DETECTION OF URBAN GROWTH PATTERNS LINKED WITH SOCIAL-SCIENCE DATA ACROSS CITIES IN SOUTHEASTERN NIGERIA

DISSERTATION

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Abstract

The lack of large-scale social-science data and the scientific community's preference for studying urban growth in large cities have resulted in a relatively neglected urban growth trend at the regional and global levels in mid-sized cities. Monitoring urban growth changes in mid-sized cities is imperative because they have a direct bearing on the growth patterns of metropolitan cities. Understanding how growth occurs in mid-sized cities is particularly crucial, given that the instance of an early urban development pattern in mid-sized cities typically influences other growth patterns in large cities, as changes in mid-sized cities are frequently found to lead to significant urban transformation in metropolitan cities. To address these issues and promote sustainable urban growth in accordance with the UN Sustainable Development Goals (SDGs) 11, a research framework that is capable of highlighting socioeconomic problems across Nigerian cities and proffer solutions that would lead to the realization of those goals in cities must be developed. This study sought to monitor changes in urban areas and simultaneously quantify agricultural land loss resulting from urbanization using relevant scientific literature, social-science data, and remote-sensing data. This study uses the following southeastern Nigerian cities as an illustrative case study: Warri, Uyo, Aba, and Umuahia. This is because they manifest diverse unplanned urban development patterns that are characterized by sparse built-up patterns, rural-urban migration, and local economic/population growth, which pose a threat to all nearby agrarian lands. The first objective of this study was to examine how changes in Uyo's infrastructure development and local economic growth impact urban expansion. Additionally, time-series data were used to show the trends in vegetative land loss. The integration of spatial data using different social-science data has not been scientifically explored in Nigeria and thus remains a huge knowledge gap in the country. To address this knowledge gap, the second and third objectives of this thesis focus on the influence of tax and natural resource revenue on urban growth patterns across cities in southern and eastern Nigeria, respectively. The results obtained further elaborate and validate previous studies that demonstrate that urbanization in Africa differs from urbanization in the global west.

In this study, diverse remote sensing approaches were adopted to analyse the 30m Landsat historical datasets. The 30m datasets were used to identify the spatiotemporal changes in built-up patterns to generate a time-series trend of vegetation loss from 1986 to 2018. High-resolution 5m RapidEye images were used to map various socioeconomic growth areas based on fieldwork reference datasets. Semi-structured interviews were conducted with representatives of various urban sectors and ministry heads in an effort to expand the socioeconomic data. The research objectives were considered when evaluating archived data from different government ministries. The findings reveal how the infusion of shared natural resource revenue led to both the emergence of a consumption-based economy and economic change in the local community. The distribution of natural resource revenue stimulates significant infrastructure development, increases household income, and provides basic social amenities in urban areas. Regarding urban migration, the respondents concurred that the demand for white-collar jobs (which are difficult to secure in metropolitan areas) and lack of basic social amenities have triggered rural-urban migration.

Satellite data showed a significant loss in agricultural land and new sparse built-up areas between different urban land-use classes. These spatial changes in urban areas, as proven in this study, depend directly on shared natural resources and the local economy. Furthermore, the results obtained demonstrate the mapping of mixed usage and commercial areas that directly affect local economic growth; however, these were not included in previous studies. Analysis of the socioeconomic survey data shows that infrastructural development in peri-urban areas has increased the prices of land, thereby encouraging low-income earners to sell some of their inherited landed property at fair prices to high-income earners in the hope that they will bring development to their communities. This corresponded with interviews conducted with governmental heads to ascertain whether infrastructural development is a critical driver of agricultural land loss in most suburban communities, and also affirmed that the sale of inherited lands is the order of the day.

The case study explored in this research provides a useful reference point for the numerous increasingly urbanized cities in Nigeria, particularly developing African cities that are not well represented in the existing urbanization literature. The case study shows that planning and distributing urban infrastructure development throughout communities is necessary to counter the incessant sale of land, that sensitization to the effects of the continuous loss of agrarian land should be intensified and discouraged, and that depending on shared natural resources to fund urban infrastructural developments in the study areas raises concerns about its long-term sustainability.

Zusammenfassung

Der Mangel an groß angelegten sozialwissenschaftlichen Daten und die Vorliebe der Wissenschaft für die Untersuchung des städtischen Wachstums in Großstädten haben dazu geführt, dass der Trend des städtischen Wachstums in mittelgroßen Städten auf regionaler und globaler Ebene relativ vernachlässigt wurde. Die Überwachung von Veränderungen des städtischen Wachstums in mittelgroßen Städten ist zwingend erforderlich, da sie einen direkten Einfluss auf die Wachstumsmuster von Metropolen haben. Das Verständnis, wie Wachstum in mittelgroßen Städten stattfindet, ist besonders wichtig, da ein frühes Muster der Stadtentwicklung in mittelgroßen Städten normalerweise andere Wachstumsmuster in Großstädten beeinflusst, da Veränderungen in mittelgroßen Städten häufig zu erheblichen städtischen Veränderungen in Metropolen führen. Um diese bestehenden Probleme anzugehen und ein nachhaltiges städtisches Wachstum gemäß den UN-Zielen für nachhaltige Entwicklung (SDGs) 11 zu fördern, muss ein Forschungsrahmen entwickelt werden, der in der Lage ist, sozioökonomische Probleme in nigerianischen Städten hervorzuheben und Lösungen anzubieten, die zur Verwirklichung dieser Ziele in den Städten führen würden. Vor diesem Hintergrund versucht diese Studie, die Veränderungen in städtischen Gebieten zu überwachen und gleichzeitig den durch die Urbanisierung verursachten Verlust landwirtschaftlicher Flächen zu quantifizieren. Dabei werden verschiedene relevante wissenschaftliche Literatur, sozialwissenschaftliche Daten und Fernerkundungsdaten verwendet. Diese Studie verwendet die folgenden Städte im Südosten Nigerias als veranschaulichende Fallstudie: Warri, Uyo, Aba und Umuahia. Der Grund dafür ist, dass sie verschiedene ungeplante Stadtentwicklungsmuster aufweisen, die durch spärliche Bebauung, Land-Stadt-Migration und lokales Wirtschafts-/Bevölkerungswachstum gekennzeichnet sind, die eine Bedrohung für alle umliegenden landwirtschaftlichen Flächen darstellen. Das erste Ziel dieser Studie besteht darin, zu untersuchen, wie sich Veränderungen der Infrastrukturentwicklung und des lokalen Wirtschaftswachstums in Uyo auf die Stadterweiterung auswirken. Zusätzlich wurden Zeitreihendaten verwendet, um Trends beim Verlust landwirtschaftlicher Flächen aufzuzeigen. Die Integration räumlicher Daten unter Verwendung verschiedener sozialwissenschaftlicher Daten wurde in Nigeria nicht wissenschaftlich erforscht und stellt daher im Land weiterhin eine große Wissenslücke dar. Um diese Wissenslücke zu schließen, konzentrieren sich das zweite und dritte Ziel dieser

Arbeit auf den Einfluss von Steuer- und Rohstoffeinnahmen auf die städtischen Wachstumsmuster in Städten im Süden bzw. Osten Nigerias. Die erzielten Ergebnisse vertiefen und bestätigen frühere Studien, die zeigen, dass sich die Urbanisierung in Afrika von der Urbanisierung im globalen Westen unterscheidet

In dieser Studie wurden verschiedene Fernerkundungsansätze angewendet, um die 30 m langen historischen Landsat-Datensätze zu analysieren. Die 30 m langen Datensätze wurden verwendet, um die räumlich-zeitlichen Änderungen in bebauten Mustern zu identifizieren und einen Zeitreihentrend des Vegetationsverlusts von 1986 bis 2018 zu generieren. Hochauflösende 5 m RapidEye-Bilder wurden auch verwendet, um verschiedene sozioökonomische Wachstumsbereiche basierend auf Feldarbeits-Referenzdatensätzen abzubilden. Um die sozioökonomischen Daten zu erweitern, wurden halbstrukturierte Interviews mit Vertretern verschiedener städtischer Sektoren und Ministerien durchgeführt. Die Forschungsziele wurden bei der Auswertung der archivierten Daten verschiedener Ministerien berücksichtigt.

Die Ergebnisse zeigten, wie die Zufuhr gemeinsamer Einnahmen aus natürlichen Ressourcen sowohl zur Entstehung einer konsumbasierten Wirtschaft als auch zu wirtschaftlichen Veränderungen in der örtlichen Gemeinschaft führte. Die Verteilung der Einnahmen aus natürlichen Ressourcen stimuliert eine bedeutende Infrastrukturentwicklung, erhöht das Haushaltseinkommen und bietet grundlegende soziale Annehmlichkeiten in städtischen Gebieten. In Bezug auf die Stadtmigration stimmten die Befragten darin überein, dass die Nachfrage nach Bürojobs (die in Ballungsgebieten schwer zu bekommen sind) und der Mangel an grundlegenden sozialen Einrichtungen die Land-Stadt-Migration ausgelöst haben.

Satellitendaten zeigten einen erheblichen Verlust an landwirtschaftlichen Flächen und neuen dünn bebauten Gebieten zwischen den verschiedenen städtischen Landnutzungsklassen. Diese räumlichen Veränderungen in städtischen Gebieten hängen, wie diese Studie beweist, direkt von gemeinsam genutzten natürlichen Ressourcen und der lokalen Wirtschaft ab. Darüber hinaus zeigen die erzielten Ergebnisse die Kartierung von gemischt genutzten und gewerblichen Gebieten, die sich direkt auf das lokale Wirtschaftswachstum auswirken, in früheren Studien jedoch nicht berücksichtigt wurden. Die Analyse der sozioökonomischen Umfragedaten zeigt, dass die Infrastrukturentwicklung in Vorstädten die Grundstückspreise erhöht hat und dadurch Geringverdiener ermutigt hat, einen Teil ihres geerbten Grundbesitzes zu fairen Preisen an Gutverdiener zu verkaufen, in der Hoffnung, dass diese ihren Gemeinden Entwicklung bringen. Dies stimmte mit Interviews überein, die mit Regierungschefs geführt wurden, um festzustellen, ob die Entwicklung der Infrastruktur ein entscheidender Faktor für den Verlust landwirtschaftlicher Flächen in den meisten Vorstadtgemeinden ist, und bestätigte auch, dass der Verkauf geerbter Ländereien an der Tagesordnung ist. Die in dieser Forschung untersuchte Fallstudie bietet einen nützlichen Bezugspunkt für die zahlreichen zunehmend urbanisierten Städte in Nigeria, insbesondere für afrikanische Entwicklungsstädte, die in der bestehenden Literatur zur Urbanisierung nicht gut vertreten sind. Die Fallstudie zeigt, dass die Planung und Verteilung der Entwicklung der städtischen Infrastruktur in den Gemeinden notwendig ist, um dem unaufhörlichen Verkauf von Land entgegenzuwirken; dass die Sensibilisierung für die Auswirkungen des kontinuierlichen Verlusts landwirtschaftlicher Flächen intensiviert und verhindert werden sollte; und dass die Abhängigkeit von gemeinsam genutzten natürlichen Ressourcen zur Finanzierung der Entwicklung der städtischen Infrastruktur in den Untersuchungsgebieten Bedenken hinsichtlich ihrer langfristigen Nachhaltigkeit aufkommen lässt.

Preface

This thesis was prepared based on the growing population of mid-sized cities both regionally and globally. As observed, the future of unplanned urban growth has numerous disadvantages and, if not well checked, could even hinder the realization of the UN Sustainable Development Goal 11 agenda for cities that will end in 2030. The goal was to quantify urban growth with increasing socioeconomic growth in the study area. Furthermore, we examined the social science variables that trigger unplanned urban growth using a scientific approach. This study was funded by the *German Academic Exchange Service (DAAD).*

The results of this thesis will guide further scientific studies and assist decision-makers in implementing sustainable development goals on a regional scale. The scientific part of the study was conducted by Prof. Cyrus Samimi's research team at the University of Bayreuth. Although it focuses primarily on urban growth patterns linked to social-science data as the main theme, urban growth was discussed based on ways of attaining the UN Sustainable Development Goals 11 in developing countries, and was also linked to Western countries.

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Contents

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Acronyms

GIS... Geographic Information System

GPS .... Global Positioning System

NDVI... Normalized Difference Vegetation Index

NIR .... Near Infra-Red

RF… .... Random Forest Regression

USGS.. United States Geological Survey

ASTER............................... Advanced Spaceborne Thermal Emission and Reflection Radiometer

NBS………………...…Nigeria Bureau of Statistic

NPC………………... National population commission

UN DESA………….................................…United Nations Department of Economic and Social Affairs

Part I

Research Structure

1. Research Outline

The realization of sustainable urban growth in a growing society is one of the challenges faced by cities both regionally and globally. Furthermore, the availability of quantitative socioeconomic data and urban sustainable development goals is a step towards proper planning and management in urban areas. However, developing regions have limited data availability because of the analog mode of data storage. This inadequacy has hindered easy access to the archive of local economic data and, as a direct consequence, has led to an expansion in the body of scientific literature on case studies of urbanization in Africa.

Uyo in Akwa Ibom State, Warri in Delta State, Aba and Umuahia in Abia State are used in this study as illustrative examples for other mid-sized cities in developing regions which are also characterized by enormous local economic growth, a population increase, and urban infrastructural development. Despite these growths, no scientific literature has quantitatively assessed their urban socioeconomic variables, namely peri-urban areas, local economies, and urban growth patterns, and compared them with urbanization in the Global South. While this study aims to fill this knowledge gap, it also serves as a source of information for other researchers and encourages further scientific research in this region and other developing countries.

This research explored different scientific approaches to monitoring urbanization in the study area. The Earth observation data used in this thesis provides new insights for mapping urban growth in the study areas. The urban land use classification map of the areas shows the periods during which rapid changes occurred in urban areas. The loss of agricultural land plays a significant role in climate change, leading to seasonal flooding in the study areas, and remains a primary concern for stakeholders in these urban communities. The findings of this study could aid planning, reduce agrarian land loss, regulate urban growth, based on SDGs 11 and develop an infrastructural planning scheme that can sustain urban environments. Since urban remote sensing and urban economic-geography literature is not sufficient to assess urban growth in these regions, local economic data and 5m high-resolution remote-sensing data were used to map and integrate the socioeconomic variables that precipitated the urban dynamics in a region that experienced urban growth without industrialization.

PART I – Research Introduction

This section provides background knowledge on this dissertation topic and elaborates on the literature review of several scientific studies related to urban remote sensing, urbanization in Nigeria, urbanization in the Global South, and the impact of local economic growth in urban areas at a regional and global level. The methodological approach of the study and data types are briefly described. A short introduction to the study's aims and research questions has been provided.

PART II – Publications

This section comprises peer-reviewed scientific publications and the results constituting the aims of this dissertation. The authors' contributions to the four manuscripts of this thesis are highlighted.

PART III – Synthesis

This section offers an overview, discussion, and summary of the research findings, based on the aims and objectives of the research. Outlook patterning for future research is also discussed.

2. Introduction

2.1 Urban Structure and Settlement in Nigeria

The urban structure in Nigeria has been significantly influenced by rapid urbanization (Aduku et al., 2021) and has led to spatial growth and land-use changes that affect environmental sustainability (Chukwurah et al., 2022). Accelerated urban expansion, particularly in metropolitan cities in Nigeria, has resulted in increased built-up areas and decreased vegetation cover, thus necessitating the decentralization of urban planning and integration of green infrastructure (Chukwurah et al., 2022). However, urbanization in Ghana (a part of the Global South, like Nigeria) has shown that spatial planning is crucial for managing urban growth and achieving sustainable development (Anselm, 2019). The limitations of developmental control mechanisms in Nigeria are exposed when their efficiency is taken into consideration (Aduku et al., 2021; Aluko, 2011). Studies have shown that urban growth has overstretched critical infrastructure in cities such as Kaduna, Abuja, and Lagos, with development controls proving ineffective against unregulated growth (Qurix et al., 2020; Aduku et al., 2021). Moreover, the challenges that megacities such as Lagos face highlight the need for sustainable initiatives and innovative solutions in urban planning (Anselm, 2019). In Kano, management of urban growth has been largely contingent on sustainable urbanization; nonetheless, the city experiences obstacles that hinder growth management (Unah & Okopi, 2021). In other cities, such as Onitsha, rapid urbanization has outpaced the provision of urban amenities, revealing a correlation between poor population projection, inaccurate census data, and ineffective urban planning (Madu & Innocent, 2013). The urban structure in Nigeria is characterized by rapid urbanization, which has led to spatial expansion and environmental challenges (Aduku et al., 2021; Aluko, 2011). The need for sustainable city development is evident, with recommendations for infrastructural development in mid-sized cities and peri-urban areas, efficient use of renewable energy systems (Aduku et al., 2021), and improved urban planning practices to accommodate future population growth and the demand for urban services (Madu & Innocent, 2013). Addressing these issues is critical in shaping sustainable cities in Nigeria.

Urban settlements in Nigeria are characterized by different traditional patterns or unregulated built-up areas, disorderly housing units, and industrial and commercial zones with various new residential settlements as a result of economic growth and social events within its surroundings (Ota et al., 2022; Olayungbo, 2019; Emordi & Osiki, 2008; Braimoh & Onishi, 2007; Fourchard, 2003). This complex pattern of urban development is reflected in residential areas, creating a social distinction between residential settlements, based on family income (Ota et al, 2022; Avis, 2019; Dickson & Asua, 2016). These residential types are not evenly distributed across different urban areas, with diverse and complex patterns that are similar to those of informal settlements (Pereira & Xavier Junior, 2020). These settlement patterns appear to be the largest for low-income earners and are observed in core city areas (French et al., 2021). Various commercial activities surround these locations, contributing to congested urban growth (French et al. 2021; Pereira & Xavier Junior 2020). Nevertheless, because urban labor migrants are moving into neighborhoods in search of affordable housing, the foregoing has often resulted in land-cover loss, unplanned road development, and urban periphery development (Fox et al., 2015; Onu & Onu, 2012). Consequently, urban neighborhoods are now fragmented on the outskirts of cities (Onu & Onu, 2012; Farrell, 2018). Although urban peripheral settlements are famous for being socially and religiously diverse in terms of housing new urban migrants (Fox et al. 2015; Farrell, 2018), it has been observed to lead to cluster informal-settlement patterns (French et al., 2021) that are often found in major Nigerian cities (Onu & Onu, 2012., Essien & Jesse 2024). This settlement pattern accommodates different income earners from skilled to unskilled workers (Jelili et al., 2022). Informal urban settlements remain a vital part of urban areas throughout the country (Jelili et al., 2022) and contribute to the heterogeneous and complex urban growth in Nigeria (Ismail et al., 2024). However, their characteristics differ from city to city and are often linked to unstructured urban growth patterns (Jelili et al, 2022; Ismail et al, 2024). The complexity of urban structures has given rise to segregation and the creation of new areas such as middle- and higher-income neighborhoods (Rosenzweig & Wilson, 2023). As cities emerge, new sites are being renovated (Ismail et al., 2024). This development is mainly in middle-class areas because of availability of affordable housing that often leads to informal-settlement in these areas (Essien & Jesse, 2025., Ismail et al., 2024., Rosenzweig & Wilson, 2023), thereby provoking a high influx of migrant communities in this class (Ismail et al., 2024). However, studies affirm that much of Nigeria's emerging urban growth is derived largely from middle-class income earners (Ismail et al., 2024; Rosenzweig & Wilson, 2023). Owing to the strong desire for urban property ownership among middle-class citizens (Jelili et al., 2022), several real estate development projects, including large residential estates, satellite towns, and single-financed family homes, have been initiated in underdeveloped urban areas (Rosenzweig & Wilson, 2023). Numerous midsized and large cities are frequently observed to exhibit this growth pattern (Ismail et al., 2024; Jelili et al., 2022).

2.2 Migration and Urbanization in Nigeria

Migration and urbanization in Nigeria are closely intertwined phenomena, with migration contributing significantly to the rapid urban growth witnessed in Nigeria (Avis, 2019; Fox et al., 2015; UN DESA, 2014; Standard Bank, 2014). The movement of people from rural to urban areas, driven by various socioeconomic factors, has led to the expansion of cities and emergence of new urban centers (Green, 2018; Onibokun, 2019). However, this urbanization process has not been accompanied by commensurate economic development, social change, or technological advancement (Essien, 2023); hence, challenges in urban services and management structures follow (Onibokun, 2019; Unah & Okopi, 2021). Interestingly, while some Nigerian states such as Kano have become net importers of the population and have relatively stronger financial positions, others are experiencing net population outflows and financial difficulties (Green, 2018). The Harris-Todaro model, which suggests the promise of better employment opportunities in urban areas despite the risk of unemployment, may explain the persistent rural-urban migration and high urban unemployment (Chinecherem et al., 2015). Moreover, the lack of a national strategy for urban and regional development has aggravated disparities in development across different areas (Green, 2018). Migration has proven to be a major driver of urbanization in Nigeria, engendering significant demographic changes and simultaneously posing challenges to sustainable economic development (Chinecherem et al., 2015). Disparities in the development and financial strength of different states suggest a complex and uneven pattern of urban growth (Chinecherem et al., 2015; Green, 2018). To address these challenges, there is a need for evidence-based policymaking, comprehensive urbanization and migration policies, and focus on sustainable development plans that consider the diverse and youthful population of Nigeria (Adebayo, 2024; Onwuemele, 2018).

Furthermore, according to the UN (2014), rural-urban migration plays a fundamental role in urban population growth in Nigeria. However, it creates complex settlement patterns when it persists for an extended period (UN DESA, 2014). Nigeria has four types of migration: (i) rural-urban, (ii) rural-rural, (iii) urban-urban, and (iv) urban-rural (Oyeniyi 2013). In a 1993 survey carried out by the Migration and Urban Survey of Nigeria (MUSN), rural-urban migration accounted for 63 per cent of migrants in Nigeria, while 37 per cent accounted for rural-rural migration (Mberu, 2005). However, a similar study conducted by the World Bank in 2014 revealed that 83 per cent accounted for rural-urban migration, while 17 per accounted for rural-rural migration (UN DESA, 2018). This increase was not scientifically proven, but was attributed to economic growth and deplorable infrastructural facilities in rural areas. This agrees with previous studies that economic growth can easily influence rural-urban migration (Mberu, 2005). In contrast, urban-rural migration can easily trigger rural-urban migration in many African countries due to peer pressure (Mberu, 2005). Furthermore, recent survey data from the United Nations Department of Economic and Social Affairs UNDESA (2018) showed a projected increase in rural-urban migration (Figure 1) (UN DESA, 2018).

This migration growth pattern has been experienced in many cities in Nigeria, and has increased tremendously in recent years (Aliyu & Amadu, 2017). Many cities in the country have grown more than 2% per annum (UN DESA, 2018). Most of these growths are unplanned (Cities Alliance 2007). This unanticipated urban expansion has been credited to a complex socioeconomic increase in many cities (Aliyu & Amadu, 2017), and can lead to the loss of vegetative lands, such as when croplands are converted into residential areas (Montgomery, 2004). These increased economic activities have shifted development from the urban periphery to the urban edge (UN DESA, 2018; Aliyu & Amadu, 2017). This often the recategorization of urban and rural areas, redefines their boundaries, and brings about a complex change in urban growth patterns (Fox et al., 2015; Aliyu & Amadu, 2017).

Studies have shown that urban population growth in West Africa has significantly outpaced the development of urban infrastructure, leading to a variety of socio-economic and environmental challenges (Ngounou et al., 2023; Henderson & Kriticos, 2018). The rapid urbanization observed in the region has been driven by several factors, including migration from rural areas and natural population growth (Ngounou et al., 2023). This trend has resulted in severe pressures on the existing urban infrastructure, which often struggles to keep up with the growing demands for housing, sanitation, and transportation services (Ngounou et al., 2023). These growths in Nigeria are not limited to municipal jurisdictions; they frequently spill over into neighboring cities (Avis, 2019) because of the absence of proper monitoring of this unplanned growth (Fox et al., 2015; Cities Alliance, 2007; Avis, 2019). Cities in Nigeria are considered urban if they have more than 20 000 inhabitants, depending on their relative population (Ofem, 2012). This characteristic has triggered different urban growth patterns in built-up and non- built-up areas, and has also given rise to undefined types of settlements (Fox et al., 2015).

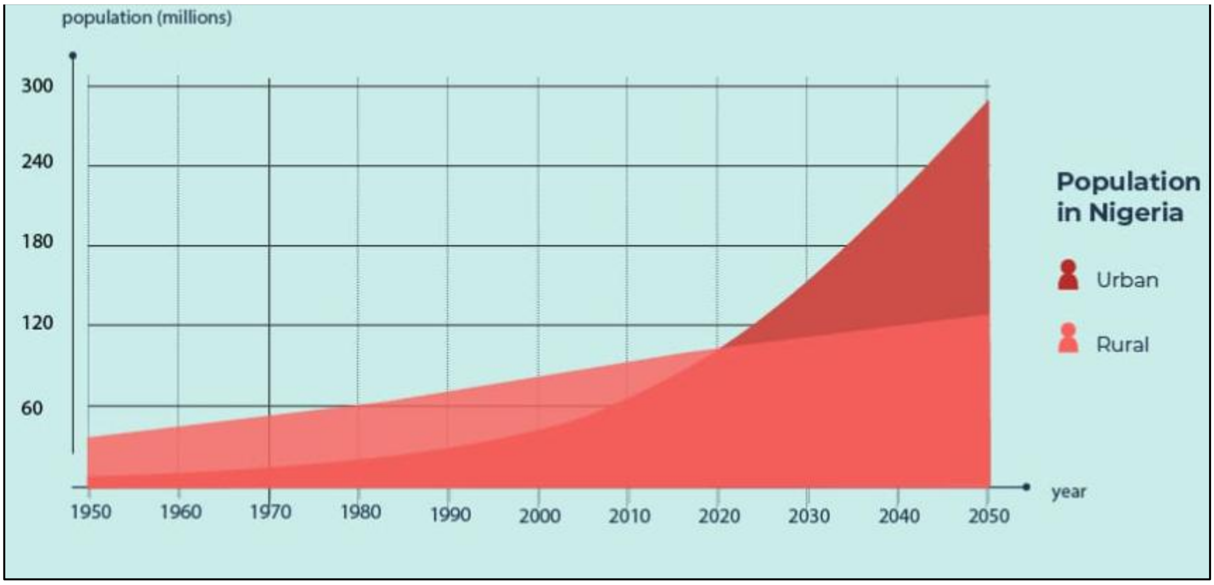

Figure1: Urban and Rural Populations in Nigeria. (Source: UNDESA, 2018)

2.3 Land Use and Urban Planning in Nigeria

Land use and regional planning in Nigeria were designed based on Federal Decree No. 88 of 1992 to regulate unplanned urban built-up areas, ease land allocation, and promote development, which has been enforced since 1978 (Aluko, 2011). However, in 2004, the Supreme Court ruled that urban and regional planning should not be regulated at the national level and that state and local governments should oversee land planning within their jurisdictions (Wapwera & Egbu, 2013). The legislation led to conflict between state and local governments regarding who should undertake urban planning, demolition, and the replanning of cities (Essien & Jesse, 2025., Essien, 2021). However, the conflict prompted the creation of state ministries that were vested with the authority to plan and regulate urban planning (Wapwera & Egbu, 2013; Essien & Samimi, 2021).

Many state governments allocate power to those ministries to implement planning laws by obtaining development permits from responsible authorities or agencies (Aluko, 2011). Failure to do so could result in the site being sealed or the structure being demolished (Aluko, 2011). Nevertheless, such action depends on the enforcement officer and the extent to which the development law has been breached (Aluko, 2011; Essien & Samimi, 2021). The municipal head does not unilaterally make this decision, but liaises with a committee of urban planners in the state since they lack the capacity to approve complex tasks that may incur significant losses to the detriment of the state government if not adequately checked (Aluko, 2011; Essien & Samimi, 2021).

This has made land use and urban planning in Nigeria complex, as they have been influenced by various factors such as population pressure, policy, and local practices (Onyebueke & Ikejiofor, 2017; Aluko, 2011). In many Nigerian cities, the peri-urban interface is undergoing transformation brought on by population pressure and encroachment on rural lands, with local communities such as the Nike people in Enugu capitalizing on dualistic customary and planning regimes to create community-mediated settlements (CMSs) (Onyebueke & Ikejiofor, 2017). However, despite disparate land law regimes, the Land Use Act of 1978 has made it possible for state governors to control urban lands, resulting in corruption and arbitrariness that hinder sustainable urban planning (Adisa, 2018). Contradictions emerge as urban planning and management responsibilities are fragmented and colonial, precipitating inefficiency and chaos in Nigerian cities (Okpala 1979., Onyebueke & Ikejiofor, 2017). Moreover, environmental hygiene issues such as poor sanitation and waste management have worsened the challenges in urban areas (Ene, 2014). Furthermore, land ownership constraints and the lack of long-term planning and governance have hampered inner-city redevelopment (Oloyede et al., 2005). These issues often change the course of development to suburban areas, transforming them into multi-purpose areas (Aluko, 2011). For example, the case study of Uyo reveals that urban plannners have diverted most of the city's development plans, such as the state-housing scheme for low-income earners, to suburban areas (Essien & Samimi, 2021; Essien, 2021). Additionally, urban planning in Nigeria faces significant challenges as a result of long-standing policy decisions, governance issues, and rapid urbanization (Adisa, 2018). The Land Use Act of 1978 had unintended consequences for urban land management, resulting in calls for its review (Adisa, 2020). The need for a centralized and effective urban planning and management system is necessary to address inefficiencies and support sustainable development. Studies have shown that improving environmental hygiene and addressing land ownership constraints are crucial to healthy living and urban growth (Oloyede et al. 2005; Okpala 1979; Ene 2014). Therefore, a multifaceted approach involving policy reform, governance improvements, and sustainable land management practices is required to address the complexities of land use and urban planning in Nigerian cities.

2.4 Urban Spatial Expansion in Nigeria

According to Essien (2021) and Cities Alliance (2007), urban spatial development in Nigeria is a multifaceted issue marked by rapid urbanization and related issues, such as environmental degradation, strain on infrastructure, and socio-economic repercussions. This phenomenon is driven by factors such as population dynamics, urban sprawl, and ineffective developmental control mechanisms (Qurix et al., 2020). For instance, in Benin City, unplanned spatial expansion has led to the proliferation of informal settlements and environmental challenges, necessitating sustainable planning to manage urban growth (Odeyale, 2023). There are cases of other cities experiencing the type of growth that leads to environmental and infrastructural stress (Tini & Light, 2020). However, spatial expansion in Nigerian cities is mainly centered on the periphery and urban edges (Avis, 2019; Farrell, 2018), further redefining the urban edge and expanding it into smaller towns (Avis, 2019). These complex urban development patterns are witnessed in most sub-Saharan Africa and are significantly different from urban sprawl (Fox et al., 2015; UNDESA, 2019; Angel, 2012). A greater percentage of Nigerian cities are characterized by diverse suburban expansion, such as industrial, residential, and commercial built-up areas that coexist with other settlements in urban areas, because most cities have failed to redesign their master plans to address this unregulated spatial expansion (Avis, 2019; Fox et al., 2015). In the context of Uyo, unplanned urban growth has created various built-up patterns in the urban areas (Essien & Samimi, 2019). This growth is notably high around the periphery and urban edge, owing to economic activities and the low cost of land in these undeveloped areas (Essien & Samimi, 2021). Urban expansion in Nigeria has transformed and redefined the boundaries of many mid-sized cities, which had hitherto been characterized by a small population, into densely populated metropolitan areas (UNDESA, 2019). This development outside their boundaries led to the formation of different satellite towns. For instance, Uyo, one of the study areas, extended its borders to merge with its nearby towns, Itu and Ibesikpo (Essien & Samimi, 2019). These urban growth patterns reflect broader global trends in urbanization with localized nuances (Angel, 2012; Essien, 2021). The need for sustainable development strategies is emphasized by the adverse effects of this growth on urban livability and the economy (Tini & Light, 2020). However, few studies have highlighted ways to address this imbalance, such as smart growth policies, growth management, and effective land use planning (Odeyale, 2023; Tini & Light, 2020; Zhu et al., 2009). These strategies aim to foster balanced development and mitigate the negative consequences of urban growth, thereby shedding more light on Nigeria's urban sustainability. This thesis was written based on this body of literature and contributes towards sustainable urbanization in Nigerian cities, as it integrates sustainable development goals 11 into the case study.

2.5 Urban Economics in Nigeria

Nigeria was ranked 162 out of 189 countries by the World Bank in 2018 as a country with a good business environment (UNDESA, 2019; Anselm, 2019). The criteria considered in this ranking were stable electricity, property registration, affordable public transportation systems, tax accountability, and export trade (UNDESA, 2019; Yapicioglu et al., 2017). Unfortunately, most cities in Nigeria are wanting in these areas (Anselm, 2019). This has hindered investment, undermined productivity, and frustrated competition in most cities (Yapicioglu et al., 2017). One of the biggest challenges of low productivity in urban areas is unstable power supply (Nzeadibe & Ochege, 2018). Studies show that most Nigerian firms experience frequent power cuts (Iarossi & Clarke, 2011), sometimes lasting up to eight hours per day, while others can stay a week without power as a result of the shift approach adopted by electricity companies to maintain energy sharing and manage high demands (Iarossi & Clarke, 2011). This has prompted big businesses operating in urban areas to generate power using other alternatives, while smaller businesses continue to struggle until they become extinct (Simon 1989., Iarossi & Clarke, 2011).

Transportation is a major issue in Nigerian urban cities. Road transportation is the primary means of conveying goods and services in cities (Iarossi & Clarke, 2011). However, most roads in Nigeria are small or narrow, congested, and poorly constructed (Iarossi & Clarke, 2011). This has resulted in a delay in the processing time used for importing and exporting goods into and from urban areas, depending on the road network of the city (Essien, 2021). Additionally, as Essien (2019) hints, this has led cities such as Uyo to invest in infrastructure development. These developments in infrastructure have increased the prices of landed property in cities (Essien & Samimi, 2021), despite the fact that the purchase of land in many Nigerian cities is diversely complicated, depending on location (Olorunfemi & Raheem, 2008). In some cities, the new owner is obligated to pay 3% of the land's value as stamp duty, 2% as land tax, and 3% as a land registration fee (UNDESA, 2019; Essien & Samimi, 2021). This long bureaucratic hurdle discourages formal land ownership in cities (Madu & Innocent, 2013).

In conclusion, the literature on urban economics in Nigeria highlights factors that influence economic growth, namely, rapid urbanization and population growth (which also have significant implications for urban infrastructure), environmental quality, and economic development (Madu & Innocent, 2013; Olorunfemi & Raheem, 2008). The economic landscape of Nigerian cities is further complicated by the prevalence of informal economic activities and mixed land use patterns (Simon, 1989; Olorunfemi & Raheem, 2008). Notwithstanding the potential for megacities to drive sustainable regional development, Nigerian cities face challenges in evolving sustainable structures, owing to unsustainable initiatives and a lack of innovative solutions in both planning and development (Anselm, 2019). This has also resulted in the increased use of outdoor sculptures in urban design, which has contributed to the socio-psychological development and aesthetic enhancement of cities (Oladugbagbe, 2016). The management of urban services, such as waste collection and recycling, remains largely informal and excluded from mainstream governance, thereby compounding the vulnerabilities of the people working in this sector (Nzeadibe & Ochege, 2018). These factors have complicated the urban economic situation in Nigeria and simultaneously shaped the informal economic dynamics (Yapicioglu et al., 2017). While there are opportunities for sustainable development and improved urban lifestyles, significant challenges continue to exist in terms of effective planning, development control, and the inclusion of informal sectors in urban governance.

