IMPACT OF VEGETAL COVER LOSS ON URBAN TEMPERATURE AND THERMAL COMFORT OF RESIDENTS IN ABUJA, NIGERIA

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October, 2023

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA,
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN URBAN AND REGIONAL PLANNING

October, 2023

DECLARATION

I hereby declare that this thesis titled: "**Impact of Vegetal Cover Loss on Urban Temperature and Thermal Comfort in Abuja, Nigeria**" is a collection of my original research work and it has not presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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CERTIFICATION

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DEDICATION

This thesis is dedicated to my son Abdullahi Imran and my lovely wife Abdulazeez Kaltumi.

ACKNOWLEDGEMENTS

I would like to acknowledge my profound indebtedness to my supervisor, Prof. O.O. Morenikeji for his constant supervision, constructive criticism, valuable guidance, direction and continuous encouragement at all stages of the research work. I remain indebted to the entire staff of Urban and Regional Planning Department, particularly, Prof. Y.A Sanusi, Prof. A. Junaid, Dr. B.B. Mohammed, Dr. Owoeye O. Idowu, Dr. M.I. Valda, Mr. Olaide S. Akande, Mallam Mohammed Ndana, Mallam Najeem, Mr. Adeleye Banji, Dr. Samuel Madeyese, Mrs. Meimunat Akanbi and others I could not mention for their support and advice.

The efforts of Prof. Musa Dalil and Dr. C.B. Ohadugha, Dr. H. D Musa cannot be over looked, in spite of their tight schedules and commitments, they always make time to read through my work and offer constructive comments and suggestions which helped and guided me through this research work. Once again, thank you for the confidence you have in me. My profound appreciation also goes to my parents, Alhaji Abbas Yahaya and Hajiya Ibrahim Hajara their encouragement, effort and suggestions towards my progress in life. To my beloved wife and my heart desire Kaltumi Abdulazeez, no one would have completed my life better than you, for your support and understanding, thank you and remain blessed. My deep gratitude goes to my close friends in persons of, Adinoyi A. Abdulmutalib, Hassan Saliu, Abdulaziz Sani Yahaya for their moral support during this course and others I could not mention; Thank you all.

ABSTRACT

Urbanization can be seen as the concentration of human activities in specific locations and regions which promotes the development of large cities and other forms of urban settlement. The growth and transformation of cities are driven by the forces of attraction between specific locations. The aim of this study was to assess the impact of vegetal cover loss on urban temperature and thermal comfort of residents in FCT, Abuja, Nigeria. Two methods used for this research are; the geospatial approach was utilized to analyze the land use and land cover (LULC), variation of vegetation covers, and land surface temperature (LST) using Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land imager (OLI) images and quantitative method to determine the thermal comfort of residents. The findings indicated that, built up area has increased by 52.1% in FCC (2602.75ha to 25158.325ha) between 1980 and 2020. The study reveals that built up area increased by 71.3% (118.17 to3102.93ha) in Kubwa and 31% (348.64ha to 2494.9ha) in Gwagwalada. The study also revealed that vegetal covers reduces from 8293.96ha to 2431ha in FCC, 614.5ha to 31.39ha in Kubwa and 838.36ha to 157.58ha in Gwagwalada due to expansion of settlement, massive infrastructural and housing development, mining, forest fire, population growth and illegal logging. The study also revealed that LST has risen by 0.8°C, 1.6°C and 1.9°C in FCC, Kubwa and Gwagwalada between 1990 to 2020. The study reveals that residents within the study area falls within the Physiological Equivalent Temperature (PET) category of moderate stress environment. The research recommends that FCT administration should embark on afforestation scheme and integrate biophilic design in its planning in order to restore the depleted land cover due infrastructural development of the city. The study recommends that urban greening be introduced in study area. Also, the recommends that urban heat development plan be developed to help reduce temperature rise within study area by introducing LST mitigation strategy.

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ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
DN	Digital Number
DPSIR	Driver-Pressure-State-Impact and Response
ETM+	Enhanced Thematic Mapper Plus
FCC	Federal Capital City
FCDA	Federal Capital Development Authority
FCT	Federal Capital Territory
GHG	Green House Gas
GIS	Geography Information System
Ha	Hectares
IS	Impervious Surface
LST	Land Surface Temperature
LC	Land Cover
LCA	Land Cover Area
LCC	Land Cover Change
LST	Land Surface Temperature
LU	Land Use
LULC	Land Use/Land Cover
MLC	Maximum Likelihood Classification
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built-Up Index
NBS	Nigeria Bureau Statistics

NIR	Near Infrared
NiMet	Nigerian Meteorological Agency
NPC	Nigeria Population Commission
OECD	Organization for Economic Cooperation and Development
OLI	Operational Land Imager
PET	Physiological Equivalent Temperature
RS	Remote Sensing
PSR	Pressure State Response
THI	Thermal Heat Index
TM	Thematic Mapper
USGS	United State of Geological Survey
UD	Urban Development
UHI	Urban Heat Island
UHIE	Urban Heat Island Effect
UTCI	Universal Thermal Comfort Index
UTM	Universal Transverse Mercator
VC	Vegetal Cover
WGS	World Geodetic System

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Nigeria is notably Africa's most populous black nation with over 180 million people (World Bank, 2016). It is expected to reach around 300 million people by 2050 (World Population Prospect, 2017; Adegoke, 2017). Nigeria as of 2012 had a GDP growth rate of 7percent per annum and is amongst highest in the world (David, 2015). Rapid urbanization, industrialization, intensive agriculture, and rising energy demand have all had a negative impact on the environment's physiochemical parameters, though the effects vary with development (Herman, 2010 and Avtar *et al.,* 2011).

The trend of increased urbanization has a variety of environmental consequences, and it appears to be never-ending, with a continuous and rapid increase over the last decades and a projected increase even faster (Azeem *et al.,* 2016). Some of the induced environmental problems associated with urbanization, include declining biodiversity, poor water and soil quality, increased runoff and sedimentation rates, transformation of the global carbon cycle and hydrologic cycle, and climate change (Sherbinin *et al.,* 2007).

Consistent urban development results from the formation of impervious surfaces, which has been identified as a major driving force in the alteration of the natural ecosystem (Zhou *et al.,* 2010). These impervious surfaces seal the soil cover, preventing rainwater percolation and groundwater infiltration.

Vegetal cover filters the air, removes pollution, reduces noise, cools the temperature, infiltrates storm water, replenishes groundwater, and provides food (Escobedo *et al.,* 2011). The expansion of urban areas, as well as the influence of human activity on ecosystems, have been key ecological concerns. The impact of land use and land cover (LULC) change, both anthropogenic and natural, has raised concerns regarding ecosystem processes and function (Chase *et al.,* 2000; Lambin *et al.,* 2001). With the introduction of vegetal cover, loss in modern cities has resulted in increased surface temperature due to built-up impermeable surfaces and high-rise buildings constructed with heavy metal use as opposed to adjacent rural landscapes characterized by land cover and pervious surfaces. This is known as an Urban Heat Island (UHI), and it is as a result of land cover modification (Xiao and Weng, 2007). The change in LULC in urban centres relates to increased concretization, traffic congestion, and decreasing vegetative cover in cities, resulting in higher temperatures than in greener periphery areas. The UHI analysis is intimately related to spatial patterns of land surface temperature, which are principally determined by the physical features of LULC (Singh *et al.,* 2014). UHI develops as a result of land surface change that favours heat storage and trapping (reduced vegetation), as well as anthropogenic heat release from automobiles, factories, and buildings (Sailor and Lu, 2004). It is one of the dangerous environmental issues that might have a detrimental impact on the ecosystem (Grimmond, 2007). It pollutes the air, alters local climate, increases ground-level ozone generation, and, eventually, affect the quality of life.

Due to huge quantity of energy consumed for cooling, quantifying the temperature effects on land cover in residential areas within cities is critical (Akbari, 2002; Pandit and Laband, 2010). Because trees provide shade, enhanced evaporative cooling, and decreased thermal absorption and retention, LULC is strongly related to land surface temperature (LST)

(McPherson and Simpson, 2003; Nowak and Dwyer, 2007; Solecki *et al.,* 2005). The lack of land cover coverage in urban areas increases LST, resulting in the UHI impact, which is a component of the overall UHI (Voogt and Oke, 2003). As a result, one of the key ecosystem services given by vegetal cover is the lowering of the UHI impact through LST reduction, which translates to lower cooling energy demands and lower dangers to human health and comfort (Hamada and Ohta, 2010; Cui and De Foy, 2012; Nowak and Dwyer, 2007). Nigeria's susceptibility to rapid Land Use and Land Cover Change (LULCC), including urbanization, rainfall fluctuations, temperature rises, hydroelectric power generation sensitivity to rainfall variation, and rapid population growth enhances vulnerability to climate change consequences. Unfortunately, much data on climate change impacts in Nigeria concentrated on coastal regions, such as sea-level rise and floods (Adelekan, 2010), land degradation and desertification in the north-eastern region (Obioha, 2008), and food production difficulties in the agro-ecological zones (Amosu *et al.,* 2012; Oyekale, 2009).

Urbanization causes an increase in LULC loss which led to temperature rise in an urban environment through anthropogenic activities such as the conversion of vegetal areas to built-up surface leads to energy generated being trapped within the environment. When heat is emitted, the temperature rises, increasing energy consumption in urban areas in order to alter the environment. In view of trend of vegetal cover loss as a result of physical development and its adverse effects on surface temperature rise within and around the city of Abuja. Therefore, the need to study the environmental impact of vegetal cover loss and its effects on urban temperature rise is indeed necessary.

1.2 Statement of the Research Problem

The urbanization taking place in major urban centres in Nigeria is diminishing the vegetation, biodiversity, and ecosystems functioning which also accelerating climate change impacts (Musa *et al.*, 2012). The rapid depletion of vegetated resources at the expense of non-evaporated land uses and other impermeable materials lead to threat to biodiversity, habitat loss, desertification which is significantly contributing to the rise in surface temperature (Adesola and Afolabi, 2013; Singh *et al.*, 2014). According to European Environment Agency (2003), investigated effect of temperature rise in European big cities, that any city with a population of one million or more is likely to suffer an increase in average temperature of 1°C -3°C as a result of urban expansion.

Considering the growing knowledge of the dangers of uncontrolled urban expansion and its multiplying effects on various aspects of human and ecological existence, experts from numerous disciplines of study have turned their focus to proposing a solution to this problem. For example, a study titled "evaluation of UHI status in Douala, Cameroon" by Enete *et al.* (2014), reveals the pattern of UHI across different land use and land cover areas. The authors discovered that commercial and high-density regions have a high LST intensity. Similarly, Mohan *et al.* (2012), confirmed the findings of Enete *et al.* (2014), indicating high-density areas are related with increased Land Surface Temperature (LST).

Nduka (2011) and Abdulhamed (2011), conducted studies on LST in major urban areas (Onitsha and Kano metropolis) utilizing ground-based measurements from meteorological stations and in-situ equipment. It is apparent that the method adopted in their studies is both expensive and time-consuming. This is because acquiring or hiring in-situ equipment for such research is relatively expensive and limited in its representation, as in-situ equipment only reflects the temperature of its immediate surroundings at a given time. As a result, such a technique is insufficient for establishing the LST of any specific city. Also, Usman and Lay (2013), Ikechukwu *et al.* (2016), Zaharaddeen *et al.* (2016), Babalola and Akinsanola (2016) and Dissanayake *et al.* (2018) investigated LST distribution as a function of vegetative cover in Lokoja, Kaduna, and Lagos as a result of vegetal cover loss but their study failed to establish any direct linkage between urban growth and LST.

However, these studies do not provide historical information on urban expansion and UHI which can serve as a useful tool that can aid in the planning and control of urban expansion for cities development. In another dimension, some scholars were able to characterize the UHI, as evidenced by the works of Adeyeri *et al.* (2017) and Enete *et al*. (2012), which revealed that UHI formation during the day is influenced by trees and skyline qualities at night. In essence, this has only been to provide information on the level of UHI for the dry and raining season as well as night and day period without consideration for human thermal comfort across each of the periods considered and neither does the study suggest the factors responsible for the UH formation.

Although consideration for human thermal comfort was adequately considered in the study of Shaibu and Utang (2013), on human comfort and microclimate conditions across different land uses, but it is crucial to highlight that the study failed to show a relationship between thermal comfort and urban expansion. Aremu *et al.* (2017), conduct a study on "monitoring and analysis of UHI in Akure using remote sensing" in response to this highlighted deficiency. The authors estimated the trend in urban expansion and UHI using Land Sat data from 1986-2014. The study showed that there is a correlation between urban expansion and UHI formation within the period under study. However, neither the level of thermal comfort nor the influence of urban expansion to LST were examined in the study. Hence, this study tends to analyse the impact of vegetal cover loss and temperature rise.

1.3 Research Questions

The following are the questions addressed by this study:

i. What is the trend of urban development and vegetal cover loss in FCT?

ii. What is the quality of vegetal cover in FCT?

iii. What is the trend in urban surface temperature variation in FCT?

iv. What the effect are of built-up changes on surface temperature in FCT?

v. What is the level of thermal stress experienced in in FCT?

1.4 Aim and Objectives of the Study

1.4.1 Aim

The aim of the study is to assess the impact of vegetal cover loss on urban temperature and thermal comfort of residents with a view of establishing the relationship between urban expansion and temperature variation within the study area.

1.4.2 Objectives

i. Assess urban development and vegetal cover loss in FCT between 1980 and 2020

ii. Assess the variation in the Quality of vegetal cover in FCT between 1980 and 2020

iii. Analyse the urban surface temperature variation based on land cover changes in FCT between 1980 and 2020.

iv. Examine the effect of built-up surface on temperature changes in FCT.

v. Assess the thermal comfort of residents within the FCT.

1.5 Scope of the study

The scope of the study spans across the four phases of Federal Capital City; Phase I (Asokoro, Maitama, Wuse, Garki, Guzape); Phase II (Katampe, Jabi, Mabushi, Kado, Utako, Wuye, Durumi, Kaura, Gudu, Apo, Gaduwa, Dutse); Phase III (Karmo, Gwarinpa, Dape, Nbora, Galadinma, Pyakasa, Kafe, Dakwo, Lokogoma, Kabusa); Phase IV (Gwagwa, Idu and Karsana); Kubwa and Gwagwalada urban area of the FCT for a period of 40 years (1980 and 2020). The choice of the study was because the area was heavily vegetated, good climatic condition, low population and master plan was provided. The 40-year period was chosen since the real construction of the city's phases began in 1980, and the capital was formally relocated from Lagos in 1991. The study locations were chosen based on the most densely populated areas of the FCT. The two satellite towns (Kubwa and Gwagwalada) are planned to function as control areas for the FCC, which is primarily populated by middle and high-income earners, as opposed to Kubwa and Gwagwalada, which are predominantly populated by middle and low-income earners. The study examines the pattern of urban development, the extent of land cover loss over time, the relationship between urban expansion and temperature rise, residents' thermal comfort, and the relationship between LULC and LST.

1.6 Justification for the Study

The relationship between vegetal loss and land surface temperature is important in understanding the impact of urban expansion for planning policies and decision on sustainable urban development. Literature has established some level of paucity in information concerning the impact of vegetal loss on urban heating (Adebayo and Zemba, 2003; Enete *et al.*, 2012, Zaharaddeen *et al.*, 2016 & Adeyeri *et al.*, 2017). Studies from Ujoh and Ifatimehin (2010), Agbola *et al.* (2014), Sejati *et al.* (2019), Ofordu *et al.* (2019), Bakoji *et al.* (2020) Ogoro *et al.* (2020), Koko *et al.* (2021) shows urban growth has resulted in vegetal cover loss in major cities in Nigeria. As a result, the purpose of this study is to investigate the loss of vegetal cover as a result of physical development, the relationship between urban expansion and thermal comfort, as well as the quantification of urban expansion that leads to increased urban temperature, which other previous studies have failed to address. The study therefore has contributed to the understanding the nexus between urban planning, vegetal loss and land surface temperature.

1.7 Limitation of the Study

One of the limitation faced by the researcher was the considerable time it took to compute LST. LST for the River Usuma of Gwagwalada and Jabi Lake were excluded from this study since lake surface temperature estimate necessitates the use of a different algorithm.

1.7.1 Assumptions of the Study

This study employs remote sensing techniques utilizing Landsat 5, 6, and 7 imageries, which have a high thermal resolution of roughly 30 meters. Land sat imageries of 30m are not normally considered for ground trothing data because they do not always reflect the detailed information on the ground surface, which can be affected by noise, whether on the ground or in the atmosphere, lowering the data's level of reliability, particularly in areas with a mix of land cover types.

1.8 The Study Area

The Federal Capital Territory (FCT) is around 8,000 square kilometres in size, with coordinates of 9^{o}4°0'N and 7°29°0'E. The FCT is bordered with Niger, Kaduna, Nassarawa, and Kogi States, from which the FCT was formed. As a result, the FCT shares some of the characteristics of both zones, making it an intriguing place for urban development.

The search for a new Federal Capital began on August 9, 1975, when the Aguda Panel was established to evaluate the dual role of Lagos as the Federal and State capital, and to advise on the viability or otherwise of Lagos serving in both capacities. Lagos' difficulties as a state and federal capital, principal seaport, and main industrial and economic centre were growing increasingly complex and intractable, causing most Nigerians to feel patriotically concerned. The Aguda Panel was tasked with recommending which of the two governments, Federal or State, should relocate if Lagos proved untenable for its dual duty (Obateru, 2004). If the Federal government is to relocate, a suitable place should be suggested. According to the report, Lagos is unsuited and no longer capable of serving as both the country's commercial and industrial nerve centre. It was suggested that the Federal Capital be relocated from Lagos to a huge swath of virgin land in the country's core. After accepting the panel findings in 1976, the then Federal Military Government decided to relocate the federal capital to Abuja (Abubakar, 2014).

The Federal Capital City was designed to accommodate an estimated population of 157,750 people when it opened in 1986, then 485,660 people in 1990, 1,005,800 people in 1995, and 1,642,100 people in 2000, with a maximum projected population of 3.1 million expected by 2009 (IPA, 1979; Benna Associates; 2009 and Abubakar, 2014). Abuja grew at a 9.3 percent yearly rate between 2000 and 2010, making it the country's fastest-growing city (Udeh, 2010; Abubakar and Doan, 2010). The central location and easy accessibility from all areas of the country, good climatic conditions, and extensively vegetated and low population density, availability of land for future expansion, physical planning convenience, and ethnic harmony were all considerations that contributed to Abuja's selection. Map of Nigeria and Abuja is shown in Figures 1.1 and 1.2. Also, the Map of FCC, Kubwa and Gwagwalada is shown in Figures 1.3-1.5 respectively.

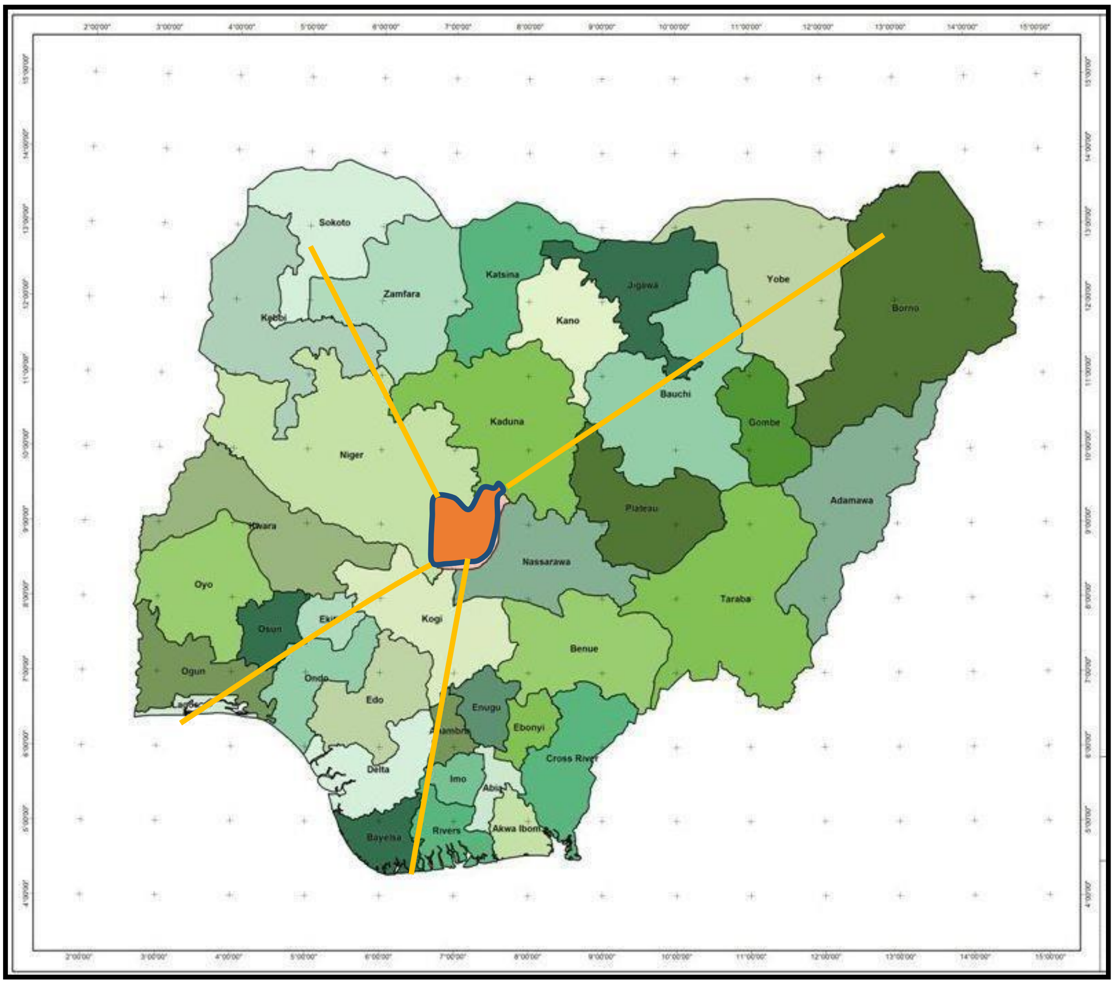


Figure 1.1: Abuja in the National Context

Source: Benna Associates, (2009)

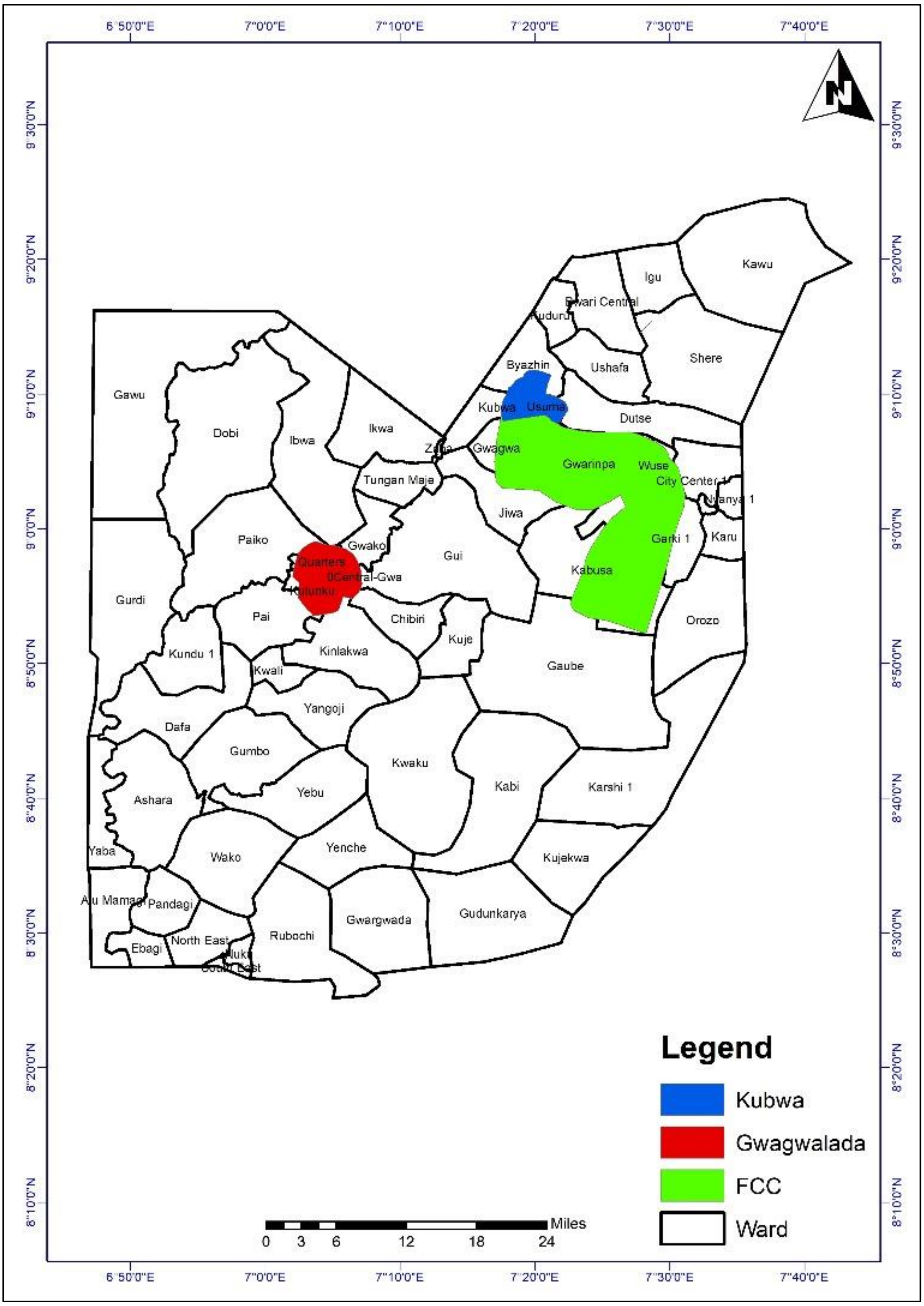


Figure 1.2: Abuja the Study Area

Source**:** Author, 2021

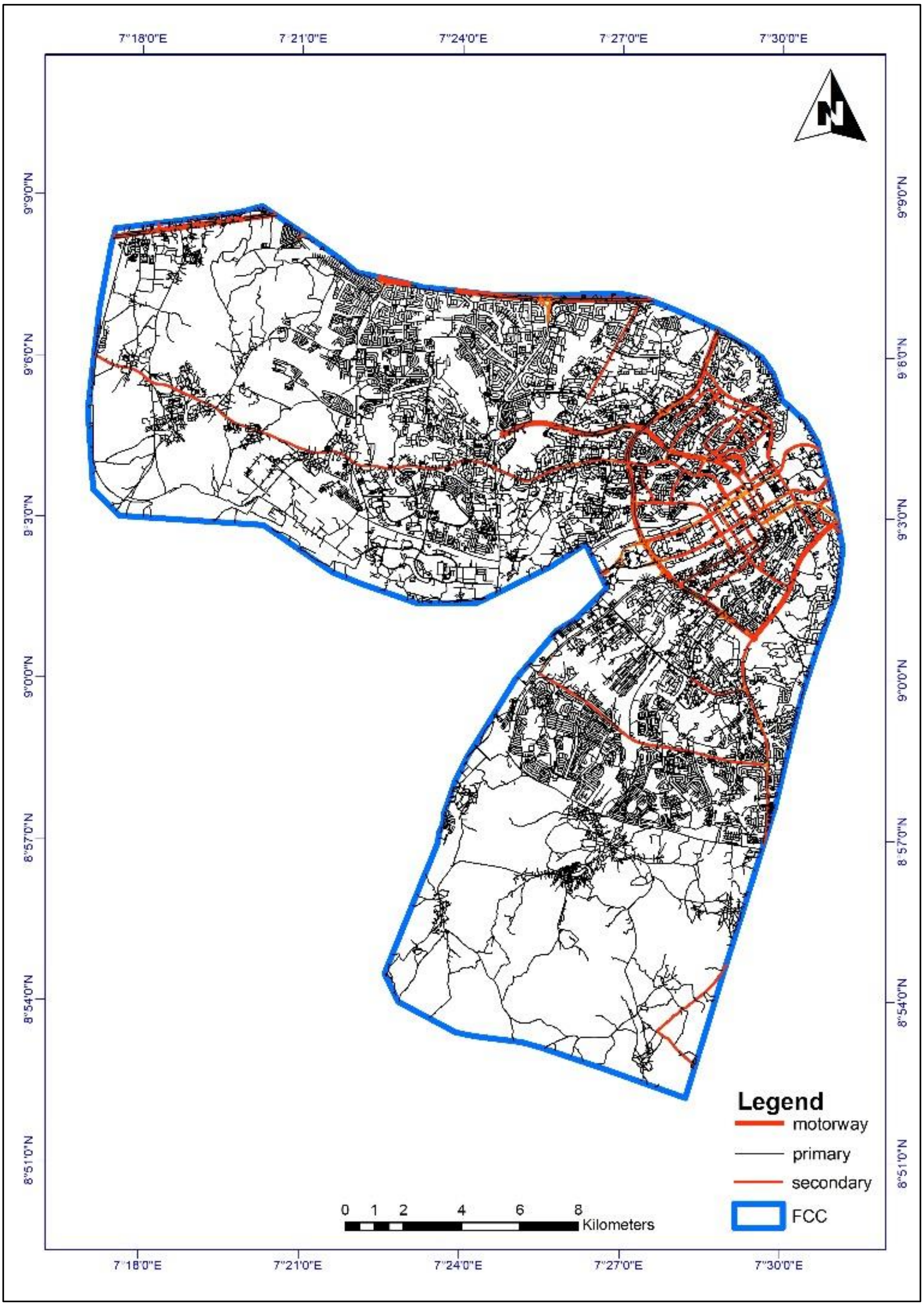


Figure 1.3: Delineation of the Federal Capital City

Source**:** Author, 2021

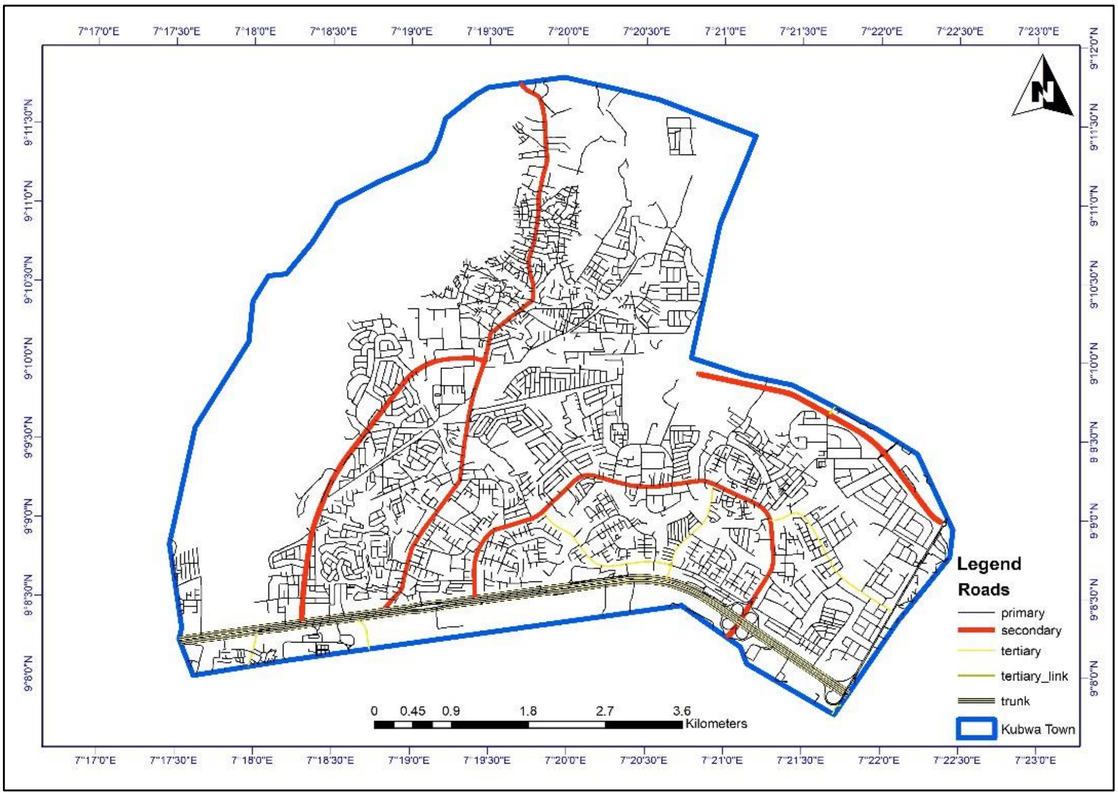


Figure 1.4: Delineation of Kubwa

Source**:** Author, 2021

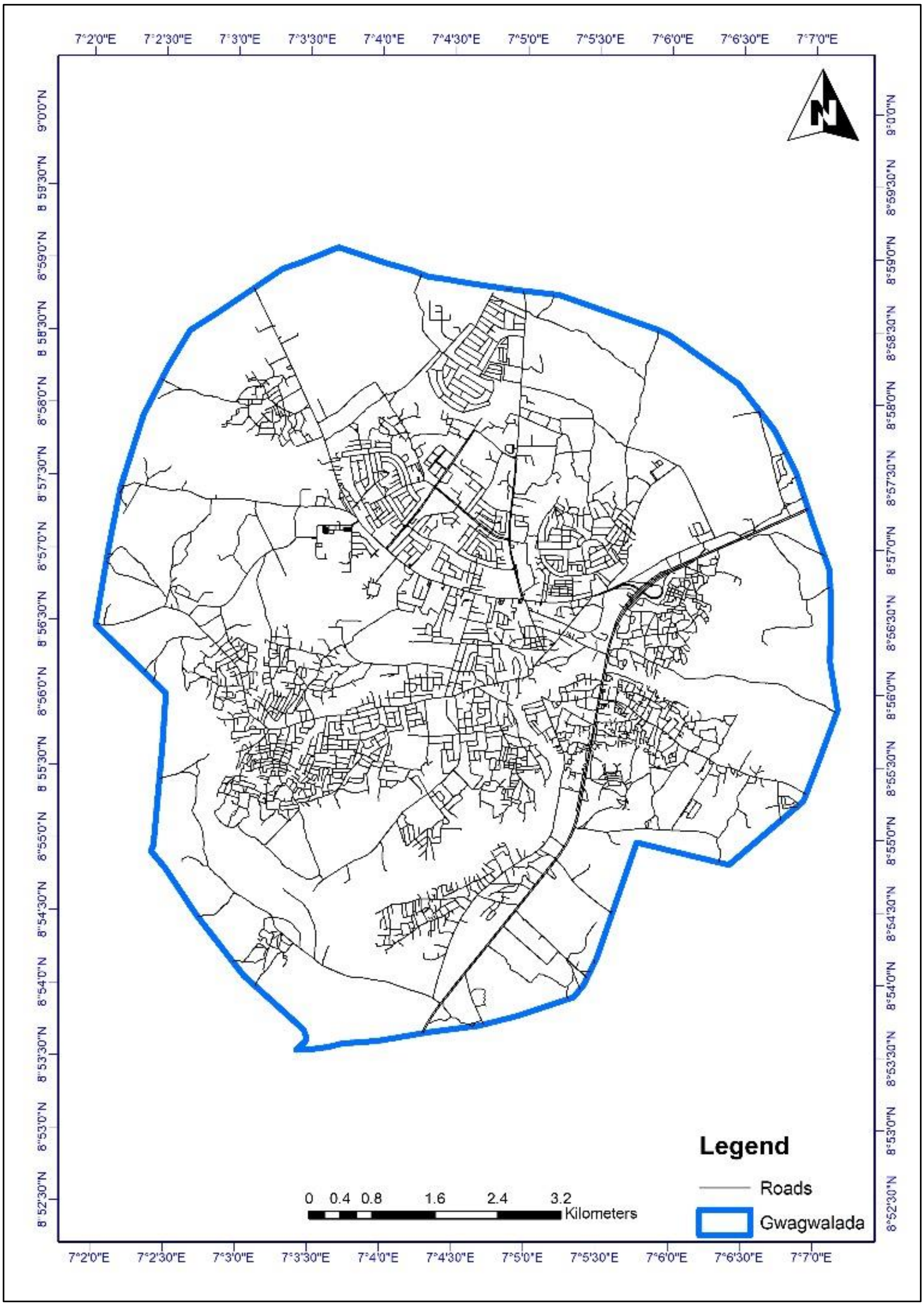


Figure 1.5: Delineation of Gwagwalada

Source**:** Author, 2021

1.8.1 Federal Capital City (FCC)

The master plan, as created and approved by the government, estimated the city eventual population to be 3.1 million people, with four phases of development envisaged (Table 1.1).

Table 1.1: Phases of the FCC and the Target Population

Phases	Projected Target Population
I	20,000
II	585,000
III	640,000
IV	1.7 million
Total	3.1 million

Source: Benna Associates, (2009)

1.8.2 Phase I of the FCC, Abuja

Phase I of the FCC's detailed land use planning and site development plan has been completed, and it is divided into five (5) districts (Table 1.2):

Table 1.2: Districts within the FCC and Planned Population in Phase I

	District	Land Budget in (Ha)	Planned Population
A	The central Area	1,658	30,000
B	Garki I and II	865	50,000
C	Wuse I and II	1,530	69, 000
D	Asokoro	897	30, 000
E	Maitama	1,050	35, 000
	TOTAL		**214,000**

Source: Benna Associates, (2009) and Abubakar, (2014)

1.8.3 Phase II of the FCC, Abuja

The Federal Capital City phase II is located west of phase 1. It covers an area of 8,600 hectares and is designed to accommodate a population of 585,000 people in 14 residential districts. Four sector centres and the Kukwaba recreational park are also located in the vicinity.

