A SPATIO-TEMPORAL ANALYSIS OF CLIMATE CHANGE AND SETTLEMENT DYNAMICS IN ABUJA AND OUAGADOUGOU IN WEST AFRICAN SAVANNAH REGION

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (PHD) IN CLIMATE CHANGE AND HUMAN HABITAT

AUGUST, 2025

DECLARATION

I hereby declare that this thesis titled: "**A Spatio-temporal Analysis of Climate Change and Settlement Dynamics in Abuja and Ouagadougou in West African Savannah Region**" is a compilation of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) have been duly acknowledged.

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CERTIFICATION

The thesis, titled: "**A Spatio-temporal Analysis of Climate Change and Settlement Dynamics in Abuja and Ouagadougou in West African Savannah Region**", by: GADIAGA Aliou (PhD/SPS/FT/2021/13001) meets the regulations governing the awards of the degree of PhD of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

For more than a decade and a half now, the percentage of the world's inhabitants living in urban areas has outstripped that living in rural areas. The population's concentration in urban area has led to spatial expansion. Spatial and demographic growth haves led to environmental and climatic impacts, including heat waves, floods, and windstorms which affect urban populations throughout the world, in particular Sub-Saharan Africa. The aim of this study was to analyse the demographic and spatial dynamics of Abuja and Ouagadougou over time. The objectives were to investigate how urbanisation patterns influence the recurrence of extreme weather events in the two cities and to compare the adaptation and mitigation strategies adopted by people to address the challenges posed by climate change in urban environments. To achieve these objectives, several methods, including the Geographic Information System, remote sensing, and statistical models, were combined to analyse satellite images, population data, qualitative data and sociodemographic data from a sample of 1,680 households. Specifically, the Google Earth Engine platform was used to classify the satellite images. In this way, urban expansion indices were calculated. The Hierarchical Analysis Process approach was also used to characterise the impacts of climate change by zone. Furthermore, logistic regressions, multiple component analysis and ascending hierarchical classification were used to assess and characterise the adaptation and mitigation strategies used by households. The results showed that both cities have experienced exponential population growth, which has led to their horizontal expansion over the last three decades. In Abuja, the surface area occupied by housing increased from 100.69 to 397 square kilometres between 2001 and 2022, leading to vegetation degradation, which fell from 6059.34 to 1433 square kilometres during the same period. In Ouagadougou, between 1990 and 2022, the area occupied by housing increased from 38.03 to 371.56 square kilometres, leading to vegetation degradation, declining from 253.04 to 68.88 square kilometres. The household survey reveals that 29.58% in Abuja and 40.07% in Ouagadougou have been affected by flooding at least once in the last 30 years. Other extreme weather phenomena, such as high temperatures and windstorms, have had impacts on the health, comfort, and activities of people in these two cities. This result revealed that despite the differing geographical, socioeconomic, and political contexts, the populations of these two cities have similarities in terms of adaptation strategies, but differ in climate change mitigation. Context-specific policies should prioritise strengthening local adaptation strategies, addressing socioeconomic disparities, and fostering urban design solutions tailored to each city's unique environmental and infrastructure challenge.

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LIST OF ABBREVIATIONS

AGW	Anthropogenic Global Warming
AHC	Ascending Hierarchical Classification
CBD	Central Business District
EA	Enumeration Area
EPA	Environmental Protection Agency
ESA	European Space Agency
ESF	European Science Foundation
FAO	Food and Agriculture Organisation
GIS	Geographic Information System
GHSL	Global Human Settlement Layer
GHS-POP	Global Human Settlement Population
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
LULC	Land Use Land Cover
MCA	Multiple Component Analysis
NASA	National Aeronautics and Space Administration the
NGO	Non-Governmental Organisations
NOAA	National Oceanic and Atmospheric Administration
PMT	Protection Motivation Theory
UHI	Urban Heat Island
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

In recent decades, urban areas have been attracting larger populations than rural areas. In African and Asian countries, urbanisation has accelerated significantly in recent decades and this has been marked by rapid population growth, driving the spatial and temporal expansion of cities. With more than half of the world's population residing in urban centres, urbanization is a worldwide phenomenon (Ali *et al.,* 2019). Using data analysed over the past 70 years, predictions show that around 60% of the world's population will live in urban areas by 2030, rising to 68% by 2050 (Chen *et al.,* 2023). In East Asia, urban expansion extended more than 28,000 square kilometres and an additional 200 million people between 2000 and 2010. Additionally, in 2010, East Asia had 869 urban areas with more than 100,000 inhabitants and more than half of these urban areas were in China (World Bank, 2015). It is estimated that urban areas are expanding at twice the rate of the urban population (IPCC, 2014).

Global population trends show that the urban population will rise from 60% to 68% between 2030 and 2050 (Chen et *al.,* 2023). Developing regions will be most affected by this growth. Between 2007 and 2025, the annual increase in urban population is expected to be only 3 million in developed regions compared to 53 million in developing regions (UN-HABITAT, 2009). In 2008, more than 50% the world's population lived in urban areas and is projected to rise to 70% by 2050 (UN-HABITAT, 2009). With around 1.6 billion inhabitants in 2007, the population of South Asia represents almost a quarter of the world's population, and the potential for demographic growth remains very high, with the population of this region expected to increase by 600 million between now and 2040

(Véron, 2008). Analysis of population growth and the rate of urbanisation have shown that, since 2000, China has had a much higher growth rate than other countries in the world (Chen *et al.,* 2023).

Heat waves or high temperatures are one of the manifestations of climate change in urban environments. heat waves and high temperatures are among the serious extreme weather events in the world (Petrovic *et al.,* 2024). At the European scale, the southern part of Europe and the Mediterranean region will be more impacted by climate change, due to an already hot and semi-arid climate (Brulebois, 2016). Heat waves will become more intense in most cities in Africa, Asia, Latin America, and the Caribbean (Satterthwaite *et al.,* 2007). The risks associated with rising temperatures due to climate change are exacerbated by urban heat islands resulting from urbanisation. (Kondo *et al.,* 2021). As a result, cities are the most exposed to the risk of heatwaves, due to the combined effects of climate change and urbanisation (Cheval *et al*., 2024). Poumadère *et al.* (2005) analysed the France heat wave episode as the European country most affected by the 2003 heat wave. In a fortnight, this heat wave resulted in an excess of 14,000 deaths from direct causes such as dehydration and hyperthermia (Poumadère *et al.*, 2005). In India, heat waves have led to an increase in mortality rates in recent years. Human deaths due to heat waves amounted to 1393 and 2500 in 2013 and 2015 respectively (Naveena *et al.,* 2021).

African urban areas in general, and West African urban areas in particular, are undergoing rapid urbanisation. Africa's urbanisation is supposedly among the quickest, despite the continent having the least developed urban growth (Güneralp *et al.,* 2017). In West Africa specifically, there were still no urban agglomerations with more than one million inhabitants in 1960, but, the number of agglomerations with less than 20,000 inhabitants was 600 in 2010, an increase of about 10 times since 1950 (Golaz, 2009). In Africa, the process of urbanisation is usually strongly influenced by the movement of people displaced due to famine drought, civil unrest, conflict, ethnic, and war (Kumssa *et al.,* 2021).

Like some of the less urbanised countries in Africa, Burkina Faso is now facing a very high urban growth rate. Ouagadougou has experienced important population growth since the 1960s. With an annual growth rate of 5.6% since 2000 and projections of 4.7% annual growth, the number of city dwellers will be around 4.4 million by 2030 (United Nations, 2018). On the other hand, the emergence of several urban centres in Nigeria typically represents its rapid pace of urbanisation, making it one of the most urbanised countries (the urban population doubles almost every 15 years) on the African continent (UN-HABITAT, 2006). The demographic and spatial dynamics of cities have consequences for the atmosphere, environment and climate change.

Studies and reports increasingly links these two global phenomena, climate change and urbanisation, which represent a dual challenge for sustainable development (UN-HABITAT, 2011a). According to Pappalardo and Batel (2015) urban growth already poses significant human challenges, ecological and economic. According to the Intergovernmental Panel on Climate Change (IPCC), climate change is considered one of the greatest threats to the livelihoods of the world's population (IPCC, 2014). Globally, 606,000 people died due to climate change-related disasters between 1995 and 2015 and these disasters affected more than 4.1 billion people (UNISDR, 2015).

Recent decades have been marked by a number of disasters linked to climate change. Currently, one of the most important and pressing issues that nations around the world are dealing with is climate change (Agboola *et al.,* 2024). Furthermore, The magnitude and frequency of hydroclimatic hazards(heatwaves, droughts, floods) may rise as a result of climate change, which could have significant consequences for the environment, health, and safety (Stevenson *et al.,* 2022). The impacts of numerous floods and landslides mainly affect poor urban neighbourhoods and are responsible for the majority of disaster-related deaths (Intergovermental Panel on Climate Change (IPCC), 2022). Between 1996 and 2005, floods were the second most frequently reported disaster and caused the deaths of more than 391,610 people worldwide (IPCC, 2022).

The Intergovernmental Panel on Climate Change (IPCC) report shows that Africa is one of the most vulnerable continents to climate variability and change (IPCC, 2007). In 2012 floods in Nigeria affected a total of 7.7 million people,, killed over 300 people and displaced an estimated 2.1 million people (United Nations, 2012).. On the economic front, billions of naira (Nigerian) worth of income was lost (United Nations, 2012). In Burkina Faso, the city of Ouagadougou experienced the first major flood in 2009. It affected between 12,000 and 33,000 households and killed 9 people (Tazen *et al.,* 2018). A post-disaster needs assessment conducted by the government in collaboration with the United Nations Development Programme (UNDP) and the World Bank estimated national losses and damages at around US$140 million (UNDP, 2010).

1.2 Statement of the Research Problem

Urbanisation has been a catalyst for economic expansion, enhanced access to education, pure water, healthcare, and the improvement of living standards. Nevertheless, this expansion poses substantial obstacles in regions that are swiftly urbanising, particularly in developing nations. Inefficient land use, increased vulnerability to climate change, and the frequent occurrence of extreme weather events such as inundation have been the result of the uncontrolled pace of urbanisation. Poor waste management, inadequate infrastructure planning, and climate-related impacts exacerbate the escalating risks that urban centres face from resource depletion, food insecurity, and economic instability. For example, in 2004, although the world's urban population was smaller than the rural population, 97% of the world's Gross Domestic Product (GDP) was generated by industry and services, most of which came from urban enterprises, and about 65% of the world's labour force was employed in industry and services (Satterthwaite *et al.,* 2007).

Nigeria's economic growth is remarkably tied to its urbanization, fuelled by significant demographic and social shifts (Bloch *et al.,* 2015). For example, between 1990 and 2013, the population increased from 96 million to 170 million and GDP increased from $31 billion to $522 billion (World Bank., 2014). This demographic and economic growth has led to numerous economic opportunities, job creation and poverty reduction, especially in urban areas. This improvement in living conditions, particularly in urban areas, can be attributed to the fact that most of economic activities are located in these areas.

The rapid urbanisation of developing countries, combined with the increased frequency and intensity of extreme and adverse weather events, is already having a devastating impact on these countries and may continue to do so over time given their weak capacity to cope with the consequences of climate change (UN-HABITAT, 2011b)**.** In developing countries, rapid urbanisation poses challenges for the distribution of people and resources, as well as for land use, leading to ineffective land use patterns (Bafana, 2016). The rapid urbanisation has led to the uncontrolled occupation of habitable areas within urban areas, but also to flood-prone areas at the middle and on the peripheries of cities. This explains why flooding in some cities is not linked to heavy rainfall or extreme weather events but to the way in which land is occupied by roads and residential buildings, which often limits the flow of rainwater (Douglas *et al.,* 2008).

Yet few plans to promote sustainability explicitly include either adaptation to climate change effects or the promotion of adaptive capacity. It is therefore very likely that the pace of progress towards the desired sustainable development will be slowed by climate change (Adger *et al.,* 2007). Indeed, the main urban challenges today include the rapid growth of several urban areas and informal settlements and the role of cities in causing or mitigating the effects of climate change, but global statistics show that these challenges have not been met (UN-HABITAT, 2009).

In Burkina Faso, the urbanisation rate is increasing rapidly. This rate was estimated at 22.7% in 2006 and is projected to reach 44% in 2035 (INSD, 2015). On the economic front, the tertiary sector, the majority of whose activities are concentrated in urban areas, is the country's primary source of income creation and accounts for almost 40% of GDP. Moreover, between 2015 and 2019, the contribution of the tertiary sector in the formation of GDP rose from 40.4% to 45.1% (UMOA, 2019). If well managed, urbanisation can continue to offer significant opportunities for economic and social development. However, the speed and scale of urbanisation in developing regions calls into question the ability of governments to plan and respond adequately to the needs of the growing number of urban dwellers (United Nations, 2011).

Climate change is already threatening urban dwellers in low and middle-income countries. The extent of damage to urban populations and economic activities caused by extreme weather events in recent decades highlights their vulnerability. For instance, flooding is becoming increasingly prevalent in African cities such as Abuja and Ouagadougou, where inadequate land use practices and expanded paved areas impede water absorption and result in severe discharge. The inadequacy of the government's ability to efficiently manage urban development and adapt to the effects of climate change exacerbates these issues.

Even though urbanisation presents opportunities for economic and social development, it also significantly contributes to greenhouse gas emissions and environmental degradation, thereby exacerbating the challenges associated with climate change. Indeed, in African cities as buildings, roads, infrastructure and other paved areas prevent rainfall infiltration into the ground, flooding is becoming an increasingly serious and frequent problem (Ramiaramanana and Teller, 2021). In most urban centres especially in fast-growing cities like Abuja, the main causes of flooding are attributable to the increase in human population, clogging of rivers and canals due to poor waste disposal habits and increase in paved areas. (Balogun *et al.,* 2020). For example, from 1992 to 2018 the city of Ouagadougou has experienced more than 50 occurrences of flooding (Francis, 2019). This has resulted in loss of life, destruction of housing and infrastructure, displacement of people and economic losses. In developed and developing countries, urban areas will increasingly feel the effects of climate change phenomena, resource depletion, food insecurity and economic instability, which is why they need to be addressed effectively if cities are to be sustainable (United Nations, 2011).

The observation is that there is a paradox because, on the one hand, urbanisation has advantages because it leads to economic growth, increases the standard of living of the population and facilitates access to services. On the other hand, urbanisation has disadvantages because of its influence on the climate and the extreme weather events that are observed. With this in mind, it is important to consider how cities could be the solution to the effects of climate change. This is because, cities play a key role in the global response to climate change in terms of reducing greenhouse gas emissions and adapting to climate change (ONU-HABITAT, 2015). Through better urban practices, the impact of cities on climate change can be mitigated and, conversely, cities can reduce the impact of climate change on themselves (Quenault *et al.,* 2011) and this can only be achieved through adequate mitigation and adaptation strategies. The paradox is rooted in the dual nature of urbanisation: it not only enhances living conditions and promotes economic prosperity, but it also increases the susceptibility of urban populations to climate-related hazards. This underscores the pressing necessity for the implementation of sustainable urban planning and the creation of resilient adaptation and mitigation strategies to increase the resilience of cities to the impacts of climate change (Riffat *et al.*, 2025).

Several studies have focused on the demographic and spatial dynamics of cities (Mahmoud *et al.,* 2016 , Hwang *et al.,* 2017 , Wang *et al.*, 2018 , Zhang and Zeng, 2018, Measho *et al.,* 2019, Karg *et al.,* 2020, Degefu *et al.*, 2021, Han *et al.,* 2022) and highlighted the impact on the urban environment and climate. Other studies have also focused on the impact of climate change on urban environments. However, understanding the link between the spatiotemporal dynamics of cities and the recurrence of extreme weather events in urban environments, as well as the strategies the adaptation to and mitigation, is becoming a necessity for fast-growing African cities such as Abuja and Ouagadougou. The critical question that persists is "how can urban centres effectively balance the benefits of urbanisation with the necessity of addressing the impacts of climate change"?

1.3 Research Questions

i. What are the characteristics of the spatiotemporal dynamics of population and urban sprawl in Abuja and Ouagadougou in West African Savannah region?
ii. What is the link between the mode of urbanisation and the recurrence of climate change impacts in urban areas?
iii. What will be the dynamics of urban growth of the two cities in 2052?

iv. How can adaptation and mitigation strategies increase urban resilience to climate change?

1.4 Aim and Objectives of the Study

This research aims to assess the impact of climate change in relation to the spatiotemporal dynamics of urban growth of Ouagadougou and Abuja within the last three decades. Specifically, this study seeks to:

i. evaluate, comparatively, the functional and structural long term temporal growth of two cities in the Savanna region of West Africa, namely Abuja and Ouagadougou;
ii. assess the impacts of climate change on the growth of these two cities, with the view of establishing a link between them;
iii. predict the future urban growth in these two cities by 2052;
iv. compare the adaptation and mitigation strategies employed by the two cities towards climate resilience.

1.5 Justification for the Study

This study is comparative research between two major West African capitals in terms of the dynamics of urbanisation over time and space and its link with the recurrence of climate change effects. In addition, this diachronic study allowed to understand the past, present, and future evolution of urban dynamics and its contribution to the increasing impacts of climate change in urban areas. More specifically, this research is justified by four benchmarks, which are policy improvement, performance improvement, and body of knowledge.

i. Policy Improvement: The results of this research aim to improve urbanisation policies in Burkina Faso, Nigeria, and in Africa in general. This study also aims to improve climate change mitigation and adaptation policies in urban areas. Specifically, the results allowed the Ministry of Urban Planning and the Ministry of Environment and Climate Change of both countries to guide their decision making and facilitate the implementation of urban projects. At the regional level, the comparison of the mode of urbanisation, the type of impact of climate change, the mitigation and adaptation strategies of urban populations provide institutions such as UN-HABITAT with information on good practices to improve policies in other African cities.

ii. Performance Improvement: The research results enable national institutions, Non-Governmental Organisations (NGO), programmes and departments working in the field of urbanisation and climate change to operationalise their intervention. In Burkina Faso, the General Directorate of Urban Planning and Land Works, the town halls of the different districts, the National Climate Change Adaptation Programme and the National Urban Planning and Climate Change Programme can improve their performance with updated data on urbanisation and the spatial distribution of climate change impacts. In Nigeria, it is the department of Urban Planning and Housing Development and the department of Climate Change who can improve their performance with these results. To better guide decision making, the disaggregation of data by district for the city of Ouagadougou and by Local Government Area (LGA) for the city of Abuja allow the district and LGA managers and the departments of the ministries to have the situation of each administrative zone in terms of the type of impact of climate change, its mode of manifestation and the adaptation strategies of the populations. This information enables them to better choose the type of intervention as well as the area of implementation.

iii. Body of knowledge: The results of the research bring knowledge on the effects of urbanisation and its influence on the urban climate to the general public. Indeed, this research, through the analysis of good practices in managing the effects of climate change in Ouagadougou and Abuja, serve as a tool for the development, planning, and dissemination of climate change mitigation and adaptation strategies. In addition, the modelling of urbanisation and climate projections in the two urban areas inform populations, planners, researchers, and decision makers of the potential impacts of climate change by 2052. Therefore, it allows for anticipation in terms of urban planning and mitigation and adaptation strategies to future impacts.

1.6 Description of Study Area

The study area covers two major cities, namely Abuja (Nigeria) and Ouagadougou (Burkina Faso). Several reasons motivated the choice of these cities. The first reason for choosing Abuja and Ouagadougou was to compare the urbanisation pattern of a capital city in a developing country and an underdeveloped country in West Africa. Secondly, in terms of population growth between 1992 and 2022, these cities have approximately the same trends. The third reason is the nature of their administrative function. Indeed, these two cities are political capitals. The choice of these two cities is also justified by their similarity, in term of their geographical location. Indeed, they are located in the centre of the countries. In addition, the two study areas have approximately the same type of vegetation as they are in the savannah zone. Finally, they are located in similar climatic zones.

1.6.1 Location of study areas

Abuja, the first study area, is the capital city of the Federal Republic of Nigeria. It is geographically located between latitudes 8° 25´and 9° 25´ north of the equator and longitudes 6° 45´ and 7°45´ (Atewamba and Yong Ngondjeb, 2020) east of the Greenwich Meridian. Abuja is bordered by Nassarawa State to the east, Kaduna State to the north, Kogi State to the south and, Niger State to the west. There are 6 Local Government Area (LGA), Abuja, Abaji Municipal, Gwagwalada, Bwari, Kuje and Kwali in the Federal Capital. Ouagadougou is the political capital of Burkina Faso. The city of Ouagadougou is located in the middle of the province of Kadiogo. It is geographically located between latitude 12°15 and 12°30 North and longitude 1°25 and 1°43 West. Ouagadougou is bordered by several rural communes. The city is bounded to the east by the communes of Saaba and Loumbila, to the west by the commune of Tanghin-dassouri, to the north by the commune of Pabré, and to the south by the communes of Koubri and Komsilga. The city currently has 55 sectors divided into 12 arrondissements. The Figure 1.1 shows the location of Abuja and Ouagadougou.

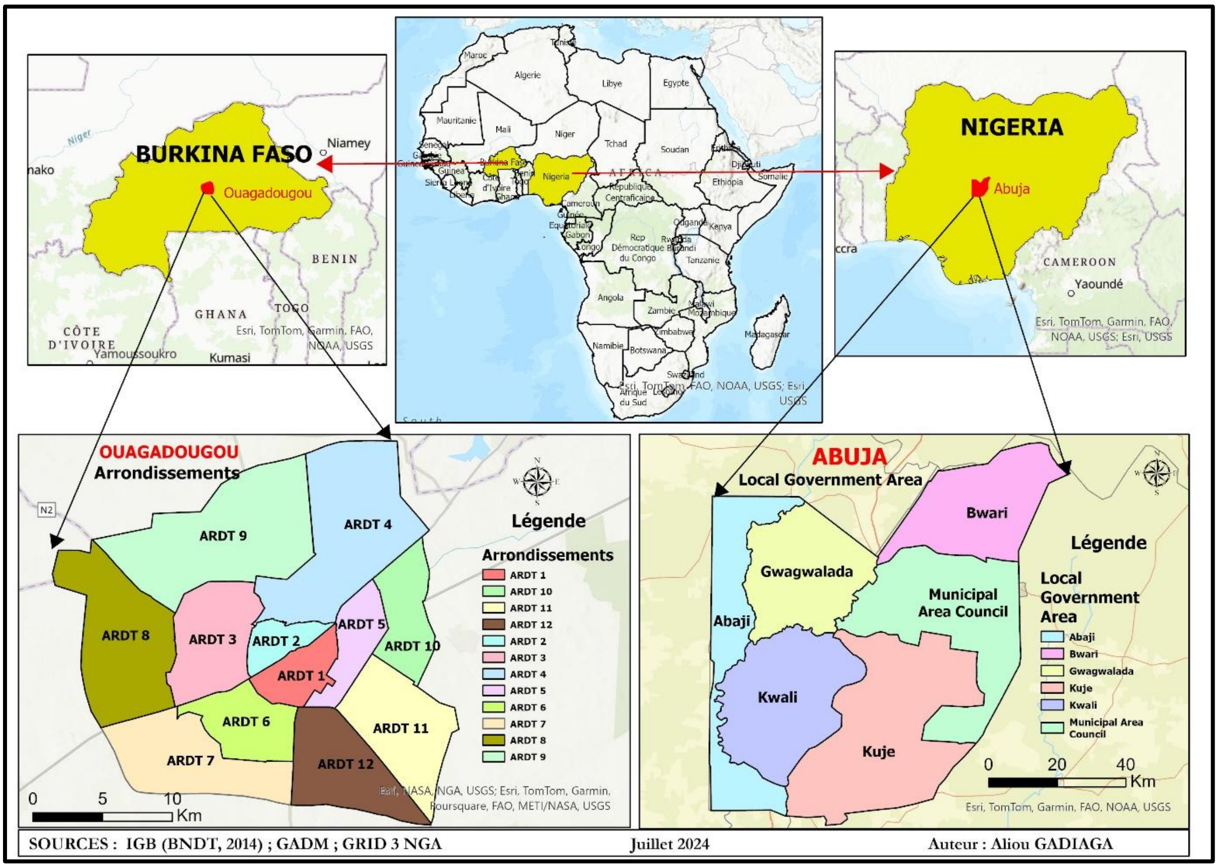


Figure 1.1: Location of the Study Area

1.6.2 Climate

In this research, the description of the climate of the study area is important due to the of flooding and heat waves in the cities. According to the classification of (Köppen, 2024) the climate of Abuja is classified as Aw Equatorial savannah with dry winter (Aw). This type of climate is characterised by an average temperature of 18°C or above during the twelve months of the year with one winter month having a rainfall of less than 60 mm. The tropical type of climate, characterised by a wet season and a dry season, is the most dominant in Abuja. Rainfall is higher in summer than in winter. The average annual temperature is around 26.0°C with an average annual rainfall of 1469 mm. Relative humidity is about 50% in the wet season and 20% in the dry season. Due to its location near the windward side of the Jos Plateau, rainfall in Abuja is mainly orographic (Okunola *et al.,* 2014) . Indeed, the lowest relative humidity is measured in January (26.36%) and the highest relative humidity is measured in August (86.72%). On average, December (0.23 days) is the month with the fewest rainy days, and the month with the rainiest days is August (28.27 days).

Because of its location in the intertropical zone, Ouagadougou has a Sudan-Sahel type climate characterised by the alternation of two (2) very contrasting seasons. A long dry season that extends from October to April and a shorter rainy season (5 months) that generally begins in May and ends in September. Rainfall is a function of the swing of the Inter-Tropical Front (ITF), which is the line of contact between the two air masses, the monsoon and the harmattan (Soma, 2015). Rainfall in Ouagadougou varies on average between 600 and 900 mm. The rainy season is marked by the monsoon winds and the dry season is marked by the harmattan winds. From November to April, the city is under the influence of the harmattan. Relatively weak winds blow at a speed that varies between 2 and 2.3 m/s. The winds become more violent between May and July (speed above 2.3m/s), but then decrease slightly in August and September. This is the period of precipitation, often accompanied by thunderstorms, which are the cause of violent (INSD, 2006).From December to January, monthly temperatures vary between 14.3 and 23.7°C and from July to September, they vary between 22 and 24°C. March to June is the driest and hottest time of the year with monthly temperatures of around 37 to 40°C. From October to November, maximum temperatures reach 35°C (Rodrigue, 2016).

1.6.3 Vegetation, soil and drainage

In Abuja, the dominant vegetation of the territory is grassy savannah, shrub savannah and tree savannah. The grassy savannah occupies the largest area of the territory. Several types of species can be found here, including Butyrospernum paradoxum, Albizia, Parkia Clappertoniana, Zygia. The shrubby savannah occupies an important part of the area and is located on the rugged terrain near the hills and ridges. The types of trees generally found in the shrub savannah are ceiba pentandra, cola gigantean, triplochiton scleroxylon, dracacna arborea. The tree savannah occupies the smallest part of the territory. Vegetation is composed of a variety of species, including butyroscarpus paradoxim, Africana anogeissus, ptrecarpus erinaceus, khaya senegalensis, prosopis africana, bombox costatum, and may others.

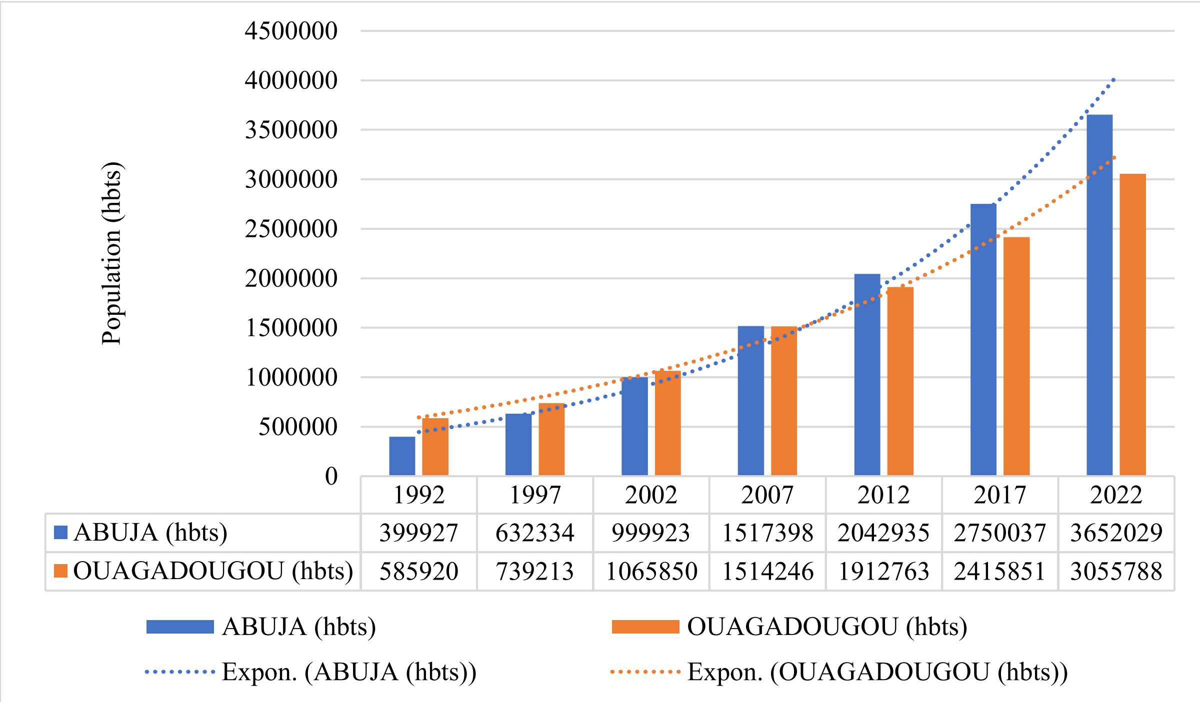
In the Ouagadougou commune, due to the low rainfall, the most dominant vegetation cover is the open shrub savannah. A wooded savannah is also found along temporary watercourses. According to Soma (2015) the city's forest reserves consist only of the classified forests of Bangr-wéogo (265 ha), the National Centre for Scientific and Technological Research (CNRST), some green spaces and portions of the green belt, and alignment plantations along the roads and in the concessions. Vegetation is made up of species such as Acacia nilotica, Acacia seyal, Azadirachta indica, Eucalyptus camaldulensis, Gmelina arborea, Lannea microcarpa, Mangifera indica, Peleoforum ferrigenum, Cassia siamea, Azadirachta indica, Eucalyptus camaldulensis, Moringa oleifera, Mangifera indica.

Relief and soil are factors that help to understand the settlement of people in certain areas. They explain the high concentration in some places and the underpopulation of certain areas. In Abuja, the soil structure is diverse. The underlying rocks are mainly composed of complex sedimentary and basement rocks. In some areas, the terrain is occupied by dissected land and hills (Mabogunje, 1977). In addition, the soils in Abuja are generally shallow and sandy in nature. On the one hand, the shallowness reflects the presence of stony lower horizons and, on the other hand, the high sand content makes the soil highly erodible (Olubunmi and Ndubuisi, 2011). The areas underlain by sedimentary rocks cover approximately 52% of the total area of the Federal Capital Territory (Balogun, 2001). The geological formation of the region includes rocks that form hilly physiographic features. The topography is undulating, rugged, and bedrock outcrops in the form of hills and inselbergs (Agunwamba, 1998).

The city of Ouagadougou is located in the vast central peneplain of Burkina Faso with an average altitude of 300 m. The geological substratum is essentially made up of migmatites and undifferentiated granites laid down in the precambrian D or Antebiriminian. This topographic formation is part of the old crystallophyllous ensemble of ante-Cambrian age, flattened and covered by a fairly continuous but irregularly thick mantle of alterites, armour, and detrital deposits (Ministere l'Urbanisme et de l'Habitat, 2008). Ouagadougou is mainly characterised by four types of soil: raw mineral soils, leached ferruginous soils, hydromorphic soils and solnetz or halomorphic soils. Hydromorphic soils cover most of the city. The nature of the soils, the flatness of the relief, and the absence of physical constraints (plains, hills, river) are factors that favour the horizontal spread of the city. In addition to soil, demography is a characteristic element of urbanisation dynamics.

1.6.4 Population trends in Abuja and Ouagadougou

The link between population growth and urban sprawl is clearly defined. Indeed, the analysis of the evolution of the population over time allows us to understand how it has occupied space. According to the data from World Population Review (2022), the population of Abuja was estimated at 399,927 in 1992 and increased to 3,652,029 in 2022. In the same period (1992 to 2022), the population of the city of Ouagadougou increased from 585,920 to 3,055,788. Figure 1.2 shows the population of the two cities during this period.



	1992	1997	2002	2007	2012	2017	2022
ABUJA (hbts)	399927	632334	999923	1517398	2042935	2750037	3652029
OUAGADOUGOU (hbts)	585920	739213	1065850	1514246	1912763	2415851	3055788

Figure 1.2: Evolution of the Abuja and Ouagadougou Between 1992 and 2022

Source: World Population Review (2024)

1.6.5 Population density in Ouagadougou and Abuja

The growth of the population in the study area has led to its spatial distribution. The Global Human Settlement Layer (GHSL) is a combination of satellite image data showing population trends worldwide and by city since 1975, with predictions for 2030 (GHSL, 2023). The spatial raster product of the Global Human Settlement Population (GHS-POP) (GHS-POP_GLOBE_R2023) depicts the distribution of the human population (Figure 1.3), expressed as the number of people per cell in 2020.

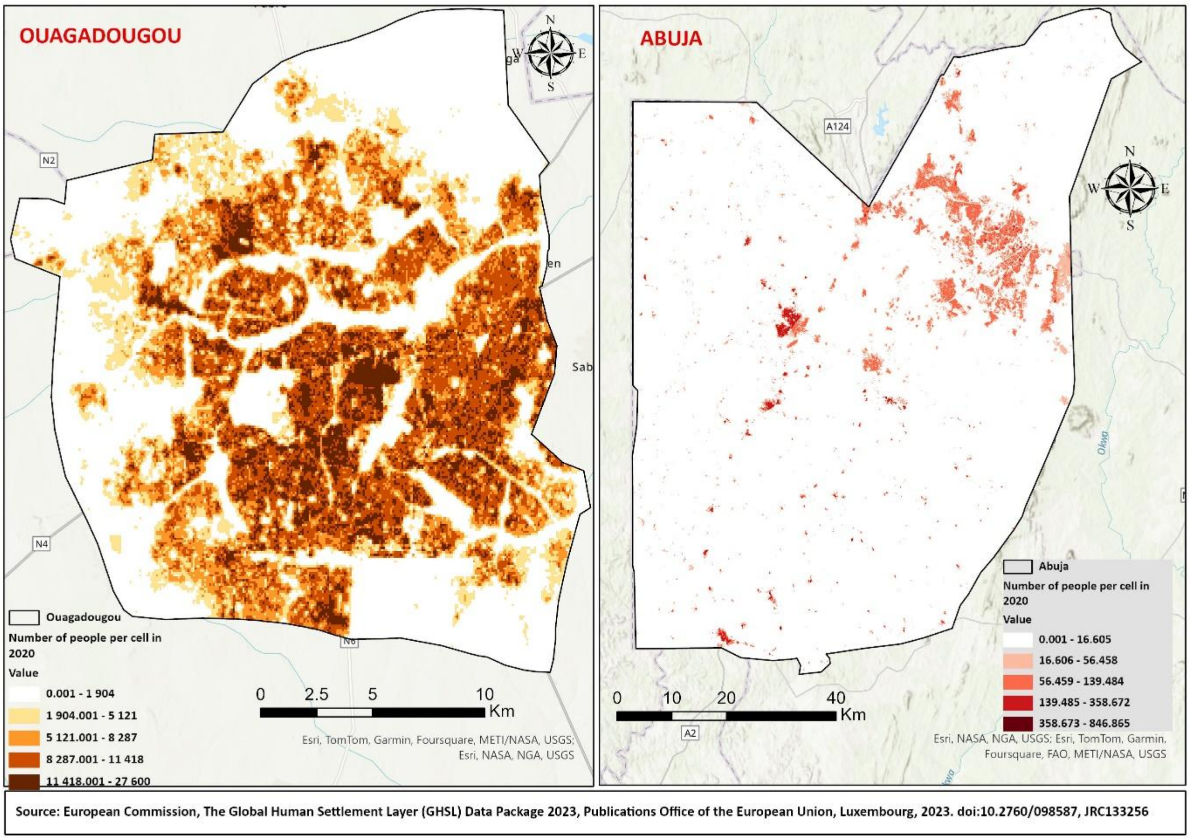


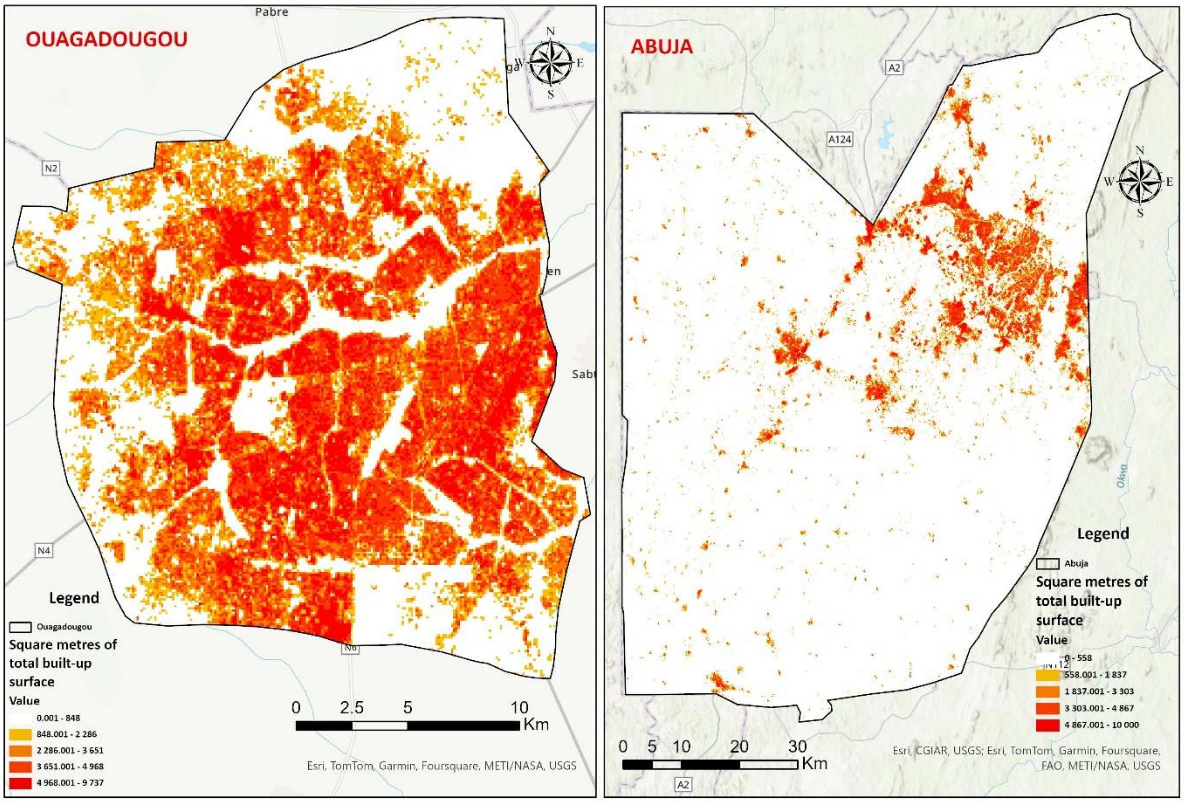
Figure 1.3: Spatial Distribution of Populations in Ouagadougou and Abuja in 2020

Source: European Commission, The Global Human Settlement Layer (GHSL) *data package 2023.*

1.6.6 Built-up Density in Ouagadougou and Abuja

The increase in population and its spatial distribution have led to an increase in the area occupied by houses. By combining the time series of Landsat and Sentinel-2 satellite images

GHSL (2023) have made a spatial interpolation of the evolution of built-up. The spatial distribution of the houses (Figure 1.4) shows the area per square metre occupied by the houses in 2020 in Ouagadougou and Abuja.



Source: European Commission, The Global Human Settlement Layer (GHSL) Data Package 2023, Publications Office of the European Union, Luxembourg, 2023. doi:10.2760/098587, JRC133256

Figure 1.4: Spatial Distribution of Built-up in Ouagadougou and Abuja in 2020. Source: Source: European Commission, The Global Human Settlement Layer (GHSL) *data package 2023.*

1.7 Scope of the Study

To better understand the link between urban growth and increased vulnerability to the effects of climate change, the period 1992-2022 was chosen to understand the phenomenon in the past and present. There are several reasons for choosing this time period. In fact, climate is perceived as the average conditions of the atmosphere in a given location calculated from at least 30 years of observations, which justifies the 30-year period to comply with the minimum time for observing the evolution of climate change. Furthermore, this time dimension coincides with a period of significant urban expansion. The year 2007 was marked by the evolution of the world population because the urban population surpassed the rural population. Therefore, it is useful to look at what happened 15 years before and 15 years after this date to better analyse these urban dynamics. Finally, this period is marked by the availability of data on general population censuses, statistics on imports and the marketing of vehicles and motorbikes, but also and above all satellite images, which will be used to analyse the spatio-temporal dynamics of the expansion of cities as well as the evolution of certain climatic parameters during the same period. In addition, the period 2022 to 2052 was chosen to simulate the future evolution of the impacts of change in the urban environment based on climate and population projections.