2.6 Mid-sized Cities and Global Challenges

Medium-sized cities, also known as mid-sized cities, are urban areas that occupy an intermediate position between large metropolitan centers and small towns in terms of population and scale (Escudero Gómez et al., 2019; Felt et al., 2018; Jian & Zhengang, 2015). Although there is no universally accepted definition, these cities generally have populations ranging from 100,000 to 500,000 inhabitants (Escudero Gómez et al., 2019; Felt et al., 2018; Jian & Zhengang, 2015). They often serve as important links between rural and urban spaces, providing access to both local and metropolitan resources (Escudero Gómez et al., 2019; Jian & Zhengang, 2015). However, Mid-sized cities in Africa present a unique set of characteristics and challenges amid the rapid urbanization of the continents (Essien & Jesse, 2025). Mid-sized cities, such as Ho in Ghana and Kpalimé in Togo, exemplify the diverse urbanization processes in Africa (Sondou et al., 2024). These cities have witnessed urban sprawl that exceeds the rate of population growth, mainly due to factors such as a lack of housing policies, ineffective urban master plans, and land speculation (Sondou et al., 2024). Moreover, many African cities face rapid growth without corresponding industrialization, often referred to as "urbanization without industrialization" (Essien, 2023). This situation can cause cities to predominantly produce non-tradable goods due to high costs of urban infrastructure and other demands, limiting their potential to diversify into tradable production (Essien, 2023). Smart city initiatives in cities such as Nairobi, Johannesburg, and Casablanca aim to leverage technology to improve urban planning and management (Bandauko & Arku, 2022). However, these initiatives often grapple with socioeconomic inequalities, inadequate infrastructure, and governance challenges, sometimes exacerbating existing spatial exclusions (Bandauko & Arku, 2022; Ahmad et al., 2024). Additionally, the development of new master-planned cities is a growing trend in Africa (Robinson et al., 2024). This movement is supported by elite stakeholders and foreign investments, contributing to the continent's urban policy discourse (Côté-Roy & Moser, 2018; Moser et al., 2021). However, such projects often face criticism for promoting a limited range of urban visions that may not reflect the broader realities or needs of African cities. While African cities are rapidly expanding, the sustainable provision of ecosystem services remains a challenge, especially in sub-Saharan Africa (Parnell & Walawege, 2011; Robinson et al, 2024; Pieterse, 2019). Urban green infrastructure offers several benefits but faces numerous barriers, including sociocultural values and governance issues, which need to be addressed to ensure long-term sustainability (Du Toit et al., 2018). The transformation of African cities continues to be shaped by historical, socio-economic, and technological factors, with mid-sized cities playing a crucial role in the continent's urban future.

Though globally mid-sized cities face many urbanization challenges and suffer setbacks, they remain a focal point for various socioeconomic and infrastructural developments (Hong & Chen, 2014; Jian & Zhengang, 2015; Katarina & Agnieszka, 2020). Urban literature shows that these cities are beset by obstacles such as low functional strength, uncoordinated industries, and weak economic support, which necessitate a strategic approach to urbanization aimed at healthy development (Hong & Chen, 2014; Jun et al., 2024). Additionally, the role of mid-sized cities in regional development is highlighted along with their ability to transform subsistence agriculture into commercially viable ventures and integrate urban-rural economies (Shackleton et al., 2015; Jun et al., 2024). Disagreements emerge when considering huge infrastructural investments that have been shown to increase the attractiveness of mid-sized cities in terms of the provision of basic amenities (Henke et al., 2022), thereby potentially decentralizing infrastructure development activities from larger metropolitan areas (Lv Jian & Zhengang, 2015). However, the provision of essential public services is necessary for inclusive growth, as observed in industrial towns, where the delivery of these services has significantly influenced the perception of inclusive growth among inhabitants (Siddiqui et al., 2021). This attribute of mid-sized city development does not hold true in this thesis's study area, where city development mostly occurs when a political alliance is formed with the federal government (Essien & Jesse, 2025). Since independence, city growth has been influenced by infrastructure development, a factor that often urbanizes an area within a short period even without the adoption of a proper planning process (Essien & Jesse, 2025). This wrong approach usually results in the formation of different segregated urban communities, the absence of public infrastructure, and ultimately promotes nepotistic urbanism (Essien & Jesse, 2025). In conclusion, apart from mid-sized cities being pivotal to regional development, they also face unique challenges that require comprehensive urban planning, as well as sizeable investment in infrastructure and public services (Jun et al., 2024). The introduction of modern infrastructure can enhance their attractiveness in terms of business and tourism, while the effective delivery of public services is essential for the furtherance of inclusive growth (Henke et al., 2022; Siddiqui et al., 2021). These findings highlight the importance of targeted policies and investments as engines of sustainable development, which can help harness the potential of mid-sized cities.

2.7 Uyo: The Study Area

This thesis presents Umuahia, Aba, Warri and Uyo as a case study. However, this study sampled Uyo as a reference case study for other cities in Nigeria and other parts of the world because of its vast infrastructural development and urban transformation. Uyo possesses all the attributes of a mid-sized city, as previously mentioned, and is located in Akwa Ibom State in southeastern Nigeria (Figure 2). This central area experienced one of the most significant man-made changes in Nigeria between 1989 and 2010 (Akpan et al., 2016). To date, the boundary between urban areas and neighboring towns is difficult to establish, largely because of the dispersed urban growth pattern in the city (Akpan et al., 2016). Currently, there is a gradual change in land use due to unregulated residential areas that spring up in other land use classes, such as industrial, commercial, and vegetative (Essien & Akpan, 2013; Essien & Samimi, 2019). This unregulated urban land use dates back to 1989, when the city was named the capital of Akwa Ibom State (Akpan et al., 2016; Essien & Akpan, 2013). There has been a massive increase in the urban population between 1990 and 2010 (almost 30% per year) due to labor migration into the city (Essien & Samimi, 2019) and a minor decline in that increase between 2010 and 2017 (about 20%) due to unemployment occasioned by a massive influx of labor force from a neighboring state (Ojo & Ojewale, 2019; Essien & Samimi, 2019). Despite the employment decline in Uyo, 70% of the city will be urbanized by 2030 (Africapolis, 2015). However, uneven urban development in the central area is a major concern for urban planners in the city (Figure 3).

Uyo is considered one of Nigeria's tourist- and industrially driven cities; it boasts a brewery as well as tomatoes, toothpicks, ceramics, and coconut factories. It can be accessed via two major routes, namely, interstate roads (Calabar-Itu Road and Ikot Ekpene Road) and intercity roads (roads linking neighboring towns), because they are centrally located. State-owned transportation in Akwa Ibom has gone into extinction. In the city of Uyo, transportation is mainly provided by individuals who use their vehicles. This makes mobility wthin the city to be relatively expensive.

Uyo has different types of land use such as residential, commercial, urban reserves, ecological parks, playgrounds, and artificial and natural habitats (Essien, 2021). These areas are subject to different spatial planning, development, and drainage controls, which affect the strategic management of cities. This means that certain land use procedures must be followed before any property is erected. This is not surprising since such constraints are influenced by a set of policies and guidelines (Akpan et al., 2016; Essien & Akpan, 2013; Essien, 2021).

Taxes in Uyo include property, investment, payee, municipal, direct, and construction taxes (Essien & Samimi, 2021). Municipal, investment, and property taxes are charged based on usage type, market value, and location (Essien & Samimi, 2021). However, these fees are low because the government overlooks many environmental policies to encourage investors to move into the city (Essien & Samimi, 2021). The construction levy in Uyo, which has the highest tax increase, depends largely on the district (Essien & Samimi, 2021). Simultaneously, land taxes are charged at 3% of the land's initial price (Essien & Samimi, 2021). This discourages urban dwellers from selling land to curtail unregulated urban growth (Essien & Samimi, 2019; Essien & Samimi, 2021). The city council enforces land charges only when a development permit is applied. However, most people do not go for this permit because of an excessively bureaucratic system, weak policies, and non-implementation of the rule of law (Essien & Samimi, 2019; Essien & Samimi, 2021).

The high cost of transportation in Uyo is often blamed on municipal-ticket taxes on private vehicles, which constitute the major source of revenue in Uyo. This municipal transport ticket is sold based on the routes drivers ply (the more routes they ply, the more tickets they have to purchase). There were plans to reduce fares by introducing multiple public transport systems and a single ticket for transport operators in the urban areas. However, the proposed plans did not pass through legislation due to the absence of a sustainable planning system. Worse still, there is no plan of granting transport subsidies to students and the elderly in the city. This difficult challenge calls for proper planning and an integrated solution to the problems faced by commuters in the city.

Uyo faces Cross River State in the south and Abia State in the east (Figure 2). This case study focuses on five urban areas around the city: Uyo urban (central), three suburban areas (Offot, Etoi, and Oku), and an agricultural area (Ikono). The city of Uyo is boosted by several social amenities such as water fountains, urban parks, modern shopping complexes, polytechnics, and universities.

The population of the city was approximately 847 480 while the number of households was approximately 70 844 in 2015 (NBS, 2019). The estimated average number of people living in a household stands around three to five persons per household (NPC, 2015). Three household types, according to income groups, were identified in the urban areas: households that earn the lowest incomes account for 60% of the urban population; households that earn average incomes amount to 30% of the urban population; and households that earn the highest incomes represent 10% of the urban population (NPC, 2015).

The city attracts people from different ethnic groups with varying socioeconomic backgrounds. As the capital of Akwa Ibom State, successive administrations channel substantial financial resources towards modernizing the city. Consequently, Uyo is one of the few cities in Nigeria that have experienced continuous urban growth in recent years (Akpan et al., 2016; Essien & Samimi, 2019). Urban growth in the city is relatively high compared to what obtains in its neighboring cities. For instance, Uyo offers more excellent job opportunities and better, easier access to basic social amenities. However, one of the biggest problems in the city is the socio-spatial segregation of communities from other backgrounds. Inadequate interactions among different urban dwellers across the city create challenges and hinder employment and education opportunities (Essien, 2021). Additionally, poor governance and planning processes have contributed to increased social and economic inequality among residents (Israel, 2018; Essien, 2021). In conclusion, most of these studies agree on the effect of urban growth in Uyo (Akpan et al., 2016; Essien & Akpan, 2013), but none have provided a quantitative analysis of the urban growth pattern using 5m resolution satellite data with socioeconomic variables. This knowledge gap distinguishes this study from the existing literature.

Figure: 2 Map of Nigeria Showing Akwa Ibom and Map of Akwa Ibom Showing Uyo.

Figure: 3 Urban Growth Patterns in Uyo

2.8 Literature Review and Research Gaps

There is linear discussion in urban literature which reveals that economic development and urban growth are typically interconnected (Seto & Kaufmann, 2003; Henderson, 2010; Ivan and Gordon, 2013; Mahendra & Seto, 2019; Mendonça et al., 2020; Sapena et al., 2020). The United Nations has reported that the urbanization process typically entails economic growth and social transformation, resulting in urban migration, poverty reduction and alterations in life expectancy (United Nations, 2019). Urban life is often characterized by the presence of social amenities, improved access to education and healthcare, well-developed road networks, and greater job opportunities (United Nations, 2019). Another research has, moreover, revealed a positive relationship between urban growth rate and GDP per capital (Ivan & Gordon, 2013; Mahendra & Seto, 2019). Research on economic geography has asserted the existence of a positive relationship between economic and urban growth (Mahendra & Seto, 2019; Mendonça et al., 2020). Although these studies have focused on cities in the western world, where rapid urbanization has not led to an improvement in the standard of living (Collier & Venables 2017, Henderson & Turner, 2020), it is important to note that their findings may not be applicable to all urban areas. According to Glaeser (2014), the root cause of this issue lies in the adverse consequences of diseconomies of scale in large urban centers in the Global South. Other studies, such as those conducted by Jedwab & Vollrath (2015), focus mainly on the detrimental impact of low economic growth in urban regions characterized by urbanization without industrialization. This is evident in countries that rely heavily on the export of natural resources, as their urban economies are geared towards consumption rather than production (Gollin et al., 2016). As stated by the World Bank (2015), cities must offer generative urbanization, which entails creating an environment that fosters resilient, productive, and inclusive economies. The current study area and other cities in Africa are notably devoid of this form of urbanization. Evidently, from the foregoing discussion, the notion that urbanization is devoid of industrialization does not hold true in Nigeria. Instead, the opposite applies in the context of Nigerian urbanization. Economic growth has recently witnessed a surge in urban migration to several cities across Nigeria. This trend is particularly noticeable given that the urban growth rate and the proportion of the urban population in the country significantly outpace those of other African nations. Considering the complexity and nuance of urbanization in Nigeria, it is unsurprising that most studies do not examine it in isolation from industrialization. Another limitation is that studies tend to concentrate on the operations of large cities rather than delving into the intricacies of urban development processes.

2.9 Global Urban Growth Integration with Remote-sensing Data

Urbanization is often characterized by the growth of urban populations, as reflected in the demographic data (Mundia & Murayama, 2010; Schaffar & Dimou, 2012). This growth can be attributed to both natural increases and migration from rural to urban areas (Schaffar & Dimou, 2012; Kontgis et al., 2014). Similarly, a study of peri-urbanization in East Asia underlines the significant demographic shifts expected in the near future, with substantial population increases in these areas due to urban expansion (Kontgis et al., 2014). Disagreements and interesting facts emerge when considering the factors that contribute to urban population growth. A study in the Athenian metropolitan region showing that natural balance significantly contributes to population growth during certain stages of a city's life cycle, while migration balance is more influential during other stages serves as a case in point (Salvati, 2020). In Henan Province, the rate of urban land expansion has outpaced population growth, suggesting that factors beyond demographic change influence urbanization (Xiuyan, 2018). Moreover, studies in Montreal (Ma et al., 2016; Ma et al., 2016) and in the Shandong provinces (Wang et al., 2023) indicate that economic development is a driving force behind urban expansion; and this is supported by the analysis of urban land changes in Yangon (Estoque, 2017) and Tehran (Haji Mirza Aghasi & Estoque, 2017). These results show that, while urban population growth is a key indicator of urbanization, the process is multifaceted and influenced by a variety of factors, including economic development, land-use policies, and demographic changes. The reviewed studies provide a meticulous understanding of urbanization, showing that it is not solely a demographic phenomenon but also a spatial and economic one. The interplay between these factors shapes the patterns and impacts of urbanization across different regions and stages of development.

Urban remote sensing refers to the use of satellite technologies to collect and analyze data to understand, monitor, and manage urban environments (Yang et al., 2019; Nguyen et al., 2018; Masek et al., 2000; Zha et al., 2003; Yuan et al., 2000). These technologies include various types of sensors mounted on satellites or aircraft to capture images and measurements of cities and their surroundings (Xiao & Zhan, 2009; Lehner & Blaschke, 2021). Remote sensing applications in urban areas are diverse, ranging from land use and land cover (LULC) change detection, urban sprawl measurement, environmental monitoring, and urban planning and governance. As exemplified by Rosni et al. (2018), remote sensing has been instrumental in characterizing urban sprawl in Kuala Lumpur, revealing leapfrog patterns of development. Comparably, the integration of remote sensing and GIS has been used to monitor LULC changes in Amman City, their results provide valuable data for sustainable development and urban planning (Nour et al., 2022). Moreover, remote sensing techniques, such as monitoring urban heat levels, islands, air, water, and soil pollution, have been employed to assess urban environmental quality (Weng & Quattrochi, 2006; Zhou, 2023). These studies have shown that urban remote sensing is an important tool for managing the complexities of urban environments. It offers a synoptic view and timely data that are essential for informed decision making in urban planning and sustainability efforts. The integration of remote sensing with GIS and other spatial analysis tools enhances the ability to monitor urban dynamics and address challenges, such as urban sprawl and environmental degradation (Krishnaveni & Anilkumar, 2020; Pham et al., 2011). As urban areas continue to grow and evolve, the role of remote sensing in urban management and planning is likely to become increasingly important.

The integration of remote sensing with socioeconomic data has paved the way for enormous amounts of urban spatial data, leading to extensive detailed mapping of urban built-up area extraction linked with social science (Zha et al., 2003; Shi et al., 2014; Zhou et al., 2014), land-cover change analysis with socioeconomic data (Li et al., 2017; Chen et al., 2015), urban land expansion detection with economic data (Angel et al., 2011; D´Amour et al., 2017), urban landscape structure detection (Yu et al., 2009; Taubenbock et al., 2014), and land-use mapping (Odenyo et al., 1977; Li et al., 2017). Research on urban land cover mapping combined with socioeconomic data is underrepresented in Nigeria and Africa. Nevertheless, there have been an integration of urban spatial data with socioeconomic variables to explore urban growth in African cities (Turok & McGranahan, 2013; Mboup, 2019; Zimmer et al., 2020). These studies have focused on large cities because of their massive congestion, high population growth, and socioeconomic disparities (Turok & McGranahan, 2013; Mboup, 2019). This indicates that a quantitative approach is needed to assess socioeconomic urban growth in mid-sized cities. A standard method that integrates local economic data with satellite data could provide better insight into rapid urban population growth in mid-sized cities across Africa. Several scientific methodologies that foster the use of national data and discourage the inclusion of local economic data and information from community dwellers, particularly suburban dwellers, exist in urban studies, both globally and in Africa (Güneralp et al., 2017; Avis, 2019; Farrell, 2018; Montgomery, 2008). However, this method uses national data to predict urban population growth in different regions, whereas various factors influence urban population growth in Africa (Güneralp et al., 2017). This calls for research that focuses on the local economy and community stakeholders from different professional backgrounds to provide comprehensive information on urban growth patterns in this region.

The development of a time-series approach linked with regression analysis, as applied by Wu et al. (2012; 2013) and Merschdorf (2020), shows a research method that could address this knowledge gap in Nigeria. It also represents a research approach that indicates the period in which initial changes occurred (Merschdorf, 2020). Linking these data with interview responses from community stakeholders and public respondents could provide insightful research results that could, in turn, aid in the proper planning of cities facing similar economic problems globally. This method can also incorporate local economic data with interview responses from people in different professions. However, it has been applied only at the regional level, with a particular focus on Asian, European, and American cities (Wu et al., 2013; Wu et al. 2012; Merschdorf, 2020). By outlining urban growth patterns, such as the period of development, reasons for the urban shift, and repercussions, these methodologies could offer pertinent information on built-up patterns and paradigm shifts in urban growth from one community to another. This promising methodological approach for tracking changes in urban growth, as a means of evaluating the impact of the local economy on urban growth, can be properly managed using SDGs 11 as a guide during urban growth decision-making.

2.10 Urban Studies Linked with Socioeconomic Data in African Cities

Urban growth in African cities is intricately linked with socioeconomic data (Mundia & Murayama, 2010; Kamana et al., 2023). Rapid urbanization often outpaces the capacity of cities to provide adequate services, leading to sprawl, as well as environmental and social consequences (Mundia & Murayama, 2010). Socioeconomic realities, alongside technological and environmental challenges, influence urban dynamics, and hence warrant coherent planning policies to guide sustainable urban development (Kamana et al., 2023). The historical and current patterns of real estate investment and property development, as influenced by political elites, have resulted in skewed wealth distribution and access to resources, thus aggravating urban challenges, such as unemployment and poverty (Madell & Karam, 2022). Furthermore, socioeconomic nuances like informal settlements, unresolved apartheid legacies in South Africa, and migration complexities impeding sustainable urban development in Africa, highlight the need for alternative development models that address these human-related challenges (Kajiita & Kang'ethe, 2024). The relationship between urbanization and development is not linear, and the benefits of urban growth are contingent on supportive infrastructure and institutional settings (Turok & McGranahan, 2013). The context of urbanization in Africa shows a significant transformation in urban planning and post-independence infrastructure, influenced by colonial legacies (Mboup, 2019). Urban literature emphasizes the complex interplay between urban growth and socioeconomic factors in African cities (Kajiita & Kang'ethe, 2024; Mboup, 2019). Sustainable urban development requires addressing socioeconomic challenges through inclusive planning, policy reforms, and investments in infrastructure and technology (Turok & McGranahan, 2013). The political context of urban growth further shapes the socioeconomic landscape of African cities, demanding tailored approaches to urban planning and development (Madell & Karam, 2022; Mboup, 2019). This study is built on these existing studies and aims to contribute and not contradict the complex socioeconomic urban formation in Africa.

2.11 Sustainable Urban Growth Linked with Socioeconomic Data

Cities worldwide face countless drawbacks that are likely to thwart their planned growth and development (Brelsford et al., 2017; Sampson, 2017). Despite the numerous planning policies made by decision-makers, the adverse effects of economic growth continue to alter the structure of cities but ironically create the provision of inclusive goods and services (UN-Habitat 2012). With proper planning and management, cities can be transformed into innovative centers that drive sustainable development (UN-Habitat, 2012; Brelsford et al., 2017; Sampson, 2017). This development typically seeks to achieve two goals: meeting the needs of present and future generations without compromising the environment (Seto et al., 2017; UN-Habitat, 2012), and inculcating the belief in human equality that allows people, regardless of their backgrounds, to thrive (UN-Habitat, 2012). Meanwhile, future cities should be planned such that they provide opportunities for everyone and access to basic amenities such as affordable housing, subsidized power supply, and a good transport system (UN-Habitat, 2012). However, owing to rapid urbanization and socioeconomic development, the growth of cities worldwide has become a significant challenge for global sustainability (Montgomery, 2008; UN-Habitat, 2012; Brelsford et al., 2017). Thus, to some degree, economic growth has improved living conditions and increased consumption of energy and natural resources. However, studies at the global level have only partially comprehended the effects of shared natural resources on city development (Montgomery, 2008; UN-Habitat, 2012; Solecki et al., 2013; Kennedy, 2011). In recent years, many studies have focused on the geophysical and environmental consequences of the increasing population of people living in cities (Güneralp et al., 2017; Güneralp et al., 2020; Montgomery, 2008), land-cover changes (Güneralp et al., 2020; Zha et al., 2003; Shi et al., 2014; Zhou et al., 2014), water pollution (Mundia & Aniya, 2006), loss of natural habitats (UNDESA, 2019; Seto et al., 2017; UN-Habitat, 2012; UN-Habitat, 2003), high energy demand, and increased greenhouse gas (GHG) emissions (UNDESA, 2019). It should be noted that the impact of these effects varies across cities. In addition, there is a positive correlation between urbanization and other human development, such as the relationship between urbanization and economic production (UN-Habitat, 2012), and urbanization aiding in the provision of quality education, improved healthcare, and access to basic amenities (UN-Habitat, 2012; Lozano-Gracia et al., 2013). Irrespective of the positive or negative results of urban growth, there is still a lack of empirical and systematic knowledge on sustainable development in Africa. Most studies measure urban spatial extent and focus mainly on similar socioeconomic variables, such as the definition of differences and population data collection, which are known to have a few limitations (Yang et al., 2019). Globally, urban growth linked to socioeconomic data has a linear debate in urban and economic literature based primarily on rural-urban migration patterns (Clergeau et al., 1998), with a simple linear gradient model revolving around land-use intensity, disturbance gradients, and the polycentric nature of innovative cities (McDonnell et al., 1997). However, such studies have typically focused on patches of vegetation loss within urban areas (Dana et al., 2002) rather than on the range of factors that influence urban land-use change, which are mainly characterized as infrastructural development. In addition, studies have identified the need to quantify the availability of shared natural resources and factors that consolidate urban land use and socioeconomic growth (Liu, 2001; Hope et al., 2003) because these may help facilitate human interaction with the environment and influence changes in the urban ecosystem (Dow, 2000; Naveh, 2000; Savard et al., 2000). Accordingly, many studies have coalesced spatial and socioeconomic data to broadly assess urban growth in some cities (Chen et al., 2017; Yang et al., 2019; Zhang & Seto, 2011). However, some limitations resulting from the unavailability of continuous large-scale spatial information and local economic data for spatial distribution analysis in urban areas still exist. To remedy this inadequacy, this thesis closely considers local economic growth in urban areas, shared natural resources (crude oil), and their positive and negative effects on the city's development and growth patterns.

2.12 Research Objectives and Research Questions

The complex urban growth patterns in most developing countries are attributable to unplanned urban growth (UNDESA, 2019; Ojo & Ojewale, 2019). This process has transformed many built-up areas into patterns that require proper monitoring (Essien & Samimi, 2019). Worldwide, remote sensing has shown significant advancements in urban and time-series mapping of heterogeneous areas worldwide (Zha et al., 2003; Shi et al., 2014; Zhou et al., 2014; Li et al., 2017; Chen et al., 2015). Several studies have used remote sensing observations to map urban areas in the study area; however, urban land use land cover was classified into three classes (built-up, commercial, and vegetation) to quantify urban areas, but without using reference data to validate their models (Nse et al., 2020; Akpan-Ebe et al., 2016; Essien & Akpan, 2013; Akpan et al., 2016). Moreover, none of them used 5m high-resolution data to provide better accuracy for the urban land-cover classification map. Hence, this thesis fills this scientific knowledge gap by using 5m high-resolution datasets linked with multiple data sources to analyze urban growth in cities across Nigeria. This will provide a better understanding of urban growth in this region, as well as furnish urban scientists and people in related fields with comprehensive information on the urban growth patterns of cities in sub-Saharan Africa.

Nevertheless, information from previous studies on changes in urban structures is vital for the development and modification of a model that provides details about spatiotemporal changes in urban and suburban areas. In the case of the study areas, this thesis (i) aims to provide further insight into changes that occurred within given periods; (ii) statistically analyses shared natural resource revenue and local economic growth to provide an improved understanding of the dynamics of urban transformation in Nigerian cities; (iii) uses UN Sustainable Development Goals (SDGs) 11 as a reference for creating and managing urban infrastructure; and (iv) applies local economic data viewpoints to shed light on urbanization in Africa and the developed world. This study adopts and applies different urban theories to provide new insights into urbanization in mid-sized cities in Nigeria. Globally, this study provides a better understanding of the influence of shared natural resource revenues in cities. Furthermore, it builds on various collections of literature on remote sensing and urban economy, which highlights urbanization in Africa. This thesis aims:

- **(i)** To quantify land-cover classes and use their spatiotemporal changes to detect phases of urban growth and highlight the driving factors behind this growth (**Manuscript 1**).
- **(ii)** To evaluate how the city's administrative taxes, living standards, and household income affect urban growth patterns in Uyo (**Manuscript 2**).

- **(iii)** To analyze the influence of urban governance on sustainable urbanization in mid-sized cities, such as Uyo, using SDGs 11 as a guideline for sustainable growth management (**Manuscript 3**).
- **(iv)** Assess the effect of shared natural resource revenue on local urban economies across cities in Nigeria (**Manuscript 4**).

The following research questions were used to address the proposed research aims. These questions have been addressed in the respective manuscript. Two research questions were used to answer the first two. The questions focused on the capability of remote-sensing data to map the heterogeneous landscape of the study areas and examined shared natural-resource urbanization that bears a semblance of the local economic boom, based on the results. Further research questions were formulated to achieve the remaining research objectives. Fieldwork observations and responses received from respondents were integrated and analyzed in various manuscripts. The questions were as follows.

- **(i)** Is a multi-temporal dataset capable of integrating a local economic dataset to quantify the phases of urban growth in Nigeria's heterogeneous landscapes? (**Manuscript 1 & 2**)
- **(ii)** How do administrative taxes and household income influence patterns of urban growth? (**Manuscript 2**)
- **(iii)** How do governance practices affect urban growth, economic growth, housing security, infrastructure, and urban development in Uyo? (**Manuscript 3**)
- **(iv)** Can SDGs 11 be adopted in Nigerian cities? (**Manuscript 3**)
- **(v)** Does natural resource revenue influence the local economic growth in Nigerian cities? **(Manuscript 4)**
- **(vi)** Can the back-and-forth migration of people in search of white-collar jobs that are difficult to find be linked to urban growth? (**Manuscript 4**)
- **(vii)** What measures are required to address infrastructure-driven urban growth? (**Manuscripts 1, 2, 3 & 4**)

3. Materials and Methods

This section presents the field survey data and methods used in our analysis. Comprehensive details are provided in **Section II** of the manuscript. Locally collected reference data formed the basis of this study. Remote-sensing data with machine learning techniques and statistical methods were used to realize the aims and objectives of this thesis. Physical observations and visits to different sites were conducted to monitor the urban growth scenarios. Government records and statistical data were accessed to evaluate completed and incomplete government projects in urban areas. Finally, interviews conducted with key stakeholders in different government ministries and members of the public provided credible information regarding the government's strategies for stimulating sustained urban development in the city.

3.1 Satellite Data

Satellite data, as evidenced by the diverse applications discussed in the literature, are a critical asset for Earth Observation (EO) and have been instrumental in advancing research in various fields (Figure 4) (Wei Chen, 2018; Feng et al., 2018; Wei Chen, 2018; Taubenbock et al., 2014; Mucina, 2010). The use of Remote-sensing Data is well established, with a standard archival method of the widely adopted "meta-data + file" approach (Wang et al., 2010; Wei Chen, 2018; Myint et al., 2011; Nguyen et al., 2018; Wu et al., 2013). Moreover, the development of cloud computing infrastructure has facilitated environmental monitoring by enabling on-demand EO data discovery, access, and processing, which are time-consuming tasks for Global Change Research (GCR) scientists (Yu et al., 2016; Mucina, 2010; Boori et al., 2015). Furthermore, the literature also introduces innovative concepts such as *Volunteered Passenger Aircraft Remote Sensing* (VPARS) which complements traditional satellite remote sensing by offering advantages like low cost and high revisit frequency (Wang et al., 2020; Wei Chen, 2018). Additionally, the potential of *Chinese Earth Observation Satellites (CEOSs)* for vegetation monitoring has been explored, highlighting the importance of diversifying data sources to enhance research opportunities (Zhang et al., 2022). The integration of artificial intelligence, including neural networks and deep learning, is also transforming the processing of satellite data for EO, thereby offering new research avenues and improving data analyses (Rosso et al., 2021). Satellite data are indispensable to EO as they provide well-established methods for imaging data and emerging systems for non-imaging data (Wang et al., 2010). Cloud computing and artificial intelligence can enhance data processing capabilities (Rosso et al., 2021; Yu et al., 2016), whereas novel approaches such as VPARS and the use of CEOSs data are expanding the scope of satellite remote sensing applications (Wang et al., 2020; Zhang et al., 2022). The remote sensing literature collectively underrepresents the dynamic evolution of satellite data usage in Africa (Feng et al., 2017; Feng et al., 2018). Remote-sensing techniques can aid in the production of urban land-use maps in heterogeneous areas (Wei Chen, 2018; Myint et al., 2011); however, urban land-use mapping that utilizes remote sensing tools remains a challenging problem in Africa (Xiong et al., 2017; Feng et al., 2018; Yin et al., 2020; Myint et al., 2011; Nguyen et al., 2018). The availability of satellite data with multitemporal resolution in these areas has paved the way for in-depth research in this region.

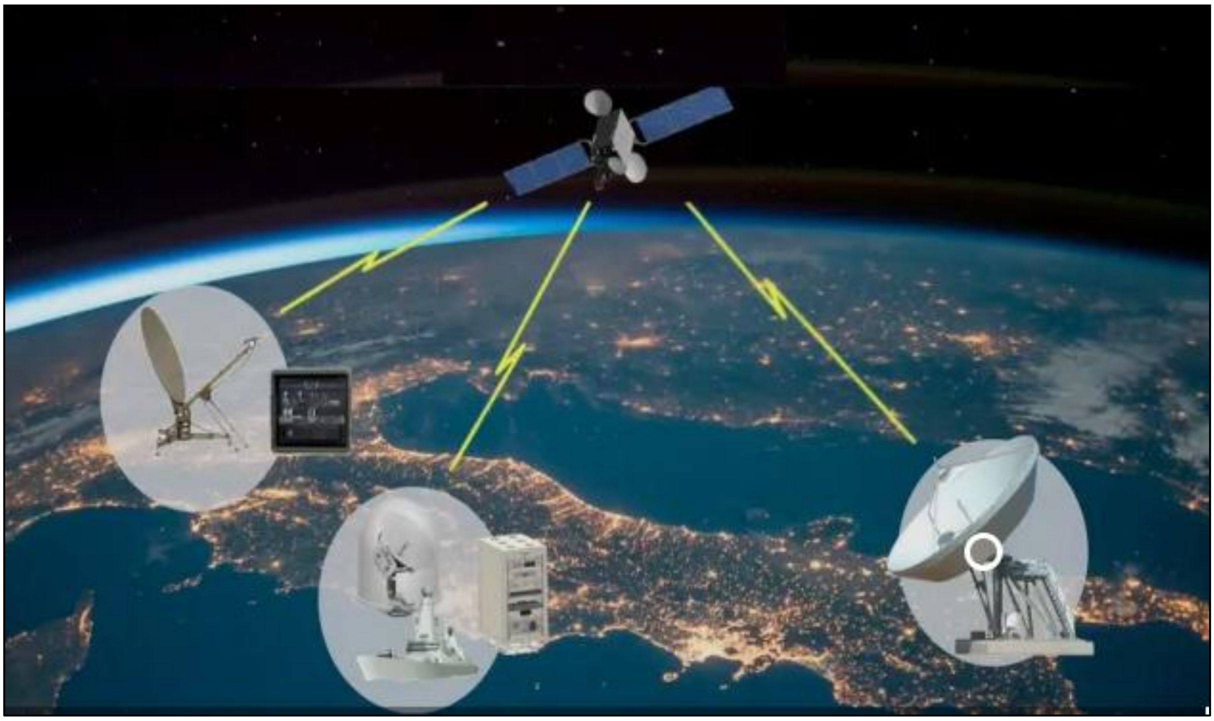

Figure: 4 signal communication of satellite (Source: Myint et al., 2011)

3.2 RapidEye Data

The RapidEye satellite constellation provides high-resolution multispectral imagery that has been effectively used for agricultural land cover and land use mapping (Sang et al., 2015; Tewes et al., 2015). The inclusion of a wide red-edge band in the RapidEye sensor enhances vegetation monitoring and improves classification accuracy (Sang et al., 2014; 2015). The object-oriented tree classifier, introduced in some studies, utilizes spectral bands, vegetation indices, and structural and texture features from RapidEye imagery, which leads to significant improvements in mapping precision and accuracy (Sang et al., 2015). RapidEye comprises a constellation of five satellite sensors. It was launched in 2008 and was deactivated in December 2019 (Planet Team, 2017). The RapidEye constellation does not have recent images, except archived ones (Coffer et al. 2020). The planet team plans to launch high-resolution images, similar to RapidEye, on their platforms (Coffer et al., 2020). The Planet RapidEye Satellite comprising multispectral data with 6.5m GSD nadir, and an all-level 1b data for the RapidEye 2 satellite were obtained from *https://www. planet.com/explorer* on 11 November 2010 (Planet Labs Inc., 2019). RapidEye ortho tiles have a 5m resolution and five identical satellites positioned in a single orbit (Tewes et al., 2015). The sensor can detect changes in urban areas. The satellite has five multispectral bands (blue, red, green, red edge, and near-infrared (NIR) (Tewes et al., 2015). These were geometrically and radiometrically corrected. Thus, sensor-related effects were corrected using sensor telemetry and a sensor model (Planet Team, 2017). Spacecraft-related and co-registered effects were corrected using high telemetry and ephemeris data (Planet Team, 2017).

3.3 Landsat Data

The Landsat program has contributed to the provision of continuous Earth observation data, which has been crucial for land-cover mapping and large-scale monitoring for more than three decades (Guo et al., 2022; He et al., 2018; Chen et al., 2017; Yang et al., 2019; Zhang & Seto, 2011; Wulder et al., 2007; USGS, 2021). Despite the unique and indispensable nature of Landsat data, there are concerns regarding potential gaps in data continuity due to technical issues with existing satellites and delays in launching new ones (Wulder et al., 2007)., Chen et al., 2017). However, while the Landsat program faces these challenges, advancements in high-performance computing and cloud platforms, such as Google Earth Engine, have enabled the processing of large volumes of high-resolution satellite data, thereby facilitating continental-scale land-cover mapping (Andrade-Pacheco et al., 2017). The utility of Landsat data extends to various applications including change-detection analysis in hydrologically sensitive areas (Aquilino et al., 2014), urban land-cover-transformation assessment using NDVI (Tran et al., 2019), and vegetation-type classification combined with Sentinel-2A data for change analysis (Rohith et al., 2023). Moreover, Landsat imagery, complemented by indigenous knowledge, has been used to assess land cover changes in regions with limited in situ data (Zacharia, 2013) and for local area land use and land cover classification (Nischitha, 2019). The data also support the spatiotemporal analysis of urban structure (Zoran et al., 2009) and the development of efficient land-cover monitoring methods using time series of satellite images (Jung & Lee, 2019). Finally, the integration of land cover knowledge databases into satellite mission programming systems exemplifies the evolution of intelligent observational capabilities (Wang et al., 2014). Landsat data remain a cornerstone for monitoring and mapping land cover changes globally, despite the risk of data continuity gaps (Wulder et al., 2007). The integration of these data with modern computational methods and other satellite imagery has expanded its applications and improved the efficiency of land cover monitoring (Chander et al., 2004; Chander & Markham, 2003). The continued use and development of methods leveraging Landsat data are essential for informed land management and policy decision-making (Kim et al., 2013; Roy et al., 2014; Chander et al., 2009; Markham et al., 2014)

3.4 Reference Data Collection

Lestari & Setiawan (2017), Khudur & Polos (2021), and Mohneu (1995) are of the opinion that data collection is a critical component of research across various domains, from educational studies to information systems and programming languages. Khudur and Polos (2021) believe that this involves systematic approaches for gathering, monitoring, and analyzing information pertinent to the research questions. However, Lestari and Setiawan (2017) argued that the methodologies and instruments used for data collection can vary significantly and could lead to inconsistencies, particularly in fields such as educational research. Moreover, according to Kara et al. (2021), the context of data collection can influence the choice of methods, whether through creative approaches in educational settings or technical means such as compile-time garbage collection in programming, as suggested by Mohneu (1995). Furthermore, while some studies have focused on the development of new frameworks and algorithms to enhance data collection processes in container-based (Khudur & Polos, 2021) and large-scale information systems (Zhou et al., 2016), others have explored the application of technology in scholarly research such as online surveys and email interviews (Singh & Burgess, 2007). Additionally, real-time data-gathering designs are important in fields such as remote sensing, where the efficiency and reliability of data transfer are of paramount importance (Zhou et al., 2016). The diversity in data collection methods is further exemplified by the interprocedural analysis in *Fortran D Programs* (Hall et al., 1996) and interactive interview systems for workflow data acquisition (Ley, 2011). Reference data collection encompasses a broad spectrum of methodologies adapted to the specific needs of the research domain (Zhou et al., 2016). Whether through surveys, interviews, technical algorithms, or programming-language analysis, the goal is to gather accurate and relevant data to inform research outcomes (Zhou et al., 2016). The choice of method is determined by the research context, nature of the data, and desired outcomes, highlighting the importance of selecting appropriate data-collection strategies (Kara et al., 2021; Lestari & Setiawan, 2017).