Table 1.3: Districts of the Phase II of the FCC, Abuja

Sectors	Districts	Land budget (Ha)	Planned population
Sector A	Katampe	577	66,080
	Jabi	650	64,814
	Mabushi	456	41,080
	Kado	450	39,192
Sector B	Utako	349	32,380
	Jahi	420	32,622
	Wuye	413	23,614
	Dakibiyu	529	57,500
Sector C	Durumi	438	37,508
	Kaura	522	32,104
	Duboyi	286	21,046
Sector D	Gudu	499	32,822
	Gaduwa	422	50,960
	Dutse	506	42,602

Source: Benna Associates, (2009)

1.8.4 Phase III of the FCC, Abuja

The FCC phase III is a long, concave strip of land extending north to south of Abuja. It has a land area of roughly 163km^2. It is divided into four sections.

Table 1.4: Districts of the Phase III of the FCC, Abuja

Sector	Districts	Land budget (Ha)	Planned Population
A	Bunkoro	578	62,905
	Gwarinpa I	363	62,615
	Wupa	297	34,570
	Kafe	412	40,095
B	Gwarinpa II	445	49,073
	Karmo	462	48,042
	Dape	325	48,658
	Nbora	479	52,262
C	Galadinma	414	50,475
	Pyakasa	580	67,758
	Dakwo	298	48,658
	Okanje	365	66,062
D	Lokogoma	391	55,690
	Wumba	428	60,958
	Kabusa	466	98,216
	Saraji	578	81958

Source: Benna Associates, (2009)

1.8.5 Phase IV of the FCC

The phase consists of phase IV North-West and Phase V west.

Table 1.5: Districts of the Phase IV of the FCC, Abuja

	Land budget (Ha)	**Planned population**
Abuja north-west	6,126	350,000
Phase IV west	4.440	380,000
Total	**10,566**	**730,000**

Source: Benna Associates, (2009)

1.8.6 Climatic condition of Abuja

Abuja has a tropical wet and dry climate, according to the Kappen climate classification. Every year, the FCT is subjected to three types of weather. There is a hot, humid rainy season as well as a scorching dry season. Between the two, the northern trade wind causes a brief interlude of harmattan, with the main traits of dust haze, increased coolness, and dryness (Balogun, 2009). The rainy season lasts from April to October, with temperatures ranging from 28°C (82.4°F) to 30°C (86°F) during the day and 22°C (71.6°F) to 23°C (73.4°F) at night. Daytime temperatures in the dry season can reach 40°C (104.0°F) while overnight temperatures can drop to 12°C (53.6°F) (Malik, 2004). Even the coldest nights can be followed by temperatures well above 30°C (86.0°F) during the day. The FCT's high altitude and uneven topography have a moderating effect on the territory's weather. Rainfall in the FCT is influenced by the territory's location on the windward side of the Jos Plateau and the zone of rising air masses, with the city getting heavy rainfall from March to November each year (Malik, 2004). The annual rainfall is 1,631.7 mm, with annual mean temperatures ranging from 25.8°C to 30.2°C (Balogun, 2009).

1.8.7 Vegetation and wildlife

The FCT is in the West African sub-Guinean region's forest-savannah mosaic zone. Patches of rain forest, on the other hand, can be found in the Gwagwa plains, particularly in the rugged terrain to the south-east of the territory, where a landscape of gullies and rough terrain can be found. These areas of the FCT are one of Nigeria's few remaining occurrences of mature forest vegetation (Malik, 2004, Malik *et al.*, 2004).

1.8.7.1 *Flora composition of the study area*

Under local environmental and edaphic conditions, the Guinea savanna ecosystem (derived savanna) is characterized by grass land vegetation of secondary structure, heterogeneous in nature, with spatially closed and sparse distribution, interspersed by randomly distributed shrubs and trees of various life forms and habits belonging to different families (FCT MDGs, 2010). *Meliaceae*, *Lamiaceae*, F*abaceae*, *Poaceae*, *Asteraceae, Anonaceae*, *Rubiaceae*, *Arecaceae*, *Verbenaceae*, *Cyperaceae*, *Rhamnaceae*, *Schrophulariaceae*, *Onagraceae*, *Marantaceae, Tiliaceae*, *Malvaceae*, *Loganiaceae*, *Ochnace* (Collin *et al.*, 2010).

During the dry season, the vegetation composition of the research area recorded a total of 57 plant species belonging to 21 families, with a diversity of life forms. *Lamiaceae*, *Fabaceae*, *Poaceae*, *Asteraceae*, *Rubiaceae*, *Cyperaceae*, *Scrophulariaceae*, *Onagraceae*, and *Malvaceae* were the most common of the nine families. The *Lamiaceae*, *Fabaceae*, *Poaceae,* and *Asteraceae* families had the maximum species diversity and abundance, whereas the other five families (*Rubiaceae, Cyperaceae, Scrophulariaceae, Onagraceae*, and *Malvaceae)* had the least (Shukla *et al.,* 2009; Edwin-Wosu *et al.,* 2013; Okereke *et al.,* 2014 and Agbelade *et al.,* 2017).

These are secondary vegetation species characteristics in an arable arid habitat. Though the studied region relates to Guinea savanna grass land vegetation, it is heterogeneous in structure due to the impact of numerous anthropogenic activities such as farming and nomadic livestock rearing, resulting in some amount of retrogressive succession with a common grass land formation. In comparison to a comparable view of vegetation analysis by, the study area vegetation is based on physiognomic classification of savanna and may still be classified as a tree savanna ecosystem of grass land vegetation (Bouliere and Hardley, 1970; Piel, 2004). The ecosystem of the research area is characterized by changing fine soil textural formation on a geomorphological level. The checklist of common vegetation distribution is shown in Table 1.6.

Table 1.6: Vegetation Checklist in FCT

S/N	Species	Family	%F	D	A	%RF	%RD	%RA	IVI	RIVI	SD	SE	A/F	Common Name	Life Form	Remark
1	*Khaya senegalensis* (Desr.) A. Juss	Meliaceae	100	11.00	11.00	2.89	4.06	2.54	9.49	3.18	1.60	0.91	0.11	Mahogany	Tree	+++++
2	*Hyptis suaveolans* (Linn.) Poit	Lamiaceae	100	20.00	20.00	2.89	7.38	4.61	14.88	4.98	3.49	1.98	0.20	Mint weed	Herb	+++++
3	*Leonotis neptifolia* (Linn.) Ait. F.	Lamiaceae	40	1.00	2.50	1.16	0.37	0.23	1.76	0.59	0.14	0.08	0.06	Christmas candlestick	Herb	++
4	*Calapogonium mucunoides* Desv.	Fabaceae – Papil.	100	15.00	15.00	2.89	5.53	3.46	11.88	3.98	2.39	1.36	0.15	Calopo	Herb	+++++
5	*Cymbopogon giganteus* (Hochst) Choir	Poaceae	60	3.00	5.00	1.73	1.11	1.16	4.00	1.34	0.17	0.10	0.08	Grass	Herb	+++
6	*Pennisetum pedicellatum* Trin	Poaceae	100	3.00	3.00	2.89	1.11	0.69	4.69	1.57	0.31	0.18	0.03	Feather pen-nisetum	Herb	+++++
7	*Pennisetum polystachion* (Linn) Schult	Poaceae	100	2.00	2.00	2.89	0.74	0.46	4.09	1.37	0.19	0.11	0.02	Feather pen-nisetum	Herb	+++++
8	*Pennisetum violaceum* (Lam) L. Rich	Poaceae	100	5.00	5.00	2.89	1.84	1.16	5.89	1.97	0.57	0.32	0.05	Grass	Herb	+++++
9	*Chromolaena odorata* (L) RM.King and Robinson	Asteraceae	60	2.00	3.33	1.73	0.74	0.77	3.24	1.08	0.03	0.02	0.06	Siam weed	Herb	+++
10	*Annona senegalensis* Pers	Anonaceae	100	2.40	2.40	2.89	0.89	0.55	4.33	1.45	0.23	0.13	0.02	NA	Shrub	+++++
11	*Phoenix dactylifera* Linn.	Arecaceae	20	0.40	2.00	0.58	0.15	0.46	1.19	0.40	0.16	0.09	0.10	Date palm	Tree	+
12	*Gmelina arborea* Roxb.	Verbenaceae	40	0.40	1.00	1.16	0.15	0.23	1.54	0.52	0.15	0.09	0.03	Melina	Tree	++
13	*Parkia biglobossa* (Jacq) Benth	Fabaceae – Mimo	40	0.60	1.50	1.16	0.22	0.35	1.73	0.58	0.14	0.08	0.04	Locust bean	Tree	++
14	*Senna tora* Linn	Fabaceae - Caesal	100	7.00	7.00	2.89	2.58	1.62	7.09	2.37	0.88	0.50	0.07	Senna	Shrub	+++++
15	*Nauclea latifolia* Smith	Rubiaceae	100	12.00	12.00	2.89	4.43	2.77	10.09	3.38	1.79	1.02	0.12	NA	Shrub	+++++
16	*Cyperus articultus* Linn.	Cyperaceae	20	6.00	30.00	0.58	2.21	6.93	9.72	3.25	1.66	0.94	1.50	Sedge	Herb	+
17	*Zizyphus spina-christii* (Linn) Desf.	Rhamnaceae	100	12.00	12.00	2.89	4.43	2.77	10.09	3.38	1.79	1.02	0.12	Christ turn	Shrub	+++++
18	*Spermacoce stachydea* Dc.	Rubiaceae	100	14.00	14.00	2.89	5.16	3.23	11.28	3.78	2.19	1.24	0.14	NA	Herb	+++++
19	*Rhamphicarpa fistulosa* (Hochst) Benth	Scrophulariaceae	100	12.00	12.00	2.89	4.43	2.77	10.09	3.38	1.79	1.02	0.12	NA	Herb	+++++
20	*Scolporia dulcis* Linn	Scrophulariaceae	60	9.00	15.00	1.73	3.32	3.46	8.51	2.85	1.28	0.73	0.25	Sweet broom weed	Herb	+++
21	*Ludwigia abyssinica* A. Rich	Onagraceae	20	5.00	25.00	0.58	1.84	5.77	8.19	2.74	1.21	0.69	1.25	Water prim-rose	Herb	+
22	*Ludwigia octavalvis* (Jacq.) P. Raven	Onagraceae	40	2.00	5.00	1.16	0.74	1.16	3.06	1.02	0.01	0.01	0.13	Water prim-rose	Herb	++

23	*Ludwigia decurrens* Walt	Onagraceae	40	1.00	2.50	1.16	0.37	0.58	2.11	0.71	0.10	0.06	0.06	Water prim-rose	Herb	++
24	*Mitracarpus villosus* (Sw) DC	Rubiaceae	80	7.00	8.75	2.31	2.58	2.02	6.91	2.31	0.83	0.47	0.11	Rubiaceae	Herb	++++
25	*Marantochloa cuspidate* (Rose) Milne-Redh	Marantaceae	40	4.00	10.00	0.37	1.45	2.31	4.13	1.38	0.19	0.11	0.25	Yoruba softcane	Shrub	++
26	*Senna ginguena* (Del) Lock.	FabaceaeCaesal	100	15.00	15.00	2.89	5.53	3.46	11.88	3.98	2.39	1.36	0.15	Senna	Shrub	+++++
27	*Grewia bicolor* Juss	Tiliaceae	20	0.20	1.00	0.58	0.07	0.23	0.88	0.30	0.16	0.09	0.05		Shrub	+
28	*Vernonia ambigua* Kotschy and Peyr	Asteraceae	20	3.00	15.00	0.58	1.11	3.46	5.15	1.72	0.41	0.08	0.75	Wild bitterleaf	Herb	+
29	*Anthephora ampullaceal* Stapf and C.E. Hubbard	Poaceae	100	4.00	4.00	2.89	1.45	0.92	5.26	1.76	0.44	0.25	0.04	Grass	Herb	+++++
30	*Brachiaria falcifera* (Trin) Stapf.	Poaceae	60	3.00	5.00	1.73	1.11	1.16	4.00	1.34	0.17	0.10	0.08	Grass	Herb	+++
31	*Vernonia galamensis* (Cass.) Less	Asteraceae	20	2.00	10.00	0.58	0.74	2.31	3.63	1.22	0.11	0.06	0.50	Iron weed	Herb	+
32	*Vernonia perrotteti* Sch. Bip.	Asteraceae	40	3.00	7.50	1.16	1.11	1.73	4.00	1.34	0.17	0.10	0.19	Iron weed	Herb	++
33	*Vicoa leptoclada* (Webb) Dandy	Asteraceae	20	2.00	10.00	0.58	0.74	2.31	3.63	1.22	0.11	0.06	0.50	NA	Herb	+
34	*Axonopus compressus Jacq*	Poaceae	100	9.00	9.00	2.89	3.32	2.08	8.29	2.77	1.22	0.69	0.09	Carpet grass	Herb	+++++
35	*Urena lobata* Linn.	Malvaceae	80	10.00	12.50	2.31	3.69	2.89	8.89	2.98	1.40	0.80	0.16	Hibiscus bur	Shrub	++++
36	*Hyptis spicigera* Lam	Lamiaceae	60	4.00	6.67	1.73	1.45	1.54	4.72	1.58	0.32	0.18	0.11	Black ses-ame	Herb	+++
37	*Hyptis lanceolata* Poir	Lamiaceae	80	2.00	2.50	2.31	0.74	0.58	3.63	1.22	0.11	0.06	0.03	NA	Herb	++++
38	*Piliostigma reticulatum* (DC) Hochst.	Fabaceae – caesal	100	6.00	6.00	2.89	2.21	1.39	6.49	2.17	0.74	0.42	0.06	NA	Shrub	+++++
39	*Crotalaria macrocalyx* Benth	Fabaceae- Papi	60	3.00	5.00	1.73	1.11	1.16	4.00	1.34	0.17	0.10	0.08	Rattle pod	Herb	+++
40	*Desmodium scorpiurus* (SW) Desv.	Fabaceae – Papil.	80	3.00	3.75	2.31	1.11	0.87	4.29	1.44	0.23	0.13	0.05	Samdan clover	Herb	++++
41	*Anthocleista schwenfurthi*	Loganiaceae	20	0.20	1.00	0.58	0.07	0.23	0.88	0.30	0.16	0.09	0.05	Cabbage tree	Tree	+
42	*Lophira lanceolata* Van Tiegh	Ochnaceae	40	0.60	1.50	1.16	0.22	0.35	1.73	0.58	0.14	0.08	0.04	NA	Tree	++
43	*Vitellaria paradoxa* Gaertn. f	Sapotaceae	60	1.20	2.00	1.73	0.44	0.46	2.63	0.88	0.05	0.03	0.03	Shear butter	Tree	+++
44	*Sida linifolia* Linn	Malvaceae	40	4.00	10.00	1.16	1.48	2.31	4.95	1.66	0.37	0.21	0.25	Flax leaf fan petals	Shrub	++

45	*Sida rhombifolia* Linn	Malvaceae	40	1.00	2.50	1.16	0.37	0.58	2.11	0.71	0.11	0.06	0.06	Wire weed	Shrub	++
46	*Mimosa pigra* Linn	Fabaceae – mimo	20	1.00	5.00	0.58	0.37	1.16	2.11	0.71	0.11	0.06	0.25		Herb	+
47	*Pueraria phaseoloides*	Fabaceae – caesal	100	9.00	9.00	2.89	3.32	2.08	8.29	2.77	1.22	0.69	0.09	Tropical kudzu	Herb	+++++
48	*Melochia pyramidata*	Sterculiaceae	40	4.00	10.00	1.16	1.48	2.31	4.95	1.66	0.37	0.21	0.25		Herb	++
49	*Tephrosia linearis* (Willd) Pers.	Fabaceae - papi	60	2.00	3.33	1.73	0.74	0.77	3.24	1.08	0.03	0.02	0.06		Herb	+++
50	*Tephrosia pedicellata* Bak	Fabaceae - papi	40	5.00	12.50	1.16	1.84	2.89	5.89	1.97	0.57	0.32	0.31		Herb	++
51	*Waltheria indica* Linn.	Sterculiaceae	60	2.00	3.33	1.73	0.74	0.77	3.24	1.08	0.03	0.02	0.06	Sleepy morn-ing	Herb	+++
52	*Chamaecrista mimosoides* (Linn) Greene	Fabaceae - caesal	20	1.00	5.00	0.58	0.37	0.16	1.11	0.37	0.16	0.09	0.25	Japanese tea	Herb	+
53	*Adansonia digitata* Linn	Bombacaceae	20	0.20	1.00	0.58	0.07	0.23	0.88	0.30	0.16	0.09	0.05	Baobab	Tree	+
54	*Striga harmonthica* (Del) Benth	Scrophulariacea e	40	2.40	6.00	1.16	0.88	1.39	3.43	1.15	0.07	0.04	0.15	Purple witch weed	Herb	++
55	*Tridax procumbense* Linn	Asteraceae	60	8.00	13.33	1.73	2.95	3.08	7.76	2.60	1.07	0.61	0.22	Coat button	Herb	+++
56	*Cyperus iria* Linn	Cyperaceae	40	2.00	5.00	1.16	0.74	1.16	3.06	1.02	0.01	0.01	0.13	Rice field flat sedge	Herb	++
57	*Fimbristylis ferruginea* (Linn.) Vahl	Cyperaceae	60	1.60	2.67	1.73	0.59	1.54	3.86	1.29	0.14	0.08	0.05	Rusty sedge	Herb	+++
	TOTAL		**3460**	**271.20**	**433.06**	**99.23**	**99.99**	**99.58**	**298.84**	**100.7**						

Source: IUCN, (2015); Okereke *et al. (*2014)

Note: %F= stand for percentage frequency. D = stand for Density. A = Abundance. %RF = stand for Relative frequency. %RD = stand for Relative density. %RA = stand for Relative abundance. IVI = stand for Importance Value Index. SD= stand for Species diversity. SE = stand for Species diversity evenness. A/F = Ratio A: F distribution pattern with the "*thumb of rule*" designated as follows: *Regular (<0.03), random (0.03 – 0.05),* and *contiguous (>0.05)* distribution. **+ (1-25) Very scarce, ++ (26-59) Scarce, +++ (60-79) Abundant, ++++> (80-α) Very abundant, NA- Not available, %F- percentage frequency.**

1.8.7.2 *Fauna composition of the study area*

In terms of ecology, animal populations play a critical role in the transfer of dietary energy and the cycling of a wide range of animal species (see Table 1.7). They range in size from small arthropods such as mites and ticks to big mammals such as the hippopotamus (Okereke *et al.*, 2014). Insects, spiders, millipedes, and other members of the phylum Arthropoda dominated the invertebrate fauna in the research area.

In terms of numbers, the insects were the most important, with the order Diptera (flies) representing the tsetse fly (*Glossina spp*.) and fruit fly (*Diptera spp*). (*Ceratitis spp*). Termites (*Macrotermes spp*.), butterflies (*Acrae terpicore*), sand flies (*Leishmania tropica*), mosquitoes (*Anopheles and Aedes spp*.), black flies (*Simulium spp*.), and bees (*Anopheles and Aedes spp*.). Garden snails and slugs represented the molluscs, but their numbers declined as they moved northward. A variety of vertebrate groupings were identified, including amphibians, reptiles, birds, and mammals (Baillie and Groombridge, 1996; IUCN, 2015).

Snakes (*Dendnaspis viridis tree viper; Bitis arietans*, Puff adder; and python sebae, Africa python); and lizards (Chameleon senegalensis, Africa chameleon; and Agama-agama, Africa chameleon). Village weavers, queleas, red eye doves, cattle egrets, hooded vultures, bush fowls, and beautiful sunbirds have all been seen in the area. Cows, goats, sheep, monkeys, and fruit bats were among the mammals seen in the FCT, which were represented by grazers (FCT-MDGs, 2010).

Most animals are crepuscular, eating in the early morning (0500-0700h) or just before twilight (1700-1930h).in the area were represented by grazers, comprising cows, goats, sheep, monkeys and fruit bats (FCT-MDGs, 2010). Most of the mammals are crepuscular in habit, feeding in the early hours of the day (0500-0700h) or just before dusk (1700-1930h).

Table 1.7: Checklist of Wildlife Species in FCT

Biological Name	Common Name	Feeding	Reproduction Method	IUCN Status	Habitat
Pandinus imperator	Scorpion	Insectivorous	Viviparity	++	Savanna
Gatrocantha sp	Spider	Insectivorous	Oviparity	+++	Savanna
Orthetrom branchiale	Dragonfly	Insectivorous	Oviparity	++	Savanna
Mantis religiosa	Praying Mantis	Insectivorous	Oviparity	+	Savanna
Zonocerus variegatus	Variegated	Phytophagous	Oviparity	+++	Savanna
Macrotermis belliciosun	Termites	Herbivores	Oviparity	+++	Savanna
Acrae terpicore	Butterfly	Phytophagous	Oviparity	++	Savanna
Leishmania Tropica	Sandfly	Haematophagous	Oviparity	+	Savanna
Apis mellifera	Honeybee	phytophagous	Oviparity	+++	Savanna
Anopheles sp	Mosquito	Haematophagous	Oviparity	++	Savanna
Simulium sp	Black fly	Haematophagous	Oviparity	+	Savanna
Glossina sp	Tse-tse-fly	Haematophagous	Oviparity	+	Savanna
		CLASS AMPHIBIA			
Bufo regularis	West African toad	Insectivorous	Oviparity	+	Savanna
Rana galamensis	Frog	Insectivorous	Oviparity		Savanna
		CLASS REPTILIA			
Chameleon senegalensis	African chameleon	insectivorous	Oviparity	+	Savanna wooded
Hemidactylus brooki	Brook's Gecko	insectivorous	Oviparity	++	Savanna
Varanus Niloticus	Nile monitor lizard	Carnivorous	Oviparity	+	Aquatic
Agama agama	West African rain-bow lizard	Insectivorous	Oviparity	++	Savanna wooded
Bitis orietons	Puff adder	Carnivorous	Oviparity		
Python sebase	African python	Carnivorous	Oviparity	+	Savanna
		CLASS AVES			
Ardeola ibis	Cattle egret	insectivorous	Oviparity	+++	Savanna wooded
Neophron Moncus	Hooded vulture	Scavenger	Oviparity	++	Savanna wooded
Masopicos Geortae	Grey woodpecker	insectivorous	Oviparity	+	Savanna wooded
Streptopeli	Red grey dove	Herbivores	Oviparity	+++	Savanna
S. senegalensis	Laughing dove	Herbivores	Oviparity	+	Savanna

s. roseogrisea	Rose grey dove	Herbivores	Oviparity	+	Savanna
Fruncolinus	Bush fowl	Herbivores	Oviparity	++	Savanna
Petronia dentate	Bush sparrow	Herbivores	Oviparity	+	Savanna
Ploceus cucillatus	Village weaker bird	Herbivores	Oviparity	++	Savanna
Quelea quelea	Quelea	Herbivores	Oviparity	+++	Savanna
Milvus migrans	Black kite	Carnivorous	Oviparity	++	Savanna
Bubo Africanus	Spotted eagle owl	Carnivorous	Oviparity	+	Savanna
Nectarinia	Copper	Herbivores	Oviparity	++	Savanna
Uprea	Sunbird				Savanna wooded
Hirundo nigrita	White throated swal-low	Herbivores	Oviparity		Savanna wooded
CLASS MAMMALIA					
Lepus capenzi	Togo hare	Herbivores	Viviparity	++	Savanna
Helioseiurus	Gambianson squirrel	Herbivores	Viviparity	+	Savanna
Oryx gazzela	Africoryx (antelope)	Herbivores	Viviparity	+	Savanna
Xerus Erythropus	West African ground	Herbivores	Viviparity	+++	Savanna
Lemniscomys straitus	Spotted grass mouse	Herbivores	Viviparity	+	Savanna
Rattus natalensis	Giant rat	Herbivores	Viviparity	++	Savanna
Cricetomys kivuensis	Crested porcupine	Herbivores	Viviparity	+	Savanna wooded
Hystrix cristata	Cane rat	Herbivores	Viviparity	++	Savanna wooded
Thryonomys	Hunting dog	Carnivorous	Viviparity	+	
Rousettus	Fruit bat	Herbivores	Viviparity	+	Savanna
Epomophorus Anurus	White bellied pargo-lin	Insectivorous	Viviparity	+	Savanna
Manis tricuspis	White bellied pango-lin	Omnivorous	Viviparity	++	Savanna
Colobus Polykomos	Black colobus	Herbivores	Viviparity	+	Savanna

Source: IUCN (2015); Okereke *et al. (*2014)

Key : + = near, ++ = Common, +++ = Abundant

1.8.8 Population of Federal Capital Territory, Abuja

The incapacity to count the base population of a study region hinders the reliability of results. The Federal Capital Territory has a population of 1,406, 239 people, according to the 2006 census (NPC, 2006), with a predicted population of 3,549,152 people in 2016. (NBS, 2016) For the purposes of this study, the population of Federal Capital Territory, Abuja was projected to 2021 using a national growth rate of 3.2 percent (NPC, 2006), resulting in a present population of 5,638,420 people. Table 1.8 shows the population of the FCT as well as livelihood statistics.

Pt = Po (1+r/100) n

R = 3.2 (population growth rate)

Po = Base population

N is the number of time intervals.

Table 1.8: Population Distribution in FCT

Area Council	2006	2016 *projection	2021 **projection	Infant Mortality	Life Expectancy
Abaji	58,642	148,000	235,122		
AMAC	776,298	1,959,272	3,112,632	45	51 years
Bwari	229,274	578,656	919,292		
Gwagwalada	158,618	400,330	635,991		
Kuje	97,233	245,403	389,863		
Kwali	86,174	217,491	345,520		
Total	**1,406, 239**	**3,549,152**	**5,638,420**		

Source: NPC, (2006); NBS, (2016) and Author Computation, (2021)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Theoretical Framework

2.1.1 The Theory of self-generated urbanisation

This theory suggests that urbanisation occurrence requires two separate conditions, which are the generation of surplus products that sustain people in non-agricultural activities and the achievement of a level of social development that allows large communities to be capable of working successfully alone (Bodo, 2019). This theory also holds that rural-urban migration was the source of this form of urbanisation, as people began to move to the cities for factory jobs (Childe, 1950; Hillier *et al.*, 2000; Maemeko *et al.*, 2021). Thus, industrialisation was identified as the driver behind the exodus movement of people from the rural settlements to urban areas. This theory has also been queried for focusing on rural-urban shift within counties as the source of the urbanisation, considering that there are other cities that are urbanized based on other factors, and not necessarily through rural-urban migration (Davis, 1972; Pred, 1977; Kwiatkowska, 2003; Danial, 2019; Christopher, 2021).

2.1.2 Modernisation theory

From the 1950s to the 1970s, this thought was popular and influential. According to the notion, urbanization occurs as a result of the introduction of new items and innovations into society via industrialization, technological application, information penetration, and cultural dissemination (Smith, 2005). When looking at urbanization through the lens of modernization, it is usual to see elements of modernization (new things) in any society that has progressed from the Stone Age to a new or modern way of doing things. Second, the importance of technology in social organization and changing society is self-evident;

after all, urbanization is usually the result. The world's current condition of urbanization and development is inextricably linked to its starting state at the dawn of industrialization (Kasarda and Crenshaw, 199; Goorha, 2010; Marsh, 2014).

Most advancements are the result of technologically driven societies, which have the potential to boost or increase economic capabilities, provide surplus food through improved agricultural systems, and use mechanical and electronic tools or machines to reduce citizen workload while increasing speed and efficiency of work done (Lenski and Nolan, 1984; Nolan and Lenski, 1985; Fourie, 2012; Acemoglu and Robinson, 2018). In this setting, it is assumed that technology is more significant than social organization. As a result, the use of technology is viewed as the primary driver of urbanisation in society. This type of urbanization is thought to have been sparked by the concentration of social amenities and development projects in certain parts of society as a result of ethnic, racial, or religious divisions, as well as corrupt politics, which has resulted in economic disparity and uneven development in today's world (Bodo, 2019).

Due to the concentration of investments and possibilities in a few regions (most likely cities), huge rural-to-urban migration is required as a result of rural-push and urban-pull factors (Berliner, 1977; Kasarda and Crenshaw, 1991; Fourie, 2012). Cities are facing challenges of a growing population size and thus increasing demands for housing and transportation. To accommodate these demands, cities especially Abuja cannot avoid physical growth in housing development and infrastructures which is one of the leading factors of vegetal cover loss in the area.

2.1.3 Urban microclimate theory

Microclimate is a small area's climate that differs slightly, but occasionally significantly, from the surrounding areas. In a city, this region can be as large as several kilometres wide or as little as a few centimetres (Klein *et al.,* 2003). The physical environment of the surrounds, as well as the climate of the region, influence microclimatic conditions. Radiation, wind movement, humidity, and air temperature are examples of things in a microclimate that differ from the surrounding environment (Erell *et al.,* 2012; Irger, 2014). A high-rise concrete building surrounded by black asphalt, for example, has a different microclimate than a low-rise timber house surrounded by a wooden deck (Shafaghat *et al.,* 2016). The built environment's shape and materials have a significant impact on a location's microclimate. The urban climate is made up of multiple microclimates, each of which can be controlled independently through architecture (Oke *et al.,* 2017).

Rapid urbanization and the replacement of natural landscapes with massive hard surfaces are the primary causes of the UHI effect. Building facades, roads, and pavements absorb heat and re-radiate it to the environment. The absence of moisture caused by impervious hard surfaces that have replaced permeable soil that could hold rainwater adds to the UHI (Chen and Ng, 2013). Because there is not any vegetation and there is no any natural cooling of the air through evapotranspiration. The UHI impact in the city is exacerbated by heat generated by human activity. Pollutants' greenhouse effect, along with heat from combustion engines and air conditioning, raises air temperature (Gaber *et al.,* 2010). The UHI effect can boost the temperature of urban air by up to 10^{o}C. Heat islands can cause pollution to build up, endangering human health and harming the natural environment.

Morris and Simmonds (2001) investigated the effects of wind and cloud on the Nocturnal urban heat island of a large city and discovered that the maximum heat island intensity in Melbourne might reach 2.4ºC in winter. Meanwhile, Van Weverberg *et al.* (2008) in Brussels modelled the contribution of UHI to a lengthy temperature time series and discovered that the heat island effect was higher in July under clear skies and calm conditions. Yamashita (1996) discovered a higher heat island intensity of 4-5ºC in the winter and 1.0-1.5ºC in the summer in Tokyo. In New York, Gedzelman *et al.* (2003) discovered that the largest heat island impact occurred in the middle of the night under clear conditions. In Granad, Montavez *et al.* (2000), discovered a heat island intensity of 3-3.5ºC. The heat island effect, on the other hand, was plainly visible, though the strength varied from place to place.

2.1.4 Theory of liveability

The quality of the urban environment in terms of residents' perceptions and expectations is referred to as liveability (Van Kamp *et al.*, 2003; Pacione, 2003; Ruth and Franklin, 2014). According to Pacione (2003), Van Kamp *et al.* (2003), and Ruth and Franklin (2014), liveability is defined as the quality of the person-environment connection in the urban setting, as it relates to inhabitants' needs and expectations of the urban environment. People's perceptions strongly influence these demands and expectations, as well as their personal values, making liveability assessment extremely difficult (Veenhoven, 2000). A liveable city, it is claimed, is a place of excellent quality where people wish to reside (Satu and Chiu 2019). Many theorists, according to Dong and Yang (2008), employ objective variables to determine liveability, such as housing costs or income, and believe that a meaningful notion is based on an individual's perception and contentment.

According to Okulicz-Kozaryn (2013), liveability is defined as the quality of life and overall well-being of a population in a city. Based on these criteria, it can be stated that liveability in terms of urban planning is defined as the link between physical environment attributes and personal satisfaction. As a result, Satu and Chiu (2019) asserted that liveability refers to people' level of contentment with their living environment, as evaluated by both objective and subjective indicators. As a result, liveability is an appropriate concept to use when researching residential satisfaction in various living environments, particularly dense living.

This study adopted the urban microclimate and urban liveability theories, because it is evident that in Abuja, the major drivers of vegetal cover losses are urban growth and anthropogenic activities. Therefore, the need for these theories is to understand microclimatic condition of the FCT due to vegetal cover losses resulting from the increasing urban growth. The theories serve as medium for this research to assess LULC/LST conditions, assess their state, identify the associated impacts and eventually, propose necessary response in order to restore protect and preserve and ensure sustainable land uses in the FCT, Abuja.

2.2 Conceptual Framework of Urbanization and Urban Heating

Urban heating is one of the most important issues in urban planning (Kleerekoper *et al.*, 2012), and it is caused by two unavoidable global trends: climate change and urbanization. Urban areas that are covered with impervious layers, vegetation, green spaces, and trees are known as key factors in reducing the outdoor temperature of cities. The expanse of urban areas and consequent diminution of natural areas has changed the surface energy balance, raising both surface and atmospheric temperatures and causing UHI and extreme heat events.

The built environment refers to material, spatial, and cultural product of human labour that combines physical elements and energy forms of living, working and playing (Wu, 2014; Li *et al.,* 2018). Humans have altered more than half of the Earth's surface as a result of rising human population and increased demand for resources such as minerals, soil, and water (Hooke and Sandercock, 2012). The most significant human alteration of the Earth system is changes in land use to produce products and services, and the urbanisation process is a primary driver of this land conversion (Gaston, 2010; Alberti, 2010). Urban areas are responsible for 78 percent of carbon emissions, 60 percent of domestic water usage, and 76 percent of industrial wood (Brown, 2021). As a result, urban development and human activities alter land use types and the availability of nutrients and water, affecting population, community, and ecosystem dynamics, and contributing to serious environmental issues such as biodiversity loss, ecosystem degradation, landscape fragmentation, and climate change (Alberti, 2010).

Changes in land use to develop cities and meet the demands of urban populations induce environmental changes such as local and global changes in biogeochemical cycles, temperature, hydro-systems, and biodiversity, which alter ecosystem structure and function (Grimm *et al.,* 2008). By modifying land use patterns and, as a result, surface radiation regimes and energy balance, urbanisation can have a considerable impact on local and regional climate (Wu, 2014). As a result, urbanisation is a major population trend and a significant component of worldwide land alteration (Pickett *et al.,* 2011).

Increased impervious land area in urban regions influences both geomorphological and hydrological processes, resulting in changes in water and sediment flows (Grimm *et al.*, 2008). The microclimate and air quality in metropolitan areas are influenced by impervious surfaces and the emission of heat from various combustion activities (Alberti, 2010). Due to increase per capita usage of fresh water and contamination of water sources by sewage and trash in cities, urbanisation has a significant impact on water resources (Wu, 2014). Furthermore, metropolitan areas, particularly those in the industrialised world, are major producers of greenhouse gases and air pollution, which create human and environmental health problems (Grimm *et al.*, 2008).

The composition and spatial layout of landscape features (for example, remnant natural areas, human-created or managed green spaces, streams, agricultural fields, architectural buildings, transit corridors, and residential neighbourhoods) are also altered as a result of urbanisation (Wu, 2014). Changes in land use that occur as a result of urbanisation have a significant impact on biodiversity, ecosystem function, and environmental quality (Alberti, 2010; Wu, 2014). Both the loss and fragmentation of natural habitats as a result of urbanisation have direct and indirect effects on vegetation diversity, structure, and distribution, with significant implications for species distribution, mobility, and persistence (Alberti, 2010). Biodiversity is undeniably important in maintaining ecosystem services, and urbanisation is linked to a number of changes in biotic interactions that affect species viability and distribution (Hansen *et al.*, 2005).

Babalola and Akinsanola (2016), found out that the vegetal cover loss leads to LST. This alteration has influenced the intensity of UHI and contributed to microclimate changes. According to the study, urbanisation has significantly impacted climatic variability, which has a regional impact on climate and socio-economic development. A similar study was carried out in Awka, by Nzoiwu *et al.* (2017), the decrease in LULC is due to a high rate of urbanisation, could result to an average increase of 2.2°C in surface radiant temperature. Due to extensive urban expansion, rising temperatures in over-developed areas could have a detrimental influence and enhance living discomfort within the city (Lindan and Oluwatola, 2015).

Lee and Kim (2022), studied urban heating problem and mitigation. The authors adopt three methods such as area based, zoning based and point based approach to mitigate urban heating. The area based approach serves as a strategy for organizing land cover and land use from the perspective of urban spatial structure. This approach tries to determine what spatial structure vegetation cover should assume in urban areas, and how this vegetation cover should be integrated with the land use in urban areas. The zoning-based approach is a strategy for mid- and-high density development districts, where lack of vegetation cover is common. This approach can serve as a guideline for density, height, and configuration of buildings based on the type of land use. The point-based approach is a strategy for individual buildings that reduces indoor temperature through design guidelines and energy efficiency measures. This approach provides response measures regarding construction materials, windows, walls, roofs, and the direction and height of buildings. The conceptual framework for urbanization and urban heating is shown in Figure 2.1.