In terms of global development, some countries are said to be developed, while others are underdeveloped or developing. The study area concerns Nigeria, which is a developing country and Burkina Faso, which is an underdeveloped country. Within these countries, the political capitals Abuja (Nigeria) and Ouagadougou (Burkina Faso) were chosen. Indeed, over the past three decades, both cities have experienced rapid demographic growth, which is reflected in the spatial expansion of their areas. Their similarity, i.e. their geographical location in the centre of the country, their belonging to the savannah zone, and their administrative function justified their choice.

This study is concerned with two phenomena, namely urbanisation and climate change. Firstly, it focuses on the analysis of the evolution of the population, the spatial expansion of cities and the environmental problems this causes. Secondly, it discusses the evolution of climatic parameters mainly temperature, precipitation and wind and their direct impact such as floods and heat waves in urban areas. Thirdly, it discusses mitigation and adaptation strategies for populations facing the effects of climate change.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Conceptual Framework

Conceptually, urbanisation is defined as an increase in the percentage of the urban population (Pacione, 2009), or the increase in the share of a society's population living in cities (Wyly, 2011), or urban population growth equals population movement from rural to urban areas, which is equivalent to urban migration (United Nations, 2005). However, it should be noted that urbanisation cannot be defined solely on the basis of population density (Pigeon, 2007); this term refers not only to population growth: high density and urban concentration (Barattucci, 2004), but also involves quantitative and qualitative changes in the economic, social and political structure of a region or country (Yadav and Sinha, 2003). The term "urbanisation" also refers to the historical phenomenon of the transformation of society, which manifests itself in an increasing concentration of the population in urban agglomerations. Urbanisation is measured by the number of inhabitants in cities in relation to the total population, the population density, the territorial extension of cities and its consequences on the way of life (Anne, 2019).

The meaning of the term "urbanisation" is quite complex and unclear depending on the discipline. Urbanisation has different meanings in different disciplines, including geography, demography, sociology and economics. For some disciplines, the focus is on the size of the population of the area. In contrast, other disciplines broaden their focus and include economic and social considerations to adjust the classification according to size. For example, if an area offers many urban services or an urban lifestyle, even if it is small, it can be classified as urban. Whereas a large settlement that is mainly agricultural and does not have urban services can be classified as rural (Dijkstra *et al.,* 2021).

Urbanisation, in fact, is the non-spatial and social process that addresses changes in behaviour and social relations. This social dimension has become important for people living in cities. Essentially, it refers to the complex change of life style according to the impacts of cities on societies (Tran, 2018).

Pigeon (2007) states that urbanisation refers to the intensification of a structural trend of human settlements towards greater densification, combined with increased specialisation of functions. The process of urbanisation in Africa is perceived less negatively by the international community. On the one hand, it is understood that urban growth is structural: no policy has been able to oppose it effectively, and it is better to accompany it than to fight it. On the other hand, the urban fact is gradually being restored in people's minds as a factor of economic and cultural development, in line with what it has been on other continents (Paulais, 2012). According to Barattucci (2004), urbanisation is also defined as an economic and social, political and cultural process that is leading humanity towards new forms of civilisation that are increasingly urban in a non-agricultural sense, characterised by high-density formations and by settlements that are totally separate from the work of the land. Urbanisation is therefore an increase in the number of people living in cities, characterised by a sprawl of areas used for housing and a decrease in natural and rural areas. Urban sprawl through land use and transport contribute to climate change through CO2 emissions, air pollution and energy consumption.

In recent decades, climate change has become a real issue for the international community. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change in its article 1 as "changes in climate which are attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which are in addition to natural climate variability observed over comparable periods"

(United Nations, 1992). Therefore, the Convention distinguishes between human activity causing climate change and natural causes causing climate change.

For the GIEC (2018) Climate change is the variation in the state of the climate that can be detected (by statistical tests, etc.) by changes in the mean and/or variability of its properties and that persists over an extended period of time, typically decades or more. Climate change may be due to natural internal processes or external forcings, including modulations of solar cycles, volcanic eruptions or persistent anthropogenic changes in atmospheric composition or land use. Climate change occurs through weather changes such as temperature, precipitation and winds (Ali and Erenstein, 2017). For O'Brien *et al* (2006), Climate change is a natural phenomenon that is being accelerated by human actions. According to the Food and Agriculture Organization (2008), climate change is the result of human actions that result in the continued and increasing emission of greenhouse gases, loss of vegetation cover and other carbon sinks. In other words, climate change is a change in climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere.

The conceptual framework of the study is based on two main factors, urbanisation and climate change. Urbanisation through, population, land use and transport lead to changes in the environment, including an increase in impervious surfaces, forest degradation, and changes in the chemical composition of the atmosphere. This change in the environment leads to environmental impacts in terms of gas emissions, air pollution and urban heat islands. These different effects lead to impacts such as flooding, heat waves, and windstorms. Faced with these impacts, urban populations use strategies to adapt to them or mitigate their effects. Figure 2.1 show the conceptual framework of this study.

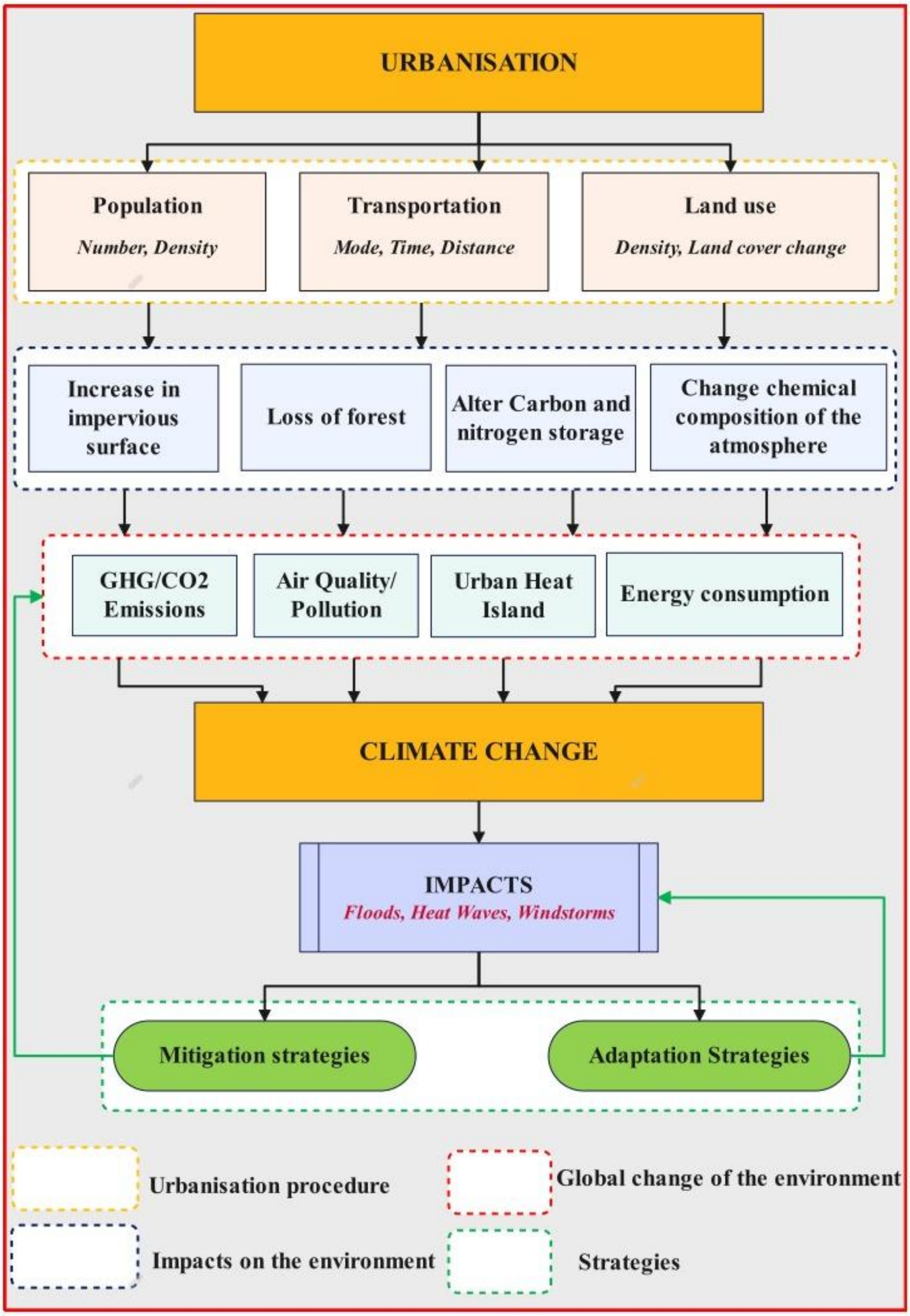


Figure 2.1. Conceptual Framework

2.2 Theoretical Framework

2.2.1 Climate change theory

2.2.1.1 *Human forcings besides greenhouse gases theory*

Joseph L. Bast's theory of human forcings and greenhouse gases argues that greenhouse gas emissions do not have the greatest impact on climate, but rather that occupation and changes in the Earth's surface, forest resource use, and the expansion of inhabited areas are the main causes of climate change (Bast, 2013). According to Roger Pielke, quoted by Bast (2013) this theory states "while natural causes of climate variation and change are undoubtedly important, human influences are significant and involve a diverse range of first-order climate forcings, including, but not limited to, the human input of carbon dioxide (CO2)". Human forcings include deforestation, urban heat islands, aerosols, and ozone.

According to this theory, urban heat islands are stronger in the city centre, medium in the peripheral areas and weaker in the rural areas. This variation is explained by the presence of vehicles, factories, houses and roads in the city centre and the presence of vegetation in rural areas. In addition, Pielke (2009) estimated that the effect of human aerosols on the regional radiative warming gradient "is about 60 times that of well-mixed greenhouse gases". Finally, deforestation releases CO2 into the atmosphere and prevents forests from sequestering carbon. According to Myhre *et al*. (2013), anthropogenic land cover change has a direct impact on the Earth's terrestrial radiation balance and also impacts on climate. In addition, land use, particularly deforestation, has significant impacts on greenhouse gas concentration.

2.2.1.2 *Anthropogenic Global Warming (AGW) theory*

The first theory of climate change argues that the catastrophic rise in global temperatures is mainly related to greenhouse gas emissions produced by human activities and that about 50% of the increase in the concentration of CO2 in the atmosphere is caused by human activities, such as deforestation, wood and fossil fuel burning (Bast, 2013).

The Earth experienced a "global warming" of about +0.6˚C between 1970 and 2000, and according to the IPCC this is due to human CO2 emissions but some scientists say it is due to normal natural variations in climate, i.e. natural global warming (Mörner, 2018). Bast (2013) states that, the Earth's climate also responds to several other types of external influences, such as variations in solar radiation and the planet's orbit, but these 'forcings', according to AGW proponents, cannot explain the increase in the Earth's temperature over the past three decades. According to Joshi and Joshi (2019), a large number of organisations such as the National Aeronautics and Space Administration (NASA), the World Meteorological Organization (WMO), the European Space Agency (ESA), the Network of African Science Academies, the European Science Foundation (ESF), the Royal Society (UK national academy of science), the National Oceanic and Atmospheric Administration (NOAA), and the US Environmental Protection Agency (EPA) believe that human activity is a major cause of global climate change. However, some organisations such as the American Association of Petroleum Geologists, the Competitive Enterprise Institute, the Heartland Institute, the Heritage Foundation, the CATO Institute, the National Centre for Policy Analysis, the American Enterprise Institute, the George C. Marshall Institute argue that nature, not human activity, is primarily responsible for climate change.

Cook *et al.,* (2013) analysed the scientific consensus of "global climate change" or "global warming" using abstracts of scientific articles. The results show that one third of the

11,944 papers, or about 3,800, support global warming. For Parncutt (2019), Greenhouse gas emissions indirectly cause future deaths through multiple mechanisms. For example, reduced food and water supplies will exacerbate hunger, disease, violence and migration. AGW proponents believe that man-made CO2 is responsible for floods, droughts, bad weather, crop failures, species extinctions, the spread of disease, coral bleaching, famines and hundreds of other disasters. They believe that all these disasters will become more frequent and more severe as temperatures continue to rise (Bast, 2013)

2.2.2 Urban growth theory

According to Planning Tank (2022), as cities expand and urban development takes place, cities undergo various changes. City structure and land use patterns have distinct characteristics and discernible trends. Thus, urban patterns are created to help us understand why a particular activity or land use occurs in a particular place or region. For example, city centres are dense in terms of population, and have high land values. The cities are characterised by diverse economic activity and vertical development. These characteristics are part of urban studies and the urban land use model.

The global urban revolution has manifested itself in different ways over the last few centuries. Urban growth over time has been referred to by concepts. According to Noureddine (2013) the effects of industrialisation in the 19th century led to major changes in urban structures. In the 20th century, appear the birth of modern urbanism. At the beginning of the 21st century, appear urban renewal, the revaluation of housing and the emerging city which houses tens of millions of inhabitants. Thus, the growth of cities has led the scientific community to develop different models.

2.2.2.1 *Burgess' concentric zone model of urban growth*

In 1925, Ernest W. Burgess was among many researchers who created a model of urban growth. This theory was developed on the basis of observations of the city of Chicago in the 1980s at the beginning of the twentieth century. Burgess theorised that urban land use is organised in concentric rings around the Central Business District (CBD), each ring having a different land use (Adhvaryu, 2010). Burgess' model defines the urban spatial organisation in concentric rings from the centre to the periphery. Burgess conceptualised the city in five concentric rings comprising successively the central business zone, the transitional zone, the residential working class zone,, the residential zone and the suburban suburbs (Noureddine, 2013).

Indeed, each is characterised by a specific type of infrastructure. The first is the most accessible because it is the centre of the city. In this area there are shops, banks, offices, hotels and restaurants, and many others. The second zone is located around the first one. It is called the transition zone and is characterised by the presence of businesses and industries. The third zone is residential. It is inhabited by workers from the second zone who wish to live near their workplaces. The fourth zone is also residential, but is characterised by high-quality housing and inhabited by the middle classes. It is made up of flat blocks and high standard flats. The fifth and last zone is the furthest from the city centre. It is the peripheral zone or the suburban area. It is characterised by the presence of agricultural areas and, therefore, more vegetation. Burgess noted that not only did the CBD exert pressure on the area immediately surrounding it as the city grew and developed, but also that inner-city housing was largely occupied by immigrants and households of low socioeconomic status. The remarkable feature of this theory is that it found a positive correlation between income status and place of residence (Adhvaryu, 2010).

2.2.2.2 *Homer Hoyt's polynuclear or sectoral urban growth model*

In 1939, Homer Hoyt developed the polynuclear urban growth model or sector theory as part of his work on socio-spatial segregation. This model is an extension of Burgess's concentric city. Each space, of distinct size, is dedicated to a specific activity and/or social status. However, Hoyt added the idea of the permanence of certain spaces. He defines these permanent spaces by their attractiveness, particularly in their proximity to transport networks (Noureddine, 2013). Homer Hoyt conducted his study of rent patterns in 25 United State cities. He came to the conclusion that land use tends to conform to a pattern of sectors rather than concentric circles. Furthermore, he notes that urban sprawl occurs mainly along roads. Furthermore, he also points out that accessibility is a factor that determines the price of rent, as the more accessible a piece of land is, the higher its rent will be. Lastly, Hoyt noted that the high income classes have gradually dispersed from the Central Business District along faster transport lines (Adhvaryu, 2010).

2.2.2.3 *Harris and Ullmann's multicentre urban growth model 1945*

In 1945, a new approach to a multicentre urban growth model emerged. This new approach was developed in the work of Harris and Ullmann. They argued that geography is a discipline of social interaction, but not only a discipline that studies the relationship of human groups to their environment. Based on earlier approaches to urban growth, they developed the multicore city model. In this model, they propose a multicentric representation of the city where independent centres develop on the basis of competition for land use. For example, light industry and commerce are located along the roads. On the outskirts of the city there is heavy industry that may be surrounded by low-income households. Thus, this pattern of development is characterised by the presence not of a single CBD, but of several.

For Planning Tank (2022), the Harris and Ullman model attempts to explain the structure of the city by taking into account complexity and growth over time. Indeed, a city may start with a single Central Business District (CBD), but over time, activities disperse and change. Dispersed activities attract people from surrounding areas and act as small nodes in themselves. These small nodes grow in importance and size and begin to influence land values and the growth of activities around them.

According to this theory by Harris and Ullman cited by Adhvaryu (2010), there are four main factors responsible for the emergence of subcentres, as follows:(i) interdependence between activities and the need to be in close proximity; (ii) the natural tendency to cluster, which are mutually profitable; (iii) incompatibility of functions and special area (land) requirements; and (iv) the high cost of land, which has had an impact on the nucleation process.

In conclusion, it should be noted that the three previous theories are different. Indeed, Burgess' concentric theory is more specific to settlements that do not have a peripheral subarea, while Ulman and Harrris multi-nuclear model correspond more to a city with suburban areas, and Homer Hyot's sector theory is more applicable to cities or medium-sized settlements. Harris and Ullmann's multicentre Urban growth model is the more suitable for this study.

2.3 Review of Related Studies

For a consistent orientation of this research, an emphasis was placed on the literature review of previous studies on the topic. The literature related to the research topic is presented thematically.

2.3.1 Spatial and temporal characteristics of urban expansion

Urban expansion in time and space has been the subject of several studies around the world using different types of data, tools, and methods. According to Zhong *et al.* (2020), it is crucial to examine how an urban area is growing as well as the factors that contribute to it. A study by Deng and Quan (2023) on intensity analysis of LULC using enhanced intensity analysis and landscape matrices carried out in Chang-Zhu-Tan Metropolitan (China) revealed an overall change in LULC accelerated in 40 years, with intensity expanding 16 times. Their study also shows that the areas occupied by the built up come mainly from spaces that were previously occupied by forests and cropland.

A research conducted by Tao and Ye (2022) on analysis of the spatiotemporal characteristics of Nanjing's urban expansion and its driving mechanisms using satellite images showed that the urban area of Nanjing increased by 3.97 times from 2001 to 2021. Furthermore, among the determining factors that promote or restrict urban expansion, the authors were able to identify topography, distance to planned municipal and sub municipal commercial centres, distance to railways and highways, and distance to the Yangtze River. However, the study does not highlight the environmental implications of Nanjing's urban expansion. In a current context marked by environmental and climatic problems, it would be interesting if the study had been able to show the future evolution of this growth of the city or the current impact of these spatiotemporal dynamics of the city on natural resources or vegetation. In this research, the aim is to fill this gap by showing how the spatial dynamics of a city can have impacts on vegetation, but also how this can increase its vulnerability to climate change phenomena such as floods and heat waves.

Huang and Zhang (2022) analysed the characteristics of urban growth in Vientiane, the capital of Laos, between 2000 and 2019. The study reveals that despite the declining annual rate of urban growth in some regions of the world, small and medium cities in Southeast Asia are facing rapid urbanisation. In terms of characteristics of urban growth, the study found that the city is experiencing rapid urban growth. In fact, between 2000 and 2019, the urban land increased from 25.93 km2 to 62.12 km2. The study concludes that this spatial dynamic of the city is a threat to the urban environment. Among the factors that have contributed to urban growth are migration, socioeconomic conditions, and especially the development of communication routes such as roads. However, the study did not specify the role of physical factors such as relief and topography in urban sprawl.

In Osogbo (Nigeria), the change detection analysis used to determine urban growth areas revealed that the built area in 1989 were 6.04 percent of the study area and increased to 36.42 percent in 2021, demonstrating a consistent growth in the size of the built-up area (Idowu *et al.*, 2023). A study carried out in Ouagadougou on Intensity Analysis for Urban Land Use and Land Cover Dynamics Characterisation using the Random Forest, Support Vector Machine and Gradient showed that the landscape is changing with a maximum annual change intensity of 3.61% recorded between 2015 and 2021 (Ouedraogo *et al.*, 2023).

Furthermore, urban dynamics are associated with the degradation of vegetation. Despite the ecosystem services that vegetation provides to urban populations, it is facing ongoing degradation as a result of urban dynamics (Richards and Belcher, 2019). Urbanisation and the dynamics of urban expansion can have an impact on vegetation in cities if urban planning is not properly controlled (Dangulla *et al.,* 2023). The study of the spatial dynamics of Tenghory (Senegal) and its effects on vegetation showed that the increase in urban population and the expansion of the built-up are among the factors that have led to the disappearance of vegetation (Faye, 2023).

2.3.2 Impacts of climate change in urban areas

The urban environment of non-coastal cities faces the impacts of climate change such as floods, heat waves, high temperatures, windstorms, and droughts. These climatic phenomena have an impact on the health, activities, comfort and homes of urban populations. In fact, in urban areas, climate change leads to a wide variety of economic, environmental, and social impacts (Khamis, 2022).

Causes of flooding vary from city to city. Research by (Assonsi *et al.,* 2014), discovered that the main reasons why the risk of flooding in the city of Ouagadougou is greater than in the past are climate change, human activity, and the quality of the buildings. In their view, the urbanisation of so-called flood-prone areas is the factor most incriminated by the population.

Another study (Francis, 2019) on flooding in the city of Ouagadougou showed that the causes are demographic growth, urban sprawl, degradation of vegetation cover, and an increase in impervious surfaces. The study revealed that the corresponding rate of impermeability is 63.23% for the entire city of Ouagadougou and concluded that the risk factors for flooding are both natural and anthropogenic.

The consequences of flooding in urban areas are multiple. A study conducted by Halder and Bandyopadhyay (2021) on assessing the impact of climate change in the planning urban area of Bilaspur. Referring to current urban dynamics, the authors argue that rapid urbanisation is one of the aspects responsible for the global land crisis and that this has adverse environmental consequences and effects on the climate. In fact, they argued that land scarcity worldwide is caused by rapid urbanisation and industrialisation. They combined Geographic Information System (GIS) and remote sensing to analyse the dynamics of land cover and land use in the Bilaspur planning area (India) over the last 40 years (1981-2020). The study concluded that the transformation of agricultural land and forests is linked to several factors, including the evolution of urban households, population pressure, and climate change. Furthermore, their results show that between 1981 and 2020, the urban area of Bilaspur has increased by about 47.9 km^2. Therefore, some land use units have been drastically reduced. For example, vegetation and forests have decreased due to anthropogenic activities. The annual UHI increased by 0.11 while the high values of the UTFVI were 0.0206 (1981) and 0.0326 (2020).

This study has shown the link between urban growth and climate change in urban areas. However, the study did not address certain aspects, particularly those related to perceptions of climate change impacts by populations. In other words, a triangulation of primary data with the results of satellite images could provide greater precision on these impacts in terms of their mode of manifestation. Also, in such a context, it is necessary to investigate the mitigation and adaptation approaches adopted by populations in the face of heat waves.

In terms of approaches to characterising climate change hazards in cities, there is the Hierarchical Analysis Process (AHP) method. It has been used by several authors to analyse the distribution of phenomena such as floods and heat waves.

For instance, Makhasana and Joshi (2023) used the Hierarchical Analysis Process (AHP) method to characterise flood susceptibilities at Mazam-Watrak in India. Their results showed a spatial distribution of flood susceptibilities in the catchment area. Thus, the approach identified areas of high susceptibility, low susceptibility and moderate susceptibility. In addition, (Ziadi and Keraghel, 2024) used this multi-criteria analysis approach to assess the vulnerability of Algiers (Algeria) to flooding. The results of the study also show a spatial distribution of vulnerability to flooding in the study area according to several levels (very high, high, moderate, low, very low). In Siraha Municipality (Nepal), Parajuli *et al.* (2023) adopted the Hierarchical Analysis Process

(AHP) approach to characterise flood susceptibilities and a map of evacuation routes. The results also show the spatial distribution of flood susceptibilities.

However, these studies used these approaches to characterise flood susceptibilities, vulnerabilities, and impacts, but did not take account of their spatial distribution by geographical area. In these studies, the local distribution is not taken into account. The maps of these impacts show only an overall distribution in the study area.

2.3.3 Mitigation and adaptation in urban area

Modifying the physical and social infrastructure of the city improves its resilience to climate change (Rebotier *et al.,* 2017). Several adaptation and mitigation strategies for climate change have been developed by certain institutions and implemented by urban populations. Since 2008, the United Nations Framework Convention on Climate Change introduced the ecosystem-based approach to adaptation to climate change, based on the management, preservation, and restoration of ecosystems (Khamis, 2022). Busayo *et al*. (2022) have implemented a comprehensive approach to the foundations of ecosystem-based adaptation. This approach integrates ecosystem services and biodiversity as a method for adapting to climate change and disaster risk reduction. It is based on mitigation, preparedness, response, and recovery. The first action is mitigation, which involves taking action in advance to reduce damage. The second action is preparedness, whose activities include testing plans, training, making arrangements, assessment, and dissemination of information to prepare peoples for the damage. The third action to be undertaken is the response. It consists of providing assistance and intervention not only during and after the damage but also to protect lives and property. For instance, Kuhlicke *et al*. (2020) mentioned that the need for citizens to take adaptation measures to reduce the impacts of climate change, particularly flooding, has been the subject of recent policy changes. But in their view, the effectiveness of these measures depends, firstly, on a good understanding of the motivations of citizens to take adaptation measures, which will enable them to be targeted in risk management practice; secondly, private adaptation measures and actions must be effective in reducing risks; and thirdly, individuals must have the capacity to implement these actions (Kuhlicke *et al.,* 2020).

Achieving global progress in humanity's response to climate change is a major concern (Berrang-Ford *et al.,* 2021). For instance, Kalbarczyk and Piegat (2021) argued that choosing measures to adapt to climate change in urban areas is difficult because it requires an individual approach. In addition, people take action to protect themselves from immediate dangers, rather than taking action to achieve long-term adaptation objectives (Carman and Zint, 2020).

However, Van Valkengoed *et al*. (2022), in their study on the climate change and adaptation actions, have highlighted the need to understand the general psychological antecedents that motivate people to undertake different climate adaptation actions. According to their research, the more people consider climate change to be a reality, caused by man and with adverse effects, the more likely they are to defend adaptation policies and look into local climate impacts and adaptation strategies.

Urban areas offer a number of advantages in terms of mitigating climate change. Due to their density, effectiveness, and acceptance of new ideas and technologies, cities can offer solutions to mitigate greenhouse gas emissions (Hoornweg *et al.,* 2011). Since the start of the twenty-first century, several cities have included mitigation more often than adaptation in the various planning processes that local governments carry out.

In terms of approaches to evaluating climate change adaptation and mitigation strategies based on sociodemographic and socioeconomic data, some studies have adopted logistic regressions, others have used Multiple Component Analysis (MCA) and Ascending

Hierarchical Classification (AHC). Agboola *et al.* (2024) used a logistic regression analysis to examine the predictors of climate change and adaptation strategies in Nigeria. Additionally, Kondo *et al.,*(2021) used a multiple logistic regression to analyse climate change adaptation and mitigation strategies of people in Fukuoka City in Japan. Furthermore, Calculli *et al.* (2021) used a Multiple Correspondence Analysis to assess public awareness of climate change and environmental issues. Their study identified participants and classified them according to their understanding of environmental impacts and awareness. Finally, using Multiple Component Analysis and Ascending Hierarchical Classification, Agboola *et al.* (2024) analysed the predictors of climate change and adaptation strategies.

2.4 Examples from Other Regions/Countries

In a broader sense where human activity's role in climate change is becoming more significant, unusually high temperatures led to an additional mortality of 14,947 people in France in 2003 (Poumadère *et al.,* 2005). Their research once again, the contribution of human activities to climate change. Indeed, their results show that human activities since the industrial era are at the root of this heat wave, but that there is a high probability that this phenomenon will occur again. However, several European countries have experienced recurrent heat waves before, but the 2003 heat wave was the deadliest, especially in France. This study shows that taking into account all the factors that contribute to climate change remains a challenge.

Naveena *et al.* (2021), investigated the statistical and spatial characteristics of heat waves in India. Specifically, the authors analysed the spatial distribution, frequency, and trend of heat waves in the country between 1951 and 2019. According to them, urbanisation and industrialisation lead to an increase in temperatures trapped in rigid ground surfaces. Furthermore, an increase in global average surface air temperature leads to an increase in the intensity and frequency of extreme weather events, including heat waves and excess precipitation. Their results show a trend towards an increase in the number of heat waves. In fact, maximum temperatures and warm night minimum temperatures have a significant impact on the mortality rate. Between 1992 and 2015 deaths due to heat waves were 22562 in the country with about 2500 deaths in 2015.

Cairo, the capital of Egypt, is one of the most populous cities in Africa. The study of Mahmoud and Gan (2018) conducted in the city of Cairo analysed the impact of urbanisation on some climatic parameters including relative humidity, temperature, and vapour pressure. Specifically, they assessed the impact of urbanisation on human thermal comfort by calculating some historical thermal comfort indices using climate data from 1950 to 2017. The study showed that low-lying areas are more favourable for population settlement. In particular, these areas have experienced an increase in land use, which has resulted in the growth of impervious surfaces. Thus, the risk of thermal discomfort varies according to the zones. For example, the urban areas of old Cairo experience higher thermal discomfort in contrast to areas with abundant vegetation cover. This research clearly demonstrates how rapid urbanisation impacts the urban climate. The particularity of this study is that it was able to show how urbanisation affects climatic parameters such as relative humidity, temperature, and vapour pressure.

In South Africa, due to rapid urbanisation and cumulative pressure on the urban ecosystem, the risk of flooding in any given year is approximately 83.3% (Busayo *et al.,* 2022). Busayo *et al.,*(2022) studied the occurrence of floods and the socioeconomic impacts in this country between 1959 and 2019. The results show that the country has experienced flood occurrences of varying magnitude resulting in loss of life, livelihoods, and significant damage. In fact, during this period, the country recorded approximately 13,762 deaths and 5,85056 affected people. For example, in terms of loss of life, there were 506 deaths in 1986, 207 deaths in 1995 and 83 deaths in 2000. In 1996, about 17 lives were lost and 7000 people were left homeless. In 2014, approximately 32 lives were lost and about 7,185 people were made homeless.

2.5 Overview and Key Issues of the Study

2.5.1 Overview of the Study

For several decades, climate change has been the subject of numerous conferences, summits and meetings. As a result of these high-level meetings, conventions, protocols and agreements have often been signed by the stakeholders. Also, as climate change is one of the most pressing issues of the 21st century, a number of institutions have been created to deal with the issue at the global level. According to *l'Info Durable* (2021), The American climatologist Charles Keeling was the first to systematically measure carbon dioxide emissions in the atmosphere. Through his work at the Mauna Loa observatory in Hawaii (United States), carried out from 1957 onwards, Keeling showed a constant increase in the concentration of CO2 in the atmosphere. He demonstrates that the greenhouse gas does not remain confined to a single location but dissipates uniformly throughout the Earth. It also correlates this increase with the burning of fossil fuels and thus highlights the anthropogenic origin of global warming.

The same media reports that the work of the American meteorologist Jule Charney, in 1979, provided a first state of knowledge. From this report, it emerges that, in the event of a doubling of atmospheric CO2, the rise in temperature would be between 1.5°C and 4.5°C (l'Info Durable, 2021). The work of these researchers set the alarm bells ringing about climate change and how it is occurring.

In response to this, a long series of conferences and summits have followed. Indeed, over the last four decades, scientists, governments and international institutions have organised multiple meetings to reduce or combat climate change.

Between 1979 and 1992, there was the World Climate Conference held in Geneva, the creation of the Vienna Convention on the Protection of the Ozone Layer, the creation of the Intergovernmental Panel on Climate Change, the World Climate Conference in The Hague, the publication of the IPCC report on the state of scientific knowledge on climate change and its possible impact on the environment and finally the Earth Summit held in Rio de Janeiro

From 1992 to 2022, which corresponds to the temporal scope of our study, there was the publication of the second IPCC report, the 2nd UN Climate Change Conference in Geneva, the 12th UN Climate Change Conference in Nairobi, and the 13th UN Climate Change Conference in Copenhagen, the 13th UN Climate Change Conference in Bali, the UN Climate Change Summit in Copenhagen, the Rio+20 Earth Summit in Rio de Janeiro, COP 21 in Paris and the signing of the Paris Agreement and the publication of the IPCC report in 2022.

Burkina Faso and Nigeria participated in all these meetings aimed, among other things, at protecting the ozone layer, cooperating scientifically to improve understanding of atmospheric processes, stabilising atmospheric concentrations of greenhouse gases in the climate system, strengthening the fight against global warming by setting quantified targets, and putting in place financial mechanisms to combat global warming.

2.5.2 Key issues of the Study

Like all countries facing rapid urbanisation and recurrent urban climate change impacts, Nigeria and Burkina Faso have passed several decrees, laws and implemented policies, plans, projects and programmes to address the causes (urbanisation) and consequences of climate change.

In Nigeria, the rapid growth of cities has put a strain on infrastructure and has led to a problem of urban development. The visible and most obvious consequence of this urbanisation is the rapid deterioration of housing and living conditions (Aluko, 2011). Specifically, this situation has given rise to multiple urban challenges such as the proliferation of informal settlements, urban poverty, significant levels of inequality between different socio-economic groups, limited access to land for women and the poor, and unmet needs for infrastructure and other basic services (Ogbazi, 2013). Urban planning is an activity that promotes the orderly, equitable and optimised use of urban space to ensure protection, peace, a functional atmosphere and pleasant working conditions. To achieve the objectives of urban planning, it is necessary to implement and enforce urban and spatial planning laws and legislation (Akut *et al.,* 2022). To ensure this urban growth and development Nigeria has developed plans, laws, policies, decrees etc.

In terms of plans, it had The First National Development Plan (1962-1968), The Second National Development Plan (1970-1974), The Third National Development Plan (1975-1980), The Fourth National Development Plan (1981-1985) and the latest Integrated National Infrastructure Plan 2014-2043, which identifies the key infrastructure bottlenecks impacting on Nigeria's competitiveness and provides the capital allocation framework that identifies the investments needed to develop infrastructure in line with the country's growth aspirations (Olika, 2021).

There are several policies including the Planning Policy, Housing Policy, National Urban Development Policy, etc. The Planning Policy, based on the Nigerian Town and Country Planning Ordinance of 1946, is designed to promote order in urban development and the establishment of planning authorities capable of controlling growth. The planning policy, based on the Nigerian Town and Country Planning Ordinance of 1946, is designed to promote order in urban development and the establishment of planning authorities capable of controlling urban growth, but it is considered an ineffective tool for controlling national urban development (Taylor, 2000). As for land policy, it has had a significant impact on housing production, the ability of urban areas to expand into rural areas; and the ability to use land more efficiently. There is the National Urban Development Policy of 2002, which aims to manage the complexity created by the rapid growth of Nigerian cities. The National Housing Policy was put in place to regulate the housing market as about 90% of urban housing is produced by private developers (Taylor, 2000). There is also the National Urban Development Policy 2012 which aims to promote a vibrant system of urban settlements, foster sustainable economic growth and ensure improved living standards and welfare (Olika, 2021).

In view of the inadequacy of the 1946 Town and Country Planning Act, it was recommended to the government to revise the Act and enact laws applicable nationwide, taking into account variations in climate, topography and other variables. Thus, the new Nigerian Urban and Regional Planning Law (NURPL), Decree No. 88 of 15 December 1992, was promulgated (Omole, 2014).

In Burkina Faso, a number of laws, policies and decrees have been developed in the field of urbanisation. There is the law on agrarian and land reorganisation, the aim of which is land-use planning, rural and urban land management, the regulation of real estate rights as well as the regime of forests, pollution, etc. According to the Ministry of Economy and Finance (2012), in an effort to manage population issues as development issues, the Government has adopted a population policy which has been revised several times. The formulation and implementation of population action programmes and their evaluation are aimed at improving the living conditions of the population and promoting social development. However, the analysis of the context has revealed a number of problems that constitute challenges to be met in order to improve the general living conditions of the population. Burkina Faso has adopted a national housing and urban development policy through a ten-year action plan for 2009-2018. To this end, the government adopts a land orientation law, in order to better control urban land (Ministry of Economy and Finance, 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Data Collection

Spatial and temporal analysis of settlement dynamics and climate change impacts requires the use of a well-adapted approach, the identification of existing studies in the field, the definition of spatial and demographic sample, and the description of data collection, processing, and analysis techniques.

3.1.1 Demographic sampling method

In order to gain a better understanding of climate impact mitigation and adaptation strategies, the cities were divided into two strata: planned areas and unplanned areas (informal settlement). A sample was drawn from each area. In each area, 21 Enumeration Areas (EA) were randomly selected. Created specifically for a census, an Enumeration Area is a geographical statistical unit with a specific number of households within it and contains between 150 and 250 households (USAID, 2012). In most surveys, a sample size of 20–30 households per cluster is sufficient if the average cluster size is 250 households or below and for the most important survey indicators, a sample take between 20 to 25 households is appropriate in urban clusters (USAID, 2012).

To achieve a sample of 420 households, 20 households were selected randomly in each enumeration area. To survey this sample of around 420 households, 21 EA are needed. The 21 EA in planned areas and 21 EA in unplanned areas were selected by the National Institute of Statistics and Demography of Burkina Faso, making a total of 42 EA for the city of Ouagadougou. The same sampling methodology was applied in both cities. The overall sample for the two cities was 1,680 households. These enumeration areas are spatially distributed in the 12 districts of Ouagadougou and the 6 Local Government

Areas of Abuja. Table 3.1 shows the distribution of households in the 6 LGAs and the 12 districts in Abuja and Ouagadougou, respectively.

Abuja Municipal Area Council (AMAC) is the most densely populated area, which explains the difference in the number of households surveyed in this LGA as opposed to the others. As the other 5 LGAs had the same characteristics in terms of population proportion, the same number of households were surveyed in each LGA. In Ouagadougou, the national institute of statistics and demography has a database of all the city's enumeration areas. The 42 enumeration areas were randomly selected from that database. After enumerating the houses in the enumeration area, the households were randomly selected to participate in the study.

Table 3.1: Distribution of the Demographic Sample in Abuja and Ouagadougou

	Abuja		
Local Government Area	**Enumeration Area**	**Household**	**Population size in 2022**
Abuja municipal Area Council	12	240	1 693 400
Abaji	6	120	127 900
Bwari	6	120	500 100
Gwagwalada	6	120	346 000
Kuje	6	120	212 100
Kwali	6	120	188 000
TOTAL	**42**	**840**	**3 067 500**
	Ouagadougou		
Arrondissements	**Enumeration Area**	**Household**	**Population size in 2019**
Arrondissement 01	2	40	102 528
Arrondissement 02	2	40	83 436
Arrondissement 04	5	100	207 647
Arrondissement 05	2	40	129 984
Arrondissement 06	4	80	222 854
Arrondissement 07	8	160	282 837
Arrondissement 08	3	60	152 880
Arrondissement 09	4	80	336 483
Arrondissement 10	6	120	263 969
Arrondissement 11	4	80	254 928
Arrondissement 12	2	40	66 314
TOTAL	**42**	**840**	**2 103 860**

3.1.2 Collection of survey and statistical data

In terms of data collection techniques and tools, in this study a GIS approach coupled with remote sensing and mobile GIS was adopted. Given the availability of high-resolution images from the Google Map platform, the delimitation, census, and mapping of houses/households were carried out using GIS software. This technique consisted of carrying out an exhaustive census, i.e. digitising all the houses in the enumeration area, using ArcGIS Pro software.

The justification for choosing the GIS method for enumerating households is linked, on the one hand, to the possibility of having an overall view and details of the Enumeration Area (EA). On the other hand, it makes it easy to check whether there are houses that have not been enumerated, unlike the other method of enumeration in the field, where verification requires a presence in the field and takes longer.

This approach is more accurate and saves time than field enumeration, which can take hours or days depending on the size of the EA. The similarity with the traditional field enumeration method is that it provides a drawing base of houses. There is also a spatial distribution of the selected houses. The only difference from the classic method of enumeration in the field is that we do not know in advance whether a house is occupied or not.

To do this, a pilot survey was carried out, which revealed that in order to have 20 households to survey in an enumeration area, at least 25 houses must be selected in the developed area and 30 houses in the undeveloped area.

QGIS software was used to randomly select the houses to be surveyed. After the draw, the GPS coordinates were exported and transferred to the Maps.Me mobile application for identification in the field. Once the house had been located using GPS coordinates, the kobotolbox application was finally used to administer the questionnaire to the head of the household or a regular, competent member of the household. The head of the household was chosen as the respondent. In the absence of the head of the household, a usual and competent member of the household who is at least twenty years old is authorised to answer the questionnaire. This study did not adopt a method to replace the households selected, which is why several visits were made to the households to find a person qualified to answer the questionnaire under the defined conditions.

This study opted for kobotolbox because it offers a variety of possibilities with a free server. Maps.me is an offline application that does not require an Internet connection. This application is very accurate and uses less battery power. The distribution of the spatial sample is shown in Figure 3.1.