In this study, 500 reference data points (GPS points, accuracy: ±2m) on urban land use and land cover were generated between May and June 2018 and May-June 2019 during field trips in Uyo. The fieldwork began with a Google Earth reference picture that showed some difficult urban land-use classes that were not sufficiently visible for visual separation. All uneven urban land use cover areas were visited during the trip. GPS points were centered around these points and their surroundings using major and minor roads to access all land-use classes. The main aim was to group different urban land use classes accordingly. GPS ground-truth data were obtained for every new urban land-use class in every new area, at short driving and walking distances. These data were collected as quickly as we had a good GPS signal. It was difficult to cover the entire study area because of the lack of good road networks and security challenges in those areas. However, the GPS point data collected were sufficient to cover all urban land-use classes in the study area.

3.5 Land-Use Classes

Studies have presented various methodologies for classifying land use (LU) and land cover (LC) classes using remote sensing data (Reddy et al., 2015). Hiwot and Maryo (2015) demonstrated the use of satellite imagery and DEM/SRTM data to classify LU/LC classes and slope categories, and found a significant presence of agroforestry systems in steep slope areas. O'Hara et al. (2003) employed multitemporal Landsat images to enhance LU/LC classification in urbanized areas and achieved high accuracy through thematic change logic. Tateishi and Mukouyama (1987) contrasted SPOT multispectral data with numerical land-use data, suggesting a focus on land cover classification rather than land use classification. Manibhushan et al. (2013) advocate fuzzy logic as a superior method of classifying satellite images over the standard maximum likelihood method, particularly in distinguishing pervious and impervious categories. Reddy et al. (2015) uses a hybrid-classification approach to categorize forest types in India, while Zhang et al. (2010) compare supervised- and decision-tree methods, favouring the latter for its effectiveness in distinguishing similar reflective luminance classes. Hill et al. (1998) describe a method for pasture land-cover classification using NOAA-AVHRR NDVI data, despite some inaccuracies in distinguishing between pasture types. Saatchi and Rignot (1997) classified SAR data into dominant forest types with high accuracy. Although some studies have highlighted the effectiveness of specific classification methods, such as the decision tree method by Zhang et al. (2010) and fuzzy logic by Manibhushan et al. (2013), others point out the inability of certain data types to classify land use accurately, as seen in Tateishi and Mukouyama's (1987) suggestion to focus on land-cover categories. Additionally, the use of multitemporal and multispectral data is a common theme across several studies, indicating their importance in capturing the dynamic nature of land use and cover (O'Hara et al., 2003; Reddy et al., 2015). Land use classification is a complex task that can be approached using various remote-sensing techniques and data types (Zhang et al., 2010). These studies collectively emphasize the importance of selecting appropriate classification methods and the potential for high accuracy in identifying land-use and land-cover classes. However, they also acknowledged the challenges associated with the accurate classification of certain types of land use, particularly in complex environments or when dealing with similar spectral properties (Hill et al., 1998; Tateishi & Mukouyama, 1987). The findings from these studies contribute to the development of more refined and accurate land use classifications. Urban land use classes were selected to represent local land use in the urban community. These classes could help urban planners deal with various urban development and spatial planning processes, such as formal and informal settlements, the identification of intensified urban areas, high flood risk zones, and sewage management and control in the area. Urban land use classes were grouped based on expert knowledge and field reconnaissance surveys. (See manuscripts 1 and 2.)

3.6 Economic Data

Economic data in the context of public sector organizations is a multifaceted concept that encompasses financial reporting, performance indicators, and the use of data for decision-making and strategic planning (Harun & Hashim, 2017; Lægreid et al., 2008). Financial indicators are indispensable to local governments as they provide analytical information that expedites management and aligns with social expectations (Arbatskaya, 2022). The quality of financial reports, which can be influenced by factors such as gender and accountability, has been shown to affect the performance of public sector organizations (Yunia & Muttaqin, 2022). Data mining is used across the public sector to uncover trends and improve various aspects of service and performance (Yunia & Muttaqin, 2022). However, challenges are associated with the use of economic data. For instance, public sector organizations may struggle with the capacity to process large volumes of data, which is necessary for monitoring Sustainable Development Goals (SDGs) and other initiatives (Abbas et al., 2023). Strategic Information Systems Planning (SISP) practices have been linked to improved performance in government agencies, indicating the importance of effective data use and strategic planning (Harun & Hashim, 2017). Accounting standards and practices such as those in India also play a significant role in the preparation and reporting of financial statements in the public sector (Yunia & Muttaqin, 2022). The evolution of reporting to meet the information needs of various stakeholders is another dimension of economic data, with new classifications emerging to adapt to changing user requests and modern public finance management approaches (Arbatskaya 2022). Autonomy and control within public sector organizations can impact the use and disclosure of economic data, as reforms have led to changes in management and accountability (Lægreid et al., 2008). Finally, the disclosure of key performance indicators in annual reports is a practice that is gaining traction, as it provides transparency and links performance to objectives and targets (Wall & Martin, 2003). The application of economic data is integral to the functioning and evaluation of public sector organizations (Arbatskaya, 2022) because it supports decision-making, strategic planning, and accountability. Therefore, its effective use is closely associated with organizational performance (Abbas et al., 2023). However, challenges, such as data-processing capacity and the need for modern reporting standards, must be addressed to fully leverage economic data in the public sector.

The economic data for the study were drawn from the government database stored in each ministry as an archive of different projects executed by various administrations (see Manuscripts 2 and 3 for details). A socioeconomic survey of living standards and household incomes conducted by the National Bureau of Statistics of Nigeria (NBS, 2020) was used. The socioeconomic survey is a national household survey that the NBS conducts every five years (NBS, 2020). Recently, updated data were used in this study. The data capture all socioeconomic activities in urban areas across all Nigerian states. Data on household incomes derived from agriculture, production, manufacturing, and the formal sector were observed to be based on minimum wages (salary scales). This information was used to calculate household incomes and classify them as low, middle, or high (NBS, 2020).

4 Data Processing

4.1 Random Forest

Random forest (RF) is a collection of *Classified Regression Trees* (*CART*) (Breiman et al., 1984; Breiman, 2001). Datasets of the same size, generated from a sample of random training data, were collected as training data or bootstraps (Breiman, 1996, 2001). When a tree is built, a sample of bootstraps that does not contain any sample of the original dataset is used as the test dataset (Figure 5) (Sarica et al., 2017). The error in the tree classification of the dataset is the out-of-bag (OOB) estimate of all the errors (Breiman, 1996) for each bagged classifier, and the training set of the OOB error is equivalent to the set of training data (Sarica et al., 2017). This aids the OOB in eliminating the need for different sets of test data (Xia et al, 2018). To group new training classes, each tree votes for each class, and RF predicts the class that receives the highest number of votes (Sarica et al., 2017). Furthermore, RF has precise rules for building trees, namely, individual testing, class allocation, and tree grouping (Xia et al., 2018). Tree parameters can overfit each other and are more stable than other machine-learning algorithms (Menze et al., 2009). Bagging in random forest also allows the selection of training data samples from the original dataset through replacement or iteration by creating new training datasets. For each iteration, the new class with the highest number of votes was selected (Xia et al., 2018). This approach helped reduce the variance and bias of misclassification and training-dataset errors (Xia et al., 2018).

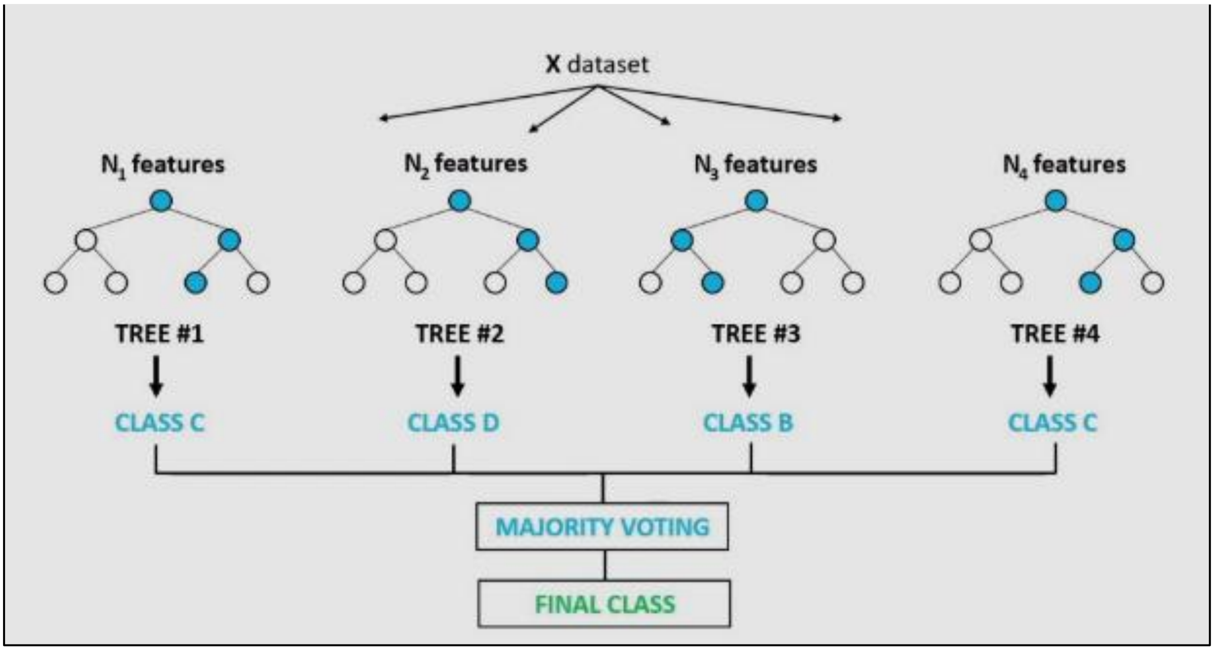

Figure: 5 Random Forest Classifier (Source: Sarica et al., 2017)

This study analyzed the changes in land cover from 1985 to 2017 using a random forest (RF) algorithm. The accuracy of RF has been widely validated in various fields (Sarica et al., 2017; Xia et al., 2018). Random forests are capable of learning intricate nonlinear relationships, such as those found in various forest ecosystems, as well as the connection between overstory and forest vegetation (Mellor et al., 2013). Textural information can offer more insight into random forest classifiers by distinguishing vegetation with similar spectral characteristics (Culbert et al., 2009). Bagging has been proven to improve the accuracy and predict the error rate of decision trees when using random features and assigns importance to each tree in the classification process (Breiman, 2001). The accuracy and error rates for each tree were forecasted using bag predictions and the mean of all samples (Xia et al., 2018). To remove noise from the image classification, we employed a 9 × 9 majority cell filter for the different classes and mosaicked all image tiles to find the best position (Culbert et al., 2009). Subsequently, we applied a nearest-neighbor technique to reconstruct pixels without data and conducted an accuracy evaluation to ascertain whether the image classification accurately depicted the land use in Uyo. Steps were taken to minimize errors in land cover classification caused by variations in reflectance that occur between the dry and rainy seasons (Feteme et al., 2016). See more in manuscript 1.

4.2 Texture Segmentation

Texture is a specific characteristic of images (Karabağ et al., 2019) and is used for feature extraction in image segmentation and classification (Reyes-Aldasoro & Bhalerao, 2006). Numerous approaches have been adopted for textural-image segmentation, such as co-occurrence matrices (Reyes-Aldasoro & Bhalerao, 2006), multiresolution subband filtering, local binary patterns, and filtering (Randen & Husoy, 1999; Reyes-Aldasoro & Bhalerao, 2006). Co-occurrence matrices, like eight rows and columns, are created in a greyscale level image (Karabağ et al., 2019) to generate eight-quantized levels (Karabağ et al., 2019). The attributes of each matrix depend on the number of times the grey-level scale has passed through the neighboring image (Karabağ et al., 2019). The co-occurrence matrix measures the grey-level textural coarseness and directionality from the features of the matrix, such as entropy, maximum probability, uniformity, contrast, inverse difference moment, and correlation will be calculated (Reyes-Aldasoro & Bhalerao, 2006). Filtering was applied to modify the pixel quality (Karabağ et al., 2019). These spatial filters were applied directly to the values of the images to filter out all noise (Karabağ et al., 2019). The frequency in the filter is typically applied when the image is converted using *Fourier Transformation* (Karabağ et al., 2019). The frequencies that pass through are classified as low-pass, bandpass, and high-pass filters (Karabağ et al., 2019). A weight of 0.2 was used for the shape parameter to reduce the weight on the shape and to produce a more homogeneous image segmentation. Additionally, the size parameter was adjusted to 0.6 to blend the smoothness of the object. After evaluating the different scale levels and testing them with different values, a scale of 20–80 was found to be suitable for the study area. We checked the segmented objects based on our selected training data, fieldwork knowledge, and differences within the same object classes. See more in manuscript 2.

4.3 Time-Series Analysis

Remote-sensing time-series datasets are widely used for environmental monitoring and they perform temporal endmembers (Pan et al., 2017). The endmembers assist in extracting, selecting, and collecting spectral signature data from an image scene (Pan et al., 2017; Plaza et al., 2011). This process is characterized by anomalies that indicate the vegetation biomass status, such as NDVI (Pan et al., 2017). The first step is to smoothen the images, which are controlled by the number of iterations (Pan et al., 2017; Rembold et al., 2015). During the initial iteration, the images were smoothed and fitted to each other (Rembold, 2015). At each iteration, the algorithm is run with different numbers of iterations, where all observed values and image periodicity (daily, monthly, and annually) are fitted into the dimension of the extension (Rembold, 2015; Pan et al., 2017). However, they are limited in integrating data from different sources, such as MODIS 250m and LANDSAT 30m (Rembold 2015). However, LANDSAT is widely used for urban growth monitoring (He et al., 2018; Chen et al., 2017; Yang et al. 2019; Zhang & Seto, 2011). This was done by calculating the probability of observed changes in vegetation at different time intervals (Rembold, 2015). The cumulative changes in the vegetation index from 1 to 100 months depended on the aim of the study and could be computed based on the period. The *break-for-additive seasonal and trend* (BFAST) algorithm incorporates the separation of time-series data into seasonal trends and residual components, allowing for the identification of both seasonal and sudden changes within the trend (Verbesselt et al., 2010). BFAST provides real-time detection and modelling of disturbances (Verbesselt et al. 2010). One of its key features is flexibility, as it can identify missing data without requiring interpolation (Verbesselt et al., 2010). Furthermore, various models can be employed to analyze time-series data and identify structural changes (Verbesselt et al., 2010). A total of 281 Landsat images were processed using the BFASTMONITOR algorithm to produce a map of changes in Uyo over time using NDVI time-series data from 1985 to 2013. See manuscript 1.

4.4 Data Overfitting in Remote Sensing

Overfitting is a critical issue in remote-sensing applications where models may perform exceptionally well on training data, but fail to generalize to new, unseen data (Rocha et al., 2017; Kernbach & Staartjes, 2022). This phenomenon is particularly problematic when dealing with high-dimensional data, such as hyperspectral images, or the application of complex machine learning algorithms, such as deep learning (Kernbach & Staartjes, 2022; Robilliard & Fonlupt, 2002; Rocha et al., 2017). However, although overfitting is a common concern across various domains, strategies for mitigating it in remote sensing are diverse and tailored to specific challenges in the field (Rocha et al., 2017). For example, the use of validation sets and backwarding methods has been proposed to control overfitting in the context of inverse remote sensing problems (Robilliard & Fonlupt, 2002). In contrast, the spiral search grasshopper optimization technique and data augmentation have been applied to improve the feature selection and address data imbalance in the object-detection method (Stateczny et al., 2022). In addition, the *Naïve Overfitting Index Selection* method was introduced to select the optimal model complexities for hyperspectral data analysis (Rocha et al., 2017). Overfitting in remote sensing is a complex problem that requires careful consideration of the model complexity, data quality, and validation techniques (Rocha et al., 2017). The remote sensing literature shows a range of methods for addressing overfitting, from classic validation set approaches and novel optimization techniques to complex selection methods such as NOIS (Rocha et al., 2017). These methods aim to enhance model generalization and ensure that remote sensing models are robust and reliable when applied to real-world data (Rocha et al., 2017; Stateczny et al., 2022). In this study, the *grasshopper optimization* method was employed to examine the hyperparameters of the dataset. The networks used in this study were evaluated using three constant learning rates: 0.1, 0.01, and 0.001. The analysis revealed that 0.1 was too large, while was too small (0.001). Therefore, it was determined that 0.01 was the optimal learning rate for the networks tested in this study.

4.5 Linear-Regression Analysis

As a statistical model, linear regression is used to define two sets of data and quantify the relationship between their variables (Kumari & Yadav, 2018). Partial correlation and regression tests show the relationship between dependent and independent variables (Kumari & Yadav, 2018). In addition, they provide information on dependent and independent variable correlations (Schneider et al., 2010). However, correlation provides a quantitative way of measuring the strength of the relationship between different variables, while regression evaluates the mathematical aspect of the relationship and predicts the value of the dependent variable based on the independent variable (Kumari & Yadav, 2018). The linear regression model uses the equation $y = mx + c$, which shows the line of best fit for the relationship between y (dependent variable) and x (independent variable) (Kumari & Yadav, 2018). The regression coefficient R^2 shows the relationship between the variables (Schneider et al., 2010). See more in manuscript 2.

4.6 Variable Coefficient R^2

The coefficient of determination (R^2) is the percentage of total change in the dependent variable triggered by the independent variable (Kumari & Yadav, 2018). These help show the relationship between the two variables and predict their outcomes. However, changes in the independent variables affected the dependent variables and quantified these changes. Where $R^2 = 1$ indicates a perfect relationship between the variables; however, when R2 = 0, a weaker relationship exists (Kumari & Yadav, 2018). See more in manuscript 2.

4.7 Landsat Data Assemblage

Landsat images of the areas of interest (Uyo, Warri, Aba, and Umuahia) were downloaded using the geographic co-ordinate system of the cities. This area covers more than 20 km. A total of 232 cloud-free images were collected from the bulk for the time-series analysis. Images were cropped and stacked according to the study area. Few images had a small cloud cover that was removed using the built-in *Bfast fmask* functionality. Landsat images with blue, green, red, and near-infrared spectral bands were stacked for all the images. However, images from 1991 to 1999 experienced *scan-line corrector* failure (Williams et al., 2006), whereas images with no distortions were stacked. A time-series with no cloud cover was generated between 1985 and 2010. See more in manuscript 1.

4.8 RapidEye Data Analysis

The analysis of RapidEye satellite imagery data is a significant aspect of remote sensing research, as it provides valuable insights into various environmental and geospatial phenomena (Chrysafis et al., 2019). RapidEye data, with its high-resolution and multispectral capabilities, have been effectively utilized in different studies to monitor biodiversity, assess vegetation, and update geospatial databases (Chrysafis et al., 2019; Yao & Zhang, 2011). Chrysafis et al. (2019) focused on the use of RapidEye imagery to estimate and map α-diversity in a protected forest area and compared the information content of RapidEye with that of Sentinel-2 MSI. This comparative evaluation is crucial for understanding the cogency and ineffectiveness of different remote sensing platforms for biodiversity monitoring. Yao and Zhang (2011), on the other hand, do not directly compare RapidEye with other sensors but emphasize the importance of object-oriented feature extraction and classification, which are processes that can be applied to RapidEye data. The reviewed studies highlight the sensor's applications and demonstrate its versatility and effectiveness in remote sensing applications (Chrysafis et al., 2019; Yao & Zhang, 2011). The comparative evaluation of RapidEye with other sensors performed by Chrysafis et al. (2019) and the methodological approach described in a study by Yao and Zhang (2011) both contribute to a broader understanding of the capabilities and potential uses of the sensor in the field of remote sensing (Chrysafis et al., 2019; Yao & Zhang, 2011). In this thesis, RapidEye scenes were analysed to produce radiometrically calibrated and atmospherically corrected images. Radiometric calibration in RapidEye requires the calibration coefficients to be changed, and all images are divided by π to convert the least component reflectance values to reflectance units of inverse steradians (sr^{-1}) (Coffer et al., 2020). The images were atmospherically corrected by Planet Team (2017) before they were downloaded. Each image is presented as multiple tiles and divided into two tiles. The images were processed for each tile before being mosaicked into a single scene. A raster was generated by resampling and interpolating the different scenes of the images, while keeping all image parameters the same. See manuscript 2.

4.9 Object-based Image Analysis (OBIA)

OBIA is a well-established method of segmenting satellite images (Blaschke et al., 2014). The images were segmented and merged based on their homogeneous properties, and classified into different object classes. In OBIA, image segmentation and its parameter settings are the most important aspects, as they can affect the results of the classified image (Drăguţ et al., 2014; Jozdani and Chen, 2020). There is no standard for how large or small objects can be created (Robson et al., 2020). However, when the created object is too large, many features can be grouped as single objects, whereas smaller objects reduce the efficacy of contextual constraints and shape parameters during classification (Robson et al., 2015). Object-based image analysis allows contextual, hierarchical, spatial, and textural data to be used, rather than relying on the spectral properties of the images (Blaschke et al., 2014; Toure et al., 2018). This creates the possibility of greater segmentation of images from existing image objects (Robson et al., 2020). Additionally, OBIA is well suited to the mapping of natural phenomena such as land-cover change (Toure et al., 2018), cropland mapping (Belgiu & Csillik, 2018), and rock glaciers (Robson et al., 2020). The contextual property is used to remove the irregular shapes of an object (Robson et al., 2015). The use of *K-nearest neighbour* (*KNN*) classifiers facilitates the categorization of images into various classes. Consequently, we selected training samples that represented different classes and reassigned each class to segmented objects (Myint et al., 2011; Vieira et al., 2012). This can be achieved in two ways: firstly, by providing the classifier with a sample of object training data; and secondly, by classifying the classifier based on the nearest neighbours of the sample (Vieira et al., 2012). One of the benefits of the KNN is its ability to differentiate between pixels with similar features and assign them to different classes, based on their highest confidence value (Wang, 2018). In this study, the *KNN* classifier was used to identify all built-up areas. See more in manuscript 2.

4.10 Interview

Quantitative research data can be obtained using various techniques such as historical or new methods, interviews, ethnography, and case study (Jarah et al., 2019). In this thesis, a face-to-face interview technique was used in the study area following the approaches of Guest & Bunce (2011) and Jarah et al. (2019). The interview began with an introduction of the research topic and elaboration of the research aims and objectives to the respondents. The primary goal was to educate the participants about how the generated data would be used. Data were collected across different governmental and non-governmental agencies such as, professional planners, and environmental experts in the city who have real experience of design and planning. Furthermore, academics like professors and PhD holders played a special role as interviewees. The process began with the fixing of appointments, followed by visits to individual ministries. The respondents requested complete anonymity. The main aim of the interviews was then highlighted. The interviews were conducted in the English language, because most of the respondents used it in their workplaces. However, some in-depth discussions were conducted in Ibibio because, as the predominant language in the state, most of the respondents could use it. Similar bits of information gathered from the interviews were grouped together based on the research questions, aims, and objectives. The data were arranged according to their categories to quantify, analyse, and interpret the data so as to acquire a detailed knowledge of the study area. See manuscripts 3 & 4.

The interviews were kept in a dynamic form, and each question had a follow-up. This prevented boring the respondents with a direct question/answer format. Issues which had arisen during the interviews were discussed and solutions were proffered. The respondents were excited to participate in this thesis because it was voluntary. The aim was to gain expert knowledge about unplanned urban growth in the study area. Sixty people volunteered to participate in the interview. Based on qualifications, the most important respondents had doctoral degrees, while the least important ones had bachelor's degrees. This shows that the respondents had both theoretical and practical knowledge of the study area. Similar analyses and answers were given by the participants, proving that they were sincere about the state of things in the study area. There were also some who shared their life and work experiences. The interviews took from April to May 2018 and were conducted either in a participant's office or at a location chosen by them. Each interview lasted for one hour, at the least. See more in manuscripts 3 & 4.

4.11 Software

R, QGIS, and Envi were used to process, visualize and analyse the urban spatial and environmental data. Quantitative socioeconomic data were also analysed using R.

PART II

PUBLICATIONS

5 Separate Contributions to the Manuscripts

Manuscript 1 (Chapter 6)

Author: Etido Essien, Cyrus Samimi

Title: Detection of Urban Development in Uyo (Nigeria) Using Remote Sensing

Journal: *Land* **2019**, *8*(6), 102; **https://doi.org/10.3390/land8060102**

Status: Published

Personal Contributions:

Data analysis 100 %, conceptualization 70 %, writing the original manuscript 100 %, methodology 80 %, review and editing 70 %, and visualization 90 %.

The concept of this study and data analysis was done by EE, CS. As well, EE and CS interpreted and discussed the results. Figures and Tables were designed by EE and implemented with the help of a cartographer (see the acknowledgement). EE wrote the first draft of the manuscript.

The review and editing of the manuscript were performed by EE and CS.

EE is the corresponding author.

Manuscript 2 (Chapter 7)

Author: Etido Essien, Cyrus Samimi

Title: Evaluation of Economic Linkage between Urban Built-Up Areas in a Mid-Sized City of Uyo (Nigeria)

Journal: *Land* **2021**, *10*(10), 1094; **https://doi.org/10.3390/land10101094**

Status: Published

Personal Contributions:

Data analysis 100 %, conceptualization 70 %, writing the original manuscript 100 %, methodology 80 %, review and editing 70 %, and visualization 90 %.

The concept of this study and data analysis was done by EE, CS. As well, EE and SC interpreted and discussed the results. Figures and Tables were designed by EE and implemented with the help of a cartographer (see the acknowledgement). EE wrote the first draft of the manuscript.

The review and editing of the manuscript were performed using EE and CS.

EE is the corresponding author.

Manuscript 3 (Chapter 8)

Author: Etido Essien

Title: Impacts of Governance toward Sustainable Urbanization in a midsized City: A Case Study of Uyo, Nigeria

Journal: *Land* **2022**, *11(1), 37; https://doi.org/10.3390/land11010037*

Status: Published

Personal Contributions:

Data analysis 100 %, conceptualization 100 %, writing the original manuscript 100 %, methodology 100 %, review and editing 100 %, and visualization 100 %.

The concept of this study and the data analysis were performed by EE. As well, EE interpreted and discussed the results. The figures and tables were designed by EE. EE wrote the manuscript.

The review and editing of the manuscript were performed by EE.

EE is the corresponding author.

Manuscript 4 (Chapter 9)

Author: Etido Essien

Title: Urban theories and urbanization perspectives in cities across Nigeria

Journal: Environ. Res. Commun. 5 (2023) 085008, https://doi.org/10.1088/2515-7620/acef4

Status: Published

Personal Contributions

Data analysis 100% conceptualization 100 %, writing the original manuscript 100 %, methodology 100 %, review and editing 100 %, and visualization 100 %.

The concept of this study and the data analysis were performed using EE. As well, EE interpreted and discussed the results. The figures and tables were designed using EE. EE wrote the manuscript.

The review and editing of the manuscript were performed using EE.

EE is the corresponding author.

6 Manuscript 1: Detection of Urban Development in Uyo (Nigeria) Using Remote Sensing

Etido Essien, Cyrus Samimi

Land **2019**, *8*(6), 102; **https://doi.org/10.3390/land8060102**

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MDPI

Project Report

Detection of Urban Development in Uyo (Nigeria) Using Remote Sensing

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Abstract: Uyo is one of the fastest-growing cities in Nigeria. In recent years, there has been a widespread change in land use, yet to date, there is no thorough mapping of vegetation change across the area. This study focuses on land use change, urban development, and the driving forces behind natural vegetation loss in Uyo. Based on time series Landsat Thematic Mapper (TM)/Enhanced Thematic Mapper Plus (ETM+)/Operational Land Imager (OLI) image data, the relationships between urban land development and its influencing factors from 1985 to 2018 were analyzed using remote sensing (RS) and time series data. The results show eight land use cover classes. Three of these (forest, swamp vegetation, and mixed vegetation) are related to natural vegetation, and three (sparse built-up, dense built-up, and borrow pit) are direct consequences of urban infrastructure development changes to the landscape. Swamp vegetation, mixed vegetation, and forest are the most affected land use classes. Thus, the rapid growth of infrastructure and industrial centers and the rural and urban mobility of labor have resulted in an increased growth of built-up land. Additionally, the growth pattern of built-up land in Uyo corresponds with socioeconomic interviews conducted in the area. Land use changes in Uyo could be attributed to changes in economic structure, urbanization through infrastructure development, and population growth. Normalized difference vegetation index (NDVI) analysis shows a trend of decreasing vegetation in Uyo, which suggests that changes in economic structure represent a key driver of vegetation loss. Furthermore, the implementation of scientific and national policies by government agencies directed at reducing the effects of urbanization growth should be strengthened, in order to calm the disagreement between urban developers and environmental managers and promote sustainable land use.

Keywords: Land use; remote sensing; urban expansion; Landsat; NDVI

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1. Introduction

Land use change is a key component of research in environmental change and management worldwide [1–3]. In particular, urban growth and urban spread have drastically transformed the physical environment [4]. The most common change is the replacement of soil and vegetation with urban features such as concrete, asphalt, and buildings [4]. Consequently, this affects the albedo and runoff characteristics of the land layers and the environment, significantly affecting local and regional land–atmosphere energy exchange processes [4]. Hence, it is important to detect urban development in order to understand urban dynamics, ecology, and climatology, and to manage resources and services in urban environments [5–7]. In this context, urban ecologists try to understand how context changes the shape of urban systems, as they both drive and respond to environmental changes [8]. Therefore, understanding the interaction between urbanization and ecological processes is recognized as a major task in urban ecology [9,10]. In today's world, the populations of big cities and clusters of cities are growing, as more people move to urban areas to participate in urban life, hoping to make a better living than in rural areas [11]. Accelerating urban growth has always been an indication of the vigor of a region's economy [5]. Such scattered growth, driven largely by technological advancement and population growth, has rarely been well planned, provoking concern over the degradation of environmental health [5]. It is essential to gain a better understanding of how urban dwellers are changing, especially in terms of how individuals add to and characterize urban growth and how urban growth can have consequences in changing the direction of population growth [12]. Even though the growth of mega-cities is often discussed, in Africa, major changes in urban populations normally happen in small and medium-sized cities [13].

In Nigeria, cities are struggling with rapid urban growth and development, and this plays a major role in land use and land cover changes in the country [14]. According to a study on land reform in Nigeria, land is seen as a social security asset to most people, because after all else has failed in the city, they can still manage to go back to their villages to demand a piece of their inherited family land and start subsistence farming [15]. Land control and land use policy must consider the fact that most people's existence relies on having access to a piece of land, and they would strongly resist and oppose any act to deprive them of this land [15]. Therefore, the government needs to pay more attention to land management and the planning of urban centers [16]. Based on detailed analysis, it is necessary to identify and evaluate land cover changes and urban settlement structures [16] in order to provide a judicious mapping of land use and urban development as a planning tool for Nigeria's economy [17].

Land use and land cover types are major indicators for understanding the relationship between environmental changes and human activities that occur in the environment [14]. Therefore, the detection of changes in land use reveals noticeable differences in the developmental process of a particular area, by monitoring it at different time periods [15]. It is an important aspect of research for detecting environmental changes [16]. Thus, in order to research past changes in land use and land cover in Nigeria, and to predict the future of land use changes, we need a proper understanding of the people who interact with the land and motivate anthropogenic activities and developmental processes [17].

The free availability of standardized multitemporal Landsat data [18] facilitates continuous analysis of temporal changes. Hence, Landsat has been used for mapping land surface changes and detecting disturbances (e.g., [19–22]), as well as for urban development (e.g., [23–31]). Two previous studies on Akwa Ibom State mainly focused on Uyo, though they did not capture the spatial development in the region and did not differentiate the built-up areas [32,33]. Their analysis was conducted for only two years (1986 and 2007). In this study, remote sensing data from Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) sensors were used to analyze the temporal and spatial extent of urban area shifts and land surface changes in the region of Uyo (a medium-size city in southeastern Nigeria), by using historical data from Landsat from 1986 to 2017. The aim of this research is to analyze urban growth and its spatiotemporal differences in order to derive the driving factors of urban change. The overall aim is addressed by these three objectives:

(i) To classify land cover classes for three years in order to quantify changes.

(ii) To run a time series analysis to detect phases of urban growth, spatially and temporally.

(iii) To link urban changes to the drivers of change.

The results are aimed at providing insight into the urban growth of a medium-size city (Uyo) in Nigeria to provide a basis for urban planning.

2. Materials and Methods

2.1. Study Area

This research was carried out in Uyo, the capital of Akwa Ibom State, Nigeria. The city lies between longitudes 37°50′ E and 37°51′ E, and between latitudes 55°40′ N and 54°59′ N. Uyo has a total area of 188.035 km^2 with an estimated population of 3,920,208 [34]. Uyo is characterized by a tropical humid climate without distinct seasonal variation. It has an annual precipitation of almost 1000 mm, with only three months with considerably low rainfall, from December to February, and little variability in temperature [35]. It was a district headquarters during the colonial era and was later upgraded to a local government headquarters. In 1987, Uyo became the state capital of Akwa Ibom. The changes and status upgrade in the area attracted development. Figure 1 shows a map of the study area.

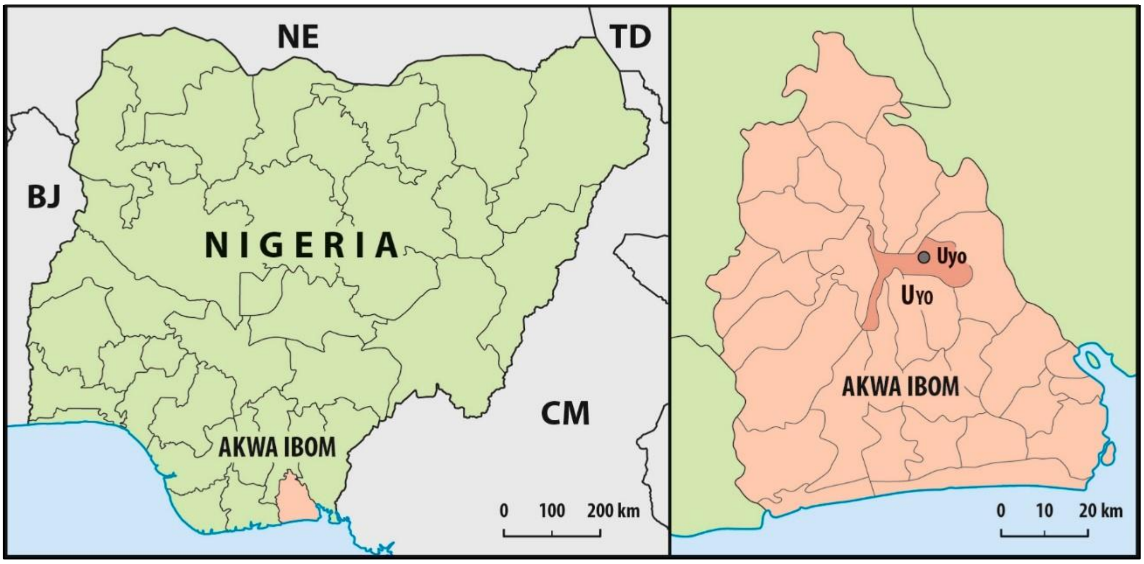

Figure 1. Map of Nigeria showing Akwa Ibom State, and map of Akwa Ibom State showing Uyo (Source: Ministry of Land Surveying, Uyo).

