	60.999	FCT
2018	22.4221	54.7715	
1988	10.6143	47.8791	Kano
2018	10.1004	39.6016	

Appendix H: Area Statistics of LULC in Kaduna (1988 and 2018)

Landcover Class	1988		2018	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)
Built Up Areas	523894.23	11.84	920052.81	20.80
Forest	1113148.98	25.16	655827.3	14.83
Vegetation	1161381.69	26.25	888918.12	20.09
Agricultural Area	1180947.06	26.70	1573714.53	35.58
Bare Surface	250177.41	5.66	365139	8.25
Water Body	194067.54	4.39	19965.15	0.45
Total Area	4423616.91	100.00	4423616.91	100.00

Appendix I: Area Statistics of Local Climate Zones in Kaduna (2018)

LCZ	LCZ Description	Area (Ha)	Area (%)
1	Compact high-rise	0.00	0.00
2	Compact mid-rise	0.00	0.00
3	Compact low-rise	3743.97	0.08
4	Open high-rise	0.00	0.00
5	Open mid-rise	0.00	0.00
6	Open low-rise	76562.73	1.73
7	Lightweight low-rise	21364.07	0.48
8	Large low-rise	0.00	0.00
9	Sparse low-rise	26286.59	0.59
10	Heavy industry	69463.27	1.57
101	Dense trees	1480929.69	33.48
102	Scattered trees	56975.87	1.29
103	Author/scrub	419403.20	9.48
104	Low plants	1019070.46	23.04

105	Bare rock/paved	1086368.05	24.56
106	Bare soil/sand	146003.48	3.30
107	Water	17426.81	0.39
		4423598.19	100

Appendix J: Area statistics of LULC in FCT (1988 and 2018)

Landcover Class	1988		2018	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)
Built Up Areas	82784.43	11.29	165674.79	22.60
Forest	128207.34	17.49	173143.53	23.62
Vegetation	165027.78	22.52	129314.52	17.64
Agricultural Area	293970.51	40.11	229596.3	31.32
Bare Surface	59067.54	8.06	31374	4.28
Water Body	3894.57	0.53	3849.03	0.53
Total Area	732952.17	100.00	732952.17	100

Appendix K: Area Statistics of Local Climate Zones in FCT (2018)

LCZ	LCZ Description	Area (Ha)	Area (%)
1	Compact high-rise	0.00	0.00
2	Compact mid-rise	40.92	0.01
3	Compact low-rise	24975.37	3.41
4	Open high-rise	1212.08	0.17
5	Open mid-rise	0.00	0.00
6	Open low-rise	824.05	0.11
7	Lightweight low-rise	12514.50	1.71
8	Large low-rise	0.00	0.00
9	Sparse low-rise	5575.01	0.76
10	Heavy industry	37137.11	5.07
101	Dense trees	16218.47	2.21
102	Scattered trees	199934.21	27.28
103	Author/scrub	225767.49	30.80

104	Low plants	148243.65	20.23
105	Bare rock/paved	59431.51	8.11
106	Bare soil/sand	0.00	0.00
107	Water	1076.62	0.15
	TOTAL	732951.00	100

Appendix L: Area statistics of LULC in Kano (1988 and 2018)

Landcover Class	1988		2018	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)
Built Up Areas	196923.96	9.56	428284.71	20.79
Forest	160500.51	7.79	101231.28	4.91
Vegetation	647013.6	31.41	322700.31	15.67
Agricultural Area	773513.19	37.55	914823.9	44.41
Bare Surface	253202.31	12.29	254795.04	12.37
Water Body	28731.15	1.39	38049.48	1.85
Total Area	2059884.72	100.00	2059884.72	100.00

Appendix M: Area Statistics of Local Climate Zones in Kano State (2018)

LCZ	LCZ Description	Area (Ha)	Area (%)
1	Compact high-rise	0.00	0.00
2	Compact mid-rise	0.00	0.00
3	Compact low-rise	205151.08	0.10
4	Open high-rise	0.00	0.00
5	Open mid-rise	0.00	0.00
6	Open low-rise	0.00	0.00
7	Lightweight low-rise	3765607.42	1.83
8	Large low-rise	0.00	0.00
9	Sparse low-rise	1473525.26	0.71
10	Heavy industry	4949218.58	2.40
101	Dense trees	0.00	0.00
102	Scattered trees	17987368.09	8.72
103	Author/scrub	84788613.05	41.12

104	Low plants	84474539.45	40.97
105	Bare rock/paved	4996923.37	2.42
106	Bare soil/sand	0.00	0.00
107	Water	3551447.71	1.72
		206192394.00	

Appendix N: Area Statistics of laduses per state in 2018

Area Statistics of LULC Kaduna in 2018		
Landcover Class	**2018**	
	Area (Ha)	Area (%)
Built Up Areas	920052.81	20.8
Forest	655827.3	14.83
Vegetation	888918.12	20.09
Agricultural Area	1573714.53	35.58
Bare Surface	365139	8.25
Water Body	19965.15	0.45
Total Area	4423616.91	100