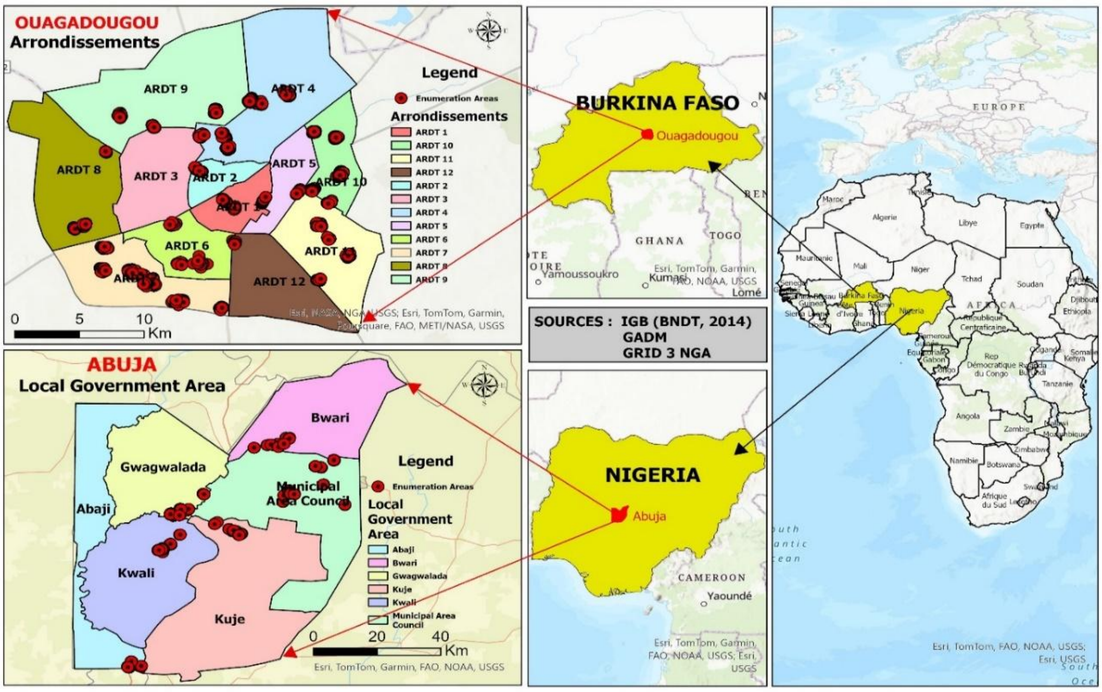


Figure 3.1: Distribution of Spatial Sample in Ouagadougou and Abuja

The household survey in the two cities was structured in several sections with well-defined variables for each section. The main sections are people's perceptions of the spatial dynamics of cities, the impacts of climate change in urban areas, strategies for adapting to and mitigating climate change in urban areas, and the sociodemographic and socio-economic characteristics of households. The main study variables are presented in Table 3.2.

Table 3.2: Sections and Main Variables of the Household Survey

SOCIODEMOGRAPHIC AND ECONOMIC CHARACTERISTICS	DEMOGRAPHIC AND SPATIAL DYNAMICS OF CITIES
Age	Perceptions city dynamics
Gender	Factors driving the city's spatial expansion
Level of education	Perceptions of the state of dust in the city
Occupation	Perceptions of vegetation degradation
Marital status	Perceptions of causes of vegetation degradation
Means of transport	Perception of possible impacts of the vegetation degradation
Source of energy	Participation in tree planting
Main source of energy for cooking	Planting trees in houses
use of public transport	
Characteristics of the habitat	
IMPACT OF CLIMATE CHANGE IN URBAN AREAS	**MITIGATION AND ADAPTATION STRATEGIES**
Impact of high temperature on health or personal comfort?	Action to withstand the heat during the night
Impact of high temperature on activities	Perception to mitigate the effects of temperatures
Impact pf climate-related illnesses, allergies or respiratory diseases	Action to protect houses during the flooding
Impact the winds on people business	Action to protect from flooding
Impact of the winds on people health	Action to protect from windstorms
Impact the winds on people comfort	Main source of energy for cooking
Impact the winds on houses	Use of public transport
Impact of heavy rain on people business	Perception of how city authorities respond to the impact of climate change
Impact of floods	Perception of Planting trees, Houses/buildings orientation and ventilation
Recurrence of floods	Perception of how cities can better adapt to climate change
perception of the mains causes of floods	Constraints or limitations to adapt to climate change
Perception of concerns about future climate change	

Web craping was used to supplement the information in the database of extreme weather events in the city. Web scrapping or data scraping is a method of introducing key information to search for publications related to impacts in scientific journals and especially in social networks. Most of the time, these events are only reported in local newspapers. Specifically, it involves querying the occurrence of a climatic event on a given date and in a given place. This method has been extremely useful in gathering additional information on the occurrence of floods, windstorms and extreme heat. It has made it possible to compile a more or less exhaustive database of the dates of the events, the boroughs and sectors concerned, as well as the quantities of rain and the material and human damage caused by these extreme weather events. This method was used to collect the missing information for 1992 and 2022. Additionally, data from the Burkina Faso general population census and world population review data for the city of Abuja were collected.

To analyse rainfall, high temperatures, heat waves, and wind speeds in the city from 1992 to 2022, climate data were collected from the national meteorological agency in Ouagadougou. The temperature data mainly concerned daily, monthly, and annual maximum and minimum temperatures. Several types of indicators are used to describe rainfall trends. In this study, the average cumulative annual and monthly rainfall and the monthly and annual numbers of exceedances of the normal threshold were collected. Finally, monthly and annual data on extreme wind speeds and directions were collected.

3.1.3 Acquisition of satellite images in raster format

These are Landsat satellite raster formats with a resolution of 30 m. They are mainly Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), and OLI-TIRS images. For the city of Ouagadougou, these are images from 1990, 2002, 2012 and 2022. In the absence of good quality images for 1992, we decided to use those from 1990. For the Abuja study area, given its large surface area (more than 7,000 km2), images from the same years as those from the city of Ouagadougou were not available. We therefore opted for the 2002, 2013 and 2022 images, which were of good quality. All images were filtered directly on the Google Earth Engine platform. The MODIS surface temperature product dataset used in this work, MYD11A2 V6.1, was acquired via the GEE platform from

NASA's Land Processes Distributed Active Archive Centre. This data set offers surface temperatures during the day and night for an average of eight days with a spatial resolution of one kilometre.

3.1.4 Data collection in vector format

Spatial data mainly shapefiles of district, sectors, LGA, localities, roads were acquired for analysis of the spatial distribution of populations by district in the city of Ouagadougou and by LGA in Abuja. They were also used to analyse the spatial dynamics of land use and land cover and the future predictions of spatial dynamics of the cities.

3.2 Method of Data Processing and Analysis

3.2.1 Demographic and spatial dynamics of the cities

To analyse satellite images, four main classes were defined in the two study areas. These are built-up, vegetation, crop/bare land and water surfaces.

Table 3.3: Land Use and Land Cover Class and Description

LULC CLASS	DESCRIPTION
Built-up	Include urban settlement (houses, roads, buildings, pavement).
Vegetation	Include forests and urban parks (woodlands, parks, dense forest, open forest).
Crop land/bare land	Include agricultural land and surfaces without vegetation (crops land, fallows, farmland, barren soils).
Water	Include natural and artificial water surface (rivers, dams, swamps, lakes, and ponds).

The classification was carried out on the Google Earth Engine platform. Image pre-processing on the platform consisted of masking clouds using bands and filtering images with a cloud coverage rate of less than 10%. Reference samples were collected for each land use land cover class. Error matrix was used to assess the accuracy of each classified map directly in GEE.

This matrix is used to calculate the Kappa coefficient or Kappa index (total number of pixels well classified in its class/total number of pixels in the class over the whole area). In Ouagadougou, the values obtained are as follows: 1990 (overall accuracy 0.95; Kappa index 0.93), 2002 (overall accuracy 0.91; Kappa index 0.87) and 2012 (overall accuracy 0.93; Kappa index 0.90) and 2022 (overall accuracy 0.98; Kappa index 0.97). In Abuja, the values obtained are as follows: 2001 (global accuracy 0.92; kappa index 0.88), 2013 (global accuracy 0.95; kappa index 0.93), and 2022 (global accuracy 0.96; kappa index 0.91).

After image classification, the land cover results were transferred to ArcGIS Pro software for statistical calculation, change detection, and cartographic design. The statistical results of the population change and habitat dynamics were used to calculate four indices.

(a) Average Annual Change (AAC)

This statistical analysis consists of calculating the rate of change observed in all classes of the whole landscape (FAO, 1996). The following equation presents the rate of change or the average annual change of a class between two dates (FAO, 1996). An area of the class at the initial date is considered to change from a starting value to an ending value during a defined period (number of years).

$$Tc = \left[\left(\frac{S2}{S1}\right)^{\frac{1}{(t2-t1)}} - 1 \right] \text{With} \qquad (3.1)$$

Tc: Rate of change

S1: Area of the class on the initial date

S2: Area of the class at the final date

t2 − t1: Number of years in the period

(b) Spatial Expansion Intensity Index (UEII)

The refers is an important indicator to describe the speed of urban land expansion over a certain period (Tao and Ye, 2022). The UEII makes the results comparable across temporal sets by normalising the mean annual expansion based on the landscape's total land area. When applied to various land uses, it helps to identify the preferences of urban expansion (Tesema Bulti and Lemmi Eshete, 2023). The UEII is the percentage of urban land by a space unit in a unit period as a percentage of its total land area (Zhong *et al.*, 2020). Its mathematical expression is

$$\boldsymbol{UEII} = \frac{\mathbf{C}j - \mathbf{C}i}{\mathbf{CT}} \times \mathbf{100} \tag{3.2}$$

where UEII is the average annual over the time i to time j, Ci and Cj are the urban land area during time i and time j, C is the total area of the built-up area of urban, and T is the time span of the research. The UEII standard is divided into five speed developments. When UEII is more than 1.92 is very speed, 1.05 to 1.92 is high speed, 0.59 to 1.05 is medium speed; 0.28 to 0.59 is low speed, 0 to 0.28 is slow speed (Al-Sharif *et al.,* 2014).

(c) Urban Growth Coefficient (UGC) or Coefficient of Elasticity

The UGF is a metric used to evaluate the rationality of urban expansion, indicating the correlation between the rate of urban expansion and population growth (Zhong *et al.,* 2020). Its mathematical expression is as follows:

$$UGC = \frac{\mathrm{A}(i)}{\mathrm{Pop}(i)} \tag{3.3}$$

where UGC is the Urban Growth Coefficient of the expansion of urban construction land in the time i, A (i) is the average annual growth rate of the urban construction land area and Pop (i) is the average annual growth rate of the urban population at the same time (i).

(d) Average Annual Urban Expansion Rate (AUER)

The average annual rate of urban spatial expansion expresses the proportion of the land use category (Built-up) that changes annually (Agbanou *et al.*, 2019).

$$AUER = \frac{\ln A_j - \ln A_i}{t_j - t_i \times lne} \times 100 \qquad (3)$$

Where *AUER is the* Average Annual Urban Expansion Rate**,** *Ai* et *Aj* Area of a class at date *i* and *j,* respectively, *tj - ti* is the number of years of evolution and ln is the natural logarithm *e* with the base of the natural logarithm (*e = 2.71828*).

To gain a better understanding of people's perceptions of the spatial dynamics of cities and the environmental consequences of these dynamics, a multivariate analysis was used, combining the survey variables and the sociodemographic characteristics of the respondents (age, gender, level of education, and occupation). Statistical and spatial analysis of the data revealed general trends, as well as similarities and differences between the two cities and within groups of individuals. The summary of the data collected, the processing carried out, and the analyses are presented in Figure 3.2.

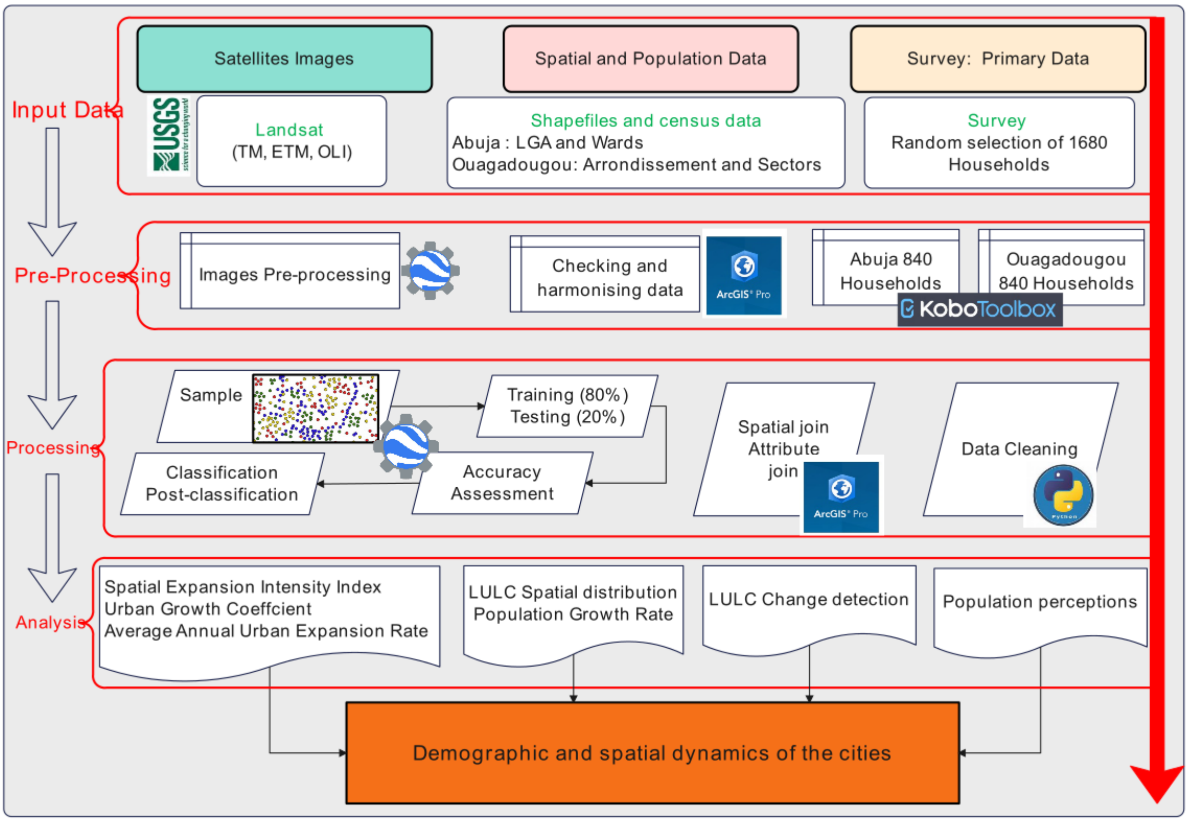


Figure 3.2: Summary of Data, Processing, and Analysis for Objective one

3.2.2 Recurrence, intensity of climate change impact in urban area

Characterising the spatial distribution of heat waves, floods and storms required processing several types of data, including climate data (temperature, rainfall, wind), satellite images (Landsat and Modis), statistical survey data, and databases of extreme weather events.

Analysis of rainfall data to determine thresholds and identify extreme rainfall events in historical records. It also involves the analysis of temporal trends to identify any increase or decrease in extreme rainfall events over time. The Standardised Precipitation Index (SPI) to quantify the magnitude of extreme rainfall events. For the analysis of temperatures and heat waves, the Heat Days Index, the duration of the heat wave and the heat wave frequency index were calculated.

The main occupancy classes that influence high temperatures or heat waves, flooding, and winds were identified in this study. These are vegetation and habitat, surface temperature, slope, drainage density and altitude. Several authors, including (Athukorala and Murayama, 2020), (Ermida *et al.,* 2020) (Guha *et al.,* 2021), (Gyimah *et al.,* 2023),, and (Sahile *et al.,* 2023) have highlighted the usefulness of remote sensing in analysing land cover and estimating surface temperatures. The two land cover classes, habitat and vegetation, were processed using the Google Earth Engine. Vegetation includes dense forests, parks, forests, and open forests). Built-up includes houses, buildings, pavement, and roads. After processing, the densities of vegetation and habitat by sector in the city of Ouagadougou were calculated and classified.

The Google Earth Engine platform was used to calculate surface temperatures. These were mainly MODIS images. These images offer a number of possibilities for estimating surface temperatures. Authors such as (Schwarz *et al.,* 2011), (Clinton and Gong, 2013), (Wu *et al*., 2019), (Meng *et al.*, 2023), used this approach in their studies. In this study, the mean surface temperatures of the three warmest months (March, April, and May) were calculated.

The DEM covering the study area was downloaded to GEE. After downloading, processing and analysis of slopes, drainage densities and altitudes were carried out using ArcGIS Pro software.

Multivariate analyses were used mainly for the statistical data. The variables for the impacts of floods, heat waves, and windstorms were cross-referenced with the sociodemographic characteristics of the respondents. In terms of the databases on extreme weather events, they were harmonised and linked to the spatial data for the sectors to characterise them.

In Ouagadougou, the densities of vegetation, built-up, population, and informal settlement per sector were calculated. In Abuja, the population, vegetation and habitat densities per LGA were calculated. All the data were rasterised and classified into 5 classes. Finally, a Hierarchical Analysis Process using QGIS version 2.18 software was used to characterise the impacts of temperature and flooding by sector for the city of Ouagadougou and by LGA for the city of Abuja. The summary of the data collected, the processing carried out and the analyses are presented in Figure 3.3.

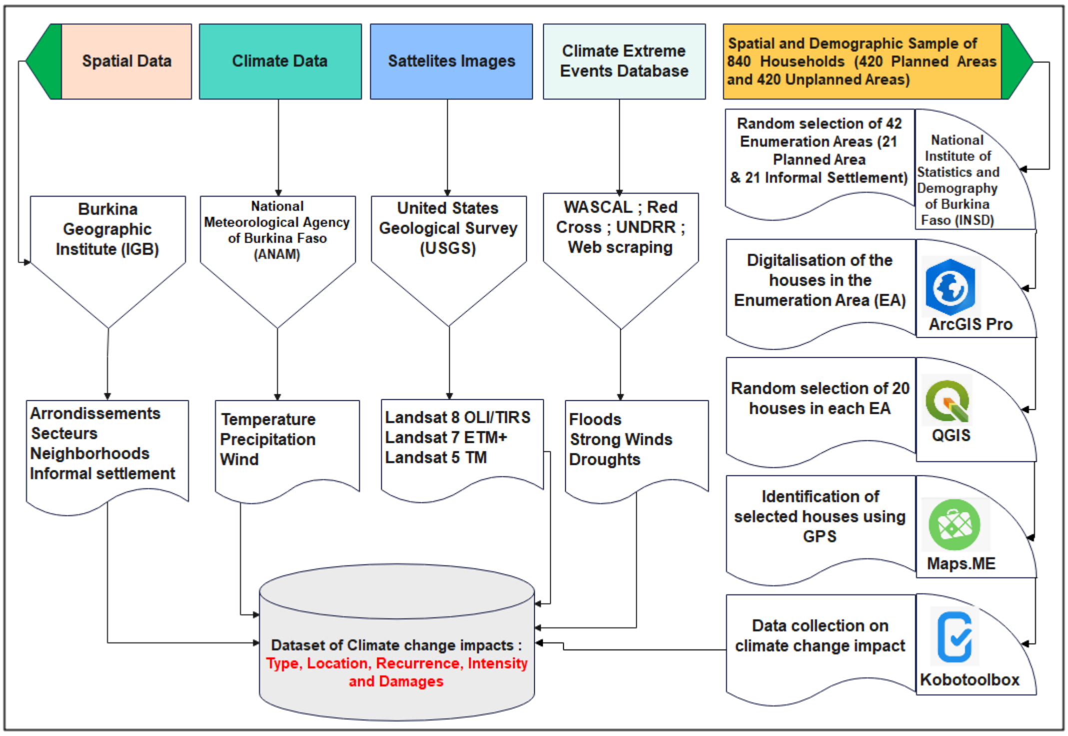


Figure 3.3: Summary of Data, Processing, and Analysis for Objective Two

3.2.3 Prediction of future urban growth

To predict the future urban growth of the two cities, prospective modelling was used based on the Land Change Modeler of TerrSet2020 software was used. The 2013 and 2022 land use layers for the city of Abuja and the 2012 and 2022 layers for the city of Ouagadougou were used as dependent variables. Protected areas, such as urban forests, were added to these independent variables because they are areas that are unlikely to be occupied by people. Distance from roads, distance from villages, population density, and altitude were used as independent variables. The steps consisted firstly of analysing the changes that had occurred between the different land use classes. Secondly, potential transitions were analysed. Thirdly, the prediction of future change in 2052 was carried out. Finally, the results were validated to ensure consistency.

3.2.4 Climate change adaptation and mitigation in urban area

There are no universal and static indicators for adaptation to climate change, due to the context in which these measures are taken and often because of their dynamism (Christiansen *et al.*, 2018). Indeed, populations adopt individual and often circumstantial measures in the face of floods, heat waves, windstorms, and droughts. However, it is possible to assess the common measures and practices commonly used by populations to mitigate effects or adapt to impacts. According to Protection Motivation Theory (PMT), three characteristics characterise people's adaptation assessments: their perceptions of the costs in terms of money, time, and effort involved in implementing the protective action, their beliefs that a protective action will effectively reduce the threat, and their beliefs in their ability to carry out the protective action (Floyd *et al.,* 2000).

Tuomimaa *et al.* (2023) have identified some of the physical and urban socio-economic characteristics in which the risk impacts of certain climatic events materialise, and through which adaptation measures can be targeted. They showed how urban characteristics influence exposure and vulnerability to certain effects of climate change and their importance and implications for adaptation. To identify and analyse the adaptation and mitigation strategies of urban populations, the types of impacts were first identified. Then, the risks (hazard, exposure, vulnerability) to which populations are exposed according to IPCC (2022) were defined. The urban characteristics used are the population, governance (Christiansen *et al.*, 2018), physical environment (soils, topography, hydrology, vegetation) and the climate (temperature, precipitation, winds) of cities. Climate change adaptation and mitigation indicators are shown in Figure 3.4.

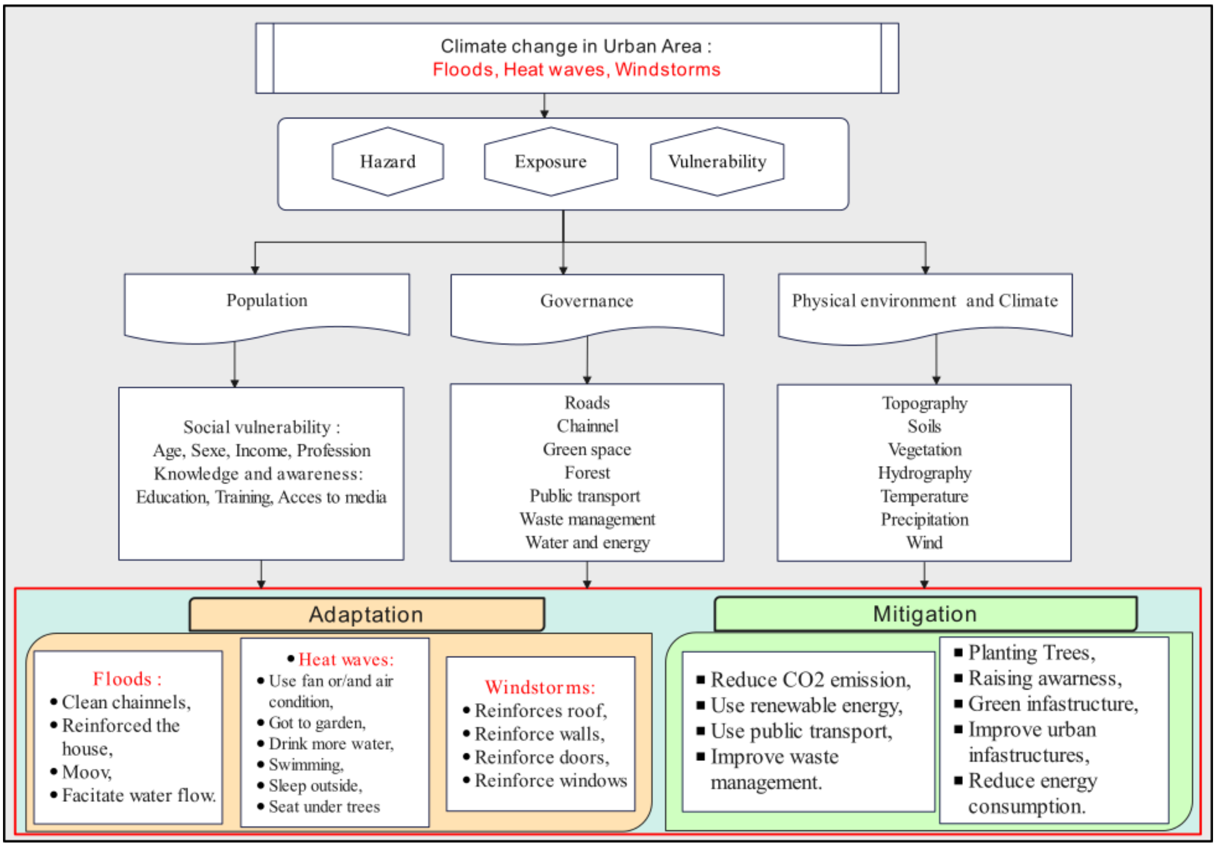


Figure 3.4: Conceptual Summary Illustration of Climate Extreme Events in Urban Area, Main Component of Human Behaviour and Physical Environment as a Driver of Climate Change and, Population Adaptation and Mitigation Indicators Based on the Theory of Planned Behaviour

To understand the differences in the mitigation and adaptation measures utilised to extreme events in the two study areas, multivariate statistics have been applied. In research fields such as education, health, geography, psychology, and sociology, multivariate statistical analyses are commonly used (Mertler *et al.,* 2021). The participants in the studies are generally individuals. This analysis made it possible to use the sociodemographic characteristics of the respondents (gender, age, status, level of education, and occupation) and the climate change adaptation and mitigation variables.

Chi^2 tests were implemented to determine the significance between adaptation and mitigation variables and the sociodemographic characteristics of the respondents.

Logistic regression was used to test the adaptation / mitigation variables to climate change and respondent characteristics. According to Backhaus *et al.* (2021), regression analysis is very important in the human and social sciences because it can be used to test relationships between a dependent variable and one or more independent variables. It allows relationships to be described quantitatively and explained. Thus, the chi-square test was used to determine the differences in terms of adaptation and mitigation to climate change (floods, heat waves, and windstorms), according to the respondents' gender, age groups, level of education, and occupation (independent variables).

Furthermore, Multiple Component Analysis (MCA) and Ascending Hierarchical Classification (AHC) are used to characterise mitigation strategies according to the sociodemographic traits of respondents. The 'FactoMineR' package in R version 4.4.0 was used to perform the MCA. This approach was used to differentiate the participants and group them according to their similarity (Lê *et al.,* 2008 ; Husson *et al.,* 2024). The output of the ACM was then used to create the Ascending Hierarchical Classification (AHC). The package "*FactoExtra"* in R version 4.4.0 was used to design the AHC (Kassambara, 2017). The summary of the types of data collected for each objective of the thesis and the analyses is presented in figure 3.5.

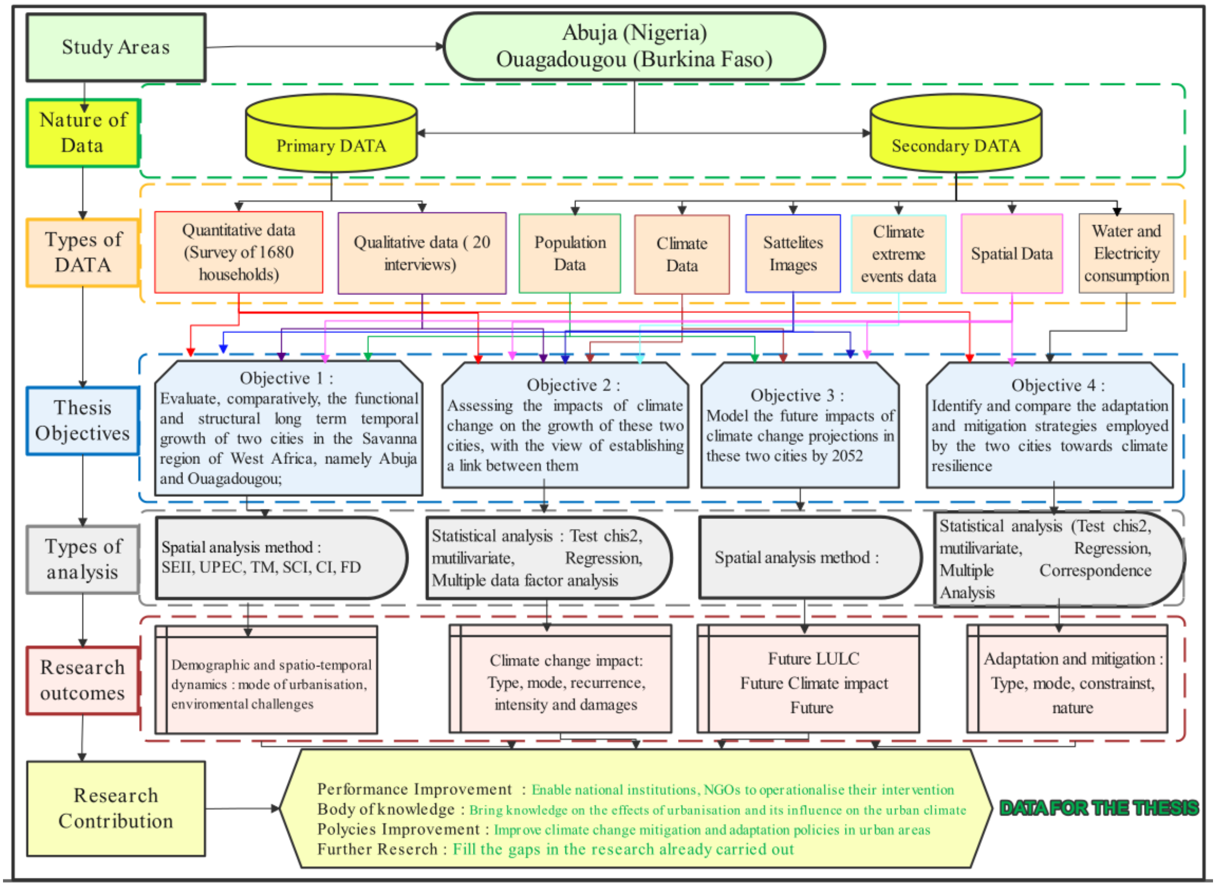


Figure 3.5: Summary of the Type of Data Collected for Each Objective of the Thesis

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Demographic and settlement dynamics in Abuja and Ouagadougou

4.1.1.1 *Demographic dynamics of Abuja and Ouagadougou*

Both study areas experienced strong population growth during the time frame of this study. According to World Population Prospects data, the population of Abuja has steadily grown from 400,000 in 1992 to 3,652,000 in 2022. During the same period, the population of Ouagadougou rose from 586,000 to 3,056,000. This shows that the population of Abuja has increased nine times over the last 30 years, and that of Ouagadougou five times. Additionally, both cities have experienced variations in terms of average annual population growth (Figure 4.1).

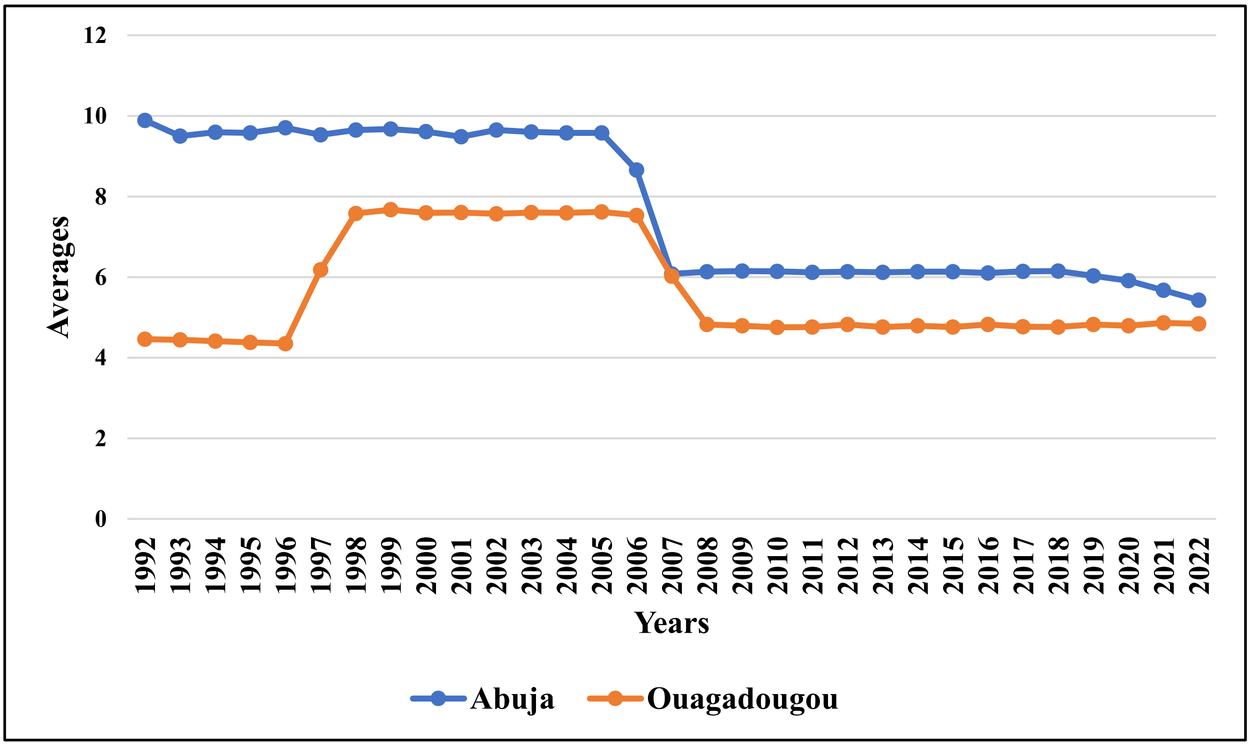


Figure 4.1: Population Growth Rate in Abuja and Ouagadougou from 1992 to 2022
Source: United Nations World Population Prospects, 2024

The analysis of the graph shows relatively stable growth from 1992 to 2005 for the city of Abuja. There was a decrease from 2006 to 2007. From 2007, there was stability until 2019, when there was a decline. During the same period in Ouagadougou, growth was stable between 1992 and 1996. Between 1996 and 1998, there was rapid growth, from 4.35 to 7.58. Between 1998 and 2006, growth was relatively stable. Between 2006 and 2008, there was a decline. From 2008 onwards, there was relatively stable growth until 1992.

The continuous growth observed in the two cities shows an unequal distribution of the population by sectors (Ouagadougou) in 2019 and LGA (Abuja) in 2022 (Figure 4.2).

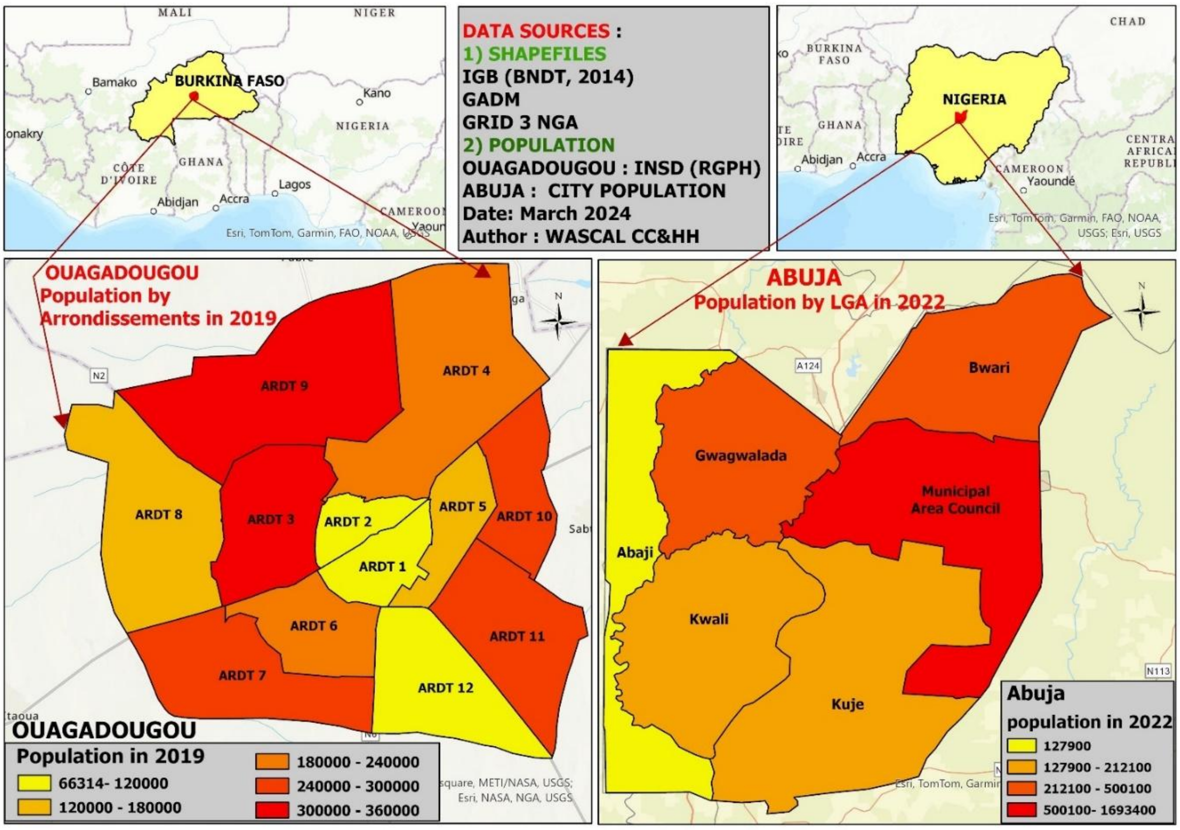


Figure 4.2: Distribution of the Population in Ouagadougou and Abuja

In Ouagadougou, the population distribution shows that the outlying districts are most densely populated, unlike the districts in the centre. This is explained by the presence of commercial activities and administrative services in the centre of the city. Arrondissement 12 is less populated because it is home to the new districts, and several administrative services are currently located in this district. In addition, this arrondissement is mainly occupied by Ouaga 2000 estate, which is a high standard housing area where accommodation is not affordable for the majority of people. In Abuja, only Abuja Municipal is the most populated LGA, unlike the others. The other LGAs, Kwali and Kuje, located in the southern part, have almost the same number of inhabitants. Bwari and Gwagwalada in the northern part have approximately the same populations. Abaji in the far west is the least populated LGA. The growth in Ouagadougou and Abuja has led to changes in land use and land cover in general and built-up in particular.

4.1.1.2 *Land use and land cover spatial distribution in Abuja and Ouagadougou*

The analysis of satellite images covering the study areas allowed to highlight the spatial distribution of land use and land cover (LULC) units over time and space. The spatial distribution of LULC units in Ouagadougou in 1990, 2002, 2012 and 2022 are presented in Figure 4.3.

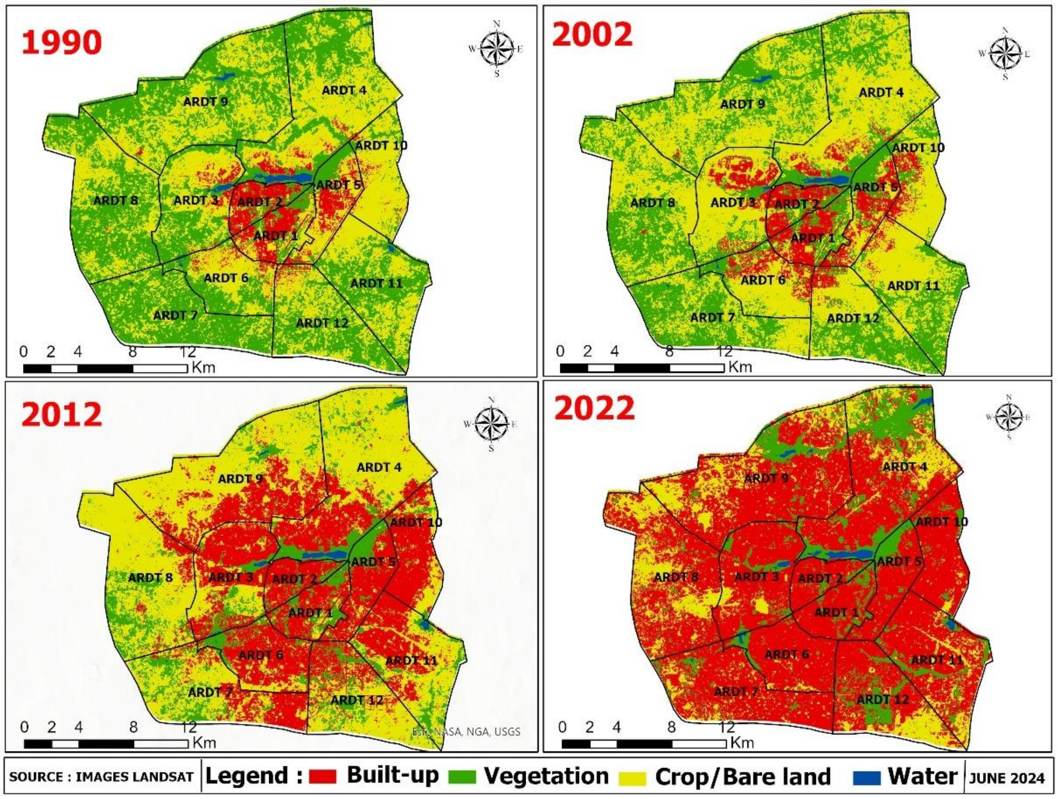


Figure 4.3: Spatial Distribution of LULC in Ouagadougou

Analysis of the maps shows that the built-up was concentrated in the centre in 1990. The built-up has moved from the centre to the outskirts. In 2022, the built-up occupies almost the entire study area. The built-up that occupied only the small portion now occupies almost the entire area. In 1990, most of the vegetation was in the southern, western, and northern parts. In 2022, vegetation occupies the least space. It is located along the dams, the protected park and the northern part. Crop/bare land was mainly found around the city centre. Over time, they have spread to other parts of the site. In 2022, they are mainly located in the west, north, and extreme south.

