URBAN GROWTH PATTERNS AND PROCESSES IN LAGOS ISLAND LOCAL GOVERNMENT AREA, NIGERIA

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ABSTRACT

Unplanned urban growth is one of the major challenges in developing countries. The literature on urban growth has focused more on horizontal growth, without a corresponding emphasis on vertical growth. Even within the urban horizontal growth analysis, greater attention has been on the dynamic patterns rather than processes of growth. This study was, therefore, designed to analyse the spatiotemporal dynamics, patterns, and processes of horizontal and vertical urban growth in Lagos Island Local Government Area (LGA), Nigeria.

Urban Morphology and Complexity theories provided the framework, while a survey research design was adopted. Lagos Island LGA was purposively selected given the concentration of high-rise buildings. A total of 1,200, out of 47,447 households were systematically selected using Neumann (2014) probability method. Socio-economic and building related data were collected through questionnaire survey. Landsat (1984, 2000, and 2015) and IKONOS (2013) images provided information on growth patterns and processes. Spatiotemporal dynamics of urban growth were analysed using change detection and ANOVA. Moran's Index (I), spatial metrics (Clumpiness index) and spatial regression were used to analyse horizontal growth patterns and processes. Three-Dimensional Spatial Index (3DSI), Nearest Neighbour Index (R_n), vertical entropy (H_n) and standard regression were used to analyse patterns and processes of vertical growth. Cellular Automata Markov model (CA-Markov) and binary logistic regression were used to predict future urban growth. Analyses were conducted at $p \leq 0.05$.

Age of household heads was 39.92±12.48 years, while 65.5% were male. Household size was 4.92±2.38 and income was ₦66,468.43±₦33,798.96 per month. Urban land area increased from 4.20km² in 1984 to 5.40km² in 2015. Net and gross changes in the built-up area were ±0.77km² and 1.45km² respectively. There were significant spatial variations in urban horizontal growth in 1984 ($F_{(1;18)}$=3.79), 2000 ($F_{(1;18)}$=5.71) and 2015 ($F_{(1;18)}$=11.75), but no significant temporal variation. Horizontal temporal growth patterns were significantly clustered (I=0.28(1984), 0.53(2000) and 0.29(2015)). Fragmentation and aggregation were the major processes of urban horizontal growth (Clumpiness index=0.87(1984), 0.84(2000) and 0.87(2015)). Population growth (β=0.98), building lot size (β=0.04), demand for space (β=0.22) and housing stock (β=0.0003) were major drivers of urban horizontal growth. Vertical growth increased between 2000 and 2015 (3DSI=6914.45) more than between 1984 and 2000 (3DSI=6601.82). Vertical growth pattern was significantly clustered (R_n=0.52), while aggregation (H_n=0.1) was the major temporal process of vertical growth. Number of financial institutions (β=0.68), rental value (β=0.46) and proximity to water bodies (β=0.63) were the major drivers of vertical growth. By 2031, about 71.5% of Lagos Island would have been built-up. Proximity to water bodies through land reclamation (β=4.11, Exp(β)=60.74) would be the most significant predictor of future urban growth.

Lagos Island Local Government Area, Nigeria has witnessed both horizontal and vertical urban growth due to fragmentation and aggregation of urban patches between 1984 and 2015. Urban horizontal growth will decrease with the increasing vertical expansion, hence the need for effective urban planning.

Keywords: Urban growth, Horizontal and vertical growth, Lagos Island, Nigeria

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> *Not unto us, O LORD, not unto us, but unto thy name give glory, for thy mercy, and for thy truth's sake. Wherefore should the heathen say, Where is now their God? But our God is in the heavens: he hath done whatsoever he hath pleased…The LORD hath been mindful of us… The dead praise not the LORD, neither any that go down into silence. But we will bless the LORD from this time forth and for evermore. Praise the LORD (Psalm 115:1-18).*

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Oh, for a thousand tongues to sing
My great Redeemer's praise
The glories of my God and King
The triumphs of His grace!