Area statistics of LULC FCT in 2018		
Landcover Class	**2018**	
	Area (Ha)	Area (%)
Built Up Areas	165674.79	22.6
Forest	173143.53	23.62
Vegetation	129314.52	17.64
Agricultural Area	229596.3	31.32
Bare Surface	31374	4.28
Water Body	3849.03	0.53
Total Area	732952.17	100

Area statistics of LULC Kano in 2018		
Landcover Class	**2018**	
	Area (Ha)	Area (%)
Built Up Areas	428284.71	20.79
Forest	101231.28	4.91
Vegetation	322700.31	15.67
Agricultural Area	914823.9	44.41
Bare Surface	254795.04	12.37
Water Body	38049.48	1.85
Total Area	2059884.72	100

Appendix O: Extracted Area Statistics of LCZ in Kaduna (2018)

LCZ	LCZ Description	Area (Ha)	Area (%)
	Built Up Areas		
1	Compact high-rise	0	0
2	Compact mid-rise	0	0
3	Compact low-rise	3743.97	0.08
4	Open high-rise	0	0
5	Open mid-rise	0	0
6	Open low-rise	76562.73	1.73
7	Lightweight low-rise	21364.07	0.48
8	Large low-rise	0	0
9	Sparse low-rise	26286.59	0.59
10	Heavy industry	69463.27	1.57
		197420.63	**4.45**
	Vegetation Cover		
101	Dense trees	1480929.69	33.48
102	Scattered trees	56975.87	1.29
103	Author/scrub	419403.2	9.48
104	Low plants	1019070.46	23.04
		2976379.22	**67.29**

Appendix P: Extracted Area Statistics of LCZ in FCT (2018)

LCZ	LCZ Description	Area (Ha)	Area (%)
	Built Up Areas		
1	Compact high-rise	0	0
2	Compact mid-rise	40.92	0.01
3	Compact low-rise	24975.37	3.41
4	Open high-rise	1212.08	0.17
5	Open mid-rise	0	0
6	Open low-rise	824.05	0.11
7	Lightweight low-rise	12514.5	1.71
8	Large low-rise	0	0

9	Sparse low-rise	5575.01	0.76
10	Heavy industry	37137.11	5.07
		82279.04	**11.24**
	Vegetation Cover		
101	Dense trees	16218.47	2.21
102	Scattered trees	199934.21	27.28
103	Author/scrub	225767.49	30.8
104	Low plants	148243.65	20.23
		590163.82	**80.52**

Source: Author (2018)

Appendix Q: Extracted Area Statistics of LCZ in Kano (2018)

LCZ	LCZ Description	Area (Ha)	Area (%)
	Built Up Areas		
1	Compact high-rise	0	0
2	Compact mid-rise	0	0
3	Compact low-rise	205151.08	0.1
4	Open high-rise	0	0
5	Open mid-rise	0	0
6	Open low-rise	0	0
7	Lightweight low-rise	3765607.42	1.83
8	Large low-rise	0	0
9	Sparse low-rise	1473525.26	0.71
10	Heavy industry	4949218.58	2.4
		10393502.34	**5.04**
	Vegetation Cover		
101	Dense trees	0	0
102	Scattered trees	17987368.09	8.72
103	Author/scrub	84788613.05	41.12
104	Low plants	84474539.45	40.97
		187250520.6	**90.81**

Plate I NNPC tower (Open high-rise) CBD, Abuja

Plate II Other parts of CBD Abuja indicating Open High-rise towers

Plate III Compact low-rise buildings around Jabi Lake area, Abuja

Plate IV More view of Abuja city showing mix built-up types

Plate V A distant view of road (paved) and other land cover types

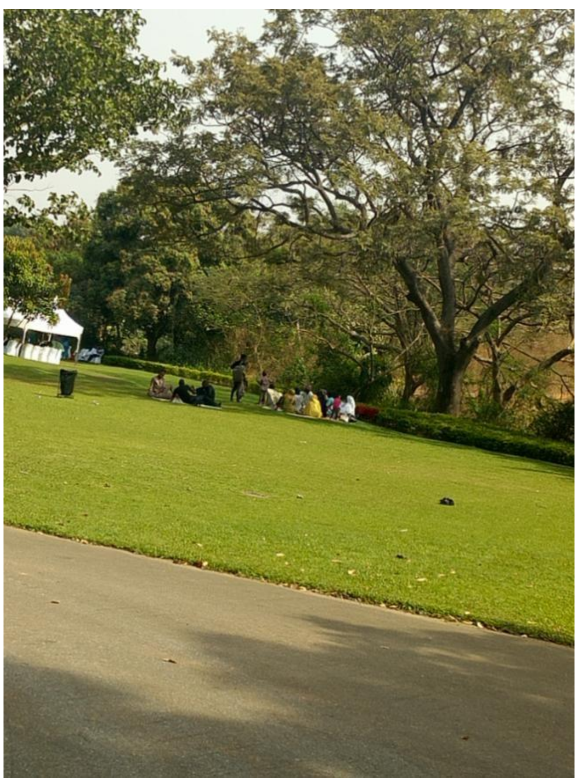

Plate VI Millennium Park, Abuja

Plate VII Other part of Millennium Park, Abuja

Plate VIII Lugbe Village View (Lightweight low-rise areas)