The years of observation in Abuja were 2001, 2013 and 2022. Only 3 dates were used due to image quality and data availability. The spatial distribution of the units in the study area is presented in figure 4.4.

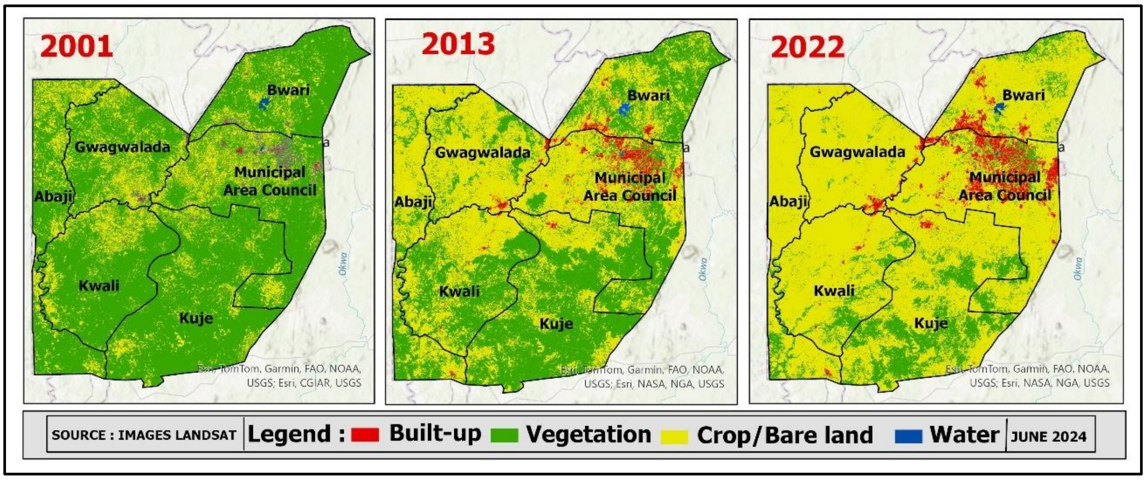


Figure 4.4: Spatial Distribution of LULC in Abuja

A look at the map shows that the built-up has occupied the north-eastern part of the centre. Between 2001 and 2022 it spread to the north and towards the centre. Vegetation is the unit that occupied all parts in 2001. In 2012, vegetation had completely disappeared in the central and western parts. It is located in the southern and north-east parts. In 2022, only the southern part is covered by vegetation. In 2001, vegetation covered most of the area, whereas in 2022 it covered only the smallest part. In 2001, crop/bare land mainly occupied the central part. In 2013, there was a shift towards the northern part in the centre. In 2022, they occupy almost the entire area.

4.1.1.3 *LULC trends and patterns in Abuja and Ouagadougou*

Land use in Ouagadougou has been characterised by an increase and a decrease in the surface area of land use units over the last three decades. Statistical analysis of the surface areas has made it possible to characterise the trends in terms of surface areas occupied by the units per year, as well as their dynamics over the observation period (Figure 4.5).

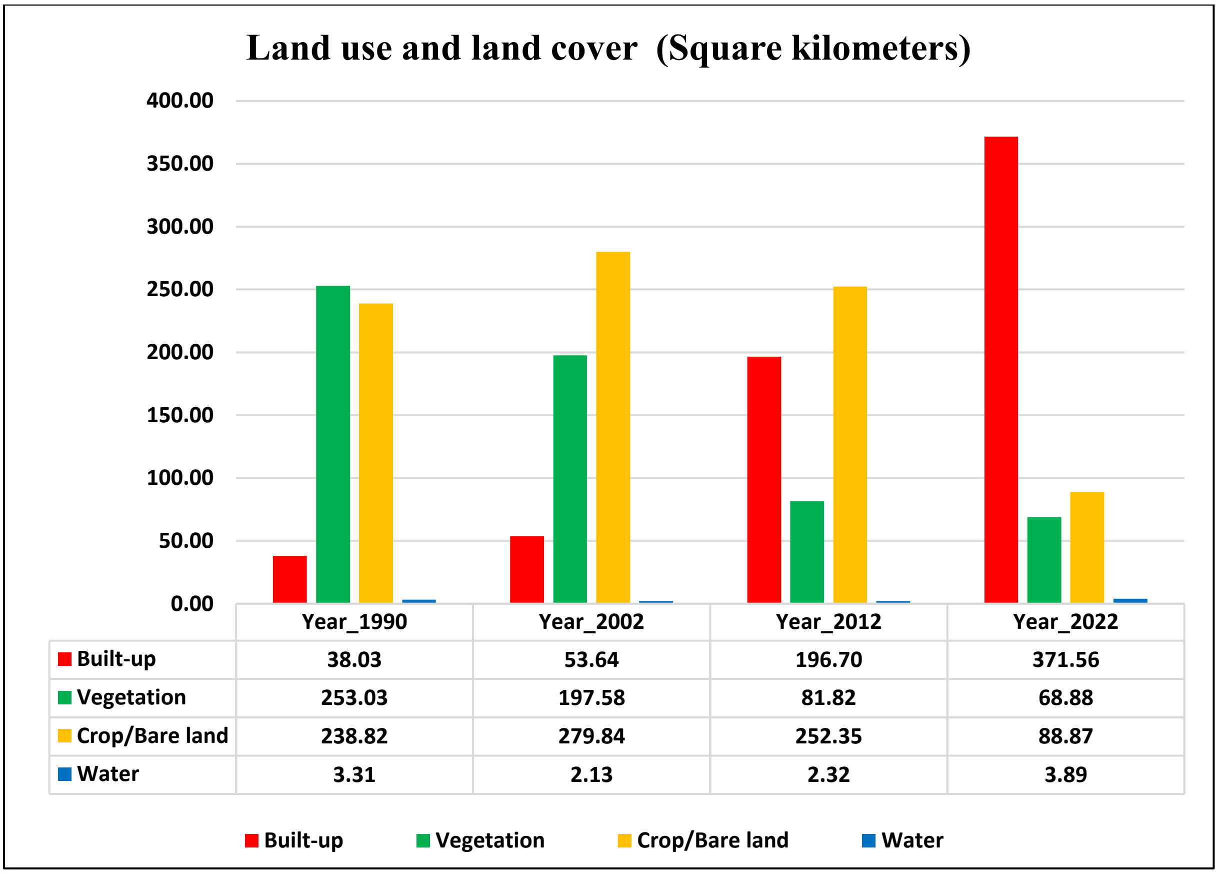
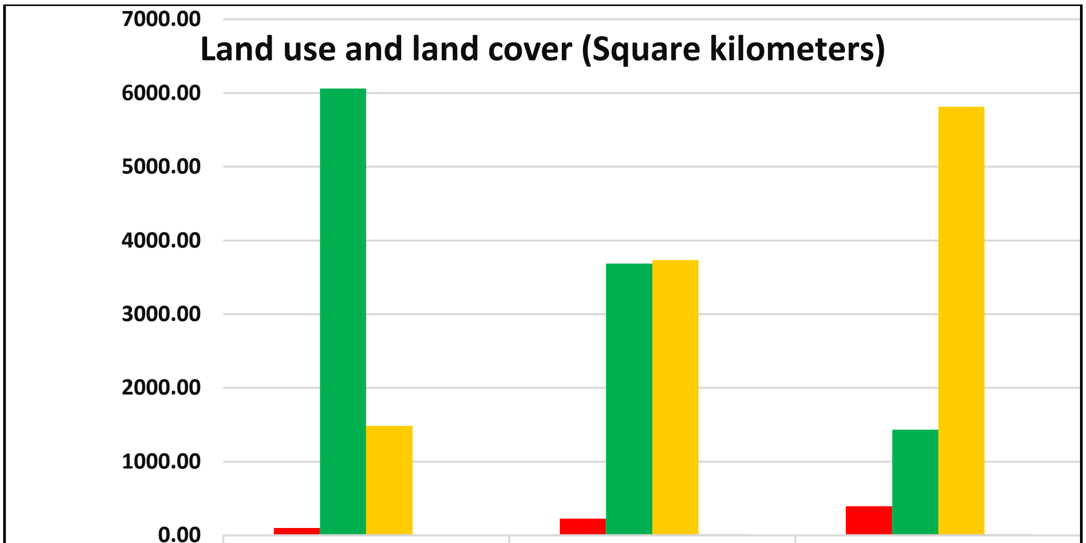


Figure 4.5: Land Use and Land Cover Trends in Ouagadougou

Analysis of the graph reveals two major facts. Firstly, from 1990 to 2022, vegetation has declined continuously. Secondly, built-up has grown steadily over the same period. The area occupied by vegetation has decreased almost fourfold, whereas the area occupied by built-up has increased almost tenfold. On the other hand, there were variations in the area of crop/bare land. Between 1990 and 2002, there was an increase, while between 2002 and 2012 and 2022, there was a decrease in the area occupied by units. There were no major variations in the area occupied by the water.

In Abuja, the same trends of increasing and decreasing surface areas of occupancy units were observed. Figure 4.6 shows the statistical results for the occupancy units in Abuja.



	Year_2001	Year_2013	Year_2022
Built-up	100.69	224.03	397
Vegetation	6059.34	3684.70	1433
Crop/Bare land	1484.11	3732.07	5813
Water	9.79	13.12	11

Figure 4.6: Land Use and Land Cover Trends in Abuja

Analysis of the graph shows that the area occupied by built-up, crop/bare land increased between 2001 and 2022. However, the area occupied by vegetation has decreased during the same period. In 2001, vegetation was the unit that occupied the largest part of the area. In 2013, vegetation, crop/bare land occupied most of the area. In 2022, crop/bare land dominate the area. The water-occupied area increased from 2001 to 2013 and decreased from 2013 to 2022.

In Ouagadougou, the analysis of changes in occupancy units showed the transformations that occurred from one occupancy unit to another and from one year to another. The results of these transformations are represented by the Sankey Diagram (Figure 4.7).

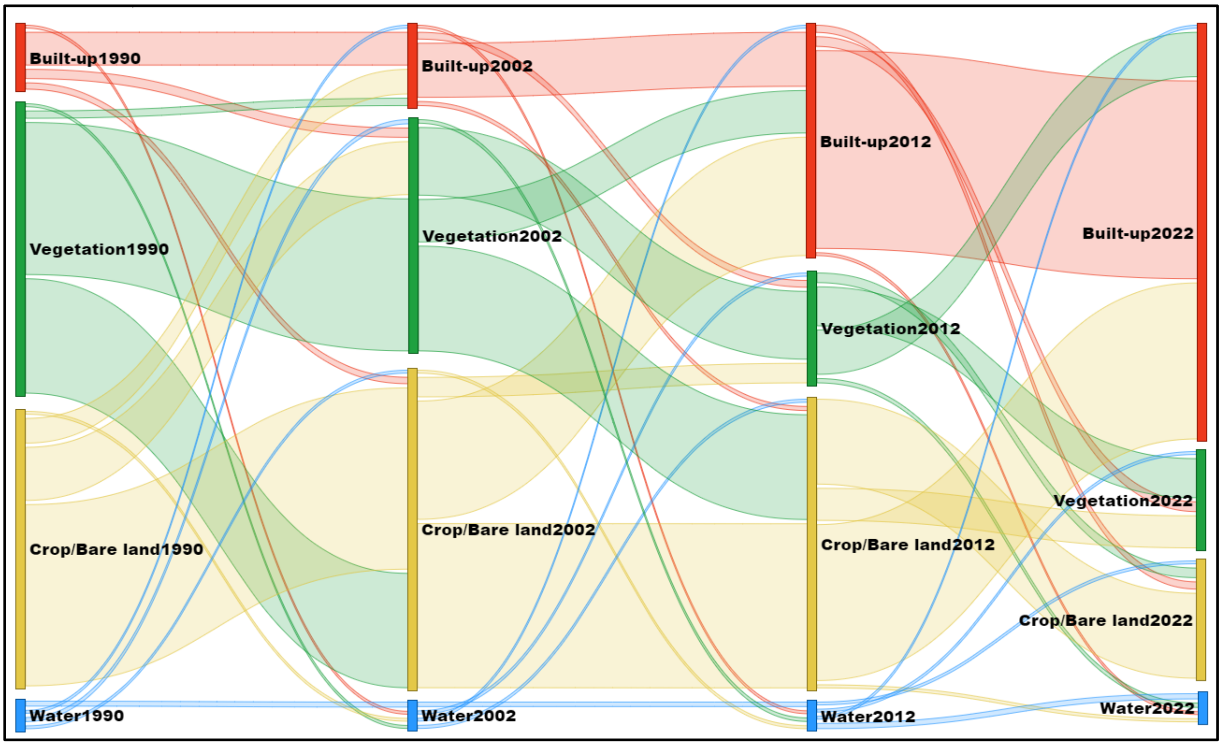


Figure 4.7: Land Use and Land Cover Change in Ouagadougou

Analysis of the figure shows significant transformations in vegetation, crop/bare land and built-up between the different decades. Between 1990 and 2002, almost half of the vegetation was transformed into crop/bare land. However, crop/bare land were transformed into vegetated and built-up. Some parts of the water surface were transformed into crop/bare land, vegetation, and built-up. Between 2002 and 2012, crop/bare land underwent the greatest transformation. In fact, almost half of the area they occupied was transformed into built-up. The same is true of vegetation, almost half of which has been transformed into crop/bare land. Water areas have followed the same trends as in the previous decade. Between 2012 and 2022, almost all the area occupied by crop/bare land that remained in 2012 have been transformed into built-up by 2022. Half of the vegetation area in 2012 was transformed into built-up in 2022. The transformations show that areas are converted from vegetation to crop/bare land and from crop/bare land to built-up.

In Abuja, transformations in occupancy units were observed first between 2001 and 2013 and then between 2013 and 2022. The results of these transformations are represented by the Sankey Diagram (Figure 4.8).

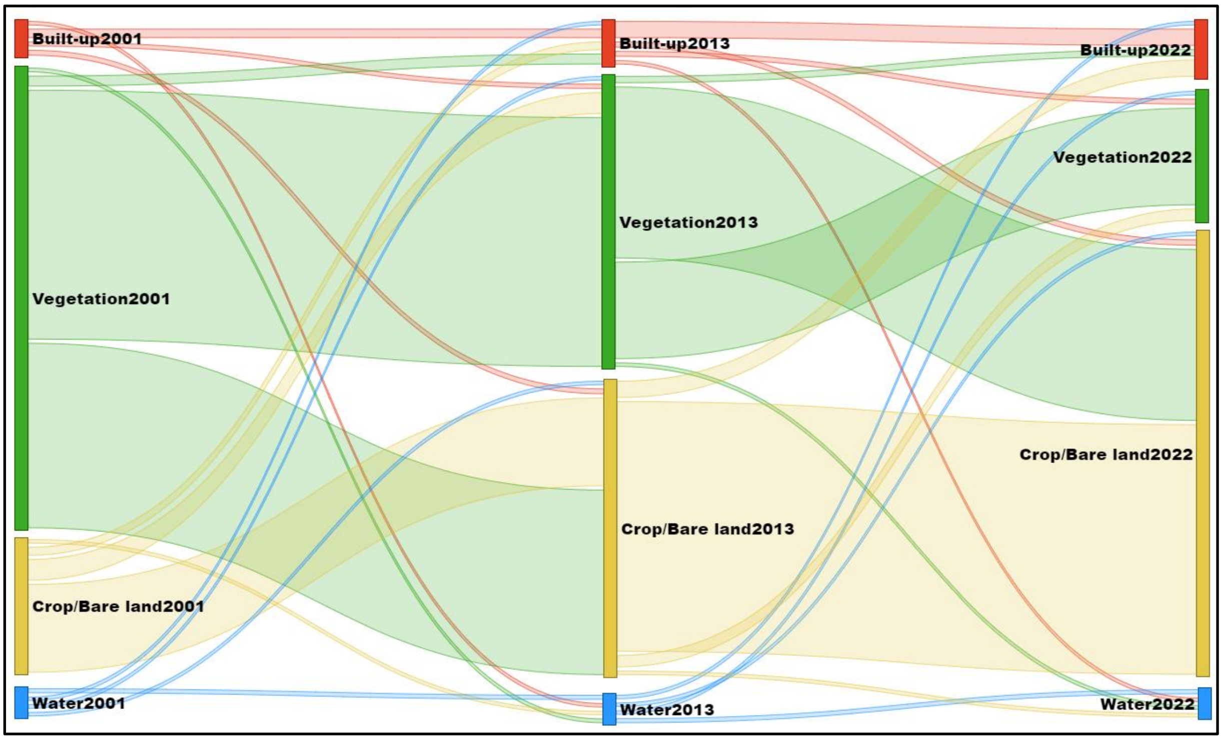


Figure 4.8: Change in Land Use and Land Cover in Abuja

Analysis of the figure shows that vegetation and crop/bare land were most affected by the changes between 2001 and 2022. In fact, in 2001, the area was mainly occupied by vegetation. In 2022, however, it is the crop/bare land that occupies most of the area. Specifically, between 2001 and 2013, a large part of the vegetation was converted to crop/bare land. Some areas of crop/bare land have been converted to built-up and vegetation. Some areas that were occupied by built-up have been converted to crop/bare land and vegetation. In addition, between 2013 and 2022, more than half of the areas occupied by vegetation were converted crop/bare land. Some of this area has also been converted to built-up.

4.1.1.4 *Quantifying urban expansion dynamics*

The results of the indexes of the spatial and temporal dynamics of urban expansion in the city of Ouagadougou between 1990 and 2022 and in the city of Abuja between 2001 and 2022 are presented in Table 4.1. In Ouagadougou, analysis of the UGC, AUER and UEII shows significant variations from one decade to the next. The Urban Growth Coefficient (UGC) or Coefficient of Elasticity, was 0.49 between 1990 and 2002, then increased between 2002 and 2012 and decreased between 2012 and 2022. The overall change over the entire period from 1990 to 2022 was 1.32. The observation results for all periods show that the index value is below normal only between 1990 and 2002 and above the reasonable value of 1.12 in the other decades over the entire 32-year period. For the Average Annual Urban Expansion Rate (AUER), the index values show a positive average annual trend over all periods. From 2.86 between 1990 and 2002, the value increased more than fourfold between 2002 and 2012. It was then halved between 2012 and 2022. During the period 1990 to 2022, the value is close to that between 2012 and 2022. For the Spatial Expansion Intensity Index (UEII), the values show a continuous increase over all the decades. Between 1990 and 2002, the value shows a low intensity of spatial expansion. On the other hand, over the periods 2002 and 2012, 2012 and 2022 and the whole of 1990 to 2022, the values show a very high intensity of spatial expansion. In Abuja, the Urban Growth Coefficient (UGC) or the Elasticity Coefficient, was 0.92 between 2001 and 2013, then increased between 2013 and 2022. The overall change over the entire period from 2001 to 2022 was 0.92. Observation results over all periods show that the index value is below the reasonable value of 1.12. For the Average Annual Urban Expansion Rate (AUER), the index values show a positive annual average trend over all periods. It has remained more or less the same not only between the first two years bands (6.66 and 6.35) but also over the whole period from 2001 to 2022 (6.53). For the Spatial

Expansion Intensity Index (UEII), the values show an increase in the index from the first to the second decade. The overall trend over the entire period, as well as the values for the different decades, reveal a very low intensity of spatial expansion.

Table 4.1: Indexes of Spatial and Temporal Dynamics of Urban Expansion

Period (Years)	Urban Expansion (Km2)	Annual Growth Rate of Urban Expansion (%)	Annual Growth Rate of Urban Population (%)	UGC	AUER (%)	UEII (%)
			OUAGADOUGOU			
1990-2002	15.61	2.91	5.88	0.49	2.86	0.24
2002-2012	143.06	13.88	6.02	2.3	12.99	2.68
2012-2022	174.85	6.57	4.8	1.36	6.36	3.27
1990-2022	333.53	7.38	5.58	1.32	7.12	1.95
			ABUJA			
2001-2013	123.34	6.89	7.48	0.92	6.66	0.13
2013-2022	172.97	6.56	5.97	1.09	6.35	0.25
2001-2022	296.31	6.75	6.83	0.98	6.53	0.18

4.1.2 Climate change impacts in Ouagadougou and Abuja

4.1.2.1 *Assessment of flood recurrence in Ouagadougou*

The data collected on flooding in the city allowed to characterise the recurrence of flooding by sector, by neighbourhood, by month and by year (figure 4.9).

Order	Neighbourhood	Occurrence	Percentage
1	Bissighin	13	16.67
2	Rimkieta	10	12.82
3	Koulouba	9	11.54
4	Ouidi	7	8.97
5	Pissy	7	8.97
6	Patte d'Oie	7	8.97
7	Pagalayiri	7	8.97
8	Dapoya	6	7.69
9	Bilbalogho	6	7.69
10	Cite AN II	6	7.69

Month	Occurrence	Percentage
May	5	7.69
June	6	9.23
July	21	32.31
August	17	26.15
September	13	20.00

Year	Occurrence	Percentage
2012	11	16.92
2013	8	12.31
2015	5	7.69
2016	11	16.92
2018	7	10.77

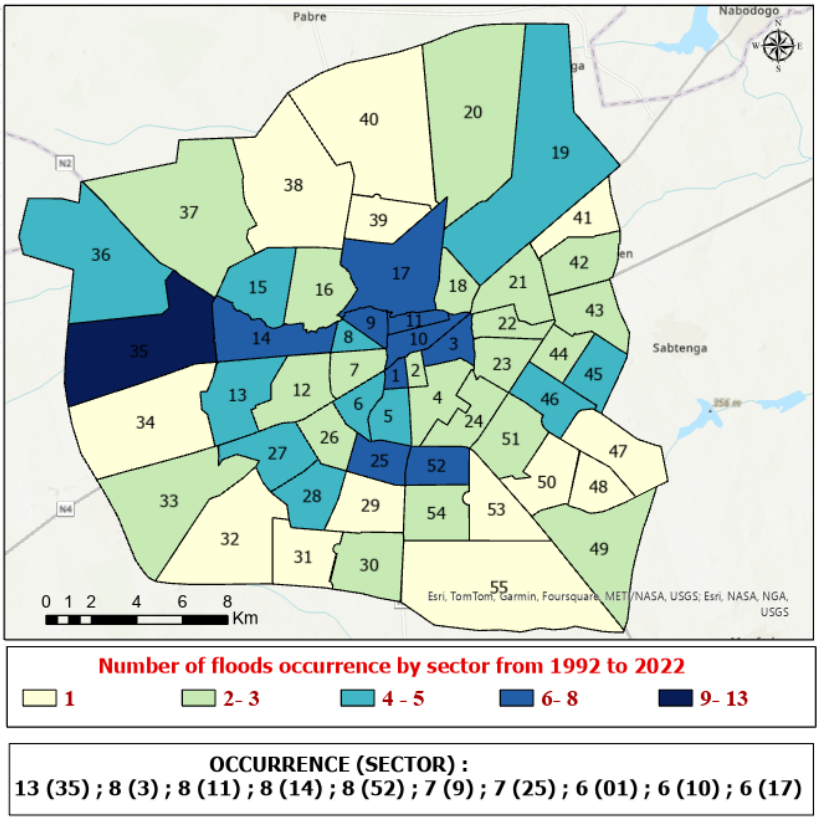


Figure 4.9: Occurrence of Flooding in Ouagadougou from 1992 to 2022

The analysis of the map shows an uneven distribution of flood recurrence throughout the city. Firstly, the analysis highlights the 10 sectors most affected by flooding during the period 1992 to 2022. Sector 35 is the one most affected by flooding, with a record of 13 occurrences. Sectors 3, 11, 14 and 52 were affected 8 times during the same period. Sectors 9 and 25 were affected 7 times and sectors 1, 10 and 17 around 6 times. During the same period, all 55 sectors of the city were affected at least once.

Secondly, l0 neighbourhoods were the most affected. These included the Bissighin and Rimkieta districts, which accounted for 16% and 12%, respectively, of the city's other districts. Thirdly, the month's most affected by flooding were July (32%), August (26%) and September (20%). Finally, among the most recurrent years in terms of flooding, 2016 and 2012, with around 16% of occurrences compared to the others.

4.1.2.2 *Temperature trends in Ouagadougou and Abuja*

In Ouagadougou, the trends of the absolute annual maximum and minimum temperatures over the period 1992-2022, show different records over the period, but characterised by rising temperatures. The annual absolute maximum temperature is the highest temperature value measured during the year. The analysis of annual maximum temperatures in the city of Ouagadougou shows that after 2009 all absolute maximum temperatures remained strictly above 42 degrees Celsius. Figure 4.10 shows the ranking of years with the 10 highest annual maximum temperature records. The annual absolute minimum temperatures are the lowest temperature values measured during the year. The analysis of annual minimum temperatures shows that 2004 recorded the highest absolute minimum temperature at 15 degrees Celsius. Figure 4.11 shows the ranking of years with the 10 highest annual minimum temperature records in Ouagadougou.

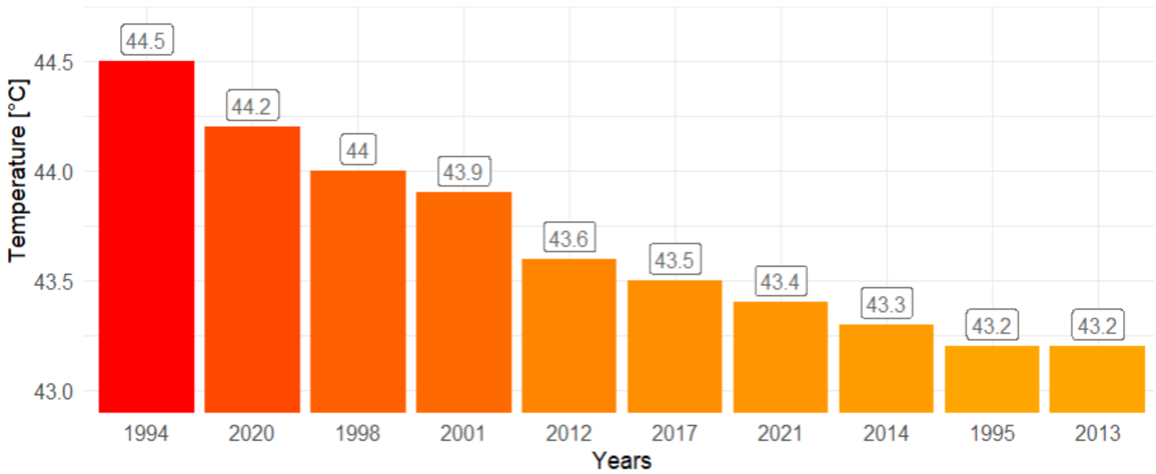


Figure 4.10: Ranking of Years With 10 Highest Annual Maximum Temperature Records in Ouagadougou

Analysis of the annual maximum temperature records shows that over the period 1992-2022, 1994 recorded the highest maximum temperature. A striking fact is that of the 10 years with the highest maximum temperatures over the thirty years, more than half are in the last ten years, showing that more and more record maximum temperatures are being recorded in recent years.

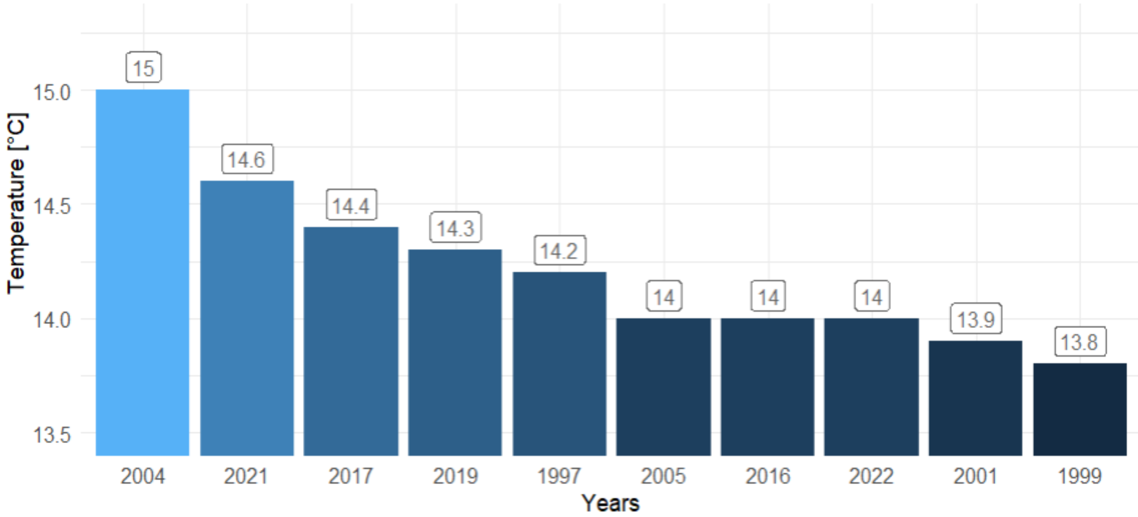


Figure 4.11: Ranking of Years With 10 Highest Annual Minimum Temperature Records in Ouagadougou

In terms of absolute minimum temperatures, 2004 recorded the highest absolute minimum temperature at 15°C, followed by 2021. As with absolute maximum temperatures, at least five out of 10 of the years with the highest minimum temperatures are in the last ten years of the 32-year period (1991-2022). This shows that the last few years have been among the warmest in terms of minimum temperatures.

In addition, the climate index of cold nights and warm nights (Figure 4.12) and cold days and warm days (Figure 4.13) shows the temperature trends during these periods.

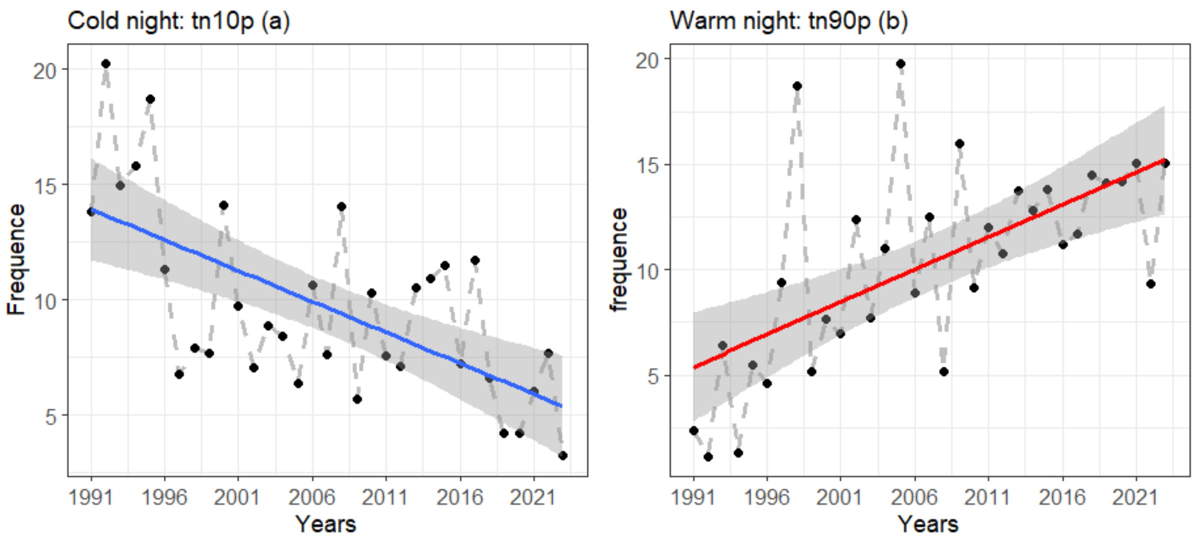


Figure 4.12: Change in the Percentage of Cold Nights and Warm Nights in Ouagadougou

Analysis of the change in the percentage of cold nights and the percentage of warm nights shows a downward trend in cold nights (a) and an increase in the percentage of warm nights over the same period (b).

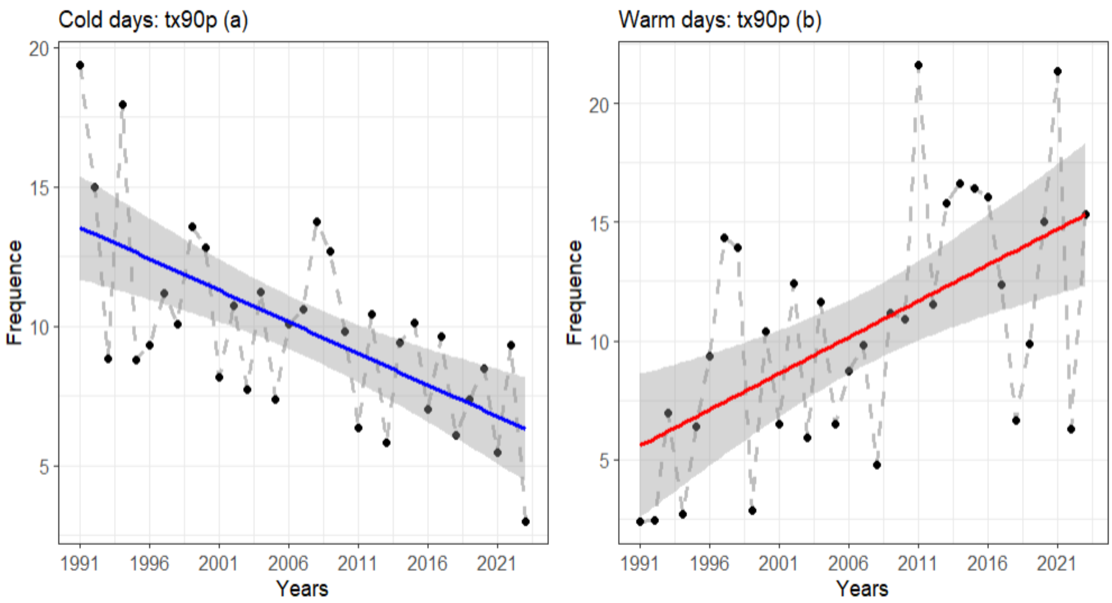


Figure 4.13: Change in the Percentage of Cold Days and Warm Days in Ouagadougou

Analysis of the change in the percentage of cold days and the percentage of hot days shows a downward trend on cold days and an upward trend in hot days.

In Abuja, the trends of the absolute annual maximum and minimum temperatures over the period 1992-2022, show different records over the period, but characterised by rising temperatures. Figure 4.14 shows the absolute maximum temperatures above 40 degrees Celsius over the period 1992 to 20022 in Abuja. Figure 4.15 shows the absolute minimum temperatures above 13 degrees Celsius over the same period in Abuja.

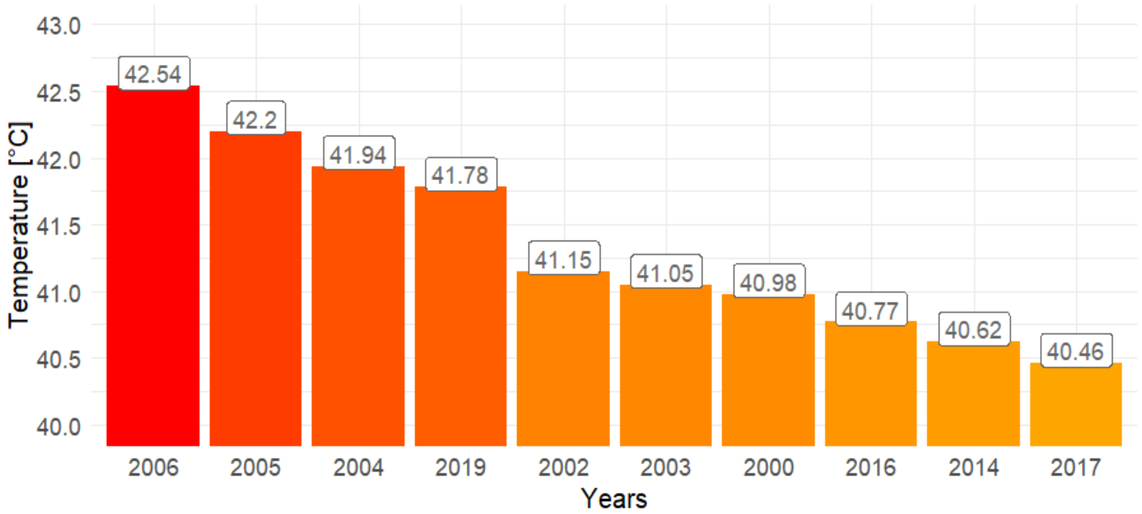


Figure 4.14: Absolute Maximum Temperatures in Abuja

An analysis of the graph shows that there have been at least 10 years in the last 30 years with recorded temperatures above 40 degrees. The year with the highest absolute maximum temperature was 2006. The results show that from 2000, temperatures began to rise steadily until 2006. The same trends can be observed between 2014 and 2019.

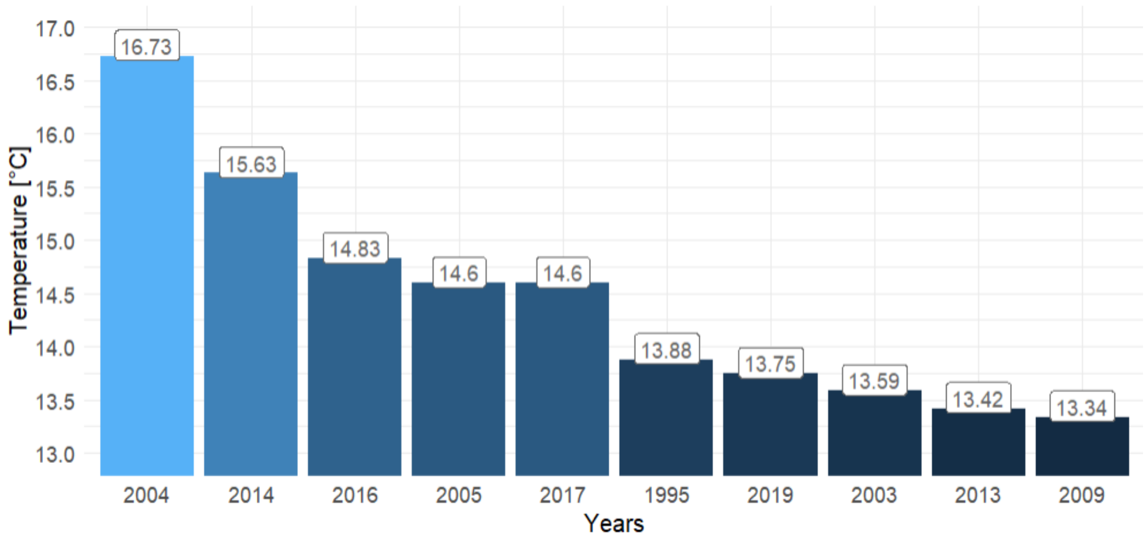


Figure 4.15: Absolute Minimum Temperatures in Abuja

Analysis of the graph reveals that at least 10 years during the observation period have had minimum temperatures above 13 degrees Celsius. The year 2004 has the highest record of the 10. There is an abrupt change between 2003 and 2004, which are both successive years.

An analysis of the city's temperatures shows trends in hot days (a) and cold days (b) (Figure 4.16) and cold nights (a) and hot nights (b) (figure 4.17).

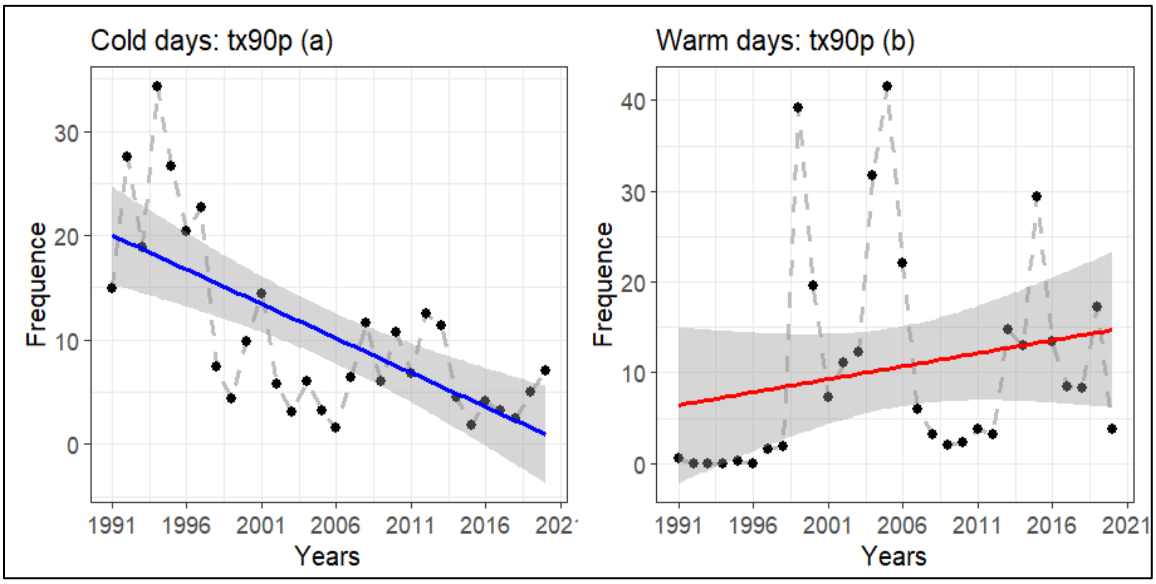


Figure 4.16: Change in the Percentage of Cold Days and Warm Days in Abuja

Analysis of the change in the percentage of cold days and the percentage of hot days shows a downward trend in cold days over the period 1991-2022 (a). Regarding the percentage of hot days, there has been an increase during the same period (b).