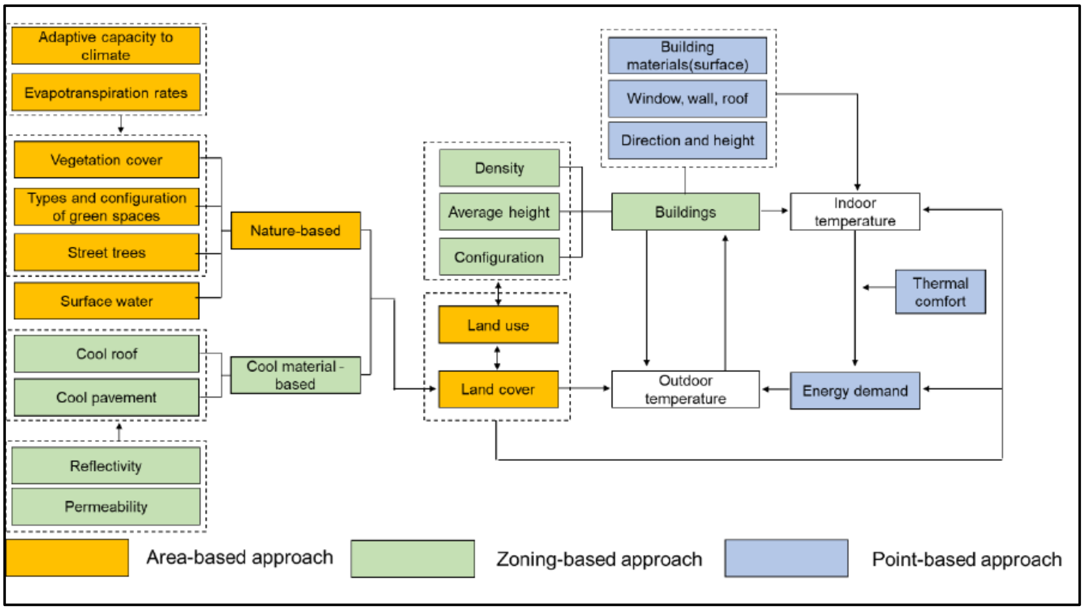


Figure 2.1. Comprehensive Framework for understanding Urban Heating

Sources: Lee and Kim, (2022)

2.3 Effect of urbanisation on thermal comfort

Amirtham (2016), conducted a UHI study in Chennai, finding that the temperature distribution within the city and suburbs has been significantly altered and that the effect of urbanisation has significantly outweighed the effect of maritime influence in the formation and maintenance of heat islands. Devi *et al.* (2021), discovered that the intensity of the heat island varies between 2°C and 4°C, and the intensity is higher during the winter season compared to the summer and monsoon seasons and that the formation of the UHI is controlled by topography and urban morphology in a study in Visakhapatnam.

Emmanuel (2005), investigated the thermal comfort of urbanisation. The author used 30 years of climate data to calculate the city's thermal comfort. The variations in land cover in the city were linked to differences in thermal comfort. According to the author, urbanisation has had a significant impact on temperature rise in the research due to a loss of vegetative cover. The author came to the conclusion that the thermal characteristics of urban fabrics in Colombo had a considerable impact on the overall surface temperature of the research, altering the inhabitant's thermal comfort. Morris (2005), looked at the incidence of UHI in Melbourne, Australia, namely in the CBD and the Industrial Suburbs (IS). According to his research, UHI was most prominent when the wind speed in the CBD and IS was less than 3 m/s. It was also discovered that at midnight, when the sky was clear, and the wind speed was less than 1.5 m/s, the heat island reached a temperature of 10^{o}C.

Johansson and Emmanuel (2006), used field measurements in five distinct regions of the city to investigate the impact of street canyon geometry on outdoor thermal comfort in Colombo, Sri Lanka. According to their findings, the air temperature was 7°C higher during the day than at night. During the day, PET readings were found to be over the top comfort limit of 33°C. Due to a combination of intense sun radiation, high temperature, and low wind speed, the thermal comfort was much above the expected thermal comfort zone. Yang *et al*. (2013), also investigated the intensity of the urban heat island effect in Singapore on a micro and macro scale. The survey was conducted in four routes to cover the entire Island of Singapore (both rural and urban). According to the study's findings, a difference of 4.01°C was discovered.

Makokha and Shisanya (2010), investigated the long-term urban change of near-surface temperature mean annual conditions in Nairobi City. The change in temperature over the thirty-four-year study period is higher for minimum temperature than maximum temperature, according to the study. Warming trends were reported to be more pronounced at urban stations than outlying stations, with temperatures rising close to the CBD. This shows the spread of urbanisation from the densely populated CBD to the suburbs.

According to Giannopoulou *et al.* (2011), the incidence of high air temperatures is dependent on rising urbanisation and industrialisation, as well as increased anthropogenic heat flows and a lack of vegetation in Athens. In Bahrain City, researchers looked into the impact of urbanisation on the thermal behaviour of newly constructed surroundings. The findings revealed that the recent process of urbanisation has resulted in a 2-5°C increase in urban temperature. Urban activity, such as ongoing construction projects, shrinking green spaces, and sea reclamation, contributes to the rise in temperature (Radhi *et al.,* 2013).

Robaa (2011), looked at the impact of urbanisation and industry on outdoor thermal human comfort in the Cairo area. According to the study, urbanisation and industrialisation processes are to blame for a rise in human hot uncomfortable sensations, which impedes human activities in cities. In contrast, rural settings contribute to optimal weather comfort for more and more human activities.

Park *et al.* (2014), used the UTCI to examine human thermal feelings on human bioclimatic maps in Nanaimo, BC, Canada, and Changwon, Republic of Korea in the summer 2009. According to the research, the most severe heat stress occurs mid-afternoon. According to Argüeso *et al.* (2015), the combined impact of urbanisation and climate change on heat stress in the Sydney region result in an increased risk of heat-stress conditions, with significantly more frequent bad circumstances in metropolitan regions.
The preliminary investigations revealed the challenging nature of estimating the influence of urbanisation in a dry tropical coastal environment, according to a study conducted by Charabi *et al.* (2011). The findings show how temperature varies at the meso and micro

scales due to numerous conflicting factors such as topography, mesoscale circulation, urban form, and landscape diversity. According to Borbora (2014), replacing natural vegetation areas with dry impervious surfaces, using building materials with high heat capacity and low surface reflectivity, and increasing anthropogenic heat emission into the urban atmosphere are all likely to change the thermal regime for Guwahati City in India.

2.4 The Concept of Land Use and Land Cover Change

Land is unquestionably one of the most vital natural resources for life, and development activities are dependent on it (Ezeomedo and Igbokwe, 2013). Any definable portion of the Earth's terrestrial surface encompassing all biotic qualities immediately above and below this surface is referred to as the land (European Commission, 2001). It includes the climate, soils, and topography near the surface, as well as surface hydrology, human settlement patterns, and the physical effects of human activity. Land can be divided into two categories. Land in its natural state versus land that has been transformed by humans to suit a certain use or a set of uses (Ezeomedo and Igbokwe, 2013).

The land serves several purposes, including environmental, economic, and social ones (Hubacek and van de Bergh, 2006). In terms of environmental issues, land serves as a soil, a water filter, and a habitat for wild wildlife and flora. Climate, water, and air systems are all intertwined with the land. Land allocates production activity, infrastructure, housing, and capital assets on an economic level. Landowners have social prestige on a social level. Land is one of three classic production inputs, along with terrestrial surface, seas, and solar energy. The land's function in economic discipline has evolved over time, and one of the land's benefits is its contribution to human well-being (Hubacek and van den Bergh, 2006).

Land could be used for grazing, agriculture, urban development, logging, and mining, among other things. The terms Land Use/Land Cover (LULC) are commonly used interchangeably (Dimyati *et al.,* 1996 and Ellis and Pontius, 2020). The physical and biological cover over the land's surface, including water, plants, bare soil, and/or artificial structures, is referred to as land cover (Ellis and Pontius, 2020). The type of use to which man has put the land is referred to as land use. It also refers to the assessment of a piece of land based on its natural qualities (Ezeomedo and Igbokwe, 2013).

Land use denotes human activities of developing and decreasing natural landscape resources. Agricultural, forestry, residential and industrial lands represent different land-use types. Human activities, such as deforestation, expansion of the artificial use of non-agricultural vegetated areas and croplands, grassland degradation, urbanization and other large-scale land use changes the natural quality of land cover (Cinar, 2015). The increasing human population, as well as the demand for food, fuel, water, and housing, has been a driving force behind the LULC shifts (Odada *et al.*, 2009). According to the Food and Agricultural Organization (FAO, 2011), the world's vegetal cover shrank by an average of 16 million hectares per year in the 1990s; Africa's net forest loss was estimated to be 4 million hectares per year between 1990 and 2000 but decreased to 3.4 million hectares per year between 2000 and 2010. Food security, climate, biodiversity, water availability, biochemical processes, and human welfare all suffer as a result of such land cover shifts (Foody 2002; Overmars and Verburg, 2005). Natural and socioeconomic variables, as well as man's use of them over time and space, determine the land use and land cover pattern of a given place (Zubair, 2006).

Factors that can be classified as natural or human-induced are referred to be LULC driving forces. Natural elements such as high rainfall intensity, sunlight, and steep relief, as well as soil types and climate change, are all driving causes for LULC transformation (Desta, 2000). Population growth rate and density, over-intensification of land usage, farm size, land tenure status, and policies are all listed as human causal variables.

A number of socioeconomic, economic, political, cultural, technological, and biophysical factors influence LULC (Lambin *et al.*, 2003 and De Groot *et al.,* 2012). One of the most critical elements of environmental change is land cover change, which poses the greatest threat to ecological systems (Foody, 2002 and Eludoyin *et al.,* 2011). Changes in land cover, whether caused by humans or nature, can have a significant impact on climate, hydrological and biogeochemical cycles, biodiversity, soil quality, and human health (Lambin *et al.,* 2003; Overmars and Verburg, 2005). This emphasizes the significance of land use and land cover studies in terms of environmental change and long-term development.

Urbanized areas are made up of a variety of intricate connections between social and economic growth and regional resource extraction that help to maintain productivity and regional living standards. Increased human activity in the city causes significant changes in LULC patterns, as well as alterations in urban ecosystems that make cities vulnerable (Yu *et al.,* 2012). It has a substantial negative impact on urban environmental conditions (Herold *et al.,* 2003). Because of their connections with global carbon cycles, ecosystem processes, biogeochemical cycles, biodiversity, and human activities, these environmental disturbances are related to global environmental and climatic change (Xiao *et al.,* 2008).

Changes in LULC are the result of population growth, which has been most noticeable in metropolitan areas (Dermographia, 2013). One of the most important drivers of land cover change in the twenty-first century is urban expansion (Seto *et al.,* 2012). Even though urban areas make only a small percentage of the earth's surface (less than 2percent), they have a substantial impact on the global and regional ecosystem (Yin *et al.,* 2019). Through biochemical and biophysical mechanisms, LULC also affects global climate (climate change) (Feddema *et al.,* 2005; Fasona *et al.,* 2005). Changes in the metabolic process, for example, resulted in changes in the carbon cycle, resulting in an increase in CO_2 levels in the atmosphere (Cox *et al.,* 2000). As a result of this increase, global earth temperatures rise, resulting in global warming. Biophysical processes change the amount of albedo on the earth's surface, which affects energy absorption and disposal (Feddema *et al.,* 2005). As a result of this change, the amount of energy reflected from the earth into space decreases. This occurs primarily during urbanization, resulting in cities having greater temperatures than non-urban locations (Urban Heat Island Effect).

2.5 The concept of land surface temperature

The phrase "urban heat island" refers to the presence of various micro and mesoscale climates that are hotter than the starting temperature at the base and nearby territories (Zhou and Wang, 2011). Streutker (2003) defines UHI as a contradiction in which a metropolitan or urban territory is significantly hotter than its agricultural zones. Furthermore, Voogt (2004) defined three forms of urban heat islands: canopy layer heat island, boundary-layer heat island, and surface heat island. Figure 2.1 depicts the profile of urban heat islands.

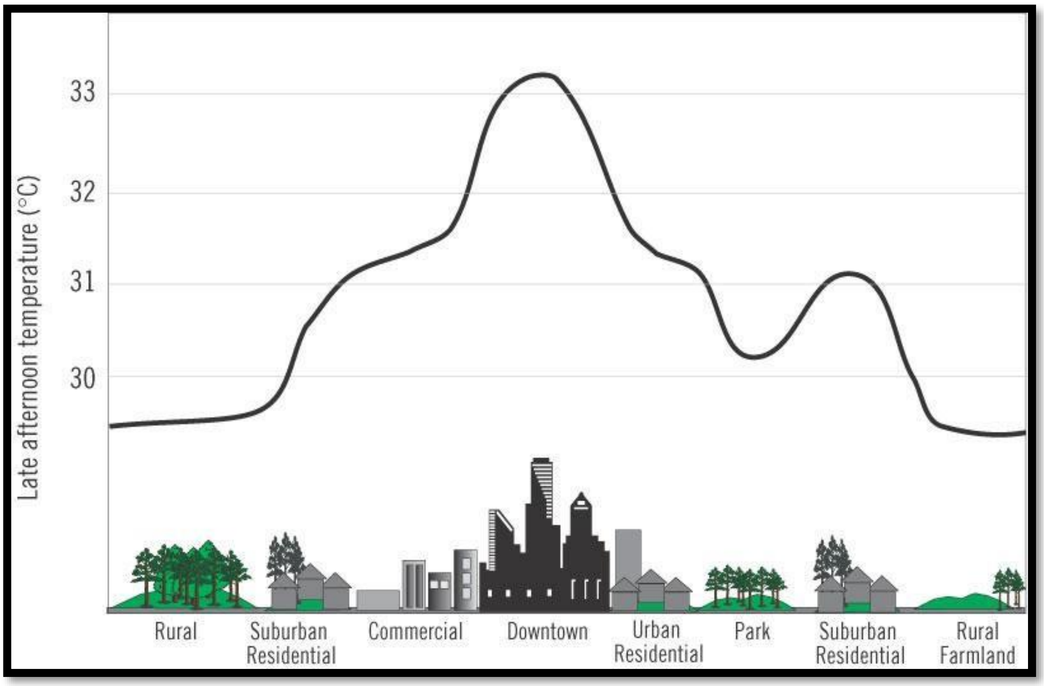


Figure 2.1: Profile of Urban Heat Island
Source: European Environment Agency (2003)

2.5.1 Factors of formation of urban heat island

According to Rizwan *et al.* (2008), anthropogenic heat from autos, air conditioners, and energy plants, as well as heat re-emitted and deposited in the urban structure, were the key sources of UHI formation. Memon *et al.* (2008b) proposed that there are two types of deciding factors for urban heat islands: controllable and uncontrollable elements. Weather parameters such as cloud cover, wind velocity, stable circumstances, periods, and anticyclonic conditions are uncontrollable. Population-related variables (such as anthropogenic heat and air pollution) and urban design-related factors (such as the Sky View Factor (SVF), green areas, and building materials) are two types of controllable factors. Figure 2.2 depicts the city's spatial vertical structure.

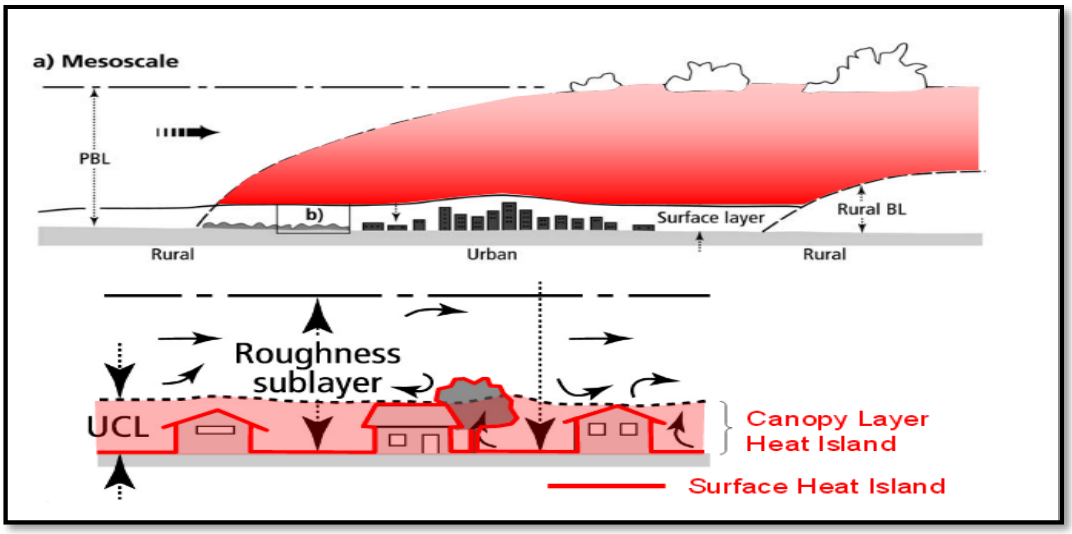


Figure 2.2: Spatial Vertical Structure (Meso-Scale) of the City

Source**:** Roth, (2013) and Awimyati, (2016)

According to studies by Oke (1981) and Unger *et al.* (2001), canyon shape is one of the most important factors influencing the development of urban heat islands. As a result, canyon geometry can be determined using either the height to width ratio or the SVF. According to (Yamashita *et al.*, 1996), who conducted a study on the link between SVF and air temperature in Japanese cities. The survey found a somewhat substantial association between SVF and air temperature in urban areas. In addition, in Goteborg, Sweden, (Eliasson, 1996) evaluated night time temperature distribution in response to changes in roadway geometry and land use. The author concluded that the sky view factor, rather than the air temperature, influenced the surface temperature. By separating a city into small regions, Unger (2004) conducted a thorough assessment of the interurban SVF temperature relationship in Szeged, Hungary. The association between air temperature differential and SVF was explored separately in each tiny location in his study before being combined. One of the characteristics that appears to impact the intensity of the urban heat island is the urban geometry.

In addition to urban layout, the kind of land use has a significant impact on UHI production. Green-covered land loses heat more quickly through evapotranspiration or sequestration. In addition, Jusuf *et al.* (2007) investigated the impact of land use on Singapore's urban heat island. The study's findings revealed that diverse land uses had an impact on metropolitan temperature. When compared to the night, the sequence of land-use type affecting ambient temperature was different during the day.

Eliasson *et al.* (2003), discovered that the kind of surface cover had an impact on the local air temperature fluctuation in their study of regional air temperature variations and urban land use in Goteborg, Sweden. Upmanis *et al.* (1998) and Upmanis and Chen (1999), conducted studies in Swedish urban parks. The presence of urban parks influences the air temperature of the surrounding built-up regions, according to their findings. Also, according to Golany (1996), there is a link between urban morphology and climate.

Another source of UHI production is anthropogenic heat. If heat from automobiles and building plants cannot be drained fast due to the urban geometry discussed above, the heat island effect will occur. Hamilton *et al.* (2009) looked at the impact of anthropogenic heat emissions on the local climate in London. They compared net shortwave radiation and human heat output using four urban environmental models that represented varying urban densities in London. According to their findings, total heat emissions from buildings were 3 to 25 times larger than incident solar radiation in the winter and 0.04 to 0.4 times greater in the summer, depending on urban density. The formation of UHI can also be influenced by wind and cloud. If there is a strong breeze, heat energy from the urban canyon could be dissipated more quickly. Cloud cover in a rural location, on the other hand, could impede heat removal by reducing longwave radiation from the earth to the sky.

Morris *et al.* (2001) discovered that the severity of the urban heat island was inversely proportional to the fourth root of both wind speed and cloud cover amount in their study. Eliasson and Svensson (2003) also used meteorological data from Swedish monitoring sites to investigate the impact of wind and cloud cover on intra-urban air temperature. Her findings revealed that as wind speed and cloud cover increased, the severity of the urban heat island reduced. Figure 2.3 depicts the meso scale and micro scale elements that contribute to the establishment of an urban heat island within a city.

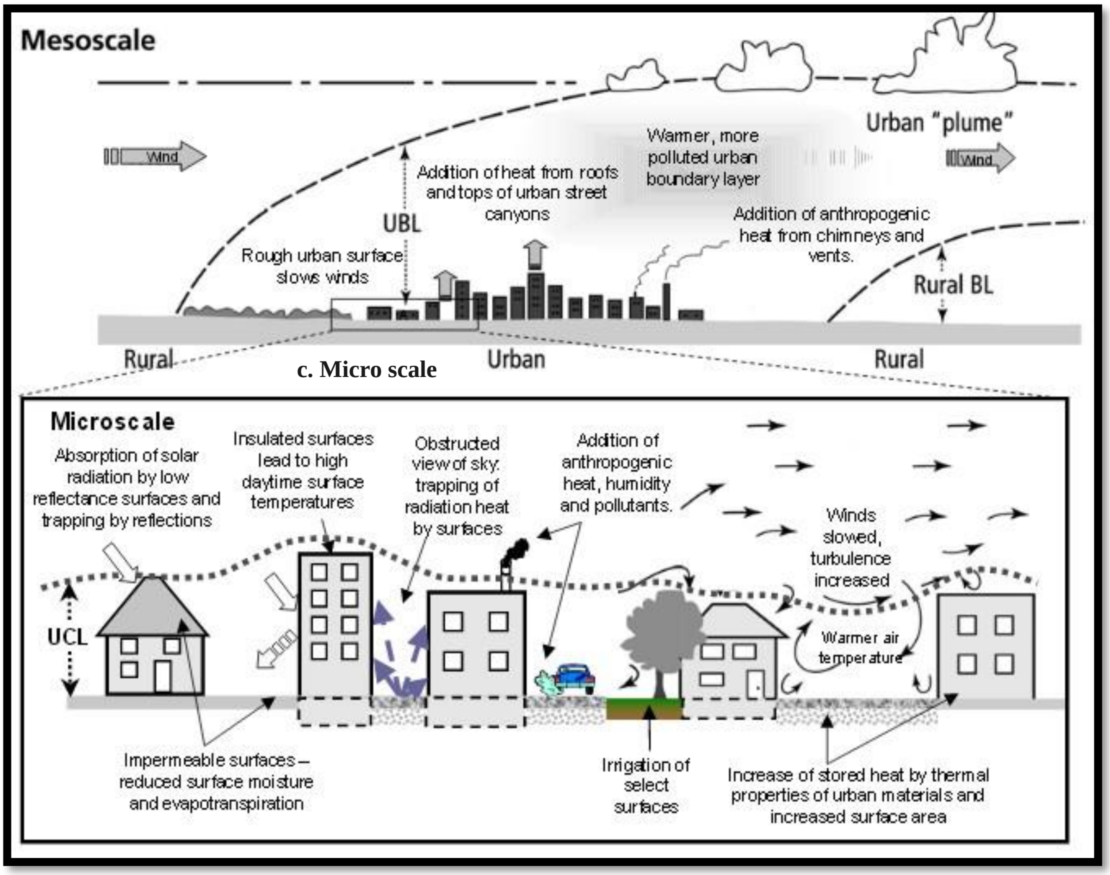


Figure 2.3: A Typical Street Canyon of an Urban Area

Source: Awimyati (2016)

2.5.2 Causes of urban heat island

UHI is influenced by two variables: elements inside the city's activity and regional climate and weather conditions. Human activities such as land use change, anthropogenic emissions, and air pollution cause factors within the city. Meanwhile, rising temperatures, clouds, and wind speed characterize the regional climate and meteorological conditions (Solecki *et al.*, 2005; Prilandita, 2009). There have been various causes cited as contributing to the city's warming. Prilandita (2009) identified several general causes of UHI.

"*Population shifts, urban and suburban growth, land use change, anthropogenic emissions and pollutants generation and dispersion, all of which interact with regional climate as well as the frequency and intensity of specific weather events" (Prilandita, 2009).*

According to Lormaneenopparat (2002), the following factors contribute to the city being warmer than the surrounding non-urban environment:

a. Evapotranspiration decreasing

Solar energy is required for both transpiration and evaporation. In a city with little green space, hard surfaces prevent water from penetrating the ground and draining it quickly into the drainage system, reducing the amount of water available for evaporation. As the amount of evaporation and transpiration is reduced, the solar energy available for this process is reduced, resulting in surface warming (Rossi *et al.*, 2014).

b. Anthropogenic heat source

In areas of high activity, significant amounts of energy are consumed by manufacturing, lighting, cooling, transportation, and other operations. The surplus heat energy generated in these locations is subsequently discharged into the atmosphere. This discharged energy constitutes a form of waste heat generation, which contributes to the elevation of urban heat levels. (Mohajerani *et al.,* 2017).

c. *Sensible heat storage*

The materials of the urban environment, such as street and building materials, have low volumetric heat capacities, which implies that the urban surface reaches a higher temperature with a given amount of radiation absorption, which heats the overlying air faster. The urban surface absorbs heat more quickly during the day, then becomes a radiating source after sunset, raising night-time temperatures (Mirzaei and Haghighat, 2010; Vyas *et al.,* 2014).

d. *Wind speed*

Wind speed is the most important factor in determining how much heat is produced or lost in the urban environment. At ground level, wind speeds in cities tend to be substantially lower than those in open settings. As a result, warm air does not dissipate as quickly as it does in rural areas (Wong *et al.,* 2011; Miles and Esau, 2017).

e. *Air pollution and greenhouse gas effect*

Some incoming solar radiation is reflected to space by gaseous particles, which can also absorb energy and re-emit it into the atmosphere. Furthermore, poor air quality can lead to increased cloudiness, which reflects long-wave radiation back to the earth (Dixon and Mote, 2003).

According to Nuruzzaman (2015), urbanization has an impact on population growth, green space provision, and living space expansion. These are the factors that influence urban solar radiation, heat, and water, all of which influence the local climate. Furthermore, the following are the primary causes of UHI effects:

i. Increase in energy consumption rate that could leads to anthropogenic heat.
ii. Decrease in greenspace and accumulative construction materials can reduce evapotranspiration capacity.
iii. Any urban form that trapped the heat and urban sprawl
iv. The greenhouse effects as a result of air pollution within an urban space

According to Das *et al.* (2020), urbanization has an impact on UHI. As a result, the urban activities and physical form are influenced by the UHI effect. The activities that effected UHI were energy consumption, greenhouse effect, anthropogenic heat, and loss of green space provision, while the man-made factors that represent the physical form of the city are urban structure, city size, population density and built-up area, street width, and building material (Giridharan *et al.*, 2004; Giridharan and Emmanuel, 2018).

Gago *et al.* (2013), investigate specific aspects of urban climate and the origins of the heat island problem. The impact of surface albedo, evapotranspiration, and human heating on the urban climate was the subject of his research. He demonstrated that green space creates ideal conditions for evapotranspiration, resulting in oases that were 2-8°C cooler than their surroundings. Buildings, the provision of green space, and the use of pavement, according to Wong (2011), influence urban temperature. Yamamoto and Ishikawa (2018), proposes measures for addressing UHI based on sustainable energy usage, including all stakeholders in city planning, building structure and design, alternative energy use, and public transportation.

2.6 Relationship between LST and LULC

Surface modifications, land cover changes, and changes in the structure and composition of the atmosphere are all caused by urban growth (Zhou and Wang, 2011). As a result of these modifications, different micro and mesoscale climates emerge, all of which are warmer than the original and surrounding climates (Roth *et al.*, 1998). The most popular technique to characterize the climatic impact of urbanisation on a regional scale (UHI) is through urban heat islands. The difference in ambient temperature between the city and its surroundings is depicted by UHI, as is the consequence of urban areas producing and storing more heat than rural areas (Aniello *et al.*, 1995; Nonomura *et al.*, 2009). Van der meer (2012) used Landsat ETM+ images combined with fieldwork and ground-truthing to estimate the acreage infested with Imperata Cylindrica and Stiga in Nigeria's moist savanna. The spectral fingerprints of Imperata and other land cover types aided in characterizing the LU/LC kinds in the area. Furthermore, Okhimamhe (2003) used ERS and Landsat ETM images as a better method for Maximum Likelihood Classification (MLC), Normalised Differences Vegetation Indexes (NDVI), and Interferometric Land Use (ILU) techniques, and the study demonstrated that ILU and NDVI images could be used to measure the accuracy of the MLC for woody vegetation cover.

Tukur *et al.* (2006) examined land cover changes in the lower reaches of the Gongola River in Nigeria using Landsat MSS data from 1976 and SPOT-XS data from 1994. For supervised classification, the maximum likelihood technique was used, and the study discovered that between 1976 and 1994, the LU and LC such as bare surfaces, cultivated and grazed fields, wood and shrub vegetation, and marshy areas and storm channels increased, while marshy areas and storm channels decreased. Alphan (2003), investigated LULC alterations in Adana, Turkey. The author based his results on satellite data collected between 1984 and 2000. The study discovered that the built-up area rose by a factor of 70 percent over the course of 16 years, with about 30 percent on agricultural land and 70 percent on formerly semi-natural territory. According to the author, the main driving forces behind the observed changes were permanent immigration and urban growth regulations.

Between 1984 and 2003, Ekpenyong (2008) used a GIS database to anticipate land use/cover change in Akwa Ibom State. According to the findings, some urban areas had turned into farmland/fallow lands and the bordering secondary forest. The mangrove vegetation has shrunk by half during that time. Other forest cover in the area has also shifted, posing a hazard to food security and the environment.

Idoko and Bisong (2010) used satellite pictures from 1987 and 2004 to analyze land-use change in the Federal Capital Territory of Abuja. The photos were classified into five categories using the highest likelihood technique. The classifications were vegetation, built-up, rock outcrop, water feature, and agriculture. The photographs from the two classes were compared to see whether there were any differences. Furthermore, a quantitative change in land use type was obtained over time. According to the report, vegetation cover declined by 85.22 percent between 1987 and 2004. The built-up area grew by 21.99 percent, while farmland grew by 0.14 percent.

The extent of UHI is determined by the type and amount of urban growth, rather than the population or the actual size of the city (Roth *et al.*, 1998; Xian and Crane, 2005). Because older cities in developed nations have previously implemented temperature mitigating measures, smaller megacities in developing countries may have a far stronger UHI effect than larger and older megacities in developed countries (Weng, 2009). Rapidly growing metropolitan surfaces have different radioactive, thermal, aerodynamic, and moisture properties than rural areas, resulting in diverging thermal disparities (Xian and Crane, 2006). Temperature rises considerably as a result of the loss of surface moisture and fractional plant cover in urban areas as urbanization continues (Owen *et al.*, 1998).

Arvind *et al*. (2006) carried out a land use and land cover mapping study in the Indian districts of Panchkula, Ambala, and Yamunanger. According to the study, the district's unique climate and physiographic characteristics influenced LULC in the area, which is influenced by agro-climatic conditions, groundwater potential, and a range of other factors. Between 1991 and 2001, Xiao *et al.* (2008) conducted another investigation on the impact of land use and land cover changes on land surface temperature in Guizhou Province, Southwest China. Their data found that between 1991 and 2001, urban/built-up land nearly tripled, whereas agricultural land declined at a similar pace of about 4percent each year. The amount of LST increased when forest and agricultural land was converted to urban/built-up territory, according to the study. Between 1991 and 2001, the average LSTs for urban and built-up terrain in China's Guizhou Province increased by 1.1, 1.5, 1.4, and 1.2 kilometres, respectively.

The changing pattern among the various LULC kinds and changes in the surface temperatures of these LULC types inside Lokoja, according to Oluseyi *et al.* (2009), have a direct relationship. The changes were responsible for a 4.22°C increase in mean surface temperature from 38.39°C in 1987 to 42.61°C in 2001, representing a 14.22°C increase in 14 years. They claim that unless the rate of decline in vegetation cover is slowed, Lokoja's radiated surface temperature will continue to rise as the cooling effect of vegetation cover is lost to impermeable surfaces that litter the urban environment.

Acha and Aishetu (2018), investigated trends in LULC in Makurdi between 1986 and 2016. According to the report, the water body has reduced from 21km^2 in 1991 to 17km^2 in 2006. The forest area decreased from 133 km^2 in 1991 to 96 km^2 in 2006 due to high population growth, whereas the built-up area increased by 179 km^2 (130 percent) from 138 km^2 in 1991 to 317 km^2 in 2006. Ukaegbu *et al.* (2016) conducted a three-decade study in Owerri on spatial evaluation of temperature and land cover change as climate change monitoring tools to evaluate land cover and temperature variation in the city as climatic change. Climate change, according to the study, is caused by development activities that contribute to the city's increasing urban heat.

Ejaro and Abdullahi (2013) conducted a study on spatiotemporal analysis of LULC in Suleja and discovered that urbanisation is primarily responsible for significant changes and adjustments in LULC. This supports Tyubee and Anyadike's (2012) finding that urbanization is the principal driver of surface and atmospheric temperatures. Ishaya *et al.* (2008) evaluated urban expansion and loss of vegetative cover in Kaduna using Landsat imagery from 1990 to 2000 utilizing remote sensing and GIS. According to the findings, Kaduna town has changed over the previous few decades due to population growth, which has resulted in vegetation loss and the expansion of the built-up area. Kaduna town owes its colonial beginnings to its success over time due to its economic, educational, and administrative significance as a seat of government.

Chigbu *et al*. (2017) examined changes in land use and land cover in the Aba urban region between 1991 and 2005 using medium-resolution satellite imagery (Landsat ETM+ from 2000 and Nigeria Sat-1 from 2005). According to the findings, water levels increased from 15.1 percent, to 22.4 percent between 1991 and 2005, owing in part to increased activities within and around waterways; built-up area increased from 21.7 percent to 36.5 percent and vegetation cover decreased from 63.2 percent in 1991 to 51.1 percent in 2000 and 41.1 percent in 2005, owing to rapid urbanisation and socioeconomic activities. Cao *et al.* (2012), for example, used Landsat TM/ETM+ to explore fluctuations in land surface temperature in response to land use/cover change in China's Sangong River basin, employing the mono-window technique to generate LULC and LST data. Their data show that LST is extremely sensitive to LULC changes, with average temperatures rising by over 10°C as a result of dark bodies from rock outcrops and anthropogenic activity.

Also, Zhou *et al.* (2011) evaluated the relationship between LST and urban expansion using Landsat photos from 1992 to 1996. They conducted a correlation analysis between LST and the NDBI (normalised difference built-up index), an indicator of an urban area, the NDVI (Normalised Difference Vegetation Index), an indicator of greenness, and the MNDWI (Modified Normalised Difference Water Index), and discovered that LST increased by approximately 3.4°C and 1.9°C, respectively, for forest and agricultural land converted into built-up areas. And, of the three indices, NDBI had the strongest connection with LST.

Keramitsoglou *et al.* (2011) conducted research on UHI in Athens, Greece. The authors used a temporal LST pattern derived from daily LST retrievals of MODIS 3000 images with a resolution of 1 km during a 9-year period. As a result of their research, they identified cooler pixels along the shore and lower LST at higher altitudes. They also discovered that bare soil and anthropogenic activity influence the UHI (Urban Heat i Island) phenomenon in Athens. This study refuted the conclusions of Chigbu *et al.* (2011) and Bernerd *et al.* (2017).

Balew and Korme (2020) undertake an LST monitoring research in Bahir Dar and its environs, discovering that the vegetation cover had a mean LST of 32.22°C in 1987 and grew to 33.91°C in 2002. According to their research, paved surfaces had a mean LST of 1.6°C higher than in 1987 and 36.62°C higher in 2002 as a result of urbanisation. Climate change, according to Me-ead and McNeil (2019), is the primary cause of LST increases of 1.6°C in the Sahara and semi-arid parts of Southern Africa in the 2050s, and 1.4°C each year in tropical African countries.

Adebowale and Kayode (2015) identified different changes in land use land cover types and their associated land surface temperature in Akure over 20-year time intervals. The authors conducted their investigation using Landsat TM and ETM+ satellite data for over two decades. According to the study, the built-up area has expanded from 17.88percent to 27.02 percent, corresponding to a 9.9°C increase in LST and an average annual increase of 0.5°C. The vegetation cover has reduced from 47.23 percent to 37.79 percent due to a 2.79°C temperature increase. The data show that uncontrolled urban growth exacerbates the rise in LST.

Eresanya *et al.* (2019) explored the shifting patterns of the LULC across Osogbo and its environs in Nigeria. The study discovered that as cities expanded, LST climbed from

22.6°C to 30°C (mean 25.2°C) in 1984 to 29.3°C to 36.7°C (mean 31°C) in 2015. Li *et al.* (2018) discovered that temperature increased from 0.042°C to 0.118°C between 1990 and 2000 as a result of the transition from croplands to urban and built-up area in their study on the influence of LULC shift on Meteorology in the Beijing-Tianjin-Hebei Region.

According to Tarawally *et al*. (2018), study of LST to LULC Changes in Sierra Leone Between 1998 and 2015, the built-up area in Bo increased by 16 km^2 while the vegetation area decreased by 14 km^2. The average surface temperature in Freetown increased from 23.7°C to 25.5°C as a result of urbanization, while in Bo town it increased from 24.9°C to 28.2°C. Jande *et al.* (2019) investigate LULC and urban growth in Gboko. The author's analysis shows that urban areas increased from 3232ha (1.68 percent) in 1987 to 8542ha (4.45 percent) in 2007, and then to 16614ha (8.65 percent) in 2017. Vegetation cover declined from 52108ha (27.13 percent) to 46523ha (24.23 percent) to 16723ha (8.71 percent) throughout the same time period. The massive loss of vegetative cover is caused by overexploitation of forest resources and illegal logging.