Plate IX Other view of Lugbe Area in Abuja

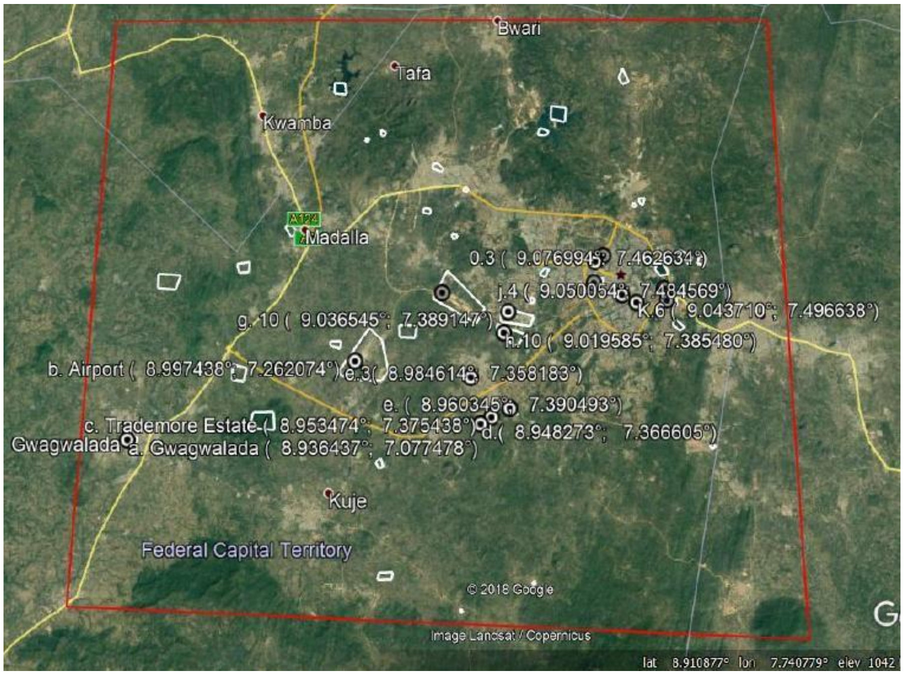

Plate XI Abuja General Field work guide

Plate XII Trademore Estate and Environs (Abuja)

Plate XIII Idu Industrial District and Environs (Abuja)

Plate XIV Wuse/Garki and the surrounding Areas

Plate XV Kubwa and the Environs

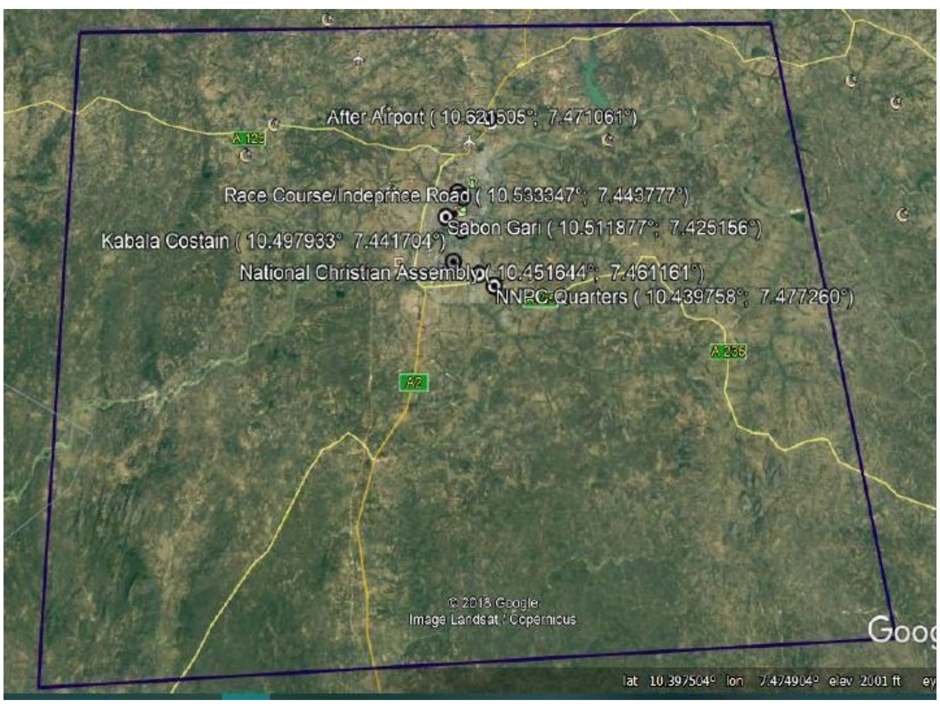

Plate XVI Kaduna General Field work guide