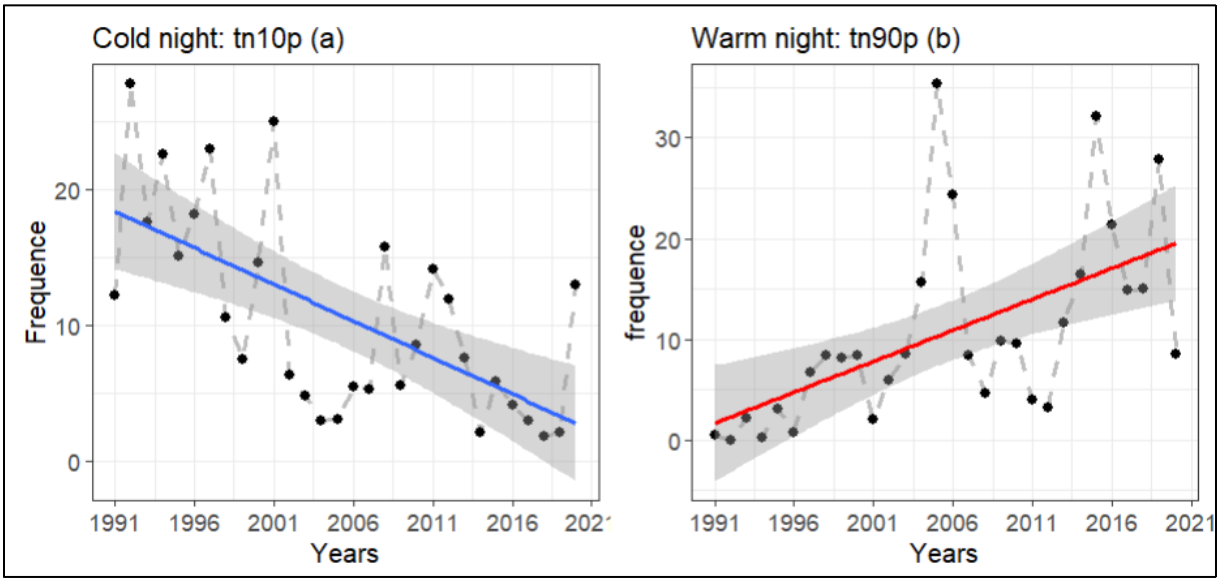


Figure 4.17: Change in the Percentage of Cold Nights and Warm Nights in Abuja

Analysis of the change in the percentage of cold nights and the percentage of warm nights shows a downward trend in cold nights. Regarding the percentage of warm nights, there has been an increase over the same period.

4.1.2.3 *Impact of extreme heat in Ouagadougou and Abuja*

To characterise the impact of temperatures by sector in Ouagadougou, the spatial and temporal evolution of variables was observed. Figure 4.18 shows the spatial distribution of vegetation, habitat, altitude, LST, population, and informal areas in, all of which influence the spatial distribution of the impact of high temperatures in Ouagadougou.

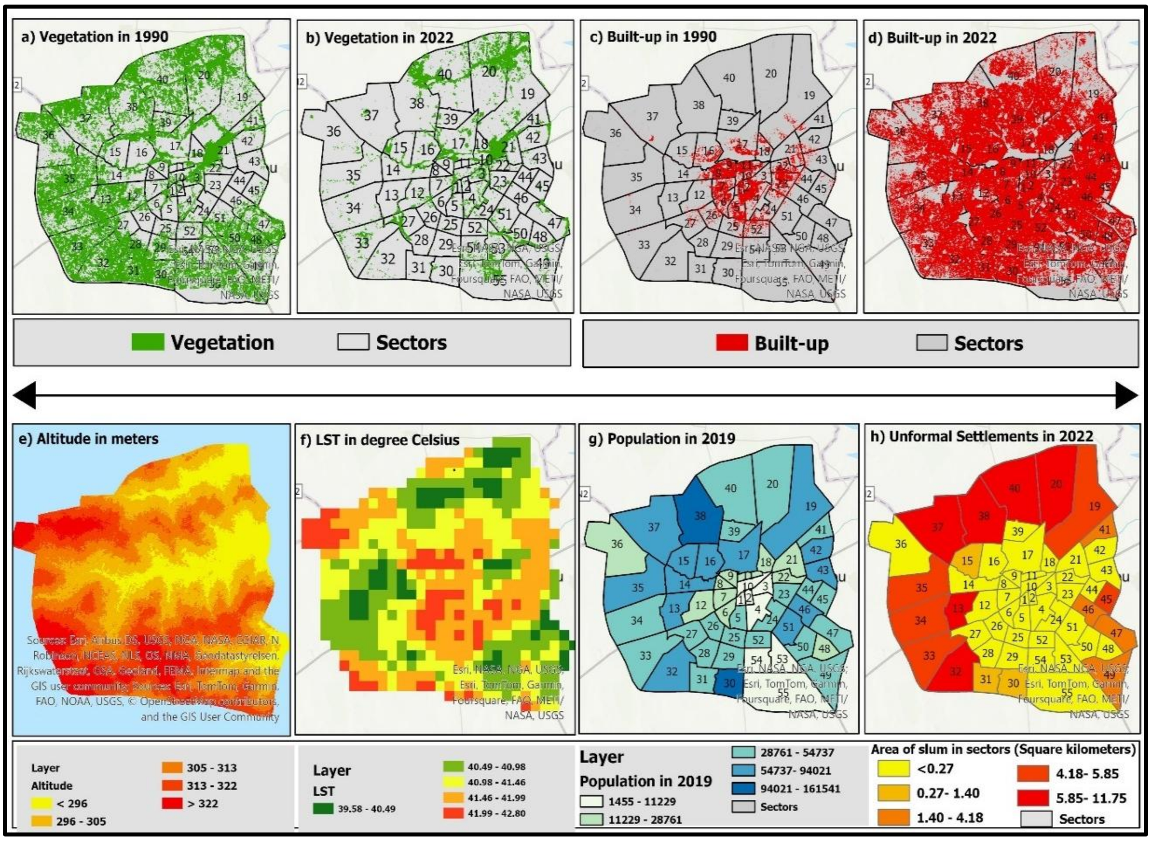


Figure 4.18: Spatial Distribution of Factors Influencing High Temperature

The results of the dynamics of the variables in time and space show a disparity throughout the study area. On the one hand, we note the disappearance of vegetation from 1990 to 2022 and, on the other, a dramatic increase in habitat over the same period. The population distribution shows that the areas located in the centre and on the outskirts in the southern part are the least populated. The distribution of informal settlements shows an absence in the central and southern sectors of the city. Undeveloped areas are concentrated in the east, north, west and south-west. The spatial distribution of these variations has enabled to analyse the distribution of the impact of temperature by sector in Ouagadougou (Figure 4.19).

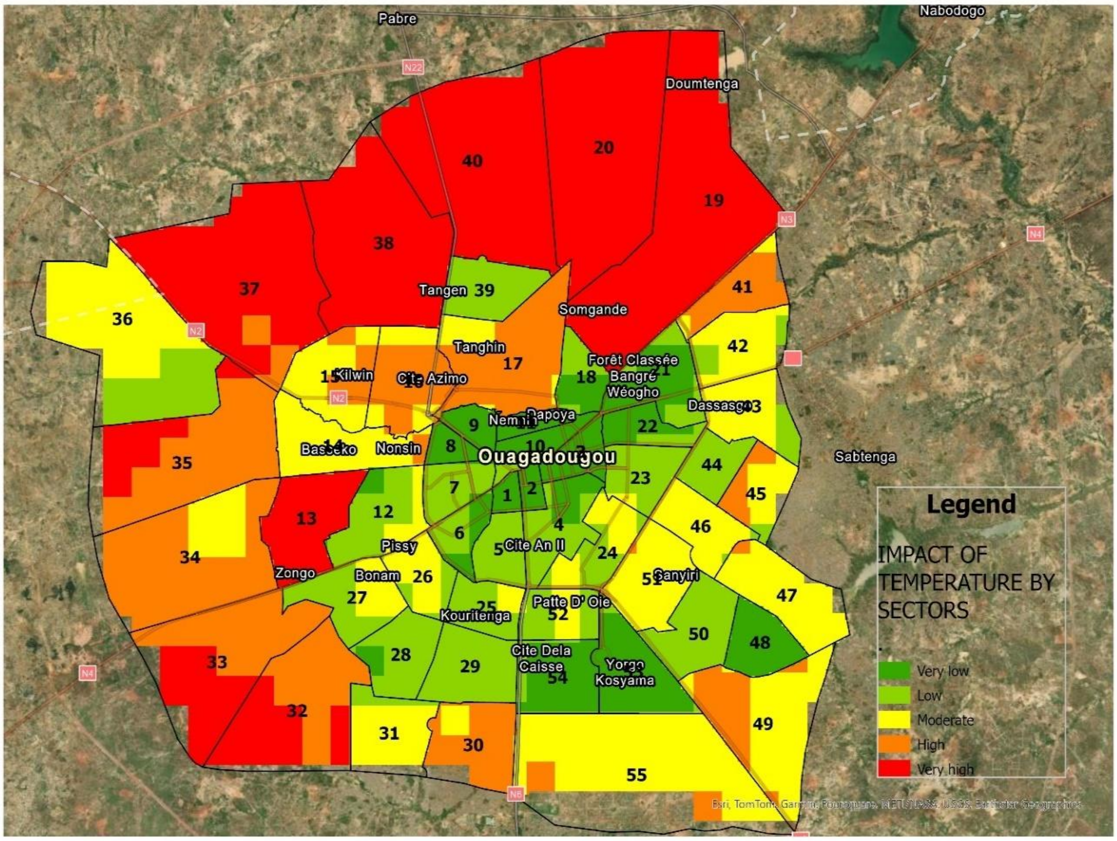


Figure 4.19: Spatial Distribution of the Impact of the Temperatures

The results of the spatial distribution of the impact of the temperatures show that the sectors in the centre and south of the town are the least affected. The sectors most affected are those located in the northern and western parts. It can also be seen that some of these areas have different parts of the city in terms of impact. The least affected sectors are those with a low population density, presence of vegetation, and a total absence of slums. The sectors that are most affected are those with the highest concentration of slums, high population density, high built-up density and no vegetation.

The analytic hierarchy process of the variables allowed a characterisation of the impact of temperatures by LGA in Abuja (figure 4.20).

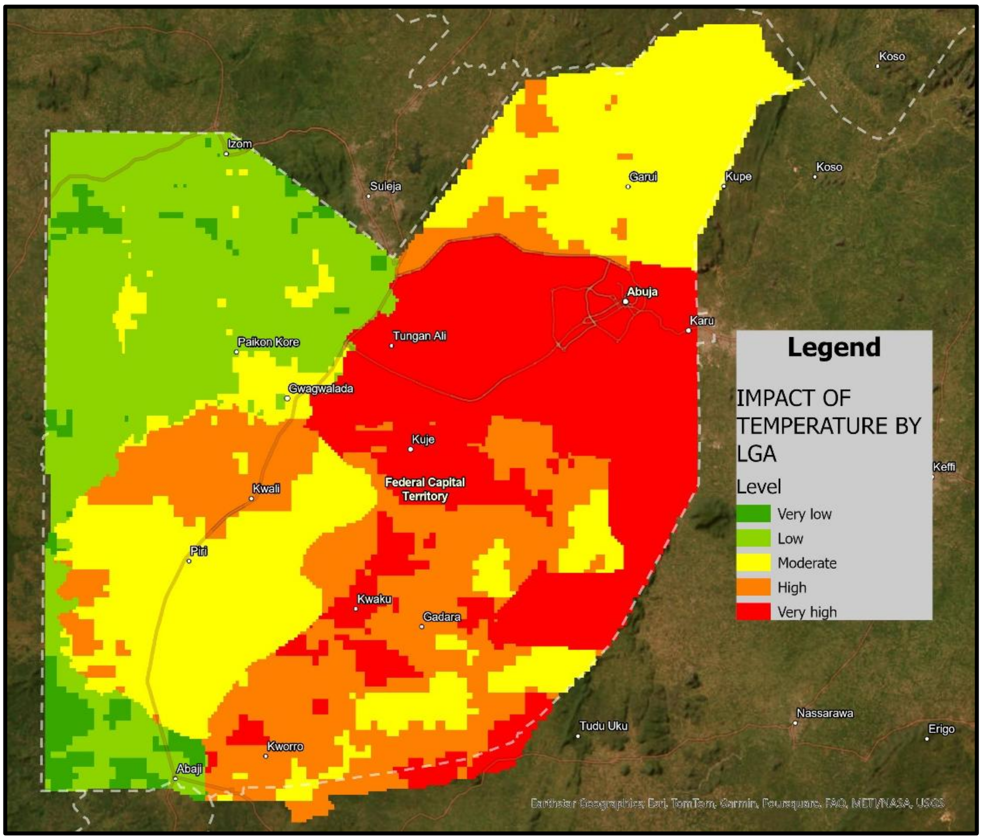


Figure 4.20: Spatial Distribution of the Impact of the Temperatures

Analysis of the spatial distribution of temperatures shows that the areas that are strongly impacted are Abuja, Kuje, and the eastern part of Gwagwalada. The impact in Kwali is high. On the other hand, there are areas of low and very low impact. The northern and south-west parts are moderately impacted. The northwest part is slightly affected.

4.1.3 Households' perception of climate change and settlement dynamics in Abuja and Ouagadougou

4.1.3.1 *Socio-demographic Characteristics of the Households*

The socio-demographic characteristics of the households interviewed in Abuja and Ouagadougou are presented in Table 4-2. In Abuja, approximately one third of the respondents (32.52%) were women and two thirds were men. The minimum age was 20 years and the maximum 70 years. The mean age was 39.74 and the standard deviation 11.18. The majority of the respondents (31.17%) were between 40 and 50. Only 4.28%

were between 60 and 70. Those 20 and 30 accounted for 25.92%. The marital status of the respondents reveals that more than 62% are married. Those who live with a partner represent the lowest percentage (0.61%). Singles accounted for around a third (32.4%) of the respondents. The level of education shows that 53% of the respondents have a university degree. Around 36% of the respondents had secondary education. Those without education represent only 2.81%. The level of education reveals a very high school enrolment rate. This is logical, given its role as Nigeria's political capital and the headquarters of several African and international institutions. In terms of occupation, more than a quarter (27.02%) are self-employed (traders and entrepreneurs), while 23.47% work in the public sector. The private sector accounts for 14.67%. Around 10% are students/researchers. There are also other categories that were not mentioned. They represent the smallest percentage (4.16%).

However, in Ouagadougou approximately 70% of the respondents were women and 30% were men. In the Ouagadougou surveys, women were more likely to be found at home than men. This can be explained by the different activities. The minimum age was 20 years and the maximum was 88 years. The mean age was 42.16 and the standard deviation 14.17. In terms of age, the results show that the city's population is very young. In fact, 24.67% are between 20 and 30, and 30.62% are between 30 and 40. These two age groups represent more than 50% of the population. The marital status of the respondents shows that more than 76% are married. Those who live with a partner represent the lowest percentage (2.55%). Singles accounted for around 11%. There was a low level of education, with 44.35% having any schooling. About 22% of respondents had primary education. Those with secondary and university education represent around 9% and 12%, respectively. In terms of occupation, the results show that 35.6% are unemployed.

Independent workers (traders and entrepreneurs) accounted for 31.23%. The smallest group is of mechanics and carpenters (4.74%).

Table 4.2: Sociodemographic Characteristics of the Households

CITY	ABUJA (818)		OUAGADOUGOU (823)	
	Frequency	Percentage	Frequency	Percentage
GENDER				
Male	552	67.48	252	30.62
Female	266	32.52	571	69.38
AGE				
20 - 30	212	25.92	203	24.67
30 - 40	229	28	252	30.62
40 - 50	255	31.17	151	18.35
50 - 60	87	10.64	119	14.46
60 - 70	35	4.28	62	7.53
70	0	0	36	4.37
MARITAL STATUS				
Married	514	62.84	627	76.18
Single	265	32.4	93	11.3
Divorced/separated	19	2.32	12	1.46
Widowed	13	1.59	70	8.51
Lives with a partner/common-law	5	0.61	21	2.55
LEVEL OF EDUCATION				
No level	23	2.81	365	44.35
Primary school	36	4.4	184	22.36
Post-primary school (1er cycle)	18	2.2	93	11.3
Secondary school (2e cycle)	298	36.43	79	9.6
Higher/University	431	52.69	101	12.27
OCCUPATION				
Independent Workers (Trader/Entrepreneur)	221	27.02	257	31.23
Public sector worker	192	23.47	38	4.62
Private sector worker	120	14.67	98	11.91
Student/Researcher	81	9.9	32	3.89
Farmer/breeder/gardener	81	9.9	22	2.67
Housewife/Unemployed	47	5.75	293	35.6
Welder/joiner/seamstress/mechanic	42	5.13	39	4.74
Other	34	4.16	44	5.35

4.1.3.2 *Perception of settlement dynamics in Ouagadougou and Abuja*

In Ouagadougou, the household survey allowed us to obtain their views on the spatial growth of the city and the factors that contribute to this dynamic. However, the opinions gathered show different points of view on the perception of the city's spatial dynamics. The majority of the participants interviewed thought that there had been a spatial increase in the city over three (03) decades. More than 90% assumed that the city is expanding, only 3.56% thought it is shrinking and 4.63% say it is stable. Figure 4.21 shows perceptions of the city dynamics according to the level of education of the respondents.

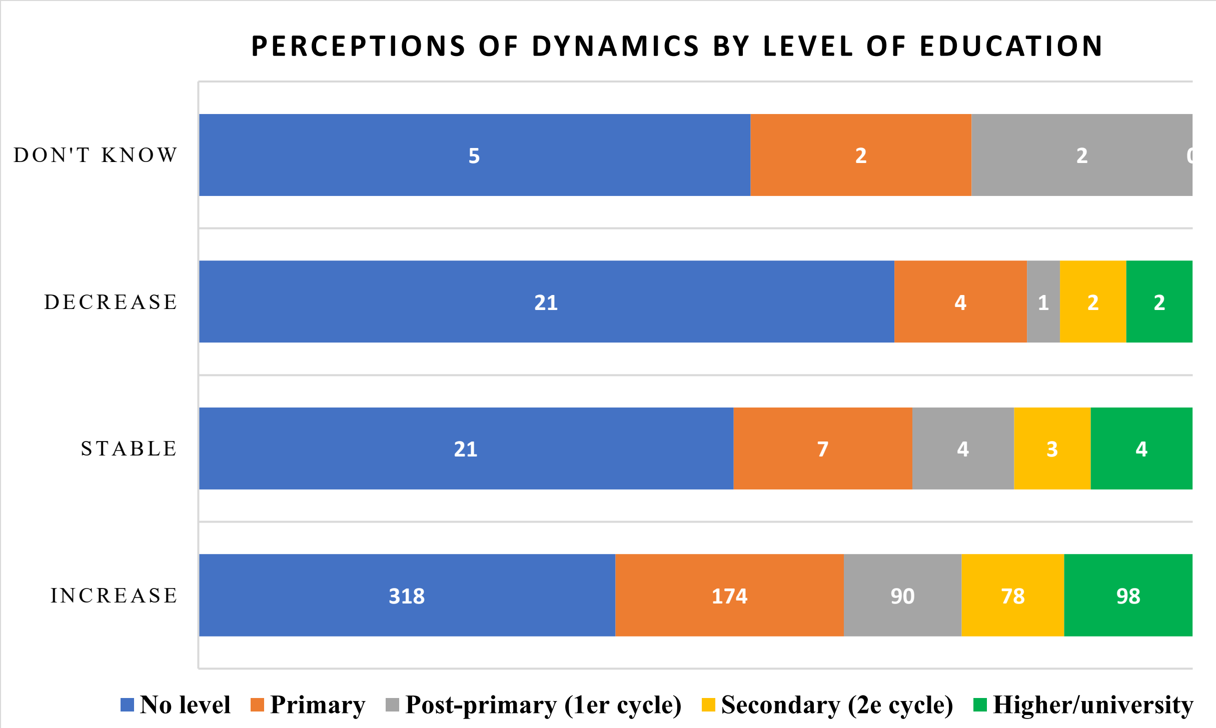


Figure 4.21: Perceptions of the Dynamics by Level of Education in Ouagadougou

Analysis of the graph shows that the level of education is very important in the perception of the dynamics of the city. In fact, among those who have no level of education, some assumed it is stable, others thought it is decreasing, and there are those who have no idea. On the other hand, the higher the level of education, the better the perception of the dynamics. For example, all those with secondary or university education have an idea of how the city is evolving.

In this way, respondents have given their views on the factors that encourage spatial expansion (figure 4.22).

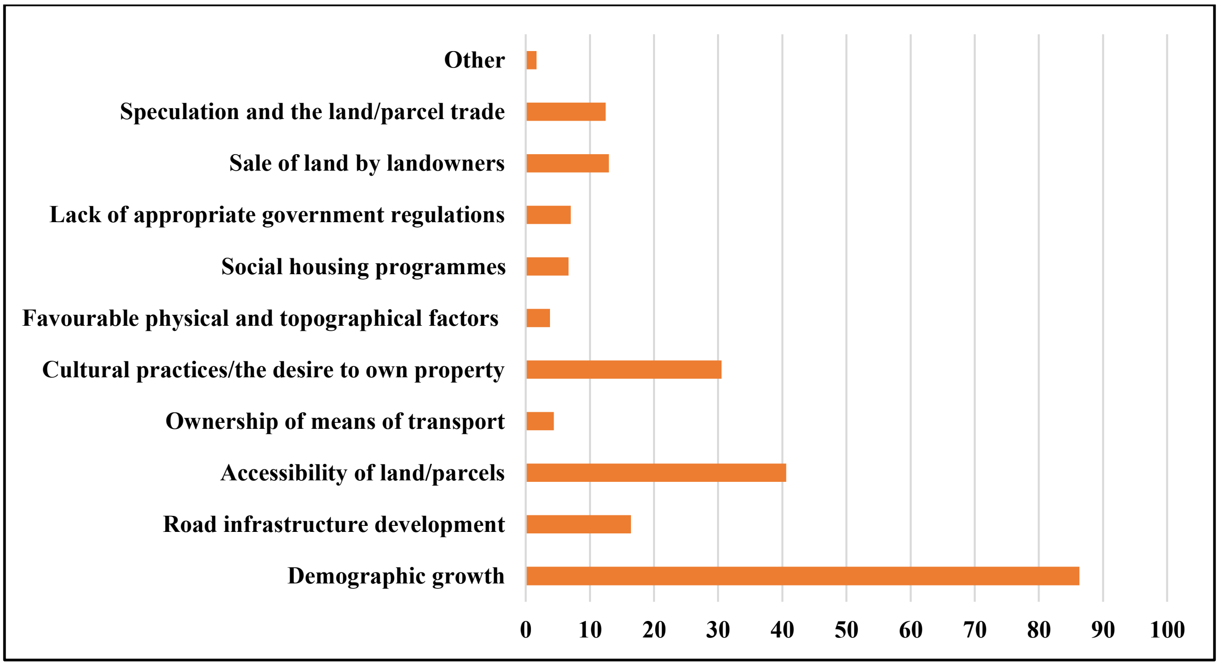


Figure 4.22: Factors of the City's Spatial Expansion in Ouagadougou

An analysis of the graph on household's perceptions of the factors contributing to the spatial expansion of towns shows that population growth is the main factor behind this growth. This was reported by 86.34% of households. Other factors include the accessibility of land (40.62%), cultural practices, i.e. the desire to have one's own house (30.52%), the development of roads (16.39%) and the sale of plots by landowners (12.95).

In Abuja, the household survey allowed us to gather their views on the spatial growth of Abuja and the factors that contribute to this dynamic. Regarding the dynamics of the city's built-up area over the last 30 years (1992 to 2022), 62.91% thought there had been an increase, 23.49% assumed that there had been a decrease, and 9.64% believed it was stable. Figure 4.23 shows perceptions according to the level of education.

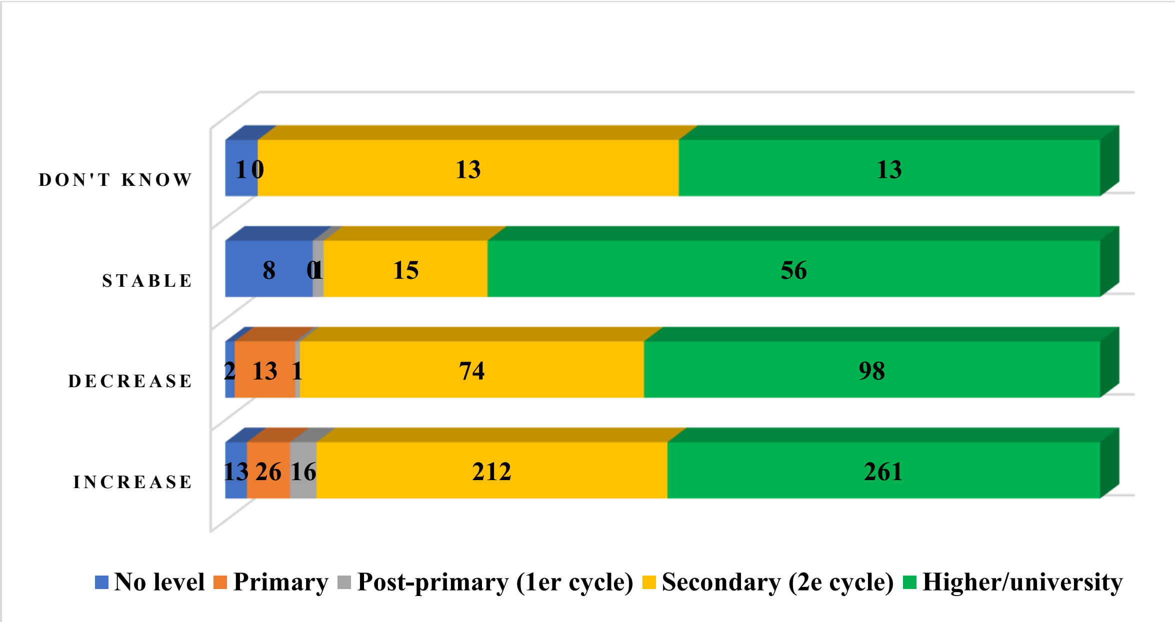


Figure 4.23: Perceptions of Dynamics by Level of Education in Abuja

The analysis shows that, at all levels, the majority of those interviewed believed that the city is marked by an increase in spatial dynamics. For those at the secondary and university level, some felt that there is a decrease or stability in spatial dynamics. Abuja is an administrative and university city, so there are people who come just for reasons of service or study. The sociodemographic characteristics participants showed that around 50% had a university degree. But the question was to find out their perception over the last 30 years. Their perception of the dynamic may depend on the number of years they have lived in the city. The precipitants in the study cited the factors that encourage the spatial expansion of the city. Figure 4.24 shows the proportions of the factors cited.

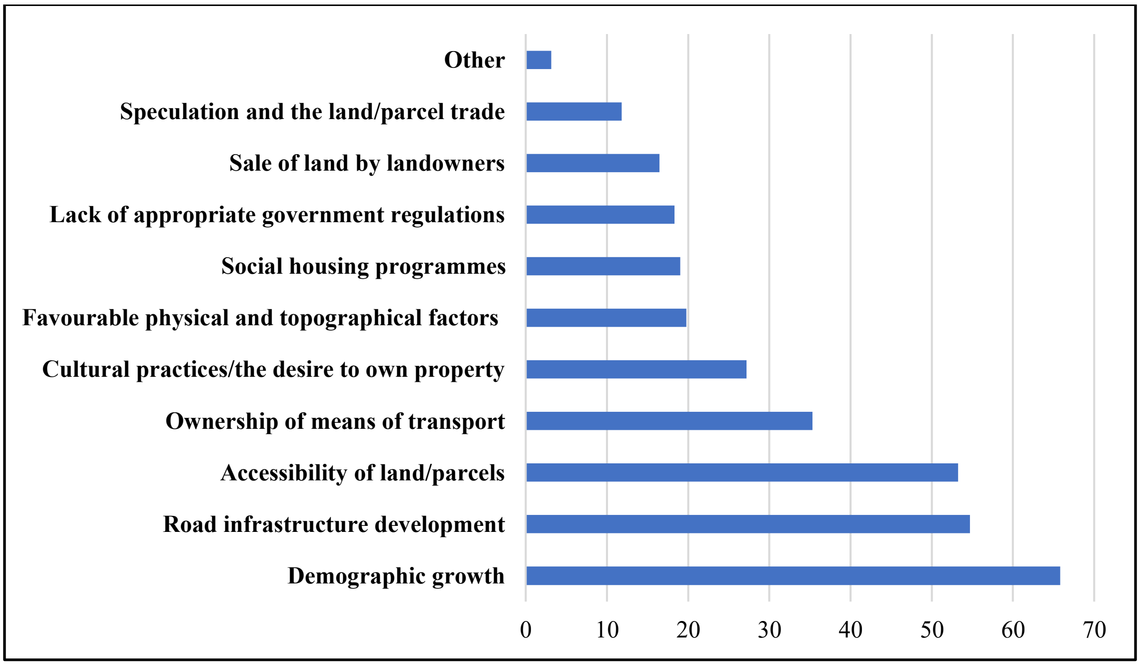


Figure 4.24: Factors of the City's Spatial Expansion in Abuja

An analysis of the graph on respondent's perceptions of the factors contributing to spatial expansion shows that population growth is the main factor. This was reported by 65.8% of households. In addition to population growth, the development of road infrastructure (54.71%), the accessibility of land (53.23%), and the possession of a means of transport (35.3) are the factors that favour the expansion of the city of Abuja. In addition, the development of social housing programmes favours the growth of Abuja (19.04%). Road infrastructure is better developed in Abuja, allowing urban sprawl.

4.1.3.3 *The effects on urban environment in Ouagadougou and Abuja*

In terms of the impact of the demographic and spatial dynamics of cities on the urban environment, the study looked at the means of transport used by the population and the level of perception of dust in cities. Figure 4.25 shows the proportions of means of transport used by the population for their mobility in Ouagadougou.

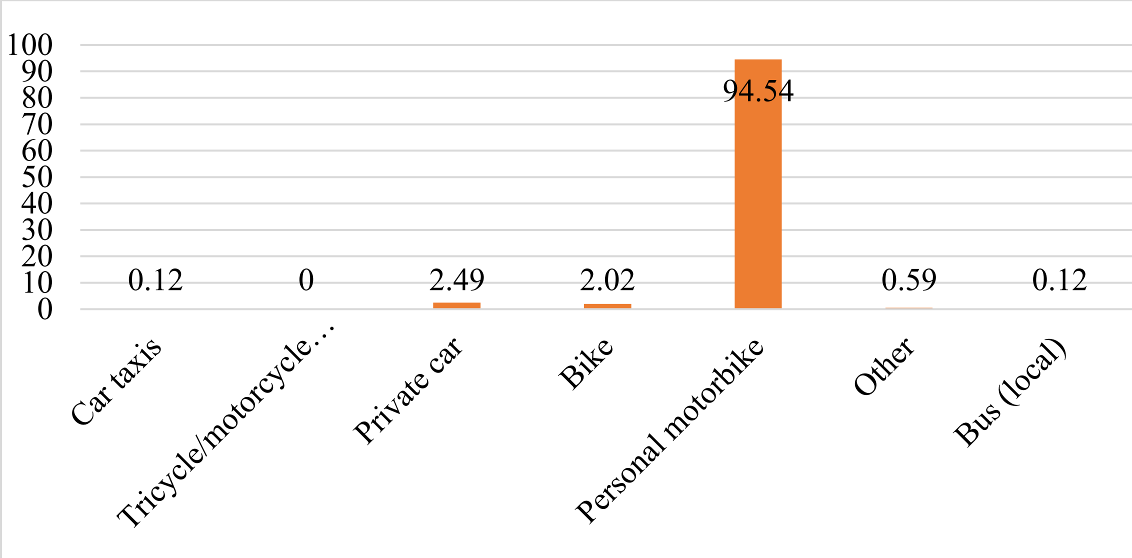


Figure 4.25: The Most Common Transport Use by households in Ouagadougou

The analysis of the figure shows that the main means of transport used by the population is the motorbike (94.54%). Private cars come second in terms of means of transport in the city. Public transport buses and taxis are seldom used. The fact that a large proportion of the population of Ouagadougou own a motorbike means that public transport (taxis, communal buses) is less developed and less used in urban mobility.

The means of transport used in urban areas cause air pollution due to the gases and dust produced when people travel. The study looked at the opinions of households on the state of dust in the city. Figure 4.26 shows the proportions of perceptions of the state of dust in the city.

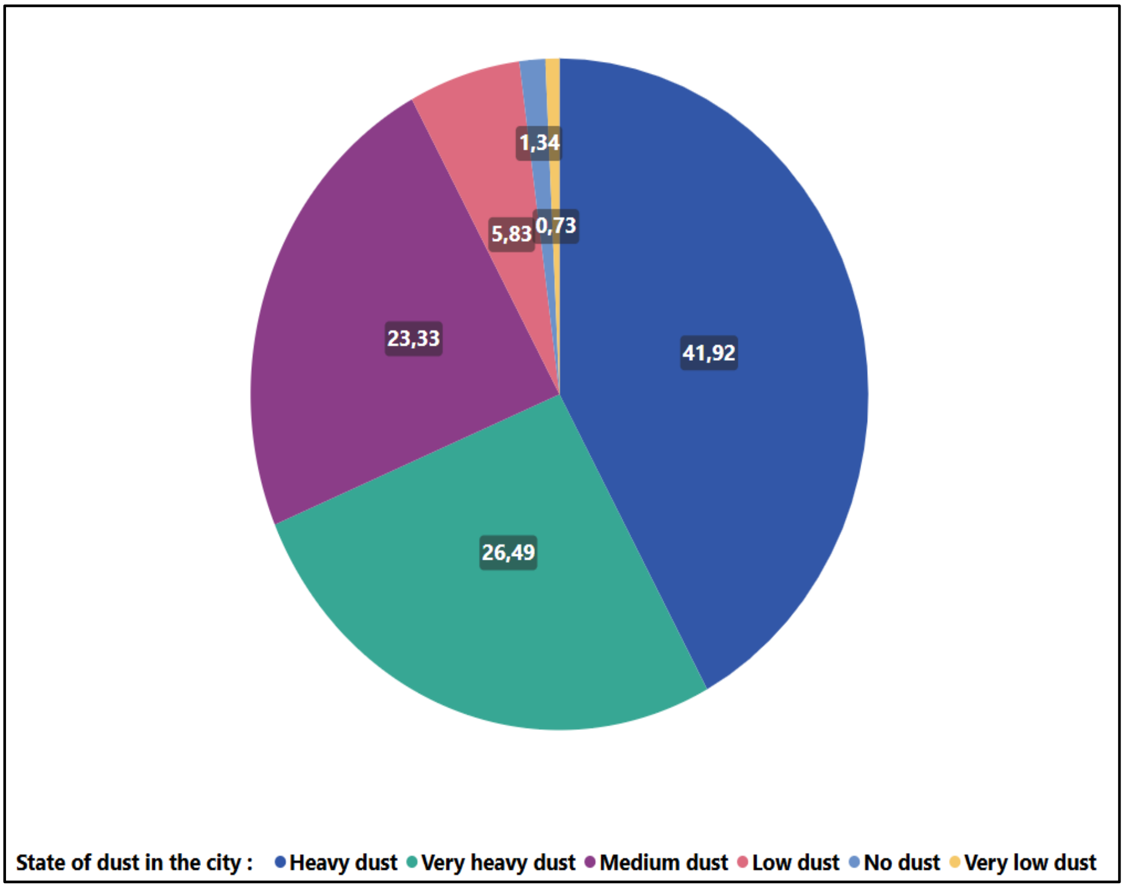


Figure 4.26: Perceptions of the State of Dust in the City in Ouagadougou

The figure showing the dust state in the city shows that over 40% believed that there is a lot of dust. Around 26% felt that the dust is very strong, and 23.33% thought that the dust is average. Those who assumed that it is weak represent 5.83%. Less than 1% thought it was very light. The results show that a large proportion of the population highlighted the presence of dust as a factor that affects the urban environment. The poor development of road infrastructure combined with the use of motorcycles by the majority of the population contributes to the amplification of dust in the city.

In Abuja, the study examined the means of transport used by the population and the level of perception of dust in the city. The proportions of means of transport used by the population to get around the city are illustrated in Figure 4.27.

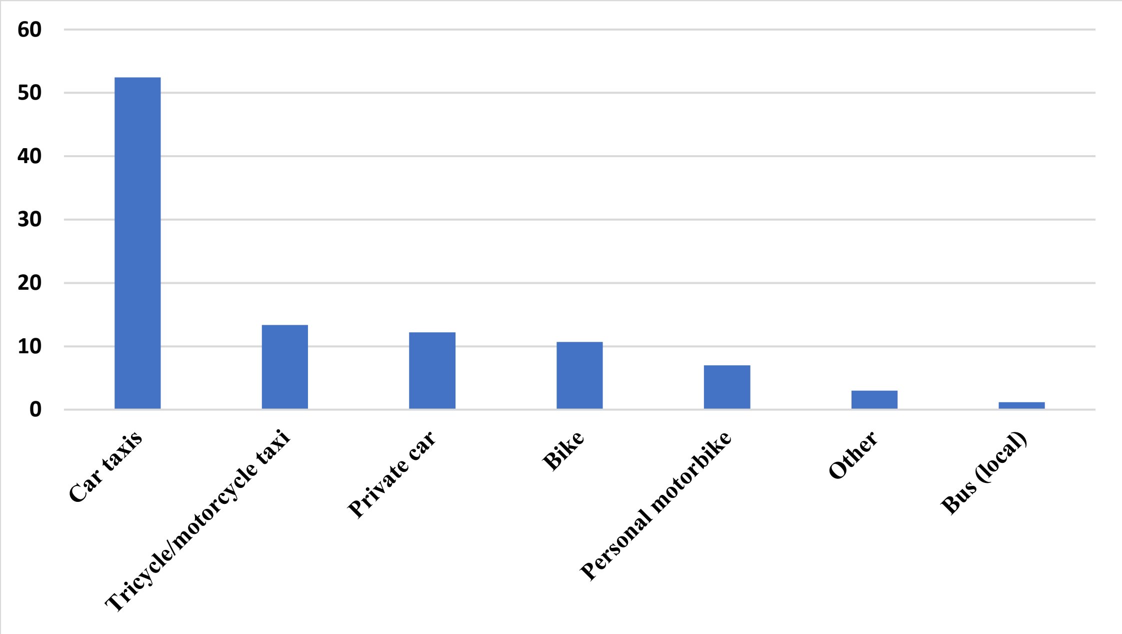


Figure 4.27: The most Common Transport Use by households in Abuja

The analysis of the graph shows that the main means of transport used by the population of Abuja is the taxi (52.44%). Motorbikes are used as taxis by 13.37% of the population. Private cars (12.21%) come third in terms of means of transport. Public transport buses are little used.

Urban transport causes air pollution due to the gases and dust caused by people travelling. The study examined households' opinions on the state of dust in urban areas. Figure 4.28 shows the proportions of the opinions on the state of dust in the city.

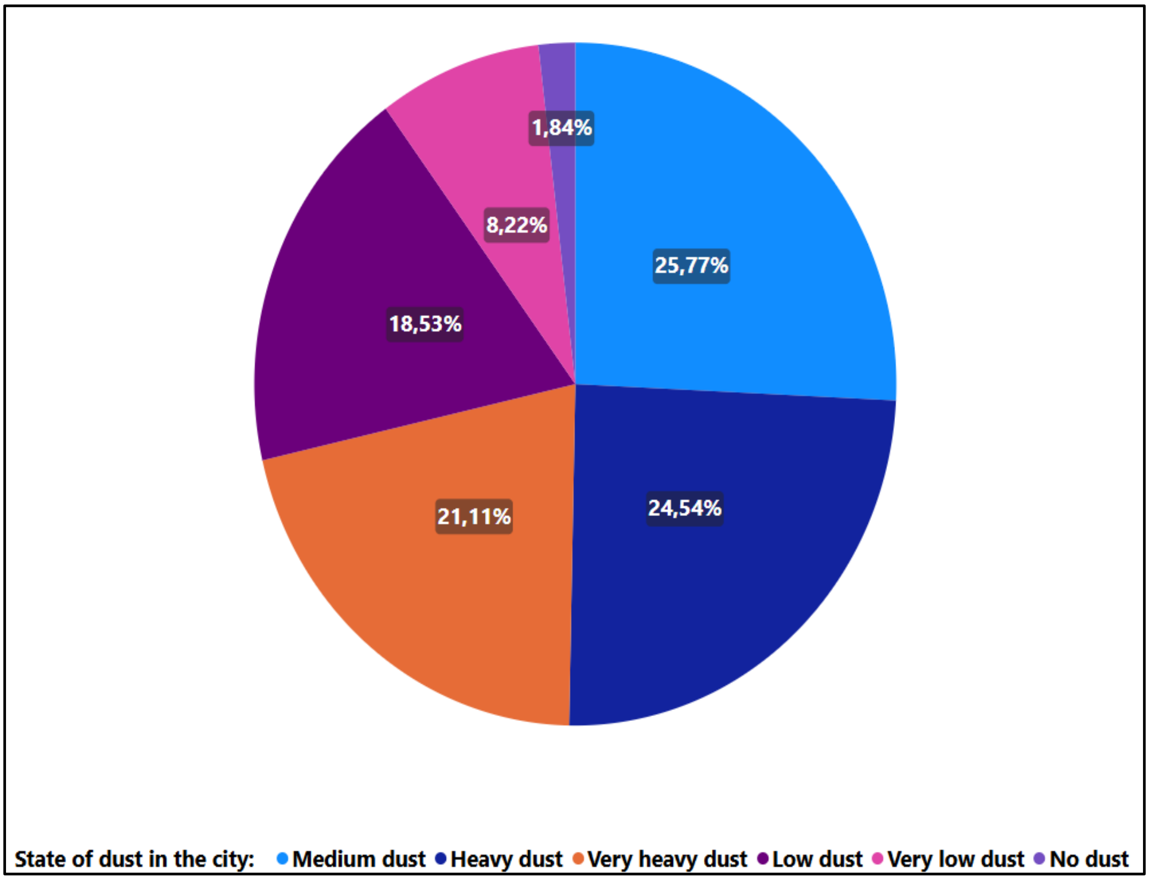


Figure 4.28: Perceptions of the State of Dust in the City in Abuja

The graph showing the state of dust in the city of Abuja shows that about a quarter of the population believed that the dust is average, less than a quarter felt that that the dust is high and 21.11% assumed that the dust is very high in the city. More than 18% thought that it is low and 8.22% argued it is very low. The pavement of roads and the use of public transport have helped reduce dust, which explains the acceptable level of dust in the city.