Jesus the name that calms our fears,
That bids our sorrows cease,
'Tis music in the sinner's ears,
'Tis life, and health and peace.

He breaks the power of cancelled sin,
And set the pris'ner free
His blood can make the foulest clean,
His blood availed for me.

My gracious Master and My God
Assist me to proclaim
To spread through all the earth abroad
The honours of Thy name.
-Charles Wesley, 1739.

H.D Olaniran,
June 2019.

CERTIFICATION

I certify that Mr Hezekiah Daramola OLANIRAN, in the Department of Geography, University of Ibadan, Ibadan, Nigeria carried out this research under my supervision.

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DEDICATION

Unto the King eternal, immortal, invisible and the only wise God. To Him be honour and glory forever and ever. Amen. (1Tim 1:17).

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CHAPTER ONE

INTRODUCTION

1. 1 Background of the study

The primary focus of this research is the examination of the dynamics of urban horizontal and vertical growth in space and in time. Existing studies on urban growth have given too much attention to the urban horizontal growth than the vertical growth of cities. In addition, the examination of the nexus between horizontal and vertical growth dynamics has not received considerable attention. This research attempts to bridge this gap by investigating growth in urban areas from two-dimensional and three-dimensional perspectives. The research views urban growth as a complex development and attempts the deployment of new analytical methods and modelling techniques to the analysis of urban growth for the benefit of society.

Understanding urban growth and its dynamics (forces or properties that stimulate growth, development, or change within urban systems) are important for a number of reasons. First, urban growth is a dynamical complex process that involves several ecological, physical and socio-economic components that operates at different spatial and temporal scales (Cheng, 2003). Understanding such complex dynamical system requires a systems perspective and modelling techniques that take into account, both spatial and temporal dimensions of urban growth systems.

Second, due to the influence of population change on investment in housing and infrastructure, the rate and dimension of urban spatial expansion are largely determined by population growth. Current population growth in most of the cities of less developed countries, particularly Nigeria is already outstripping the capacity of many state and local governments to supply necessary services and infrastructure. Understanding population dynamics and its impact on urban spatial expansion in Lagos Island will enable a good understanding of the urban development process in Nigeria and many other cities of less developed countries. It will also assist in planning, policy formulation and decision making among actors in the urban sector.

Third, apart from population growth and migration, which are known and highly emphasized factors of urban growth, several other factors influence urban spatial expansion, the form it takes and the pattern it represents in space. These factors determine the direction of growth (whether outward or upward) and are key variables in the analysis and modelling of urban systems. To understand urban systems and achieve sustainable urban growth, both the biophysical and socio-economic forces that drive urban growth need to be understood and evaluated; first for the understanding of pattern and process and second to enable prediction and planning of future urban growth of the city.

Fourth, a major focus of urban analysis over the years has been the understanding and explanation of the spatial processes of urban growth. Previous explanations of urban growth patterns and processes had followed the socio-economic analysis. However, recent development has shown that the application of geospatial analysis techniques involving remote sensing technology and geographical information systems (GIS) can provide alternative approaches to the analysis and explanation of urban growth. Geospatial analysis provides a distinct perspective on the world. Events, patterns and processes can be spatiotemporally determined through the unique lens of geospatial techniques. Adopting geospatial technologies in urban growth analysis will help in tracking and explaining structural and functional changes in a complex urban landscape like Lagos Island.

Lastly, cities spatial expansion in different regions of the world is moving at a greater speed than at any other time in human history. It had been projected that world cities will grow by 2.5 times in area by 2030 (Angel, 2005). The implication of this is that urban land area will account for the greater proportion of the total land area of the countries of the world; the result will be increasing scarcity of land for urban development and a significant reduction in the total arable land. A major strategy adopted to contain the horizontal spread of urban growth in most Western and Asian countries is increased upward expansion of the city’s space. Considering vertical development as an alternative strategy for sustainable urban development seems plausible. It is imperative therefore to examine patterns and processes of urban vertical growth, in order to determine future implications of both horizontal and vertical expansion of urban space. This is very essential, particularly in cities of less developed countries where urban planning problems have become intractable challenges.