2.2. Data Collection

Global Positioning System (GPS) points were picked at different locations in Uyo, and information was also obtained from satellite images. During the field trip, different land cover types were identified, and photographs and coordinate points were taken at each location. Information on land use types in the area was gathered by interviewing native leaders who had worked in Uyo since it was established as a state capital, using their local languages. Based on the information obtained from the people interviewed and a reconnaissance survey conducted in the area, the land cover types of Uyo were classified into eight classes: forest, cropland, mixed vegetation, swamp vegetation, dense built-up, sparse built-up, borrow pit, and water bodies. Forest includes areas that are largely covered by trees and approximately more than 0.8 ha. Cropland includes areas that are mostly used for the cultivation of crops. Dense built-up includes areas that are populated with different kinds of buildings that are very close to each other (less than approximately 3 m). Sparse built-up includes areas that are scattered with both buildings and cropland. Mixed vegetation includes areas that comprise cropland, swamp vegetation, and forest land. Swamp vegetation includes bog areas with different tree covers. Borrow pit includes areas with large excavations of sand for construction work. Water bodies include areas characterized by flowing water, such as a lake, river, or stream [19].

2.3. Remote Sensing Data

Landsat images were used to monitor changes in land use and land cover from 1985 to 2018.
Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) images with cloud cover of less than 80% were bulk downloaded for the study area. Landsat (Tier 1) images are known to have the highest data quality, and they were radiometrically calibrated by the United States Geological Survey (USGS) when ordered using the standard method [36]. A total of 281 images, an average of eight Landsat images per year, were bulk downloaded. There were no Landsat images between 1992 and 1998 for the study area (path/row 188/56).

2.4. Training Samples and Reference Data

The training samples were chosen using an on-screen digitizing method in QGIS® [37], using red/green/blue (RGB) false color (urban) band combinations 7, 6, and 4 of Landsat images and other field data. Table 1 lists the numbers of training samples. For accuracy assessment, validation of an adequate amount of testing data is required per class of interest [38]. Therefore, it is essential to have sufficient testing data to test a statistically valid error matrix to represent classification accuracy. The validation of post–land cover classification results is naturally difficult due to the absence of field observations at different times [19]. In order to validate the accuracy of the 1986 and 2003 image classifications, the results were compared to the achieved 2017 images. Since there were validation data from the fieldwork and different classes in the post-classified images, it was still possible to identify some features.

Table 1. Samples of the training data.

	Training Samples Category	
	ROI	**Pixels**
Water bodies	95	5321
Swamp vegetation	101	8942
Sparse built-up	105	10,422
Mixed vegetation	98	7356
Forest	97	8945
Dense built-up	94	8132
Cropland	110	12,435
Borrow pit	70	4851

ROI = region of interest.

2.5. Land Cover Classification and Change Detection

Changes in land cover from 1985 to 2017 were analyzed using a random forest (RF) algorithm. The accuracy of random forest has been generally affirmed in various fields, but it has not been used much in ecology [37]. Random forest is a classification that involves a combination of trees organized so that independent identical trees circulate random vectors and each tree casts a vote for similar trees in the same group [39]. Random forest also aids in learning complex nonlinear connections, such as those in various forest systems, and the connection of overstory to forest vegetation [40]. Textural information can give more knowledge to a random forest classifier by separating vegetation with similar spectral information [41]. Bagging seems to enhance accuracy and estimates the error rate of the trees when random features are used [39] and gives the importance of each tree in the classification. Accuracy and error rates are predicted for each tree using the bag predictions as well as the mean of all samples [42]. To extract the noise from image classification, we used a 9 × 9 majority cell filter for the different classes, and thereafter we mosaicked all the image tiles by finding the best position [41]. Following that, we used a nearest-neighbor method to restore pixels that had no data and performed an accuracy assessment to see if the image classification was a clear representation of Uyo land use. In order to reduce errors in land cover classification resulting from reflectance differences in the dry and rainy seasons [19], land cover classification was based on only rainy season Landsat images. Rainy season images have the advantage of showing crop cultivation and healthy vegetation [19]. The total accuracy of the land cover classification was evaluated using a confusion matrix to measure the similarity compared to 2017 classification results (Figure 2) and the field data. For individual land cover types, a confusion matrix was created and the total accuracy, user and producer accuracy, and kappa statistic were calculated for every class type [19,37]. The total accuracy was determined by dividing the number of classified elements by the number of pixels added in the assessment levels [19]. The kappa statistic is another way of assessing classification accuracy by subtracting the effect of random accuracy and measures whether a classification is better than a random classification [19].

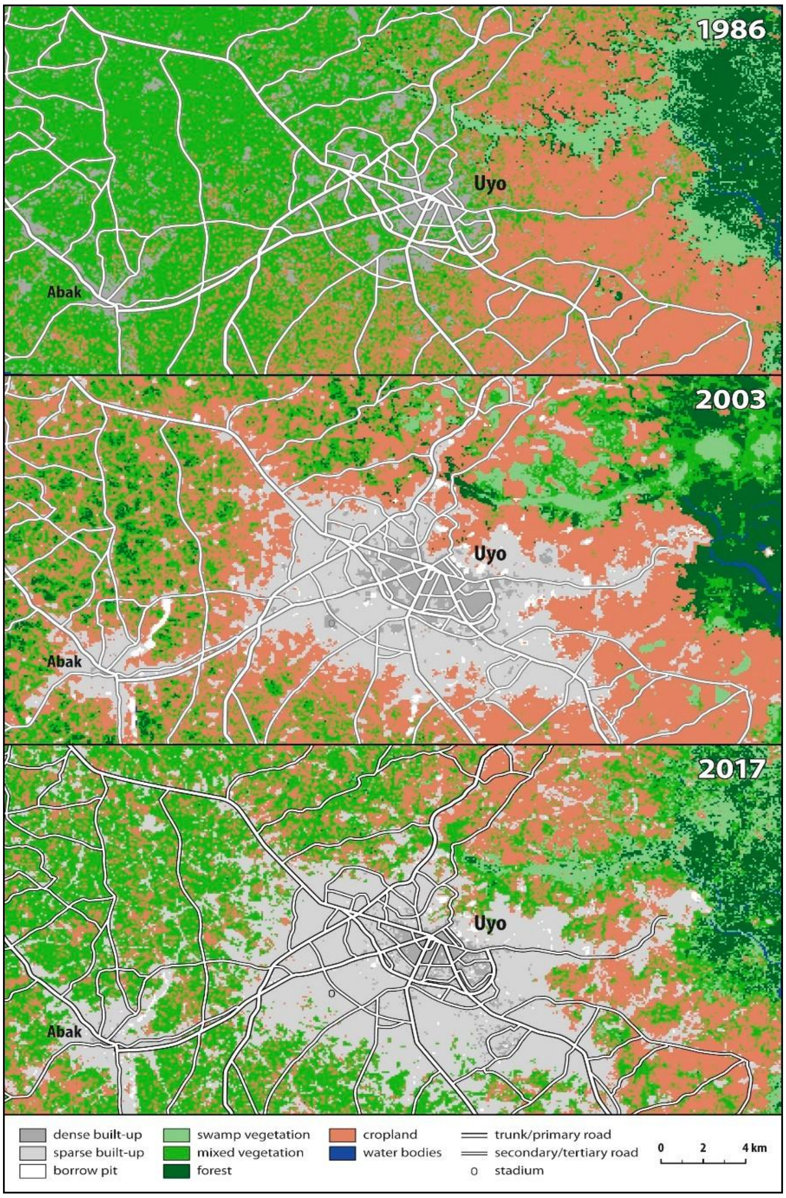

Figure 2. Land cover maps of Uyo for 1986, 2003, and 2017.

2.6. Time Series Analysis

The Break For Additive Seasonal and Trend (BFAST) algorithm integrates the dissolution of time series into seasonal trends and remainder components in a way that can detect seasonal and abrupt changes within the trend. BFAST examines and provides functionality to detect a disturbance in real time and models it. The BFAST approach is very flexible and can detect missing data without interpolation [43]. Moreover, it has different models that can be used to fit the time series data and detect structural changes [43]. A total of 281 Landsat images were stacked in BFASTMONITOR; similarly, we also extracted the normalized difference vegetation index (NDVI) time series data from 1985 to 2013 (Figure 3) and created a map of changes that occurred in Uyo with time using the BFAST algorithm.

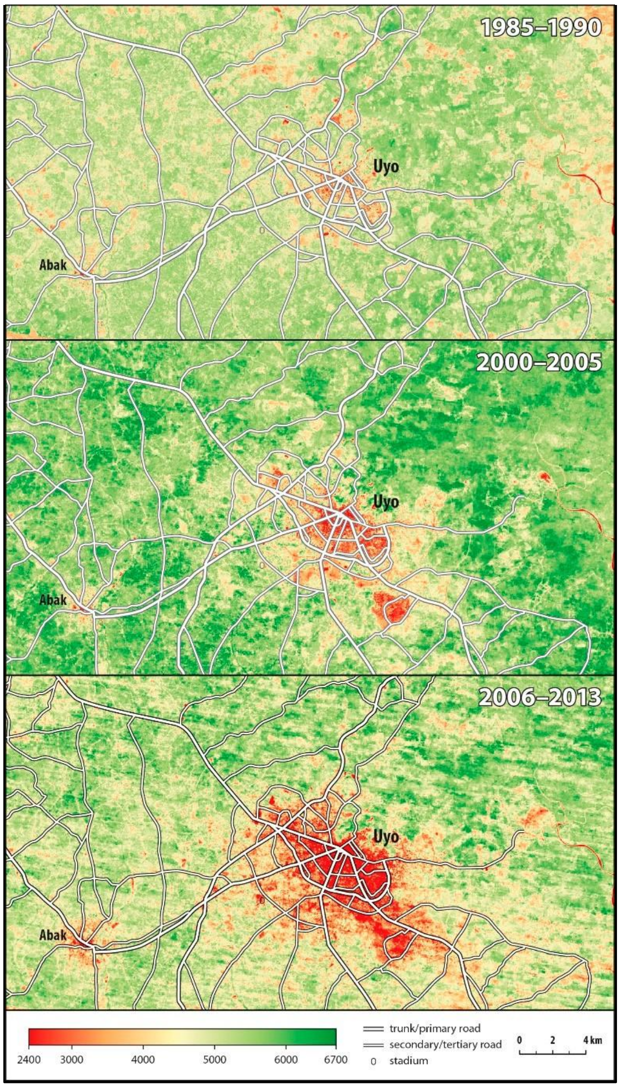

Figure 3. Median normalized difference vegetation index (NDVI) for the study area.

3. Results

3.1. Changes in Land Cover Patterns

To assess the quality of land cover classification, we used an internal out-of-bag random forest accuracy assessment method. Field and satellite data showed that the total accuracy of land cover change using a confusion matrix was 90% with a kappa statistic of 0.73 in 1986, 93% with a kappa statistic of 0.79 in 2003, and 95% with a kappa statistic of 0.83 in 2017 (Table 2). Land use and land cover types vary in Uyo; Figure 2 shows there was a trend of massive increase of built-up areas over the past 32 years. Table 3 shows there was a huge decline from 1986 to 2017 in forest area, from 414.94 to 219.41 km^2; swamp vegetation, from 48.94 to 18.31 km^2; and mixed vegetation, from 48.94 to 29.53 km^2. Changes in the built-up area grew from built-up land alone in 1986 to dense built-up, sparse built-up, and borrow pit in 2003, which have continued to grow. In 1986, built-up land had an area of 24.85 km^2; it increased to 15.75 km^2 dense built-up, 154.25 km^2 sparse built-up, and 4.85 km^2 borrow pit in 2003, and to 26.42 km^2 dense built-up, 251.51 km^2 sparse built-up, and 9.79 km^2 borrow pit in 2017. The total change in built-up area increased to 287.72 km^2 in 2017. This shows a significant increase in the built-up area with an average change of 8.98 km^2 per year, which means built-up land keeps changing every year due to the continuous increase in economic activity in the area.

Table 2. Landsat 1986, 2003, and 2017 image classification confusion matrix class. (a) 1986

	Built-Up	Cropland	Forest	Mixed Vegetation	Swamp Vegetation	Water Bodies	UA%
Built-up	**312**	7	0	57	0	0	91%

Cropland	1	**439**	0	23	0	0	86%
Forest	0	0	**440**	0	40	1	82%
Mixed vegetation	34	27	1	**423**	0	0	80%
Swamp vegetation	0	0	49	0	**383**	0	92%
Water bodies	0	0	8	0	0	**173**	96%

Kappa statistic = 0.731, total accuracy = 90%, UA= user's accuracy.

(b) 2003

	Borrow Pit	**Cropland**	**Dense Built-Up**	**Forest**	**Mixed Vegetation**	**Sparse Built-Up**	**Swamp Vegetation**	**Water**	**UA%**
Borrow Pit	**87**	0	0	0	1	7	0	0	94%
Cropland	0	**404**	0	0	6	0	0	0	96%
Dense built-up	0	0	**345**	0	0	1	0	0	98%
Forest	0	0	0	**391**	24	0	19	0	87%
Mixed vegetation	0	14	0	20	**366**	0	10	0	89%
Sparse built-up	3	0	0	0	0	**438**	0	0	98%
Swamp vegetation	0	0	0	26	18	0	**360**	0	88%
Water bodies	0	0	0	3	0	0	2	**68**	98%

Kappa statistic = 0.792, total accuracy = 93%, UA= user's accuracy.

(c) 2017

	Borrow Pit	**Cropland**	**Dense Built-Up**	**Forest**	**Mixed Vegetation**	**Sparse Built-Up**	**Swamp Vegetation**	**Water Bodies**	**UA%**
Borrow Pit	**154**	1	0	0	0	2	0	0	97%
Cropland	0	**336**	0	0	0	0	0	0	98%
Dense built-up	0	0	**212**	0	0	1	0	0	100%
Forest	0	0	0	**369**	3	0	0	0	93%
Mixed vegetation	0	0	0	3	**270**	0	1	0	93%
Sparse built-up	1	0	0	0	0	**379**	0	0	95%
Swamp vegetation	0	0	0	0	3	0	**313**	0	97%
Water bodies	0	0	0	3	0	0	0	**98**	100%

Kappa statistic = 0.839, total accuracy = 95%, UA= user's accuracy; Numbers on the diagonal of the matrix show trees that vote in each class (identified in bold), off-diagonal numbers are misclassification (error of commission).

Table 3. Land cover use statistics of Uyo from 1986 to 2017.

Land Cover Class	1986 Land Cover (km²)	2013 Land Cover (km²)	2017 Land Cover (km²)	Change in Land Cover (km²) 2003–2017
Built-up	24.85			
Dense built-up		15.75	26.42	10.67
Sparse built-up		154.23	251.51	97.26
Borrow pit		4.85	9.79	4.94
Swamp vegetation	48.94	28.91	18.31	–10.6
Mixed vegetation	44.2	35.38	29.53	–5.85
Cropland	232.73	261.6	284.41	–19.81
Forest	414.94	249.35	219.41	–29.94
Water bodies	1.01	1.04	1.01	

3.2. NDVI Trends in Uyo

NDVI time series (Figure 3) show that from 1985 to 1990, the changes in vegetation in Uyo occurred at a slower rate until 2000 and beyond, when the vegetation (forest, swamp vegetation, mixed vegetation) started decreasing rapidly without increasing any time of the year, while the cropland went up and down because of its seasonal variation (Figure 4). Applying BFAST to the NDVI time series for urban growth generated over time shows significant changes in the time trend component. The changes were detected by creating a loop and extracting the average pixels in the NDVI data of the study area (Figure 4). This also shows the yearly trend (Yt) of vegetation (forest, swamp vegetation, mixed vegetation) in Uyo, which indicates that it keeps decreasing without recovering in any year, and the time trend (Tt) shows a continuous trend of decreased vegetation in Uyo due to a continuous increase in built-up area, while the seasonal trend (St) shows changes in cropland continuing at a normal rate.

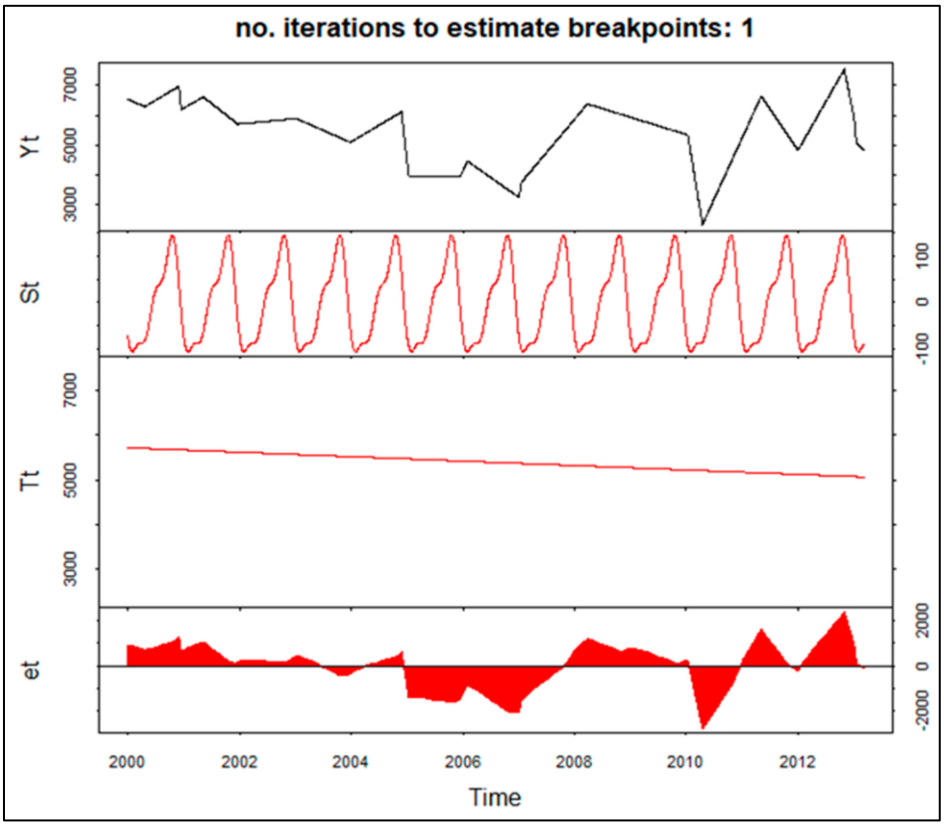

Figure 4. Yearly time (Yt), seasonal trend (St), time trend (Tt), residual component (Et).

3.3. Changes in Economic Structure

The achievements in economic development of the state can be evaluated in terms of the income received from the federal account, which was increased from 8 billion naira to 17.5 billion naira in 2007, since Akwa Ibom State is one of the Niger Delta states that produce crude oil, a major export of the country. Growth in the economy boosts the process of urban construction, with a large demand for land resources increasing economic activities; likewise, the economic output could lead to increased land demand for urban expansion [44]. With robust economic growth, the local government of Uyo, the capital of Akwa Ibom State, aiming to expand its internally generated revenue for development purposes, demolished thatched houses and shop shade covers and even relocated a big market in the city center that was in the dense built-up map of 2003 (Figure 2), in order to construct modern roads and create drainage channels for flood control in the city. This shows that economic growth triggered a need for more land development, leading to rapid growth of built-up areas from the urban center to its surrounding areas (Figure 2), as seen on the 2017 map.

3.4. Population Growth

The National Census of Nigeria carried out in 1991 put the provisional population of Akwa Ibom State at 2,409,613. Out of this figure, the population of urban Uyo was 244,762 [34]. The current population of the state based on the published National Population Commission (NPC) census record is 3,920,208. In 2006, urban Uyo alone was 309,573 [34]. As a result of the strategic location of the town and its being the state capital, there is a corresponding significant influx of people from far and near. Apparently, this is directly responsible for the built-up expansion in urban Uyo (Figure 2). Another effect of population explosion, especially in developing countries like Nigeria, is increased poverty levels among the people due to a lack of sufficient resources for the growing populace [45]. This could be a precedent for overcrowding of urban cities, wrong use of land and environmental resources, and consequently huge loss of biodiversity.

4. Discussion

Urban growth in developing nations is mostly caused by population growth due to infrastructure in urban centers and the mobility of labor [46]. The results of this research are in agreement with previous studies [32,33], but there is much improvement in our study. The area of our research was not centered around urban Uyo alone but included Uyo and its surroundings. Also, the direction of change is shown in our study (Figure 2). Moreover, there are also new findings in this research because of ongoing development in the area. The urbanization of Uyo, which before was centered around the city center, what is today designated as the Ibom Plaza, has expanded to remote areas of Mbiabong, Etoi, Afaha Oku, Ikot Oku Ubo, Ofot, Osong Ama, Itam, and Mbierebe [32]. This has now shifted direction to the Abak local government area and its surroundings. Figure 2 shows that there is densification in the center of Uyo and there is no expansion toward the northern part of the area, meaning that the development trends mainly follow the road network in Uyo. Changes in raster always result in breakpoint timing values, so we have to convert breakpoints into yearly changes in the raster layers (Figure 5). The highlighted color in the maps in Figure 5 shows yearly changes that occurred in Uyo for some monitored pixels at different times of the year. There was almost no change before 2010 and not much change after 2013. Major changes took place in 2010 and 2011, and this was the peak period when the government cleared a lot of land for development purposes, since its aim was to transform Uyo into a modern city (Figure 5). The interviews conducted in the area show that land is cheaper in the local Abak area and it has a direct access road to Uyo (Figure 5), so average people can easily acquire land in the local Abak area.

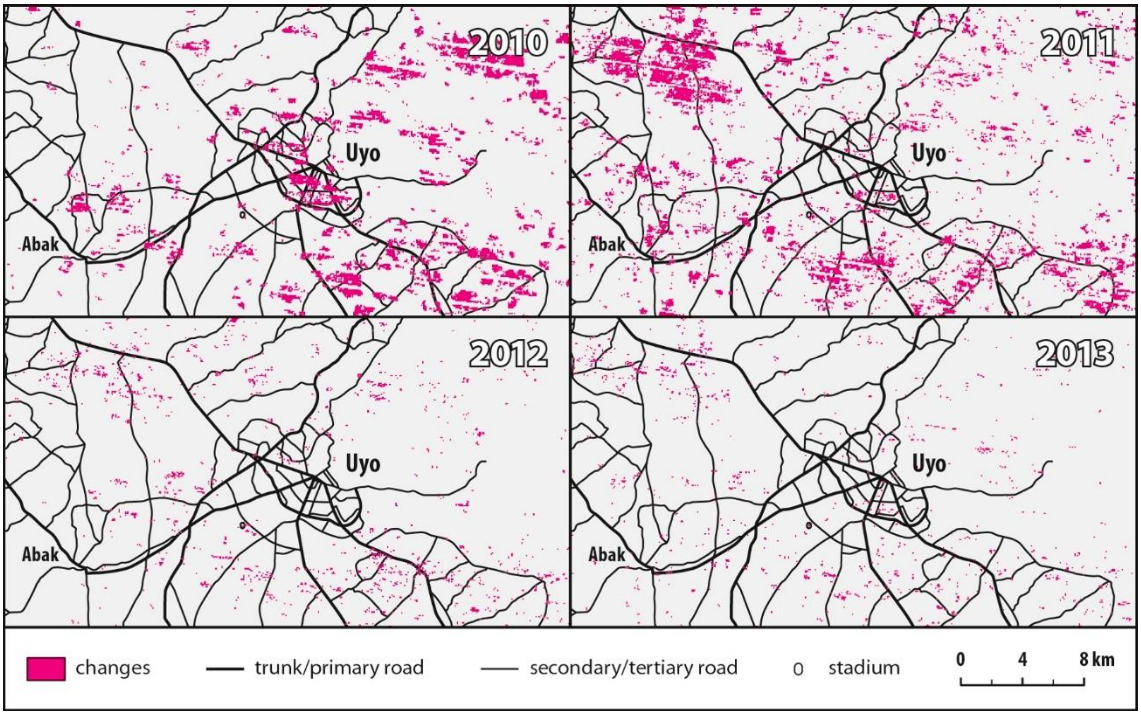

Figure 5. Time series data of Uyo showing changes over monitored years in the study area.

Population statistics of Uyo show that the effect of population growth in the urban areas is faster, while it is slower in the rural areas, because out of the total population of Akwa Ibom State, 78% of the people stay in Uyo. Similarly, other studies on urban development have also shown that population growth is one of the major factors of urban growth in Uyo. Again, with the recent robust allocations from the federal government to the state government, the government tries to make judicious use of the money by investing more in infrastructure development in the city. Thus, Uyo, as the capital city, has attracted several government institutions. The results of this research also show a dramatic shift in land cover change, which corresponds well with changes in structures of land surface and land use in Uyo. This research also shows the direction of land cover change in Uyo, which is moving from the center of the city to the local Abak area (Figure 2). The analysis further shows details of the spatial characteristics of changes in the built-up area in Uyo from the slow development period to the social economic development period from 1985 to 2017 (Figure 2). In general, the increased urban built-up area was caused by changes in economic structure, population growth, and urbanization. During this rapid economic development period, there was an obvious trend of population migration from rural areas to urban regions mostly for the mobility of labor, and this is considered to be one of the important driving forces. The classification accuracy of 95% shows that satellite data were efficiently used to analyze different types of vegetation in Uyo. Further analysis of the results from interviews conducted in the area shows that changes in economic structure, urbanization, and population growth are the most important causes of expansion of the urban built-up area within a limited time scale of 17 years.

Urbanization

Urban expansion is indicated by increased population in an area. The results of the census conducted in 1991 and 2006 in Uyo show a general increase in the populations of urban centers [34]. Urban growth has tremendously increased the urban population and urbanized some nearby rural areas. Consequently, this has resulted in various impacts on the environmental systems on a larger scale [43,47,48]. Another major impact of urbanization is deforestation and changes in land cover/land use. Landsat images of the study area for 1986, 2003, and 2017 clearly explain this effect. The areas of vegetation cover show a drastic decrease. This change can be attributed to new forms of land use, such as infrastructure development. The previous administration constructed a modern stadium with a capacity of 40,000, currently said to be the best stadium in Nigeria, which is frequently used by the national football team. Additionally, there are newly built structures such as Silver Bird Cinema Centre, a five-star hotel with a modern golf resort, newly constructed roads, an E-library, and Ibom International Airport. In fact, all these were built in the last eight years. Figure 2 shows that these new structures have opened new links and development directions toward the Abak area. Population growth has led to the development of houses by the state government in and around the closely settled zones of urban

Uyo to meet the high demand. The state is said to surpass most other states in terms of housing infrastructure delivery [45,49]. The socioeconomic interviews conducted in the area show that investors tend to acquire more land than public workers, and community people are willing to sell their land because the investors are thriving in their businesses and usually purchase the land at high prices. This shows that development triggers the public to invest more in infrastructure in Uyo, and there is a continuous stretch of agricultural land lost to urban growth. Moreover, it shows that there was an intense need for land development due to rural–urban migration and labor mobility during the recent industrialization and urbanization, and this encouraged excessive land use in Uyo and stimulated the growth of built-up lands.

5. Conclusions

All three objectives were achieved in this research. It was possible to perform a robust classification showing a differentiated pattern of land cover change and temporal changes. The results show significant land cover change in the mixed vegetation and forest areas. These areas are close to the center of Uyo for flood control. This was analyzed by using satellite images and running a time series analysis on them. The main observed land cover change trends occurred after 2000, mainly from forest to cropland and sparse built-up. Although the BFAST method to detect changes in vegetation over a long period was appropriate, it could still be improved because it cannot fully detect missing data over a long period. Further research will be needed to discuss this problem. The changes correspond with increasing economic and political decisions combined with poor governance, leading to population growth and unplanned urban development. The master plan of Uyo keeps changing because of infrastructure development by different governments, and this directly affects the unstable land cover change. Therefore, to reestablish Uyo as a state with a secure environment, it is necessary to ensure socioeconomically and environmentally sustainable development. For more insights on differentiated urban development, socioeconomic data should be linked to satellite data to evaluate how household income directly affects urban development and differentiation of urban patterns.

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7 Manuscript 2: Evaluation of Economic Linkage between Urban Built-Up Areas in a Mid-Sized City of Uyo (Nigeria)

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Article

Evaluation of Economic Linkage between Urban Built-Up Areas in a Mid-Sized City of Uyo (Nigeria)

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Abstract: Urban growth has transformed many mid-sized cities into metropolitan areas. One of the effects of this growth is a change in urban growth patterns, which are directly linked with household income. Hence, this paper aims to assess the effect of different economic variables that trigger urban built-up patterns, using economic indicators such as city administrative taxes, a socio-economic survey of living standards, household income and satellite data. The regression model was used and adapted, and a case study is presented for the mid-sized city of Uyo in southeastern Nigeria. The result shows sparse built-up growth patterns with numerous adverse effects. Although, there is awareness of the impact of unregulated sparse built-up growth patterns in the literature, little attention has been given to this growth pattern in Africa. The results also show that increases in federal allocation (27%), investment tax (22%), direct tax (52%) and indirect tax (26%) have led to urban expansion into vegetative land and have a causal correlation with different built-up areas. Hence, medium and high-income earners migrate to suburban areas for bigger living space and a lack of basic social amenities affects the land value in suburban areas. They also assist in the provision of social amenities in the neighborhood.

Keywords: remote sensing; land-use change; urban growth; socio-economic variables; federal allocation

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1. Introduction

Urban growth has transformed the built-up patterns of many mid-sized cities into dense urban areas [1]. Urban growth is seen as the physical expansion or uneven growth of undeveloped areas [2]. One of the many effects of this growth is a change in urban growth patterns, which are directly linked with household income [1,3]. These changes differ through time and space [4,5]. At a global scale, the increase in urban populations is triggered by natural population growth and migration towards urban areas for a better standard of living, education, and income [6–9]. These migration patterns of urban growth have complex economic, social, and governance effects [2]. Individuals migrate to urban areas for different reasons [2], including economic, social, and administrative/political reasons [1].

From an economic point of view, factors such as increases in income, the development of road infrastructure and increases in commuting [3,10–13], and from an administrative viewpoint, factors such as lack of proper planning of suburban areas [2] and unregulated land prices have encouraged residents to move to urban areas for better living conditions [1,14]. All of these factors lead to the desire to move and the construction of different residential built-up areas in urban areas that allow for various lifestyles while maintaining the same access and advantages of living in the city center [1]; thus, encouraging further expansion of urban land. This has also enabled rural dwellers to move to cities, to occupy urban areas and create different types of built-up patterns in these areas [1], and to have the same access to social amenities as well as urban life.

Furthermore, a number of studies report that foreign investment, unemployment, economic and population growth are significant factors for shifts in urban development [9,15,16]. Most urbanization studies focus on large cities due to their massive congestion, high population growth, and socio-economic disparities [17–19]. However, the infrastructural needs that usually trigger urban growth in mid-sized cities are generally neglected [14]. The limited research may be attributed to researchers' lack of attention on urbanization in mid-sized cities compared to large cities [17,18]. Hence, understanding urban development in mid-sized cities is crucial because the early pattern of development in mid-sized cities usually affects the patterns of urban growth in big cities [19]. Besides, small and mid-sized cities were found to lead in major urban transformation into metropolitan cities [19]. In this context, Uyo is a prime example of a mid-sized city with a resource-driven economy. The city has experienced urban growth due to infrastructural development, population, and economic growth [14].

Nigeria is one of Africa's largest developing countries with enormous population growth [20]. It is presently experiencing one of the most dynamic urban transformations in the world [20]. After independence in 1960, the country added more than 62.5 million dwellers to its urban areas, with a forecast projecting a further 226 million inhabitants in urban areas by 2050 [20]. A recent government survey showed a rise in rural–urban migration since independence, and unemployment in the rural areas is the primary cause of this migration [21,22]. In Nigeria, robust economic growth in urban areas has functioned as a pull factor over recent years [20]. Even though the economy has experienced a recession, people still move to urban areas [23]. Although, urban and economic growth are frequently entangled, when properly managed, they can bring new developmental strategies for sustainable urban development [18,23]. Understanding the links between socio-economic and urban development helps to provide empirical information as the basis for proper management.

Urban growth has been measured using different tax variables, for example, Wu [24] evaluated the effect of land taxes on urban residential areas, Brueckner and Kim [25] and Peng and Wang [26] examined the effect of land and property taxes on urban residential sprawl, and Ambarwati et al [27] and Tscharaktschiew and Hirte [28] explored transport policies and the effect of improving the public transport network on a city's residential development. In summary, those studies highlight: (i) land taxes positively impact pressure on urban sprawl patterns, (ii) property taxes are efficient tools for urban growth, (iii) land taxes encourage the use of public transport and limit scattered development, and (v) household settlement depends on social amenities and economic income. However, these studies are mostly based on Asian and European cities. As they mostly assume household incomes based on social amenities or property types, this is quite different to Africa due to the lack of social amenities in many households [3,29]. For this reason, our overall objective was to use Uyo as an illustrative example and analyze the city's administrative taxes, a socio-economic survey of living standards, household income, and satellite data to assess the impact of urban growth patterns in the city. We also aimed to answer the following research questions. (i) How do administrative taxes influence patterns of urban growth? (ii) How do household income and social amenities affect urban land value? (iii) What is the linkage between these socio-economic variables and satellite data?

2. Study Area and Materials

2.1. Study Area

Uyo is situated in the southeastern part of Nigeria between longitudes $37^{\circ}50^{0}$ E to $37^{\circ}51^{0}$ E and latitudes $55^{\circ}40^{0}$ N to $54^{\circ}59^{0}$ N (Figure 1). It is the capital city of Akwa-Ibom State and is located in the center of the state. It has a total area of 362 km^2 and a low-lying plain with no hills. Uyo is one of the largest commercial cities in southwestern Nigeria after Port Harcourt and Calabar, with an estimated population of 305,961 in 2006 and 429,900 in 2016 [30]. Since the colonial era, the city has been the head of administration and became the state capital in 1987 [30]. This has attracted infrastructural development and prompted the governmental authority to design a master plan for the city to cope with unplanned urban regeneration [14], However at present, urban development is inconsistent with the city's master plan [14].

Figure 1. Map of Nigeria showing Akwa Ibom State, and map of Akwa Ibom State showing Uyo. Source: Essien & Samimi, 2019.

2.2. Data Source

In this study, we used three different approaches to create methodological frameworks for this research. These were based on the socioeconomic variables in the study area and adapted from previous studies [31,32]. Firstly, we drew our data primarily from the socioeconomic survey of living standards and household income from the National Bureau of Statistics of Nigeria (NBS). The socio-economic survey is a national household survey that NBS conducts every five years [33]. We used their recently updated data for our analysis. These data capture all the socio-economic activities in the urban areas in all of the states in the country. We assessed data on household income such as agriculture, production, manufacturing, and the formal sector based on their minimum wage (salary scales). We used these data to calculate and classify household income based on low, medium, and high income [33].

Secondly, we used the city's administrative data on federal allocation, direct and indirect tax, and investment tax (Table 1) from the Ministry of Internal Affairs (MIA). MIA is a government ministry that is responsible for all the internally generated revenues of the state. Our focus was on the administrative taxes of our study area (Uyo) because they continue to increase compared to others socioeconomic variables. These taxes are daily or monthly payments made by small-scale or big enterprises, such as new business tax, property tax, construction tax, and urban development tax. These taxes are charged based on location, the purpose of investment, number of employees and total capital.

Thirdly, we used Rapid Eye images to monitor urban land cover change from 2010 to 2018 in Uyo. Rapid Eye ortho tiles have a 5 m resolution and five identical satellites positioned in a single orbit [34]. The satellite has five multispectral bands (blue, red, green, red edge, and near-infrared (NIR)) [34]. These were geometrically and radiometrically corrected. Thus, sensor-related effects were corrected using sensor telemetry and a sensor model. Spacecraft-related and co-registered effects were corrected using high telemetry and useful ephemeris data [35]. We used Rapid Eye orthoimages with a cloud cover of less than 10% and downloaded eleven images for our study area. We captured the images during the rainy season (June and July) and the core period of vegetation growth. Four images cover the entire study area, whereas seven images cover it to some extent. Post-classification results are often difficult to validate due to no field observation at that time [36]. To do so, we collected ground reference data for training and validation through our fieldwork in the study area. We created the sample so that each class represents the actual class proportion in the field [37]. We selected a random sample of 320 pixels and a GPS coordinate point at different land cover classes as reference data with detailed vegetation types to ensure that large sample sizes were available for each class and the data were distributed in proportion to their quantity. We overlaid points at random on the 2010 and 2018 multispectral images [38] to identify each pixel's urban land cover type, which was visibly mixed with other urban land cover types, and examined the variation between the two images. We divided the reference data into two parts, 70% for training and 30% for validation data [39] to statistically compare the different urban land cover types and perform an assessment of the accuracy of the classification. We computed the accuracy assessments using confusion matrices based on 30% of our reference data. We used the user's accuracy (UA), producer's accuracy (PA), the Kappa statistic (κ), and urban land cover class percentage as validation metrics for the different land-use classes [39].

Table 1. Description of the variables.

Independent Variables	Dependable Variables	Description
	Land-use change	Statistical changes that occur in land use over time.
Direct tax		Tax levied directly from individual income or corporate organization by the government.
Indirect tax		Tax levied on the sale of goods by either a manufacturing company or small business.
Investment tax		Tax levied by the government on investors when intending to open a company. This tax depends on the total capital the investor plans to invest.
Federal revenue		An amount paid by the federal government to all the local governments monthly for utilities and projects' maintenance.