Ahmad *et al*. (2019), did a study on LULC Change on Land Surface Temperature in Sokoto, Nigeria, between 2013 and 2018. Because of the region's climate, bare land has a higher LST value between 37°C and 41°C than any other land use class. Crum and Jenerette (2015) evaluated the impact of LULC on California surface and air temperature. The researchers measured LST on standardised asphalt, concrete, and turf grass surfaces across the climate gradient and discovered a 7.2°C and 4.6°C temperature drop from asphalt to vegetative cover in the coast and desert, respectively. According to the authors, vegetation covers in urbanized areas of southern California, USA, lower air temperature

(Ta) and LST, as well as spatial variation in LST, whereas manmade surfaces and land uses have the opposite effect. Furthermore, regional climatic trends have an impact on these interactions.

Zhou and Wang (2011) evaluated the effect of LULC change on LST in Kunming, China's fastest-growing city. Water and vegetation were found to be important in lowering the urban heat island effect, whereas built-up and barren terrain were responsible for the increase in LST. Similarly, Shen *et al*. (2015) investigated Chongming Island in Shanghai, China, and discovered that the Island's LULC change dynamics had a substantial impact on the LST. The conversion of spatial location and quantitative change in plant cover over the Island equalled around 44.4 percent of LULC-type locations. The overall LULC dynamicity increased from 2.97 to 3.95 hectares over the study period, according to the findings.

According to Dewan and Corner (2014), the expansion of urban built-up surfaces over natural land covers such as floodplains and agricultural areas has become noticeable, affecting the geographical and temporal distribution of surface temperature significantly. Increased LST was observed to be associated with decreased vegetation cover and subsequent increases in urban land cover, showing that the UHI impact amplified with time.

Yan *et al.* (2014) discovered that air temperature had a significant impact on LST at different times and seasons. The effects of various land cover types on air temperature varied, as did their spatial extent dependence. During particularly hot periods, such as heat waves, UHIs spread and increase, posing a health concern and perhaps increasing energy demand for cooling (Alavipanah *et al.*, 2015). Olang *et al.* (2011) explored spatiotemporal shifts in land cover changes and associated environmental implications in the Nyando Basin. Landsat images from 1973, 1986, and 2000 were used by the researchers. According to their findings, the basin's forest cover has reduced by nearly 20percent. Agricultural areas, on the other hand, increased by almost 16percent. As a result, the modifications were associated with risky land use practices.

Mundia and Aniya (2006) used three Landsat images and socioeconomic data in a post-classification analysis to map the geographical dynamics of LULC and identify the urbanisation trend in Nairobi city. According to the study, urbanization has resulted in land loss and urban sprawl. The most important drivers of urban expansion were discovered to be economic growth and proximity to transit systems. Eludoyin *et al*. (2011) conducted a study on LULC Changes in Obio-Akpor Local Government Area, Rivers State, Nigeria, and found that agriculture, mangroves, primary forest, and sparse vegetation all dropped by 8.09 percent to 45.34 percent over time. Secondary forest, built-up area, and water all increased from 5.88 percent to 74.55 percent, respectively. The report only gives basic data on the shifting land cover trend. It did not, however, specify the LULC changes and instead relied only on GIS analysis. This study raises a variety of methodological concerns in terms of integrating socioeconomic and geospatial technology, particularly in establishing who defines and comprehends which land cover classifications (Mayaux *et al.*, 2004).

It would have been prudent to conduct a household poll to gauge how the residents felt about the modifications. Rapid urbanisation and land cover changes have both contributed to this drastic change in natural surface features (increased land surface temperature and surface solar radiation). Rising land surface temperature and area have a substantial impact on human health. The scientists also suggested that when radiation levels climb over the global solar radiation index, ultraviolet radiation levels may rise, putting the local population at risk of heat stroke, skin cancer, and heart disease (Orimoloye *et al.,* 2018).

According to Adeyeri and Okogbue (2014), uncontrolled urban growth has resulted in environmental and ecological concerns such as flooding and UHI. Furthermore, the rapid growth of the urban population is seen as demanding the development of new urban infrastructure (Igun and Williams, 2018). To accommodate this requirement, natural surfaces such as plants are being replaced by non-vegetated surfaces such as asphalt and bricks, which can absorb heat and release it later. As a result of the change in land cover, the land surface temperature is predicted to rise.

Land surface temperature is an important feature in global climate change study, anticipating radiation budgets, heat balance investigations, and as a control for the climate dynamics and modelling frame. As a result, the external temperature affects the surfaces of self-heating areas, and urbanisation has resulted in a significant reduction in vegetative areas, resulting in an increase in surface temperature (Kayet *et al.,* 2016). Remote sensing and Geographical Information Systems (GIS) have been demonstrated to be beneficial in monitoring land use and cover changes, as well as providing essential information for planning and research.

2.7 Approaches of Remote Sensing used for Land Surface Temperature Analysis

There are two methods in retrieving Land Surface Temperature (LST) such as; multispectral Thermal Infrared (TIR) and Hyperspectral TIR.

2.7.1 Multispectral thermal infrared (TIR)

There are three types of Multispectral TIR LST retrieval techniques: single-channel, split-window, and multichannel algorithms.

i. The Single-Channel Algorithm

Qin *et al.* (2001) suggested a single-channel technique (SC) to derive the LST from Lansat-5 data using near-surface air temperature and water vapor concentration. Jimenez-Munoz and Sobrino (2003) and Jimenez-Munoz and Sobrino (2009) proposed a method for obtaining LST from any satellite TIR and data with an FWHM of around 1 um and known LSE and total water vapor content. In addition, Jiménez-Muoz and Sobrino (2003) provided a generalised single-channel technique for extracting LST from any thermal in-frared data. Only one thermal band is used to retrieve LST in the Single-Channel method. Either band 10 or 11 can be used with Landsat 8.

Käfer *et al.* (2020) used single channel (mono-window and enhanced single channel) and field measurements to determine land surface temperature in Southern Brazil. The three approaches had a high coefficient of determination, with the radioactive transfer equation (RTE) between 0.9 and 0.98, according to the authors' findings. The study also discovered that while calculating LST, the single channel algorithm gave the fastest results from the reference and was statistically better than the modified single channel method.

ii. Split-Window or Multi- Channel Algorithms

McMillin (1975) was the first to propose the split-window approach for calculating sea surface temperature. The atmosphere's influence is reduced by combining the brightness temperatures of two channels (McMillin, 1975). This method is because the difference between the at-sensor radiances measured simultaneously into neighbouring channels is proportional to the air attenuation incurred by the surface emitted radiance. The multi-channel approach is used by several satellite sensors, including AVHRR, MODIS, SEVIRI, and FY-3, since it requires little atmospheric data, which is difficult to gather for most satellite sensors, and it is also simple to use (Sun and Pinker, 2003; Hulley and Hook, 2011).

iii. Multichannel Algorithms

MODIS, ASTER, AVHRR, and Landsat 8 all have several thermal infrared channels, therefore the Multichannel algorithms can estimate LST and LSE from them. These algorithms can extract both LSE and LST at the same time (Peres and DaCamara, 2004).

2.7.2 Hyperspectral thermal infrared (TIR)

The iterative spectral smooth temperature/emissivity separation method (ISSTES), Linear Emissivity Constraint Temperature and Emissivity Separation method (LECTES), Artificial Neural Network (ANN), and the extended two step retrieval method are all hyperspectral TIR LST retrieval methods (TSRM).

i. Iterative Spectral Smooth Temperature/Emissivity Separation Method (ISSTES)

Borel (1997) presented the ISSTES method for iteratively retrieving LST and LSE from hyperspectral TIR data assuming appropriate atmospheric adjustment. The sensitivity of the approach to the smoothness assumption and measurement noise was studied by Ingram and Muse (2001), who discovered that the assumption does not create considerable inaccuracy in the recovered findings, but the retrieval accuracy of the method is dependent on the signal-to-noise ratio (SNR).

ii. Linear Emissivity Constraint Temperature and Emissivity Separation Method (LECTES)

The LECTES implies that the LSE spectrum is divided into M segments, each of which fluctuates linearly with wavelength (Wang *et al.*, 2011). The number of equations is n X M, and the number of unknowns is M X 2LSE+1LST for hyperspectral TIR data with M segments (n channels in each segment). For hyperspectral TIR data, the requirement of n X M2M+1 is easily met. The LECTES approach generates fewer single points and is more resistant to both white noise and ambient radiance mistake. Only hyperspectral TIR data is applicable for the LECTES technique, which necessitates precise atmospheric adjustment.

iii. Artificial Neural Network (ANN)

In remote sensing, the Artificial Neural Network (ANN) is commonly employed. The ANN technique simulates brain activity in two steps: learning to acquire knowledge and storing knowledge via interneuron connection strengths (Mas and Flores, 2008). ANN methods are used to recover surface and atmospheric characteristics without knowledge of the intricate physical mechanisms because to its non-linear feature. Wang *et al.* (2010), for example, developed an ANN to recover the LST, LSE, and atmospheric profile from hyperspectral TIR data simultaneously. An ANN was utilized by Mass and Flores (2008), Aires *et al.* (2001) and Albawi *et al.* (2017) to recover LS, atmospheric profile, and LSE from ASTER data.

iv. The Extended Two Step Retrieval Method (TSRM)

By assuming that the LSE spectrum can be represented by numerous principal component scores to reduce the number of unknowns, Li *et al.* (2013) suggested the extended Two Step Retrieval Method (TSRM) to simultaneously retrieve LST, LSE, and atmospheric profile from hyperspectral TIR data. The expanded TSRM approach does not require any additional atmospheric data, and its retrieval accuracy is superior to empirical methods (Wang *et al.*, 2021).

2.8 Image Classification, Index Computation and Change Detection

2.8.1 Image classification

Land cover classification approaches range from supervised to unsupervised classification, from metric to non-parametric to parametric; soft and hard fuzzy; and pixel, prepixel, and object-oriented based (Keuchel *et al.,* 2003; Im and Jensen, 2005). In the sense that they both convey concealed information regarding spectral fingerprints of land cover, unsupervised and supervised classifications are similar (Soofi *et al.,* 2017; Soofi and Awan, 2017). When the area is unknown, the former is frequently employed, although the latter delivers more accurate findings. Both categorization methods can be employed as stand-alone procedures, however they are frequently combined to assess accuracies in specific circumstances (Richards and Richards, 2022).

2.8.1.1 *Unsupervised classification*

Analysts employ image clustering methods such as K-means and ISODATA to first group pixels into "clusters" depending on their features in order to construct "clusters," as shown in Table 2.1. Following the selection of clustered algorithms, the number of groups to be generated must be determined. For example, you could make 10, 25, or 36 clusters. As a result, unsupervised categorization is the most fundamental technique, as it does not require samples from the analyst or planner.

2.8.1.2 *Supervised classification*

In supervised classification, features are first distinguished, then their spectral separability is examined (Lillesand and Keifer, 1994). In terms of classification accuracy, this technique generally outperforms unsupervised classification, however unsupervised classification is favoured in terms of ease. One disadvantage of this classification is that if fresh data (samples) are provided, the classification process must be repeated. During independent utility, Castellana *et al.* (2007) recognized the limitations of both supervised and unsupervised classification approaches, which prompted them to propose a novel classification strategy called the "hybrid classification method" (Al-doski *et al.*, 2013). When employing images acquired with more modern sensors, which are typically characterized by increased spatial and spectral resolution, obtaining adequate results using supervised and unsupervised algorithms alone is rarely challenging (Lewiriski and Zaremski, 2004). As a result of scientists developing advanced classification procedures, the Automated Classification Approach is developed by (Ratanopad and Kainz, 2006), Object-based Classification by (Gamanya *et al.*, 2009), Classification Method by (Zhang *et al.*, 2017), Standardized Object-Oriented Automatic Classification (SOOAC) methods based on fuzzy Logic, Knowledge-based Stratified Classification, Artificial Neural Networks (ANN) by Chen *et al.* (2010).

Table 2.1: Summary of Image Classifications

Classification process	Algorithms	Description
Supervised	Maximum Likelihood, Mahala Nobis distance, Spectral angle mapper, Spectral correlation mapper, Minimum Distance, and Parallelepiped classification.	Training samples or signatures are defined by the analyst to represent different land cover feature and each pixel is classified based on statistical analysis
Unsupervised	ISODATA and K-means.	Prior ground information not known. Pixels with similar spectral characteristics are grouped as clusters.
Non-metric	Classification by Rule-based decision tree	Uses both real-valued data and nominal scaled data statistical analysis
Non-Parametric	Nearest-neighbour classification, Neural networks, Fuzzy classification and support Vector machines etc.	No prior assumptions are made
Soft (non- Parametric)	Fuzzy code classification logic	The diverse nature of real-world features are considered, a proportion of the land cover type found within the pixel is assigned a pixel similar to it.
Hard (parametric)	Supervised and Unsupervised classifications	Uses discrete categories
Pre-Pixel		Pixel by pixel classification.
Object-oriented		The image is regenerated into a similar object and classification is performed on each object and pixel
Hybrid Approaches		Includes expert systems and artificial intelligence

Source: Jensen (2005)

2.8.1.3 *The normalized difference vegetative index (NDVI) index computation*

Although the shadow effect tends to exaggerate the water body present in the research region, the Normalized Difference Vegetative Index (NDVI) is processed in a similar fashion to the water index. Although including this is discovered to be decreased or removed by using an elevation model of the area, this is rarely the case (Knight, 2006). The use of NDVI analysis to investigate vegetation canopies and to identify the pattern and seasons of the best growth in vegetation is widespread. Other research has found that the environment in which an agricultural product grows has a significant impact on its yielding process. Panda *et al*. (2010) analysed the reflectance of the vegetation in Oakes, North Dakota, using the Soil Adjusted Vegetative Index, Perpendicular Vegetative Index, and NDVI, among other indices.

The extraction of information on land surfaces using the Imagine software's indices is a new invaluable technology that goes a long way in leveraging algorithms to deliver useful information. The built-up index, water index, vegetative index, and water index all help to understand the information contained in Landsat imaging for specific places (Xu, 2007).

2.9 Numerical Models used for Urban Heat Island (UHI)

2.9.1 Envi-met model

Perini and Magliocco (2014), employed ENVI-met to quantitatively explore the influence of building density, building height, atmospheric conditions, amount and type of vegetation on temperature distribution, and outdoor thermal comfort in a typical city region. They discovered that larger urban densities result in higher temperatures for the same building height. Because of the shadowing effect of taller structures, temperatures are lower. However, the authors discovered that green areas on the ground are more beneficial than green roofs in lowering summer temperatures.

Taleghani *et al.* (2014), used ENVI-met to compare the local microclimate for several urban morphologies (single blocks, linear blocks, and a courtyard block) (singular blocks, linear blocks, and a courtyard block). They discovered that the courtyard creates a protected microclimate that gets less solar radiation than solitary or linear urban structures during the summer. As a result, they recommend for the use of courtyards in metropolitan areas with temperate climates, such as those found in Western Europe.

Yang *et al.* (2011), conducted an empirical study of ten Shanghai high-rise residential quarters. To quantify the thermal consequences of density, building arrangement, and greenery, onsite design factors were established. The daytime and night time atmospheric UHI models that were subsequently created explain up to 77 and 90percent of UHI fluctuation, respectively. Based on their findings, the authors recommend various design methods to decrease the UHI effect. Increasing site vegetation cover through selective tree planting and altering building layout and mass to optimize shading during the day while facilitating site ventilation at night are two examples.

The air temperature in Hong Kong was monitored at seven locations over six months by Giridharan *et al.* (2007). They discovered that the sky-view factor, surface albedo, altitude, vegetation over one metre in height, average height to floor area ratio, and closeness to the sea are all important factors in reducing daytime and night time UHI. The influence of exceptional values on UHII is diluted when daytime and night time data are combined. As a result, the outputs of many models should not be used to create design solutions.

Alcoforado and Andrade (2006) studied the relationship between air temperature and land use and topography characteristics in Lisbon (Portugal). They showed that the night time canopy-layer UHII depends on sky-view factor, building height, and percentage of built-up area, but also to a significant extent on microclimatic geographic parameters such as altitude, elevation, and distance from the Tagus River. During the summer of 2010, Coseo and Larsen (2014), collected air temperature data in eight Chicago neighbourhoods. The percentage of impermeable surface and tree canopy inside an urban block explained 68percent of the UHI at night, according to the researchers. During heat events, the intensity of this link grew stronger, and these two variables explained 91percent of the UHII. Based on these findings, the authors advise that any impermeable surfaces on the ground be replaced with vegetation. They also advise that conventional roofs be replaced with green or cool (reflective) roofs to reduce UHI. These authors' procedures are used to construct reliable climatic maps within urban municipalities, but they are not complete enough, thus this work improves on them by using situ-measurement, climatic data from relevant agencies, and statistical methods.

2.9.2 The oke canyon model

To recreate the urban canyon effect, Oke (1981) constructed an urban model. His model was made using polystyrene, plywood, and polyethylene film and was hardware-built. A rural model was also built in the same fashion, but with more plywood sheets and fewer plywood blocks, to ensure that both the rural and urban versions used the same amount of construction material. To replicate varied street canyons, the model employed different height to width ratios (Levermore and Cheung, 2012). The model is used by the author to compare passive radioactive cooling rates between urban and rural areas at night after sunset. The model was left in a room at 20°C until equilibrium was attained, then transported into the cold chamber to see how quickly it cooled (Vardoulakis *et al.,* 2003).

As a validation, the simulation results were compared to actual weather data gathered from field observations. The difference in passive radioactive cooling effect after sunset between urban and rural circumstances was convincingly proven in a clear and quiet night. This paradigm did, however, have some drawbacks (Lee *et al.,* 2016). Finally, this model was unworkable. It was a model of hardware. Every time a certain street canyon is mimicked, a new model must be generated (Kovar-Panskus *et al.,* 2002; Kotopouleas *et al.,* 2021).

2.9.3 Driver-pressure-state-impact and response model

Land cover state, change, pressures, and potential management solutions all benefit from LULC data. The DPSIR model is used to evaluate cause-and-effect interactions between interacting components of social, economic, and environmental systems in the past, recent, and future. The DPSIR model explains how human activity (also known as a driving force) places pressure on land resources and, as a result, alters the environment's condition. People's health, ecosystems, and natural resources can all be affected by the state of the environment. These effects can prompt management techniques, policies, or activities that change the driving forces, pressures, and, ultimately, the status of the environment (European Environment Agency, 2003).

The European Environment Agency was the first to adopt the Model framework (Muller and Burkhard, 2007; Zacharias *et al.,* 2008). The DPSIR technique is a more advanced version of the OECD's Pressure State Response (PSR) paradigm (1993). The framework developed is used to organize data on the state of environmental resources and the interaction between human actions that may have an impact on environmental change.

The DPSIR is a useful model since it allows for simultaneous evaluation of socioeconomic and environmental variables (Walmsey, 2002; Elliot, 2002; Zacharias *et al.*, 2008). As cities grow, social and economic developments operate as drivers, putting pressure on the environment's resources and causing changes in its state, such as changes in the environment's physical, chemical, and biological characteristics (Pirrone *et al.*, 2005). Furthermore, these changes may have an impact on ecosystems, human health, and natural processes, which, in turn, may trigger social and political responses.

DPSIR was considered for this investigation because anthropogenic activities are the primary drivers of LULC changes in Abuja (Dalil *et al.*, 2017). As a result, the study was able to detect and analyse the driving forces and their pressures on the LULC/LST conditions, assess their state, identify the associated impacts, and finally propose the necessary responses in order to restore, protect, preserve, and ensure sustainable land uses in the FCT of Abuja. The use of the DPSIR model to checkmate the vegetated and non-vegetated LULCs of Abuja, considering their social and economic aspects. Figure 2.4 depicts the DPSIR model.

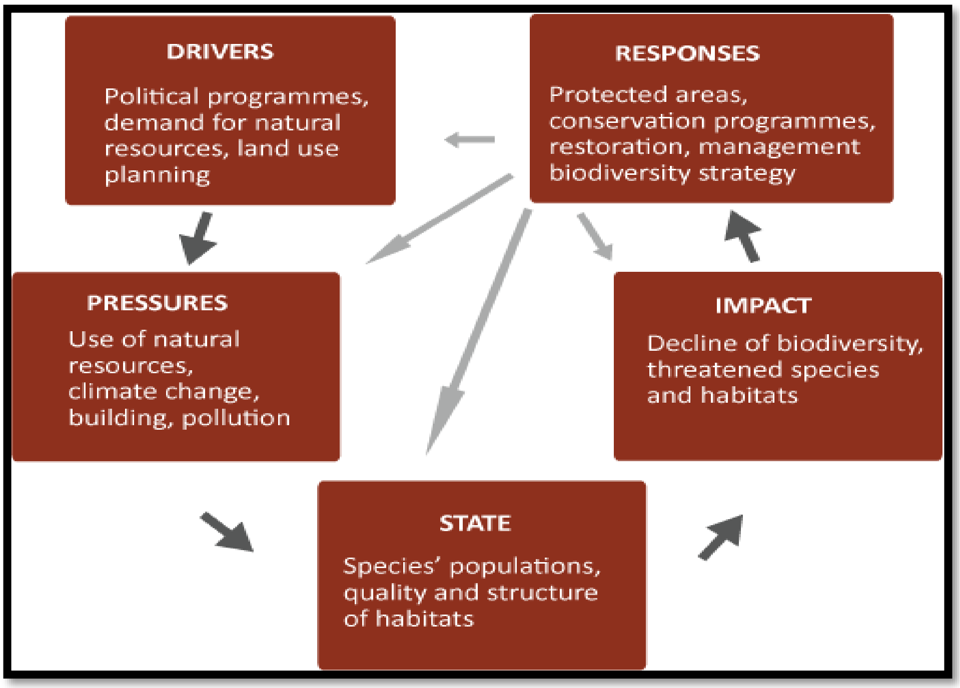


Figure 2.4: The DPSIR Model
Source: Pirrone *et al.* (2005)

2.6 Summary

The influence of urban heat islands on livelihood and the environment is described in the literature review (Prilandita, 2009). The growing urban temperature is dependent on various factors, according to the literature. The elements might be endogenous factors that originate from within the city and are manmade, as well as external factors that originate from nature. As cities grow, urban heat island factors will become more prevalent. Furthermore, it is a problem in a cycle: as human activities expand, so will energy consumption, built-up area, and automotive emissions (GHG emission). As a result, the urban heat island phenomenon is occurring, and this phenomenon can have an impact on energy consumption, thermal comfort, the environment, and health issues.

Some studies concentrate solely on one component to determine the UHI effect, such as population or building density (Lau, *et al.*, 2015; Das *et al.*, 2020). The other looked at the factors that influence UHI without going into detail about major aspects based on the features of the city (Okeil, 2010; Wong, 2011; Gago, 2013). They also primarily concentrated on providing measures to mitigate the effect rather than understanding the major elements that influence it (Gago, 2013; Santamouris, 2015).

This study tries to cover the knowledge gaps by analysing the significant factors that influence UHI based on city characteristics with using strategies instrument to reduce or address the effect. This research focus in determine the most significant factors as well as focus in response option that contained in local policy or institutions to address urban surface temperature.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Research Design

To answer the study's research questions, the study used an integrated geospatial and quantitative approach. The geospatial technique entails using satellite data to examine the influence of urban expansion on vegetal cover loss, vegetation cover fluctuation, and surface temperature in order to meet objectives 1, 2, and 3. The quantitative technique, on the other hand, entails the use of a standardized questionnaire to assess the thermal comfort of FCT inhabitants. Figure 3.1 depicts the methodological flow chart, while Table 3.1 depicts the research design.

Table 3.1: Research Design Table

S/N	Objectives	Type of Data	Data source	Method of data Analysis
1.	Assess the urban development and vegetal cover trend in FCT between 1980-2020	Landsat imageries of 1980, 1990, 2000, 2010 and 2019	USGS/NARSDA	Geo-spatial analysis
2.	Assess the variation in the Quality of vegetal cover in FCT	Satellite imageries	USGS	Geo-spatial analysis
3.	Determine the urban surface temperature variation based on land cover changes in FCT between 1980-2020	NDVI/NDBI analysis, image emissivity and radiometric correction	USGS/NARSDA	Geo-spatial analysis
4.	Examine the effect of built-up surface on temperature changes in FCT	Measurement of temperature, air velocity, humidity and field survey	Field survey	Geo-spatial and descriptive analysis
5.	Assess the thermal comfort of resident within the FCT	Questionnaire, kestrel weather meter, digital anemometer, micro	Field survey	Standards from ASHRAE/ISO, UTCI and descriptive analysis

	therma ter	thermome-	

Source: Author Computation, (2021)

Note: FCC= Federal Capital City; NDVI =Normalized Difference Vegetation Index; NDBI= Normalized Difference Built up Index; ASHRAE=American Society of Heating, Refrigerating, and Air Conditioning Engineers; UTCI= Universal Thermal Comfort Index

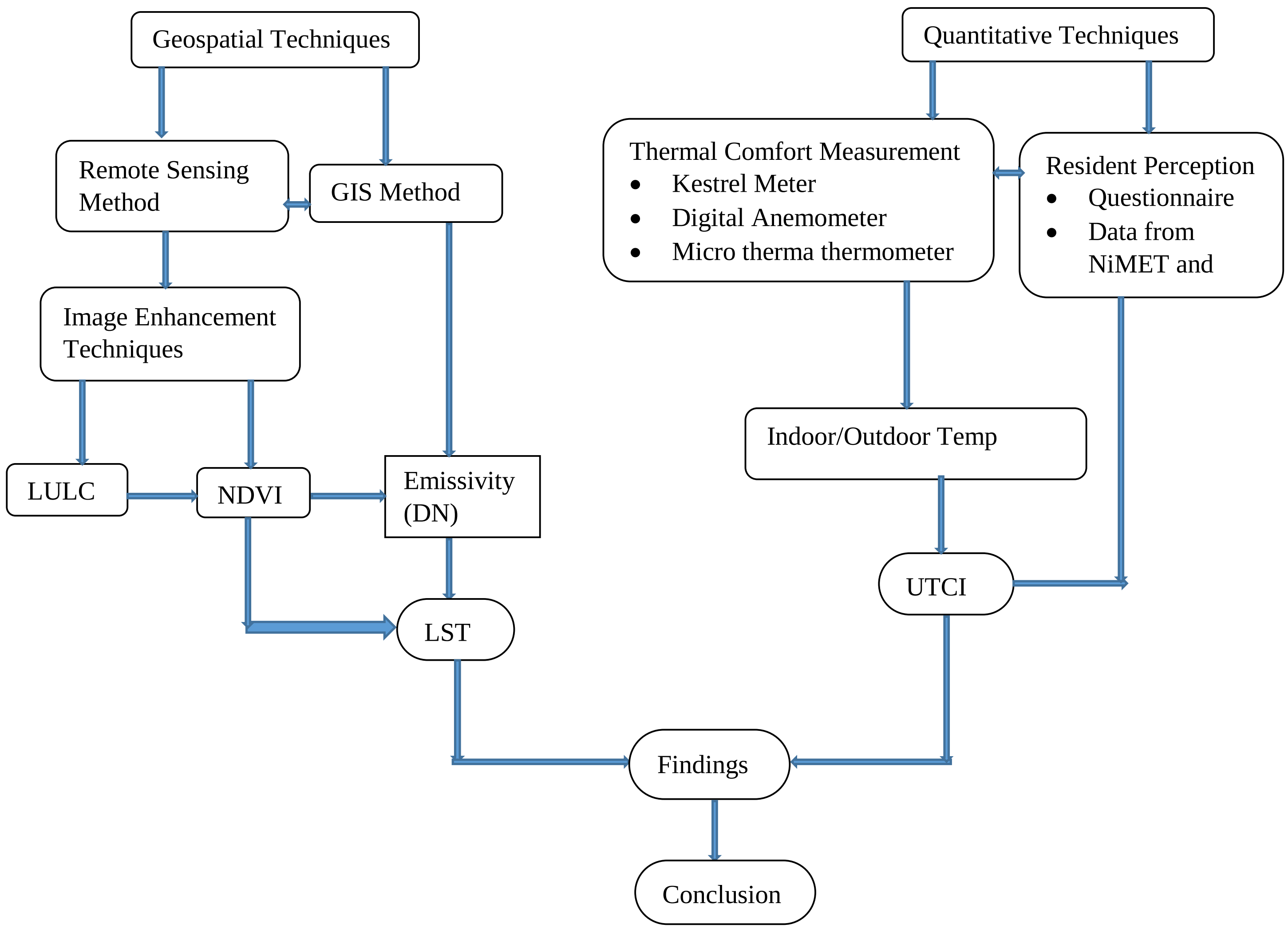


Figure 3.1: Flow Chart of the Research Methodological Process

Source: Author, 2021

3.2 Population and Sample Size of the Study Area

The number of LST hotspots found in the study area was used to determine the study's population. In FCC, Kubwa, and Gwagwalada, a total of 150 LST hotspots have been discovered during the field survey. Only 111 of the LST hotspot sites are located within built-up areas. As a result, the study population was chosen from hotspot areas within built-up areas. Because the number of hotspot locations within built-up areas is very low, all the places were chosen as sampling points for the study.

The population is the foundation for any research project; the inability to count the base population of a study area does not imply that the data and conclusions are reliable. The estimated number of households in the research area is referred to as the study population. According to FCDA (2009), the FCC's population was expected to be 412,215 in 2009, with Kubwa having a population of 110,523 in 2006 and Gwagwalada having a population of 157,770 in 2006. The population estimates were projected to 2018 using the projected formular, Pt = Po (l+r/100)11 and the national average growth rate of 3.6 percent. As a result, Table 3.2 shows the research area's base and projected population.

$$Pt = Po\ (l+r/100)^{n} \tag{3.1}$$

Where, Pt is the projected population.

Po =Base population

r = 3.6 (population growth rate)

N = Time interval of population projection

Table 3.2: Projected Population Distribution of Study Area

Area(s)	Base Population	**2018 Projected Population
FCC	412,215	566,710
Kubwa	110,523	168,955
Gwagwalada	157,770	241,180
Total	**680,508**	**976,845**

Source: Author Computation, 2021

3.2.1 Sample size of the study area

Taylor (2008) agreed that the appropriate sample size is based on several accuracy factors that must be considered: the size and attributes of the population; the desired margin of error, which determines the precision of the results; the desired confidence level, which ensures the sample would have the true population value within the range of the desired accuracy; the degree of variability, which measures how distributed within the population are the attributes being measured; and the degree of variability, which measures how distributed within the population are the attributes being measured. According to Liu *et al.* (2008), a bigger sample size results in a smaller margin of error. The Salant and Dillman (1997) sample size formula was used to establish the sample size that would be a good representative of the research population based on these arguments. The formula is as follows:$N_s=\frac{N_p\,(p)(1-p)}{(N_p-1)\left(\frac{B}{C}\right)^2+(p)(1-p)}$ (3.2)

$$N_s=\frac{976845*(0.5)*(1-0.5)}{(976845-1)\left(\frac{0.05}{1.96}\right)^2+(0.5)(1-0.5)}$$

$$\frac{244211.3}{635.95}=384$$

Where:
Ns= completed sample size required
Np= Sample population
P= proportion expected to answer in a certain way (50percent or 0.5 is most conservative)
B= acceptable level of sampling error (0.05 = $\pm$ 5percent; 0.03 = $\pm$ 3percent)
C= Z statistic associated with the confidence interval (1.645=90percent confidence level; 1.960=95percent confidence level; 2.576=99percent confidence level)

Using the Saliant and Dillman sample size calculation, the study's sample size was calculated to be 384 people. Based on the population of the study area (FCC, Kubwa, and Gwagwalada), the sample size was dispersed across the study area. The sample sizes for FCC, Kubwa, and Gwagwalada were 223 for FCC, 66 for Kubwa, and 95 for Gwagwalada. The sample size of the study area is shown in Table 3.3.

Table 3.3: Sample Size Distribution in the Study Area

Study Area	**Base Population**	**Sample Size**
FCC	412, 215	223
Kubwa	110,523	66
Gwagwalada	157, 770	95
Total	**680, 508**	**384**

Source: Author Analysis, 2021

3.3 Types and Source of Data Collection

The data employed in this study include mostly remotely sensed data, climate and population information, and data on residents' thermal comfort in Abuja's study region. The test sites were Kubwa and Gwagwalada urban areas of the FCT, while Abuja was utilized as the control site because it is the most urbanized within the study area.

3.3.1 Geospatial data sources

The study's principal data sources were remote sensing data (satellite imagery), which were used to investigate the association between Land Use/ Land Cover Changes (LULCC), Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Impervious Surface (IS).

The study used Landsat images from five distinct years obtained from the USGS portal. The images were double-checked to confirm that the same season was chosen for each of the five time periods: 1980, 1990, 2000, 2010, and 2020. Landsat 5 thematic (TM) mapper sensors, Landsat 7 enhanced thematic (TM+) mapper sensors, and Landsat 8 operational land imager sensors satellite remote sensing data (USGS, 2013). The quality, duration of the study, time of observation, frequency of observation, and availability of remote sensing data sources were all factors in the decision. Landsat TM imagery has been utilized in heat island research on LST and provides appropriate spatial resolution at 120m for investigation at a local (city-wide) and macro (large structure) level. Table 3.4 shows a summary of the image's information used in the study.

Table 3.4: Summary of Metadata used for the Study

	1990	**2000**	**2010**	**2019**
Landsat scene ID	LT418905419 90331XXX03	LT5189054200 0028XXX02	LC8189054201 0107LGN00	LC8189054201 8107LGN00
Acquisition date	1990/11/27	2000/01/28	2010/02/22	2019/04/30
Output format	Geotiff	Geotiff	Geotiff	Geotiff
Spacecraft ID	Landsat 5	Landsat 7	Landsat 8	Landsat 8
Sensor ID	TM	ETM+	ETM+	OLITIRS
Pathand Row	189, 54	189, 54	189, 54	189, 54
Resolution	30 metres	30metres	30metres	30metres

Source: USGS, (2019)

3.3.2 Data preparation and analysis

Image pre-processing procedures were carried out for the purposes of this research. Importing, layer stacking, and sub-setting of the image depending on the FCT boundary, geometric correction, radiometric correction, and removal of stripes, pan sharpening, and other image enhancing techniques are all part of the pre-processing process. Radiometric correction was used to eliminate air noise and make the sensor data more indicative of the ground truth circumstances. The image was also georeferenced using the FCT's boundaries. To preserve uniformity, the UTM WGS 86 (zone 32N) coordinate system was used for raster and vector data throughout the study when geo-referencing and re-projecting.

3.3.3 Image enhancement

Techniques for improving the visual difference between features in a scene are referred to as image enhancement (Billah and Rahman, 2004). Image augmentation is a technique for enhancing image data so that it can be shown or recorded more successfully for later visual interpretation. The basic goal of image enhancement is to make information in images more understandable for human viewers or to give better input for other automated image processing techniques.

3.3.4 Image classification

Image classification is the process of obtaining information classes from a multiband raster image or extracting information depending on the object's reflectance for a specific purpose, such as transforming image data into thematic data. Pixels are assembled to represent LU/LC classes in digital image classification systems. Supervised classification techniques were used in this study. To classify an image, the supervised classification approach leverages the spectral signature produced from training examples. Each year's supervised classification image contains pixel categorizations using a training area for each LU/LC class. The LULC pattern was mapped using Multispectral Bands from 1 to 5 and 7 for TM 1980, 1990, and ETM+ 2000, 2010, and OLI 2019 1 to 7 Bands of pre-processed images.

The classification technique employed was supervised classification, in which each terrain feature was classified using signatures that served as samples. The non-parametric rule's decision rule was parallel piped, and the parametric rule's decision rule was Maximum Likelihood. Maximum Likelihood Classification (MLC) was thought to be more precise than parallelepiped classification. Built-up areas, Open spaces, Waterbody, Rock outcrop, and Vegetation are the five classes that were employed in the study for picture classification. As indicated in Table 3.5, each year of study has the same number of classes and colour codes.

Table 3.5: Land Cover Classification Scheme of the Study Area

Land Cover Classes	**Descriptions**
Built Up Areas	Urban Land, Rural Land, Buildings, Residential Areas
Greens	Forest, Farmland, Trees, Flowers, Roadside Trees, Vegetation around Water bodies and Shrubs
Water Bodies	Sea, Rivers, Lakes, Ponds and Drainage System
Bare Land	Open Spaces, Un-vegetated land, Desert land, Bare Soil, Sand land and Marshy land
Rock Area	Rocks, Hills, Mountains and Sparse Scrub Vegetation

Source: Authors, 2021

3.3.5 Method of carrying out normalized difference vegetation index (NDVI)

Difference in terms of normalization was done through the algorithm in Erdas Imagine to calculate the vegetative and built-up indices. Bands (3, 4, and 5) were used in these analyses to achieve results. The NDVI demonstrates the healthiness of vegetation within the research area; for example, healthy vegetation includes enough water. The water index is just a substitute because its results show an increase in the presence of water within a plant cover. This analysis is included in the study to demonstrate the amount of vegetative cover in the study region (Gao *et al.,* 2012). The NDVI formula is shown. as:

$$NDVI = \frac{N1R-PAR}{NIR+PAR} \quad (3.3)$$

NDVI - Normalized Difference Vegetation Index

NIR- Near Infrared Band Imagery

PAR - Photosynthetic Active Radiation Band Imagery

NDVI = (Band 4- Band 3)/ (Band 4+ Band 3+ Band 5)

The reflectance of this selected band employed in computing the vegetative index in Erdas Imagine is given as (NIR-Red)/ (NIR+ Red), and the result of this study fundamentally provides a path to solving vegetation mapping challenges. The Built-up index was used as part of the analysis to show the size and extent of built-up regions within the study area. The NDBI is reliant on the NDVI analysis' output, so subtracting the recorded NDVI map from the NDBI image yields positive values for built-up and barren soils, as well as null and negative values for the other land covers (0-254). (NASA, 2010; Gao *et el.*, 2012). The equation for the analysis is given as.

$$NDBI = \frac{MIR - PAR}{MIR + PAR} \tag{3.4}$$

NDBT - Normalized Difference Built Index

MIR- Mid Infrared Band Imagery

PAR - Photosynthetic Active Radiation Band Imagery

3.3.6 Land surface temperature (LST) retrieval method

The analysis of land surface temperature necessitates a spatiotemporal model with a Model Maker tool designed to retrieve Land Surface Temperature (LST) and characterize variations in urban heat island as well as urban growth. The authors initially estimated Spectral Radiance, Brightness Temperature, NDVI, and Emissivity from TM and ETM+ imageries, which were then utilized to construct LST using an author-designed technique.