Undoubtedly, urbanization and its associated drivers have indeed become a prominent focus of the twenty-first century scholarly discourse; however, as studies proliferate on these, similarly, disagreements keep multiplying, particularly as to how exactly cities and their growth should be conceptualized and studied (Scott and Storper, 2014). It is aimed that a study on urban growth dynamics in cities of less developed countries like Lagos from new scientific perspective and methodologies based on geospatial technology however modest will contribute to proper conceptualization, analysis and explanation of patterns and processes of urban horizontal and vertical growth.

1.2 Statement of the problem

A major theme in urban geographical analysis is the characterisation of urban growth as a system and the understanding of its spatial and temporal dynamics. In line with this theme, the present research proceeds on a number of mutually interacting levels. First, it seeks to understand urban growth as a complex system from the perspective of complexity theory deploying the methods of remote sensing and GIS. Complexity theory is a relatively new conceptual framework concerned with the understanding of systems characterized by nonlinear behaviour, feedbacks, self-organization, irreducibility, and emergent properties, in which the whole is not only more than but also different from the sum of its parts (Baynes, 2009). From the complex systems perspective, urban growth may be viewed as a system that develops from complex interactions between three critical sub-systems namely; planned urban system, developed urban system and developable non-urban system (Cheng, 2003). Primary to the understanding of urban growth is a clear understanding of these complex dynamic interactions.

Cities are complex systems, whose growth processes are influenced by a complex interplay between horizontal and vertical development. While the urban horizontal growth is being measured by the extension of the city's boundary into fringe areas, the construction of tall buildings has been used to represents the vertical expansion of the city's space (Zhang, et al., 2017; Lin, et al., 2014; Shi, et al., 2009 and Fan, 1999). While the dynamics of horizontal expansion have been given considerable research attention, the dynamics of urban vertical growth has not been adequately researched. This raises a number of issues to be addressed. First, how do we determine urban vertical growth, second what are the factors driving urban vertical growth? Three what is the relationship between horizontal growth and vertical growth? Lastly, what is the spatial pattern of urban vertical growth? An unambiguous understanding and quantification of the growth of the city, both in two- dimension (lateral) and three-dimension (vertical growth) is required to answer these questions.

Further, significant and discernible changes in the spatial structure and landscape of urban areas of less developed countries, particularly Nigeria had been observed. While this has been widely reported in the literature, less is known about the specifics in terms of the form and nature of the spatial changes. Crucial in understanding the nature of spatial changes in the urban landscape is the understanding of the patterns and processes of these changes. While the process relates to urban growth dynamics, the pattern is the outcome of the processes of urban growth. A major problem in this regard is how to measure, analyse and model the pattern of urban growth in space and time.

In urban development planning, an important subject is the prediction of the land use transition in an urban area. Prediction helps in the decision-making process. Planning without a proper understanding of the system will increase system uncertainty. To reduce system uncertainty, modelling and simulation are required, first to increase the understanding of urban systems and second to reduce subjectivity in decision-making. Multi-temporal data from various sources and varying scale with remote sensing and geographical information systems provide an analytical and problem-solving approach that could help decision-making in urban planning (Cheng, 2003).

The central goal of urban growth research is to investigate patterns and processes of urban growth and the available policy options for planning and management. Achieving this demands gaining a better understanding of urban expansion and its key dimensions. It also requires an understanding of the forces that are driving expansion either laterally or vertically. The problem here is what are the specific drivers of urban growth? Given the foregoing, this research sets out to answer the following questions;

i. What is the conceptual basis for understanding and evaluating urban growth?
ii. What are the urban growth patterns and processes and how can they be quantitatively determined using multi-temporal imageries.
iii. How can the spatial and temporal complexity of urban growth be deciphered?
iv. How can the patterns and processes of urban vertical growth be determined?
v. What are the driving forces behind horizontal and vertical growth in Lagos Island?
vi. What are the implications of the present pattern and processes of urban growth and what can or should be done about it?