4.1.3.4 *Vegetation degradation and potential impacts*

In Ouagadougou, the study paid particular attention to the opinions of the households interviewed about their perception of changes in the vegetation cover of cities compared with the past. The results show that respondents have different apprehensions about the dynamics of forest resources and the causes of this. Approximately 74% said there is a decrease in vegetation cover, 19.95% indicated that vegetation cover is increasing, 4.39%

presumed that there is no change, and 1.43% have no idea about the state of vegetation.

Questions were only asked to those who thought that vegetation cover was decreasing to find out the causes of the disappearance of vegetation in cities. The main factors in the decline of vegetation include the spatial expansion of the city, land subdivision and excessive logging. In fact, 82.4% reported that the main factor is the spatial expansion of the city. Figure 4.29 shows the number of factors that contribute to the decline in vegetation according to the level of education.

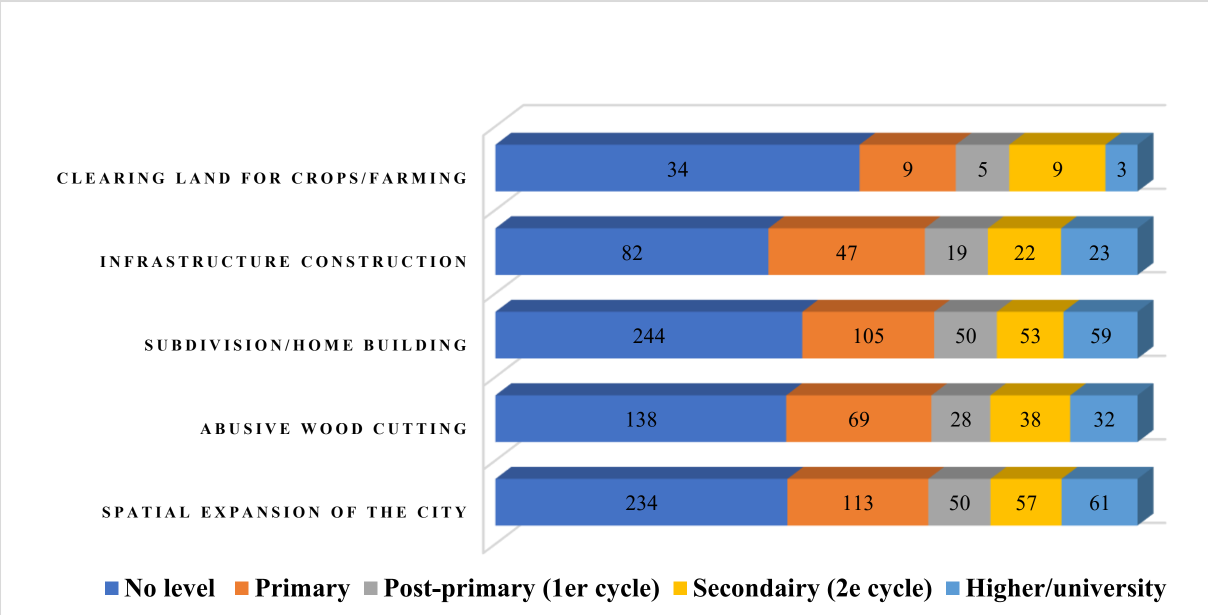


Figure 4.29: Causes of Vegetation Deterioration in Ouagadougou

Analysis of the graph shows that the majority of those with primary to university-level education are unanimous that urban growth is the main cause of vegetation regression. Most respondents with no level of education believed that it is the subdivision of land. The results show that the level of education is of little importance in participant's perception of urban growth and the factors that lead to environmental degradation. This shows that people are aware of the realities facing cities.

The opinions on the potential impact of the degradation of vegetation cover degradation were collected. The results show that they are aware of the potential consequences. In

Ouagadougou, 69.48% of the population thought that the loss of vegetation cover would increase heat waves in urban areas. About the same number (68.88%) assumed that rainfall will decrease. Around a third (33.25%) said that this will lead to the recurrence of climatic hazards such as flooding. A quarter (25.53%) of those interviewed thought there would be an increase in wind speed. Figure 4.30 shows the perceptions of potential impacts according to the age of the respondents.

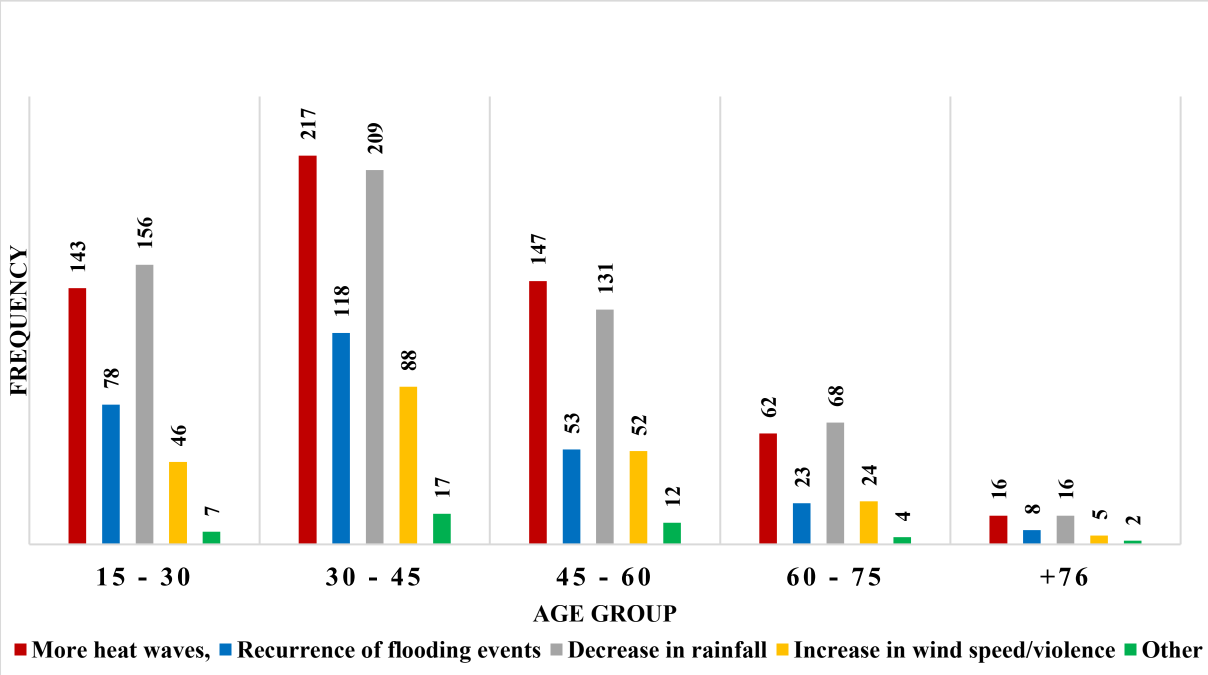


Figure 4.30: Perceptions of Potential Impacts in Ouagadougou

All age groups mentioned that the two main impacts of vegetation regression are increased heat waves and decreased rainfall. Flooding and increased wind speeds were mentioned as minor consequences after heat waves and reduced rainfall.

In Abuja, household's perceptions of the dynamics of vegetation varied. More than 50% said that the vegetation cover was decreasing, 34.88% thought it was increasing, 1.28% indicated there was no change and those who did not know the state of the vegetation represented 1.98%. The perceptions of households on the factors contributing to vegetation decline are shown in figure 4.31.

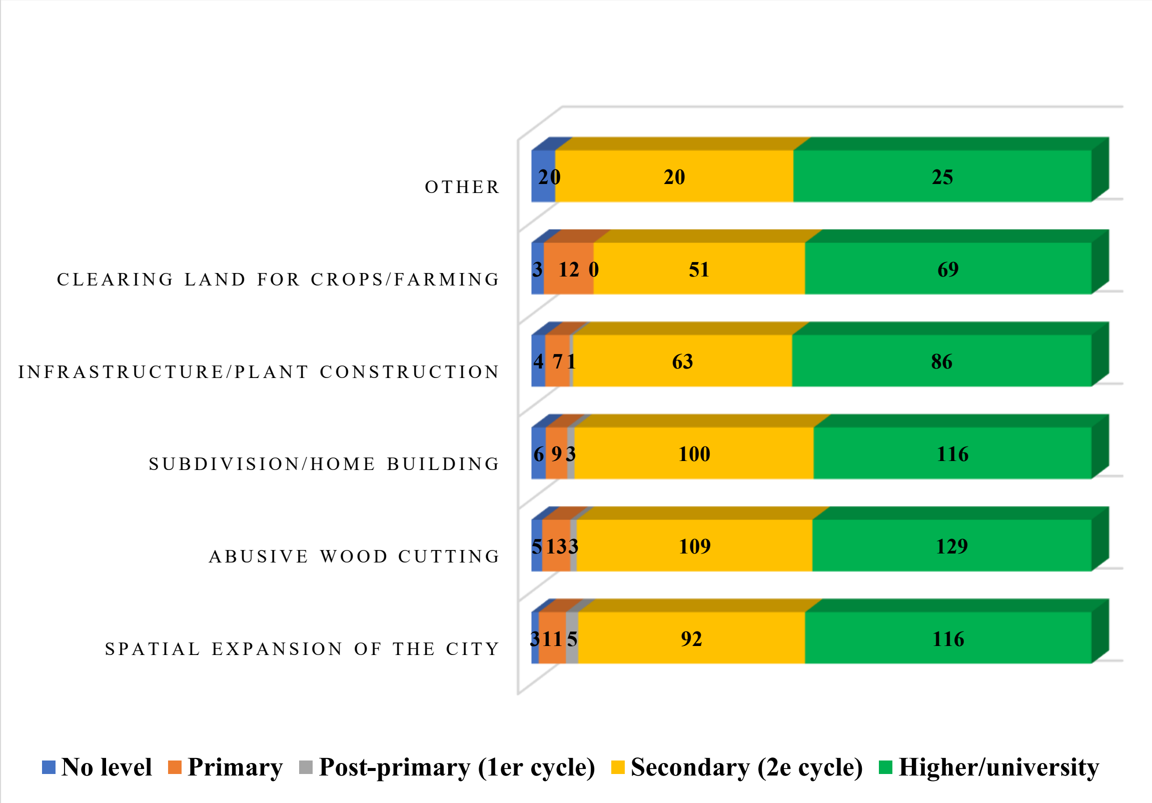


Figure 4.31: Causes of Vegetation Decline in Abuja

The results show that the majority of those with primary, secondary and university education believed that the primary cause of vegetation degradation is excessive logging. Most respondents with post-primary education thought it is the spatial expansion of the city. Most of those with no education believed that it is linked to other causes. The two main causes of vegetation regression in Abuja are excessive logging and the horizontal expansion of the city.

Generally, the degradation of vegetation cover can lead to extreme climatic phenomena. The opinions of the population were collected to find out what the consequences of the degradation of vegetation in the city might be. Most of the respondents surveyed (63.49%) thought that heat waves were one of the possible impacts of degradation of the vegetation cover. Some 57% felt that this would lead to the recurrence of flooding. Regarding the increase in wind speed, 41.51% said that this could be caused by the disappearance of plant cover. 37.67% presumed that this could lead to a reduction in rainfall. Figure 4.32 shows the perceptions of potential impacts according to the age of the respondents.

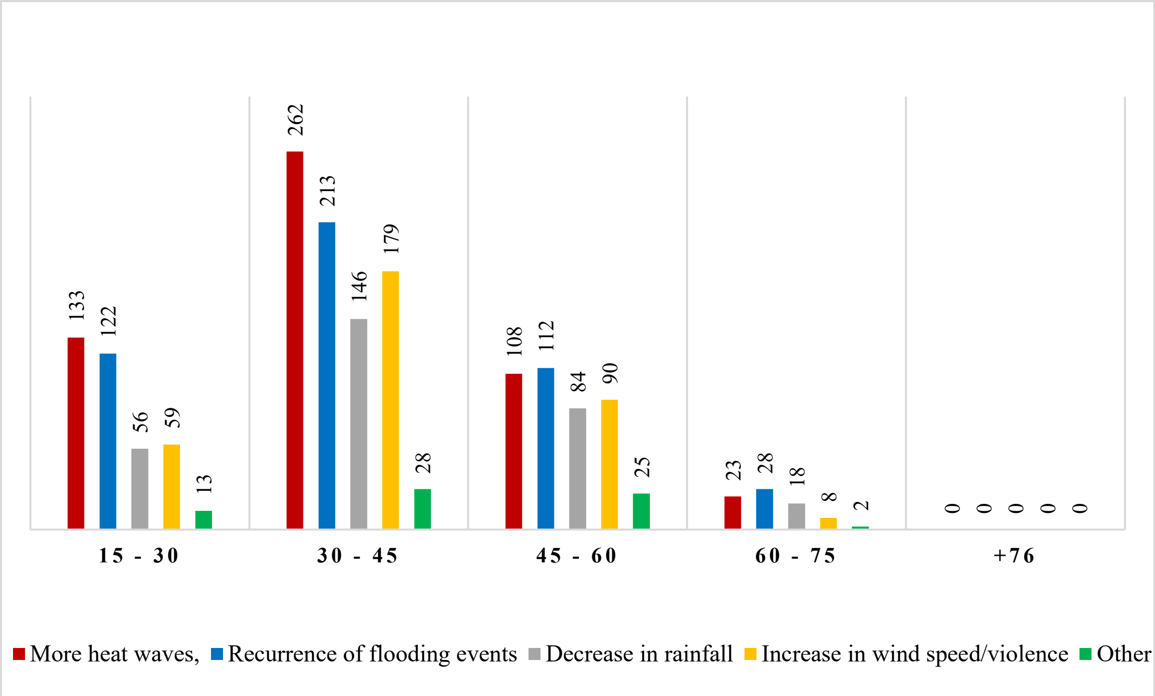


Figure 4.32: Perceptions of Potential Impacts in Abuja

For all age groups, most of the respondents mentioned that the two main impacts of vegetation regression are the intensification of heat waves and flooding. Increased wind speeds and reduced rainfall were cited as secondary consequences of heat waves and flooding. These results show that people are coping with the problems caused by the city's demographic and spatial expansion.

4.1.3.5 *Floods recurrence and intensity in Ouagadougou and Abuja*

In Ouagadougou, the results show that 40.7% of households had been affected by flooding at least once in their current residence in the last 30 years. As a reminder, the flood of 1 September 2009 affected almost the entire city. In terms of the number of times household have been affected by flooding in their area, 75.82% have been affected between 1 and 3 times and 11.94% between 4 and 6 times between 1992 and 2022. These results can be explained in part by the frequency of flooding in the undeveloped areas of the city. 46.93% said that in the event of heavy rain in the city, their homes could be flooded. These findings reveal an awareness of the existence of flooding. The study looked at all the causes of flooding in the city. According to household perceptions, these are climate change through heavy rainfall (72.9%), the absence of channels or lack of maintenance of drainage channels (50.18%), uncontrolled occupation of flood-prone areas (41.07%), poor urbanisation policy (32.93%), the quality of house building (29.28%), lack of information about flood risk (20.66%), degradation of vegetation cover (16.4%) and changes in river shape.

This study explored the main cause of floods in the city. Around 68% believed that the main cause is urbanisation. Only 32% thought it was related to the amount of rainfall in the city. Figure 4.33 shows the perception of the main cause of flooding in Ouagadougou according to the level of education.

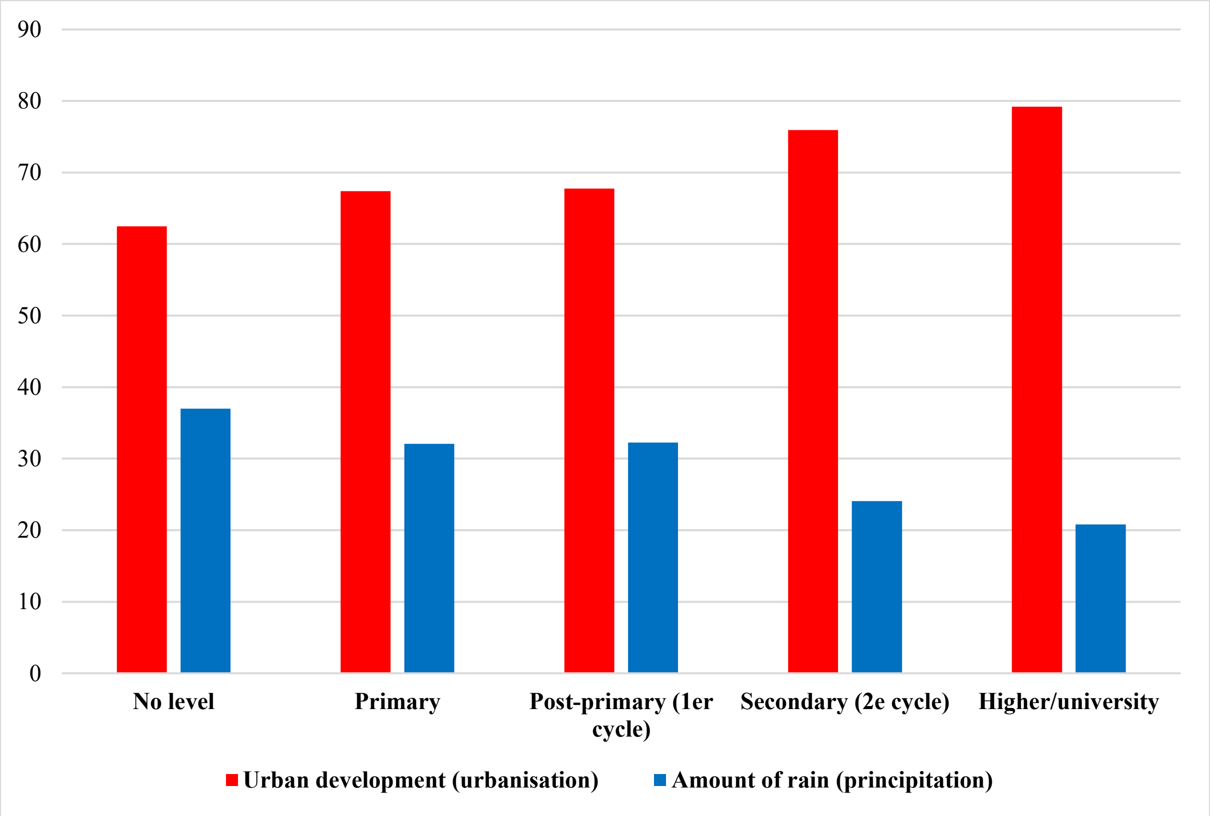


Figure 4.33: Household's Perception of the Main Cause of Flooding by Level of Education

Analysis of the graph shows that all levels of education believed that the main cause of flooding in the city of Ouagadougou is related to urbanisation. In fact, the amount of rainfall is no longer the factor that normally causes flooding.

In Abuja, the results shows that 29.58% of households had been affected by flooding at least once in their current residence in the last 30 years. Households have been affected several times by flooding in their area. Between 1992 and 2022, 80.99% had been affected between 1 and 3 times, 6.2% between 4 and 6 times. Around 20% said that in the event of heavy rain in the city, their homes could be flooded. These findings reveal a growing awareness of the existence of flooding. In Abuja, respondent's opinions on the causes of flooding in the city are varied. The first is climate change through heavy rainfall (72.62%), poor urbanisation policy (59.66%), especially in informal settlements, and lack of information about the risk of flooding (58.92%), uncontrolled occupation of flood-prone areas (46.7%), the absence or lack of maintenance of drainage channels (36.55%), the degradation of plant cover (30.44%) and the modification of major and minor river beds (15.16%). As for the main cause of flooding in the city, 64.18% felt that it was climate change through torrential rain. Some (32%) reported that the urbanisation pattern is the cause.

In Ouagadougou, high temperatures have an impact on the health, comfort and activities of urban populations. Around 62% of those surveyed said that high temperatures had an impact on their business. This included product quality (48.05%) and reduced customer frequency (37.01%). In terms of health and personal comfort, there was an increase in water consumption (79.71%), insomnia (69.62%), general fatigue (55.29%) and headaches (50.79%). Regarding the hottest year in recent decades, 24.82% believed that 2022 was the hottest. Around 45% thought it was the years between 2012 and 2021, and 6.08% indicated it was the years between 2002 and 2011. Around 65% said that high temperatures have often caused water shortages in the city in recent years.

More than 75% argued there is an increase in the risk linked to water safety due to high temperatures and heat waves. Regarding mortality and morbidity linked to high temperatures, 87.25% reported that there is a risk of an increase. Around 45% are very worried about climate change today and 55.29% are very worried about climate change in the future. Figure 4.34 shows perceptions of the impact of high temperatures according to the age of the respondents.

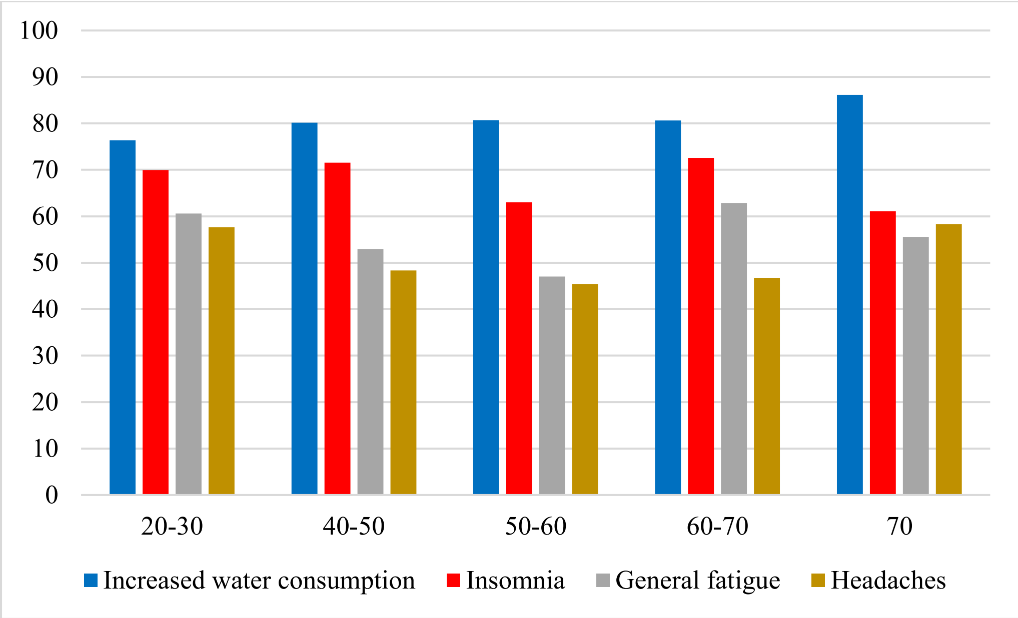


Figure 4.34: Impact of High Temperatures According to the Age of the Respondents

Analysis of the graph shows that increased water consumption is the most common impact for all age groups. In second place in terms of impact for all age groups is insomnia. Headaches affect more those aged between 20 and 30 years and those aged 70 and over.

In Abuja, participants said that the high temperatures had had an impact on their health, comfort and activities. In terms of health and personal comfort, there was an increase in water consumption (64.18%), general fatigue (52.08%), headaches (49.14%), and insomnia (28.85%). More than 52% of those interviewed said that at least one member of their household had been hospitalised due to the impact of the high temperatures. Around 69% of those surveyed reported that high temperatures had had an impact on their activities. This included product quality (56.51%) and reduced customer frequency (50.88%). Around 67% thought that the years between 2012 and 2021 were the hottest and 12.65% felt that the years between 2002 and 2011 were the hottest. Around 50% said that high temperatures have often led to water shortages in the city in recent years. More than 57% believed that there is an increased risk to water safety due to high temperatures and heat waves. More than 54% thought that there is a risk of increased mortality and morbidity linked to hot weather. Around 55% are very worried about climate change today and 41.2% are very worried about climate change in the future.

4.1.3.6 *Impact of windstorms on households in Ouagadougou*

The results revealed several impacts of windstorms on health, activities, and personal comfort of urban populations. In terms of respondent's health, 85.3% reported the frequency of colds, 68.65% the frequency of coughs, and 38.4% the frequency of eye aches. Around 5% said they had suffered accidents or injuries related to winds. Only 4.37% reported that the winds had had no impact on their health. Regarding the impact on business activities, there was soiling at work (71.57%), damage to equipment or goods (42.41%), destruction of premises (29.28%) and poor sales of products (11.66%). In terms of personal comfort, the wind has an impact on the soiling of clothes (93.68%), the soiling of houses (84.57%), and the soiling of vehicles, motorbikes, and tricycles (24.91%). This leads to increased water consumption in urban areas for washing clothes, vehicles, and motorbikes. In recent years, the intensification of windstorms has resulted in damage to the roofs of houses (49.82%), cracks in walls (22.36%), damage to electrical cables (6.2%) and collapse of houses or walls (2.92%).

4.1.4 Future urban growth in Abuja and Ouagadougou

The results of the future urban expansion in 2052 show that in Abuja, three main factors influence the most influence built-up expansion. With an overall accuracy of 51.92%, settlements are the first factor in this dynamic. The second factor is roads, with an overall accuracy of 52.41%. The third factor is altitude, with an accuracy of 53.95 %. The results of built-up evolution (Figure 4.35) show a disparity in the spatial distribution of the built-up in 2052.

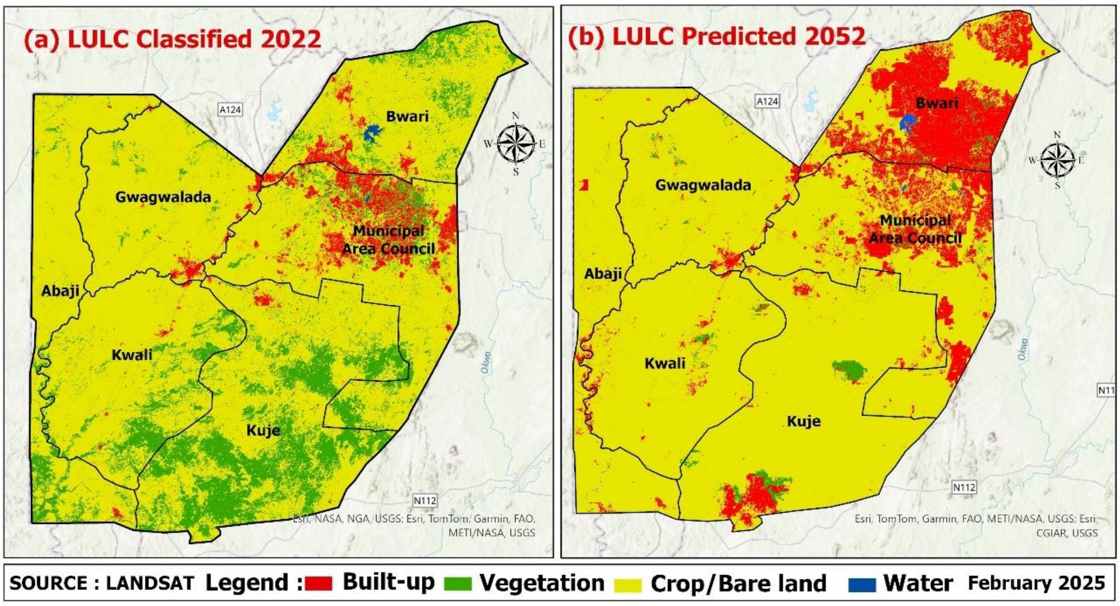


Figure 4.35: Spatial Distribution of LULC Classified in 2022 (a) and Predicted in 2052 (b)

An analysis of housing dynamics between 2022 and 2052 shows a change in the area occupied by built up. In fact, the north-east part will see the greatest concentration of housing in 2052. The south-eastern and southern parts will also see an increase in inhabited areas. Some areas will also see an increase, notably the central and south-western parts. The results also show that this development has taken place along roads.

In Ouagadougou, the prediction of land use and land cover in 2052 the entire study area will be occupied by built up (Figure 4.36), except for the dams and the classified forest.

Vegetation will also disappear in other parts of the city. Crop and bare land will also be occupied by built up.

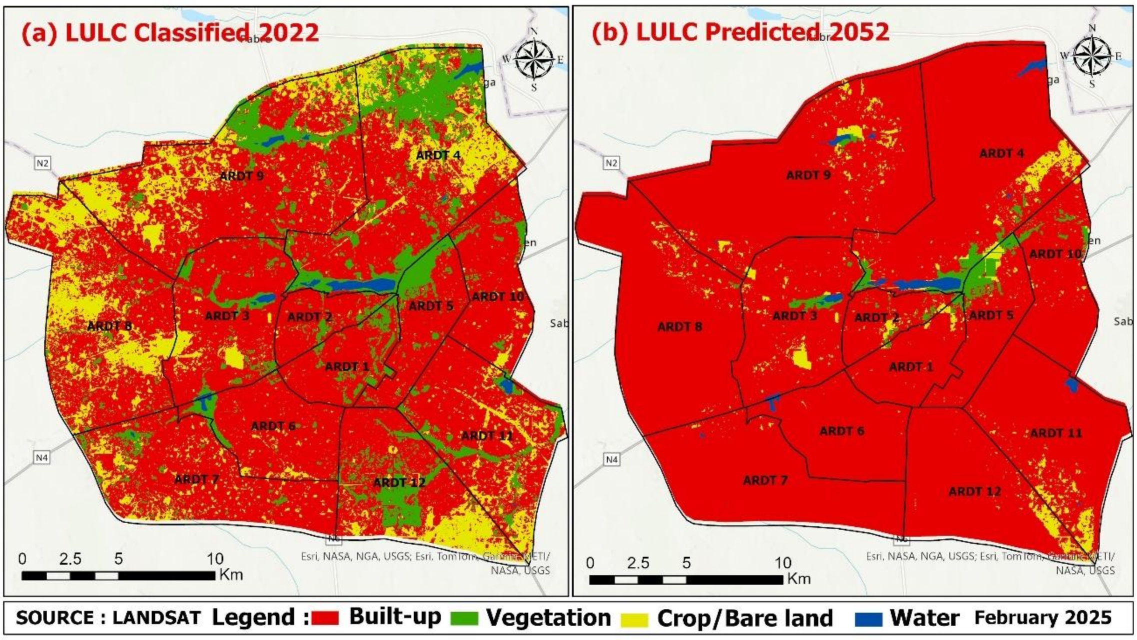


Figure 4.36: Spatial Distribution of LULC Classified in 2022 (a) and Predicted in 2052 (b)

4.1.4.1 *Future land use and land cover trends in Abuja and Ouagadougou*

In Abuja, the statistical results of the classes (Table 4.3) show that the built-up area occupied around 5% of the study area in 2022, but this unit will be multiplied by 3 in 2052 and will occupy an area of around 812 square kilometres. In addition, the area occupied by crop and bare land will increase by around 10%. However, vegetation will be completely destroyed because it was occupied 18% of the area in 2022 but only around 1% will remain in 2052. In fact, the area of vegetation that will be destroyed by 2052 is estimated at 1331.77 square kilometres.

Table 4.3: Proportion of LULC Classes, Percentage and Changes in Abuja

LULC Units	LULC 2022		LULC 2052		Changes 2022-2052
	Area_Sq	Percentage	Area_Sq	Percentage	Change
Built-up	397	5.19	1209.61	15.80	**812.61**
Vegetation	1433	18.72	101.23	1.32	**-1331.77**
Crop/Bare land	5813	75.95	6332.01	82.73	**519.01**
Water	11	0.14	10.79	0.14	**-0.21**

In Ouagadougou, the results of the prediction (Table 4.4) showed that the built-up area occupied around 70% of the study area in 2022, but this unit will occupy around 94% with 502.41 square kilometres. The area occupied by crop and bare land will decrease from 16% to 3%. However, vegetation will be destroyed because it was occupied 12.92% of the area in 2022 but only around 3% will remain in 2052. Indeed, the area of vegetation that will be destroyed by 2052 is estimated at 71.96 square kilometres.

Table 4.4: Proportion of LULC Classes, Percentage and Changes in Ouagadougou

LULC Units	LULC 2022		LULC 2052		Changes 2022-2052
	Area_Sq	Percentage	Area_Sq	Percentage	Change
Built-up	371.56	69.68	502.41	94.23	**130.85**
Vegetation	68.88	12.92	9.97	1.87	**-58.91**
Crop/Bare land	88.87	16.67	16.91	3.17	**-71.96**
Water	3.89	0.73	3.88	0.73	**-0.01**

4.1.4.2 *Logic of the future urban dynamics in Abuja.*

The prediction of future urban dynamics has revealed that development will take place particularly along villages and will be more accentuated in areas where there is currently a concentration of villages. The logic reveals that urban development will take place along roads. The future urban dynamics show that it is mainly the north-eastern part that will experience the greatest spatial expansion of the city in 2052 (Figure 4.37).

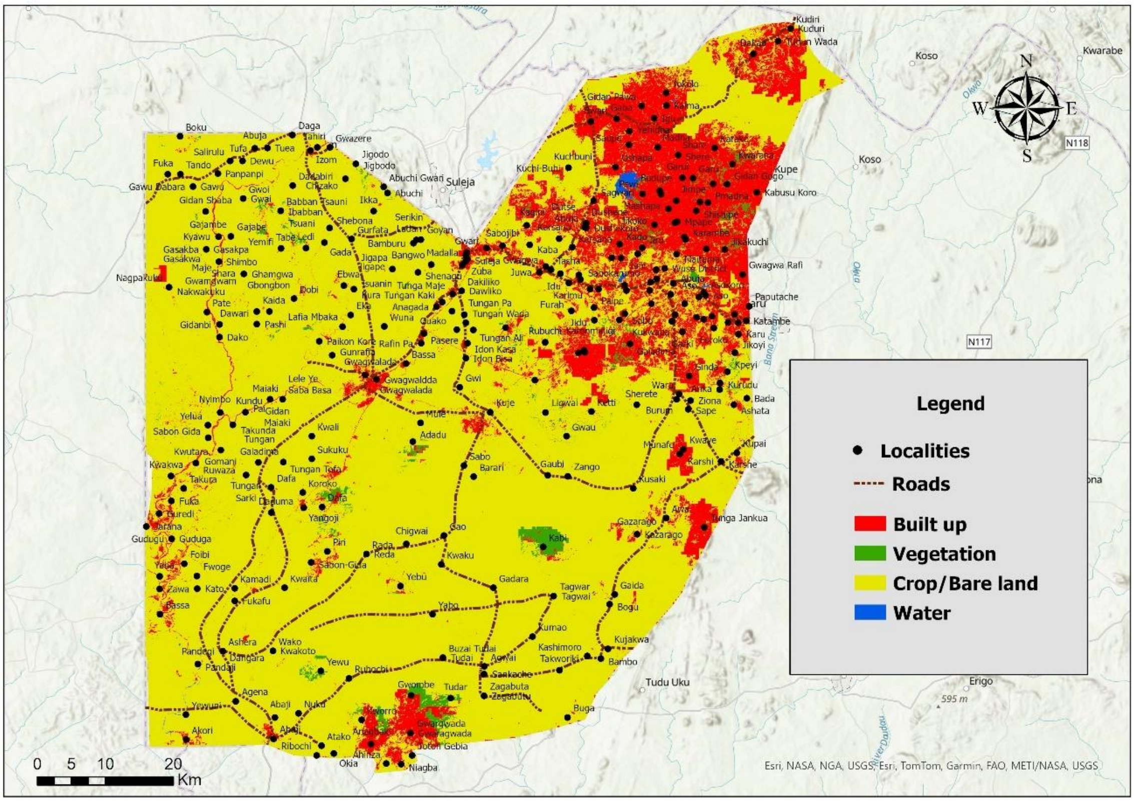


Figure 4.37: Logic of the Future Urban Dynamics in 2052

Urban dynamics in 2052 showed that in the eastern part of the city, the spatial expansion of the city will take place around the villages of Gwagwa, Rafi, Kubabo, Jikakuchi, Katambe, Mape and Jimpe, among others. In the north and north-east, the villages of Madana, Karako, Yehidna, Saupe, Kwarana, Guru, Budupe, Kaima, Gidan-Pawa, Dakaa, Tudun-Wada and Kuduri are among those targeted. In the central part, urban development will take place in Kuje, Gwagwalada, Bassa, Sukuku, Koroko, Dafa, Sabon-Gida, Dobi and Kore. In the southern part, it will be around the villages of Abaji, Akori, Kworro, Gwombe, Gwargwada, Ahinza, Toton, Niagba, Kamadi, Yebu and Ashera. In the western part, it is around the localities of Bassa, Zawa, Foibi, Guduga, Fuka, Kwakwa and Kakwakuku.

4.1.5 Climate change adaptation and mitigation in Abuja and Ouagadougou

4.1.5.1 *Sociodemographic characteristics and climate change adaptation*

Multivariate analysis and logistic regression revealed significant links between certain adaptation variables and sociodemographic variables. For example, in terms of adaptation to hot weather, there was a significant link between level of education and permanent use of air conditioning and fans. Also, those with a higher level of education tend to go to the forest, green spaces, restaurants, and scrubland. This is partly justified by their knowledge of the positive effects of these green spaces and forests. There is also a link between age and visits to forests, gardens, and green spaces. Finally, there is a significant link between occupation and permanent use of air conditioning and going to the forest, green spaces, and gardens. In fact, workers in the private sector, the public sector, students and researchers are more inclined to adopt these strategies than the categories.

4.1.5.2 *Sociodemographic characteristics and climate change mitigation*

The Chi^2 test revealed a significant correlation between age and the use of renewable energy such as solar, wind, and biogas. However, logistic regression showed that the older a person is, the less likely they are to use solar energy. In other words, age seems to be a determining factor in the adoption of solar energy. Younger people tend to use it more than older people. This is due to the proliferation of smartphones, tablets, and electronic devices such as televisions, music radios, and lamps. These devices consume more energy, which explains the use of solar energy by young people. The Chi^2 test and logistic regression also revealed a significant correlation between the use of the main energy source and age. In addition, the Chi2 test and logistic regression reveal a significant correlation, on the one hand, between the use of renewable energies, including solar energy and wind energy and the level of education and, on the other hand, between the main source of energy and the level of education. Finally, there is a significant link between perception of tree planting and the level of education. Those with a higher level of education consider tree planting to be one of the actions to mitigate high temperatures in urban areas, unlike those with a lower level of education.

4.1.5.3 *Climate change adaptation strategies in Abuja and Ouagadougou*

In Abuja, the population developed a variety of strategies to cope with different climate change hazards such as heat waves, flooding, and winds. Among the actions most frequently taken by households to adapt to heat waves are drinking more water (83.86%), taking a bath several times (55.87%), and using the fan permanently (50.61%). Population in Abuja have more opportunities and facilities for adaptation. They use air conditioners (27.87%) due to the low cost of electricity, go to the forest (8.44%) and go to green spaces (20.54%) due to the presence of several forests and green spaces. To cope with heat waves at night, some people sleep outside (38.75%), while others (26.65%) spend more time in gardens and restaurants.

In addition, among the actions that can help reduce the effects of heat, participants mentioned the way they build. In fact, the way the city is laid out and the way people build are important factors in adapting to heat. In Abuja, 71.15% felt that it was the way they built that enabled them to reduce the effects. Observations of the surveyed houses of the households revealed that the construction methods of the houses are wide and airy.

In terms of taking precautions to protect themselves against windstorms, 67.73% of the households interviewed said they had taken precautions. The measures taken by the population to protect their homes included reinforcing roofs (82.95%), walls (72.74%) and reinforcing doors and windows (52.71%).

In fact, several actions were taken by the population during the floods. The majority of those who said they had been flooded in their current area of residence took the following actions. They placed sandbags in front of the door (67.36%), reinforced the structure of the house (66.94%), dig a channel to facilitate the passage of water (58.68%), and clean drainage channels (52.07%).