The normalized statistical approach is used to classify the LST, and normalized heat images are computed at different periods. As a result, an urban heat conversion matrix can be used to illustrate the changes in urban heat on the map in a simple and direct manner. This processing is done in ArcGIS, with each stage of the process having its own formula. The following stages is used in retrieving land surface temperature from Landsat imagery:

Stage 1: Conversion of Digital Numbers (DN) to Top of Atmosphere (TOA) Radiance

The radiance rescaling factor contained in the metadata file of the collected imagery can be used to convert OLI and TIRS band data to TOA spatial radiance in Operational Landsat Imager (OLI) and TIRS band data (Zhou and Wang, 2011).

$$L\lambda = \frac{\text{Lmax-Lmin (DN-QCALmin) + Lmin}}{\text{QCALmax – QCALmin}} \tag{3.5}$$

Where $L\lambda$ = TOA Spectral Radiance (watts/cm2 *srad*μm)

ML = Band Specific multiplicative rescaling factor from the metadata file (Radiance_Multi_...)

Al - Band Specific additive rescaling factor from the metadata file (Radiance_add_...)

QCAL= Quantized and Calibrated standard product

Note: that the Pixel values are the DNs, At-Satellite Temperature = Temperature of the satellite at the time the image was taken.

The At-Satellite Temperature would give result in degree Kelvin were converted to degree Celsius by introducing a divisor 272.15.

Stage 2: Conversion of Radiance to At - Satellite Brightness Temperature

TIRS band can be converted from spectral radiance to brightness temperature using the thermal constants Ki and K2 for each band provided in the metadata file (Zhou *et al.*, 2014):

$$T = \frac{K_2}{1n\left(\frac{K_1}{L_\lambda}+1\right)} \tag{3.6}$$

Where T = At - Satellite Brightness Temperature (in Kelvin)

$L\lambda$ = TOA Spectral Radiance (watts/cm2 *srad*/μm)

K_1 = Band Specific Thermal Conversion Constant from the metadata file (K_1 constant_Band_x) where x is the band number.

K_2 = Band Specific Thermal Conversion Constant from the metadata file (K_1 constant_Band_x).

Stage 3: Deriving Land Surface Emissivity (LSE)

The computed Normalized Difference Vegetative Index Raster previously processed for the imageries utilized in the project is used to calculate the Land Surface emissivity. The NDVT raster for the specific year would be utilized to compute the LSE for the different years of research where the surface temperature is determined (Zhou *et al.*, 2014).

$$e = 0.004 \text{ PV} + 0.986 = \text{Constant} \tag{3.7}$$

$$PV = (NDVI - NDVI_{min}/NDVI_{max} - NDVI_{min})^2 \tag{3.8}$$

Where: PV = Proportion of Vegetation

NDV1: Normalized Difference Vegetative Index

Stage 4: Deriving Land Surface Temperature (LST)

$$T = BT / 1 + \omega \times (BT / P) \times \ln(e) \tag{3.9}$$

BT = At - Satellite Brightness Temperature

ω = wavelength of emitted radiance (11.5μm)

$P = h * c/s\ (1.438 * 10^{-2})$

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)

P = 14380 = Constant

3.4 Quantitative Data used for the Study.

Direct observation through personal visits was conducted in all four phases of the FCC, Kubwa, and Gwagwalada to assess land-use changes and temperature differences. Atmospheric temperature was also measured physically at numerous locations throughout the research area. Structured questionnaires were distributed to residents of the FCC, Kubwa, Gwagwalada to ascertain their mitigation measures adopted in coping with extreme heat weather in the study area. GPS was employed to gather the geographical coordinates of the sample sites in the study area during a field survey. Atmospheric temperature data, humidity was gotten from NiMet, and land use map of the FCC, was gotten from Federal Capital Development Authority (FCDA).

3.4.1 Instrumentation for data collection

Primary data on the issue of land use and land cover changes, temperature variation/ records within the study area was collected using quantitative research instruments such as questionnaires from various ministries, agencies and departments, and units of government establishments responsible for land administration and regulation, as well as data from city residents. The questionnaires used to collect these main data were tailored to address the research fifth objectives. This structure was created to ensure that the inquiries and questions answered were relevant to addressed the research's specific goals.

3.5 Method of Climate Data Collection

The Federal Capital City, Kubwa, and Gwagwalada served as the study test sites. Meteorological stations and satellite image-based sensing techniques were used to collect data on environmental characteristics. For the time series analysis, the climatic data used in this study were monthly and yearly values of minimum and maximum temperature recorded data, which were sorted in decades. The data was gathered from the Nigerian Meteorological Agency (NiMet), Abuja (Head Office at the airport and sub-offices in Maitama, Maraba, Kwali, and Kuje), and the Nigeria Bureau of Statistics (NBS), and covers the years 1980 to 2020. The monthly average of daily environmental characteristics such as temperature, humidity, wind velocity, and others are essential indicators of the behaviour of extremes that are typically responsible for thermal impacts (Zhang *et al.*, 2013).

3.5.1 Measurement of atmospheric microclimatic variables

Physical measurements of microclimatic parameters that influence the human energy balance were carried out for the purpose of this study to determine various environmental factors that affect the thermal comfort of the study area's residents, including air temperature, radiant temperature, air velocity, and humidity. The parameters were measured using a handheld Extend Psychrometer RH300 with a humidity range of 10-90 percentand a 3 percentprecision, as well as internal and outdoor temperatures of 4 to 158 degrees

Fahrenheit with a 0.1-degree Celsius accuracy (Plate I).

Plate I: Extench Psychrometer
Source**:** Author, 2021

A digital anemometer (AVM 07) that checks the air condition, heating system, wind speed, and temperature, with humidity of 80°, air temperature of 0-60°C with accuracy of 0.5°C/0.9°F, and wave height of 0-14°C with accuracy of 0.1°C, with humidity of 80°, air temperature of 0-60°C with accuracy of 0.5°C/0.9°F, and wave height of 0-14°C with accuracy of 0.1°C (Plate II).

Plate II: Digital Anemometer

Source: Author, 2021

Micro Therma thermometer was used for the study; the instrument is built with micro-processor for automatic re-calibration. The instrument measures temperature rate with the range between -270 - !768°C having a resolution of 0. l°C with accuracy of ±0.2°C and 1000 hours' battery life (Plate III).

Plate III: Micro therma (Thermometer)
Source: Author, 2021

A weather meter (Kestrel 3500 series) with a Global Positioning System (GPS) of 2.0 meter was also utilized to capture coordinates of the sites at 1.1m above ground level. For the measurement of changes in daily atmospheric conditions, the instrument is calibrated with the following specifications: temperature measurement range -29°C to 70°C with an accuracy of 0.5°C, relative humidity measurement ranges from 5percent - 95 percent with an accuracy of 3.0, and wind speed measurement range 0.6-0.0 m/s with an accuracy of 0.1. (Morning, Mid-day and Evening). The thermal heat index within the study area were compared using the Physiological Equivalent Temperature (PET), as well as the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and ISO Thermal Sensation Scales (Tables 3.6 and 3.7).

Table 3.6: Physiological Equivalent Temperature (PET) in Nigeria

PET Range Nigeria	Thermal for Sensation	Grade of physiological stress	PET range for Western/Central Europe
≤11	Very Cold	Extreme Cold Stress	≤4
>11≤15	Cold	Strong Cold Stress	4≤8
>15≤19	Cold	Moderate Cold Stress	8≤13
>19≤23	Slightly Cold	Slightly Cold Stress	13≤18
>23≤27	Neutral	No Thermal Stress	18≤23
>27≤31	Slightly Warm	Slight Heat Stress	23 ≤2 9
>31≤36	Warm	Moderate Heat Stress	29≤35
>36≤42	Hot	Strong Heat Stress	35≤41
>42	Very Hot	Extreme Heat Stress	>41

Source: Omonijo and Matzarakis, (2011)

Table 3.7: ASHRAE 55 and ISO Thermal Sensation Scale

S/No	Range	Thermal sensation
1	±3	Hot
2	±2	Warm
3	+1	Slightly Warm
4	0	Neutral
5	-1	Slightly cold
6	-2	Cool
7	-3	Cold

Source: ASHRAE, (2013) and ISO, (1994)

Table 3.8: UTCI Equivalent temperature category

UTCI (°C) range	Stress Category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal stress

Source: Błażejczyk *et al.* (2010)

3.5 Data Presentation

Charts, illustrations, tables, and figures were used to present the findings. Table 3.9 shows the Geographical Information System (GIS) and remote sensing tools that were utilized to improve the study's results.

Table 3.9: Summary of data analysis used for the study

Software/Version	Description	Analysis
Erdas 14	This software would be used for all image processing.	Layer stacking, composite bands formation, classification, index analysis, Land Surface Temperature analysis, change detection analysis and prediction analysis
ArcGIS 10.4.1	Buffer analysis showing the UHI and urban cold island of built-up areas and map embellishment process	The analysis will be carried out on the digitized map of the five images to show the areas that have high LST rate in the city over the years
Microsoft Excel 2016/SPSS 23.0	Statistical representation of classified features	Charts for statistical output of some image analysis would be carried out in this software for better comprehension.

Sources: Author, 2021

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

This section of the research presents the data analysis and examines the findings obtained during the research. The results and statistics produced from classified satellite images of the study area (Federal Capital City, Kubwa, and Gwagwalada) from 1980 to 2020 show distinct changes in the study area's land use/ land cover (LULC). The extent to which urban development, as measured by changes in LULC, and the effect of surface temperature within the study area are examined.

4.1 Land Use and Land Cover Trend in Federal Capital Territory (1980-2020)

The Erdas imagine 14 was used to assess the magnitude of LULC in the study region for four (4) spatial-temporal periods of 1980-1990, 1990-2000, 2000-2010, and 2010-2020, based on four (4) important determinants such as (a) built-up area (b) bare ground (c) vegetation, and (d) water body.

4.1.1 Magnitude of land use/land cover change in FCT (1980-1990)

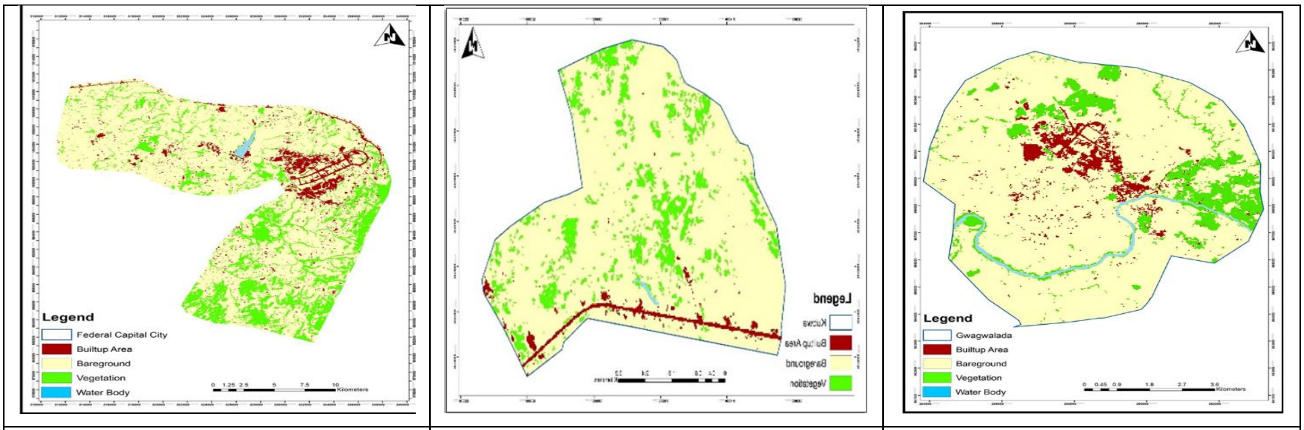
The results of the LULC analysis for the study area in 1980 are shown in Table 4.1. For the study region, four major groups of LULC were considered: built-up area, bare ground, vegetation, and water body. The study area built-up area includes residential, commercial, and industrial land uses, as well as transportation infrastructure. The major land use in FCC in 1980 was bare surface, which spanned 32306.42 hectares (74.6 percent) of the total land area, built up covers 2602.75 hectares (6.0 percent), vegetation covers 8293.96 hectares (19.2 percent), and water bodies cover 102.72 hectares (0.2 percent).

Table 4.1: LULC of the study area in 1980

Land uses	FCC		KUBWA		GWAGWALADA	
	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)
Built-up	2602.75	6.0	118.17	2.8	348.64	5.0
Bare ground	32306.42	74.6	3497.04	84.2	5720.91	82.5
Vegetation	8293.96	19.2	538.20	13.0	838.36	12.1
Water body	102.72	0.2	-	-	22.9	0.3
Total	**43305.84**	**100.0**	**4153.41**	**100.0**	**6930.81**	**100.0**

Source: Author Analysis, 2021

Also, in Kubwa, built-up area occupying 118.17 hectares (2.8 percent), bare ground occupies 3497.04 hectares (84.2 percent), and vegetation covers 538.2 hectares (13.0 percent). Similarly, in Gwagwalada area with land coverage of 6930.81 hectares, the built-up area covers 348.64 hectares (5.0 percent), bare surfaces cover 5720.91 hectares (82.5 percent), vegetation occupies 838.36 hectares (12.1 percent), and water body covers 22.9 hectares (0.3 percent) respectively. The LULC's map is presented in Figure 4.1.



FCC	KUBWA	GWAGWALADA

Figure 4.1: Land Use/Land Cover Map of FCT in 1980
Source: Author Analysis, 2021

4.1.1.1 *Land use/land cover of 1990 in the study area*

Table 4.2 reveals that the bare surface for the year 1990 in the Federal Capital City covers a total of 35506.26 hectares, the built-up area covers 4458.96 hectares, which accounts for about 6.0 percent of the total land area, in 1980 which has increased to 10.3 percent in 1990 that almost amount to 90 percent increment. However, water body covers 102.15 hectares, vegetation has drastically reduced from 19.2 percent from 1980 to 7.2 percent just with the space of ten years, this is due to the fact the city is undergoing tremendous capital project within this period.

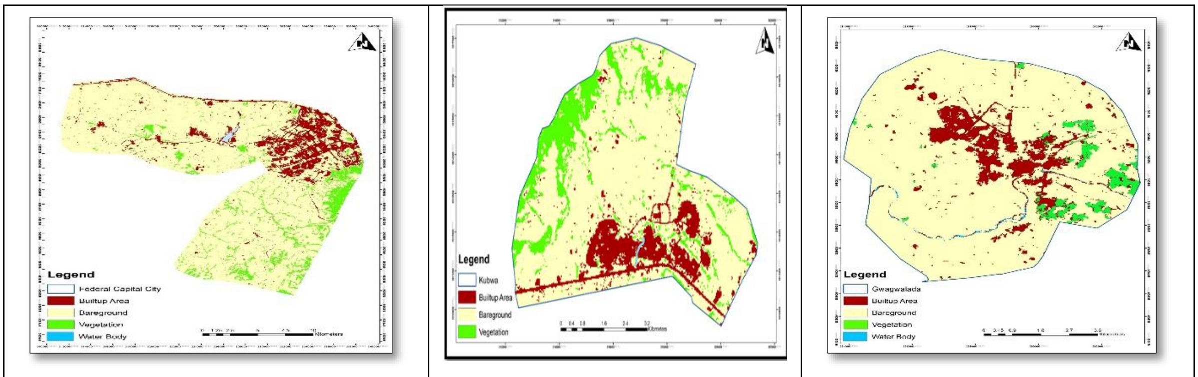
It was observed that the bare ground surface gained some slight increment from 74.6 percent to 82.0 percent between 1980 and 1990 due to clearing of land for development and engagement of agricultural production by the natives and the artisans within this period. Therefore, the analysis carried out in Table 4.2 reveals that in 1990, built up areas for Kubwa covers 614.5 hectares, bare grounds cover 3028.5 hectares, and vegetation covers 510.41 hectares. Anthropogenic activities such as road construction, bridge construction, industrial location, deforestation, and population growth contributed to the increase and change of bare surface. This is in line with Mundia and Aniya's (2006) findings, which show that economic growth and proximity to transportation lines were the two most important factors in fostering urban expansion inside a city.

Table 4.2: LULC of the study area in 1990

	FCC		**KUBWA**		**GWAGWALADA**	
Land uses	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)
Built-up	4458.96	10.3	614.5	14.8	786.06	11.3
Bare ground	35506.26	82.0	3028.5	72.9	5875.2	84.8
Vegetation	3238.47	7.5	510.41	12.3	246.78	3.6
Water body	102.15	0.2	-	-	22.77	0.3
Total	43305.84	100.0	4153.41	100.0	6930.81	100.0

Source: Author Analysis, 2021

Also, in Gwagwalada, there were slight increase in development, built-up account for 100 percent increase from 1980 to 1990 because the capital city is undergoing construction, most of the civil servants and businessmen resides in the area in carrying out the daily activities. The bare surface noticed some slight increase from 5720.91 to 5875.2 hectares, vegetated areas suffer a decline from 838.36 to 46.78 hectares, while water body covers 22.77 hectares. This study supports the findings of Ishaya *et al.* (2008), rise in urban growth is attributed to vegetal cover loss and population influx. The LULC map for the year 1990 for FCC, Kubwa, and Gwagwalada is shown in Figure 4.2.



FCC	KUBWA	GWAGWALADA

Figure 4.2: Land Use/Land Cover Map of FCT in 1990
Source: Author Analysis, 2021

4.1.1.2 *Rate of changes in land uses in FCT between 1980-1990*

The result as summarised in Table 4.3, shows that in FCC built up has increased by 1856.46Ha (4.3 percent); bare surface increase by 1199.84Ha (7.4 percent), vegetal cover reduces by -5055.49Ha (-12 percent). Also, in Kubwa, built up increased by 408.33Ha (9.9percent), bare surface decreases by -468.54 Ha (-11.3 percent), and vegetal cover gain slightly increase by 60.21Ha (1.4 percent) due to 500 hectares of land for farming scheme and 350 hectares for secondary forestry by IITA. While, built up area in Gwagwalada increase by 437.42 Ha (6.3 percent), bare ground by 154.29Ha (2.3 percent), and decrease in vegetal cover by -591.58Ha (-85 percent). This demonstrates that a variety of economic, cultural, political, and biophysical factors influence LULC alterations (Lambin *et al.,* 2001 and De Groot *et al.,* 2012).

Table 4.3: Rate of Change in FCT between 1980-1990

	FCC		KUBWA		GWAGWALADA	
Land uses	Area Coverage (ha)	percentage of change (%)	Area Coverage (ha)	percentage of change (%)	Area Coverage (ha)	percentage of change (%)
Built-up	1856.46	4.3	408.33	9.9	437.42	6.3
Bare ground	1199.84	7.4	468.54	-11.3	154.29	2.3
Vegetation	-5055.49	-12	60.21	1.4	-591.58	-8.5
Water body	102.15	0.2	-	-	22.77	0.3
Total	43305.84	100.0	4153.41	100.0	6930.81	100.0

Source: Author Analysis, 2021

4.1.2 Magnitude of land use/land cover changes between 1990-2000

4.1.2.1 *Land use/land cover of FCT in 2000*

Table 4.4, shows that in the year 2000 the bare surface of FCC has reduced from 3028.5 hectares to 33659.73 hectares which is about 6 percent decrease due to massive development going on within the capital city. Built-up increased by 5percent from 4458.96 to 6697.98 hectares, vegetation further decreased to 2853.09 hectares, and water body cover 95.04 hectares.

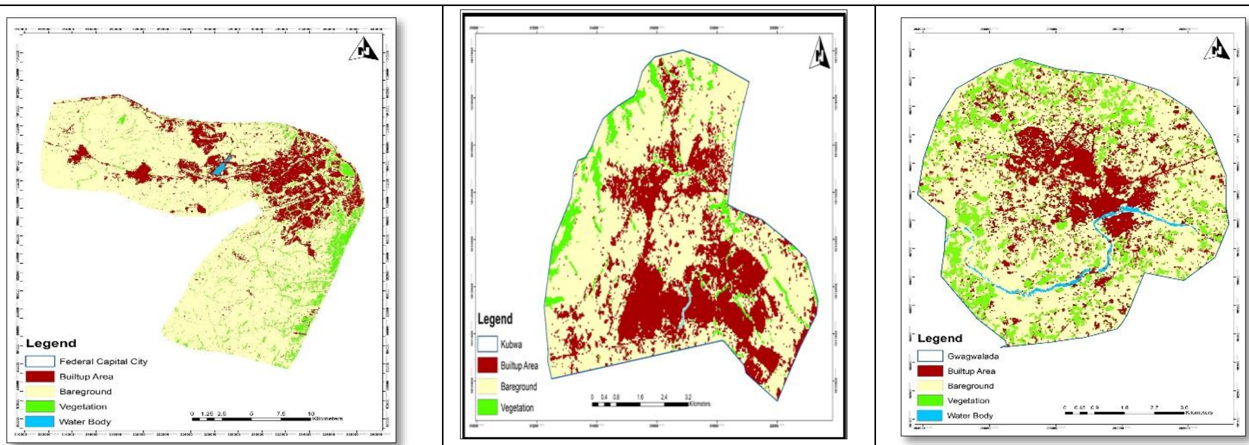
Table 4.4: LULC of the study area in 2000

	FCC		KUBWA		GWAGWALADA	
Landuses	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)
Built-up	6697.98	15.5	1702.92	41.0	1007.06	14.5
Bareground	33659.73	77.7	1979.64	47.7	5685.2	82.0
Vegetation	2853.09	6.6	470.85	11.0	213.81	3.1
Water body	95.04	0.2	-	-	23.9	0.3
Total	43305.84	100.0	4153.41	100.0	6930.81	100.0

Source: Author Analysis, 2021

Also, in the year 2000 shown in (Table 4.4), revealed that built-up area in Kubwa occupied 1702.92 hectares doubled its size by over 200 percent increase due to massive demolition exercise that takes place within the FCC led by FCTA, bare ground suffered a reduction in size due to massive population explosions in the area from 3028.5 to 1979.64 hectares and vegetation covers loss of (1.3 percent) decrease in size.

Also, in Gwagwalada bare ground decreased its size to 5685.2 hectares, built-up increased by about 3 percent due to displacement of people within the capital city. Vegetation losses its cover from 246.78 to 213.81 hectares, and water body covers 23.9 hectares. Urbanization and demographic trends are key components of worldwide land transformation, according to Pickett *et al.* (2011). Figures 4.3 shows the LULC map of the three areas under study.



FCC	KUBWA	GWAGWALADA

Figure 4.3: Land Use/Land Cover Map of FCT in 2000
Author Analysis, 2021

4.1.3 Magnitude of change in FCT between 2000-2010

4.1.3.1 *Land use/land cover of the study area in 2010*

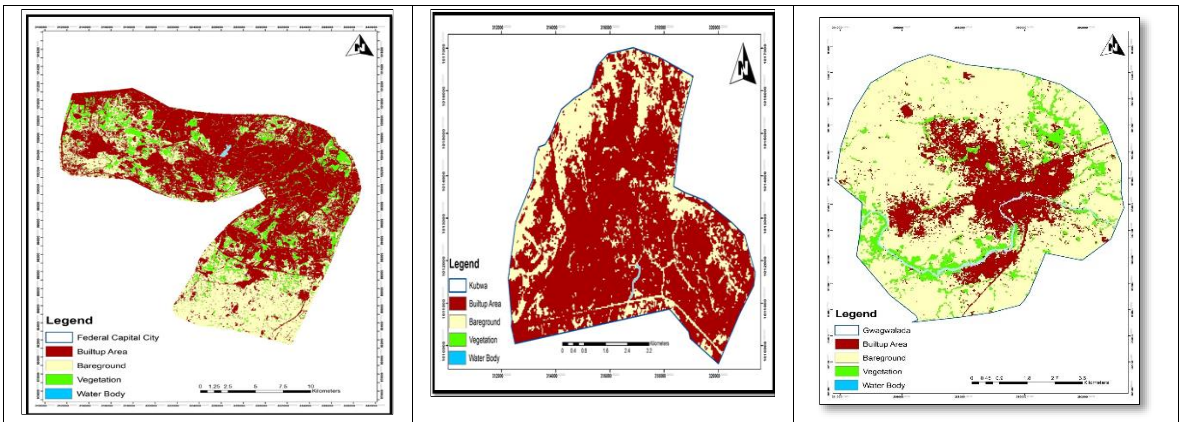
Result presented in Table 4.5 reveals that in the year 2010, the FCC witnessed massive development with movement of agencies headquarters from Lagos to Abuja, and established other government agencies due to change of power from military to democratic leadership. Therefore, the bare surface of the FCC decreased to 20458.83 hectares, built-up area amounted to about 180 percent increase from 6697.98 to 20226.61 hectares, because of the emergence of settlements like Chika, Alliete, Galadimawa, Pyakassa, Iddo, Gosa, Angwan Cement, Idu-Karmo and Dape while vegetation drastically declines from 2853.09 hectares to 2523 hectares due rapid urbanization taking place within the city and water body occupies 97.4 hectares.

Table 4.5: LULC of the study area in 2010

	FCC		**KUBWA**		**GWAGWALADA**	
Landuses	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)
Built-up	20226.61	46.7	2523	60.7	1889.9	27.3
Bareground	20458.83	47.2	1536.24	37.0	4762.8	68.7
Vegetation	2523	5.8	94.17	2.3	184.5	2.7
Water body	97.4	0.2	-	-	93.6	1.4
Total	43305.84	100.0	4153.41	100.0	6930.8	100.0

Source: Author Analysis, 2021

Similarly, the study reveals that Kubwa in 2010, bare surface decreased to 1536.24 hectares decreases due to the emergence of mining activities, construction of Kubwa express highway and movement of the IITA farming scheme to Abeokuta while the built-up area covers 2523 hectares. This implies that built-up increased from 1402.92 hectares in 2000 which accounted for 33.8 percent to 2523 hectares (60.7 percent) in 2010, due to massive population influx into the area and high demand for housing. Also, Table 4.5 reveals that bare surface decreased by 13 percent which is now left by 4762.8 hectares in Gwagwalada, the built-up increased by 13 percent also, to about 1889.9 hectares due to high construction of housing to meet the needs of the people. Vegetation covers decline from 213.81 to 184.5 hectares, and water body covers 93.6 hectares. Figure 4.4 shows the LULC changes of the study area.



FCC	KUBWA	GWAGWALADA

Figure 4.4: Land Use/Land Cover Map of FCT in 2010
Source: Author Analysis, 2021

4.1.4 Magnitude of change in FCT between 2010-2020

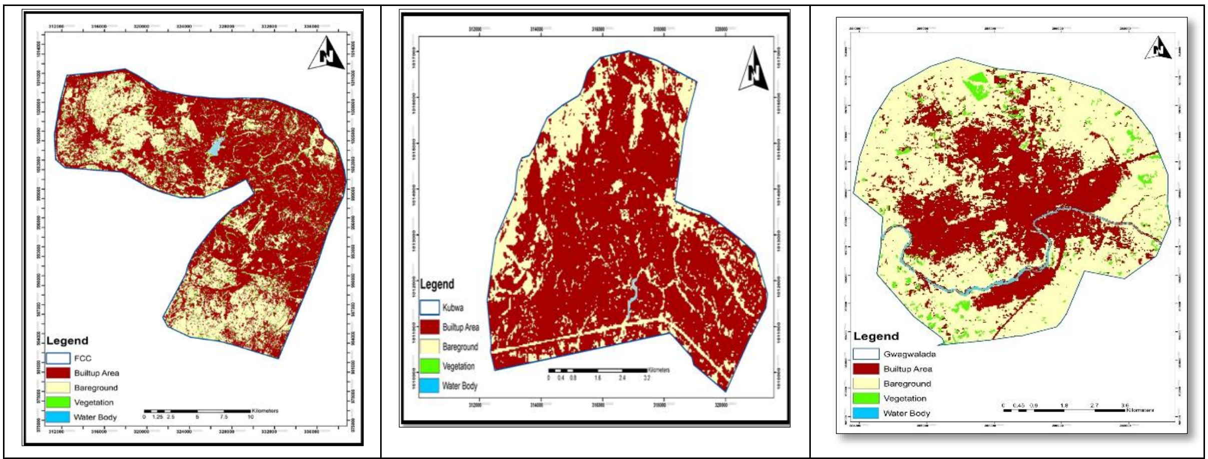
4.1.4.1 *Land use/land cover of the study area in 2020*

Table 4.6 reveals that in FCC, bare surface reduces its covers by 11 percent between 2010 to 2020 while built-up area increased (due to continuous development within the city) to 25158.325 hectares (11 percent) and vegetation reduce its cover to 2431 hectares (-0.2 percent). Also, in Kubwa the built-up is increased from 2523 hectares in 2010 to 3102.93 hectares in 2020, bare ground reduced from 1536.24 hectares in 2010 to 1019.09 hectares in 2020. The study also depicts that Gwagwalada built up has increased tremendously from 1889.9 to 2494.9 hectares from 2010 to 2020 due to rapid urbanization and the presence of the university and small cottage industries. While, vegetation reduced from 184.5 to 157.58 hectares. The land cover changes for the year 2020 is shown in Figure 4.5.

Table 4.6: LULC of the study area in 2020

	FCC		KUBWA		GWAGWALADA	
Landuses	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)
Built-up	25158.325	58.1	3102.93	74.7	2494.9	36.0
Bare ground	15620.215	36.1	1019.09	24.5	4193.01	60.5
Vegetation	2431	5.6	31.39	0.8	157.58	2.3
Water body	96.3	0.2	-	-	85.32	1.2
Total	43305.84	100	4153.41	100.0	6930.81	100.0

Source: Author Analysis, 2021



FCC	KUBWA	GWAGWALADA

Figure 4.5: Land Use/Land Cover Map of FCT in 2020
Source: Author Analysis, 2021

4.1.5 Overall land use/land cover changes in FCT between 1980-2020

Table 4.7 depicts the overall rate of change in built-up areas inside the FCC from 1980 to 2020, revealing a large rise in built-up areas (52.1 percent) in FCC due to urban expansion over that time. Due to population influx and a shift in the national capital from Lagos to Abuja, the built-up area in 1990 was double that of 1980, indicating a major expansion happened in a short period of time (10 years). There was a 71 percent increase in 1990, 50 percent in 2000, and the year 2010 recorded the highest rate in built-up surface with a staggering rate of 205 percent. While, 2020 recorded a slow development rate of 23percent due to high development control measure put in place by FCTA and the outbreak of coronavirus globally. This corroborate with the findings of Herold *et al.* (2003); Lambin *et al.* (2003) and Yu *et al.* (2017) which stated that population increase could be an indispensable factor that causes urban expansion. Similarly, Kubwa being the satellite town developed by the FCTA administration to carter for the housing need of the people due to the infrastructural development that was happening in the FCC then recorded a tremendous development in the year 1990 with a rate of 346 percent and a slight decrease in the year 2000 with 166 percent and 80 percent in 2010 and the year 2020 recorded an average of 23 percent.

Also, Gwagwalada urban area experienced a high turn of development in the year 1990 with a growth rate of 124 percent and 28 percent in 2000. The town also, witnessed another exponential growth again in 2010 by 88 percent and 32 percent in 2020. Population pressure is clearly one of the key drivers of land use and land cover changes, as evidenced by the destruction of forest and vegetation cover for the purposes of urban expansion and everyday necessities, according to the study. This is consistent with the findings of Zeleke and Hurni (2001), Amsalu *et al*. (2007), and Haregeweyn *et al*. (2012), who found that population growth combined with migration from rural to urban regions results in urban expansion at the expense of vegetative cover.

This sporadic urban growth was speculatively caused by the rising price of land closer to the city centre because all land within the city is increasingly expensive compared to areas outside of the ring road (Toffin, 2010). The growth of industries at the margins of the city limits has also contributed to this growth (Thapa and Murayama, 2009). With the industrial growth, many residents who traditionally would have looked for work in the heart of Abuja now could work and live on the outskirts of the city.

Table 4.7: Overall Rate of change in FCT between 1980-2020

	FCC		KUBWA		GWAGWALADA	
	1980-2020		1980-2020		1980-2020	
Land uses	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)	Area Coverage (ha)	(%)
Built-up	22555.575	52.1	2984.76	71.9	2146.26	31.0
bare ground	-16686.205	-38.5	-2446.56	-58.9	-1527.9	-22.0
Vegetation	-5862.96	-13.6	-	-	-680.78	-9.8
Water body	96.3	0.2	-	-	85.32	1.2
Total	43305.84	100	4153.41	100.0	6930.81	100.0

Source: Author Analysis, 2021

Also, the study revealed that the bare surface within the FCC in 1980 is 32349.42 hectares and reduced with an annual rate of change of 10 percent in 1990, it further decreased from 35506.26 to 33659.73 hectares by (-5 percent) in the year 2000. While, it witnessed a very sharp decrease within a 10year gap (2000 and 2010) from 33659.73 to 20458.83 hectares (-39 percent) and reduces to -24 percent in the year 2020 (see Figure 4.7). This could be due to anthropogenic activity such as road development, bridge construction, deforestation, and population growth.

Figure 4.6 shows that Kubwa also witnessed an annual reduction of its bare surface by -13 percent in the year 1990. Also, due to migration, construction and mining activities the town experienced a drastic decrease in its bare surface from 3028.5 to 1979.6 hectares accounting to -35 percent decrease and slightly reduced to -18 percent in the year 2000 and further decrease by -36 percent in the year 2020. This is in line with Mundia and

Aniya (2006), findings, which revealed that economic growth and proximity to transportation lines were the two most important factors in fostering urban expansion inside a city. Also, in the Gwagwalada area (Figure 4.7), there is a progressive decrease in the bare surface due to demands for land for housing and other construction purposes. It is seen that between 1980 and 1990, the bare surface accounted for 2 percent and slightly reduced by -3 percent in the year 2000 and drastically decreased to -16 percent in 2010 and -125 percent in the year 2020. This is due to the increment in infrastructure development within the town which played a major role in influencing decrease in bare surfaces.

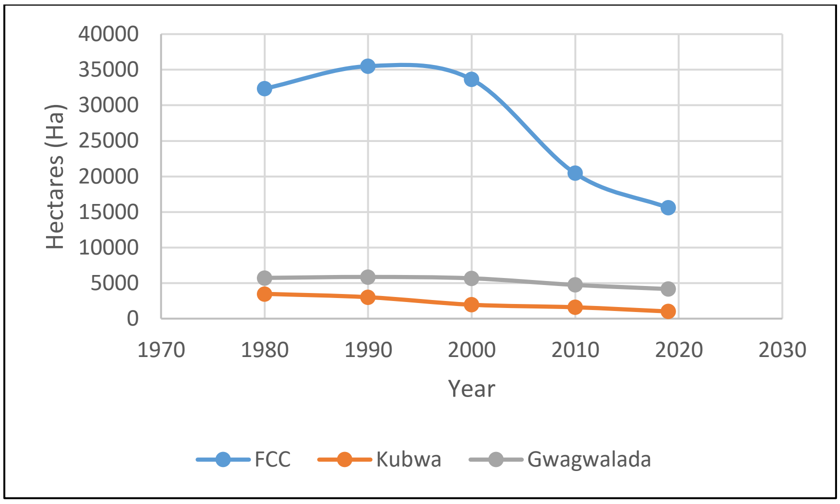


Figure 4.6: Rate of change of bare ground in the study area
Source: Author Analysis, 2021

According to the analysis given in Table 4.7, vegetal cover had a total area coverage of 8293.6 ha (19.2 percent) of the study area in 1980, and later in 1990 and 2020, it shows a steady drop from 3238.47 ha (7.5 percent) to 2431 ha (5.8 percent) in FCC. From 1990 to 2000, the land cover decreased by (-5105.48ha to -12 ha), with an annual decrease rate of -61 percent in 1990 to -12 percent in 2000. Similarly, the percentage change in this land cover category in the second period (2000-2020) followed a similar pattern, decreasing from (-12 to -4 per year) in the research area to (-385.38ha to -92 ha). This dramatic declined in forest cover could be best linked, to the expansion of settlement, forest fire, population growth, illegal logging, charcoal, and fuel wood extraction.