The better we understand the how and why of urban growth, the more effective our employment or development of methodologies and techniques efficient in understanding, analysing and modelling its spatiotemporal patterns and processes. The more intelligently also we can deliberate on those aspects of urban growth systems that needed to be planned, re-planned and manage.

1. 3 The aim and objectives of the study

This study aimed at analysing spatiotemporal changes in urban growth, in order to identify its associated drivers and understand inherent complexity in urban growth taken Lagos Island as an example. The specific objectives are to;

1. Evaluate spatial and temporal changes (dynamics) in the structure and growth of Lagos Island between 1984 and 2015.
2. Examine the spatiotemporal patterns and processes of horizontal and vertical urban growth in Lagos Island.
3. Relate satellite-derived estimates of changes in urban growth to physical and socio-economic drivers.
4. Identify specific factors influencing the vertical growth of the city.
5. Examine the relationship between horizontal and vertical urban growth.
6. Model the vertical landscape of the built environment in Lagos Island.
7. Assess the future urban growth and suggests strategies for future planning of the city.

1.4 Relevance of the research

The goal of applied geography had been stated to be the application of geographic knowledge and skills to the resolution of social, economic and environmental problems (Pacione, 2011). Indeed the relevance and value of any geographical research to the society can only be assessed based on its ability to address problems or challenges that confront modern societies. One of the challenges of the 21st-century world is increased urbanisation and uncontrolled expansion of urban areas in virtually all parts of the world. Addressing urban growth with its concomitant problems in a city of less developed countries from empirical research is a significant and a modest contribution to societal development.

Scientifically, urban growth is a topic that straddles many scientific disciplines that apply numerous scientific and technical applications. Recent developments in geospatial techniques, particularly in the areas of geographical information systems (GIS) and remote sensing (RS), spatial statistics, land cover/land use modelling and complexity science is providing new leverage for deciphering the spatial and temporal dimensions of urban growth (Cheng, 2003). As observed by Longley and Tobon (2004), extending the interests of urban geographers towards more direct, timely, spatially disaggregate urban indicators is a key in developing the data foundations for a new, data-rich and relevant urban geography. The combined use of remote sensing, GIS and spatial statistics in this research is expected to lend credence to previous researches, strengthen current position on the use of these techniques and methodologies in urban research and provides direction for future research. It will facilitate new understanding and insight about urban growth, thereby moving urban research away from relying solely on theoretical abstraction and hypothesis with non-spatial statistical data.

Despite the plethora of researches in urban analysis, the knowledge of the physical and socio-economic drivers of the patterns and processes of urban growth is inadequate. Scenario simulations of future urban growth with several land-use categories within urban areas particularly in cities of less developed countries still suffer deficiencies because of problems of data availability and resolution. As a result, identification and interpretation of urban growth patterns, interpretation of the inherent complexity of urban growth and deciphering urban growth processes have become a major challenge in urban planning (Cheng, 2003). A study of urban growth with multi-date and multi-source imageries would help in identifying and modelling the dynamics influencing urban growth. It will help in presenting the emerging geographic pattern and processes involved.

Having a theoretical and methodological understanding of the processes of vertical growth in the city is a major impetus of this research. In the past, researches about urban expansion have focused on horizontal expansion. Weizman (2002) once argued that "the cartographic, top-down aerial gaze had long dominated both mainstream and critical geopolitical discourses." According to him, "this had worked to flatten spatial imaginaries, geopolitics is a flat discourse that largely ignores the vertical dimension and tends to look across rather than to cut through the landscape. This was the cartographic imagination inherited from the military and political spatialities of the modern state" (Weizman, 2002). To date, similar flattening of discourses and imaginaries still dominate critical urban research most especially in the Anglophone world (Graham and Hewitt, 2012). Therefore, an examination of the processes of urban vertical growth particularly, from developing country like Nigeria will contribute significantly to the global discourse on urban growth.