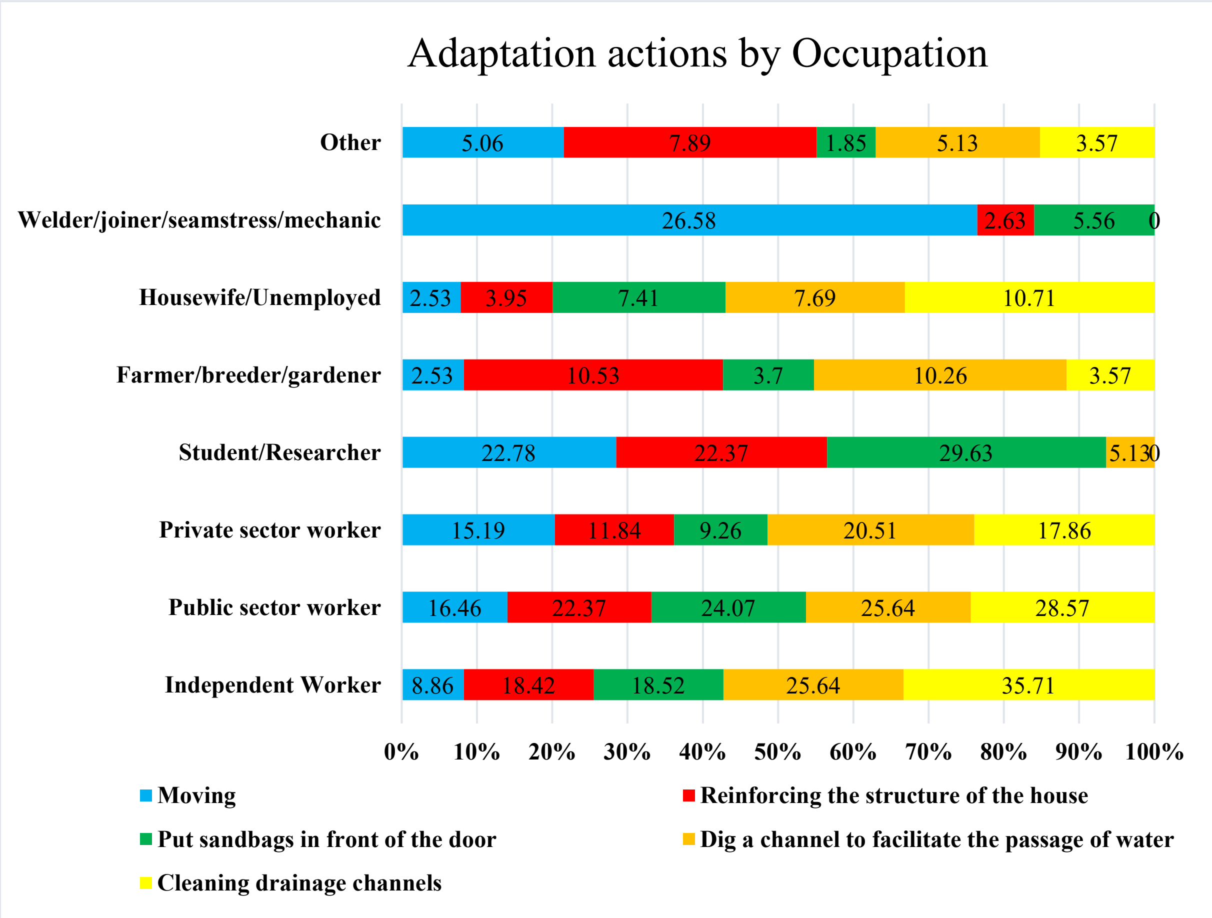


Figure 4.38: Households Adaptation Strategies to Flood in Abuja

For those who were flooded elsewhere in the city before coming to their current place of residence, they adopted actions at the time they were flooded. Figure 3 shows the actions used by these households.

Analysis of the graph shows that more than the majority, around 60%, have moved out for area because of the flooding over the past 30 years (1992 to 2022). Among them, the most numerous are welder, joiner, seamstresses and mechanics (26.58%), students/researchers (22.78%), and public sector workers (16.46%). In terms of strengthening the house structure, approximately 58% had to adopt this action to adapt to the impact of flooding. These include public sector workers (22.37%) and students and researchers. Regarding cleaning drainage channels, the results showed that independent workers (traders and entrepreneurs) are the most likely to have adopted this strategy.

Respondents were asked if they would accept a relocation proposal if it was reported that their area of residence was at risk of flooding. As a result, 89.39% of the participants in Abuja were in favour of relocation.

In Ouagadougou, households adopt multiple attitudes to adapt to the effects of heat waves. During the day, the most frequently taken by households to adapt to heat waves are drinking water more than usual (97.93%), showering several times (76.18%) and sitting under a shady tree (55.77%). Figure 4.39 shows how households withstand to heavy heat waves during the day.

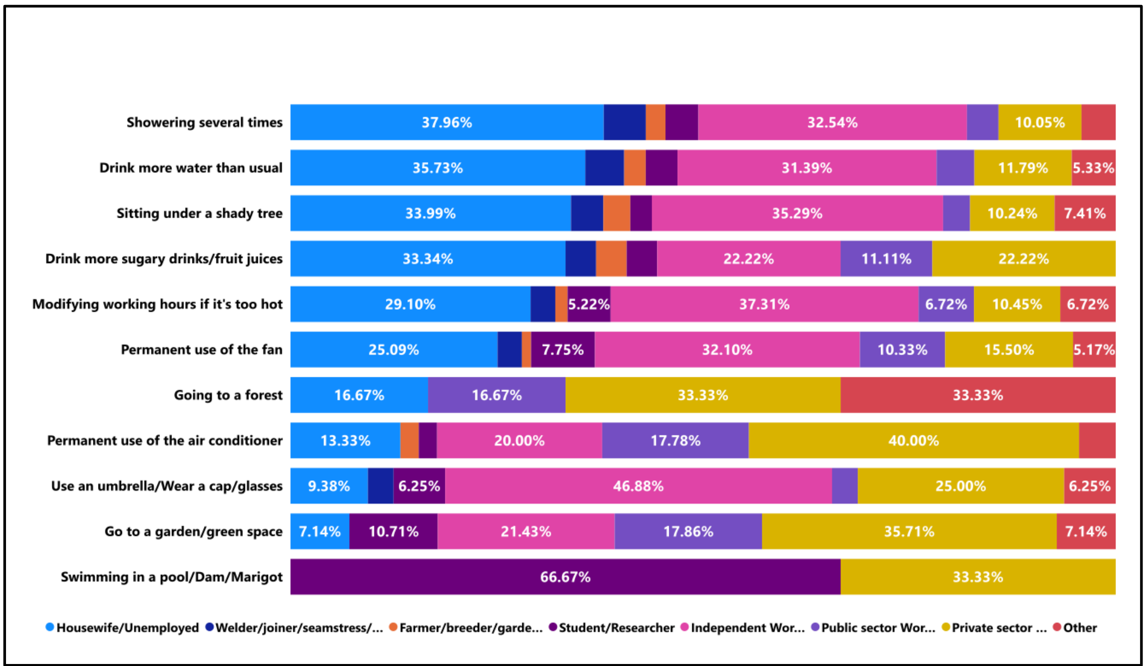


Figure 4.39: How Households Cope with the Heat Waves During the Day in Ouagadougou

The results of adapting to heat waves during the day revealed the solutions available and used by people depending on their profession (Figure 4.39). Swimming is the favourite activity of students, researchers, and private sector workers. Given the nature of their work, independent workers, entrepreneurs, and traders use umbrellas, hats, and glasses to cope with the high temperatures. Welders, mechanics, carpenters, and tailors do not use air conditioners, do not bathe in swimming pools, and do not go into the forests. Their coping strategies include drinking more water and fruit juice, showering several times, and sitting under shady trees. Permanent use of air conditioning is the preferred action of public sector, workers, the private sector and the independent workers. In addition, around 50.18% sleep outside at night. For drinking more water and showering several times, the trends are the same. In Ouagadougou, people spend more time outside at night due to high temperatures and frequent power cuts.

In terms of taking precautions to protect themselves against windstorms, only 33.05% had taken measures to protect themselves against this climatic effect. Of those who have taken measures against high winds, 77.57% have reinforced the roofs of their houses, 66.91% have reinforced the walls of their houses, and less than half (42.65%) have reinforced their windows and doors. These adaptation methods show that some people do not take into account the reality of climate change. Adaptation methods are adopted on a case-by-case basis. The results show that participants are more concerned about the roofs of their houses. This proves that strong winds cause more damage to the roofs of houses.

In Ouagadougou, respondents who said they had been flooded in their current area of residence took the following actions. The most important action is to protect important objects from flooding. More than 85% take this action first. 36.72% locked the doors of their homes, 21.79% put electronic equipment on tables or chairs, 36.72% drilled holes in walls to make it easier for the water to pass through. Some households (16.72%) dig trenches around their houses, raise the height of their doors (11.64%) and build dykes to stop the water (7.46%). 78.59% of respondents in Ouagadougou are favoured relocation if their area of residence was reported at risk of flooding.

4.1.5.4 *Climate change mitigation strategies in Abuja and Ouagadougou*

In Abuja, respondents believed that planting trees (78.36%), airing houses (65.89%) and orienting houses or buildings (54.52%) are factors that help reduce high temperatures. Indeed, the layout of the city as a whole and of the neighbourhoods in particular can allow good air circulation, and the presence of trees helps to cool the hot air. The level of education provided a clearer picture of this perception. Figure 4.40 shows household's perceptions of the factors that help mitigate high temperatures, according to their level of education.

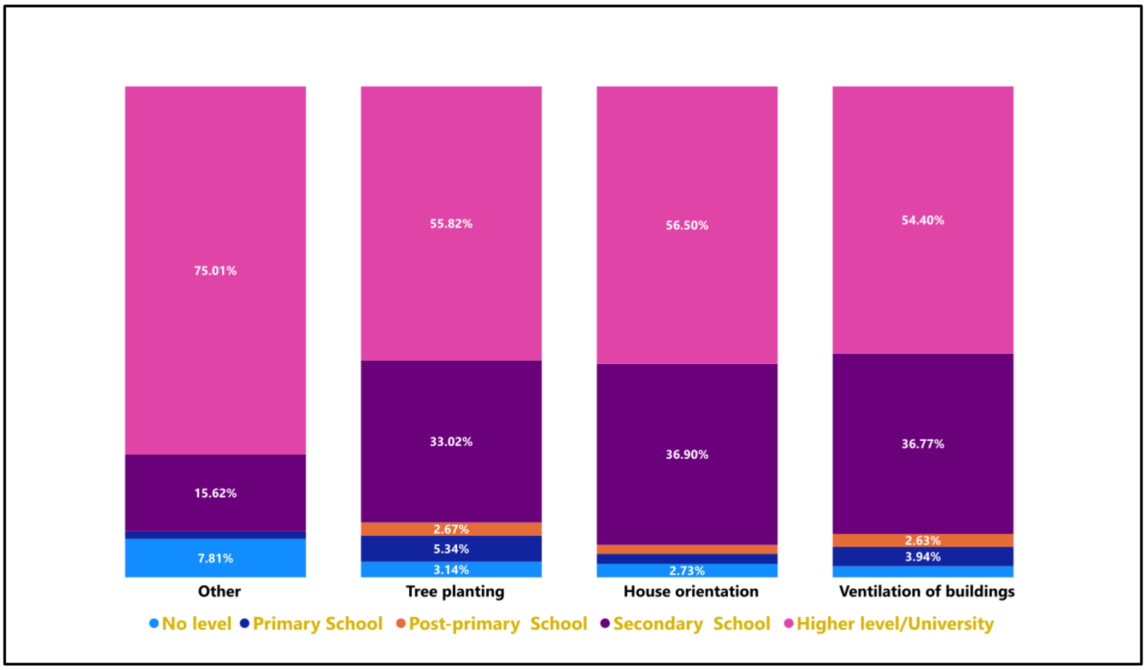


Figure 4.40: Perception of Climate Change Mitigation Actions

Respondents have a very good perception of how planning in terms of city layout can mitigate the harmful effects of climate change. Analysis of the graph shows that the level of education is a key factor in perception. Participants with university and secondary education have a better understanding of the actions to be taken. In addition to these actions, respondents reported that there are other factors that can help mitigate high temperatures. More than 73% of those with a university degree said there were other factors.

Given that the level of education is an important factor in the perception of mitigation actions, mitigation programmes should be more focused in high schools and universities to be more effective. Indeed, the implementation of actions is more effective when stakeholders are aware of the phenomenon.

In terms of climate change mitigation strategies, there is the promotion of the use of public transport for urban mobility. The study assessed the degree of use of public transport, that is, taxis and municipal buses. This involved assessing the number of times the households interviewed took either the Bus or the Taxi per month. In Abuja, public transport is the most used by the population to get around the city. Around 17% of Abuja's population use either taxis or buses throughout the month. Around 19% take the taxi or bus between 1 and 5 times a month, 21.64% between 6 and 10 times, and 15.28% between 11 and 15 times. Use of public transport by the respondents is shown in Figure 4.41 according to their occupation.

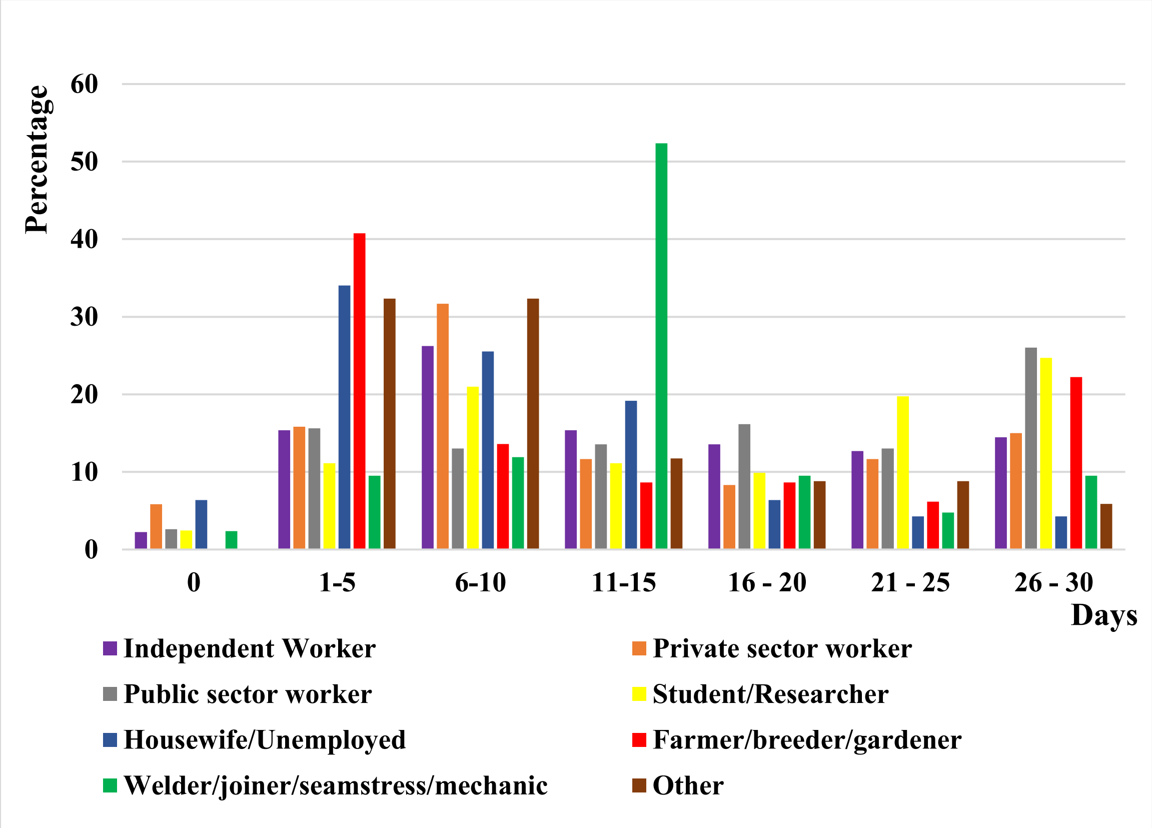


Figure 4.41: Frequency of Use of Public Transport During the Month in Abuja

The results showed that all categories use public transport during the month. Those who used it more during the month (26 to 30 days) were students, researchers, public sector workers and farmers, gardeners, private sector workers, and the self-employed. These were the categories that carry out activities that require them to be on site. These activities were generally carried out during the week, which explains the high use of public transport. On the other hand, those who did not use it at all during the month are the unemployed and private sector workers. The hypothesis of non-use is that the unemployed have no trip to do and workers in the private sector have their own means of transport. The results showed good support for the use of public transport, which is a very important element in mitigating the effects of climate change by reducing emissions.

The study also investigated the main energy source used by the populations. Around 90% of households in Abuja use electricity, 4.89% use solar panels, and 2.86% use generators as their main source of energy. These results can be explained by the fact that in Abuja, even in unplanned areas, there is an electricity supply. However, it should be noted that respondents used various sources of energy. The main energy source used by the respondents is shown in Figure 4.42 according to their age.

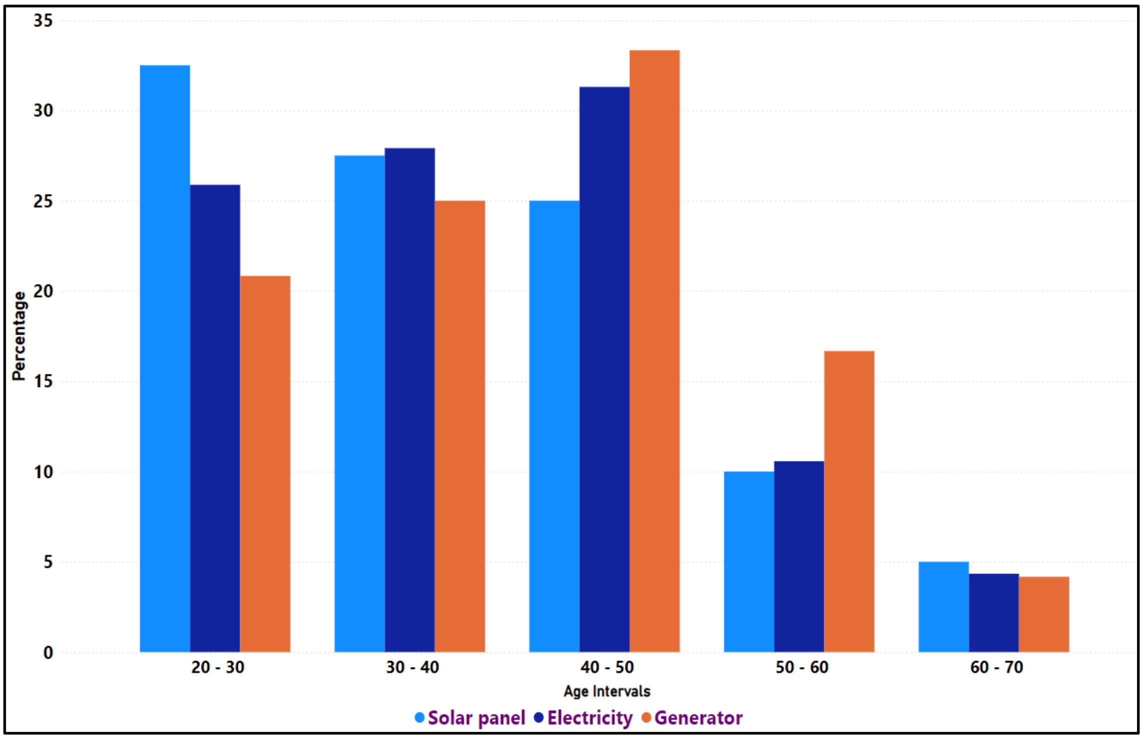


Figure 4.42: The Main Source of Energy in Abuja

Analysis of the figure confirms that the older people are, the less solar energy they use. In other words, younger people use more natural energy sources than older people. As for other energy sources, including electricity and generators, there was no significant difference in terms of use according to age.

Households use a certain energy source to cook their food. The energy sources used by people include gas, firewood, charcoal and electricity. The main source of energy for food preparation is gas. It is used by more than 57% of households. The second most important source is firewood, which is used by 17.36% of the population. Nearly 14% use charcoal. These statistics show that there is a segment of the population that continues to use energy derived from forest exploitation. However, forests play a vital role in mitigating climate change.

In Ouagadougou, respondents mentioned that planting trees, orienting houses, and ventilating buildings are important factors in reducing high temperatures in the city. However, houses in Ouagadougou are tightly packed and there is less ventilation. Due to its geographical position, the lack of trees and vegetation in the city and the way it is built, the population suffers enormously from the effects of heat waves.

The findings showed that solar energy (54,07%) is most used. Around 43% of the population do not use any of these types of energy. Solar panels are used by households living in areas without electricity.

The results showed that 87.61% of the population in Ouagadougou do not use public transport. Of the households interviewed in this study, 70.22% said that motorcycles were their main means of transport.

Households use various sources of energy. The study looked at the main energy source used by the populations. The results revealed that 41.43% use electricity and 47.51% use solar panels.

These results can be explained by the fact that in Ouagadougou there is no electricity supply in the unplanned areas, which explains the use of solar panels. The main energy source used by the respondents is shown in Figure 4.43 according to their age.

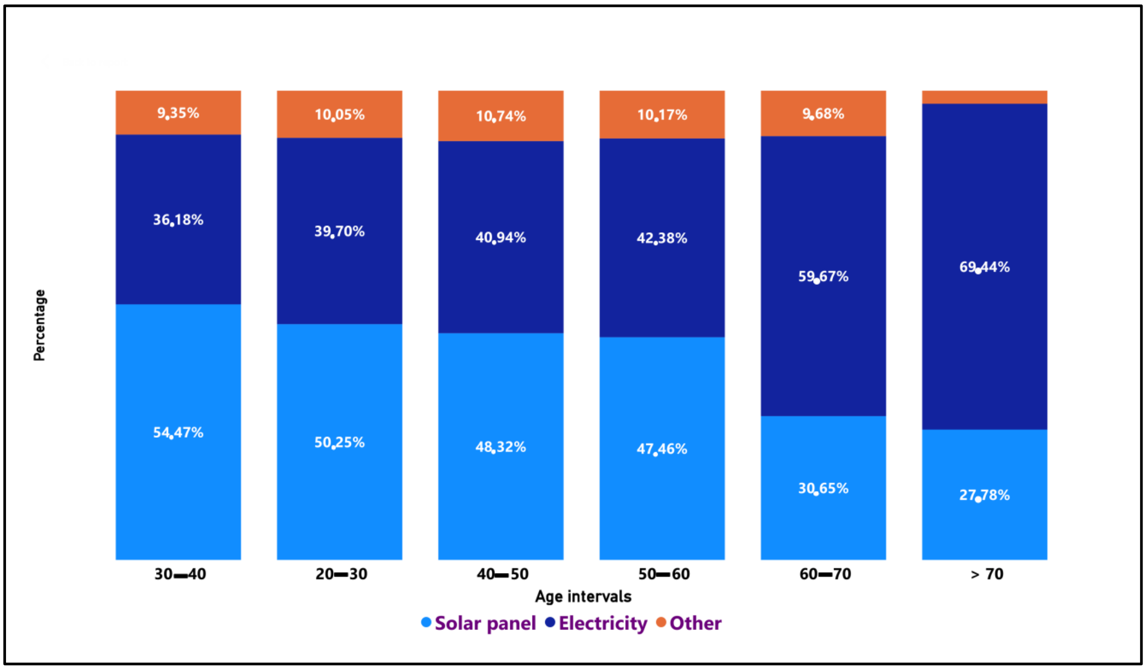


Figure 4.43: The Main Source of Energy

A comparison of the main energy sources used by households shows disparities in terms of use according to age group. On the one hand, analysis of the graph shows that solar energy is the energy source most used by the first four age groups. However, electricity is the energy source most used by the last two age groups. More specifically, the results show that as age increases (from the 30-40 age group onwards), the use of solar energy gradually decreases. On the contrary, the use of electricity increases as age increases. All age groups also use other energy sources in almost equal proportions.

To cook food, households use specific energy sources. In Ouagadougou, residents mostly use gas, firewood, charcoal, and electricity as energy sources. The main source of energy for food preparation is gas. It is used by more than 55.53% of households. The second most important source is charcoal (24.54%). Finally, 18.83% of households use firewood and 0.85% use electricity to cook. This information showed that a certain percentage of households still use energy that comes from forest.

4.1.5.5 *Households' characteristics and mitigation indicators in Abuja and Ouagadougou*

The setting of the minimum cumulative inertia criterion of 80% enabled to determine the optimal number of dimensions to retain in the ascending hierarchical classification in Abuja. In fact, the eigenvalues show that 24 dimensions need to be retained in order to achieve 80.22% of the total information (Figure 4.44a). The figure (Figure 4.44b) shows the gains in inertia obtained when moving from a cluster k to a cluster k+1. These gains decrease as the number of clusters increases. The setting of the elbow criterion has made it possible to find the point at which the reduction in inertia becomes much less important. From this point onwards, adding an extra class no longer significantly improves the quality of the segmentation. The gains in inter-cluster inertia are much greater when moving from 1 to 2 clusters (first black bar) and from 2 to 3 clusters (second black bar). Then, the gains decrease significantly from 3 to 4 clusters (first red bars). The elbow is the point at which adding an extra cluster leads to a reduction in the gain in inertia, in other words, a loss of homogeneity. In this case, it is from cluster 3 onwards that the marginal gain in inertia falls sharply, so the kink is located at cluster 3, which indicates that the first three clusters should be retained. Figure 4.43 shows the distribution of the 3 clusters retained (Abuja) in the factorial axes of the AHC (Dimension 1 and Dimension 2).

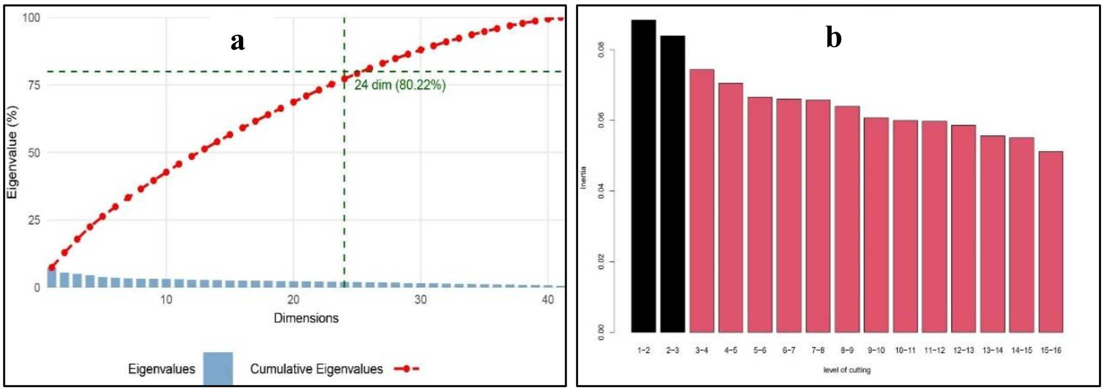


Figure 4.44: Optimal Number of Dimensions for Hierarchical Ascending Classification and Cluster Selection. a) Eigenvalue Scree Plot, b) Inter-cluster Inertia Gain

In Abuja, the first cluster consists mainly of people aged between 20-30 years with a high level of education and whose profession is student/researcher. These people do not use natural energy sources, although they do use gas for cooking and electricity for lighting. They also believed that tree planting, house design, and the way houses are situated are factors that can help mitigate the effects of climate change. In this cluster, 72.59% of the people are aged between 20-30 years, 66.74% possess university degrees, over 64% are men, over 77% are single, and 92.40% are students/researchers. In this cluster, around 80% use gas for cooking and 60.92% use electricity for lighting. Most (90%) thought that planting trees and orienting houses (71.68%) are actions that can help mitigate climate change in urban areas.

Older married people, primarily farmers, breeders, or gardeners with primary education, make up the second cluster. These people use wood and charcoal for food preparation and solar energy for lighting and assumed that planting trees is a way of mitigating climate change. Specifically, 71.42% of people are between 60 and 70 years old, around 51% are married, and 91% have primary education. In this cluster, only 47.06% believed that tree planting helps to mitigate climate change. Specifically, 80.43% use wood for cooking and 56.03% use solar panels.

The third cluster comprises public sector workers with higher education. They use renewable energy sources such as a solar power for lighting and gas for cooking. A high proportion of married men characterised this cluster. People in this cluster stated that ventilating houses, orientating them and planting trees can mitigate the effects of climate change.

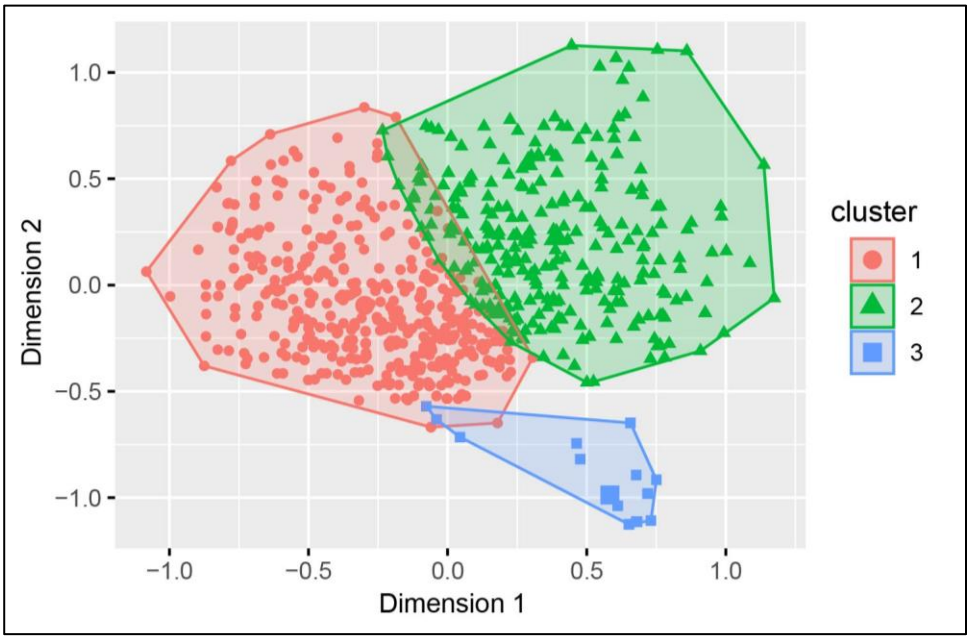


Figure 4.45: Distribution of Respondents by Cluster in Abuja

In Ouagadougou, the setting of the minimum cumulative inertia criterion show that 26 dimensions must be retained in order to achieve 81.19% of the total information. The setting of the inter-cluster inertia gains enabled to determine the number of clusters to retain. Figure 4.44 shows the distribution of the 3 clusters retained in the factorial axes of the AHC (Dimension 1 and Dimension 2).

The first cluster consists mainly of married women aged between 30 and 40 years with a low level of education, who are unemployed or housewives. They mainly use solar energy to light and firewood for cooking, and only half of them said that planting trees will help mitigate the effects of climate change. More specifically, 89.76% of people in this cluster use solar energy and 78.63 use firewood as their main source of energy for cooking. Only 50% indicated that planting trees helps to mitigate the effects of climate change. In this cluster, 59.67% are married, 58.43% are female and 60.98% are between 30 and 40 years of age. In terms of level of education, 65.34% do not have schooling and around 64% are unemployed or housewives.

The second cluster specifically comprises older people with a university education who are widowed or single and do not use solar or other natural energy sources. In this cluster, some people reported that tree planting can help mitigate the effects of climate change and others assumed the opposite. Specifically, 62.5% are between 60 and 70, about 51% are widows/widowers, more than 85% use electricity as their main source of energy, about 19% use firewood for cooking, and 35.66% use gas. In particular, this cluster does not use natural energy, and 33.6% believed that planting trees helps to mitigate the effects of climate change, while 24% argued the opposite.

The third cluster consists mainly of older people working in the public sector, who do not use solar energy or any other natural energy source, but who use electricity as their main source of energy. They also have a relatively high level of education, but have a low perception of the mitigation effects of climate change. In this cluster, 35.19% of the population are aged between 20 and 30, 92.10% work in the public sector, and about 52.70% have a secondary education. Only 18.09% thought that airing and ventilating their homes would help mitigate the effects of climate change. The majority (66.60%) of people in this cluster are single and use gas to prepare food. In this cluster, 2.54% use firewood to prepare food and 3.63% use charcoal.

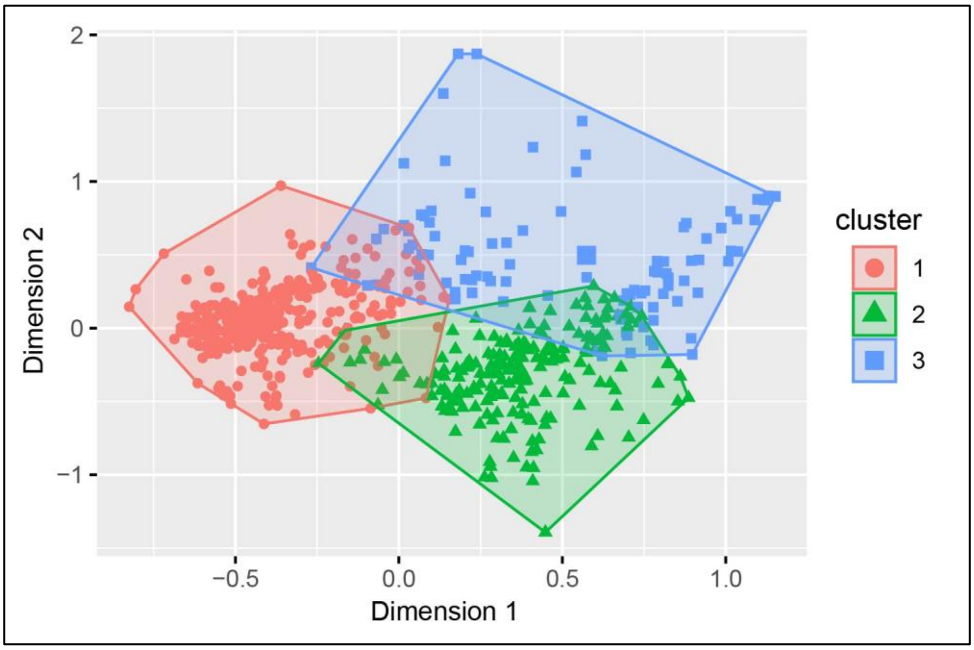


Figure 4.46: Distribution of Respondents by Cluster in Ouagadougou

4.1.5.6 *Actions to improve adaptation and mitigation strategies*

Climate resilience refers to the ability of cities to protect their inhabitants and infrastructure from the effects of climate change and from extreme weather events; These include urban climate regulations, urban water management, air quality improvement and habitats and biodiversity preservation (Croce and Vettorato, 2021). The study collected the opinions of the populations of the two cities on measures or actions to improve adaptation and mitigation strategies. Figure 4.47 shows the actions to improve the strategies.

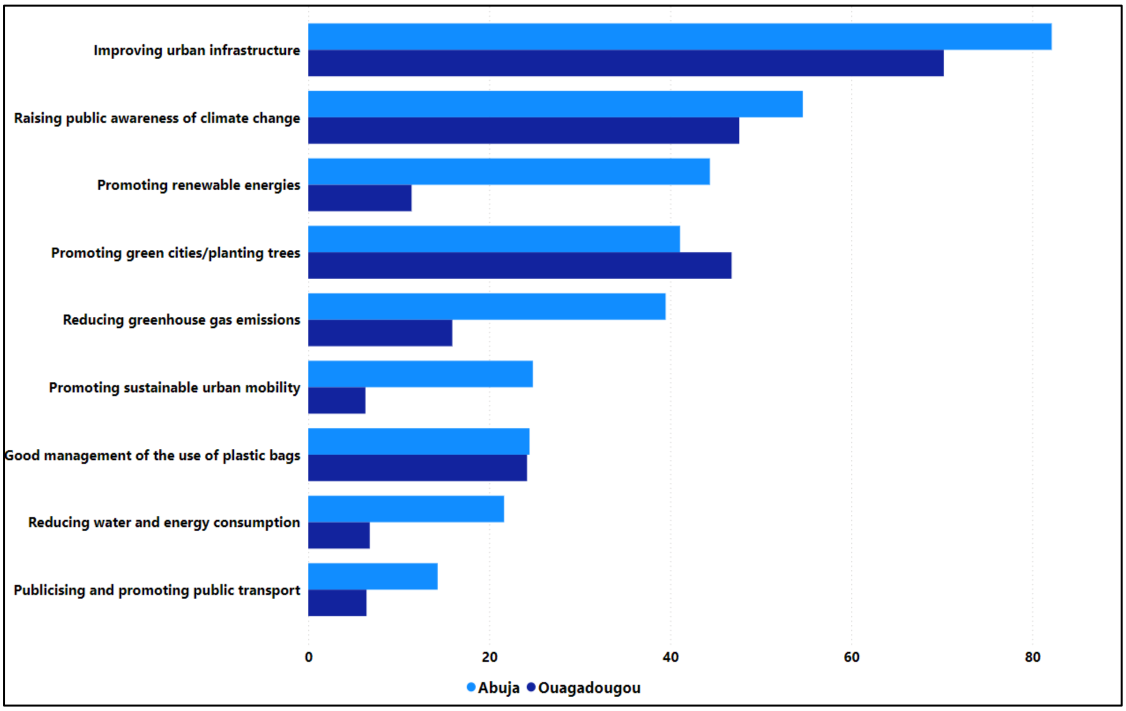


Figure 4.47: Actions to Improve Adaptation and Mitigation Measures in Cities

According to Ouagadougou people, to improve the city's adaptation to climate change, urban infrastructure needs to be improved (70.55%), citizens need to be made more aware of climate change (47.63%), green cities need to be promoted by planting trees (46.78%), the management of plastic waste in the city needs to be improved (24.18%), gas emissions need to be reduced (15.91%) and the use of renewable energy sources needs to be encouraged. In Abuja, the same views were expressed on improving urban infrastructure (82.15%), raising population awareness (54.65%), promoting renewable energy (44.38%), planting trees (41.08%) and reducing gas emissions (39.49%). In fact, reducing emissions is crucial to address the issue of climate change and limit the increase in global temperature and the management, preservation, and restoration of ecosystems reduce the exposure of a territory to climate change (Khamis, 2022). Perceptions reveal that the most important actions are improving urban infrastructure and raising public awareness of climate change. In terms of urban transport, although it is well developed in Abuja compared to Ouagadougou, the people of Abuja feel that it should be promoted. In

Ouagadougou, the development of urban transport does not seem to be a priority in view of perceptions. People use motorbikes and personal vehicles. This is a constraint to mitigating and adapting to climate change. However, the views of city dwellers show that tree green city and the planting should be promoted. This makes sense given the lack of woodlands, parks, and green gardens in the city.

4.2 Discussions

4.2.1. Demographic and spatiotemporal dynamics of the cities

4.2.1.1 *Spatio-temporal Patterns of settlements dynamics*

The world's urban population overtook the rural population in 2007. Coincidentally, that was the same year that the growth rates of the two cities were almost identical, and we have seen a decline since then. The growth rate of Abuja has remained relatively higher than that of Ouagadougou throughout the period 2007-2022. Despite this decline over the last 15 years (2007-2022), this has led to an increase in the spatial sprawl of the two cities. The results from other countries around the world show several trends in the dynamics of settlement. For example, the built-up area, which occupied 359 sq km. in 2016, underwent an increase in 2021 by 11% and rose to 455 sq. km in the Kuwait metropolitan region (Al-Dousari *et al.,* 2023). In the metropolitan area (Chile), Rojas *et al.*, (2013) found that in 20 years (1990 to 2009), it expanded from 9000 hectares to more than 17,000 ha for a 96% increase in the built-up. In Sokoto (Nigeria), the results show that the built-up area had continuously expanded and grown in size from 1990 to 2022. The average rate of expansion was calculated at 3.96% between 1990 and 2000, 2.3% between, 2000 and 2010 and 2.44% between 2010 and 2022 (Dangulla *et al.,* 2023). Kumasi Area of Ghana The results from 1986-2023 pointed to an upsurge in a built-up extent as of 8% to 41% (Koranteng *et al.*, 2023).

Moreover, cities will continue to evolve over the coming decades. In Abuja, the urban dynamic will undergo major change. In fact, the surface area of inhabited areas will triple by 2052. The city of Ouagadougou will also see a sprawl of inhabited areas. At present, the city extends beyond its administrative boundaries. Because of the lack of space, new housing estates are being built in the surrounding communes. These findings on the future development of the cities have been reported by several authors (Sari *et al.,* 2023 ; Ambarwulan *et al.,* 2023 ; Koko *et al.,* 2023 ; Ibrahim *et al.,* 2016).

4.2.1.2 *Perceptions of the causes of urbanisation*

The results of this research show discrepancies in the causes of urbanisation in the study areas. Despite the flatness of the terrain in Ouagadougou, only 3.8% of the interviewees cited this as a factor that encourages urban sprawl. Therefore, the desire to have one's own home leads people to look for housing in newly developed neighbourhoods or in undeveloped areas on the outskirts of the town, which accentuates their expansion. Despite Ouagadougou's poor road infrastructure, land speculation and land sales by landowners are factors contributing to its horizontal expansion. Notwithstanding the nature of the terrain in Abuja with its mountains, the population (19.78%) felt that this factor was not as restrictive to the spatial expansion of the city. Manifestations of the urbanisation phenomenon and community perceptions of its dynamics and impacts differ from one country to another and from one city to another (Been *et al.,* 2016). People in both cities cited population growth, road development, and access to land as the main factors in the spatial dynamics of cities. In India, a developing country like Burkina Faso and Nigeria, the evolution of urbanisation is also characterised by population growth,, economic growth and political decisions (Kumar and Devendra, 2023). The demographic and spatial dynamics of cities often have environmental consequences.

4.2.1.3 *Environmental consequences of cities dynamics*

Richards and Belcher (2019) analysed the dynamics of vegetation in 4,256 cities around the world. The results show a decrease in vegetation cover in 2307 urban centres, but that the most rapid decrease was observed in African countries. Changes in vegetation dynamics are significantly influenced by human activity (Liu *et al.,* 2022). In particular, an increasing demand for settlement expansion is driving rapid land cover changes, particularly in developing countries (Ngwira and Watanabe, 2019). The changes observed in Ouagadougou show that the spatial expansion of the city has led to the dissipation of 27% of the area initially occupied by vegetation. In Abuja, anthropogenic activities, such as clearing land for agricultural purposes and urban sprawl, have led to the disappearance of 23% of vegetation.