3. Methods

3.1. Statistical Analyses

The linear statistics model for this research has been described in detail by [31,32,40,41] with regard to its application, standardization, and validation. The model combines statistical data with numerical analysis, is suitable for predicting urban built-up changes, and can also be used to explore different statistical approaches [31,40]. We choose a total of 5 variables to represent the socio-economic growth of the study area, and they have a minimal collinearity of one based on our variance inflation factor (VIF) test. We measured the socio-economic spatial variation in different built-up areas following the example of [31,32,40] as a guide to explore different socioeconomic variables. The selection of this model depends mainly on the likelihood distribution used to model the dependent and independent variables. Besides, the economic data were arranged sequentially (increase in the federal allocation per year). The model has a Pearson probability distribution and a logIn [31]. Pearson residuals revealed no spatial autocorrelation for data in the study area. We assessed the deviance residuals to examine the potential outliers [31]. Variance inflation factors between the independent variables used in these analyses never exceeded two, and most were significantly less, which showed that collinearity was not a significant issue [31]. The model was used to examine the relationship between different urban land cover types

(low-density built-up area, medium-density built-up area, high-density built-up area, and government built-up area) and socio-economic variables. The linear model equation is as follows:

$$\log(Y) = \alpha + \beta \log(X) + e \quad (1)$$

where Y is the urban land cover type (km^2), X is the socio-economic variable (naira in local currency), α and β are the regression coefficients, and e is the residual error [42]. Regressions were separately computed for each of the urban land cover types, using a coefficient of determination R^2 to validate the model's performance and a high value of R^2 shows a good model performance [42–44] (Table 1). The statistical significance of regression coefficients-based estimation of t-statistic testing for significant coefficients at $p > 0.004$ was considered as an additional measure for the model's selection [42].

3.2. Object-Based Image Analysis

Object-based image analysis (OBIA) is a technique that separates satellite data into significant objects [45]. One of the numerous advantages of using OBIA in image classification is its ability to analyze an object in space rather than a pixel in space [46,47]. One of the common techniques used to generate the object is image segmentation [46]. Segmentation is a method of dividing a satellite image into homogenous objects by merging pixels with similar spectral signatures [48,49]. Segmentation groups pixels with similar features and ensures good image classification results with better accuracy [50]. However, the segmentation algorithm parameters need to be adjusted to get the shape, size, and scale of the resulting object [51], and no generally recognized method is widely used to determine the scale for different environmental applications of OBIA in remotely sensed images [46].

The shape parameter usually determines the spectral homogeneity, while the size parameter balances the object's smoothness [51]. We chose the scale parameter based on how big we wanted our image because the decision on the scale level usually depends on the object's size [51]. We used a weight of 0.2 for the shape parameter to reduce weight on the shape and to produce more homogeneous image segmentation. As well, we adjusted the size parameter to 0.6 to blend the smoothness of the object. After evaluating different scale levels and testing them with different values, a scale level of 20 to 80 was found to be suitable for the study area. We checked the segmented object based on our selected training data, fieldwork knowledge, and differences among the same object classes.

We used K-nearest neighbor (KNN) classifiers to classify the images into different classes and selected samples of training data that represented different classes to reassign each class to the segmented objects [46,51]. This can be achieved in two ways; by giving the classifier the sample of the object training data, and the classifier classifies it based on the nearest neighbors of the sample [46,52]. The advantage of KNN is that it can spectrally separate similar pixels of the same features and assigned segments into different classes with the highest-class confidence value [50]. We used the KNN classifier to identify low-density built-up areas, medium-density built-up areas, high-density built-up areas, government built-up areas, and vegetation (Table 2). We selected these classes based on economic activities in the areas.

Table 2. Land use classification type.

Land-Use Type	Description
Low-density built-up area	Occupied by either high-income or low-income earners depending on the majority of inhabitants in a neighborhood with a similar type of income. Characterized by high rental fees for businesses and residents, high level of security, a lot of undeveloped land, and near the urban designated area that has most of the social amenities.
Medium-density built-up area	Residential area mostly occupied by medium-income earners, near the suburban area and the main road. Affordable rental fees, not too clustered, not so many unsealed streets.
High-density built-up area	These are residential areas mostly occupied by low-income earners. Characterized by many informal businesses, clustered houses, cheaper rents, slums, security problems, many unsealed and filthy streets, unstable power supply, and highly polluted.
Government built-up area	Characterized by government buildings, offices, new infrastructures, and very few residential buildings owned mostly by old occupants of the area.
Vegetation	Low and high vegetation canopy, cropland, football fields, gardens.

4. Results

4.1. Economic Growth in Uyo

Economic growth leads back to an increase in the state government revenue. This revenue includes investment tax, direct and indirect tax, and federal allocation (FA). Hence, the historical revenue data extracted from the State Ministry shows that the federal allocation increased annually from 273.665 million Naira (NGN) (USD 98,519) in 2010 to 4.5 billion NGN (USD 1.6 million) in 2018, with an annual growth rate of 27.01% in Uyo. These increases were due to the push for decentralization and for the state to control its natural resource revenue (oil-rent) [53]. Conversely, investment tax increased from 1.4 billion NGN (USD 504,000) in 2010 to 4.1 billion NGN (USD 1.4 million) in 2018, with an annual growth rate of 22.77%. This tax increase was influenced by informal economic growth. Similarly, the direct tax increased from 1.3 billion NGN (USD 468,000) in 2010 to 9.7 billion NGN (USD 3.4 million) in 2018, with an annual growth rate of 53.87%. The increase in the formal sector, such as education has likely offset these tax dynamics. Furthermore, the indirect tax increased from 7.4 million NGN (USD 2664) in 2010 to 4.8 billion NGN (USD 1.7 million) in 2018, with an annual growth rate of 26.65%. Industrialization, such as open markets, increased petty trading, increases in the labor force and an increase in income have acted as the main drivers of this urban growth (Figure 2).

Annual computation of the results shows that increases in federal allocation (27%), investment tax (22%), direct tax (52%) and indirect tax (26%) have led to urban expansion into vegetative land, and have a causal correlation with different built-up areas (Figures 3 and 4, Table 3). According to [33], the investment tax in Nigeria can be increased or decreased based on the investment value. However, from 2010 to 2018, the minimum investment tax in the country, i.e., small-scale enterprises in the urban area, increased by 20% [33]. Additionally, each of the urban communities are allowed to increase the tax to 40%, depending on the building plans of the investor [33]. Small household investments take place among low-income and middle-income earners. These investments tend to grow and expand to big enterprises, significantly encouraging relocation or expansion to different urban built-up areas for larger investment space and customers (Figure 2). This agrees with related studies [1,31,42] that suggest that changes in the different built-up areas, i.e., a 4% increase in the low-density built-up area, an 11% increase in mediumdensity built-up areas, and a 0.6% increase in high-density built-up areas (Table 4) are triggered by economic growth. Additionally, real estate (rental) values have increased for middle and high-income households (up to +2%) and decreased for low-income households (up to −0.4%) (NBS, 2020), making the household distribution in the urban areas relatively uneven [14].

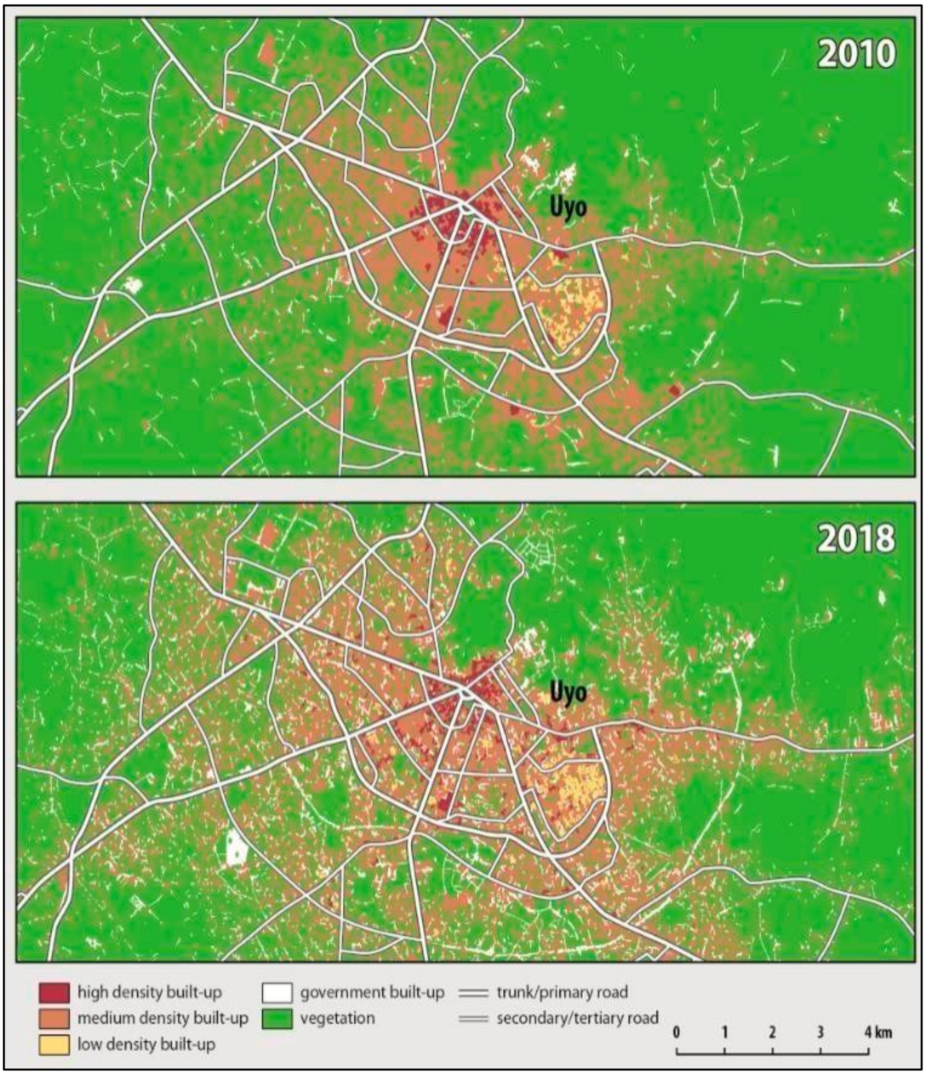

Figure 2. Urban land-use land cover changes in Uyo.

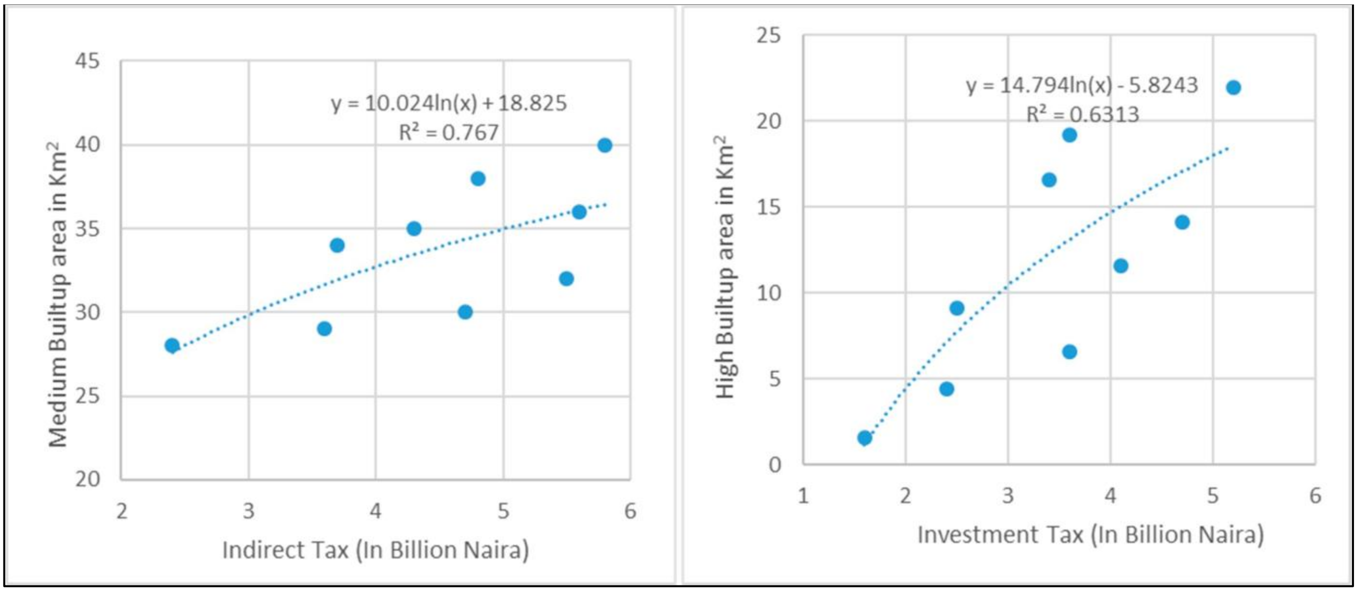

Figure 3. Relationship between socioeconomic variables and medium-density built-up areas in Uyo from 2010 to 2018.

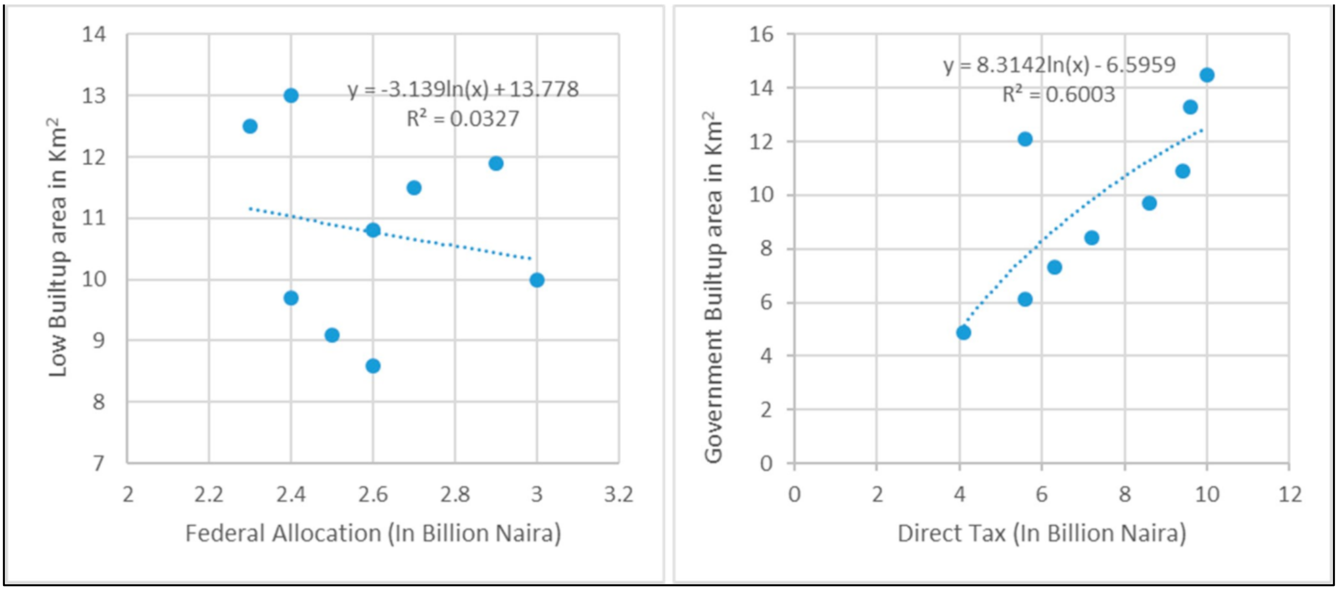

Figure 4. Relationship between socio-economic variables and government built-up areas in Uyo from 2010 to 2018.

Table 3. Correlation coefficients between socio-economic variables and built-up areas.

Direct Tax	Indirect Tax	Investment Tax	Federal allocation
0.03***	-0.56***	0.71***	0.62***

Table 4. Land-use change statistics in Uyo from 2010 to 2018.

	Area(km²) 2010	Area(km²) 2018	Land-use %	Land-use change (%) 2010 - 2018	Annual change (km²/yr.)
Low-density built-up	8.6	13.0	6.0	4.4	0.5
Medium-density built-up	28.4	40.3	19	11.9	1.5
High-density built-up	1.6	2.2	3.0	0.6	0.7
Government built-up	4.9	14.3	8.8	9.3	1.2
Vegetation	43.5	26.7	63.8	-16.8	-2.1

4.2. Social Amenities in the Urban Area

In our analysis, there was evidence of lack of basic amenities for urban dwellers [33], and according to a recent survey by NBS 2020, there has been an increase in informal settlement across the city. In total, 35% of urban respondents in Uyo have been living in an informal settlement for more than ten years [33]. Few were even born there [29,33], suggesting that despite the government's infrastructure development and claims, the inhabitants of those areas are homeless people [33]. These are urban migrants that cannot afford a better standard of living and have decided to wait for an economic shift. Further, these informal settlements are generally connected to infrastructural development by the government, which demolishes the buildings to build modern infrastructure and create access to basic needs such as water, electricity, and security.

However, informal settlements find it challenging to access these services. A few high-income earners sometimes reside in medium and low-density neighborhoods because land is relatively cheap compared to low-density areas. They buy up large areas, clear it and construct magnificent buildings for residential or commercial purposes with high-end facilities and amenities. Low-income residents sometimes have to pay these high-income neighbors as their alternative suppliers of basic amenities such as water and power because it is relatively cheap and reliable compared to the public services [29]. Half of the city population has no access to purified drinking water; 50% of urban dwellers drink borehole water, 20% rainwater, 10% surface water, and 12% drink improved bottled water [33]. These statistics (Figure 5) show the variation in the provision of quality water, an essential social need, indicating there is almost no water supply from the government. Nevertheless, 70% of urban households still rely on water sources such as rainwater and boreholes that are widely associated with waterborne diseases such as diarrhea and cholera [33].

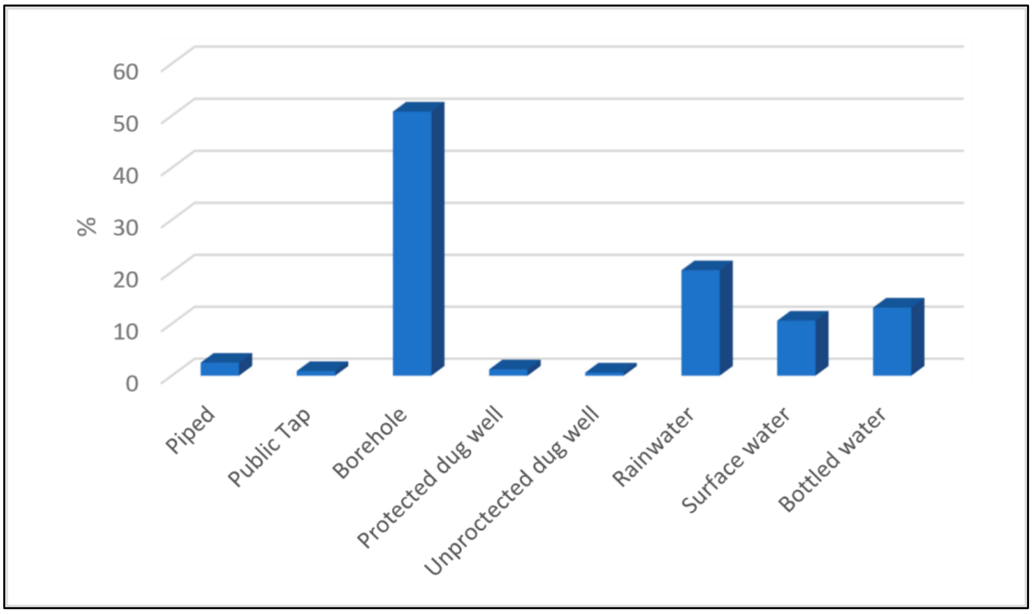

Figure 5. Drinkable water in the urban area in Uyo.

Furthermore, no settlement in Uyo has a constant public power supply. The data shows that about 61% of urban dwellers have access to electricity. Still, an estimated billing system, the high cost of electricity, and frequent energy outages have meant that many urban households rely on an improvised alternative power supply, such as gasoline and fuel power-generating plants [29]. These power-generating plants cause constant environmental and noise pollution [29]. Many urban businesses also rely on this source for their daily use. Again, high-income earners switch on their security street lights at night, which serve as an alternative light at night to avert urban crime in the neighborhood [54]. This has encouraged urban communities to sell land at a reduced cost to these high incomes earners with the hope of bringing development and social amenities to their urban neighborhoods. Hence, low and high-income households reside close to each other in the urban area (Figure 2), thus creating a different pattern of urban growth in the city. Although, there are government agencies that regulate urban built-up patterns in the area, their rules are weak and ineffective due to the personal gain they derive from high fines and taxes from urban defaulters [29].

4.3. Household Income

According to NBS data at the state level, the monthly household income of low-income workers ranges from N 20,000 to N 40,000 (65%), from N 50,000 to N 100,000 (21%) for medium-income workers, and from N 100,000 to N 500,000 (14%) for high-income workers [33]. The level of income has played a significant role in urban growth in these areas, i.e., a low-income household sometimes sells off their inherited land or property to educate their children and provide for their basic needs [33]. Also, some families are been rendered homeless due to governmental infrastructure development that cuts across their inherited landed property without adequate compensation to property owners [55]. The Nigerian Land Use Act counters the land tenure system of land ownership, and the authority attributes all undeveloped lands to the state [55]. Hence, low-income earners easily sell their land for development purposes to high-income earners to avoid it being taken with force by the government. This has created visible segregation within urban communities. Low built-up areas are occupied by either high-income or low-income earners (Figure 2), depending on the majority of inhabitants in a neighborhood with a similar type of income. The high-income earners often collectively contribute to infrastructural development [33], hence encouraging the relocation of businesses and migration to new settlements, resulting in an unplanned cluster pattern of urban expansion within these neighborhoods.

Notably, the effect of income inequalities has created different patterns of urban growth among urban dwellers. While 14% live in affluence and have a lot of landed property in different urban built-up areas, 65% live below the average living standard [33]. The authorities have tried to bridge these income inequalities by providing microeconomic loans for low-income earners (non-interest loans to start or support their businesses) and creating jobs for different classes of its urban dwellers [29]. However, most of these jobs are formal and mainly in the educational sector (Figure 6) due to the insignificant number of manufacturing industries in Uyo (Figure 6) [29,33]. The occupants depend mainly on imported goods, and the government relies on the revenue from natural resources for the city's maintenance and development [29]. The authority should support investors in creating more manufacturing and innovative industries to provide more opportunities to low-income earners.

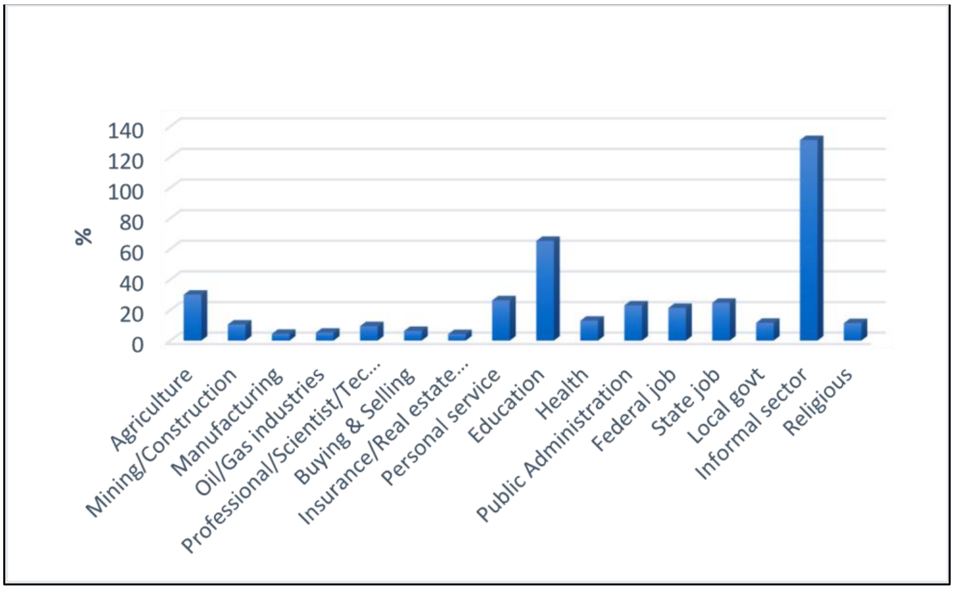

Figure 6. Employment sectors in Uyo.

4.4. Urban Land Cover Change in Uyo

Land-cover change in Uyo had an overall accuracy of 89%. In 2010, the user and producer accuracy were 89% and 86%, and in 2018, they were 84% and 83%, respectively. Accuracies at the urban land-cover class level were more varied, i.e., the user accuracy for 2010 changed from 88% to 96% for low-density and government built-up areas, respectively. For other classes, a similar pattern was observed, with the high-density built-up area having the lowest user accuracy of 86% in 2010 (Table 5). Equally, vegetation and highdensity built-up areas had the highest accuracies of 97% and 99% in 2018, respectively (Table 6). In general, about 5.6% of the land-cover class in Uyo experienced a tremendous transformation within these eight years (2010-2018). Low-density built-up and government areas experienced an increase in area, with increases of 13.0 km^2 (4%) and 14.3 km^2 (9%), respectively, from 2010 to 2018 (Figure 2). From the interval-based analysis, variation occurred at diverse rates depending on the land-cover type. Medium-density built-up areas also experienced the highest increase of 40.1 km^2 (11%) in 2018 compared to its size in 2010. Similarly, the high-density built-up area increased in size over the period by 2.2 km^2 (0.6%), with most of these areas converted from vegetative regions. For this reason, vegetative areas had the highest area loss of 26.7 km^2 (16%) between 2010 and 2018 (Table 4).

Table 5. Rapid Eye 2010 image classification confusion matrix class.

Class	Low Density Area	Medium-Density Area	High-Density Area	Government Area	Vegetation	UA
Low-density Built-up	34,403	0	5	7	0	88%
Medium-density Built-up	2	1,137,207	0	9	0	88%
High-density Built-up	0	0	64,968	0	0	99%
Government Built-up	0	14	0	199,704	0	86%
Vegetation	0	2	0	0	5,035,248	97%

UA = User Accuracy, kappa statistic = 0.715.

Table 6. Rapid Eye 2018 image classification confusion matrix class

Class	Low Density Area	Medium Density Area	High Density Area	Government Area	Vegetation	UA
Low Density built-up	52,261	0	0	9	0	90%
Medium Density built-up	13	1,614,859	6	0	0	89%
High Density Built-up	0	19	89,028	4	0	86%
Government Built-up	0	0	7	573,926	0	91%
Vegetation	0	0	0	3	4,141,456	98%

UA = User Accuracy, kappa statistic = 0.89.

Urban land change has occurred arbitrarily across Uyo for different land-cover types (Figure 2). Vegetation areas have continuously decreased in size as the built-up area has increased in size. Increases in the informal sector have continuously decreased the size of vegetative land areas (Figure 2). For example, the low-density built-up area gradually changed to medium-density built-up and government areas due to increased population density and infrastructural development, such as access road networks and electricity installation [14]. Similarly, medium and high-density built-up areas experienced significant growth across the study period due to urban regeneration [14]. These results show that urban expansion has created different patterns of land cover types, negatively affecting agricultural land (Figure 2).

Tables 5 and 6 provide object-based classification accuracies results. The overall accuracy of the classification was 84.6% in 2010 and 89.6% in 2018. The classification showed a kappa coefficient of 0.715 and 0.824, respectively. The overall accuracy in government and medium-dense areas was 88% and 86%, respectively. However, it was difficult to distinguish the government area from the road because both pixels were classified as one using the K-nearest neighbor OBIA method.

5. Discussion

The results of our study demonstrate the use of city administrative taxes, a socioeconomic survey of living standards, household income, and satellite data to assess the primary drivers of urban growth in different built-up areas in Uyo (Figure 2). We performed an analysis on the socio-economic variables using an approach adapted from [31,32,40,41] in the study area. According to the NBS 2020 statistical data for Uyo, low-density built-up areas are situated near the designated urban area. Households in the medium-density built-up areas are near suburbs and the main road, and households in low-density built-up areas live near the urban periphery. These results affirmed that the availability of social amenities is an indicator of economic growth [56], which triggers a continuous increase in all built-up patterns due to urban infrastructural development that is mostly intertwined with economic growth [57].

Results for the link between socio-economic variables and urban built-up areas show a positive correlation with major variations in the urban built-up areas (Figures 3 and 4). This agrees with [58], who suggested that most cities use their revenue for development purposes, especially where most urban dwellers are not farmers. However, our findings provide new insight into some of the reviewed literature [56] that sees land revenue as an efficient tool for steering urban growth and increasing construction in existing builtup areas. Hence, the future effect of this increasing revenue in cities tends to be more predictable and does not depend on any urbanization issue such as housing density [59]. To this end, our study calls for guiding frameworks to be developed when investing city's revenue in infrastructure and social amenities. Revenue can be used to plan and shift urban development to all communities in the city.

Furthermore, our satellite data are not counter to other similar studies on the effects of socio-economic growth on urban growth patterns [31,32,60,61]. However, our land cover classification provides comprehensive urban land cover change data for Uyo in southeastern Nigeria. Previously, urban land cover data for Uyo were only at a 30 m spatial resolution [14,62,63], while studies using high-resolution data (5 m) have been limited in Africa, even at the national level. Constraining urban drivers' understanding of change in various urban land cover classes has resulted in an undefined path for projections on urban land cover change. The 89% accuracy of our map of urban land cover change linked with socio-economic variables makes it appropriate for use as a high multi-temporal resolution map that shows the key drivers of urban land cover change. Furthermore, our research has shown the vital role that informal economic growth in southern Africa has played on urban expansion.

Data Uncertainty

The setting of segmentation parameters that control the size, shape, and scale of the object probably affects the classification of the images [51]. However, our different trials regarding this parameter setting affect our classification results because our study area is characterized by different anthropogenic effects. Delineating the boundaries of objects was not easy due to the absence of sharp or hard boundaries.

Land cover types such as high-density built-up areas have no shape or clear boundaries, while government built-up areas were difficult to separate from low built-up areas due to low contrast. However, our accurate delineation of land cover objects might have been time-consuming, but we were able to get homogenous objects for each of the classes. We defined urban land cover classes based on our extensive ground reference data of the area. The training dataset was large enough, so the minority classes were not under-predicted to favor the majority classes in the training data [64]. However, some uncertainties still exist, with a few misclassifications, which mainly occurred in the lowdensity, medium-density, and government built-up areas (Tables 5 and 6). There was higher uncertainty in the 2018 classification of the urban land-cover class level. There was confusion between medium-density and government built-up areas and confusion between high-density and government built-up areas (Table 6). We believe this effect was very minimal.

6. Conclusions

This study assesses urban growth patterns using economic indicators such as socioeconomic variables, the socio-economic survey of living standards, household income, and satellite data in different urban built-up areas. Our results are supported by other studies and are the first for sub-Saharan Africa. The results for the city of Uyo shows that (i) an increase in socioeconomic revenue has led to urban expansion and there is a causal correlation with different built-up areas, (ii) a lack of basic social amenities decreases the value of land in the suburban areas, and (iii) medium and high-income earners often migrate to suburban areas for bigger living space. Although, this urban growth pattern is widely recognized as a problem for urban planners, these results contribute to creating awareness of the weak urban planning laws in the study area and in other African cities. They could also guide the monitoring of urban growth in different urban land cover classes. Similarly, our study could also be used to redesign the city and aid in sustainable urban management, and help the authorities globally with spatial planning to monitor unplanned urban growth.

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8 Manuscript 3: Impacts of Governance toward Sustainable Urbanization in a midsized City: A Case Study of Uyo, Nigeria

Etido Essien

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Impacts of Governance toward Sustainable Urbanization in a Midsized City: A Case Study of Uyo, Nigeria

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Abstract: Urban studies in Nigeria mostly focus on large cities and metropolitan areas, with minimal attention given to sustainable urban development in midsized cities. In this study, we address this knowledge gap and examine the policies and practices driving urban growth in Uyo, a midsized city in Nigeria. Specifically, we evaluate to what extent the prevailing urban governance culture and practices move the city toward or away from being inclusive, safe, resilient, and sustainable—central tenets of UN Sustainable Development Goal (SDG) 11. This study critically explores the strategic and operational approaches deployed by public stakeholders in pursuit of urban development, housing security, and economic and infrastructure development. We find the lack of continuity in commitment to urban infrastructural development projects and a flawed land tenure system that exacerbates housing insecurity are the two most critical challenges to address in attaining the goals of SDG11 in Uyo. The former calls for better fiscal management and adoption of good governance practices across the administrative hierarchy. The land tenure system can be made equitable and less cumbersome by overhauling the 1999 Land Use Act law of the country. Our findings can inform policies to make midsized cities facing similar challenges more inclusive, safe, resilient, and sustainable.

Keywords: urban sustainability; land tenure; urban growth; governance; development; urban planning

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1. Introduction

The number of people living in urban areas has increased rapidly over the past decades, especially in developing regions of the world [1]. The urban growth in many developing countries has been much faster than the pace of infrastructure development [2]. Furthermore, the growth of small- and midsized cities has been a major contributor to high levels of urbanization [3]. Though Africa's high urbanization rates may look similar to those of other rapidly growing cities, it is important to note that factors that drive urbanization in this continent operate differently from those experienced in developed countries and even in other developing countries [4,5].

Nigeria is one of the largest countries in Sub-Saharan Africa, and has been the third most rapidly urbanizing country after China and India [6,7]. Farrell (2018) contended that most of the emerging cities in Sub-Saharan Africa are in Nigeria. Indeed, 50% of Nigeria's population resides in urban areas, and the urban population is projected to reach 87% by 2050 [7,8], which will require massive infrastructural development [1,9,10].

To date, most of the rapid growth of the cities in Nigeria has happened in an unplanned and unrestrained manner [9,11]. This points to the fact that both scientific and policy approaches to sustainable urban growth must urgently address these issues [12,13]. A review of the literature shows different approaches to how changes in technology, economic conditions, and governance influence change in cities as they develop [14] in addition to economic growth, demographic change, and environmental factors [15–17].

Globally, urban studies typically focus on large cities and metropolitan areas, with minimal attention given to sustainable urban development in midsized cities, characterized by widespread urban poverty and degradation of infrastructure [2,13,18,19]. Many midsized cities, having been subjected to various infrastructural development projects over the years, have experienced uneven urban growth, due to a lack of proper planning that takes into account urban sustainability [20]. Further, most urban studies rely on statistics from the United Nations, World Bank, and African development reports, which rely on official national data. To our knowledge, no other study in the African context has evaluated urban governance-based fieldwork and local data to compare cities' progress towards SDG 11 goals. In this study, we evaluated the prevailing urban governance culture and practices in Uyo, a midsized city in Nigeria, to identify which governance factors are the most influential in moving the city toward or away from being inclusive, safe, resilient, and sustainable— central tenets of UN Sustainable Development Goal (SDG) 11—which acknowledges that a multitude of factors can influence urban sustainability both through strong national policy commitments and local governance initiatives [8,18]. To this end, we use Uyo as a representative case study to address the following questions: (1) What, if any, strategic and operational approaches are deployed by public stakeholders toward sustainable urban development in Uyo? (2) How do governance practices affect the economic growth, housing security, and infrastructural and urban development in Uyo?

2. Study Area and Materials

2.1. Study Area

Uyo, the capital of the state of Akwa Ibom, is a midsized city in Nigeria that has been rapidly developing over the past few years due to an increase in allocation of the state oil rent revenue in 2006 [21,22]. The state of Akwa Ibom is located in southeast Nigeria [20], and receives the highest oil rent revenue from the federal government compared to other states in the country, because the state has the highest oil production in the country. This revenue has prompted rapid infrastructural investment within the city [20,23], and has also resulted in the rural–urban and interstate migration of people to the city in search of better living conditions [24]. In 1960, the population of Uyo was 36,061, which grew to 847,480 by 2015 and is estimated to reach 1,135,775 by 2020 (Figure 1), representing a 6% annual change [25]. Thus, the city´s population increased more, when it became the capital of the state in 1987 [24]. The city has attracted citizens from different ethnic groups with varying socioeconomic backgrounds. As it is the capital of Akwa Ibom, substantial financial resources have been channeled toward modernizing the city by successive governmental administrations [20]. Consequently, Uyo has been one of the few cities in Nigeria that has experienced continuous urban growth in recent years [23] (Figure 1). Urban growth in the city is relatively high compared to that of its neighboring cities because there are greater job opportunities and relatively better access to basic social amenities. However, one of the biggest problems in the city is the socio-spatial segregation of communities from different backgrounds [20]. Interactions among the different groups of urban dwellers across the city create challenges as well as opportunities in employment and education [6]. However, poor governance and planning practices have contributed to an increase in social and economic inequalities among its residents [26].