Also, in Kubwa there is a slight decline in the vegetal cover between 1980 to 1990 and further decrease from 60.21 ha in 1990 at (11 percent) to 172.44 ha (29 percent) in the year 2000. And the year 2010, there was 94.17 hectares vegetal cover left in the study area. Gwagwalada township saw a similar decrease in vegetal cover from 838.26 ha in 1980 to 246.78 ha in 1990, with a magnitude change of -591.48 ha and an annual rate of change of (-71 percent). The trend continues as it saw another heavy vegetal loss in the year 2000, with an annual rate of change in vegetal cover of (-13 percent), and a decrease from -29.31 ha in 2010 to -26.92 ha in 2020 which account for an annual change in vegetal cover of -14 to -15 percent respectively.

4.2 Variation in the Quantity of Vegetal Cover Loss in FCT

4.2.1 Change in vegetal cover loss in FCT

Table 4.8 reveals that in FCC the vegetal cover was 8293.96 Ha in 1980. The rate of change for vegetal cover decreased by 61 percent in 1990, 12 percent in 2000, 2010 and 4 percent in 2020. In Kubwa, the vegetal cover was 614.5 Ha in 1980 and by the year 1990 and 2000, the rate of vegetal cover loss is 17percent and 8percent respectively. Similarly, in Gwagwalada the vegetal cover was 838.36 Ha in 1980. However, the rate of change in vegetal cover loss were 71 percent in 1990 and 13 percent in 2000. The trend continued in 2010 as the town further witnessed decreased in vegetal cover with an annual rate of change of 14 percent and 15 percent in year 2020 respectively. This implies that, the FCT has witnessed massive decline in its vegetal cover which serves as carbon sink from 1980-2020 due to land use conversion as a result of urban expansion and population growth.

Table 4.8: **Quantity of Vegetal Cover Loss in FCT**

Years	FCC			Kubwa			Gwagwalada		
	VC (Ha)	**Change in (Ha)**	**Rate of change (%)**	**VC (Ha)**	**Change in (Ha)**	**Rate of change (%)**	**VC (Ha)**	**Change in (Ha)**	**Rate of change (%)**
1980	8293.96			614.5			838.36		
1990	3238.47	-5055.49	-61	510.41	-104.09	-17	246.78	-591.48	-71
2000	2853.09	-385.38	-12	470.85	-39.56	-8	213.81	-32.97	-13
2010	2523	-330.09	-12	94.17	-7.912	-5	184.5	-29.37	-14
2020	2431	-92	-4	31.39	-2.637	-3	157.53	-26.92	-15

Source: Author Analysis, 2021

Note:

VC: Vegetal Cover

Ha: Hectares

FCC: Federal Capital City

%: Percentage

4.2.2 Normalized vegetation index (NDVI) of quantity vegetal cover loss in FCT

Table 4.9 shows the NDVI values for FCC, Kubwa, and Gwagwalada in 1980, 1990, 2000, 2010, and 2020 respectively, to estimate the quality of vegetal cover in the research area. NDVI values range from +1 to -1. NDVI values of 0.1 or below are common in rocky areas and bare ground.

In FCC the quantity of vegetal cover was 75percent in 1980. The vegetal cover reduces in its quantity from 2 percent to 73 percent in 1990. Also, the quantity of vegetal cover further reduces by 17 percent in the year 2000 and 20 percent in 2000 and 6 percent in 2020. Also, the quantity of vegetal cover in Kubwa in 1980 was 62 percent. The town witnessed 7 percent reduction in its vegetal cover quality in 1990 and 9 percent in 2000. The quantity of the vegetal cover further decreases by 13 percent in 2010 and 5 percent in 2020 respectively. However, the trend continues as Gwagwalada town with vegetal cover quality of 57 percent in 1980 witnessed a 10 percent decreased in 1990 and 3 percent decrease in 2000. There was 10 percent reduction in vegetal cover quality from 44 percent to 34 percent in the year 2010 and 2 percent in 2020 (see Table 4.9). This study supports the findings of Tyubee and Anyadike (2012) to the effect that urbanisation, industrialisation and population are primary drivers of vegetal cover loss.

Table 4.9: NDVI values of the Study Area

Year(s)	NDVI Values		
	FCC	Kubwa	Gwagwalada
1980	0.75	0.62	0.57
1990	0.73	0.55	0.47
2000	0.56	0.46	0.44
2010	0.37	0.33	0.34
2020	0.31	0.28	0.32

Source: Author Analysis, 2021

The normalized vegetation index (NDVI) for FCC had a positive NDVI value of 0.75 in 1980 and a negative value of -0.96 in 1980, with a mean of -0.1. (Figure 4.8). The city also reported NDVI values as high as 0.73 and as low as -0.18 in 1990, with a mean value of 0.27, indicating that vegetation density was high in 1980 and 1990. With an NDVI rating of positive 0.56 and negative -0.35 with a mean of 0.1 in 2000, the city's vegetation quantity was drastically reduced. In 2010, a further decrease in the city's falling vegetation density was reported, with a positive NDVI value of 0.37 and a negative value of -0.09 with a mean of 0.14. A similar trend in vegetation decrease was also observed in the year 2020, with NDVI values of 0.31 and -0.10 with a mean of 0.105 as shown in Figure 4.7.

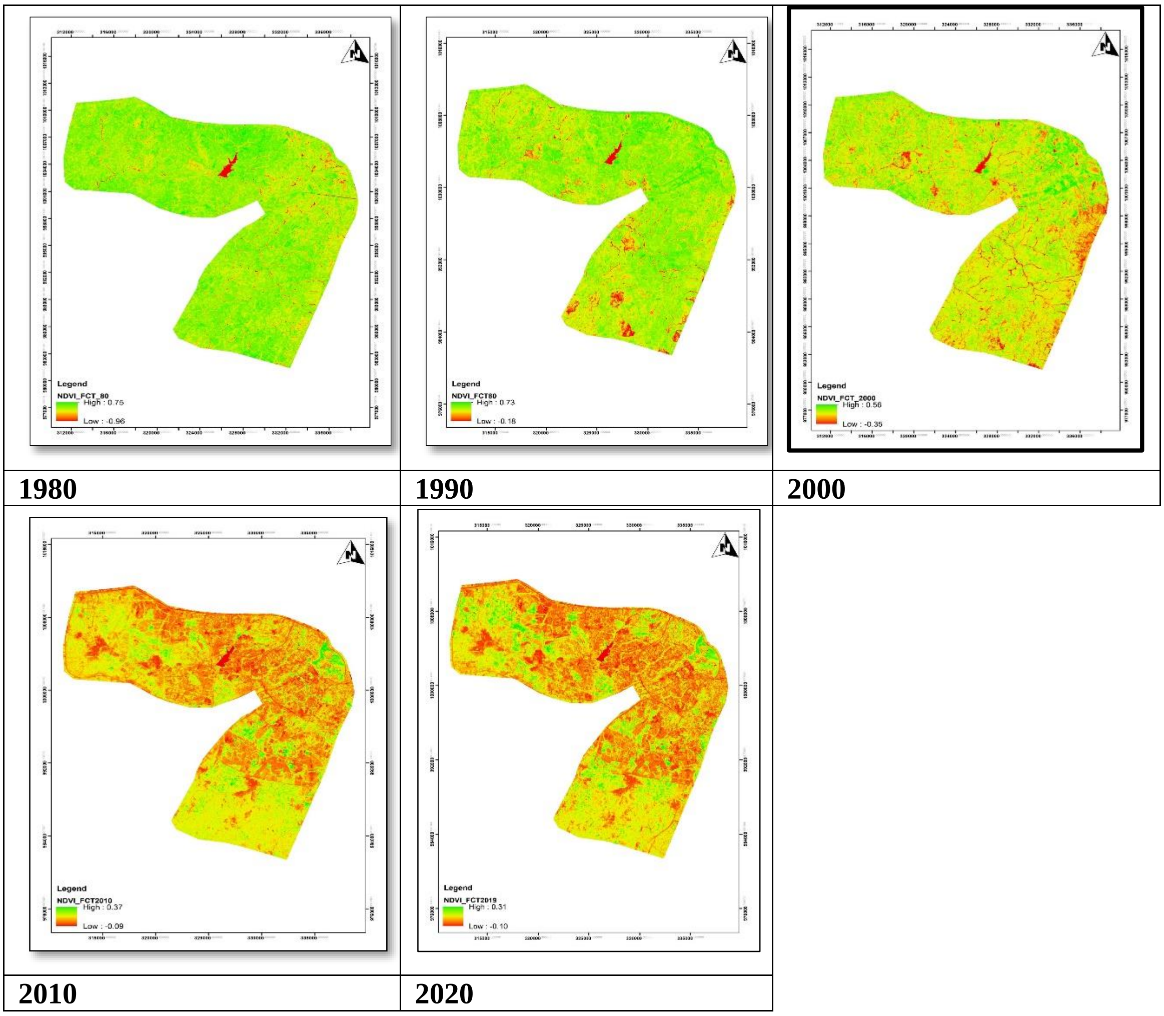


Figure 4.7: NDVI Map of FCC

Source: Author Analysis, 2021

Kubwa had an NDVI value of 0.62 and -0.62 with a mean of 0.23 in 1980, indicating that there was a lot of vegetation in the area. The town had an average NDVI value of 0.55 and -0.09 in 1990, with a mean of 0.23. In addition, the NDVI was 0.46 and -0.06 with a mean of 0.2 in 2000, and by 2010, the vegetation index had dropped to 0.33 and 0.01 with a mean of 0.17, indicating an extremely low vegetation density in the area. The NDVI value was 0.28 and 0.02 by 2020, with a mean of 0.15. The NDVI map of Kubwa is shown in Figure 4.8.

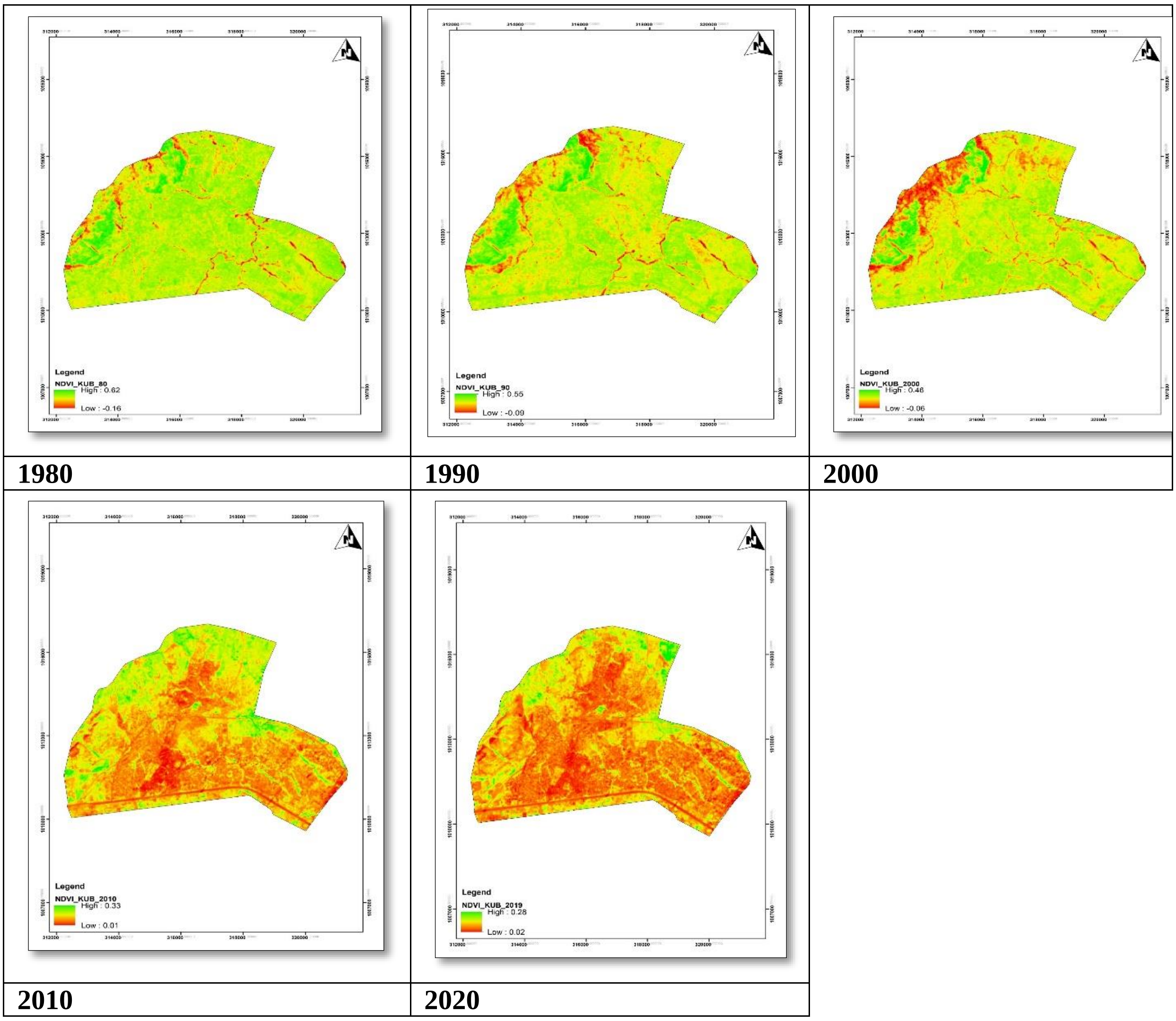


Figure 4.8: NDVI Map of Kubwa

Source: Author Analysis, 2021

Figure 4.9 reveals that in 1980, the NDVI value recorded in Gwagwalada has positive and negative NDVI values of 0.57 and -0.03 with a mean of 0.27 which shows there was an average vegetation abundance in the area. In 1990, the NDVI value were 0.47 and -0.05 with a mean of 0.21. In the year 2000, the NDVI values were 0.44 and 0.00 with a mean of 0.22. By the year 2010, the NDVI values were 0.34 and -0.06 with a mean of 0.14, and in the year 2020, the NDVI were 0.32 and -0.04 with a mean of 0.14. This shows that between 1980 and 2020 there is 32percent vegetal cover loss in the area.

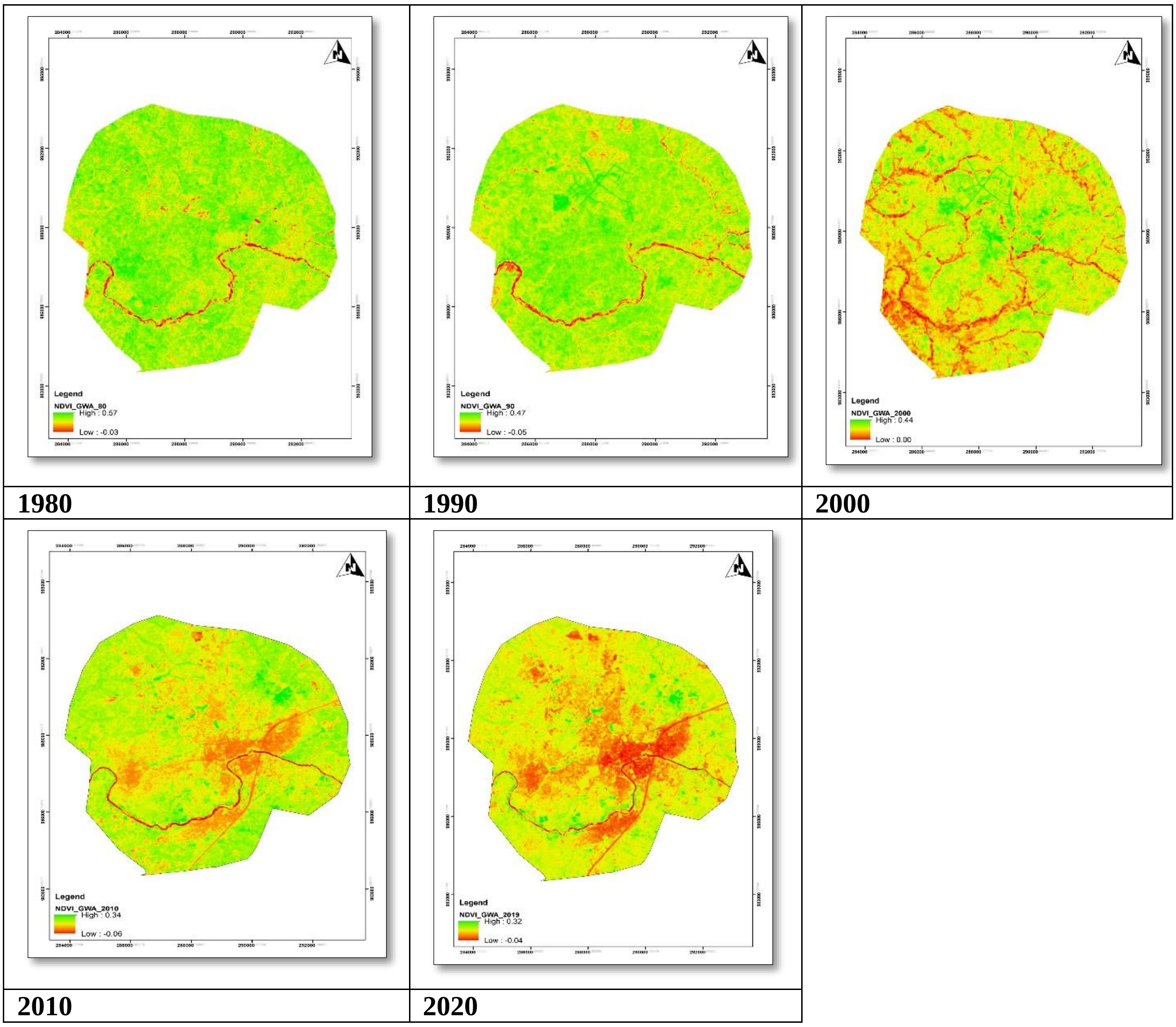


Figure 4.9: NDVI Map of Gwagwalada

Source: Author Analysis, 2021

The NDVI value is in the range of -1 to +1, according to Rouse (1974). Negative values indicate inactive vegetation, as well as vegetation with decreased density and health, such as water bodies, buildings, highways, and open spaces. In contrast, thickly vegetated areas, such as paddy fields and mangrove forests, have similarly positive or higher NDVI values. This is because green vegetation is more sensitive to the R band in terms of absorption than the NIR band, and so the NIR band's reflectance is greater than the R band, influencing the higher NDVI score.

The NDVI data were separated into two groups: non-vegetated land and vegetated land. Negative and zero values in the NDVI data represent non-vegetated land, whereas positive values represent vegetated land. Between 1990 and 2020, there were considerable differences between vegetated and non-vegetated lands. Meanwhile, the non-vegetated land use and land cover has become the dominating type of land use and land cover. As a result, the NDVI data demonstrate that Abuja's rapid expansion has converted more and more vegetated areas to non-vegetated surfaces.

4.3 Urban Surface Temperature Variation based on Vegetal Cover Changes in FCT

The normalized vegetation index (NDVI) is a dominant factor in LST derivation processes, and it is used invariably in any LST study. The role of NDVI is to reveal where the vegetation is thriving or under stress, as well as changes in vegetal cover due to human activities NDVI is directly used in the determination of LST emissivity and thus a significant factor for LST estimation. Spatial-temporal pattern of LST of the study area during the four temporal periods, (1980-1990, 1990-2000, 2000-2010 and 2010-2020) reveals that the study area exhibited higher LST as shown in Table 4.10. The Federal Capital City had 8293.66 ha of vegetal cover with a recorded LST value of 37.5°C in 1980. The vegetal cover of Kubwa in 1980 was 614.5 ha with LST value of 38.5°C. While the vegetal cover for Gwagwalada was 838.36 ha in 1980 with LST value of 38.2°C.

The vegetal cover of FCC was 3238.47 ha in 1990 with LST value of 37.7°C. Kubwa had a vegetal cover of 510.41 ha and LST 39°C in 1990. Gwagwalada had 246.78 ha of vegetal cover and 38.9°C in 1990. In the year 2000, a similar trend was observed, with FCC having vegetal cover of 2853.09 ha with LST value 38°C; Kubwa had vegetal cover of 470.85 ha with LST of 40.1°C and Gwagwalada had vegetal cover of 213.81 ha with LST of 40°C respectively (see Table 4.10).

The trend continues; in 2010, the FCC had vegetal cover of 2523 ha with LST of 38.5°C; Kubwa had 94.17 hectares of vegetal cover left and had a LST value of 40.4°C and Gwagwalada had vegetal cover of 184.5 ha with LST of 40.6°C respectively. Similarly, in the year 2020, as shown in Table 4.10. The FCC had vegetal cover of 2431 ha with LST of 38.9°C; Kubwa had LST value 40.9°C; and Gwagwalada had vegetal cover of 157.53 ha with LST of 40.9°C. The study implies that between 1980 and 2020, surface temperatures in the FCC, Kubwa, and Gwagwalada increased by 0.8°C, 1.6°C, and 1.9°C, respectively. This is consistent with Richardson's (2015) research of UHI in Austin, a fast-growing metropolis, over a 30-year period. According to the author's results, the city's temperature increased by 4.7°C from 1993 to 2011. The spatial distribution of the LST of FCC, Kubwa, and Gwagwalada is shown in Figure 4.10.

Table 4.10: **Urban Surface Temperature Variation based on Land Cover Changes in FCT**

Year (s)	**FCC**				**Kubwa**				**Gwagwalada**			
	LST (°C)	VC (Ha)	decrease in VC (Ha)	LST rise (°C)	LST (°C)	VC (Ha)	decrease in VC (Ha)	LST rise (°C)	LST (°C)	VC (Ha)	decrease in VC (Ha)	LST rise (°C)
1980	37.5	8293.96			38.5	614.5			38.2	838.36		
1990	37.7	3238.47	-5055.49	0.2	39.0	510.41	-104.09	0.5	38.9	246.78	-591.58	0.7
2000	38.0	2853.09	-385.38	0.5	40.1	470.85	-39.56	1.6	40.0	213.81	-32.97	1.8
2010	38.5	2523	-330.09	1.0	40.4	94.17	-7.912	1.9	40.6	184.5	-29.31	2.4
2020	38.9	2431	-92	1.4	40.9	31.39	-2.637	2.4	40.9	157.53	-26.97	2.7

Source: Author Analysis, 2021

Note:

VC: Vegetal Cover

LST: Land Surface Temperature

Ha: Hectares

°C: degree Celsius

FCC: Federal Capital City

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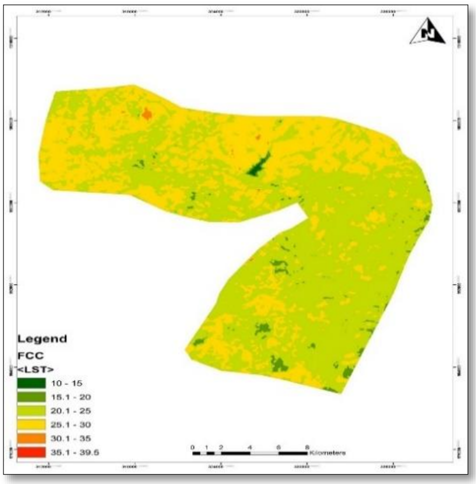
<td>
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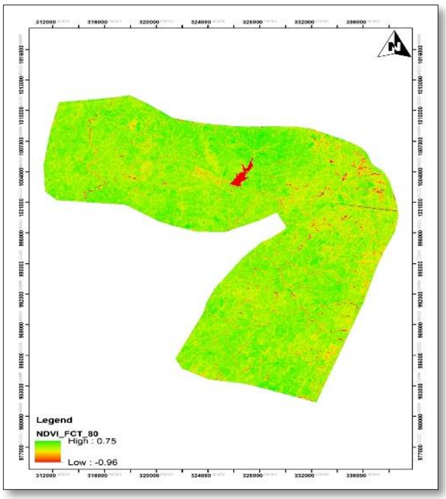
<td>
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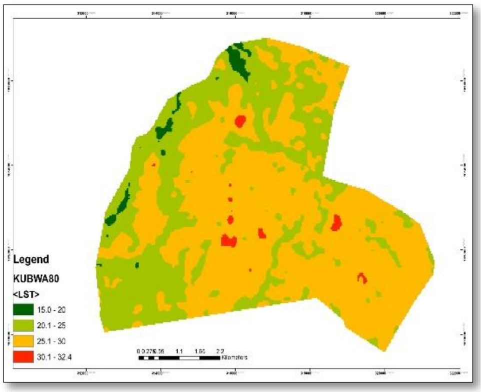
<td>
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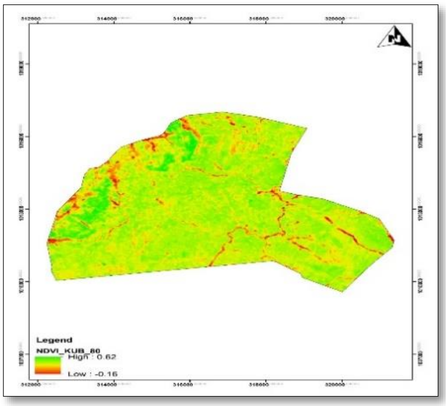
<td>
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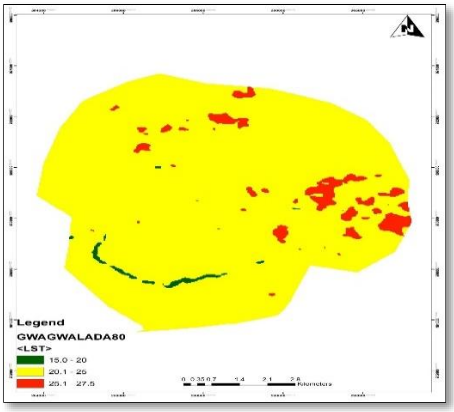
<td>
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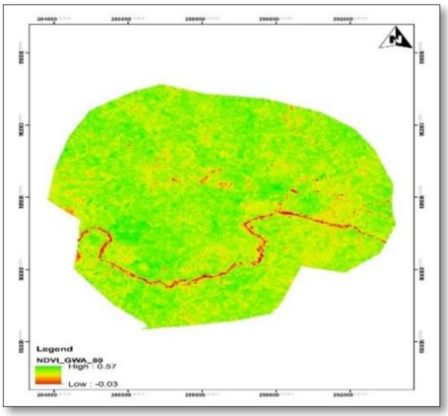
<td>
</td>
<td>Gwagwalada</td>
</tr>
<tr>
<td>LST</td>
<td>NDVI</td>
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Figure 4.10: Spatial Map of LST of the study area in 1980
Source: Author Analysis, 2021

4.3.1 Variation in LST and vegetal cover loss (1980-1990)

Figure 4.11 reveals that the variation in land surface temperature (LST) of the study area. In FCC, vegetal cover was 3238.47 ha with recorded LST of 37.5°C. The year 1990 the city loss 61 percent of its vegetal cover (-5055.49 ha) which give rise to LST of 0.2°C. This shows that the Federal Capital City is still densely vegetated with pockets of communities such as Takushara, Gwagwa, Kpepegyi, Kurudu, Orozo, Gwandara, and Jiwa prior to the construction phase of the city during that period, resulting in the low surface temperature observed in 1980. And the modest increase in surface temperature at the time was due to the destruction of approximately 845 villages throughout the region to make space for the nation's newly discovered capital (Olaitan, 2019 and Obiadi and Onochie, 2018). The spatial pattern of LST increased from the northern west part of the city (Gwagwa, Deidei, Dakwa, Karmo and Jiwa); Southwest (Lugbe, Aleita, Gosa,) and Northeast (Mpape). The research reveals that vegetal cover account for 19.2 percent of the total land coverage as against 6.0 percent for built up area in 1980.

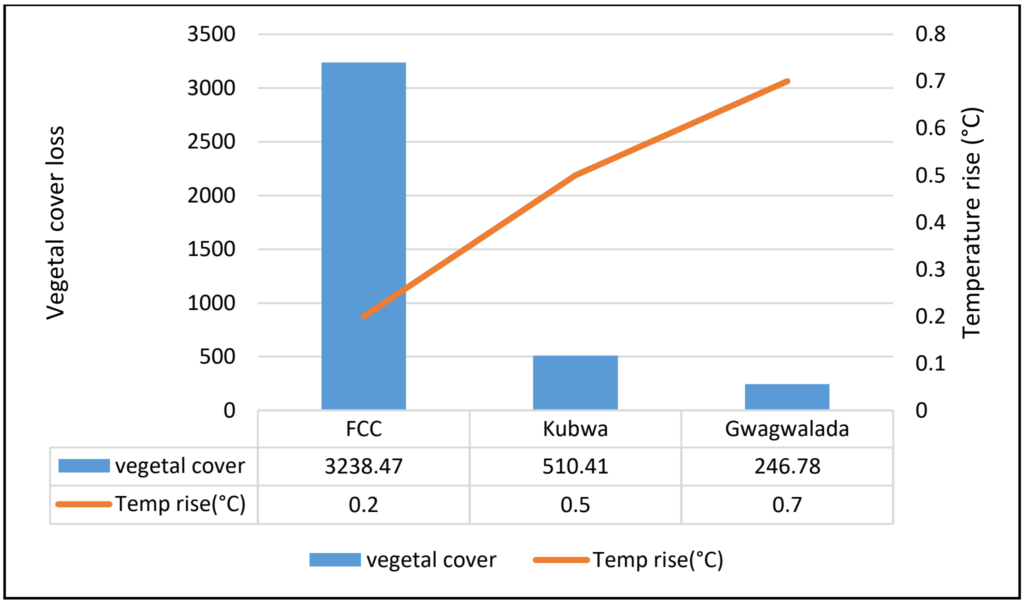


Figure 4.11: Variation in LST and Vegetal Cover Loss (1980-1990)
Source: Author Analysis, 2021

In the Kubwa, the vegetal cover was 614.5 ha in 1980 with LST of 38.5°C. The vegetal cover decline by 17 percent (-104.09 ha), as result of this decrease the LST rise by 0.5°C in 1990. This is due to the resettlement scheme that was initiated by Federal Government of Nigeria and United Nations to resettle Gbagyi tribe within the FCC areas of Garki, Maitama, Jabi, and Kukwaba villages (Abumere, 1981; Sylvester, 2014). The vegetal cover of Gwagwalada in 1980 was 838.36 ha with LST of 38.2°C. The town witnessed drastic loss in its vegetal cover by 71 percent (-591.58 ha) and 0.7°C rise in LST in 1990. This implies that the Gwagwalada area of the FCT was still a very small village with low population. Figures 4.12 Shows the distribution of LST pattern for the study area.

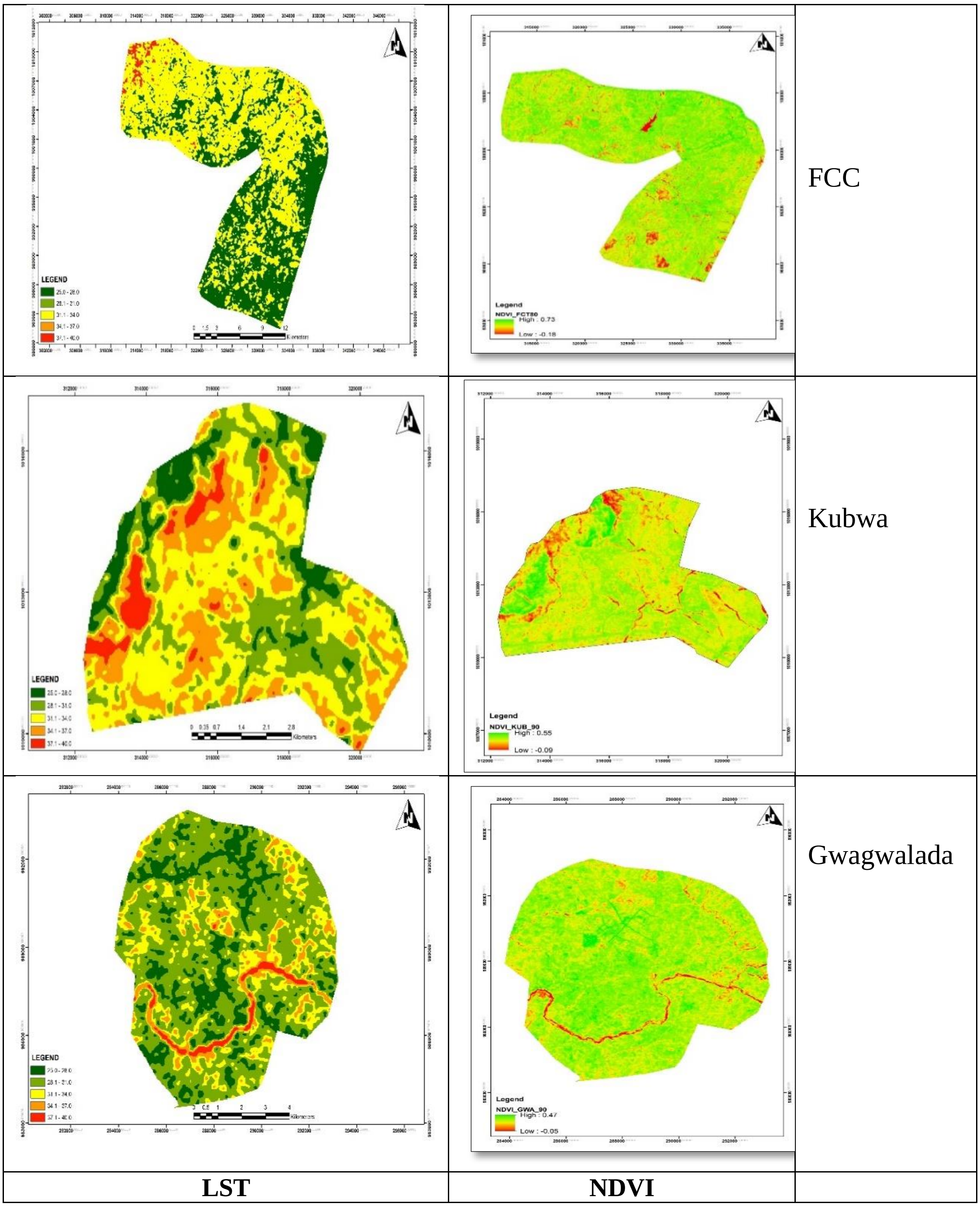


Figure 4.12: Variation in LST and Vegetal Cover in 1990

Source: Author Analysis, 2021

4.3.2 Variation in LST and vegetal cover in the year (1990-2000)

Figure 4.13 reveals that vegetal cover for FCC in 2000 suffers decline by 12 percent (-385.38 ha) and had an increase in LST of 0.5°C as compared to 0.2°C of LST experienced in 1990. The loss of vegetal cover and the rise in LST was due to infrastructural and housing development which give way for the emergence of settlements like Utako, Jabi, Gwarinpa, Apo, Durumi and Kado districts. This implies that depletion of vegetal cover in the city is as result of urbanization that is taking place. Thus, studies from Weng *et al.*, (2004); Barsi *et al.* (2014) and Priyankara *et al.* (2019) show that LULC transformation is a common phenomenon in the expansion of impervious surfaces like buildings, concrete roads, asphalt, and parking lots. And the rapid expansion of these impervious surfaces at the expense of other land-cover types like vegetation, wetlands, and water bodies increases the thermal accumulation of an area. These extreme LULC changes are the main indicator of urbanisation, and it is the driving factors to increase LST.

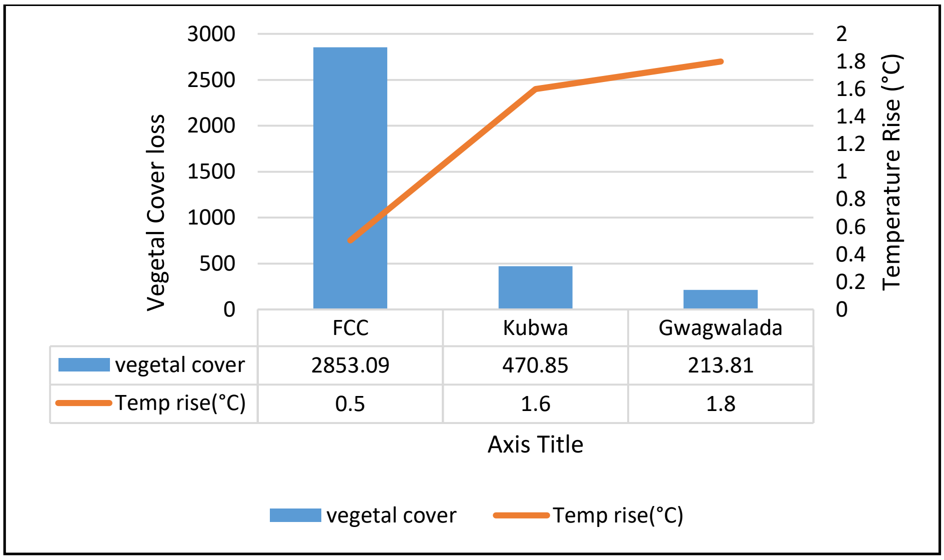


Figure 4.13: Variation in LST and Vegetal Cover Loss (1990-2000)
Source: Author Analysis, 2021

In Kubwa, vegetal cover decreases from 510.41 ha in 1990 to 470.85 ha (-8 percent) in 2000 with LST rise of 1.6°C. Also, the vegetal cover for Gwagwalada was 246.78 ha in 1990 but witnessed 13 percent decrease (-32.97 ha) in 2000 with LST rise of 1.8°C. This implies that the increasing urbanization in Kubwa and Gwagwalada engenders the replacement of natural landscape elements (vegetation cover, waterbody, etc.) with artificial elements (built-up area and other non-vegetative features), and in response to this, surface energy balance is usually altered resulting in rising temperature (Santamouris *et al.,* 2011; Alavipanah *et al.,* 2015; Adeyeri *et al.,* 2017 and Xiao *et al.,* 2008). This explains the scattered temperature hotspots observed within the study area. The spatial distribution of LST for the year 2000 is shown in Figures 4.14.