According to Koranteng *et al.* (2023) a number of other studies have shown that urbanisation is a development that leads to a permanent reduction in agricultural land, forests, and surface water. Additionally, the growth in housing construction and urban infrastructure leads to deforestation and disrupting ecosystems (Kumar and Devendra, 2023). In the metropolis of Osogbo (Ghana), from 1989 to 2021, increasing urbanisation, socioeconomic factors, and human activities such as construction will contribute to the alteration of the natural environment (Idowu *et al.,* 2023). The expansion of settlements due to population development is one for causes of the vegetation to deteriorate (Faye, 2023). Deforestation due to urbanisation is another problem that generates environmental problems (Ali *et al.,* 2019).

In addition to the impact of urbanisation on the environment in terms of pollution, other consequences include increased temperatures, floods, droughts, and windstorms. The main impacts of urbanisation on the urban environment are gas emissions from transport and industrial activities (Kumar and Devendra, 2023)**.** The urban population is often exposed to considerable risk as a result of urban development (Satterthwaite *et al.*, 2007). However, the response of vegetation to urbanisation and the accompanying changes in land use and land cover in urban areas depend on the type of urbanisation and the climatic region (Dangulla *et al.*, 2023). In certain areas of Abuja, in particular, urban planning has led to an increase in vegetation by planting trees on the streets and also by protecting certain natural forests. In Ouagadougou, the protection of the "*Bangre weogo*" park and certain other areas have made it possible to protect forests and increase the density of vegetation in these areas.

4.2.2 Simultaneity of Climate change impact in urban areas

Populations are affected simultaneously by floods, heat waves, and windstorms. Rapid and poorly controlled urbanisation, with an increase in the number of undeveloped areas, combined with the consequences of climate change, is making people living in poor cities even more vulnerable (Williams *et al.,* 2019). It is essential to understand the spatial distribution in time and the occurrence of climate risks to better assess the impacts and choose appropriate adaptation measures (Passos *et al.,* 2024). The impacts of climate change manifest themselves differently from one area to another. This is due to the different characteristics of the people, the habitat and the environment of the area. Due to their geographical location, urban populations in undeveloped areas are more vulnerable and more exposed to increasingly frequent and severe climatic hazards (United Nations Human Settlements Programme (UN-Habitat), 2022). People exposed to high temperatures can suffer harmful consequences (Martinez-Soto *et al.,* 2023). Heat waves are a threat to human health and cause excess mortality (Di Napoli *et al.,* 2019).

The study revealed that of the households surveyed, 21.87% said that at least one member of their family had been hospitalised due to high temperatures. Heat-related illnesses are linked to extreme heat (Faurie *et al.,* 2022). Van den Wyngaert *et al.* (2021) showed that between 2013 and 2017 in Flanders (Belgium), heat waves and high temperatures did not lead to any changes in terms of hospitalisation, but the increase in mortality linked to heat waves was very significant. Some of the health problems linked to high temperatures are heat attacks, dehydration, and respiratory problems. (Martinez-Soto *et al.,* 2023). This can lead to people dying, as was the case in Europe, where more than 70,000 people died in 2003. (Robine *et al.,* 2007).

4.2.3 Climate change adaptation and mitigation in Urban areas

Adapting populations to the impacts of climate change is recognised as an absolute necessity. It is essential to consider adaptation actions of populations, insofar as individual actions can have beneficial consequences in the short term (Anderson *et al.,* 2018). It is essential to assess global progress in adapting populations to climate change. National and local authorities around the world are working to learn about measures to adapt to climate risks, recognise successes, identify risk gaps, guide national adaptation plans, and assess progress towards the global adaptation goal (Berrang-Ford *et al.,* 2021).

4.2.3.1 *Comparative assessment of adaptation and mitigation strategies*

The ability to prepare for and respond to climate risks and impacts is strongly influenced by a city's socioeconomic and political context (Boyd *et al.,* 2022). Urban development patterns often shape the configuration of these areas, which can significantly affect their adaptability to climate change (Roest *et al.,* 2023). The cities of Ouagadougou and Abuja exhibited similarities and differences in terms of socioeconomic traits, urban planning, physical characteristics of the environment, and climate. Despite these differences, both city residents are experiencing the adverse effect of climate change and are implementing various adaptation measures.

In response to heat waves, residents of both cities adopt similar strategies such as increasing water consumption, frequent washing, and continuous use of fans. Their reactions to windstorms and floods also exhibit comparable behaviours. Energy use in both cities include electricity and solar power for lighting, while gas, firewood, and charcoal are used for cooking. However, adaptation measures during heat waves diverge between the two cities. In Abuja, residents seek refuge in green spaces or forests and consume sugary drinks, while in Ouagadougou, people prefer to sit under trees during the day and sleep outside at night.

For mitigation efforts, Abuja employs public transport, a strategy not utilized in Ouagadougou. Abuja's focus on reducing gas emissions aligns with its developmental context, while Ouagadougou prioritises tree planting. This emphasis on greenery is particularly relevant given the current lack of streets, neighbourhood, and administrative tree planting in the city. Given these contextual realities, it is essential to tailor adaptation strategies to the specific characteristics of each city for enhanced effectiveness (Kalbarczyk and Kalbarczyk, 2022). Policies and actions must be customised to address the unique conditions and needs of each urban area.

4.2.3.2 *Factors that influence awareness of adaptation measures*

Few studies have investigated the reasons why people adopt specific adaptation strategies to deal with climatic phenomena (Babcicky and Seebauer, 2019). The results of this study show that households' awareness of adaptation measures is determined by the fact of being affected, knowledge of the people affected by the phenomenon, and the fact of thinking that the phenomenon will occur again. Numerous studies have examined the factors that motivate people to adapt (van Valkengoed and Steg, 2019). According to Mondal *et al.* (2021), the intention to apply climate change mitigation measures is influenced by the level of education of households. The level of education is very important for access to information on climate change. The study revealed that those with a higher level of education had a good perception of the measures to be implemented. Numerous elements, such as knowledge, social, demographic, and economic aspects are only a few of the many variables that affect households' ability to adapt (Kuhlicke *et al.,* 2020). Therefore, further research is needed to determine exhaustively which variables must be taken into account.

4.2.3.3 *Limits of adaptation and mitigation strategies*

In the field of adaptation research, the study of the limits of adaptation strategies remains underdeveloped (Mercator, *et al.,* 2021). At the population level, the main limitations are the lack of financial resources and the lack of training and awareness raising about climate change. At the institutional level, the authorities are not very involved. In terms of adaptation and mitigation actions, there is the use of renewable energy, the planting of trees in houses or participation in reforestation campaigns. In Abuja, 29.83% do not use any source of natural energy, while in Ouagadougou it is more than 43%. In addition, more than 80% (Ouagadougou) and 66.38% (Abuja) have never participated in a reforestation campaign.

Therefore, to assess the involvement of the authorities in the prevention and management of climate hazards in the two cities, the study paid particular attention to the perceptions of the local authorities' response to the effects of climate change. In Ouagadougou, 36.94% thought that the authorities were not reacting at all, 49.7%, thought that the authorities' reaction was insufficient, 7.41% thought that the reaction was moderate and, only 2.79% said that the reaction was adequate. In Abuja, 30.2% felt that the authorities were not reacting at all, 36.43% felt that the authorities were reacting inadequately, 24.21% felt that the reaction was moderate and 5.62% said that the reaction was adequate. 2.08% said that the authorities' response was very adequate. These results highlight the insufficient participation of local authorities, despite their crucial role in developing and implementing effective adaptation strategies (Khamis, 2022). In Burkina Faso, while most institutions acknowledge the need for adaptation in response to climate impacts, the actual implementation of measures remains limited due to financial constraints, communication gaps, and lack of coordination (Basson *et al.,* 2020). Most cities that make an almost negligible contribution to greenhouse gas emissions into the atmosphere are those facing the greatest risks of the adverse consequences of climate change, and most have significant limitations in their capacity to adapt (Satterthwaite *et al.,* 2007).

4.2.3.4 *Actions to improve adaptation and mitigation strategies*

According to Olazabal and Ruiz De Gopegui (2021), adaptation in the current institutional and regulatory context is essential to ensure long-term sustainable adaptation action. It is essential to develop and apply a methodological approach that will capture and analyse the space of adaptation solutions in cities. It is possible to avoid making wrong decisions by building on the experience of cities that have already implemented good adaptation measures (Kalbarczyk and Piegat, 2021). Some scientific research and recent climate assessment reports have begun to identify the individual and collective adaptation actions that people can take to cope with the effects of climate change (Carman and Zint, 2020). Climate resilience refers to the ability of cities to protect their inhabitants and infrastructure from the effects of climate change, and from extreme weather events; these include urban climate regulations, urban water management, air quality improvement, and habitats and biodiversity preservation (Croce and Vettorato, 2021). In Ouagadougou, respondents suggested that improving adaptation to climate change would require the commitment of authorities, communities, and all stakeholders to strengthen urban infrastructure, increase awareness about climate issues, promote city greening through tree planting, and manage plastic waste more effectively. Similarly, in Abuja, the focus was on improving urban infrastructure, increasing public awareness, promoting renewable energy, and reducing gas emissions. Factors such as demographics of the city, political leadership, economic factors, institutional structures, environmental activism, and strong civil society are key exogenous and endogenous variables that contribute to successful adaptation and mitigation (Castán Broto and Westman, 2020). With the aim of improving adaptation and mitigation strategies, the opinions of the population were gathered on their willingness to pay contributions to protect themselves against the effects of climate change. Around 70% (Abuja) and around 60% (Ouagadougou) expressed their willingness to pay for to contribute financially to protect against floods, heat waves, and storms. Furthermore, regarding public opinion towards energy saving practices, respondent in Abuja, 35.33% believed that households could save, between 20% and 40% of energy through serious measures, while 19.32% thought that 40% to 60% of energy could be saved. In Ouagadougou, 17.27% and 7.06% respectively shared similar views. These findings underscore the importance of implementing policies that promote awareness of energy-saving behaviours and introduce insurance schemes to protect vulnerable populations from climate-related risks.

4.3 Summary of Findings

The summaries of the findings of the study are as follows:

Firstly, the results of this study show that population growth in cities has led to spatial expansion of cities. In terms of surface area occupied by built-up, Abuja's city has grown from 100.69 square kilometres in 2001 to 224.03 square kilometres in 2013, then 397 square kilometres in 2022, showing a change in time and space. Regarding the city of Ouagadougou, urbanisation has led to a horizontal expansion of housing, with the surface area increasing from 38.03 square kilometres in 1990 to 53.64 square kilometres in 2002, then from 196.70 square kilometres in 2012 to 371.56 square kilometres in 2022.

Secondly, the results reveal environmental consequences linked to the demographic and spatial dynamics of the two cities. In addition to the degradation of vegetation, the urbanisation of the two cities has led to an increase in the recurrence of extreme climatic events, including floods, heat waves, and windstorms. In Abuja, in terms of loss of vegetation cover, the vegetation-occupied area fell from 6059.34 to 3684.70 square kilometres between 2001 and 2013, and then from 3684.70 to 1433 square kilometres between 2013 and 2022. In Ouagadougou, around 75% of the area covered by vegetation has been destroyed by urbanisation. Between 1992 and 2022, around 30% and 40 per cent of people surveyed in Abuja and Ouagadougou, respectively, had been affected by flooding at least once. The results also show that certain populations have been affected either by floods, windstorms, or heat waves, or often by all 03 phenomena over the last three decades.

Thirdly, the results reveal several adaptation and mitigation strategies used by the populations of these two cities in the face of flooding, windstorms, and heat waves during the day and at night.

Finally, the results show that by 2052, the city of Abuja will experience an increase in the area occupied by housing. This development will certainly have consequences for the environment, as was the case between 2001 and 2022.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The aim of this study was first to analyse the demographic and spatial dynamics of the cities of Abuja and Ouagadougou, as well as the urban population's perceptions of these dynamics and the environmental consequences that they engender. Firstly, in terms of demographic growth, both cities have experienced rapid growth over the last three decades. In terms of spatial dynamics, the results of this study reveal growing urbanisation, characterised by an exponential increase in the surface area occupied by housing. Horizontal expansion of cities has been encouraged by inadequate urban planning and implementation of urbanisation policies. Urban development has also led to an increase in the use of transport, resulting in a proliferation of dust and air pollution in cities. Vegetation is also affected by urban sprawl. Thus, the perceptions of urban populations on the demographic and spatial dynamics of the cities have enabled a better understanding of the way in which city dwellers perceive the evolution of the urbanisation phenomenon in time and space, as well as the consequences that this engenders. Additionally, people's perceptions of the growth of the two cities and the problems they face are proving to be an important point for the implementation of participatory actions to improve urban planning and management.

Secondly, the study assessed the impact of climatic hazards, including high temperatures, windstorms, and floods, on the health, activities, and daily comfort of urban populations. The spatial distribution of the phenomena by sector in the city of Ouagadougou and by LGA in the city of Abuja shows disparities between the different urban areas. More specifically, the spatial analysis of the impacts showed that some areas are more affected simultaneously by windstorms, high temperatures, and flooding than others. Additionally, information collected from households confirmed that the same populations are sometimes simultaneously affected by several climatic hazards. The study reveals that population density, degradation of vegetation cover, poor planning, and lack of public awareness are factors that contribute to the recurrence of extreme weather events. The study of the spatial and temporal distribution of floods and extreme heat provides a theoretical basis for urban planners, borough managers, NGOs, and local residents to improve the living environment and promote sustainable urban development.

Finally, this study evaluated mitigation and adaptation strategies adopted by urban populations in Abuja and Ouagadougou to protect themselves from the adverse effects of climate change. The results showed that the respondents in both cities adopted various measures to adapt to each climate phenomenon, but the level of adoption of these measures differs from city to another. The findings revealed a low level of adoption of climate change mitigation measures. The results also showed that the authorities reacted poorly to extreme weather events in these two cities. These strategies reveal the resilience of urban populations, demonstrating the need to use an integrated approach at all levels to mitigate the effects of climate change. The results show a characterisation of the populations according to their sociodemographic status and their behaviour and perception with regard to climate change mitigation. This characterisation of populations provides information for decision makers who wish to identify targets for the implementation of climate change mitigation projects or programmes in urban areas. This study contributed to the development of a better understanding of the determinants of the adoption of behaviours related to structural adaptation. The results will enhance the scientific community's knowledge of how urban populations adapt and will help to improve the planning of adaptation actions. Considering the recurrence of these events in the two cities in the last 30 years, it is necessary to develop adaptation indices for each climatic phenomenon.

5.2 Recommendations

The main findings of the study and the conclusion have led to recommendations for policy improvement and enhanced performance.

5.2.1 Policy improvement

The results of the research showed the demographic and spatial expansion of cities, which initially led to the degradation of vegetation. This in turn has led to environmental and climatic problems, including flooding, heat waves, and windstorms. These climatic hazards have had an impact on the health, activities and housing of urban populations. Faced with these diverse and recurring impacts, people have adopted several actions. Unfortunately, the study revealed shortcomings in terms of urban planning and environmental conservation, as well as limitations in adaptation and mitigation strategies.

Based on these findings, the study recommends improvements in urban planning policies. Improve the management of settlements, prohibit settlement in marshy areas, combat the proliferation of informal areas that destroy the environment and improve urban infrastructure. Promote the use of public transport and encourage better energy management in services. In terms of environmental protection and conservation, the study recommends promoting the development of green spaces in cities. Encourage protection of the environment and vegetation. Encourage tree planting. Encourage participation in reforestation campaigns. Take into account the improvement of vegetation cover in the development of new sites. The study recommends raising awareness on the impacts of urbanisation and the effects of climate change. Show how their participation in implementing actions can help combat climate change at the local and global level. Also, promote climate change education at all levels of education. Develop courses and subjects adapted to different levels. Organise training courses on the causes, consequences, and solutions to climate change. Finally, improve the management of natural disasters by providing proactive responses to the impacts of change. Identifying the areas concerned and providing information on appropriate measures before, during and after events. Prevent the occurrence of climatic phenomena by improving public access to weather forecast information. Set up warning and prevention systems for climatic phenomena.

Specifically, Burkina Faso's national policy for housing and urban development has a number of weaknesses that hamper its effectiveness and implementation. The main weaknesses include the lack of financial resources to implement housing and urban development programmes. Weak involvement of private players in financing social housing. Difficult access to property loans for low-income groups. Rapid and uncontrolled urbanisation due to inadequate planning and poor coordination between the various institutions responsible for housing and infrastructure. Furthermore, the regulatory framework is not sufficiently enforced. There is also speculation in the land market, leading to an increase in land prices. There is a shortage of social housing adapted to the needs of low-income populations. Added to this is the development of precarious neighbourhoods without access to basic services. Building materials are often expensive and do not fit local conditions. There is a lack of a clear policy to encourage environmentally friendly and sustainable housing.

The results of this study also highlight the expansion of the city, the degradation of vegetation, and the recurrence of the impacts of climate change linked to the city's urbanisation. The results show that the city will expand in the coming decades, leading to the complete disappearance of all vegetation except the classified forest. To improve the national housing and urban development policy, Burkina Faso must strengthen urban planning, diversify funding sources, improve access to land, and promote sustainable housing that takes into account adaptation and mitigation of climate change. Strong measures must be taken to combat land fragmentation, the proliferation of undeveloped areas, and the degradation of vegetation.

5.2.2 Performance improvement

The study found that a large proportion of urban populations have already experienced several types of climate change impact simultaneously in the past. People are also concerned about the future impacts of climate change. The study revealed that in the future, cities will experience demographic and spatial growth, as has been the case in recent decades. This future urban growth could lead to other impacts. To anticipate this, the study recommends that the Ministry of Housing and Infrastructure promote the use of materials that are suitable and affordable for the population in the construction of their homes. The Ministry of Urban Planning should adapt urban development plans to take account of future projections, and ensure that people already living in flood-prone areas are relocated to non-risk areas. The Ministry of Energy must promote the use of renewable energies such as solar panels, wind power, and biogas. The Minister of Transport and Urban Mobility must develop and diversify public transport and encourage people to use it.

5.3 Contribution to Knowledge

The study established that rapid population growth has driven significant spatial expansion in Abuja and Ouagadougou. In Abuja, built-up areas increased from 100.69 square kilometres in 2001 to 224.03 square kilometres in 2013, and 397 square kilometres in 2022; reflecting a steady urban growth. Similarly, Ouagadougou experienced horizontal housing expansion, with built-up areas rising from 38.03 square kilometres in 1990 to 53.64 square kilometres in 2002, 196.70 square kilometres in 2012 and 371.56 square kilometres in 2022. This expansion has brought severe environmental consequences in the two cities. In Abuja, vegetation cover decreased from 6059.34 square kilometres in 2001 to 3684.70 square kilometres in 2013, and further to 1433 square kilometres in 2022. In Ouagadougou, 75% of vegetated areas was depleted. These dynamics have heightened the recurrence of floods, heat waves, and windstorms in the two cities. Furthermore, the study established that between 1992 and 2022, about 30% of respondents in Abuja and 40% in Ouagadougou experienced flooding at least once, while many households were affected by multiple extreme events, particularly over the last three decades. The study further revealed that residents of both cities have adopted diverse adaptation and mitigation strategies to cope with flooding, windstorms, and heat waves. These findings imply that rapid settlement expansion has exacerbated multiple extreme climate events in Abuja and Ouagadougou.

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APPENDICES

APPENDICE A: Households Questionnaire

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE (WASCAL)

POST-GRADUATE SCHOOL, SCHOOL OF PHYICALSCIENCES

DOCTORAL RESEARCH PROGRAMM ON CLIMATE CHANGE & HUMAN HABITAT

QUESTIONNAIRE ON CLIMATE CHANGE IN URBAN

Presentation

Hello. Dear Sir/Madam. My name is ________________________________ and I work for the Federal University of Technology in Minna (Nigeria) and the Joseph KI-ZERBO University (Burkina Faso). Thank you for welcoming me and giving me some of your time to answer my questions.

Information

The Minna Federal University of Technology, in collaboration with the Joseph KI-ZERBO University in Ouagadougou, is carrying out a study entitled **A *Spatio-temporal analysis of climate change and settlement dynamics in Abuja and Ouagadougou, a savannah region in West Africa***. The objectives of this study are, on the one hand, to analyse the demographic and spatio-temporal dynamics of the two cities and the link with the recurrence of the effects of climate change (heat waves, floods, storms/winds and droughts) in urban areas. Secondly, to assess how adaptation and mitigation strategies make cities more resilient to the effects of climate change.

Consent

Your participation in this study would be a great help to us. I would like to reassure you that the information you give in this interview will not be divulged and will remain strictly confidential. Anything you say during the interview will only be used by members of the research team for the purposes of the research. All the information you give us will remain strictly confidential and will not be shown to anyone other than members of our team. Your name will not be mentioned, and every effort will be made to ensure that you cannot be recognised from what you say.

Before continuing, do you have any questions about this study?

SECTION I: INFORMATION FOR THE COLLECTORS

The purpose of this section is to identify the interviewer, the interview location, the date and the time. ***Please ensure that this information is correctly selected before continuing***.

1. Choose your name

- *Interview1*
- *Interview2*
- *Interview3*

2. Choose language

- English
- French

3. Location

- Ouagadougou, Burkina Faso
- Abuja, Nigeria

4. Survey area

Abuja	**Ouagadougou**
Choose your LGA/Neighbourhood/ZD	Choose borough/sector/neighbourhood/ZD

5. Choosing the interview date

DD/MM/YYYY

6. Choose the start time for the interview

HH/MN/SD

SECTION II: DEMOGRAPHIC AND SPATIAL DYNAMICS OF CITIES

This section aims to understand the perception of the interviewed persons on demographic and spatio-temporal dynamics of cities, as well as the factors associated with these dynamics and their impact on natural resources.

7. What do you think of the city's building dynamics over the last 30 years (1992 to 2022)?

- Increase
- Decrease
- Stable
- Don't know
- No answer

8. What factors are driving the city's spatial expansion?

Instructions: Relaunch the question and choose the modalities

- Demographic growth

- Accessibility of land/parcels
- Road infrastructure development
- Ownership of means of transport
- Cultural practices/the desire to own property
- Social housing programmes
- Physical/topographical environment conducive to expansion
- Sale of land by landowners
- Speculation and the land/parcel trade
- Lack of appropriate government regulations
- Other
- Don't know

9. What is your assessment of the state of dust in the city?

- Very heavy dust
- Heavy dust
- Medium dust
- Low dust
- Very low dust
- No dust
- Don't know

10. What is the most common transport that people use to get around the city?

- Private car
- Personal motorbike
- Car taxis
- Bus (local)
- Tricycle/motorcycle taxi
- Bike
- Other
- Don't know

11. Where is the city most polluted by plastic waste?

- Allotment and non-allotment areas
- Public authorities (public and private)
- The markets
- Bus and transport company stations
- Health centres
- Schools
- Places of worship
- Public roads
- Public reserves
- Other

- Don't know

12. Have you noticed any change in the city's vegetation cover compared with the past?

- Increase
- Decrease
- No change
- Don't know

13. What are the causes of the decline in plant cover?

- Spatial expansion of the city
- Abusive wood cutting
- Subdivision/home building
- Infrastructure/plant construction
- Clearing land for fields
- Other
- Don't know

14. In your opinion, what are the possible impacts of the degradation of plant cover?

- More heat waves,
- Recurrence of flooding events
- Decrease in rainfall
- Increase in wind speed/violence
- Other
- Don't know

15. Are there any trees in the house or in front of the house?

- Yes
- No
- No answer

16. Have you ever taken part in a reforestation campaign in this town?

- Yes
- No
- No answer

SECTION III: IMPACT OF CLIMATE CHANGE IN URBAN AREAS

This section assesses people's perceptions of climate change. On the one hand, it seeks to understand how people perceive the dynamics of the various climatic parameters over time and space. On the other hand, this section aims to understand the recurrence of the impacts of climate change on people's health, housing, activities and daily comfort.

17. Which of the following situation does Does your household experience?

- Increased energy consumption
- Increased water consumption

- Increased fuel consumption
- No increase in consumption
- Don't know
- No answer

18. Have the temperatures of recent years had an impact on your business?

- Yes
- No
- Don't know
- No answer

19. What impact do temperatures have on your business?

- Increased costs
- Impact on product quality
- Reduction in customer frequency
- Increase in customer frequency
- Don't know

20. Have recent temperatures had an impact on your state of health or personal comfort?

Instructions: Relaunch the question and choose the modalities

- Increased water consumption
- Insomnia
- General fatigue
- Headaches
- No impact
- Don't know
- No answer

21. Have you noticed an increase in climate-related illnesses, such as seasonal allergies or respiratory diseases, in this city?

- No, not at all
- A little
- Moderately
- Many
- Extremely
- Don't know
- No answer

22. What impact do the winds have on your business?

Instructions: Relaunch the question and choose the modalities

- Damage to equipment/goods
- Soiling the premises
- Destruction of premises
- No impact on business

- Other
- Don't know

23. What impact do the winds have on your health?

Instructions: Relaunch the question and choose the modalities

- Frequency of colds
- Frequency of cough
- Frequency of eye pain
- Soiling of the body/clothing
- Accidents/injuries
- No impact on health
- Other
- No answer

Frequency of colds	More	Less	Not at all
Frequency of cough	More	Less	Not at all
Frequency of eye pain	More	Less	Not at all
Soiling of the body/clothing	More	Less	Not at all
Accidents/injuries	More	Less	Not at all
No impact on health			
Other			

24. What impact do winds have on your everyday comfort?

- Soiling of clothes/body/furniture
- Soiling of vehicles/motorcycles/tricycles
- Product shortages
- No impact
- Don't know

25. What impact have the winds had on your home in recent years?

Instructions: Relaunch the question and choose the modalities

- Soiling the courtyard
- Soil degradation
- Wall cracks
- Impact on the roof
- Damage to electrical wiring
- Collapse of the house
- No impact
- Don't know
- No answer

26. What impact will heavy rain have on your business?

- Inaccessibility of business parks
- Damage to shops
- Damage to goods
- Other
- No impact from heavy rain
- Don't know

27. What impact will heavy rain have on where you live?

- Water stagnation in the yard
- No water in the streets
- Cracks in houses
- Destruction of household goods
- Rubbish in or around the yard
- No impact from heavy rain
- Other

▪Don't know

28. What impact will heavy rain have on your day-to-day comfort?

- Soiling the courtyard
- Soiling the means of transport
- Difficulty getting around
- Soiling clothes
- No impact from heavy rain
- Other
- No answer

29. Have you been personally affected by the flooding in this area?

- Yes
- No
- No answer

30. In the past, have you been affected by flooding elsewhere in the city before coming to this area?

- Yes
- No
- No answer

31. What have you done to protect yourself from flooding?

- Reinforcing the structure of the house
- Put sandbags in front of the door
- Dig a channel/hole to facilitate the passage of water
- Cleaning drainage channels
- Other
- Nothing
- No answer

32. What did you do at the time to protect yourself from the flood?

- Moving
- Reinforcing the structure of the house
- Put sandbags in front of the door
- Dig a channel/hole to facilitate the passage of water
- Cleaning drainage channels

- Other
- No answer

33. How many times have you been affected by flooding?

Number of times

34. Which year do you think was the most intense?

Note the year

35. Do you think your house could flood in the event of heavy rain?

- Yes
- No
- Don't know

36. Do you know anyone who has been affected by the impact of climate change?

- Yes
- No
- Don't know
- No answer

37. What climate phenomena have they been affected by?

- Flooding
- Drought
- High temperature
- Windstorms
- Other
- Don't know

38. What is your relationship with these people?

- Parents
- Friends
- Neighbours/other people
- Colleagues
- Other
- No answer

39. Are you personally able to protect your home from flooding?

- Yes
- No
- Don't know

40. What do you think are the causes of flood risk?

Instructions: Relaunch the question and choose the modalities

- Climate change/heavy rainfall
- Bank erosion
- Uncontrolled occupation of areas
- Lack of information on flood risk
- Poor urban development policy
- Degradation of plant cover
- Modification of major and minor beds
- Pollution (plastic, waste, air)
- Absence or lack of maintenance of canals

- The quality of the construction of the homes
- Other
- Don't know

41. What do you personally pay most attention to in preparing for flooding?

- Weather forecast
- Rain intensity/frequency
- Rising water levels in dams
- Condition of the house
- Condition of drainage channels
- No answer

42. What is your assessment of the damage, i.e. your belongings lost or damaged during the last flood?

- Very large
- Huge
- Medium
- Moderate
- No damage
- Don't know

43. Have you used a motor-driven pump to evacuate water from your home?

- Yes
- No
- Don't know

44. How much do you estimate your flood-related losses and damage to be?

❖ ....F.CFA/NAIRA

45. Does flooding seem like an event to you?

- Very serious
- Grave
- Not at all serious
- Don't know

46. What do you think was the main cause of the flooding in the town?

- The amount of rain
- Urban development
- Don't know
- No answer

47. How do you assess the frequency of flooding in the city in recent years?

- Very common
- Common
- Neither frequent nor rare
- Rare
- Very rare
- Don't know

48. What was the hottest year you've experienced in the last 30 years (1992 to 2022?

Type the year

49. Has anyone in your household ever been hospitalised because of the impact of high temperatures?

- Yes
- No
- Don't know

50. Have you experienced any droughts or water shortages in the city in recent years?

- Yes
- No
- No answer

51. Do you think there is an increased risk to water security because of the droughts and heatwaves in the city?

- Yes
- No
- Don't know

52. Do you think there is an increased risk of mortality and morbidity linked to heat waves in this city?

- Yes
- No
- Don't know
- No answer

53. How concerned are you about climate change at the moment?

- Very concerned
- Worried
- Little concerned
- Not at all worried
- Don't know
- No answer

54. How concerned are you about future climate change?

- Very concerned
- Worried
- Little concerned
- Not at all worried
- Don't know
- No answer

SECTION IV: MITIGATION AND ADAPTATION STRATEGIES

The aim of this section is to find out what mitigation and adaptation strategies people use to cope with the impacts of climate change in urban areas.

55. Who do you think should be responsible for reducing or protecting the city from flooding?

- The State
- Local councillors/Mayors
- Weather forecasting services
- The population
- The NGOs
- Other

- Don't know

56. Are you prepared to pay or contribute to protect yourself against the effects of climate change?

Flooding	1.Yes 2.No 3.No answer
Heat waves	1.Yes 2.No 3.No answer
Drought	1.Yes 2.No 3.No answer
Windstorms	1.Yes 2.No 3.No answer

57. What do you think about the wind situation in the future?

- Increased speed/strength
- Reduced speed/force
- No change
- Don't know

58. Have you taken precautions to protect yourself against windstorms?

- Yes
- No
- No answer

59. What have you done to protect yourself against windstorms?

- Reinforcing walls
- Reinforcing the roof
- Reinforcing openings
- Other

60. Do you use a naturally produced energy source?

- Solar energy (Solar panel)
- Wind energy (Energy produced by the wind)
- Biogas
- No natural energy sources
- Other
- No answer

61. When it comes to buying electronic equipment, what do you pay most attention to?

- *The price*
- *Quality*
- *The brand*
- *The colour*
- *Date of manufacture*
- *Power (Volt, Whats)*
- *Don't bother*
- *No answer*

62. If a household took serious steps to save water, how much water do you think they could save?

- *Less than 20 %*
- *20 à 40 %*
- *40 à 60 %*
- *60 à 80 %*
- *Plus 80%.*
- *Don't know*

63. If a household took serious steps to save energy, how much energy do you think it could save?

- *Less than 20 %*
- *20 à 40 %*
- *40 à 60 %*
- *60 à 80 %*
- *Plus 80%.*
- *Don't know*

64. What do you do to beat the heat during the day?

- Drink more water than usual
- Drink more sugary drinks/fruit juices
- Modifying working hours if it's too hot
- Showering several times
- Permanent use of the fan
- Permanent use of the air conditioner
- Swimming in a pool/Dam/Marigot
- Go to a garden/green space
- Going to a forest
- Sitting under a shady tree
- Use an umbrella/Wear a cap/Wear glasses
- No answer

65-1 What do you do to withstand the heat at night?

- Drink water more often
- Drink more sugary drinks/fruit juices
- Go to a green area/restaurant or scrubland
- Showering several times
- Permanent use of the fan
- Permanent use of the air conditioner
- Sleeping outside
- No answer

65-2 What do you do to withstand the heavy heat during sleeping whether on weekdays or weekends?

- Showering several times
- Permanent use of the fan
- Permanent use of the air conditioner
- Sleeping outside
- No answer

67. Do you think the way you build helps to reduce the effects of temperature?

- Yes
- No
- Don't know

68. How can the neighbourhood be configured to mitigate the effects of temperatures?

- Tree planting
- Ventilation of buildings
- House orientation
- Other
- Don't know

69. What action are you taking during the flood?

Instructions: Relaunch the question and choose the modalities

- Close the door on the house
- Isolating valuables
- Place electronic equipment on tables or chairs
- Digging trenches around houses
- Building dykes to stop the water flowing
- Securing the house with waterproof materials
- Use sandbags to prevent water from entering the house
- Drill holes in walls to allow water to pass through easily
- Raising the door of the house with one or two coats
- Other
- Do nothing
- Don't know
- No answer

70. In the event of a claim, what resources do you have to cover your day-to-day needs?

- Economy/Savings
- Recourse to insurance
- Recourse to the State
- Recourse to neighbours
- Recourse to parents
- Use of friends
- Other
- Don't know

71. In your opinion, who should be responsible for looking after people affected by flooding?

- Status
- Insurance
- Emergency services
- Town Hall
- Acquaintances/family
- NGO
- Other
- Don't know

72. Would you accept an offer to relocate if you were told you lived in an area at risk of flooding?

- Yes
- No

- No answer

73. In your opinion, what are the various constraints or limitations in terms of adapting to the effects of climate change?

- Lack of financial resources
- Lack of information on the phenomenon
- Lack of public will
- Lack of technology
- Lack of warning system
- Other
- Don't know

74. How do you think the city can better adapt to the effects of climate change?

Instructions: Relaunch the question and choose the modalities

- Improving urban infrastructure
- Reducing greenhouse gas emissions
- Raising public awareness of climate change
- Promoting renewable energies
- Promoting green cities/planting trees
- Reducing water and energy consumption
- Promoting sustainable urban mobility
- Publicising and promoting public transport
- Good management of the use of plastic bags
- Other
- Don't know

75. How are the city's local authorities responding to the effects of climate change?

- No reaction
- An inadequate response
- A moderate reaction
- An appropriate response
- A very appropriate reaction
- Don't know

SECTION V: ACCESS TO INFORMATION AND DECISION-MAKING ON CLIMATE CHANGE

The aim of this section is to find out about people's exposure to the media or to information about the effects of climate change. It also aims to find out about the various training courses and awareness-raising activities received by the population in relation to climate change. Finally, it aims to find out how people perceive climate change in the future and their attitude towards it.

76. Have you ever waited to hear about the effects of climate change through the media or other sources of information?

- Yes
- No
- No answer

77. What effects have you heard about?

- Flooding
- Heat waves
- Drought
- Windstorms

- Rising sea levels
- Hurricane
- Landslide
- Other

78. Which locality did the information relate to?

- Your city only
- Elsewhere in the country
- Burkina Faso/Nigeria
- In other African countries
- In the world
- No answer

79. How did you obtain this information?

- At school/University
- On social networks
- The radio
- Television
- In the newspaper
- Through a friend/family member
- At a conference
- Raising awareness
- Posters/Billboards
- Other
- No answer

80. Do you know where to get reliable information on climate change in your country?

- Yes
- No

81. Do you know of any associations or community-based organisations working on climate change?

- Yes
- No
- Don't know

82. Have you already received an awareness-raising session on climate change and its impacts?

Flooding	1. yes 2. no No answer 3. No answer
High temperatures	1. yes 2. no No answer 3. No answer
Windstorms	1. yes 2. no No answer 3. No answer
Drought	1. yes 2. no No answer 3. No answer
Other	1. yes 2. no No answer 3. No answer

83. Are you regularly informed about the risk of flooding?

- Yes
- No
- No answer

84. Are you regularly informed about heatwaves?

- Yes
- No
- No answer

85. Are you regularly informed about windstorms?

- Yes
- No
- No answer

86. What are your sources of information?

- Meteorological services
- The radio
- The TV
- Social networks
- Newspapers
- Other

87. Have you received any training on reducing energy consumption?

- Yes
- No
- No answer

88. Have you received any training on reducing water consumption?

- Yes
- No
- No answer

89. Have you received training in the use of renewable energies such as solar, wind and biogas?

- Yes
- No
- No answer

90. Are you looking for a weather forecast?

Temperature	**1.Never 2.Often 3.Always**
Precipitation	**1.Never 2.Often 3.Always**
Winds	**1.Never 2.Often 3.Always**
Humidity	**1.Never 2.Often 3.Always**

91. Where do you look for this information?

- On the phone's applications
- On the radio
- On television
- On social networks
- In the newspapers

- Other
- No answer

92. Have you received any information about temperature trends in the coming years?

- Yes
- No
- Don't know
- No answer

93. Have you received any information on rainfall trends for the coming years?

- Yes
- No
- No answer

94. Have you received any information about wind trends in the coming years?

- Yes
- No
- No answer

95. How concerned are you about how climate change could affect urban populations or their businesses in the future?

- Very concerned
- Worried
- Little concerned
- Not at all worried
- Don't know

SECTION VI: SOCIO-DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS

The purpose of this section is to collect information on the socio-demographic characteristics and socio- economic conditions of the household, as well as the demographic characteristics of the respondent, including age, level of education, marital status, etc. Please note that some respondents may be reluctant to provide you with certain information. Be aware that some respondents may be reluctant to provide you with certain information. If this is the case, remind the respondent that the survey is entirely confidential, and allow them to take the time they need to answer, so that they feel comfortable about giving you this information.

96. Is the respondent the Head of Household?

- Yes
- Other household member

97. What is your relationship with the head of household (Ask if not the CM)?

- Wife/Husband
- Son/daughter
- Son-in-law/daughter-in-law
- Grandson / Granddaughter
- Parent
- Step-parent
- Brother/sister
- Help with housework
- Other
- No answer

98. What is the gender of the respondent?

- Men
- Woman

99. How old are you?

Enter age in completed years

100. What is your level of education?

- No level
- Primary
- Post-primary (1er cycle)
- Secondary (2e cycle)
- Higher/university
- No answer

101. What do you do for a living?

- Public sector worker
- Private sector worker
- Student/Researcher
- Entrepreneur/sole trader
- Retailer
- Farmer/breeder/gardener
- Welder/joiner/seamstress/mechanic
- Housewife/Unemployed
- Other

102. What is your marital status?

- Single
- Married
- Lives with a partner (common-law)
- Divorced/separate
- Widowed
- No answer

103. How many people live with you in your household?

Number of household members

104. How long have you lived in this house?

Number of years

105. What is your ownership status of the yard/house?

- Owner of the house/yard
- For rent
- A friend's/relative's/colleague's yard or one entrusted to them
- Other

106. How long have you lived in the city?

- Between 0 and 5 years
- Between 6 and 10 years
- Between 11 and 15 years old

- Between 16 and 20 years old
- Between 21 and 25
- Between 26 and 30
- Over 30 years

107. Main characteristic of the habitat

What is the main material of the floor?	**What is the main material of the roof**	**What is the main material of the exterior walls?**
• Soil / sand • Dung • Wooden boards • Fins / bamboo • Polished parquet or wood • Vinyl strips • Tiling • Cement • Carpet • Other	• No roof • Stubble / straw / leaves • Clods of earth • Mats • Fins / bamboo • Wooden boards • Cardboard • Sheet metal • Wood • Zinc / fibre cement	• No wall • Bamboo / cane / palm Earth/Banco • Bamboo with mud • Stones with mud • Plywood • Cement • Stone with lime/cement • Bricks • Cement blocks

108. What means of transport do members of the household have?

- Airplane
- Car
- Motorbike
- Tricycle
- Bicycle
- Moped
- Charette
- Other

109. What is your main means of transport?

- Airplane
- Car
- Motorbike
- Tricycle
- Bicycle
- Moped

- Charette

110. Average time (in minutes) between home and work?

Number of minutes

111. How often do you take the bus or taxi in a month?

o Number of times

112. What energy sources do you use in your home?

- Electricity
- Solar panel
- Generator
- Other

113. What is the main source of energy for the home?

- Electricity
- Solar brochure
- Generator

114. Do you experience power cuts?

- Very often
- Often
- Rarely
- Not at all
- No answer

115. How often do you use your generator?

- No generator
- Less than 2 hours/day
- 3 to 6 h/day
- 7 to 10 h/day
- More than 10h
- No answer

116. What is the main source of energy for cooking food?

- Gas
- Electricity
- Biogas
- Firewood
- Charcoal
- Straw/grass
- Other
- No answer

117. What is the main source of water used by the household for domestic activities?

- Tap
- Drilling
- Well
- Marigot
- Dam

- No answer

118. Do you experience water cuts?

- Very often
- Often
- Rarely
- Not at all
- Do not use tap water
- Don't know
- No answer

119. Which activity do you think uses the most water in your household?

- Dishes and cooking
- Laundry
- Shower and WC
- Washing motorbikes and cars
- Cleaning your home
- Watering trees
- Other

120. Can you give us your telephone number?

- Yes
- No
- No answer

121. Enter the respondent's telephone number

Enter number

122. We would like to know your first and last name?

Name :

First name :

SECTION VII: FINALISING THE QUESTIONNAIRE

123. Save the household's GPS coordinates

124. Choose the date and time for the end of the interview

125. Maintenance status

- Complete
- Partly complete
- Refusal
- Other