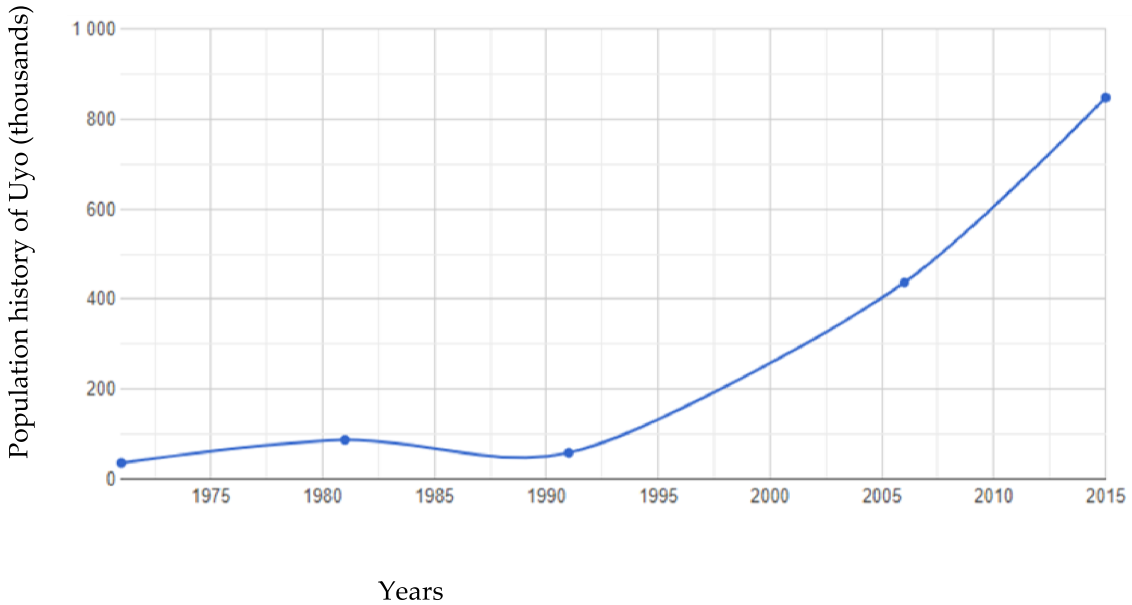

Figure 1. Urban population growth in Uyo (source: NPC, 2015).

2.2. Data Collection

In Uyo, qualitative data were examined and presented through a narrative event explored by the interviewers; as well, we reviewed governmental documentation data from each ministry related to urban development, which were examined and are discussed in our results. A structured technique and approach taken from [27,28] were used in formulating our research questions to answer important questions such as: How many projects have been completed, abandoned, or are still in progress since 2000? What is the role of the community in every project planning process? What are the criteria for compensation and what further provision does the government make to assist displaced people? The interview guide questions were presented to the respondents as a checklist and had been given to the respondents before the interviews. The checklist questions were designed as a guide for understanding and interpretation of the data [29].

Furthermore, we reviewed data from the state government's infrastructural development projects of each of the government ministries from 2000 to 2018 to gather more knowledge about the development strategies in the study area, because this was the peak period of infrastructural development in the city [20]. These data include project awards and commissioning, fund allocation to different sectors, housing schemes and policies, population growth, urban infrastructural development and maintenance plans, which were compiled to assess the developmental trend and future sustainable plans [8,30]. We critically studied all of the gathered information to evaluate to what extent the policies were aligned with the guidelines stated in SDG 11 to make cities inclusive, safe, resilient, and sustainable.

3. Method

3.1. Structured Interviews

The data for this research were collected through structured interviews, fieldwork, and a reconnaissance survey of the city. We followed the approach suggested by [27], that 10 to 20 in-depth interview cases are adequate to obtain information. However, a higher number of respondents could be used if more respondents were accessible and willing to take part in the interview process [28]. As well, we visited different infrastructural facilities in Uyo's urban and suburban areas to establish detailed knowledge of the existing urban growth. We also reviewed governmental documents to assess the urban governance and policies in the city.

First, we conducted discussions and interviews with key urban policymakers to obtain information about government policies and planning in response to the rapid growth of the city. During this process, the focus was on six target governmental ministries related to urban planning, policy, and economic development, and 60 public participants (Table 1). These were the Ministry of Works, the Ministry of Land and Housing, the Ministry of Economic and Rural Development, the Ministry of Urban and Town Planning, the Ministry of Internal Revenue, and the Ministry of Information and Strategy. We identified one key respondent from each of these ministries. The criteria for the selection of these key respondents were based on their rank (directorate level) and the number of years they were employed in the ministry. The respondents were people that had at least twenty-five years' experience working with different governmental heads.

Table 1. List of key respondents in different sectors.

	Key Respondents	Positions
1	Ministry of Information and Strategy	Director
2	Ministry of Work	Director
3	Ministry of Land and Housing	Director
4	Ministry of Economic and Rural development	Director
5	Ministry of Urban and Town Planning	Director
6	Ministry of Internal Revenue	Director
7	Community Stakeholders	Leaders
8	Academic sector	Researchers

9	Commercial Businesses	Business owners
10	Public servants	Level 12
11	Private professional experts	CEO

3.2. Qualitative Data Analysis

The interpretation and grouping of the classified data were done following theoreticalbased models proposed by [31]. The objective was to group different classes of data to obtain information about factors that influence urban sustainability in the study area. The interview was structured with insightful questions and guided checklist questions. We began each interview by elaborating on the objective of the interview to the respondent, to inform the respondent on how the generated data would be used to respond to our research questions. We used a three-step data framework of grouping data into different categories [31]. This approach separates data that are similar to each other based on respondents having the same questions [27,28]. Most of the responses were similar, and we computed them to generate data. We grouped similar data into the same categories and extracted vital information from the data. Our findings are discussed in detail in the sections below.

4. Results and Discussion

4.1. Economic Growth in Uyo

Sustainable economic growth can drive high production levels, create modest jobs for all and encourage entrepreneurship [8]. This would entail accountability and responsibility that would bring changes within the different economic sectors in various communities and economic enlightenment to handle its impact on society and urban areas [8]. In Uyo, according to the interview results (Figure 2), economic reforms and infrastructural development have transformed the city into a rapidly growing urban area due to high revenue obtained from the extraction of its main natural resource (crude oil) [20]. These revenues, channeled from the federal government, have been the primary source of income driving the state economy for years, even though the state government had created a few industries within the city neighborhoods, such as a paper mill in Oku Iboku and a paint factory in Etinan [32]. These industries create employment for the young labor force, and also aid in sustaining the economic growth of the city and the state. Moreover, a significant chunk of the generated revenue is reinvested in the city because of its position as the state capital based on our government data report.

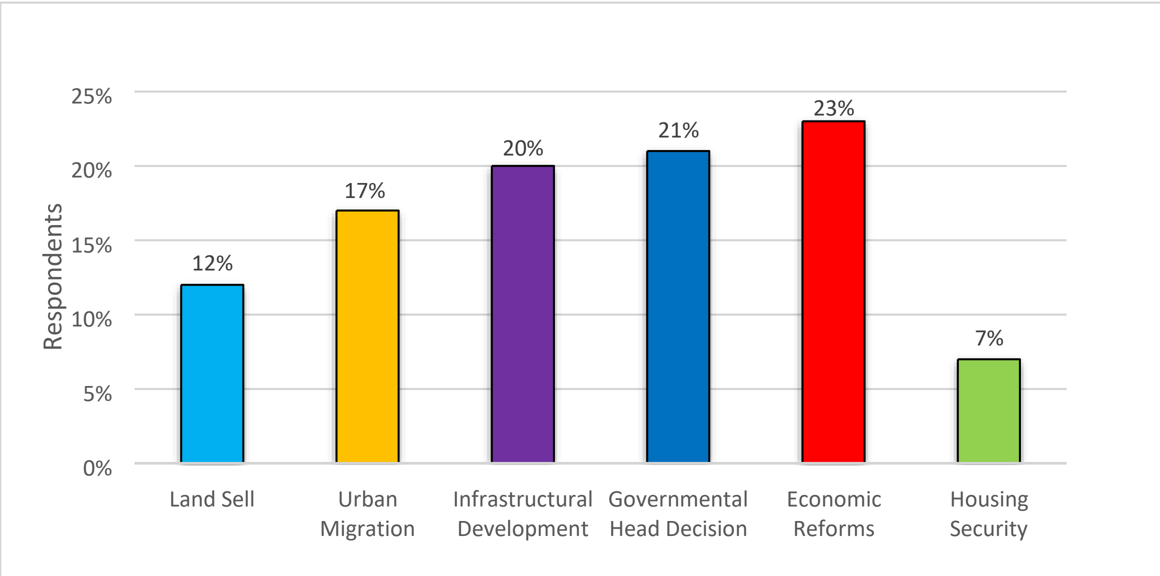

Figure 2. Factors influencing urban growth in Uyo.

Economic growth and reform (Figure 2) have also created employment in different sectors of the city economy (Figure 3), but manufacturing is among the slowest-growing sectors, despite most of the labor force increasing (Figure 3). Studies have shown that manufacturing industries managed by the governments in some African countries have struggled in contemporary times [5], even though there have been improvements in the education and informal economic sectors (Figure 3). These results were attributed to governmental decisions (Figure 2), the frequent turnover of governmental administrations, poor accountability, and the collapse of state-owned industries (Figure 2). This probably explains why the Nigerian government has recently embarked on large-scale privatization of state assets built during the post-independence era [33].

In response to unplanned urban growth in the city, the state's masterplan was redesigned toward achieving its urban development plans [20]. However, though few heads of administrations have focused on completing the projects that were already initiated prior to their terms, most instead emphasize creating small-scale industries such as pencil, toothpick, and cassava processing mills to provide quick employment opportunities for the growing labor force and export purposes. However, because of poor product quality and inconsistency in these industries, the goods manufactured with these raw materials are rarely used within the state, being more expensive than comparable products on the market, and are not exported as intended. Furthermore, the funds generated from these companies are misused [34].

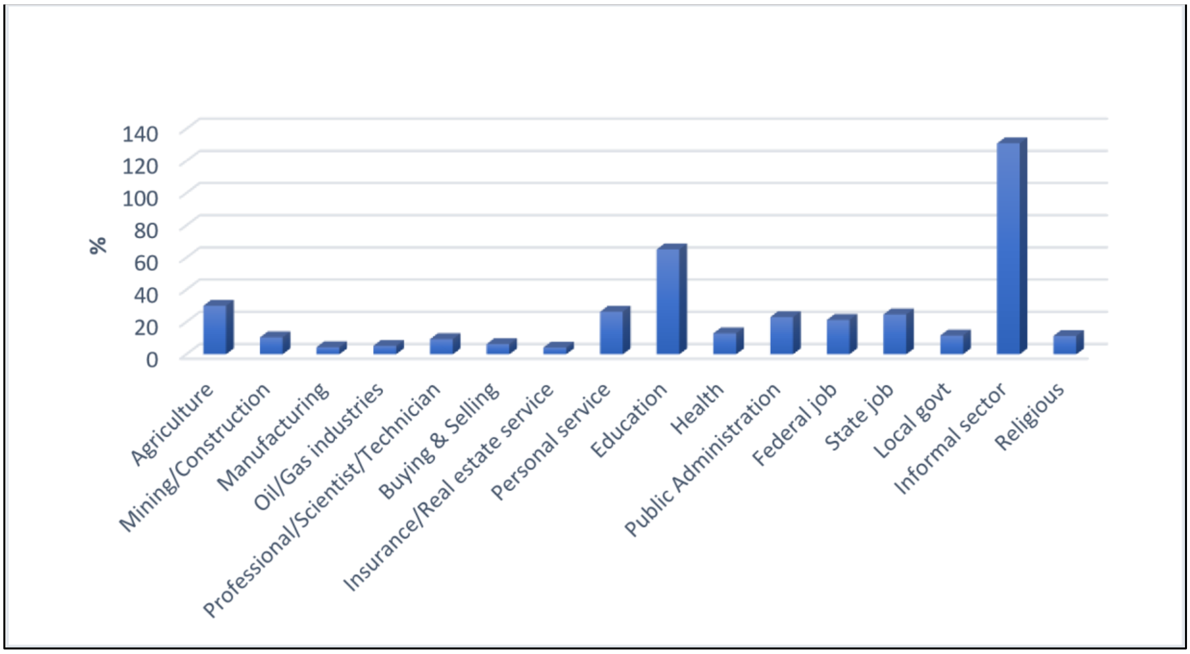

Figure 3. Employment sectors in Uyo (source: Essien & Samimi 2021).

Consequently, these industries usually fold up at the end of the tenure of the administration that opened them due to changes in management by the new government (Figure 2). Based on our respondents' data, governmental decisions (Figure 2) have hindered the successful, sustained diversification of the city's economy, which is essential to attain SDG 11. Our data show (Figure 2) that governmental heads channel most of the revenue generated from natural resources to investment in small-scale projects with different products, such as wine, tomato, and flour mill industries. Although these industries were meant to alleviate poverty by providing employment to citizens, they were also designed for export to boost the economy [35]; however, these goals do not appear to have been achieved and do not support SDG 11.3, which entails sustainable planning and management in all countries. To address these issues, government administrations need to focus more on the continuity of governmental projects and the regulation of small-scale businesses in urban areas. This would also help governmental heads assess how their economic growth plans align with SDG 11.A, which endorses positive economic growth.

4.2. Large-Scale Infrastructural Development in Uyo

Sustainable infrastructure development must be inclusive and respect human rights; that is, such infrastructure must meet the needs of the poor by increasing infrastructure access, supporting general poverty reduction, and positively impacting GDP per capita [35]. However, the development trend in Uyo shows that the city is yet to follow any of the strategies that may lead to sustainable and just urban growth in the provision of energy, water, and affordable housing [36]. Based on the reviewed governmental data, there are no plans to provide a structured public transportation system in the city to reduce traffic congestion. The government efforts instead center on improving road infrastructure and providing free education for primary and high school levels.

According to some of the governmental respondents, a major urban transition of Uyo depends on infrastructure development, but sustaining this development is a major concern for stakeholders. There are many urban sustainability problems in Nigeria, such as poor energy supply, unregulated water supply, indiscriminate sewage disposal, unpaved streets, and loss of urban vegetation [37]. Due to their importance for quality of life and economic development, some administrations have tried to mitigate some of these problems. For example, past administrations invested more in roads, yet the city is still congested because infrastructure for public transportation, such as buses and railways, has been neglected. The respondents highlighted that most of the large-scale infrastructure in the state does not serve its intended purpose.

Based on our governmental data, the state invested USD 1 billion into building a power plant for reliable energy supply to the city, but abandoned the project after a change in administration, claiming the project went over budget. Hence, parts of the city have no electricity, while others experience frequent outages. Most occupants and companies use alternative means of power supply, such as power generators, causing a lot of noise and air pollution [38]. In addition, most government-sponsored projects take much longer than scheduled to complete because of poor planning and lack of proper oversight.

Furthermore, some respondents are concerned that most of the large-scale investments in the state do not receive any capital return. Based on our review of the governmental data, the administration invested USD 52.3 million in buying the first state-owned commercial airline (Ibom Air) in the country, rather than maintaining the recently constructed airport that was aimed to function as an international airport. Due to the state´s geographical location, the airport was to serve not only local travelers but also international travelers of the southern region of Nigeria. The most pressing question is what are the existing plans and policies to sustain such investments from collapsing at the end of each government's tenure. Policies that encourage such investments tend not to be linked with the SDG

11.3 target.

4.3. Housing Security in Uyo

The very first target of SDG 11 stipulates ensuring access for all to adequate, safe and affordable housing and basic services, and upgrading slums by 2030 [8]. The UN report states that the provision of affordable housing and shelter is a fundamental human right, and it is considered an essential requirement of better living conditions [39]. Although major inequalities exist among many urban dwellers, there is a critical need for better housing conditions in developing countries [39], particularly with their rapidly growing urban centers and populations, adjudged to be the fastest growing in the world [40].

Uyo is one of the few capitals in Nigeria where a remarkably high proportion of state population resides in the city [24], and according to the respondents, the city has experienced drastic population growth due to migrants coming from poorer parts of the country in search of better opportunities (Figure 2). Consequently, housing costs are high in the city center, and this has generated heterogeneous patterns of built-up areas (Figure 4). Public housing programs meant for middle-income earners and civil servants are grossly insufficient to meet demand (Figure 5); also, qualifying for such housing means overcoming many bureaucratic hurdles [35,40]. This situation results in people sourcing alternative means of housing such as converting cargo containers meant for importing and exporting goods to dwellings and shops on the suburban fringes of the city (Figure 4).

In our review, many of the respondents adjudged the poor housing security in Uyo to formal residential buildings often being demolished to open up space for the construction of various public infrastructure projects, such as the construction of a recreation center (Ibom Plaza) and an overpass (Atiku Abubakar). Although the development of the overpass has helped boost economic integration of the city with other states and eased traffic, many people were forcefully displaced and poorly compensated for the loss of their homes and properties for development purposes (Figure 2). This resulted from the 1999 Land Use Act law of the country, which posits that all land within the state belongs to the government [41], and as such, the compensation paid to such individuals only reflects the value of the existing building structures or agricultural crop grown on the land.

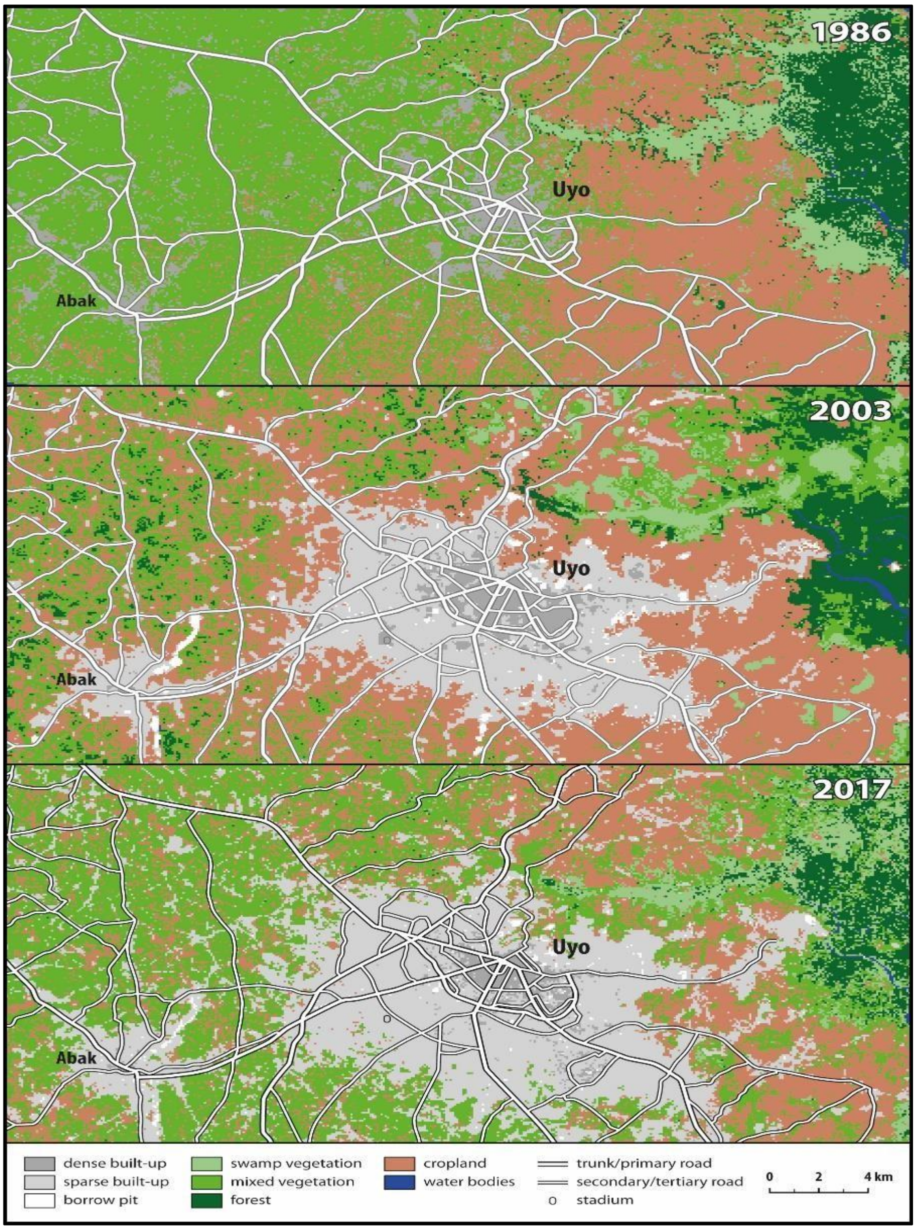

Figure 4. Land cover maps of Uyo for 1986, 2003, and 2017 (source: Essien & Samimi, 2019).

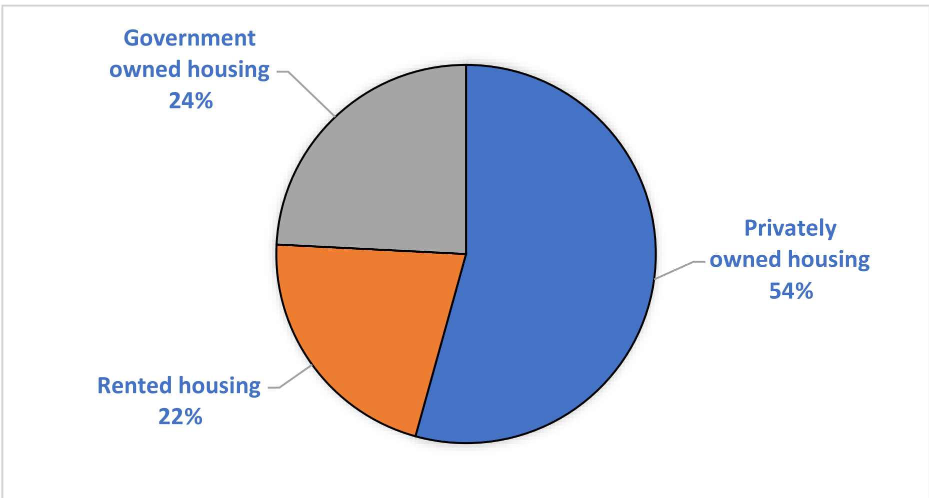

Figure 5. Breakdown of housing type in Uyo.

Based on data from respondents in the governmental ministries, there have been government initiatives in the past to build affordable housing units for the civil servants in the state, but these initiatives were hijacked by corrupt politicians who claimed to be civil servants to buy the houses and resell them at a higher rate to the general public. Therefore, in addition to the provision of affordable housing for low-income citizens through governmental funding, there should also be legislation to regulate housing prices within the urban centers [35]. However, at present, there is not even an affordable housing plan for non-governmental and low-income earners. This is contrary to SDG 11.1, which supports affordable and adequate housing for all.

4.4. Governance Practices

Urban governance in Nigeria is highly compartmentalized, without adequate interdepartmental collaboration [42]. Moreover, the state planning authority (i.e., the Ministry of Town Planning and Rural Development (MTPRD)) rarely adheres to its stated environmental planning ethics or follows its existing master plan [43]. Though this ministry was tasked with planning and ensuring that every approved building meets specified quality levels and standards, most buildings are approved without proper scrutiny. Importantly, it is expected that more than 60% of the urban centers to be opened in Nigeria by 2050 have yet to be planned [6]. This calls not only for provision of strict planning laws but also their effective enforcement by public stakeholders to regulate urban infrastructural development [40].

According to the information gathered from the governmental ministries and related literature of many other developing countries [5,40], Uyo follows a system of disbursing funds from the state to the local governments, and this limits the financial independence of local governments [44]. Generally, even though the state generates revenue from taxpayers from the local governments under its jurisdiction, they still depend largely on federal funds. The state government usually requests financial support from the federal government for large-scale projects and sometimes even for minor projects, and in turn, the federal government usually sources foreign investment for the state government. This support may come in the form of a loan, depending on the bilateral relationship with the foreign country [45]. Initially, foreign loans were meant to provide support to huge projects that cannot be financed by the state, but at present, such loans are being used to service major and minor infrastructural projects within states depending on the governmental head decision (Figure 2). However, the focus should instead be on generating funds within the state to support, at least, minor projects rather than collecting foreign loans. Funds can be generated within the community if there is a good and transparent system of tax collection from high-, medium-, and low-income earners [46].

The majority of the respondents are of the view that beyond tax accountability [46], fiscal policy and budget management also need to become more transparent at all levels of government. Proper assessment should be done by the federal government before releasing funds to the state governments for project implementation, and continuous project auditing should be done to ensure that these projects are executed at the planned time to achieve their purpose. This will help to achieve sustainable infrastructural development goals that alleviate poverty for vulnerable people [30], reduce misuse of public funds for unsustainable projects that burden the governments with debt they may not repay, and/or avoid establishing tariffs that end users cannot afford [30,36].

A comprehensive review of our respondents' data from the different governmental ministries shows that the Nigerian system of governance is characterized by turnover of administrations every four years, and this is mostly accompanied by a change in planning and administrative policy by the incoming heads of the administrations (Figure 2). It is common for government heads to squander public funds on their pet projects (Figure 2). For example, a previous government head liked golf and decided to build a golf resort in the city just because of his love of golf, while his predecessor liked football and decided to build one of the best stadiums in Nigeria (Godswill Akpabio Stadium) although the city already had a stadium that could have been renovated or restructured, using the vast amount of bare land surrounding it for expansion. Instead, this old stadium was simply abandoned and is no longer maintained. If the old stadium had been renovated instead, the funds used towards building the new stadium could have been channeled into other needed infrastructure developments such as industries capable of creating more employment opportunities for the majority of the city's urban dwellers, who work in unskilled jobs [47].

Furthermore, based on the view of governmental stakeholders, even sound infrastructure developments often fall victim to rivalry among political parties. A new government might simply discontinue the project it inherited from the previous administration, claiming corruption or mismanagement, and spend the first two years of its administration investigating its predecessor's governmentally awarded contracts. Often, there is also incentive to re-award these projects to political allies or cronies. All these issues easily distract an incoming administration from delivering good governance to its constituents, resulting in incomplete infrastructural development projects in the city [43]. This approach needs to be reviewed because it has restrained most of the cities not only in Nigeria but across Sub-Saharan Africa from being appropriately developed [5].

Finally, as asserted by some of the respondents (Figure 2), the opinions of community leaders are rarely taken into consideration when making urban development plans within the state. Community leaders should act as a direct link between the people and the government when implementing urban development projects [48], yet these leaders are hardly consulted. There is evidence of productive collaborations among community leaders, government officials, and private investors in cities such as Navi Mumbai in India, Pudong in China, and New Town in Vietnam, bringing their respective cities closer to the community dwellers to achieve unified development [48]. This system of governance should be adopted in Uyo and SDG 11.A should be integrated into every piece of legislation and policy at all levels of the government in Nigeria.

4.5. Toward Sustainable Urban Growth in Uyo

In 2015, the United Nations (UN) member states adopted 17 goals (referred to as the Sustainable Development Goals, SDG) as part of the vision of the 2030 Agenda for Sustainable Development, and a period of 15 years was proposed to achieve these SDGs [8]. Although progress in achieving these goals has been made in many cities across the globe, there are many more that have yet to take any tangible action [8]. With just a few years left to achieve these goals, during the 2019 summit, world leaders called for speedy action to be taken and institutions to be strengthened to achieve these SDGs by the target date of 2030 [8].

Many countries in Sub-Saharan Africa face enormous challenges in achieving SDGs. Never-ending power struggles and contestation of authority distract the elected governments from implementing good governance in cities [49]. Likewise, in Uyo, there is an urgent need for tighter interaction and coordination among respective urban governance entities. Decision-makers should always try to properly manage friction during the transition of power between governmental administrations to promote sustainable infrastructural development. This will help increase productivity [35], reduce the number of incomplete projects within the state, and promote unification in achieving the overall goals of every project. Strategies for managing state-owned industries should be designed to achieve highquality and affordable products. These sustainability strategies will also help to eliminate the chances of industries and infrastructure collapsing as a result of poor management or governance.

Currently, in Nigeria, the land-use law provides the government sovereignty over all land in the state, neglecting the communal and land tenure system of land ownership [41,50]. Land can only be owned after proper land registration at the Ministry of Land and Housing, although the associated administrative processes mean years of bureaucratic hurdles [40]. Citizens with little knowledge of the law or limited financial means to register their land may begin building structures for shelter without proper registration and approval. The provisions of SDG 11 should be integrated into legislation and policy at all levels of government in Nigeria. This should include rules and regulations that govern land use planning practices in the country. Regarding this aspect, the 1999 Land Use Act law that governs land in the country needs to be reviewed. A systemic approach to urban governance that can educate the people, speed up land registration processes, and promote collaboration among different departments toward moving the city toward SDG 11.A should be encouraged.

Housing challenges have been largely overlooked within the city (Figure 2). The state government should aim at providing housing security for urban dwellers, especially the poor and displaced people. Housing policy should be designed and implemented by the Ministry of Land and Housing. Housing rent should be regulated and made affordable to the public without constant increases, which will help to reduce the existing level of inequality among urban dwellers [35,40]. The government should properly monitor the implementation of all these strategies to ensure that the aims and objectives of SDG 11.1 are achieved in the city.

Poor accountability and lack of transparency in revenue collection [46] and implementation of infrastructural projects have increased the fiscal challenges in Uyo. An efficient and transparent system of tax collection from businesses and workers, as well as the remitting of these taxes to the government, should be designed and implemented by the ministry of internal revenue. These taxes will help to boost the city's economy, as well as the development and maintenance of some infrastructural facilities.

5. Conclusions

In this study, we examined the urban governance policies and practices in Uyo, a midsized city in Nigeria, in light of SDG 11: Sustainable cities and communities. This study agrees with other related scientific studies, and it is the first in Sub-Saharan Africa to analyze urban governance towards sustainable development. Specifically, we analyzed the influence of governance practices in the city on infrastructural development, housing security, economic growth, and urban development. Our findings show that the main causes of the poorly planned development in the city are: (i) the friction between successive governmental administrations, (ii) the lack of allocated funds for housing security and the maintenance of many existing infrastructures, and (iii) the lack of transparency and accountability in revenue collection and execution of projects within the city. Using Uyo as a case study, we highlighted the specific challenges that many other midsized cities in Sub-Saharan Africa and other developing countries share. We also identified potential ways to address these challenges in creating healthy, just, and equitable environments with a high quality of life from the local to the national level.

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9 Manuscript 4: Urban theories and urbanization perspectives in cities across Nigeria

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Urban theories and urbanization perspectives in cities across Nigeria

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Abstract

One of the emerging research trends from urbanization is the study of urban growth patterns. These growth patterns are primarily based on the growth of the local economy that directly affects agricultural lands. In Africa, the local economy has spurred the extinction of many agrarian sectors. Yet, few studies at the regional level have paid attention to these changes. Using diverse scientific literature on global urbanization, urban remote sensing, and economic geography, this study aimed to understand the theory behind urban developments in Nigeria. The primary data were collected in two study regions in the country's eastern and southern parts, making it a large dataset to assess urban formation in these areas. We examined the evolution of urban development from the perspectives of infrastructural development, expansion, change in land use, and urban job migration opportunities that affect agrarian activities. White-collar job opportunities are limited in urban areas, substantially increasing the startup of small-scale businesses. We introduce the notion of natural resource urbanism, which implies urbanization that is triggered by the influx of natural resource revenue to strengthen the dwindling local economy. The infusion of a shared natural resource revenue creates a reform in the local economy and the advent of a consumption-based economy. A shared natural resource revenue drives massive infrastructural developments, but the dependence on the availability of those natural resources in the states raises concerns about its long-term sustainability for strengthening the local economy.

1. Introduction

Many recent studies have focused on urban concepts in big cities, propelled by the growth in scientific literature on urban theory in the global south and showing more interest in the urbanization processes in less agglomerated areas (Taubenböck *et al* 2012, Brenner and Schmid 2015, Simone 2020), but less attention has been given to the relatively fast-growing cities in Africa. This focus on the global south has expanded the urban literature database with comparative urbanism, provincial and universal theoretical debate, and the scrutiny of the northern theory on other cities (Kalnay and Cai 2003, McFarlane and Robinson 2012, Vanum 2012, Peck 2015, Nijman 2007, 2015a).

We go into these discussions with a study of urban growth perspectives in Nigeria, known as the fastest-growing nation and the agricultural giant of Africa (Bloch *et al* 2015, Sean *et al* 2018, Ojo and Ojewale 2019). Our study areas are decentered away from the global south that draws so much attention for urban studies. We argue that this focus on undeveloped regions less represented in the literature on urbanization is relevant to some of the debates in urban theory. Furthermore, the urbanization processes in southeast Nigeria are far from being overlooked. They are a major ethnic group with the third fastest urbanization of cities in Nigeria (Achionye *et al* 2018, Essien 2021). In this study, we focus primarily on the economic changes that drive these urban developments. According to the literature, rural–urban migration has been one of the major causes of urban transition due to the availability of employment opportunities in urban areas across Nigeria (Bloch *et al* 2015, UNCTADstat. 2014, World Bank 2016)—a transformation that has resulted in the high cost of local products, reflecting the low production of agricultural products(Essien 2021). The empirical part of our study focuses on four mid-sized cities across two regions in Nigeria. Warri and Uyo are in the south while Aba and Umuahia are in eastern Nigeria. We collected our primary data from the National Bureau of Statistics of Nigeria (NBS) 2020, which is a rich data set for our study regions. We utilized three different literature databases: urban formation at a regional level, economic geography, and urban remote sensing. While previous studies were significant, they offer limited applicability to Nigerian urbanization. We engaged a broader multiplicity approach (van Duijne et al 2022) and combined frame switching with the transduction method (van Meeteren et al 2016). Frame switching consists of utilizing theoretical perspectives to interpret limited empirical facts(van Duijne et al 2022). The transduction method examines the relationship between empirical observation and theoretical formulation (Schmid et al 2018, van Duijne and Nijman 2019). One of the primary debates we are concerned with is the impact of the shared natural resource revenue on urban areas. This allocation is mainly used to redesign the urban areas due to the lack of substantial growth in the local economy. Our findings show that restructuring and modernizing the urban areas has caused a decline in agricultural production with no alternative substantial job opportunities in the urban areas, leading to the opening of small-scale businesses littered around the urban areas. The shared natural resource revenue plays a significant role in the urban development and local economic reform. This revenue drives urban reformation, but its dependence on the natural resource availability in the state raises questions about its long-term sustainability.

a Urban theories and formations in Nigeria

Based on the transformation in its mid-sized and mega cities, the Nigerian urbanization level is notably high. Globally, it is one of the fastest-growing urbanized nations, with half its 1.8 million inhabitants currently residing in urban areas(NPC 2021, Ojo and Ojewale 2019). Urban opportunities employ the largest number of people by far, in contrast to agriculture, which has previously been the primary source of livelihood for many years(NBS 2021, UNCTADstat 2014, World bank 2016). Urban expansion rates have certainly increased in recent years, despite the low economic growth and limited employment opportunities in the urban areas(NPC 2021, UNCTADstat 2014). As such, Nigerian urbanization negates conventional urban theory, which shows a positive correlation between urban growth and economic growth (Mahendra and Seto 2019, Mendonça et al 2020, Sapena et al 2020). The research literature provides different explanations for Nigeria's exploding urban growth. Some viewpoints suggested that this resulted from an increased demand for human labor due to the ongoing construction work despite the dwindling economic growth (Sean et al 2018, Essien 2021). Others point to the low accommodation costs in suburban areas that allow migrants to easily commute to the urban areas on a daily basis(Essien 2021). Rural–urban migration has been attributed as the primary driver of urban growth (UNCTADstat 2014, Bloch et al 2015, Kyle 2018) due to the lack of basic utilities such as water, electricity, and telecommunication in the rural areas. Furthermore, the major threat to these environments is the significant loss of agricultural land. Urban studies in Nigeria have shown that over the last twenty years, sixty million people have changed their source of income from agrarian work to a non-agricultural income (NPC 2021, UNCTADstat 2014). Nevertheless, some still cannot find another better source of income. The demise of agriculture occurs despite the lack of alternative urban job opportunities, leaving many households with an uncertain future. This is primarily ascribed to the lack of farm mechanization, low crop yields, and low agriculture wages(World bank 2016, NBS 2021). These studies offer an important framework for investigating the perspectives of economic growth and urban growth in the emerging cities in Nigeria. This stands as a guide for our empirical study, and in designing an appropriate conceptual framework, we will provide an in-depth assessment of the four cities in our case studies.