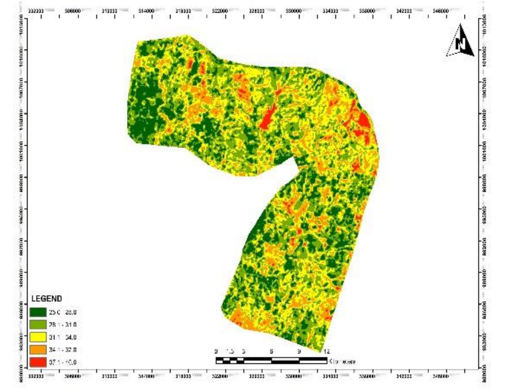
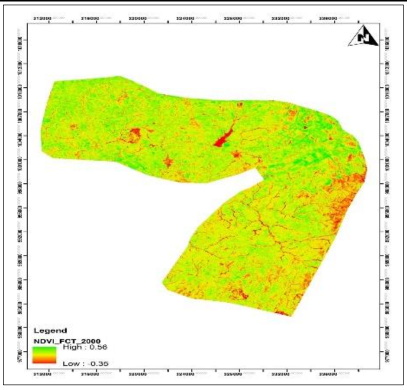
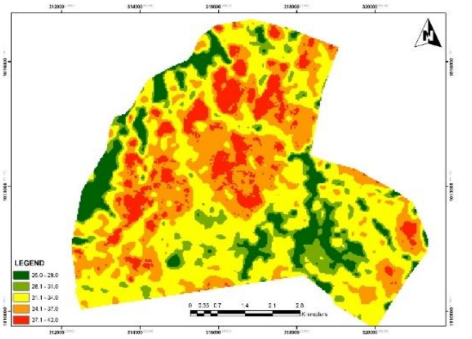
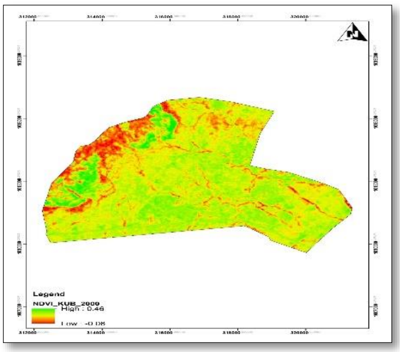
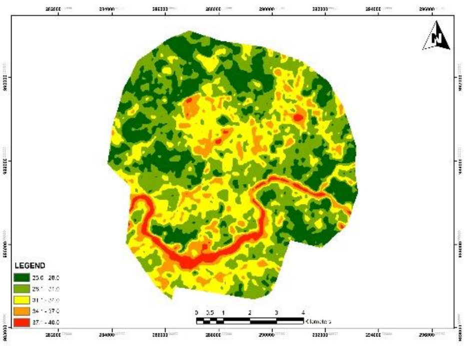
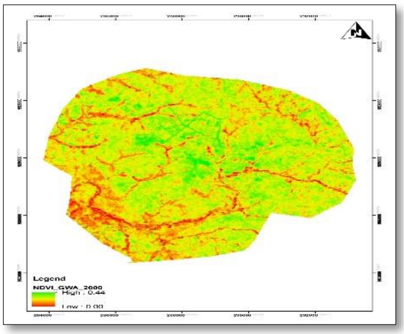
		FCC
		Kubwa
		Gwagwalada
LST	**NDVI**	

Figure 4.14: Map of LST in the study area in 2000

Source: Author Analysis, 2021

4.3.3 Variation in LST and vegetal cover in the year (2000-2010)

Figure 4.15 shows the Spatial analysis of LST and vegetal cover of the study in the year 2000-2010. The study carried out reveals that vegetal cover in FCC in 2000 was 2853.09 ha with LST value of 38°C is recorded as the hottest year due to 12 percent loss in its vegetal cover and development of road infrastructure like ONNEX and OSSEX and witnessed rise in LST of 0.5°C. In 2010, the vegetal cover suffers another 12 percent decrease in its vegetal cover with slight 0.3°C in LST. The 0.3°C increase recorded between the 2000 and 2010 was due the effort put in place by the FCT administration during Mallam Nasir El-Rufai tenure to control the haphazard development and distortion of the master plan within and around the city and the establishment of enforcement units such as development control department and park and recreation department.

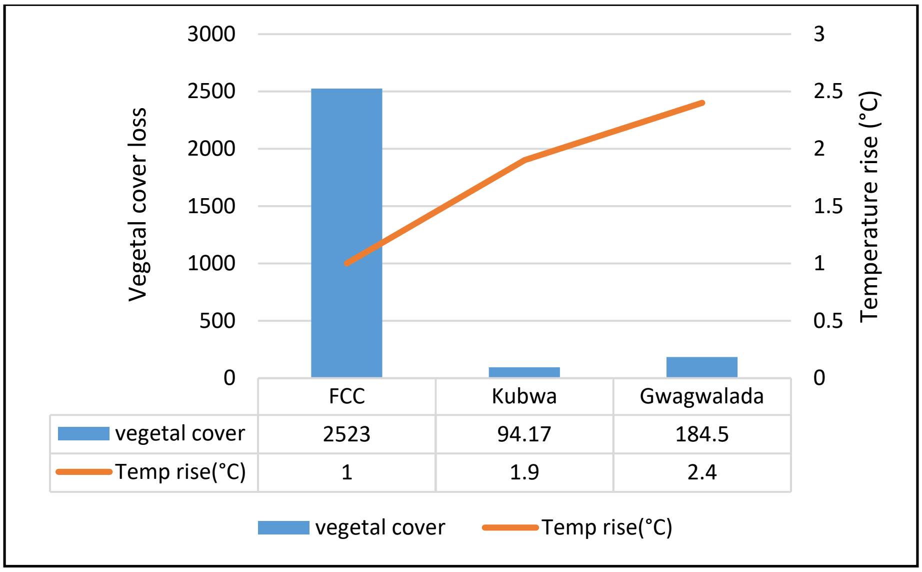


Figure 4.15: Variation in LST and Vegetal Cover Loss (2000-2010)
Source: Author Analysis, 2021

Meanwhile, in Kubwa town the vegetal cover reduced by 8 percent in 2000 which account for 470.85ha with recorded LST of 40.4°C by the year 2010 with 94.17 hectares of vegetal cover left in the area. In Gwagwalada, a similar trend was observed with an increase in LST by 0.5°C due to 13 percent and 14 percent loss of vegetal covers in 2000 and 2010 respectively as result of urban expansion respectively. The study reveals that the vegetative cover of the study areas has decrease due to the high demand for homes and infrastructural development. Studies by Amamoo-Otchere *et al.* (1998), Adesina (2005), Linda and Oluwatola, (2015); Koko *et al.* (2021) revealed that over 400,000 hectares of vegetation cover are lost annually in Nigeria, with a greater percentage of the vegetation cover lost due to increased infrastructural development, industrialization, mineral exploration, and settlement expansion. The research area's ever-increasing surface temperature is attributable to changes and conversions of vegetated surfaces to impermeable surfaces (Musa *et al.,* 2012). This research backs up the findings of Zhang *et al.* (2013), who found that changes in LULC and population shifts cause significant changes in spatial-temporal patterns in UHIs. Figure 4.16 illustrate the spatial map of LST distribution of the study area.

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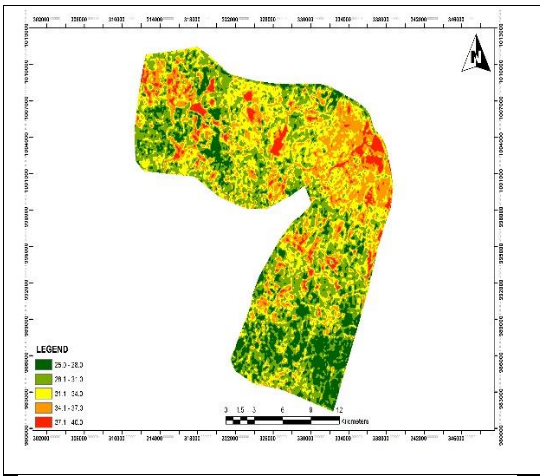
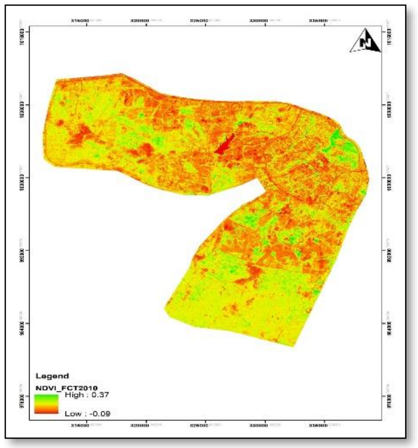
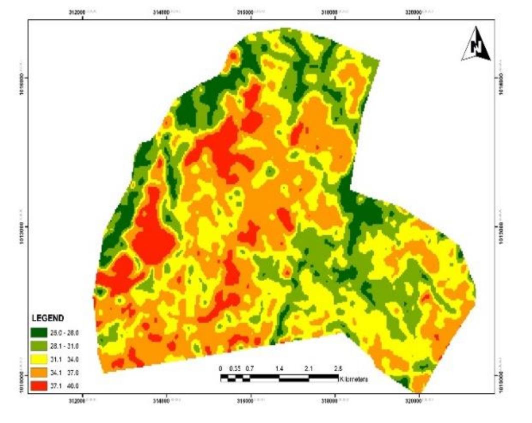
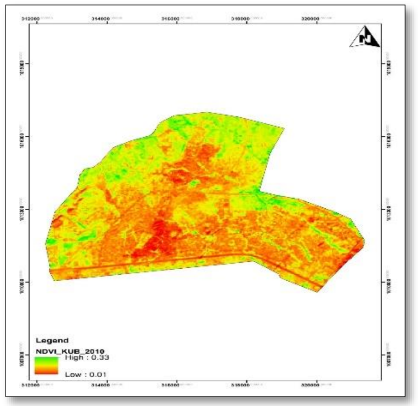
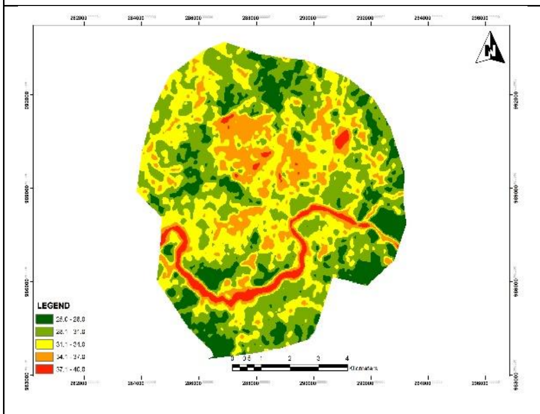
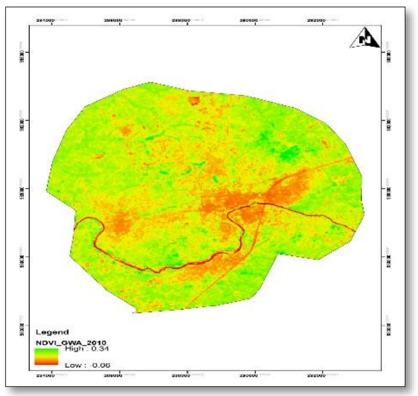
<tr><td></td><td></td><td>FCC</td></tr>
<tr><td></td><td></td><td>Kubwa</td></tr>
<tr><td></td><td></td><td>Gwagwalada</td></tr>
<tr><td>LST</td><td>NDVI</td><td></td></tr>
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Figure 4.16: Map of LST of the study area in 2010
Source: Author Analysis, 2021

4.3.4 Variation in LST and vegetal cover in the year (2010-2020)

Figure 4.17 reveals that there was 12 percent decrease in vegetal cover in FCC from 2523 ha in 2010 to 2431 ha in 2020 and recorded a LST of 40°C. This reduction in vegetal cover has resulted in increase in LST by 4°C. This increase in LST within the study area was due to massive demolition exercise that was carried out in the early 2000s and the springs of new settlements and mining activities in the study area. This is in line with Ukaegbu *et al.* (2016) which confirms that changes in impervious surfaces as a result of urban growth significantly produce a corresponding effect in increasing urban heat in the city.

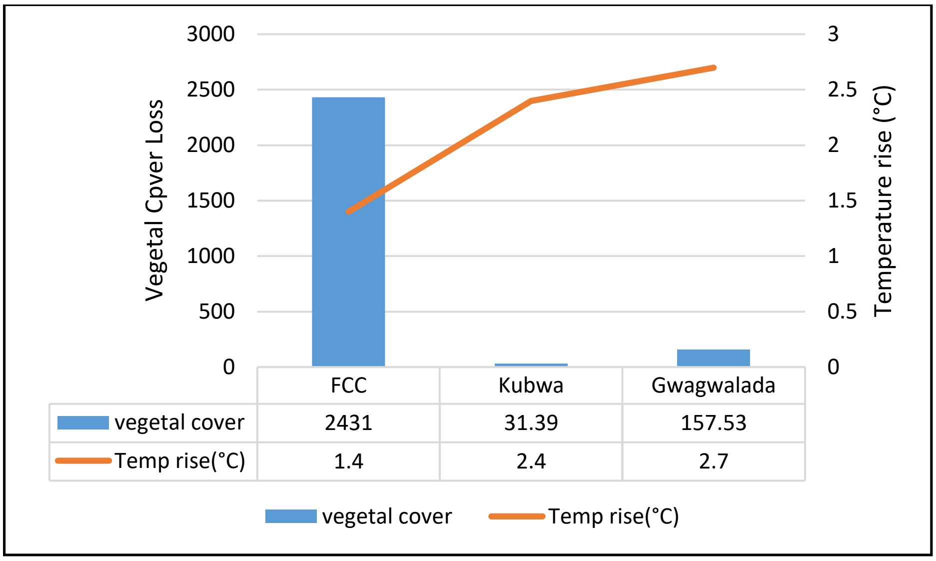


Figure 4.17: Variation in LST and Vegetal Cover Loss (2010-2020)
Source: Author Analysis, 2021

However, in Kubwa, one of the satellite towns in FCT, the LST rose by 0.4°C from 38.5°C to 38.9°C between 2010 and 2020. This implies that built-up areas are devoid of vegetation, especially tree covers that would have provided shade that cool the air through evapotranspiration, has been altered (Mavrakis *et al.*, 2015; Fu and Weng, 2016; Nouri *et al.*, 2022). Also, in Gwagwalada, vegetal cover further suffers another 15 percent de-crease from 184.5 ha to 157.53 ha between 2010 and 2020 with a rise in LST of 5°C. This implies that population explosion, climatic change, and rapid urban growth are the main drivers that lead to the increase in surface temperature within the study area.

The study observed that the increase in temperature is enhanced by urban activities such as; construction developments, mining activities, and illegal logging in FCT. This is in line with the study of Adesola and Afolabi (2013) which reveals that major urban areas in Nigeria is experiencing an increasingly high level of land transformation and conversion due to the increased rate of urbanization. The high rate of depletion of the vegetated resources at the expense of non-evaporated land uses such as concrete, asphalt and other impervious materials are seriously contributing to the rise in surface temperature in the Federal Capital Territory, Abuja. This affirmed that process of urbanization leads to an increase in the urban temperature (Radhi *et al.*, 2013) and decrease in the vegetal cover as a result of the rapid rate of urbanization can give rise to an average increase of 2.2°C in surface radiant temperature (Nzoiwu *et al.*, 2017). Figure 4.18 illustrate the map of LST spatial distribution of the study area.

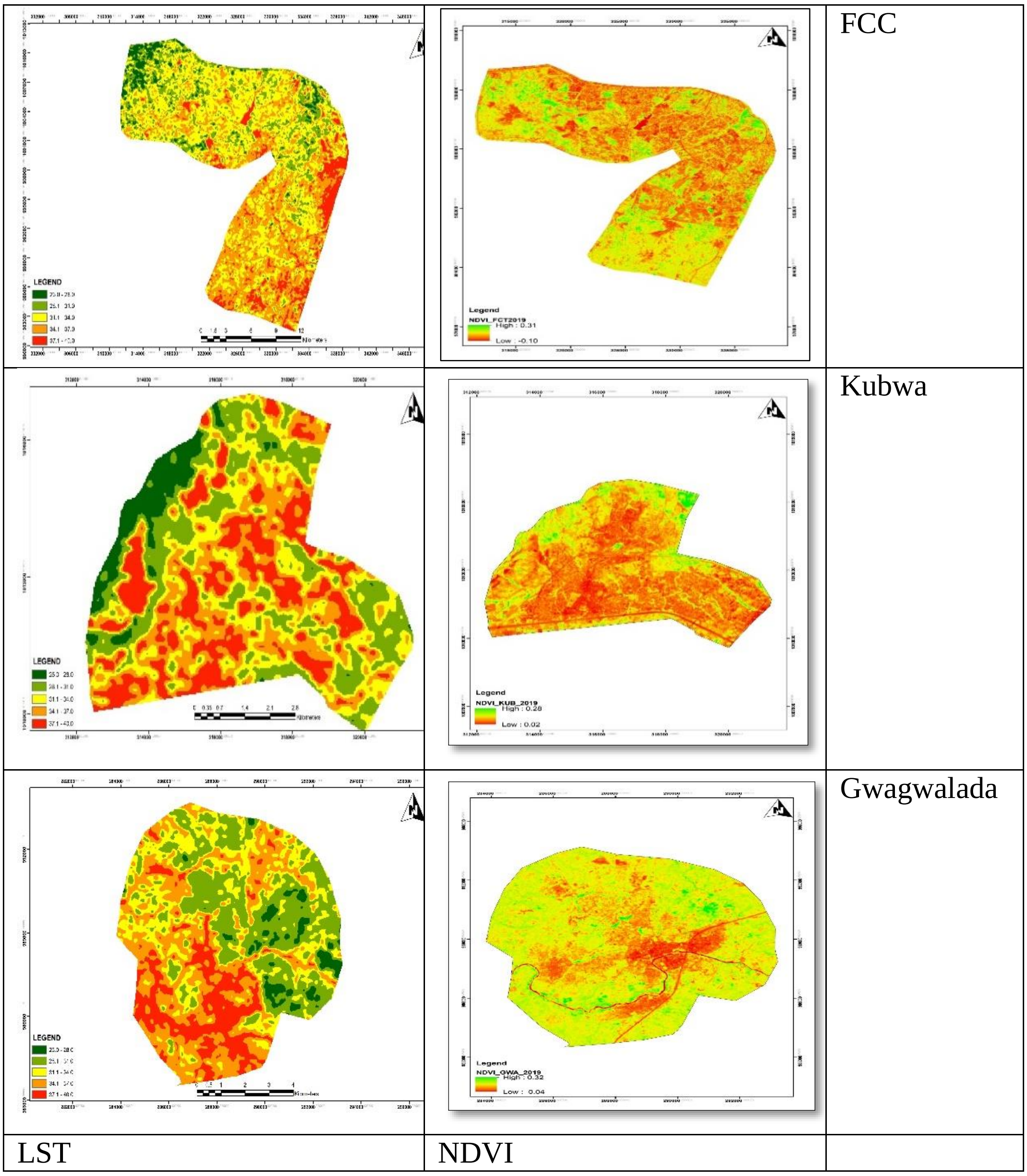


Figure 4.18: Map of LST of the study area in 2020
Source: Author Analysis, 2021

4.3.5 Correlation between vegetal cover loss and LST rise in the study area

A Spearman correlation was performed to determine if there is a correlation between Vegetal cover loss and Temperature rise. The data was transformed using Box-Cox transformation technique to transform non-normal data into a normal distribution.

Figure 4.19 reveals that result of the Spearman correlation showed that there was a significant correlation between Vegetal cover loss and Temperature rise in the study area with, r (10) = -0.63, p = .029. This study is in line with the findings of Mayer *et al.* (2003) and Ifatimehin, *et al.* (2010) that decrease in vegetal cover, cultivated lands, forested lands and water bodies as a result of urban expansion can have significant impacts on local weather and climate.

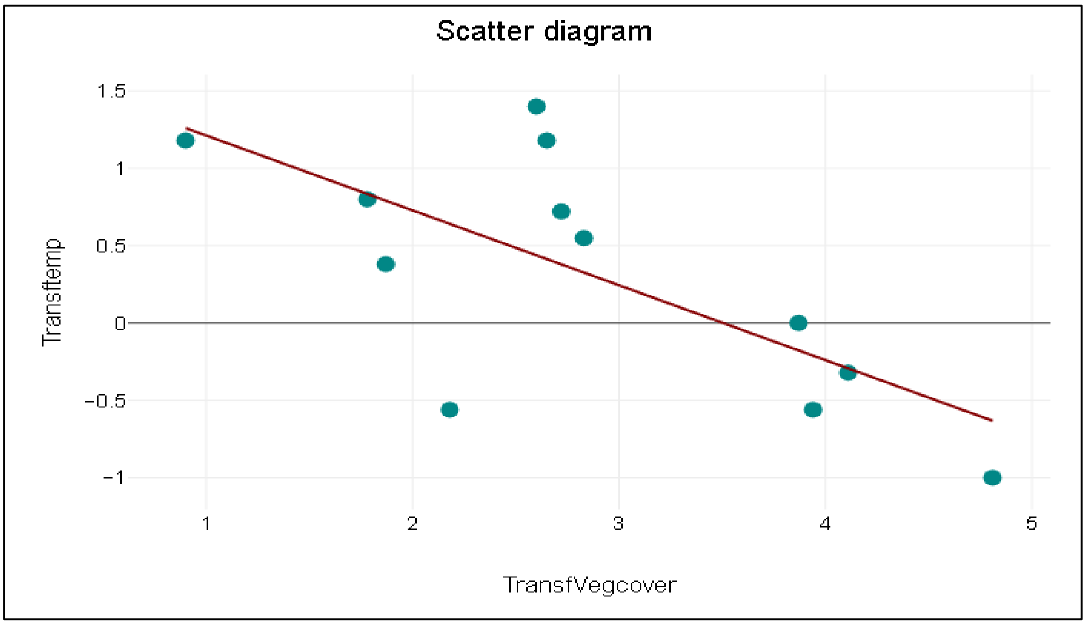


Figure 4.19: Scatter diagram of Vegetal Cover Loss and Temperature Rise
Source: Author Analysis, 2021

4.4 Effect of Built-Up Surface on Temperature Changes in the Study Area

Table 4.11 reveals that in FCC built up area in 1980 was 2602.75 ha was for 6 percent of the total land coverage. By the year 1990 the built area increased by 71 percent to 4458.96 ha, as result of this increase the LST rose by 0.2°C. By the year 2000, the built-up area further increased by 50 percent which resulted in the rise of LST of 0.5°C. The increase in surface temperature observed in city between 1990 and 2000 was due to initiation of the FCT Administration to open new district for infrastructural and residential development such as, Guzape, Kaura, Gwarinpa, Jabi, Utako, Nbora, Mabushi, Lokogoma and

Idu industrial district. However, the built-up area witnessed 205 percent increase in 2010 from 6697.98 ha to 20226.61 ha with 1°C temperature rise. The exponential increase in built up area was due to massive urban development that took place within the city. In the year 2020, the built area further increased by 23 percent with 1.4°C rise in temperature. The increase in temperature was as a result of heavy infrastructural and massive housing development between 2010 and 2020. It was during this period the FCTA lunched the land swap programme which gave birth to district such as, Katampe, Kagini, Jahi, Wuye, Maitama extension, Wumba, Wasa, Dape, Kafe, Karsana, Wupa, Ketti, Sheretti, Burum, Waru, Shape, Kabusa and Dakibiyyu.

Table 4.11: Built Up Area effect on Temperature Changes

Years	**FCC**		**Kubwa**		**Gwagwalada**	
	Built up (Ha)	LST rise (°C)	Built up (Ha)	LST rise (°C)	Built up (Ha)	LST rise (°C)
1980	2602.75		118.17		348.64	
1990	4458.96	0.2	614.5	0.5	786.06	0.7
2000	6697.98	0.5	1702.92	1.6	1007.06	1.8
2010	20226.61	1.0	2523	1.9	1889.9	2.4
2020	25158.325	1.4	3102.93	2.4	2494.9	2.7

Source: Author Analysis, 2021

However, in Kubwa, the built-up area was 118.2 ha in 1980 and increased by 346 percent in 1990 with give rise to LST of 0.5°C. In year 2000, built up area further increased by 166 percent from 408.33 ha in 1990 to 876.42 ha in 2000 which result in temperature rise of 1.6°C. The trend continues in 2010 as built area again by 80 percent and 23 percent in 2020 with 1.9°C rise in temperature respectively (see Table 4.11). Meanwhile, in Gwagwalada, built up surface increased by 124 percent from 350.64 ha to 786.06 ha from 1980 to 1990 with an increase in temperature of 2.4°C. Furthermore, the built-up surface increased by 28 percent, 88 percent and 32 percent in 2000, 2010 and 2020 with gave rise to over 0.3°C in each temporal year.

The study revealed that as the cities grow as a result of urban expansion, the heat island effect expands both in extent and intensity (Mavrakis *et al.,* 2015; and Nouri *et al.,* 2022). Also, the pattern of development features such as construction of road and housing and deforestation lead to temperature rise (Adeyeri *et al.,* 2017; Chapman *et al.,* 2017; Orimoloye *et al.,* 2018 and Fabeku *et al.,* 2018). Also, the study revealed the current state of land use dynamics and its potential implications on land surface thermal characteristics over the study area as well as the influence of human activities on the natural landscape, particularly the built-up areas. This is as a result of over time population influx and recent development in the region have given to land surface temperature of FCT, Abuja Nigeria.

4.4.1 Correlation between growth in the built-up area and temperature changes in the study area

The correlation between built-up and temperature for the years under study; 1980, 1990, 2000, 2010, and 2020, is presented in Table 4.12. The result reveals there is a strong positive relationship between temperature changes over time and built-up surfaces in Kubwa with r-value of 0.984. While in FCC and Gwagwalada shows a strong correlation matrix having recorded r-value of 0.134 and 0.903 for the built-up area and temperature changes. This study is in line with the findings of Zhou *et al.* (2011), who examined the relationship of LST and urban growth. The author's findings show that there is strong correlation between surface temperature increase and urban growth. Zhou and Wang (2011), indicate that rapid urbanization altered the local thermal environment, increasing the LST in zones within the urban core. The finding corroborates with Eliasson *et al.* (2003), in their study of spatial air temperature variations and urban land use in Goteborg, Sweden, found out that reduction in vegetative cover also had an impact on the local air temperature variation.

Table 4.12: Correlation matrix of built up and temperature changes

Variable		**Built up**	**LST**
Built up	Pearson's r	—	
	p-value	—	
LST	Pearson's r	0.984*	—
	p-value	0.016	—

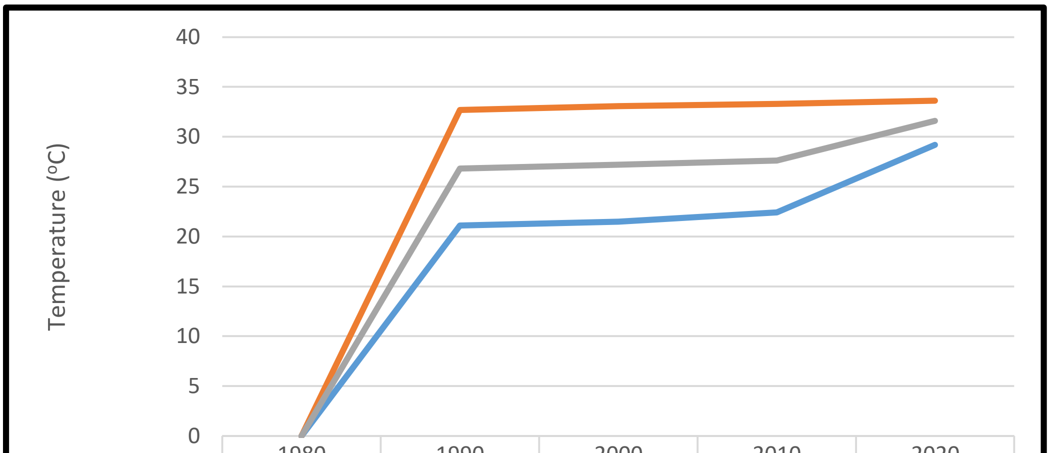
Source: Author Analysis, 2021

4.4.2 Air surface temperature measurement in the study area

Figure 4.20 reveals the air temperature measurement of the study area between 1980-2020 based on NiMet records. In the year 1980 no record of air temperature for the Federal Capital Territory, since the capital of the nation was still in Lagos and no Ministry or Agency in charge of temperature data collection such as NiMet. In 1990, the minimum recorded air temperature was 21.1°C and maximum temperature of 32.69°C with a mean value of 26.8°C; the minimum and maximum air temperature of 2000 were 21.5°C and 33.06°C with a mean of 27.2°C. Similarly, the temperature trend recorded in the year 2010, with minimum 22.4°C and maximum 33.29°C with a mean value of 27.6°C. However, and a sharp increase in temperature was recorded in year 2020 with minimum 29.2°C and maximum 33.6°C and a mean value of 31.6°C.

The result shows that the study area experienced 0.4°C maximum temperature variation increases between (1990, 2000, and 2010) and 4°C in minimum between the 2010 and 2020. Within a ten (10) year gap, there was 4.8°C increase in air temperature between

1990 and 2020 in the study area. This study agrees with the findings of European Environment Agency, (2003) which report that any city that is above l million or more are likely to experience an increase in average temperature by 1°C-3°C as a result of urban expansion. However, this temperature discrepancy has been measured to be as much as a 12°C difference (Lawson and Carter, 2009) and corroborate with the findings of Fanan *et al.* (2011) stating that urban expansion led to vegetation cover loss which give rise in surface temperature in an urban area.



	1980	1990	2000	2010	2020
Minimum	0	21.1	21.5	22.4	29.2
Maximum	0	32.69	33.06	33.29	33.6
Mean	0	26.8	27.2	27.6	31.6

Figure 4.20: Temperature Variation in the Study Area
Source: Author Analysis, 2021

4.5 Assessment of Thermal Comfort of Residents of the Study Area

Table 4.13 reveals the outdoor temperature measured within the period of October 2019 to November 2020, shows that the mean minimum temperature recorded for FCC is 27.4°C and mean maximum of 35.4°C, while the minimum temperature recorded in Gwagwalada is 27.2°C and maximum at 36.2°C and Kubwa with the record of the minimum temperature of 27.3°C and maximum temperature of 34.9°C. The field measurements are shown in Table 4.13 and compared with the Physiological Equivalent Temperature (PET) in Nigeria and Thermal Heat Index (THI) to ascertain the level of the thermal condition of the residents of the study area.

Table 4.13: Recorded temperature in the study area (2019-2020)

Study area	$AvMin_{Temp}$ (°C)	$AvMax_{Temp}$ (°C)	Mean (°C)	Mean Humidity	THI (°C)	PET thermal sensation	Remark
FCC	27.4	35.4	31.4	30	51	Warm	Moderate Heat Stress
Kubwa	27.3	34.9	31.1	23	47	Warm	Moderate Heat Stress
Gwagwalada	27.2	36.2	31.7	17	53	Warm	Moderate Heat Stress

Source: Author Analysis, 2021

The result shows that residents within the FCC, Kubwa and Gwagwalada falls within the category of moderate stress with recorded mean temperature of 31.4°C, 31.1°C and 31.7°C respectively (See Figure 4.21). This implies that 65.2 percent of the land cover within the FCC falls below the stipulated limit of the physio-equivalent temperature of Nigeria as formulated by Omonijo and Matzarakis (2011). While, 34.8 percent of the land area are above the thermal stress level of Nigeria.

This result supports the findings of Akande and Adebamowo (2010); Adaji *et al.* (2015) which argued that hot and humid climate can affect thermal comfort and the overall well-being of people. The findings confirm those of Omonijo and Matzarakis (2011), Balogun and Balogun (2014), who observed that heat stress in Akure using bio-climatological conditions as parameters to observe the thermal comfort of the city. Their results show that most of the people within the city feel discomfort during the timid period.

Borbora and Das (2014), also argued that replacement of vegetal cover areas with dry impervious surfaces, the use of building materials with high heat capacity and low surface reflectivity into the urban atmosphere are likely to modify the thermal regime. Panariti *et al.* (2014) focused on the impact of urban texture on the outdoor thermal comfort in the city of Durres in Albania and conclude that the urban texture in the case study influenced the outdoor thermal comfort. The study is also in line with the findings of Radhi *et al.* (2013) who conducted a study in the city of Bahrain analysing the impact of urbanization on the thermal behaviour of newly built environments. The result revealed that the process of urbanization leads to an increase in the urban temperature by 2-5℃. The increase in temperature is enhanced by the urban activity such as on-going construction processes, shrinkage of green areas, and sea reclamation. The implication is that the rapid growth of urbanization and rapid loss of vegetal cover within and around Abuja could greatly lead to rise in the temperature of the area if adequate planning methods are not put in place to check the implication.

The result was further computed using the heat index temperature scale as shown in Table 4.13. The result shows that the average heat index temperature of the FCC is 51°C, Kubwa 47°C and Gwagwalada at 53°C which are all at the danger level of heat disorder. At this condition, the residents could suffer heat cramps and heat exhaustion are likely; heat-stroke is probable as well with continued activity. This result is in corroboration with the findings of Park *et al.* (2014) in his study of human thermal sensation on human bioclimatic in using the Universal Thermal Climate Index (UTCI) in Nanaimo, BC, Canada, and Changwon, Republic of Korea state that there’s a direct link between temperature and thermal comfort and that high temperature are associated with high discomfort as compared to the experience in lower temperature of a similar setting. Argüeso *et al.*

(2015) came up with the findings that joint contribution of urban expansion and climate change will lead to increased risk of the heat-stress condition.

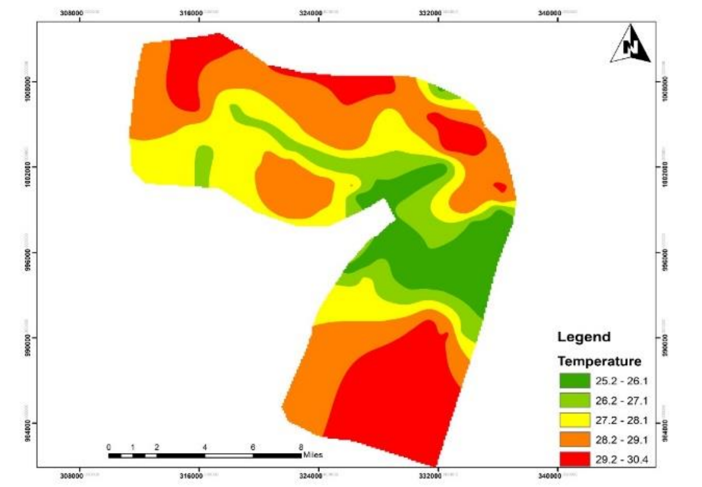
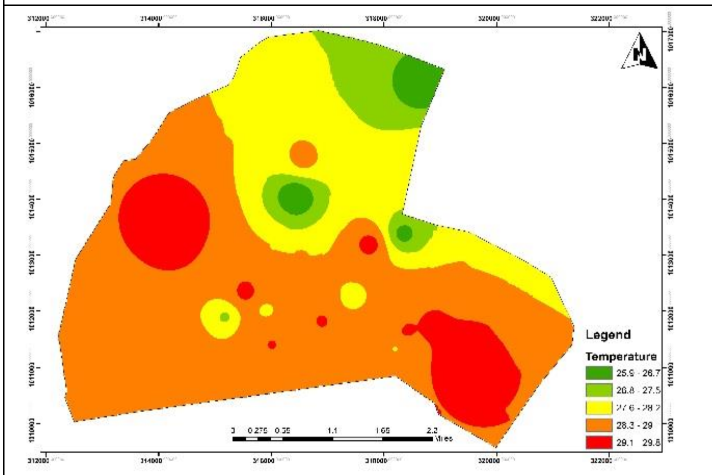
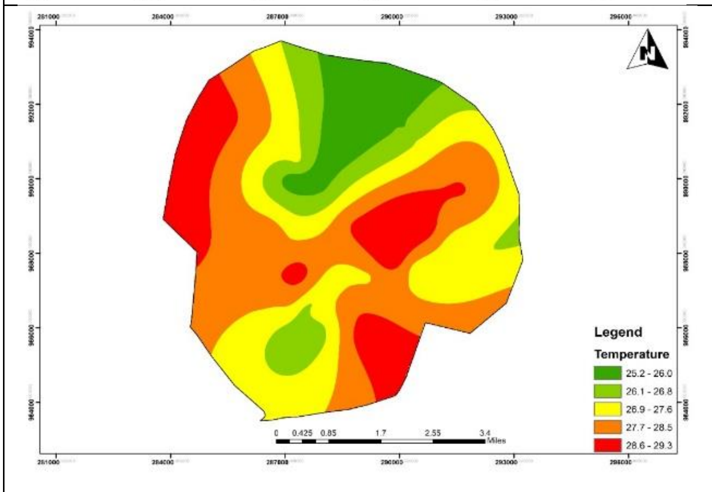
	FCC
	Kubwa
	Gwagwalada

Figure 4.21: Urban Thermal Comfort of Resident
Source: Author Analysis, 2021

4.5.1 Strategies used by residents in controlling thermal comfort in the study area

Figure 4.22 reveals that in FCC, 89.7 percent of the respondents agreed that they used window blind/shade to regulate their thermal comfort situation and 10.3 percent agreed they did not use window blinds/shades. While, in Kubwa 93.9 percent of the residents agreed that they used window blind/shade in controlling their thermal comfort and 6.1 percent agreed they did not. And in Gwagwalada, 95.8 percent utilized window blinds for thermal comfort management, whereas 4.2 percent says they did not, as illustrate in Figure 4.22

Window blinds are controlled primarily by occupants' visual comfort, rather than air temperature or other environmental conditions, according to studies by (Inkarojrit, 2005). The window control behaviour was shown to be primarily related to the indoor temperature by Raja *et al*. (2001). The frequency of window opening began to increase when the inside globe temperature reached 20°C. When the inside globe temperature hits 27°C, the frequency of window opening increases to approximately 100 percent. Yun and Steemers (2008), observed a similar result in a field investigation in two natural ventilation office buildings in Cambridge, UK, throughout the summer. They claimed that the main driving element for window control behaviour was the inside temperature. When the inside temperature hit 22°C, the frequency of window control increased, and when the indoor temperature exceeded 26.3°C, all the windows were open.

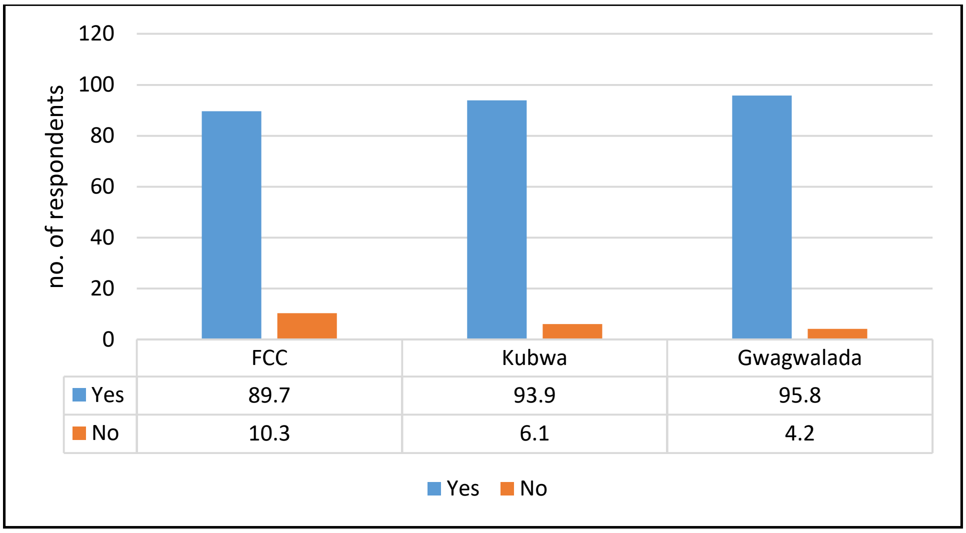


Figure: 4.22: Use of window blind/ shades

Source: Author Analysis, 2021

Figure 4.23 shows that in FCC, 84.8 percent of respondents used air conditioning to regulate their thermal comfort, while 15.2 percent did not. In Kubwa, 63.6 percent use air conditioning and 36.4 percent did not and in Gwagwalada, 40percent use air conditioning and 60 percent did not. However, 7.6 percent of the resident in FCC agreed that make of the tree shade in controlling their thermal comfort situation and 92.4 percent says they do not make use of tree shade, as they do not have trees planted in their respective except in parks and gardens.

Furthermore, 97.8percent of respondents in FCC use a fan to regulate their thermal comfort, while 2.2 percent do not. Also, 81.8 percent of the residents uses fan and 18.2 percent use and do not use a fan to regulate thermal comfort in Kubwa. While, in Gwagwalada 93.7 percent and 6.3 percent use and do not use a fan to regulate thermal comfort. This implies that outdoor and indoor thermal comfort could impact on the productivity and health of the residents (Atthajariyakul and Leephakpreeda 2004; Kosonen and Tan 2004;

Skoog *et al.*, 2005; Zhao *et al.*, 2021). From the study carried out finds out, that the minimum temperature recorded in the study area were 27.2°C and maximum at 36.2°C which were above the thermal comfort threshold of 23-26°C and 20-22°C for human occupancy in each space by ASHRAE (2013) for summer and winter seasons.

The demand for cooling appliances to regulate the thermal comfort of residents has increased as a result of an increase in surface temperature in the study area as a result of vegetal cover loss through the urbanization process. Residential properties in Nigeria account for the largest share of electricity consumption at 78 percent (Nwachukwu *et al.*, 2014; Gungah *et al.*, 2019). According to studies, air-conditioned buildings in the United Kingdom (UK) use roughly 50 percent more energy than naturally ventilated buildings due to the use of mechanical devices like fans and pumps (Ratti *et al.*, 2005; Sharmin and Steemers, 2020). This means that people alter their attire, activity, and posture to meet their environmental conditions, or manipulate the windows, fans, and air conditioning to suit their environmental conditions (Imran *et al.*, 2021).

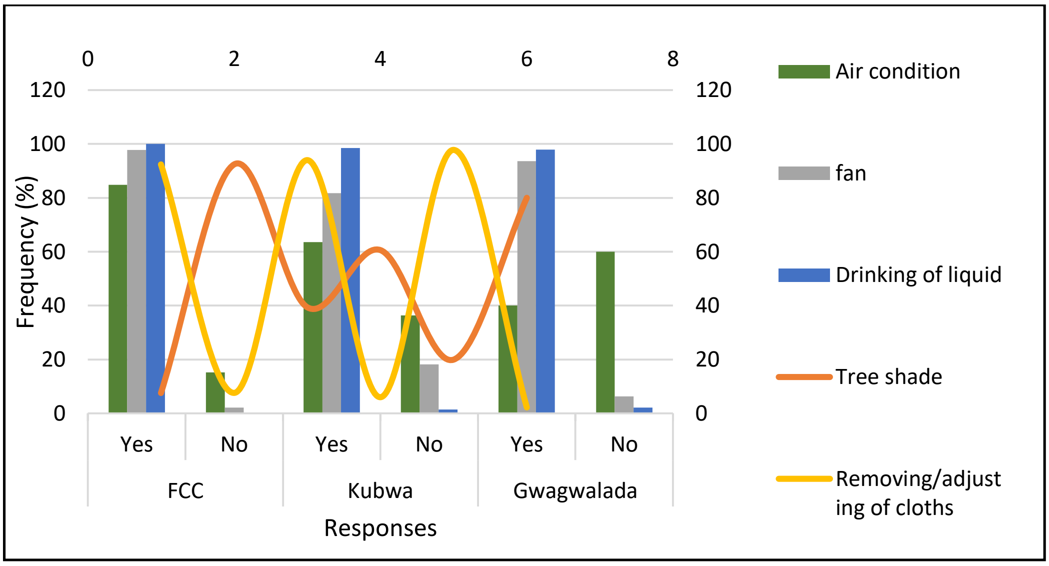


Figure 4.23: Method used in Regulating Thermal Comfort

Source: Author Analysis, 2021

4.5.2 Thermal comfort sensation of residents

The subjective thermal sensation votes utilized in this study are based on the ASHRAE standard 55-2010s seven-point thermal sensation scale. The following is a seven-point scale of thermal sensation: +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral point), -1 (slightly cool), -2 (cool), and -3 (cold) are the temperature scales (cold). Figure 4.24 shows that 2.7 percent, 0.9 percent, and 1.3 percent in FCC, Gwagwalada, and Kubwa referred their current thermal sense to be cold. In FCC, Gwagwalada, and Kubwa, 3.6 percent, 1.8 percent, and 2.7 percent favour a cool thermal state. In Gwagwalada and Kubwa, 16.2 percent and 2.0 percent, respectively, prefer the temperature to be slightly cooler.

While 9.0 percent and 3.0 percent preferred their thermal condition to be at normal room temperature in FCC and Kubwa respectively. Meanwhile, 19.8 percent, 8.5 percent, and 22.5 percent want their thermal condition to be slightly warm in FCC, Gwagwalada, and Kubwa. Also, 0.9 percent, 1.3 percent, and 0.9 percent of the respondents want their thermal condition to be warm in FCC, Gwagwalada, and Kubwa as well. While 1.8 percent and 1.0 percent prefer their thermal condition to be hot in FCC and Gwagwalada. This means that most residents want their thermal sensations to be between slightly cold during the hot season, neutral, and slightly warm during the cool season, as people spend an average of 80 percent of their lives indoors (Skoog *et al.,* 2005 and Zhang *et al.,* 2022). Indoor comfort has an impact on occupant productivity and health (Atthajariyakul and Leephakpreeda 2004; Kosonen and Tan 2004). From the study carried out finds out, that the minimum temperature recorded in the study area were 27.2°C and maximum at 36.2°C which were above the thermal comfort threshold of 23-26°C and 20-22°C for human occupancy in each space by ASHRAE (2013) for summer and winter seasons.

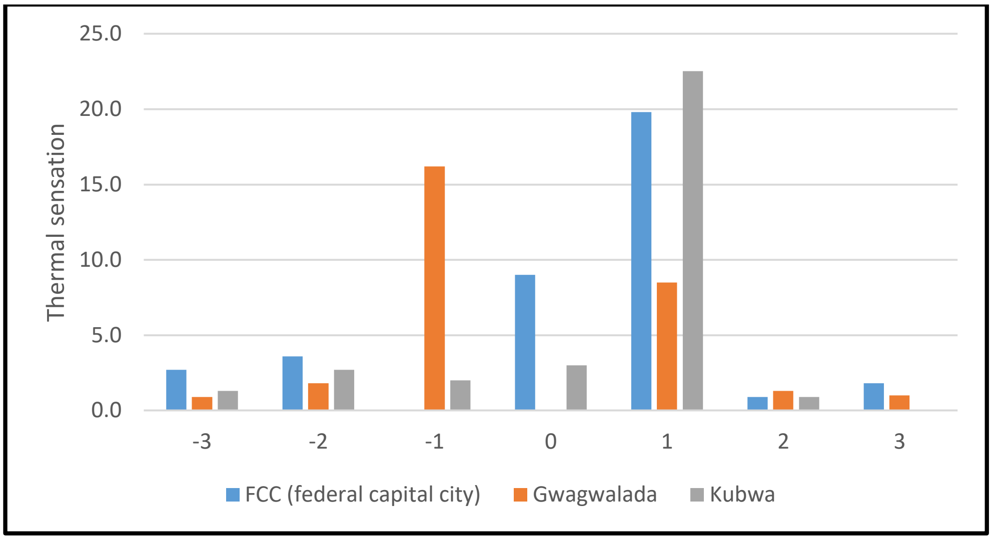


Figure 4.24: Thermal Comfort Sensation

Source: Author Analysis, 2021

4.6 Summary of Findings

The study was carried out to assess the vegetal cover loss on urban surface temperature and thermal comfort of residents in FCT, Abuja. It was on the basis that the study examines the issue of urban expansion pattern, the extent of land cover loss, quantification of urban expansion to temperature rise, thermal comfort of residents and relationship between LULC and LST.

The study established that in FCC, built-up has increased twice from (2602.75ha to 4458.96ha) in 1980 to 1990, due to population explosion and shift in the national capital from Lagos to Abuja. There was a 71 percent increase in 1990, 50 percent in 2000, and the year 2010 recorded the highest peak in built-up surface with a staggering rate of 205 percent while 2020 recorded a slow development rate of 23 percent due to high development control measures put in place by FCTA and the outbreak of coronavirus globally. Also, in Kubwa, built- up surface increased from 1980 to 1990 with a rate of 346 percent and slight decrease in the year 2000, with 166 percent and 80 percent in 2010 and the year

2020 recorded an average of 23 percent. While, in Gwagwalada recorded sharp increase from 1980 to 1990 with a growth rate of 124 percent, 28 percent in 2000, witnessed another exponential growth again in 2010 by 88 percent and 32 percent in 2020.

The study established that bare surface within the FCC, in 1980 was 32349.42 hectares and reduced with an annual rate of change of 10 percent in 1990, its further decreased from 35506.26 hectares to 33659.73 hectares by (-5 percent) in the year 2000. While it witnessed a very sharp decrease from 33659.73 hectares in 2000 to 20458.83 hectares in 2010 with account for (-39 percent) and reduces to -24 percent in the year 2020. In Kubwa, bare surface decrease from -13 percent from 1980 to 1990, and further decrease from 3028.5 to 1979.6 hectares accounting to -35 percent decrease (and slightly reduced to -18 percent within year (2000- 2010) and further decrease by -36 percent in the year 2020. Also, in the Gwagwalada area, between 1980 and 1990, the bare surface account for 2 percent and slightly reduced by -3 percent in the year 2000 and drastically decreased to -16 percent in 2010 and -125 in the year 2020. This is due to the increment in infrastructure development of study area from time to time has played a major influence on the decrease in bare surface areas.

The study established that vegetal cover loss in FCC decrease by -61 percent from 1980 to 1990, -12 percent in 2000 and 2010 and further decrease to -4 percent in the year 2020. Also, in Kubwa there is a slight decline in the vegetal cover between 1980 to 1990 and further decrease from 60.21 ha in 1990 at (11 percent) to 172.44 ha (29 percent) in the year 2000. And the year 2010 there was total or no vegetal cover left in the study area. Gwagwalada township witness a similar decrease in vegetal cover from 838.26 ha in 1980 to 246.78 ha in 1990 with a magnitude change of -591.48 ha and an annual rate of change of (-71 percent), the trend continues as it sharply witnesses another heavy vegetal loss in the year 2000 with an annual rate of change in vegetal cover to (-13 percent), and decrease from -29.31 ha from 2010 to -26.92 ha in the year 2020 account for an annual change in cover of -14 to -15 percent respectively

The study also established that the LST value in 1980, the minimum and maximum LST of the Federal Capital City were 10°C and 39.5 °C with a mean of 24.75°C. Whereas the minimum and maximum LST of Kubwa was 15°C and 32.4°C with a mean value of 23.7°C and minimum and maximum LST of Gwagwalada was 15°C and 27.5°C and mean of 21.25°C respectively. In the year, 1990 the minimum and maximum LST for FCC were 25.6°C and 39.7°C with a mean of 32.65°C; Kubwa has a minimum and maximum LST of 25°C and 40°C with a mean of 32.5°C and minimum and maximum LST of Gwagwalada was 20°C and 35.0°C with a mean of 27.5°C respectively.

A similar, trend was experienced in the study in the year 2000, with FCC having minimum and maximum LST of 20°C and 44°C with a mean of 32°C; minimum and maximum LST of Kubwa was 25°C and 35°C with mean of 30°C while the minimum and maximum LST of Gwagwalada was 25°C and 40°C with mean of 32.5°C. The trend further continues, in the year 2010, the minimum and maximum LST of FCC was 20.1°C and 40°C with a mean of 30.05°C; Kubwa with minimum and maximum LST of 25°C and 35°C with a mean of 30°C respectively. Likewise, the minimum and maximum LST of Gwagwalada was 25°C and 35°C with a mean of 30°C.

Similarly, the minimum and maximum LST of FCC in the year 2020 was 20.1°C and 40°C with a mean of 30.05°C; Kubwa with minimum and maximum LST of 25°C and

40℃ with mean of 32.5℃ and Gwagwalada with minimum and maximum LST of 27℃ and 35℃ with a mean of 31℃ respectively. The study shows that there has been an increase of 5.3℃, 8.8℃, and 9.75℃ in surface temperature within the FCC, Kubwa, and Gwagwalada between 1980-2020.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study established that in FCC, built-up area increased twice its size from (2602.75ha to 4458.96ha) in 1980 to 1990, due to population explosion and shift in the national capital from Lagos to Abuja. There was a 71 percent increase in 1990, 50 percent in 2000, and the year 2010 recorded the highest peak in built-up surface with a staggering rate of 205 percent while 2020 recorded a slow development rate of 23 percent due to development control measure put in place by FCTA and the outbreak of coronavirus globally. Also, in Kubwa, built- up surface increase from 1980 to 1990 with a rate of 346 percent and a slight decrease in the year 2000, with 166 percent and 80 percent in 2010 and the year 2020 recorded an average of 23percent.

While, in Gwagwalada recorded sharp increase from 1980 to 1990 with a growth rate of 124 percent, 28 percent in 2000, witnessed another exponential growth again in 2010 by 88 percent and 32 percent in 2020. Also, study reveals that vegetal cover has reduced from 8293.96ha to 2431ha (70 percent) in FCC, 614.5ha to 31.39 ha (94.9 percent) in Kubwa and 838.36ha to 157.58ha (81.2 percent) in Gwagwalada.

The study revealed that between 1980 and 2020, surface temperatures in the FCC, Kubwa, and Gwagwalada increased by 0.8°C, 1.6°C, and 1.9°C due to infrastructural and housing development in the study area. The study established that the thermal comfort within the study area falls within the category of moderate stress environment.

5.2 Recommendations

After a detailed discussion of the study, the pertinent recommendations are that:

The FCT administration should embark on afforestation scheme in order to restore the depleted land cover of the city in districts such as Lokogoma, Karsana, Guzape, Jahi, Lugbe, Gwarinpa Kagini, Deidei, Jiwa, Dape, Karmo, Tasha, Apo and Kabusa districts.

Urban greening be introduced in FCC (areas such as Gwarinpa by 3rd Avenue, Gaduwa, Lokogoma, by Larix homes, Sunshine homes, Pent city estate, Orchard estate; Jahi, Maitama along Dala hill street, Lake chad crescent, Angulu lake street and Asokoro around A.A Rano filling station). In Kubwa, (phase 3 by PW market; channel 8, Byadgyi, Bzango, 2.1 and 2.2) and in Gwagwalada (old kutunku, new kuntunku, phase 1, Angwan-dodo, phase 3, Dagiri and Dukpa) to help restore the depleted vegetal cover in the study area.

Biophilic design should be adopted by the FCTA administration in the proposed new districts such as Sheretti, Buru, Waru and Ketti to help mitigate LST and improve the liveability of the resident of the FCT.

Urban heat development plan be developed to help reduce temperature rise within study area by introducing LST mitigation strategy, which help in decreasing the surface temperature which, in turn, reduces the heat transmitted into buildings and the atmosphere. Through the establishment of park and open spaces, planting trees along streets, walkways and between buildings. Also, introducing landscaping elements within the city that can help create places of refuge during a heat wave, and effective management of water runoff during storms.

Relevant city planning authorities should adopt increase heat reflection strategy by painting surfaces and structures white or other light colours within and around the city. This technique can be very effective at reversing the urban heat island effect.

Reflective or permeable pavements technology be encouraged which helps to lower surface temperatures and reduce the amount of heat trapped on the surface. Furthermore, decision makers and city planners should designate areas within a city as car-free zones and ensure that such areas are only accessible by public transport, foot or bicycle, thereby, reducing emissions of heat, pollutants and greenhouse gases.

Green roof strategy be adopted as an alternative strategy for buildings by planting vegetation on the roof. The presence of plants shades the roof and prevent heat storage. This method helps in heat mitigation, building aesthetic and increase in property value.

National / State government departments, meteorological institutes and emergency response departments should develop a heat wave action plan to monitor temperature changes within and around the city. Also, quarterly evaluation and update the heat wave response plan should be done after each heat season.

5.3 Suggested Area for Further Research

This research assesses the impact of vegetation loss on urban temperature and residents' thermal comfort in Abuja. Research on this study was not able to compare the findings produced by remote sensing with those obtained from in situ measurements of air temperature because of the lack of climatic data, time, and location. A further study is suggested to cover this aspect to advance the current study by making predictions about the surface temperature conditions as urban expansion continues in the future.

5.4 Contribution to Knowledge

The original contribution of this research findings lies in its comprehensive analysis of urban expansion and temperature variations in the Federal Capital Territory of Nigeria, specifically in the areas of Federal Capital City (FCC), Kubwa, and Gwagwalada, spanning four decades from 1980 to 2020. The study shows that between 1980 and 2020 vegetal cover has reduced by 70 percent in FCC, 94.9 percent in Kubwa and 81.2 percent in Gwagwalada. Also, the study revealed that between 1980 and 2020, surface temperatures in the FCC, Kubwa, and Gwagwalada increased by 0.8°C, 1.6°C, and 1.9°C due to infrastructural and housing development which has significantly reduced the vegetal cover.in the study area. The identification of the thermal comfort category as a "moderate stress environment" underscores the potential challenges faced by residents in terms of heat stress, which can inform urban planning and climate adaptation strategies in this rapidly growing region. The study highlights the significant growth in built-up areas in these regions, attributing it to factors such as population growth and government policies. Furthermore, it uncovers a notable increase in surface temperatures within these urban areas over the same period, primarily as a consequence of infrastructural and housing development. The identification of the thermal comfort category as a "moderate stress environment" underscores the potential challenges faced by residents in terms of heat stress, which can inform urban planning and climate adaptation strategies in this rapidly growing region.

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APPENDIX A

THERMAL COMFORT QUESTIONNNAIRE

IMPACT OF VEGETAL COVER LOSS ON URBAN TEMPERATURE AND THERMAL COMFORT OF RESIDENTS IN FCT, ABUJA, NIGERIA

This survey is a PhD research work, which aims to investigate the impact of vegetal cover loss on urban temperature and thermal comfort of resident in FCT, Abuja, Nigeria. In order to obtain broad and objective result. Your answers will contribute to thermal comfort study and thermal environmental estimation in the study area

Please note: all of your answers are completely anonymous and confidential

PART 1

Location:_______________ Date:____________________ Time:______________

GENERAL INFORMATION

1. Please indicate your gender
   ( ) male ( ) female

2. Please indicate your age range
   ( ) less than 19 years old ( ) 19–29 years old ( ) 30–39 years old
   ( ) 40–49 years old ( ) 50–59 years old ( ) 60–69 years old
   ( ) 70–79 years old ( ) above 79 years old

3. How long have you lived in your area?
   ( ) less than 1 year ( ) 1–5 years ( ) 6–10 years
   ( ) 11–15 years ( ) more than 15 years

CONDITION OF YOUR HOME

4. How would you describe your home space?
   ( ) Enclosed space ( ) open plan office

5. How would you describe the ventilation system of your?
   ( ) natural ventilation ( ) air-condition system ( ) mixed-mode

6. How many persons are in your household?
   ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) more than 5 persons

7. How many external windows are there in your house?
( ) 0 ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) more than 4 external windows

PART 2 OF QUESTIONNAIRE

THERMAL COMFORT

1. What has been the general trend in your THERMAL COMFORT in your home?
( ) Staying the same ( ) Deteriorating ( ) Improving ( ) Fluctuating

2. How comfortable is the thermal environment in your house now?
( ) Very Uncomfortable ( ) Uncomfortable ( ) Somewhat Uncomfortable
( ) Somewhat Comfortable ( ) Comfortable ( ) Very Comfortable

THERMAL SENSATION AND PREFERENCE

3. What has been the general trend in your Thermal Sensation?
( ) Staying the same ( ) Getting colder ( ) Getting Warmer ( ) Fluctuating

4. Which single temperature sensation do you most prefer right now in your house?
(Please select a single option)
( ) Cold ( ) Cool ( ) Slightly cool ( ) Neutral ( ) Slightly warm ( ) Warm ( ) Hot

5. How do you Actually Feel Right Now?
(Please select a single option)
( ) Cold ( ) Cool ( ) Slightly cool ( ) Neutral ( ) Slightly warm ( ) Warm ( ) Hot

Please note here if your CURRENT THERMAL SENSATION is not fully captured by the scale
above: (i.e. "Very Cold", "Very Hot", in between two of the available scale options, etc.)

LOCAL DISCOMFORT AND COMPLAINTS

6. Where do you most feel your thermal discomfort? (Please select all options that apply)
( ) Head ( ) Chest ( ) Back ( ) Pelvis ( ) Arms ( ) Hands
( ) Legs ( ) Feet ( ) All Over (No Particular Area)

CONTROL AVAILABILITY

8. Which of the following controls can you adjust?

( ) Window(s) ( ) Door(s) ( ) Blinds ( ) Fan

( ) Air-Conditional ( ) Thermostat ( ) None of these Controls are Available

CONTROL USE

9. Which type of method do you used to control/adjust your thermal comfort?

( ) Window(s) ( ) Door(s) ( ) Blinds ( ) Fan

( ) Air-Conditional ( ) Thermostat ( ) Others (Please Specify)

10. How did this action affect your thermal comfort?

( ) Staying the same ( ) Getting colder ( ) Getting Warmer ( ) Fluctuating

ACTIVITIES

11. What activities have you been engaged in for the past 15 minutes or less?

(Note: Only make a selection for activities that were actually engaged in)

( ) Typing ( ) Reading/Writing (Seated) ( ) Reading/Writing (Standing)

( ) Having Conversation (Seated) ( ) Having Conversation (Standing)

( ) Filing (Seated) ( ) Filing (Standing) ( ) Walking About (Inside)

( ) Walking About (Outside) ( ) Eating ( ) Lifting/Packing

( ) Others (Please Speficy) ____

12. What activities have you been engaged in for the past 15 to 30 minutes?

(Note: Only make a selection for activities that were actually engaged in)

( ) Typing ( ) Reading/Writing (Seated) ( ) Reading/Writing (Standing)

( ) Having Conversation (Seated) ( ) Having Conversation (Standing)

( ) Filing (Seated) ( ) Filing (Standing) ( ) Walking About (Inside)

( ) Walking About (Outside) ( ) Eating ( ) Lifting/Packing

( ) Others (Please Speficy) ____

CLOTHING

13. What kind of clothing are you wearing right now?
    - (   ) Traditional
    - (   ) English
    - (   ) Others (Please Specify)___________________

14. What determines your work cloth? (Please select all options that apply)
    - (   ) Office clothing policy
    - (   ) Weather condition
    - (   ) Culture
    - (   ) What is available
    - (   ) Colour of clothing
    - (   ) Fashion
    - (   ) Others (Please specify) ___________________

15. Using the list below, please check each item of clothing that you are wearing right now. (Please select all options that apply)

( ) Short-Sleeve	( ) Long-Sleeve	( ) T-shirt
( ) Long-Sleeve Sweatshirt	( ) Sweater	( ) Vest
( ) Jacket	( ) Knee-Length Skirt	( ) Ankle-Length Skirt
( ) Dress	( ) Shorts	( ) Athletic Sweatpants
( ) Trousers	( ) Undershirt	( ) Long Underwear Bottoms
( ) Long Sleeve Coveralls	( ) Overalls	( ) Slip
( ) Nylons	( ) Socks	( ) Boots
( ) Shoes	( ) Sandals	

APPENDIX B

CORRELATION ANALYSIS

Correlation between Vegetal Cover Loss and LST Rise

Pearson's Correlations (FCC)

Variable		Decrease1	LST1
1. Decrease1	Pearson's r	—	
	p-value	—	
2. LST1	Pearson's r	0.754	—
	p-value	0.246	—

Pearson's Correlations (Kubwa)

Variable		Decrese2	LST2
1. Decrese2	Pearson's r	—	
	p-value	—	
2. LST2	Pearson's r	0.978 *	—
	p-value	0.022	—

* p < .05, ** p < .01, *** p < .001

Pearson's Correlations (Gwagwalada)

Variable		Decrese3	LST3
1. Decrese3	Pearson's r	—	
	p-value	—	
2. LST3	Pearson's r	0.910	—
	p-value	0.090	—

* p < .05, ** p < .01, *** p < .001

Correlation between Builtup area and Temperature changes in the study area

Pearson's Correlations (FCC)

Variable		BLTA	LstA
1. BLTA	Pearson's r	—	
	p-value	—	
2. LstA	Pearson's r	0.134	—
	p-value	0.866	—

Pearson's Correlations (Kubwa)

Variable		BLTB	LstB
1. BLTB	Pearson's r	—	
	p-value	—	
2. LstB	Pearson's r	0.984 *	—
	p-value	0.016	—

* p < .05, ** p < .01, *** p < .001

Pearson's Correlations (Gwagwalada)

Variable		BLTC	LstC
1. BLTC	Pearson's r	—	
	p-value	—	
2. LstC	Pearson's r	0.903	—
	p-value	0.097	—

* p < .05, ** p < .01, *** p < .001

APPENDIX C

UNIVERSAL THERMAL COMFORT INDEX MEASUREMENT IN THE STUDY AREA

Latitude	Longitude	Area	min temp	max temp	Average Tempt	UTCI
9.06568	7.39083	FCC	28.6	32.6	30.6	36.2
9.06569	7.39084	FCC	28.2	32.1	30.15	35.4
9.06572	7.39085	FCC	28.2	30.5	29.35	34
9.06569	7.39085	FCC	28.1	30.3	29.2	33.7
9.06571	7.39085	FCC	28.5	30.7	29.6	34.4
9.0657	7.39099	FCC	28.4	30.3	29.35	34.1
9.11745	7.40512	FCC	28.7	30.5	29.6	34.4
1002561	332701.5	FCC	27.4	29.2	28.3	32.3
1001085	331214.9	FCC	29.6	27.6	28.6	32.7
1003583	334195.7	FCC	29.3	27.3	28.3	32.3
1003898	333110.1	FCC	30.1	35.6	32.85	41.2
1004078	332489.5	FCC	30	35	32.5	41.3
1005433	335666	FCC	30.2	35.3	32.75	41
1005523	335292	FCC	30.7	34.8	32.75	41
1001207	336063.6	FCC	30	34.6	32.3	39.8
1001210	336070.2	FCC	29.7	33.3	31.5	38
1000645	336468	FCC	29.6	32.8	31.2	37.4
9.1540391	7.32371997	Kubwa	30.1	32.2	31.15	37.7
9.15413126	7.32380581	Kubwa	29.8	32.6	31.2	37.7
9.15416136	7.32413003	Kubwa	29.3	32.9	31.1	37.5
1000366	335443	FCC	29.9	30.9	30.4	358
1000320	334904	FCC	29.3	30.8	30.05	35.3
999677	334359	FCC	29.1	30.9	30	35.1
998734.9	333402.7	FCC	29.9	30.7	30.3	35.6
998802	333715	FCC	29.4	30.6	30	35.1
998181.9	332924.4	FCC	28.6	30.6	29.6	34.4
997432	333457	FCC	28.2	30.5	29.35	34.1
997550	333557	FCC	28.1	30.3	29.2	33.7
998734.9	333402.7	FCC	28.5	30.7	29.6	34.4
1000573	336763	FCC	28.4	30.3	29.35	34.1
1000159	333606	FCC	28.7	30.5	29.6	34.4
1001006	334145.5	FCC	27.4	29.2	28.3	32.3
1002777	336012.5	FCC	29.6	27.6	28.6	32.7
8.941010814160109	7.093910509720445	Gwagwalada	30.3	35	32.65	41.6
8.940982483327389	7.093902714550495	Gwagwalada	30.8	35.6	33.2	42.9
8.94094007089734	7.093978570774198	Gwagwalada	30.3	35.6	32.95	42.4
8.940950129181147	7.093966668471694	Gwagwalada	30.6	35.5	33.05	42.7

8.941813884302974	7.0943361427634954	Gwagwalada	30.1	35.4	32.75	41.9
8.941845232620835	7.094344943761826	Gwagwalada	31.1	35.7	33.4	43.5
8.941807472147048	7.094331029802561	Gwagwalada	30.8	36	33.4	43.5
8.941836808808148	7.094347793608904	Gwagwalada	31	35.8	33.4	43.5
8.9418271696195	7.0943420100957155	Gwagwalada	31	35	33	42.4
8.941807723604143	7.094290629029274	Gwagwalada	31.2	35.8	33.5	43.8
8.9419205	7.09423212	Gwagwalada	30.8	34.9	32.85	42.1
999424	335349	FCC	29.9	30.7	30.3	35.7
999590	335349	FCC	29.4	30.6	30	35.1
1003608	333969.4	FCC	28.6	30.6	29.6	34.4
1001305	331195	FCC	28.2	30.5	29.35	34.1
998165	337810.2	FCC	28.1	30.3	29.2	33.7
9.06567921	7.39082702	FCC	28.5	30.7	29.6	34.4
9.06568879	7.3908374	FCC	28.4	30.3	29.35	34.1
9.06571583	7.39085013	FCC	28.7	30.5	29.6	34.4
9.06569049	7.39084996	FCC	27.4	29.2	28.3	32.3
9.06570866	7.39084653	FCC	29.6	27.6	28.6	32.7
9.06570125	7.39098669	FCC	29.3	27.3	28.3	32.3
9.11726865	7.404836	FCC	26.4	28	27.2	30.6
9.14485	7.34935	Kubwa	28.3	27	27.65	31.5
9.14484	7.3495	Kubwa	28	33.7	30.85	37.1
9.14519	7.34923	Kubwa	30.2	34.9	32.55	40.9
9.15404	7.32372	Kubwa	30.4	34.7	32.55	40.9
9.15413	7.32381	Kubwa	30.3	34.3	32.3	40.2
9.15416	7.32413	Kubwa	30	34	32	39.5
9.15414	7.32425	Kubwa	31	35	33	42
9.1540391	7.32371997	Kubwa	30	34.9	32.45	40.7
9.15413126	7.32380581	Kubwa	30.7	34.9	32.8	41.4
9.15416136	7.32413003	Kubwa	30.7	34.8	32.75	41.4
9.1541431	7.32424624	Kubwa	30.9	32.9	31.9	39.5
9.15338635	7.32642234	Kubwa	30.8	34.8	32.8	41.4
9.15229077	7.32668745	Kubwa	30.2	34.6	32.4	40.4
9.15135695	7.3267114	Kubwa	30	34.9	32.45	40.7
9.15061419	7.3267669	Kubwa	30.3	34.9	32.6	40.9
9.14999756	7.32698437	Kubwa	30.1	34.5	32.3	40.2
9.15057465	7.32862966	Kubwa	29.6	32.7	31.15	37.7
9.15031655	7.3302953	Kubwa	30.5	32.9	31.7	38.8
9.1560312	7.3329829	Kubwa	30.3	32.8	31.55	38.6
9.15611467	7.33305228	Kubwa	30.7	32.7	31.7	38.8
9.15603021	7.33321907	Kubwa	30.4	32.1	31.25	37.9
9.15615019	7.33326265	Kubwa	29.1	30.8	29.95	35.4
9.15603599	7.33310492	Kubwa	29.6	31	30.3	35.9
9.15602498	7.33308141	Kubwa	29.2	31	30.1	35.5
9.15598963	7.33316198	Kubwa	29.6	30.5	30.05	35.5
9.15605915	7.33306712	Kubwa	29.7	30.8	30.25	35.9
9.15603789	7.33313104	Kubwa	28.1	30.5	29.3	34.1

9.15605039	7.33378486	Kubwa	28.4	30.6	29.5	34.5
9.1540391	7.32371997	Kubwa	28.5	30.5	29.5	34.5
9.15413126	7.32380581	Kubwa	26.4	30.7	28.55	32.8
9.15416136	7.32413003	Kubwa	27.3	29.6	28.45	32.8
9.1541431	7.32424624	Kubwa	27.2	29.4	28.3	32.5
9.14484408	7.34950366	Kubwa	27	28.9	27.95	32
8.94101	7.09391	Gwagwalada	27.6	29.2	28.4	41.7
8.94098	7.0939	Gwagwalada	30.8	34.9	32.85	42
8.94094	7.09398	Gwagwalada	31	34.9	32.95	42
8.94095	7.09397	Gwagwalada	31.2	35	33.1	42.3
8.94181	7.09434	Gwagwalada	30.6	34.8	32.7	41.2
8.94185	7.09434	Gwagwalada	30.7	34.3	32.5	40.7
8.94181	7.09433	Gwagwalada	30.1	32.8	31.45	38.4
8.941010814160109	7.093910509720445	Gwagwalada	30.4	33	31.7	38.8
8.940982483327389	7.093902714550495	Gwagwalada	30.6	32.9	31.75	39.1
8.94094007089734	7.093978570774198	Gwagwalada	30.1	32	31.05	37.5
8.940950129181147	7.093966668471694	Gwagwalada	30	32.9	31.45	38.4
8.941813884302974	7.0943361427634954	Gwagwalada	29.8	31.2	30.5	36.3
8.941845232620835	7.094344943761826	Gwagwalada	29.5	30.9	30.2	35.8
8.941807472147048	7.094331029802561	Gwagwalada	29.6	30.8	30.2	35.8
8.941836808808148	7.094347793608904	Gwagwalada	29.6	31	30.3	35.9
8.9418271696195	7.0943420100957155	Gwagwalada	29.3	30.8	30.05	35.6
8.941807723604143	7.094290629029274	Gwagwalada	28.8	30.7	29.75	35
8.94111653	7.09403732	Gwagwalada	29.6	30.7	30.15	35.8
8.94101406	7.09380452	Gwagwalada	27.2	29.7	28.45	32.8
8.94097984	7.09385235	Gwagwalada	28.3	28.1	28.2	32.3
8.94096131	7.09392215	Gwagwalada	30.7	34.3	32.5	40.7
8.9408793	7.09419439	Gwagwalada	30.1	32.8	31.45	38.4