1.2. Global and regional theories on urban economic geography

A linear debate in urban literature shows that economic growth and urban growth are normally linked (Seto and Kaufmann 2003, Henderson 2010, Ivan and Gordon 2013, Mahendra and Seto 2019, Mendonça et al 2020, Sapena et al 2020). According to the United Nations, the urbanization process is generally associated with economic growth and social transformation that has brought about urban migration, life expectancy changes, and poverty reduction (United Nation 2019). Life in urban areas is associated with the availability of social amenities, access to better health care, education, good road networks, and better job opportunities(United Nation 2019). Furthermore, studies also show there is a positive correlation between urban growth rate and GDP per capita (Ivan and Gordon 2013, Mahendra and Seto 2019). Studies in economic geography argue this assertion of a positive correlation between economic growth and urban growth. However, these studies focus primarily on cities in the Global South, where rapid urbanization has not transformed or triggered an increase in the standard of living (Collier and Venables 2017, Henderson and Turner 2020). Glaeser(2014) attributed this to the adverse effects of diseconomies of scale in metropolitan cities in the Global South, while other studies have mainly emphasized the negative effects of low economic growth in urban areas, which is urbanization devoid of industrialization (Jedwab and Vollrath 2015). This is noticeable in national economies that seem to be dependent on natural resource exports, which results in many of the big cities having economies that are based on consumption instead of production (Gollin et al 2016). According to the World Bank (2015), cities need to offer generative urbanization, which involves cities providing an enabling environment for resilient, productive, and inclusive economies. This type of urbanization is lacking in our study area and other African cities. However, as highlighted above, the contention about urbanization being devoid of industrialization does not appear to be applicable in Nigeria. Nigerian urbanization indicates the opposite. In recent years, a relative economic growth has influenced and accelerated urban migration in many cities across the country. Nigeria's urban growth and the share of urban population growth are far above many other African countries. It is potentially unsurprising, therefore, that Nigeria does not feature in most studies on urbanization devoid of industrialization. Another limitation of these studies is that they focus on the mechanisms of the big cities, not the urban development processes.

1.3. Urban remote sensing theories

Globally, remote sensing has been used to monitor urban growth at various spatial resolutions(Schulz et al 2021, Song et al 2018, Taubenböck et al 2012), and time series data have been used to monitor urban sprawl in European cities(Barneset al 2001, Soule 2006, Fuladlu et al 2021). However, it remains challenging to map urban land use cover in Africa (Xiong et al 2017, Yin et al 2020a), due to the heterogeneous landscapes of the region (Schulz et al 2021) and the multiple small-scale farming leading to the misrepresentation of urban land use classes(Nabilet al 2020). Furthermore, sub-Saharan Africa has experienced enormous unplanned environmental challenges such as climate change, population growth, and low agricultural production, which encourage the continuous change in urban land use (FAO 2016, Essien 2021). Various satellite products from low to high spatial scales that have been used to map land use on the continent, such as Globland (30 m) (Chen et al 2015), Copernicus Global Land Cover(100 m) (Buchhorn et al 2019), FROM-GLC (10–30 m) (Gong et al 2019), ESA GlobCover(300 m) (Arino et al 2008), and the 20 m ESA CCI Landcover Prototype (CCI Land Cover 2017). However, Nabilet al (2020) argue that the significant discrepancies between the land use classes and the accuracy of the products were relatively low for cropland. This is especially notable in Africa, where small pieces of land are characterized for different purposes, and there is a high level of subsistence farming with diverse landscapes. Further studies in this region with high-resolution data have focused more on the agrarian land and did not map the various built-up urban areas(Nutiniet al 2013, Sedano et al 2019). This points to the availability of only coarse-resolution land cover maps in this region or land cover maps that are linked with global coverage (Schulz et al 2021), as well as drawing attention to the lack of consistent land cover maps of Nigerian cities in urban literature, given that Nigeria is the fastest-growing nation in Africa (World bank 2016). This inconsistency has created a need to develop a consistent urban land use map that shows different urban development stages in mid-sized cities across the country.

1.4. Aims and objectives of this study

The literature on urbanization has provided some essential conventional paths for this study on urbanization perspectives in cities in Nigeria. We build on previous studies and contribute to various theories, and we examine this literature to show the limitations and relevance to our case studies. This research on the study areas is conducted using Earth observation data and engaged frame-switching pluralism (Barnes and Sheppard 2010, van Meeteren et al 2016). The main aim of this research is not to add more contradictory theories among the various strands of literature, but to offer a better understanding of the urban growth perspective in cities across Nigeria.

2.Conceptual framework

Most of the literature on urbanization is insightful but has limitations when it comes to urban growth in Nigeria. As mentioned earlier, our exploratory study and the approach is built on remote sensing data, frame switching, transduction, and strategy pluralism, allowing us to use numerous theoretical viewpoints in a continuous interplay with empirical observations(van Meeteren et al 2016, Schmid et al 2018, van Duijne et al 2022). The conceptual framework (figure 1) is centered across four distinct arguments from previous literature. We will elaborate on these arguments in the section below. According to the research literature on urban geography, the first argument is that employment opportunities in urban areas are the key drivers of urban population growth in the Global South. This employment-based growth is accompanied by local economic reform in terms of the demand and increase in

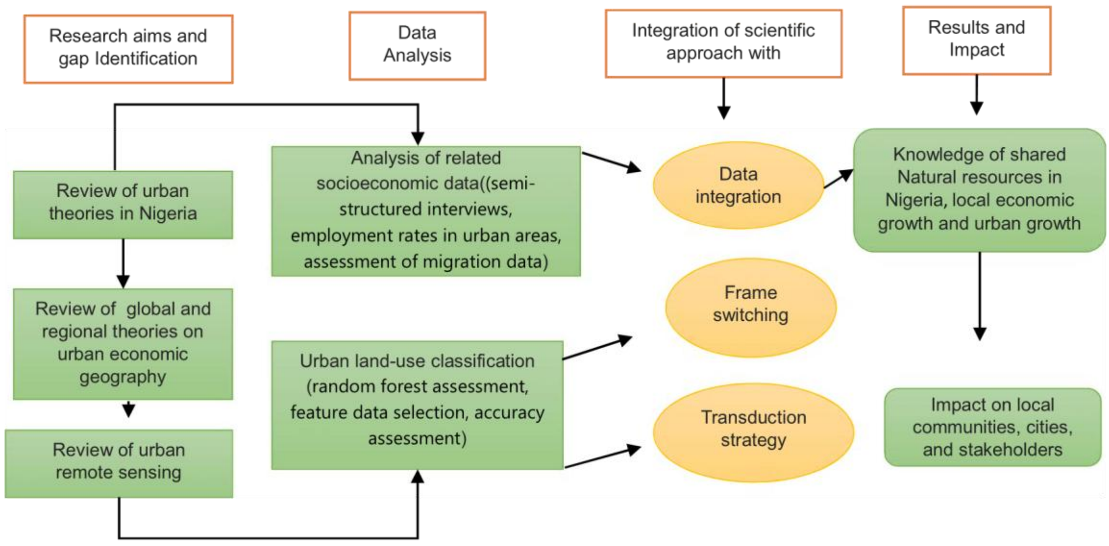

Figure 1. The methodological framework for the assessment of urban theories using remote sensing data, frame switching, transduction, and strategy pluralism to provide a new insight on urban growth patterns in Nigeria.

production. However, in Nigeria, employment opportunities in urban areas are relatively limited. In contrast, the local economy that was previously based on agricultural products is being continuously diminished, and is not being replaced by the urban economy reform. Secondly, the migration patterns in these emergent cities are entirely different from those in developed countries. With the increase in thatched houses in the urban areas, immigration is significantly high due to the people gathering around the urban areas to queue for white-collar job opportunities that are relatively difficult to find. In some cases, people move to another city to keep hunting for urban job opportunities. Can this be attributed to the urban population growth based on people moving from city to city? Similarly, data on emigration is relatively high depending on the state's natural resource availability. However, this lack of economic prospects in urban areas has given rise to families selling their landed properties to raise funds to start a small-scale business or giving these funds to the male children to use and looking for greener pastures in the nearby cities(while the family stays and hopes the male children can change the fortune of the family). This is not the rural–urban migration that is common in most of the urban geography literature. We argue that predominantly male children migrate to work as laborers, while the sale of agricultural land is used to finance this migration. Thirdly, based on the urban remote sensing literature, land use maps are essential for urban and environmental planning. However, mapping large areas with heterogeneous patterns remains challenging in sub-Saharan Africa due to the availability of only coarse satellite images in the region (Schulz et al 2021). Innovation in remote sensing applications has increased the availability of high-resolution satellite images and provides access to data for various scientific purposes; however, the research focus and methodological approach vary according to the different situations and environmental needs. We argue that the random forest (RF) approach is suitable for mapping agglomerated settlements across Nigeria's cities. Fourthly, the disproportionate share of revenue from natural resources into the local economy, and the massive infrastructural development, modernizes and recreates Nigeria's cities with funds generated from the sale of the country's natural resources(crude oil). Revenue from natural resources distributed by the federal government is the primary source of capital for many cities in Nigeria. This has aided the expansion of the local economy, provided no-interest loans to small-scale start-up businesses, and improved the infrastructure (electricity, water, and new road networks) to link nearby urban communities. We argue that the disproportionate shares of the revenue from the natural resources can shape and alter cities' master plans. We discuss our findings in the next section.

2.1. Study layout and cases Studies

This empirical research was performed in three phases: (i) the creation of urban land use land-cover maps using data from the Landsat historical archive, (ii) the collection of reference data from visits to the case study areas, and (iii) the collection of data from a recent socioeconomic survey of the states and urban areas in Nigeria from the National Bureau of Statistics(National Bureau of Statistics 2020). Our land use and land cover analysis was in the states of Delta, Abia, and Akwa Ibom, with total populations of five million six hundred and thirty-six

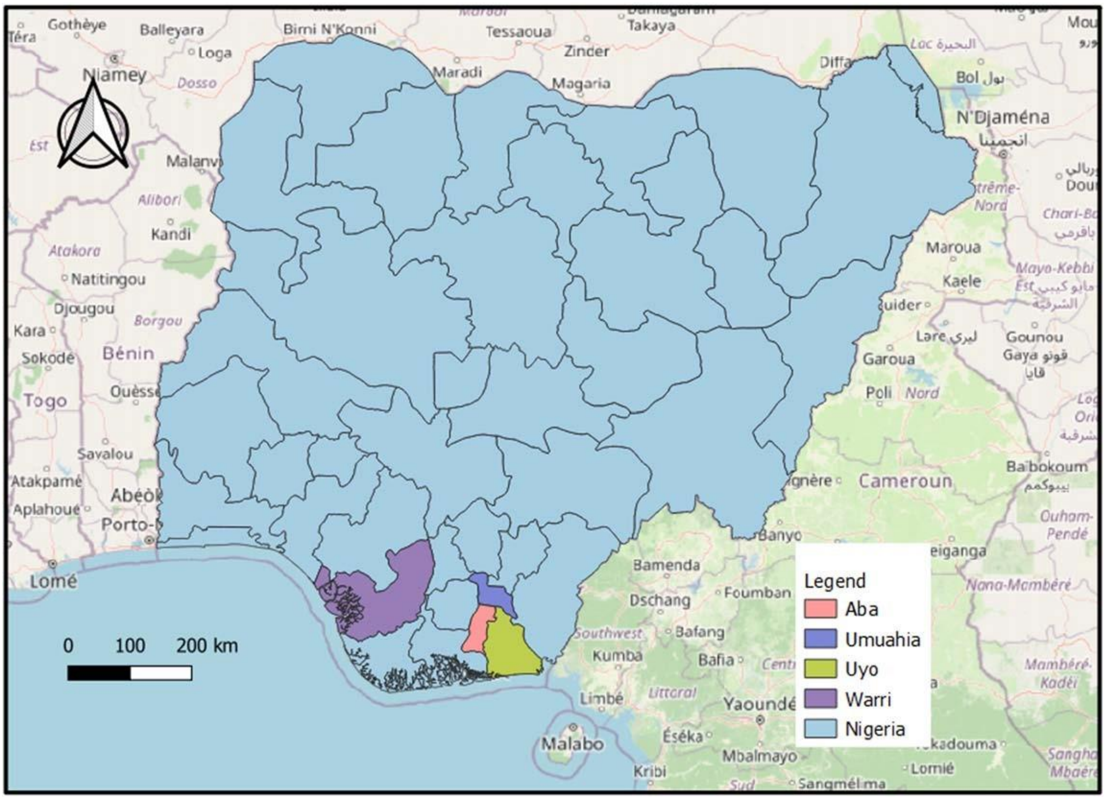

Figure2. AmapofNigeriashowingthelocationofthefourmid-sizedcities.

thousand one hundred, three million seven hundred and twenty thousand, and five million four hundred and fifty-one thousand, respectively. The study areas were selected due to their distinct urban characteristics. We analyzed data on population size, employment and unemployment in the study areas from 2000 to 2020, and we aligned this data to the spatial boundary of each of the states(figure 2). According to population data for the year 2000, the total share of the Nigerian population living in the urban areas of the state capital was 31 percent. For Delta, with a population count of one million three hundred thousand, it was 24 percent; for Abia, with a population count of seven hundred and forty thousand, it was 12 percent; for Akwa Ibom state, with a population count of nine hundred and eighty thousand, it was recorded at 17 percent. In 2018, Delta had 26 new suburban areas, which were former rural and fishing areas, and more than 74 percent of people in these areas depended on nonagricultural and fishing incomes. Abia had 17 new suburban areas, which were former rural areas, and 40 percent depended on agricultural incomes, and Akwa Ibom had 23 new suburban areas, and 68 percent depended on non-agricultural incomes. Our land use and land cover analysis shows that the areas with road networks created substantial clusters, and the additional population of people living in these areas meant that the overall population count was exceeded because the official population count is usually within the urban spatial boundaries. The second stage of the study design involved nine field visits to the research areas(two in Delta, four in Abia, and three in Akwa Ibom). These served to visit sites that were not visible with our satellite data, gather reference data, select case study areas for our primary data analysis, and group the different urban land use classes. In many sites, infrastructural development, such as road networks, had improved, and major highways linking states had been expanded due to the regional economic increases between states(Essien and Cyrus 2019). We selected two study areas in the south (Warri and Uyo) located in Delta and Akwa Ibom, respectively, and two in the east (Aba and Umuahia) located in Abia (figure 2). The satellite images from the year 2000 show that Warri and Uyo had already experienced an early form of structural development; in contrast, Aba and Umuahia had little clusters in the urban areas and a high proportion of nonurban areas surrounding different settlement types. The settlement patterns in these areas(Aba and Umuahia)were not well defined. However, they were known as the core areas that pioneer rural–urban migration in the region (Ogu et al 2017). The settlement patterns in Warri and Uyo were distinct from each other in terms of population size and rural–urban migration, with the settlements in Warri and Uyo appearing to be more complex than in Aba and Umuahia. The Warri and Uyo settlements consist of eighteen urban communities with a combined population of 3.4 million people. The total share of people with skilled and unskilled employment is currently 61 percent, increasing from 34 percent

Table1.Landcovertypesanddescriptions.

Land cover types	Class descriptions
Residential	Building and impervious surfaces within the urban areas
Commercial	Small and large-scale business areas
Mixed usage	New buildings, small-scale businesses, and neighborhood farming activities
Cropland	Land for agricultural purposes and small-scale farming activities
Forest	Natural vegetation and tree plantation areas
water	Stagnant streams and flowing water bodies

in 2000. The Aba and Umuahia settlements consist of nine unplanned urban settlements with a combined population of 1.1 million. The share of people employed has increased from 20 percent in 2000 to 48 percent in 2020. The population growth in Warri and Uyo has been attributed to immigration as these are the headquarters of most of the major oil firms in Nigeria. In contrast, growth in Aba and Umuahia is seen as natural growth. Thirdly, we used our primary data collected from the national households and business survey by the National Bureau of Statistics in Nigeria. The data consist of 72 semi-structured interviews with key informants by region, 317 household surveys, and industry access to electricity and the age of their workers. Our study focused on the findings based on household surveys that are related to occupation, source of income, commuting, migration, and results from industry surveys related to the size, location, and type of business, and the supply network. The interview data aid in interpreting the household and industries survey data. At the same time, our analysis aims to throw more light on urban geographies in our case study and the urbanization patterns of the areas.

3.Methods and remote sensing approach

Our approach consisted of data pre-processing, calculation of texture and spectral properties for each image, and classification using the random forest algorithm (RF). We downloaded atmospherically corrected Landsat five thematic mapper I, Landsat seven enhanced thematic mapper plus(ETM+) and Landsat 8 operational land imager(OLI) data from the USGS Earth Explorer portal(Earth Explorer, 2020). The data were subsets to our study areas of interest, and the spectral properties of the data were imported for green, red, blue, and near infrared. For each year and scene, we stacked different bands with similar spectral properties to obtain the true and the false colour of the image to use for urban land cover classification. Each of the images was cloud-shadow free and consisted of around 8-to-80-pixel-level observations (i.e, the month and year). We checked the data at different temporal scales for monitoring seasonal variation. We grouped our feature sets into six urban land use classes based on field visits and reference data. We used our feature sets to build the RF, which included feature selection, model training, and parameter iteration. Model training, quality assessment, and validation were carried out with independent testing and training datasets.

3.1. The urban land cover classification plan

For a detailed urban land cover change map from 2000 to 2020, we defined our urban land use classes based on the built-up areas and vegetation types in the study area using a rectangular extent to measure the city's administrative units. We used the same extent for the other cities to the quantify urban land cover changes that occurred within the same extent in the cities. Despite our extent's spatial resolution, we used reference data for consistency and terrain base accuracy. However, we based our final urban land cover classification on what we surveyed in the field and what we mapped using satellite data, i.e, we identified several other vegetation types in the field. However, since our focus was not on different vegetation mappings, we merged them with classes of similar types. We classified our data based on the built-up areas, location to the main road, nature of the built-up areas, and new buildings in the areas. We mapped urban land cover change from 2000 to 2020 with a 30-m grid cell size. Our satellite-based urban land cover classification for southeastern Nigeria relied on training data from our fieldwork. We used GPS coordinate points as our reference data during our reconnaissance survey of the study area and randomly selected each point of the urban land class type, subsequently using the reference data to identify different urban land cover classes in the areas and creating six land cover class types in the study area (table 1).

Table 2. Household incomes in urban areas.

	Warri(N=246)	Uyo(N=312)	Aba(N=231)	Umuahia (N=201)
Household incomes from agriculture	5.4%	7.3%	5.1%	8.2%
Household incomes previously from agricultural products	15.9%	17.1%	21.9%	25.1%
Household incomes from private enterprise	33%	27%	46%	41%

Source: Author, based on NBS households survey2020.

3.2. Random forest classification scheme

We used a random forest classifier(Breiman 2001) to group different land cover pixels. Random forest is a robust tree-based classifier that can detect noise (Pelletieret al 2017) and builds several trees from random prototypes of the training data (Denisko and Hoffman 2018). We set the two main parameters in our RF algorithm—the number of trees to be nurtured (ntree) and the number of generated features(mtry). We set the ntree parameter so multiple iterations can generate a better result (Fox et al 2017). This is applied when the number of the predictor variables is large (Stroblet al 2009). The mtry parameter equally affects each distinct tree's correlation and intensity, influencing the generalization error and classification accuracy (Breiman 2001). We set both parameters to get the best performance of our model. For ntree, we set the number of iterations of trees to 500 and increased the values based on our results, and for mtry, we ran different iterations for every subset of our training data. We selected the model with the best results, i.e, the model with the least prediction error and the best accuracy compared to the validation data (Calderón-Looret al 2021). Six urban land cover types were classified using the random forest model (figure 4). To validate our training data, we divided the training data randomly into two parts. Subsequently, we used 70% of these training data for the urban land cover classification and 30% for the validation data (Calderón-Looret al 2021).

3.3. Feature data selection

A large input of datasets usually affects the classifier's performance by generating multi-collinearity and redundant data (Paul and Kumar 2019, Schulz et al 2021). Feature selection tends to lower the noise level in the data by removing redundant features through aggregating smaller features into useful parts(Cao et al 2017). With random forest classifiers, features were generated and tested to check the performance of the model. The first set of data containing all the bands was selected without using the feature selection. However, the second set of data was selected based on reduction of multi-collinearity (Katrutsa and Strijov 2017). This was accomplished through the calculation of the correlation matrix of all features and a stepwise process of removing pairs of features with correlations higher than 0.7; the filter feature was a set based on mutual information and multicollinearity using an approach (Jin et al 2019, Kiala et al 2019) for feature sets that had correlation values higher than the marginal threshold.

3.4.Accuracy assessment and post-classification

We used the validation data to compute eight confusion matrices, one per year, to determine the producer, user, and overall accuracy of the urban land cover classification. To check the urban land cover classification error, we computed the omission and commission errors(Olofsson et al 2014). Additionally, we used the urban land cover classes to calculate per-class pixel confidence metrics to measure these contract levels(Shadman Roodposhtiet al 2019). To assess the accuracy of our urban land cover change map, we randomly spread our GPS coordinate points across each urban land use class. We visually examined all the pixels and the temporal changes in urban land cover classes for each year. Subsequently, we computed statistical metrics to assess urban land transition in the different classes(table 1). Post-land cover classification between changes in other land cover classes often leads to estimation errors(Olofsson et al 2014). However, we used our reference data to measure the adjusted error in each urban land cover class(Olofsson et al 2014).

4.Results

4.1. The local economy in the urban periphery of Nigeria

The transformation in the employment sector is the primary force instigating rural–urban migration in Nigeria. Our findings in table 2 show that the majority of the people do not engage in agricultural income-earning. Presently, in Warri and Uyo, less than 12.7 percent of the household depends on an agrarian income, in contrast to 13.3 percent in both Aba and Umuahia. Furthermore, 33 percent of households in both Warri and Uyo, and 47 percent in both Aba and Umuhia, indicated that they previously made a living from agricultural incomes. This shift in employment activities can also be seen among the youth of the areas, allowing agricultural activities

Table 3. Urban occupations by sector.

Occupation of households in urban areas	Warri(%)	Uyo(%)	Aba(%)	Umuahia(%)
Private enterprise owner	49.1	43.6	55.4	48.1
Construction employees	3.6	5.2	1.3	2.4
Public workers (Government)	14.2	16.4	9.6	12.4
Petty traders (Hawkers)	6.7	5.3	9.5	7.3
Private, professional practice	2.3	1.6	1.4	1.8
Labor worker (manual)	13.7	16.4	9.3	12.8
Farmers	8.3	9.5	9.2	10.2
Apprenticeship workers		1.3	3.1	2.6
Skillful workers (Technicians)	2.1	3.4	1.1	3.3

Source: Author, based on NBS households survey 2020.

Table 4. Migration in urban areas.

	Warri%(N=212)	Uyo%(N=201)	Aba%(N=198)	Umuahia %(N=205)
Immigration	16.4	14.8	6.3	5.1
Emigration	5.1	7.3	10.2	12.3

Source: Author, based on NBS households survey 2020.

to sink into extinction, indicate a higher increase of unemployed people in the urban areas. This increase shows that the Aba and Umuahia switch is more recent than that in Warri and Uyo. Figure 4 show that most households working in the urban centers live in the unplanned suburban areas, characterized by informal settlement patterns, particularly in Warri and Uyo. Many have abandoned their subsistent farming and commute long distances in search of a white-collar job. Warri and Uyo provide more job opportunities than Aba and Umuahia due to their larger sizes and being the location of major crude oil industries in the region. Table 3 indicates the type of work in households living in the urban periphery, and findings show 14.2 percent in Warri, and 16.4 percent in Uyo are public workers, and 49.1 percent and 43.6 percent are private enterprise owners in Warri and Uyo, respectively. In comparison, 9.6 percent and 12.4 percent are public workers in Aba and Umuahia, respectively, and 55.4 percent and 48.1 percent of urban residents in Aba and Umuahia, respectively, are in private enterprises. This primarily consists of retail shops, hair salons, photocopying centers, and other forms of businesses. The interview data show most households go into private enterprise due to limited employment opportunities in the urban areas, while some sell their family landed property to fund the enterprise. In some cases, they must serve a master(business owner)without salary for seven years(with only a stipend) to accumulate unpaid salary to start their own business in the eighth year. This practice is quite common in Aba and Umuahia. The second most common employment opportunities in the urban areas are as manual workers(13.7%, 16.4% in Warri Uyo, respectively, and 9.3% 12.8% in Aba and Umuahia, respectively), such as brick layers, tailors, phone repairers, street hawkers, small roadside businesses, and drivers. Companies are rarely big or large-scale in Nigeria. In Warri and Uyo, more than 40 percent of the companies are small, in contrast to 70 percent in Aba and Umuahia. Over 80% of these companies do not have more than twenty employees, including the owner and his household. Table 4 indicates that the local population often seek employment opportunities elsewhere due to limited job opportunities in their communities. Few of the companies in Warri and Uyo are larger than those in Aba and Umuahia, implying that urban migration is imminent and is more rampant than in Aba and Umuahia (table 4). As shown in table 5, most of these companies sell spare parts, electronics, secondhand clothing, phone accessories, and other small-scale products. Production is carried out on a small scale and goods are rarely exported. These companies produce goods such as crude oil, aluminum doors, fashion designs, baked goods, shoes, and others. In some cases, due to low sales, products can only be made based on customers' requests, indicating a low turnover for these companies. However, Aba and Umuahia engage more in small-scale economies, where most workers commute long distances to hawk different items along motorways in the urban centers, though this has a minimal effect on urban land in Umuahia (figure 4). In the different suburban areas, there is clear proof of a cluster around the various built-up areas(figure 4), and retail businesses are likely to emerge more in the different regions. Furthermore, labor migration is low in Aba and Umuahia. Nevertheless, it plays a significant role in urban densification in Warri and Uyo through people relocating to these areas in pursuit of jobs with oil firms, which are rare and, thereby, result in people

Table 5. Firm employment rate in urban areas.

	Warri%	Uyo%	Aba%	Umuahia%
Education (private and public service)	33.1	29.2	20.3	25.1
Construction(private)	3.3	5.6	1.2	3.5
Technology(technicians)	2.6	1.9	3.7	2.9
Health (private and public)	9.3	7.8	6.3	9.7
Merchandising (sales, wholesale, and retail)	46.3	48.8	61.4	54.6
Production	1.3	2.1	0.7	
Transportation	2.4	3.2	5.3	2.4
Professional practice firm (real estate values, etc)	1.7	1.4	1.1	1.8

Source: Author, based on NBS households survey2020.

opening small-scale businesses to survive in the urban areas. Many companies import goods from within their region. In Warri and Uyo, 31% of the companies' goods are produced in the region, while in Aba and Umuahia the level is over 64%. Finally, urban transition in Warri and Uyo has existed for a long time. The urban areas are densely packed with various unapproved buildings marked for demolition due to the lack of governmental approval. The urban population cannot be sustained by the small manufacturing sector. This has forced more people to work outside the urban areas. However, the local economic patterns in the four cities are similar, such as the prevalence of small-scale and retail businesses. Additionally, while the local economic growth in Warri and Uyo appears higher, it has not evolved significantly in contrast to Aba and Umuahia

4.2. The federal allocation remittance

The increases in the shared natural resource revenue to most states in Nigeria have influenced urban growth in cities across the country. This revenue is being shared based on the natural resources found in the states. The Delta and Akwa Ibom states are among the pioneers that have driven Nigeria's economy with their natural resources(crude oil). The inflow of this revenue from the federal government plays a key role in urban development and the growth of the local economy in cities across Nigeria. In addition, studies show that the influx of capital from activities elsewhere usually accelerates, but does not maintain, the local economic process (van Duijne et al 2022). These revenue influxes were related in the four cities, but were particularly very effective in Warri and Uyo, which received more share of the oil revenue from the federal government than Aba and Umuahia due to the presence of oil wells in their states. This capital inflow triggers growth in these localities. Examples include: (i) increasing salaries for public workers, which encourages expansion in retail sectors—in Warri and Uyo, public servants are known to open small-scale businesses to boost their household incomes; (ii) supporting individual businesses and companies to boost their production and reduce unemployment in the cities—across the four cities, 46% of private enterprises and 33% of individuals have benefited from this revenue; (iii)supporting infrastructural development, such as road construction, mounting electricity poles, expansion of drinking water distribution networks, and other infrastructural projects. According to the 64% of household responses in the survey data, cities have evolved in the past twelfth years, pushing development, extinction of agricultural land, and demolition/reconstruction of cluster settlements to modernize their cities. However, a shared natural resource revenue is essential to urban geographers in evolving urban developments. A shared natural resource revenue as shown in figure 3, can be perceived as a major driver of urban growth in these regions, resulting in injected urbanism, which means investing income generated elsewhere (van Duijne et al 2022). An estimated 78 percent and 82 percent of revenue sources in Warri and Uyo depend on the shared natural resource revenue, in contrast to Aba and Umuahia, which uses its local economic revenue to sustain urban development (figure 3). This can be attributed to poor infrastructural development and the slow urban development pace in Umuahia (figure 4). In Warri and Uyo, the shared natural resource revenue aids in financing infrastructural expansion, creating more white-collar employment, providing no-interest loans to private enterprises, and creating a consumption-based economy and unplanned building expansion patterns. However, there is uncertainty for long-term urban sustainability in these areas receiving the natural resource revenue. If the external revenue source is not properly managed, the urban formations and their resilience may be challenging to maintain in the long term.

4.3. Urban land cover classification

We produced multi-temporal high-resolution land cover maps using a consistent random forest (RF) classifier methodology for southeastern Nigeria from 2000 to 2020 (figure 4). The classification's overall accuracy was from 82% to 91%, and the producer and user accuracy ranged from 67% to 99%, for the study areas. The accuracies were not consistent at the class level, i.e, the user accuracy for Warri in 2020 ranged from 60% to 90%

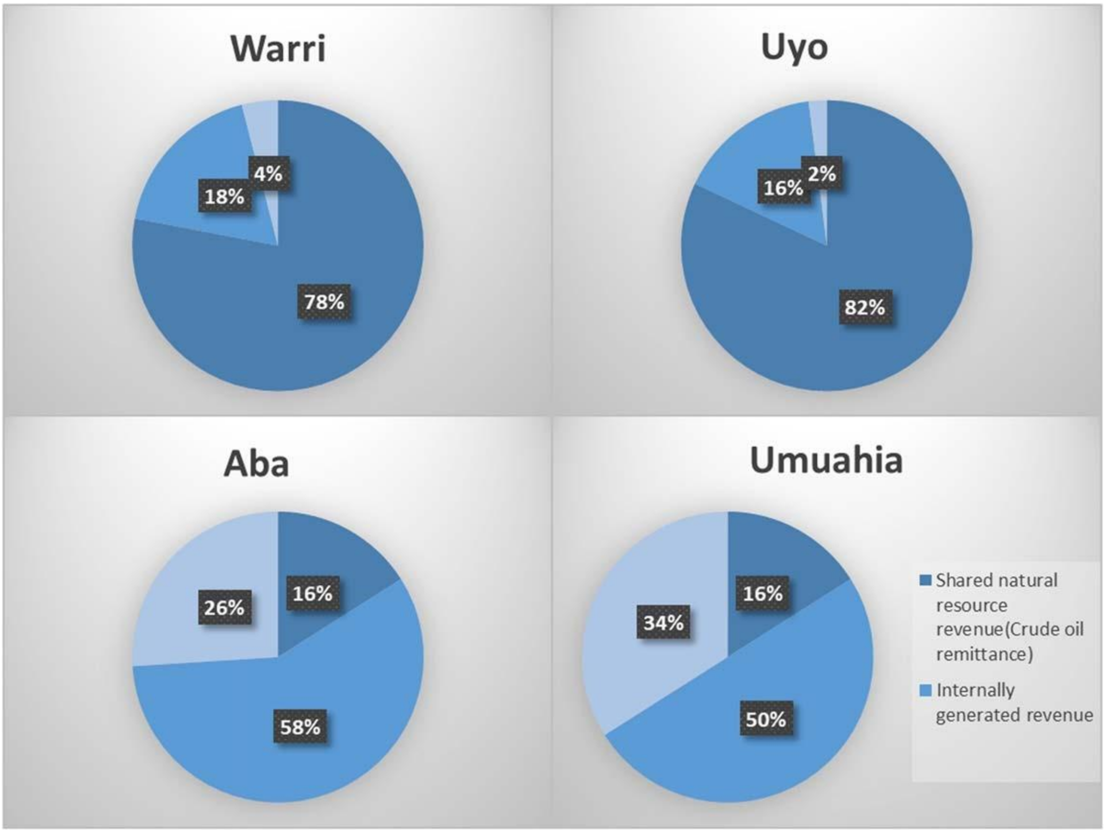

Figure3. Source ofthestates' revenue(Source:Author,basedonNBShouseholdssurvey2020).

for residential and commercial areas; however, for mixed usage and cropland the producer accuracy ranged from 80% to 90% (tables 6 and 7). This followed a similar pattern for other years, with residential and mixed usage having the lowest producer and user accuracy (tables 6 and 7). We also found a few misclassifications in residential and commercial areas. Similarly, the land cover map of Warri shows a high level of ambiguity, with confusion between commercial, residential areas and mixed usage (tables 6 and 7). The land cover map illustrates that around 12.6% of the total land has experienced a significant land cover change in the study areas. Residential areas in Warri and Uyo experienced the highest expansion of 5% (35 km2) and 21% (42 km2), respectively, in 2020 compared to the area covered in 2000, increasing mainly from previous croplands(tables 6 and 7). Contrarily, forest areas have undergone the biggest decrease in size from 2000 to 2020 by 11.5% (−92.5 km2) in Warri, and 34% in Uyo (−65 km2). Cropland also experienced an area loss of 27.1% (−67.1 km2)in Warri and 62% (−65 km2)in Uyo, with most of these areas being transformed into commercial and mixed usage areas. The residential land cover class in Warri was relatively stable from 2000 to 2020, with a 5% increase in area (table 6). In Aba and Umuahia, the residential areas experienced a relative expansion of 19% (40 km2), 5% (18 km2) by 2020, spreading across different land cover classes than its size in 2000. Again, forest areas suffered the highest losses, decreasing by between 2000 to 2020 by 44% (−58 km2) in Aba and 13% (−93 km2) in Umuahia (table 7). Cropland areas also suffered relative losses of 39% (−92 km2) in Aba and 27% (−59 km2) in Umuahia, with most of these areas being transformed into residential and mixed-usage areas(table 7). Furthermore, Warri and Uyo experienced a more significant increase in residential, 26%, and mixed usage, 46%, from 2000 to 2020 (figure 4) based on the negative impact of urban migration (table 4). In contrast, Aba and Umuahia experienced changes of 24% in the residential area that are not relatively continuous towards the city's center, and mixed usage has increased by 37% (figure 4) due to the relative increase in small-scale businesses in this area. Aba has been the commercial city for the entire southeastern region with a market-oriented base economy. As shown in (table 6), mixed usage and commercial area are the urban land cover classes that experience the highest increase in all four cities. These classes are solely located in the urban communities where many migrants create informal settlements, and most local economic activities occur. These activities put further pressure on residential areas and other classes within the urban communities by forming clusters along many built-up areas. This can also lead to urban agglomeration that can foster the emergence of new suburban areas if not adequately monitored.

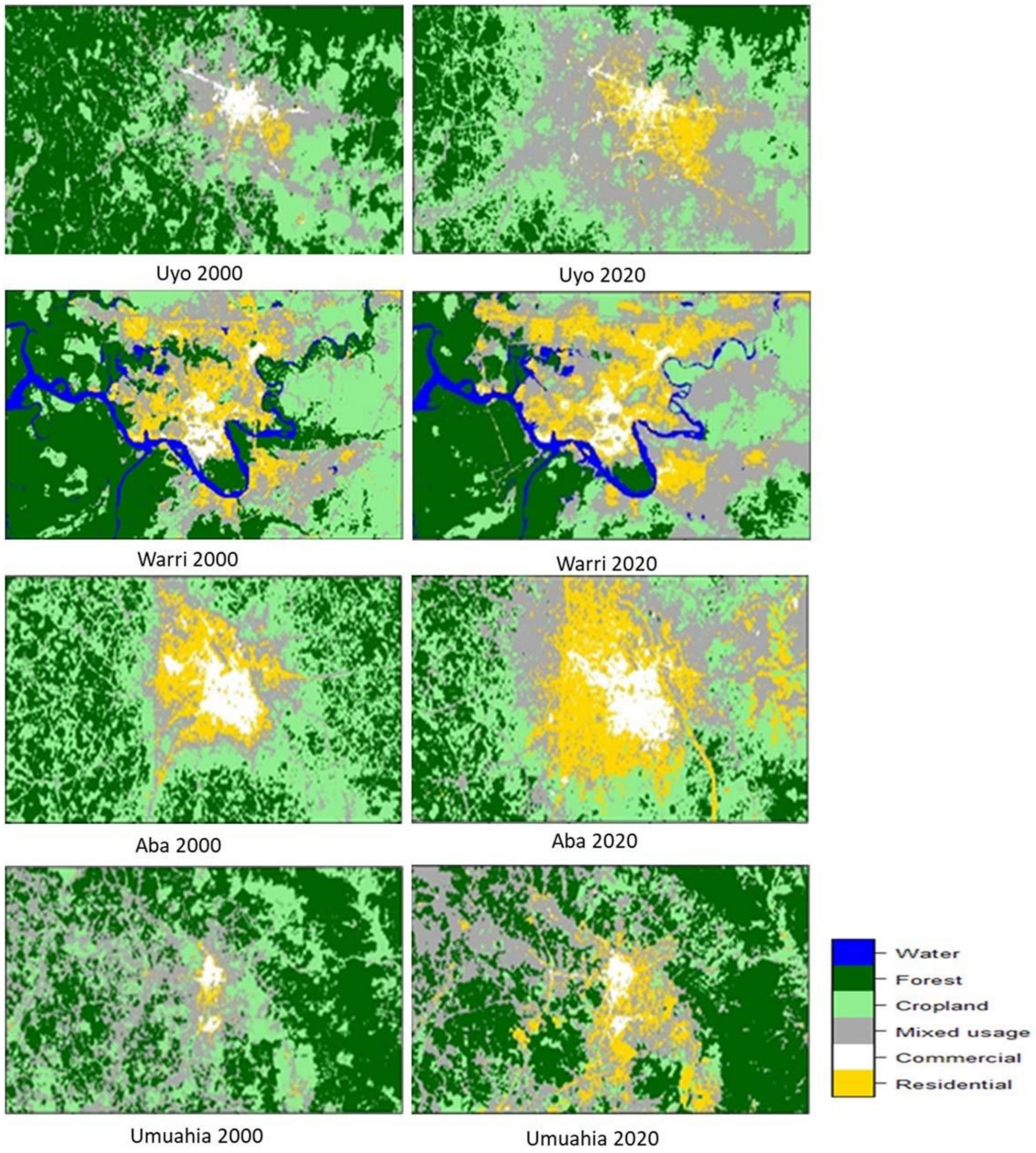

Figure4. Amapoftheurbanland coverchangeinthefourNigeriancitiesstudied.

5.Discussion

Our study aimed to explicate the urban formation process in Nigerian cities and to build on the present traits of urban literature. The literature on urban growth has provided significant insights into urban growth in metropolitan cities(Taubenböck et al 2012, Güneralp and Seto 2013, Brenner and Schmid 2015, Mahendra and Seto 2019, Sapena et al 2020, Simone 2020). However, there are few studies on urban growth in African cities (Güneralp et al 2017, Pieterse 2019), and a scientifically reflexive empirical study is vital to address this limitation (Nijman 2015a, Robbin et al 2022). We explored the remote sensing data, structure switching, and transduction approaches, allowing us to consider different theoretical viewpoints in a continuous interplay with empirical observations(van Meeteren et al 2016, Schmid et al 2018, van Duijne et al 2022). Our study shows that the urban growth processes in Warri and Uyo are primarily triggered by labor migration, agreeing with the results of the existing literature on urban studies(Gao et al 2014, Liet al 2015, van Duijne et al 2022). In Aba and Umuahia, our findings show that a low income and the lack of modern facilities to process agricultural products are the key drivers of the local economic reform. However, the production of agricultural goods is low across the different cities in Nigeria, which has created more informal settlements in the urban areas(figure 4), and Warri and Uyo have formed relatively small urban clusters in these settlements. The local goods are not exported outside the country and are rarely distributed outside the region due to poor road

Table 6. Changes in urban land classes from 2000 to 2020.

	Aba(area/km^2)			Umuahia (area/km^2)			Uyo(area/km^2)			Warri(area/km^2)		
Land cover types	2000	2020	Changes%	2000	2020	Changes%	2000	2020	Changes%	2000	2020	Changes%
Residential	21	40	19	13	18	5	21	42	21	30	35	5
Commercial	13	25	12	10	18.5	8.5	13	23	10	14	15.2	1.2
Mixed usage	34	54	20	55	72	17	41	63	22	53	77	24
Cropland	131	92	−39	86	59	−27	127	65	−62	94	67.1	−27.1
Forest	102	58	−44	106	93	−13	99	65	−34	104	92.5	−11.5
Water										13	6.1	−7.1

Table7.ConfusionmatrixandvalidationpointsforWarri2020urbanlandclassification.

	Residential	Commercial	Mixed usage	Cropland	Forest	Water	PA	UA
Residential	258	65	177	0	0	0	0.7	0.6
Commercial	17	479	4	0	0	0	0.8	0.9
Mixed usage	55	2	423	17	0	3	0.7	0.8
Cropland	0	0	0	460	40	0	0.9	0.9
Forest	0	0	0	4	496	0	0.9	0.9
Water	0	0	0	0	0	500	0.9	1.0

***** ******

PA: Producer Accuracy; UA: User Accuracy

networks in some areas. This has meant that the goods are produced for retail and consumption only in the local regions. With regard to migration, the urbanization processes in our study areas differ from the urban growth in the developed world. Emigration is relatively low due to limited employment opportunities and the high cost of living in the big cities such as Lagos and Abuja. Immigration is moderate since people don't understand the local economic settings in cities, resulting in migrants going back and forth when they can't find urban employment opportunities. This means that the local populations are relatively stable across the regions. However, in the study areas it is common to sell the family-landed property to fund and encourage the male children to go into private business, after having gained more experience learning the business elsewhere in the community. This approach has given rise to various retail enterprises and created new urban formations. The adverse effects of the loss of family-landed property and agricultural land has been neglected in the past (Essien and Samimi 2021). The sharing of revenue from natural resources(crude oil) by the federal government, and other local income sources, has boosted the reform of the local economy and shaped many informal settlements in the urban areas. This has resulted in an urbanization process that depends on remittance income from other places(van Duijne et al 2022). Our study shows that the spatial characteristics of urban growth in the four cities and their urban formations are relatively different. The agrarian land cover is small, and areas with a high level of economic restructuring are urbanizing. The patterns of built-up areas in Aba and Umuahia reflect local economic reforms in terms of expansion in residential and commercial areas(figure 4). In contrast, Warri and Uyo show more of an infusion of the shared natural resource revenue from the federal government in terms of urban infrastructural development and the implementation of different housing schemes by the state government. Furthermore, our results show that the mixed usage and commercial areas have user accuracies of 81.2 percent and 90 percent, respectively, and producer accuracies of 70 percent and 80.6 percent, respectively, which we consider to be high given that previous studies did not identify these classes(Akpan-Ebe1 et al 2016, Nse et al 2020). In particular, bare land and vegetation covers were better differentiated from cropland than in previous studies in the same study area. Bloch et al (2015) used a pixel-based approach to map urban areas across Nigeria, but mixed usage was not differentiated from built-up areas. This may be a result of the urban agglomeration in sub–Saharan Africa. This is why recent studies have mostly used image segmentation and high-resolution satellite data to map land use cover in Africa (McCarty et al 2017, Neigh et al 2018, Schulz et al 2021). However, our results show that the Landsat 30-m resolution was able to map mixed usage and commercial areas when using a three-by-three matrix filter with a 30 m grid cell size, which agreed with previous studies(Jin et al 2019, Sedano et al 2019, Samasse et al 2020). In addition to the qualitative improvement by differentiating previous land use classes(mixed usage and commercial areas) in our urban land use map, we discovered that the existing urban land cover map was not able to depict commercial areas. A significant part of the commercial area was classified as a built-up area by similar studies(Akpan-Ebe1 et al 2016, Nse et al 2020). Relying on satellite data alone, as previous studies have (AkpanEbe1 et al 2016, Nse et al 2020, Mashiet al 2021), could have its limitations in identifying commercial areas in sub–Saharan Africa, particularly the informal and cluster settlements, which are the core developmental areas that usually trigger the local economic growth in Africa. Especially in our study areas, informal settlements have intensified urban expansion in the residential areas by absorbing adjacent new suburban areas into the urban periphery due to accelerated small-scale local economic growth (figure 4). These spatial expansions keep focusing on the periphery of existing urban communities and put pressure on the urban edge to be continuously shifted for development purposes. These results concur with other studies(UNCTADstat 2014, World Bank 2016)showing that peripheral growth and increases in urban land cover change significantly affect a city's development. In addition, the suburban land expansion in 2020, as shown in our spatial maps, is marked by residential areas emerging as unplanned informal settlements, while commercial areas and mixed usage areas coexist with planned and unplanned residential growth (figure 4). Similarly, commercial and mixed usage space is pervaded by open spaces, recreation centers, informal markets, and small-scale retail shops. In Aba, for instance, the local economy has triggered the increase of commercial and mixed usage areas along road networks and newly developed suburban areas, i.e., many shopping malls have been opened within the road networks close to the urban edge. These structures comprise supermarkets, Shoprite, and other diverse small-scale business activities influencing urban land cover changes (figure 4).

6.Conclusions

In this study, we show that our case study provide a reference base for the many urbanizing cities in Nigeria, especially the developing cities in Africa that are underrepresented in the research literature on urbanization, but are experiencing the loss of agricultural land and reforms in the local economy. Sharing the revenue from the natural resources triggers urbanization and could be practiced in other parts of Africa and the undeveloped world, where this revenue is used as the nation's primary income source. In Nigeria, this economic restructuring is creating new challenges for the millions of people living in the urban areas, and this study empirically identifies the source of these social problems. In addition, we provide a comprehensive urban land cover map of four cities in Nigeria and demonstrate the capability of remote sensing to map core agglomerated settlements in Nigeria. Our urban land cover map can be used for various purposes, such as the perception and exploration of urban expansion, analyzing the local economic situation, and monitoring and planning growth in built-up areas. Our results demonstrate the mapping of mixed usage and commercial areas, which are the direct effects of local economic growth but have not been included in previous studies.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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PART III
SYNTHESIS

10 Results and Synthesis

This thesis aims to employ different scientific methods to examine urban growth dynamics in cities across Nigeria and access shared natural resource revenue, as well as local economic and remote-sensing data. Furthermore, it uses a research framework that shows the detailed effects of shared natural resource revenue and the local economy on urban lands. This approach can stand globally as a guide and can be adopted and modified for other scientifically related studies on urbanization in Africa. This study explored quantitative data analysis methods to accomplish the research aims and objectives of this thesis. The aims of this study were as follows:

RESEARCH AIM:

I. To quantify land-cover classes and use their spatiotemporal changes to detect phases of urban growth and highlight the driving factors behind this growth (Manuscript 1).

II. To evaluate how the city's administrative taxes, living standards, and household income affect urban growth patterns in Uyo (Manuscript 2).

III. To analyze the influence of urban governance on sustainable urbanization in mid-sized cities, such as Uyo, using SDGs 11 as a guideline for sustainable growth management (Manuscript 3).

IV. To assess the effect of shared natural resource revenue on local urban economies across cities in Nigeria (Manuscript 4).

RESEARCH QUESTION:

(i) Is a multi-temporal dataset capable of integrating a local economic dataset to quantify the phases of urban growth in Nigeria's heterogeneous landscapes? (**Manuscript 1 & 2**)

(ii) How do administrative taxes and household income influence patterns of urban growth? (**Manuscript 2**)

(iii) How do governance practices affect urban growth, economic growth, housing security, infrastructure, and urban development in Uyo? (**Manuscript 3**)

(iv) Can SDGs 11 be adopted in Nigerian cities? (**Manuscript 3**)

(v) Does natural resource revenue influence the local economic growth in Nigerian cities? **(Manuscript 4)**

(vi) Can the back-and-forth migration of people in search of white-collar jobs that are difficult to find be linked to urban growth? (**Manuscript 4**)

(vii) What measures are required to address infrastructure-driven urban growth? (**Manuscripts 1, 2, 3 & 4**)

10.1 Assessment of Urban Growth in Cities in Nigeria

The historical Landsat Earth observation data provided detailed information on urban land-use changes in Uyo, Warri, Aba, and Umuahia using different satellite spectral bands. These data were used as primary data and aided in monitoring urban land use change patterns in the study areas. The urban spatial datasets were available in a 30m resolution raster format, enabling further spatial analysis to the regional level and vector format, such as cropping out the extent of the study area. The regional Landsat 30m resolution data were stacked, and different iterations were run to generate the time-series data. The data showed structural trends between 1985 and 2018, with vegetative areas experiencing the greatest loss from 2001 to 2018 (manuscript 1). Household survey data were analyzed using a linear regression model to identify changes in local economic activities in urban areas (manuscript 2). As anticipated, the results showed a positive correlation between urban land use classes and selected socioeconomic variables (manuscript 2). From 2001 to 2018, significant changes occurred in the major built-up areas and extended to suburban areas. Although the 5m high-resolution satellite datasets produced better classification accuracy than the 30m coarse datasets, misclassification and uncertainties persist because of the lack of large training datasets in the study areas. To present comprehensive information about urban growth sustainability, the perceptions of stakeholders and urban community dwellers, as well as the causes of urban growth, were examined through face-to-face discussions and interview questionnaires (manuscript 3). Suburban areas were expected to exhibit minor changes in urban growth due to a lack of access to roads and basic social amenities (manuscript 3). However, the results proved that changes occurred in both urban and suburban areas due to local economic growth, which led to people selling off their inherited lands to attract infrastructural development, better income, and city life (manuscript 4).

In contrast to time-series trends, the data analyzed from governmental stakeholders, urban community heads, and public respondents agreed that changes in the local economy were the key factors influencing unplanned urban growth in the study area. In terms of local economic assessments, data were only derived from government records, which are usually documented by each state government through their ministries, as regional economic data have been widely criticized for generalizing the economic situation of cities (Fox et al., 2015; Standard Bank, 2014). The analysis showed a significant increase in the urban population of the study areas in contrast to previous years, owing to an increase in shared natural resource revenue reserved for urban infrastructural development in a bid to attract investors into the study areas. This growth is similar to the local economic growth (manuscript 4). The 5m and 30m resolution data detected an increase in agricultural land loss. In terms of built-up patterns, data from RapidEye images showed new emergent sparse built-up areas in the suburban areas. Simultaneously, fieldwork observation points to urban development spilling into suburban areas (manuscript 2). Discussions with stakeholders and public respondents' data analysis revealed that the state government is constructing residential houses in these areas to provide low-income-earning civil servants with affordable housing units, without proper planning (manuscript 3).

Global studies on urbanization have focused mainly on big cities and have used estimated national data from various agencies, such as the UN and World Bank, to provide information on urban growth in Africa (UNDESA, 2019; Seto et al., 2017; UN-Habitat, 2012; Güneralp et al., 2017; Avis, 2019; Farrell, 2018; Montgomery, 2008; Fox et al., 2015). Against this background, the results of this research show that local economic data are necessary to evaluate urban growth patterns, because city growth depends on the socioeconomic activities of the area. Integrating socioeconomic data with remote sensing aids to provide detailed information on urban development and the factors that influence various changes in the study area (manuscript 2). Additionally, the use of local economic data (i) provides specific information based on factors that influence urban growth; (ii) provides useful information to scientific communities researching urban growth in developing countries; (iii) provides a clear picture of urbanization across cities in Nigeria, which differs from urbanization in the western world; (iv) contributes to urban literature rather than contradicting urban and economic theories on urbanization in Africa; (v) stands as a guide for administrative heads when formulating effective urban-growth management strategies that would lead to sustainable urbanization; and (vi) assists in reducing data uncertainties. As shown in the time-series trend, satellite data from 1990 to 1999 were not available to provide yearly changes in the study area (manuscript 1). However, stakeholders and public respondents provided information regarding the changes that occurred during this period. Regarding socioeconomic data, urban and economic literature used a predictive approach to estimate the economic growth effect of urban land use in Africa, based on Earth observations and national population growth data, without accessing shared natural resource revenue (Güneralp et al., 2017; Avis, 2019; Farrell, 2018). Although the satellite data showed new information and linked it with national population data that were evenly distributed, they did not provide a more regional view of the urbanization situation of individual cities. Instead, urban growth is generalized, whereas urban population growth in the study areas depends on the state's investment in infrastructure development, as well as on the capacity of the local economy to provide employment opportunities for urban migrants. The method applied in this study offers regional and up-to-date information on urban socioeconomic growth relevant to local urban dwellers, stakeholders, urban scientists, and professionals in related fields. In contrast to previous studies, methodological approaches were based only on 30m Landsat resolution data (Akpan et al., 2016; Essien & Akpan, 2013) and the perceptions of urban growth in Nigeria triggered by rural-urban migration (Akpan et al., 2016; Essien & Akpan, 2013), with scant attention given to the shared effects of natural resource revenue on urban development. The results show that natural resource revenue is used to restructure cities in the study area because of the nation's constant dwindling economy. Major urban infrastructure in Uyo and Warri are implemented using shared natural-resource revenue. In contrast, cities with low shared natural resource revenue, such as Aba and Umuahia, lagged behind in terms of the availability of modern infrastructure in their urban peripheries (manuscript 4).

Local economic data were obtained from the archived records of different government ministries. The data shows various increases and decreases in the local economy. In the study area, new socioeconomic data, such as tax variables, were extracted and evaluated, in contrast to previous studies on socioeconomic variables (Chen et al., 2017; Yang et al., 2019; Zhang & Seto, 2011) (manuscript 2). Integrating local economic data with satellite data presents several challenges, particularly when evaluating sources with missing data. This situation was observed when the Landsat satellite camera malfunctioned from 1993 to 1999 (Chander et al., 2004; Chander & Markham, 2003; Kim et al., 2013; Roy et al., 2014). Local economic data also showed a few contradictory observations, such as incorrect data entry and missing data in some relevant periods. It is vital to assess the uncertainties and limitations of the different data sources to validate the spatial analysis of the results. Regarding satellite data, uncertainties were measured using the statistical accuracy of the confusion matrix. The study's limitations resulted from the non-segregated built-up patterns that spread across urban areas, in combination with formal and informal housing units that lie side by side. These effects were reflected in the 5m RapidEye and 30m resolution Landsat data, as well as in the random forest predictions, and helped to increase the accuracy of the urban land-use classification maps owing to the availability of a large training dataset. However, this approach is inadequate for urban land use classification in heterogeneous landscapes.

The local economic growth observed in Uyo and Warri is influenced by numerous factors that attest to shared natural resource revenue, which is the key driver of change in urban areas (Manuscript 4). This study provides new insights into quantitative approaches for measuring urban growth using local and regional economic data, in contrast to global urban literature (Güneralp et al., 2020; Montgomery, 2008; Yang et al., 2019; Zhang & Seto, 2011). However, this study used an empirically derived approach that can strengthen the existing socioeconomic research methodology and discourage a predictive approach that involves the use of national data to assess urban economic transformation.

In this study, interview methods, such as participants' occupations, the strength of companies in urban areas, migration of urban dwellers, and questionnaire development were elaborately discussed. Furthermore, the methodology focused more on discussions with policy makers and community stakeholders but gave little attention to individual opinions because of tight schedules. This can be improved by giving participants more time to go through the interview questionnaires and conduct regular field trips to the study area in different seasons to monitor changes and natural vegetation growth in urban areas. Although this method requires more time and money, it can help reduce data uncertainties.

In conclusion, the integration of various data sources provides valuable information on shared natural resource-driven urban growth patterns using the study areas as a case study. These approaches complement other data sources and reduce the uncertainties associated with urban land-use classification. The integration will encourage the use of large-scale training data to improve the accuracy of urban land-use classification from regional to global levels. Nevertheless, integrating local economic data with remote sensing data at the regional level provides insights into governance, and shared natural resources inspire development that resembles economic growth. The UN Sustainable Development Goals 11 was established and encouraged to be implemented in cities across the globe using the study areas as a case study. However, developing countries find it difficult to achieve these goals. To this end, the results of this thesis make it necessary for stakeholders in various professions across different backgrounds to liaise with one another to realize UN Sustainable Development Goal 11 in developing countries.

10.2 Urban Economic Growth and Remote-sensing Research

With limited research on socioeconomic growth and its impact on urban areas in developing countries, this thesis adopts a methodological approach and uses new socioeconomic variables to evaluate changes in urban areas over time and assess the periods in which these changes occurred in various built-up areas. The time-series algorithm was modified to determine the periods during which the study areas experienced changes, and the relationships between different socioeconomic variables linked with the satellite data were empirically elaborated (manuscript 2). Besides lending insights into changes in the urban areas, the time-series analysis and the land-use map effectively contribute in various ways, including (i) trends showing the rate of change in urban areas, (ii) segregated settlement patterns in the suburban areas, (iii) congested growth in the city center, (iv) sparse built-up areas in the urban fringes, and (v) unplanned urban expansion in different built-up areas (manuscripts 1 and 2). Furthermore, the results demonstrate that the generated time-series data linked with socioeconomic variables can be intertwined with urban growth in the study area and that, when properly managed, they can (i) provide common ground by filling the segregation gap between the rich and the poor in the urban area, and (iii) foster an increase in shared natural resource revenue, possibly aiding in the planning process that is known to integrate all urban factors. The results of the time-series data agreed with the statistical analysis results of various socioeconomic data. The multiple data sources of this research, through the involvement of different environmental practitioners, will facilitate collaboration among experts who share common goals and promote the actualization of UN Sustainable Development Goal 11 (SDGs) for cities (manuscript 3).

Scientists and practitioners from various backgrounds, such as urban planners, heads of government ministries, social and environmental analysts, and urban community dwellers, participated in validating the findings of this study in addition to the empirical validation. The research aim was communicated to the participants before the discussion. This explains the high number of respondents who responded to the research questionnaire. In contrast, urban dwellers in the study area are known to be reluctant to engage in research discussions, especially if they are not promised an incentive afterwards. The head of each government ministry insisted on anonymity before participating in discussions.

Considering the broad data analysis in this thesis, various scientific literature, methods, and ideas from acknowledged experts were used to validate the data (manuscript 4). A statistical method was adopted from Wu et al. (2012, 2013) and Merschorf et al. (2020) to link various socioeconomic variables with satellite data (manuscript 2). Regression analysis was performed and guided by the existing scientific literature (Wu et al., 2012, 2013; Merschorf et al., 2020). Regression model analyses provide more insight into the relationships between dependent and independent variables (Merschorf et al., 2020). The results indicate that significant urban changes occurred when the shared natural resource revenue increased owing to the decentralization of the natural resource sharing formula (manuscript 2). The heads of government ministries and urban respondents did not influence the objectives of this research but only suggested ways to create sustainable urban growth (manuscript 3).

To date, local economic growth data have not been linked to satellite data to monitor urban growth in the study area. However, they were integrated with the interview data to help propose measures that could induce sustainable urbanization with the vast ongoing infrastructure development in the study areas. In sustainability sciences, most methodologies for urban development in Africa are based on UN data, interviews, and corruption (Avis, 2019; Farrell, 2018; Fox et al., 2015). These methods typically use a few people, mostly stakeholders, and predefined research questions. These approaches are effective in addressing science-specific questions. However, fusing local economic data and the UN SDGs 11 with interviews conducted with various stakeholders charts a straight path that could be adopted to achieve sustained urban development not only in the study area and in cities across Nigeria but also globally.

10.3 Focal points of the study

This study (Manuscript 1) analyzes land-use changes in Uyo, Nigeria, focusing on the impact of urban development on natural vegetation from 1985 to 2018. Utilizing remote sensing and Landsat image data, this research identifies eight land cover classes, with natural vegetation (forest, swamp, mixed) severely affected by urban sprawl. The key drivers of vegetation loss include economic restructuring, urbanization, and population growth. NDVI analysis indicated a trend of decreasing vegetation, necessitating strengthened policies to mitigate the impact of urbanization. The study calls for improved governance and planning to balance development with environmental sustainability. This research is important because it addresses the rapid urbanization in Uyo, Nigeria, and its impact on natural vegetation, providing a detailed mapping of land-use changes over several decades. Understanding these dynamics is crucial for sustainable urban planning and environmental management. By analyzing the relationships between urban growth, economic changes, and vegetation loss, this study highlights the need for effective policies to balance development with environmental preservation. The findings contribute to a broader understanding of urbanization trends in developing nations, particularly in Africa, where small and medium-sized cities experience significant demographic shifts.

This (manuscripts 2) examines urban growth patterns in Uyo, Nigeria, focusing on socioeconomic factors and their impacts on built-up areas. Using data from city administrative taxes, socioeconomic surveys, and satellite imagery, this study identified the primary drivers of urban expansion, such as household income and the availability of social amenities. The study found that increased socioeconomic revenue leads to urban growth, while a lack of amenities lowers suburban land value. Medium- and high-income earners tend to move to the suburbs for more space, highlighting the issues in urban planning laws. This study aims to assist in sustainable urban management and guide the monitoring of urban growth, offering insights for better spatial planning in similar African cities. This research is significant because it provides a comprehensive analysis of urban growth patterns in Uyo, Nigeria using a variety of economic indicators and satellite data. By understanding the primary drivers of urban growth and the socioeconomic dynamics in this mid-sized city, this study offers valuable insights that can inform urban planning and policy making. These findings highlight the challenges associated with unplanned urban development and underscore the need for effective urban management strategies. This research is particularly important for sub-Saharan Africa, where rapid urbanization is often not matched by adequate planning and infrastructure development.

Furthermore (manuscript 3) focus on the urban development challenges and governance practices in Uyo, a midsized Nigerian city, in relation to the UN Sustainable Development Goal (SDG) 11, which emphasizes inclusive, safe, resilient, and sustainable cities. It identifies major challenges such as inconsistent commitment to infrastructure projects and a flawed land tenure system contributing to housing insecurity. The study suggests that better fiscal management, governance, and overhaul of the 1999 Land Use Act could improve the situation. Uyo's case sheds light on similar issues faced by other midsized cities in Sub-Saharan Africa, highlighting the need for equitable development policies. The city's rapid growth, driven by oil revenue and migration, has outpaced infrastructure development, exacerbating socio-economic inequalities. This research is important because it focuses on sustainable urban development in midsized cities, specifically Uyo in Nigeria, which is often overlooked in favor of larger metropolitan areas. Understanding the challenges and governance practices affecting these cities is crucial for promoting inclusive and resilient urban growth in line with UN Sustainable Development Goal 11. By identifying key issues, such as flawed land tenure systems and discontinuity in urban development projects, this study provides valuable insights into creating more equitable and sustainable urban environments. This research not only helps inform policy decisions in Uyo but also offers lessons that can be applied to similar midsized cities in Africa and other developing regions.

Additionally (Manuscript 4), highlights the effects of economic shifts on agriculture. It emphasizes the role of natural resource revenue in fostering urbanization and economic restructuring, leading to infrastructural development and the rise of a consumption-based economy. This research focuses on the cities of Warri, Uyo, Aba, and Umuahia, illustrating how labor migration and low agricultural production drive urban growth and economic reform. It addresses the challenges posed by poor infrastructure and limited export opportunities, underscoring the implications for informal settlements and local economies. The study also presented a comprehensive urban land cover map, showcasing the utility of remote sensing for urban planning and analysis. This research is important because it provides critical insights into urban growth patterns in Nigeria, a rapidly urbanizing nation in Africa. Understanding these patterns is essential for policymakers and urban planners, as they address the challenges of urban development, such as the loss of agricultural land and economic restructuring. By examining the role of natural resource revenue in driving urbanization and its impact on local economies, this study highlights the potential of these findings to inform urban development strategies not only in Nigeria, but also in other developing regions facing similar challenges. This study contributes to existing literature by focusing on underrepresented cities in Africa, providing a comprehensive urban land cover map, and utilizing remote sensing technology to enhance urban planning and management.

Key insights from our study:

i. Urbanization Impact: The study reveals that urban growth in Uyo has led to significant changes in land cover, with natural vegetation being replaced by built-up areas, driven by infrastructure development and population growth. (Manuscript 1)

ii. Socioeconomic Drivers: The research identifies economic restructuring, urbanization, and population growth as key factors influencing land use changes, emphasizing the role of socioeconomic dynamics in shaping urban landscapes. (Manuscript 1)

iii. Policy Implications: The findings suggest the need to strengthen government policies to mitigate the adverse effects of urbanization, promote sustainable land use, and resolve conflicts between urban developers and environmental managers. (Manuscript 1)

iv. Urban Planning Challenges: This research highlights the inconsistency between current urban development and the city's master plan, emphasizing the need for improved urban planning laws and governance to effectively manage urban growth. (Manuscript 2)

v. Socioeconomic Impact: This study reveals that medium- and high-income earners prefer suburban areas for larger living spaces, indicating socioeconomic patterns that could influence future urban development and planning efforts in Uyo and other similar cities. (Manuscript 2)

vi. Governance Challenges: The study highlights the impact of poor governance practices, including lack of transparency and accountability, on urban development in Uyo, leading to poorly planned infrastructure and increased social inequalities. (Manuscript 3)

vii. Land Tenure and Housing: A flawed land tenure system exacerbates housing insecurity in Uyo, underscoring the need for reforms, such as overhauling the 1999 Land Use Act, to make land access more equitable and less cumbersome. (Manuscript 3)

viii. Strategic Policy Recommendations: The research emphasizes the importance of continuity in urban development projects and better fiscal management across administrative levels to align with SDG 11 and promote sustainable growth in midsized cities. (Manuscript 3)

ix. Economic Restructuring: The study identifies the infusion of shared natural resource revenue as a key driver of urbanization in Nigeria, which leads to significant economic reforms and challenges in urban areas. (Manuscript 4)

x. Urban Growth Drivers: The research highlights labor migration, low income, socioeconomic revenue, the availability of social amenities and inadequate facilities for agricultural processing as primary factors influencing urban growth and economic changes in Nigerian cities. (Manuscript 4)

xi. Urban Planning Tools: The development of an urban land cover map using remote sensing is a valuable tool for analyzing urban expansion, local economic conditions, and planning growth in built-up areas, which can be applied to other urbanizing regions. (Manuscript 4)

10.4 Research Framework

This thesis exploits a practical methodological research framework to measure the urban growth dynamics in cities across Nigeria. It detected changes in local economic growth, urban built-up patterns, and the adverse effects of shared natural-resource revenue on urban land, in contrast to previous studies that used national population data to evaluate urban growth (Farrell, 2018; Fox et al., 2015). A methodological framework was developed based on related studies (Wu et al., 2012, 2013; Merschorf et al., 2020) and fieldwork experiences. This approach aims to guide further scientific studies of urban growth in developing countries. The research was divided into four phases: (i) identification of the research aims and objectives (see the respective manuscripts), (ii) data acquisition and data type for the research, (iii) data analysis and validation, and (iv) results. The first phase aimed to establish contact with different stakeholders and target groups to provide vital information regarding the research questions. Additionally, spatial data were evaluated to determine the data type that best suited the research aim (Masek et al. 2000; Zha et al. 2003; Yuan et al. 2000). However, various spatial resolution data types provide information on changes in the study area. The shared natural resource revenue data were obtained from the annual economic data report of Nigeria's Bureau of Statistics, a national agency approved by the federal government to handle statistical matters.

Furthermore, cooperation was secured with government heads in various ministries to access local economic data and information regarding changes in urban areas. The research scope was further expanded to include experts and public respondents from various fields. The questionnaires were shared to potential respondents for subsequent individual interviews (Guest & Bunce, 2016; Jarah et al., 2019). After data collection and initial review, an interview with the head of each government ministry was planned to discuss the findings of the initial data review. The discussion aligns with the preliminary results and research aims and objectives. For urban land-use change, the objectives include classifying land-use types based on different classes with reference data, identifying economic variables that instigate an increase in urban population, and analyzing time-series data to extract yearly changes in the study areas.

In phase two, an in-depth urban land-use classification was analyzed using different machine learning approaches (Sarica et al., 2017; Xia et al., 2018; Breiman, 1996). Individual interviews were analyzed to ascertain people's perceptions of urban growth in the study areas based on the structure of the research questionnaires (Jarah et al., 2019) and ways to achieve sustainable urban development by integrating the SDG 11 goals. The yearly socioeconomic data report of the study area was evaluated to obtain vital information on the local economic growth of the study area. To understand the direction of urban growth, companies and local economic data were extensively analyzed to provide information regarding the strength of individual firms, as well as the back-and-forth migration that takes place in urban areas. In phase three, all data were validated using sample reference training data from the study area and interview questionnaires (Jarah et al., 2019). These data have been integrated using various scientific approaches (Wu et al., 2012, 2013; Merschorf et al., 2020). For data integration, similar data were separated and grouped (Guest & Bunce, 2016; Jarah et al., 2019). Different data were analyzed based on the urban land-use class, and a few discrepancies were observed in the results. The results were presented and discussed by our scientific research group to obtain further comments on the steps required to improve the research. In the final phase, the outcomes of the analyses were presented in four peer-reviewed scientific publications.

The presented four-step framework, based on urban remote sensing and urban economics geography literature, can aid in creating cooperation between researchers and urban stakeholders. This study provides a practical analysis of urban sustainability in developing countries, an area with a wide, underrepresented gap (Güneralp et al., 2017). This research framework serves as a valuable guide for researchers studying urban expansion in developed nations and countries facing similar local economic challenges. This study is the first in Nigeria to analyze urban growth linked to shared natural resource revenue and local economic data.

11 Outlook

Achieving the objectives of this research in a challenging socioeconomic growth era with fast-growing urbanization has led to some complex research questions and limitations, such as linking social science data and urbanization theory (in the context of Nigeria) with urban growth. The results of this thesis should serve as a model and contribute to the existing literature on urban growth in mid-sized cities both in Africa and globally. However, the research framework on socioeconomic variables linked to satellite data provides a methodological approach for further studies on urban growth. No previous studies have linked satellite data to social science data in the study area. Therefore, the stepwise process of this study can be adopted or modified for future research on urbanization in small-, mid-sized, and metropolitan cities.

This study focused on Uyo, Warri, Aba and Umuahia, all in southeastern Nigeria, as an illustrative case study for other global mid-sized cities or developed nations with similar or related case studies such as shared natural-resource income, population, and a local economic-growth pattern in different sectors of the economy. It is recommended that research in these areas should focus on integrating new socioeconomic variables to monitor urban growth in the respective study areas. Further studies on urban growth linked with social-science data should be carried out in places other than Uyo (for example, in northern or western Nigeria, Ghana, and southern Africa), with an emphasis on how local population growth influences urban built-up areas with different socioeconomic conditions or complex situations. Following the adopted approach, new methodologies and further studies could focus on the effects of the distribution of social amenities on urban areas in sub-Saharan Africa. In poorer countries, awareness of the effects of unplanned urban development should be created, especially in suburban areas, where most inhabitants use agricultural products to boost their local economies. This thesis's integration of socioeconomic variables and satellite data utilizes new variables and contributes to the non-existing urban growth database that is linked with socioeconomic variables in Nigeria. The approach of this thesis can be used to evaluate land-use and land-cover changes in different communities across cities globally. Future studies could analyze the effects of urban diversity and sociocultural integration among cities. The selection of spatial data is always limited to its availability as quantitative data, and the assessment of socioeconomic variables depends on having access to the data. However, the spatial resolution of the images should be properly evaluated to select the images that best fit the area. Interview questionnaires should also focus on the current socioeconomic conditions of the areas. While this thesis only evaluated yearly socioeconomic data at five-year intervals for the urban land-use classification map, the limitations and data uncertainties faced in the course of making this study act as a stepwise approach that guides further related studies. Apart from satellite data, the integration of similar data from interview questionnaires with continuous quantitative economic data would represent a problem-solving strategy employed by other professional disciplines that take interest in the integration of data for environmental impact assessment, land-use change/dynamics, and urban studies.

The methodological approach was influenced by the availability of various datasets, e.g. 30m Landsat data, 5m RapidEye data, socioeconomic variables, and computational abilities. However, future studies could use higher multitemporal resolution data such as 1m quick-bird data, to minimize data uncertainties. Socioeconomic variables can be analyzed using a machine-learning approach or a new statistical model that is most suitable for the data type. In terms of local socioeconomic data acquisition, which was difficult to obtain in this thesis, further studies should be conducted three months prior to fieldwork. The analysis of socioeconomic variables, integrated with satellite data, was performed within Uyo and its environs owing to the lack of regional data in this thesis. Nonetheless, further studies should increase its extent to other regions to achieve comprehensive urban mapping to larger extents. Although Uyo was chosen as the administrative area and focal point of this study, the findings demonstrate that sustainable urban infrastructural development is another challenge for the region. To address this problem, future studies should outline the UN Sustainable Development Goals 11 agenda and integrate it into all the aspects of urban development. Finally, this study not only provides insights into sustainable urban infrastructural development and relates the results to analytical methods, but also provides various approaches that researchers can use when analyzing sustainable urban development.

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PART IV

APPENDIX

(Eidesstattliche) Versicherungen und Erklärungen

(§ 9 Satz 2 Nr. 3 PromO BayNAT)

Hiermit versichere ich eidesstattlich, dass ich die Arbeit selbstständig verfasst und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe (vgl. Art. 97 Abs. 1 Satz 8 BayHIG).

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