Urban growth is a three-dimensional process (Shi, et al, 2009), but few studies have explained urban growth from a three-dimensional perspective. Some studies had addressed the issue of the height of buildings. For example, Alfred (1980), using diminishing marginal return and land rent, analyzed building height. He showed that buildings height has a limit, because the extra expenses for foundation and thick wall, elevator, together with some resulting depreciation of the lower floors, will make more loss than gains by adding one more floor, hence vertical expansion in urban space has its limitations. Others have studied the layout structure of buildings (Wright, 1971) and the environmental effects of urban vertical expansion (Hoch, 1968). However, the understanding and analysis of patterns and processes of vertical urban growth have not received corresponding attention compared to urban horizontal growth. This research fills this gap, by providing detailed explanations on the pattern and process of vertical growth in Lagos Island.

In Nigeria and most countries of the less developed economies, understanding the causes and effects of horizontal growth has been the major focus of urban research, while the vertical dimension of growth is largely neglected. For example, Adeboyejo (1994, 2000) studied the structure and dynamics of central places in southwestern Nigeria. He emphasized the hierarchy of cities. Ayeni (1974) carried out predictive modelling of urban growth using principles in thermodynamics. Adegboyega and Aguda (2010) attempted spatiotemporal analysis of urban sprawl in a fringe area around Ibadan in Southwestern Nigeria. Eniolorunda and Dankani (2012) assessed the urban growth pattern in Sokoto metropolis using multi-temporal satellite data. Fabiyi (2006) employed the techniques of remote sensing to evaluate land use and land cover change in Ibadan metropolis. He observed occurrences of growth by fission in the metropolis. Mabogunje (1968) undertook a comprehensive analysis of the structure and growth pattern of cities in Nigeria from ecological theories perspectives and Salami (1997) examined urban growth and rural land retreat in Ibadan. All these studies looked at urban growth from a two-dimensional perspective.

The neglect of the third dimension of growth in the studies highlighted above and many other related ones is principally due to the fact that the majority of African cities are experiencing rapid urban horizontal than vertical expansion. In addition, resources in terms of public and private investments to build vertical futuristic urban agglomerations are not available in many African countries. The only area where vertical development is taking place at a noticeable scale is the city of Lagos in Nigeria. The recently proposed Atlantic City project and Isale-gangan redevelopment scheme in Lagos are a good example of vertical development. Undertaking empirical research about such area will help in exploring the futuristic implications of vertical development and help in developing effective urban management strategies. Up to the present, the knowledge of patterns and processes of urban growth in most urban Islands of the world is still limited, Lagos Island inclusive. This research holds the view that empirical findings from Lagos Island will provide new levels of understanding that will help in planning and managing growth processes on Islands, particularly in this era of global warming and climate change.

One of the principal aims of urban planning is to achieve a liveable city. Achieving this requires an understanding of factors that drive city growth. Both physical and human factors (especially human actions and decisions) are important drivers of urban growth. A major contribution of this research is to discover, examine and explain multiple processes of urban change and ways of enhancing urban density through the promotion of vertical growth. This research views vertical expansion as a new research frontier in urban research. Findings from this research will lay the foundation for future research in urban growth prediction and planning, particularly in Nigeria and other African countries.

1.5 The choice of Study Area

This research considers Lagos Island local government areas; a part of metropolitan Lagos referred to as the original city of Lagos as the study setting. It is called the original city because it is where Lagos began to spread (Oyesiku, 1999). Traditionally, the area is known as Eko. The Aworis, a Yoruba sub-ethnic group, established it as a small fishing settlement around 1450.

1.5.1 Physical setting and Climate

Lagos Island area is located on latitude 6^0 26' 30" and 6^0 28' 00" North and longitude 3^0 22' 45" and 3^0 24' 45" East along the West African coast. It is bounded in the south by the Lagos harbour, in the North by the Lagos Lagoon and the Mainland Local Government area, in the east by Eti-Osa Local Government Area and in the West by the Lagos harbour district of Apapa in Apapa Local Government Area. Geographically, it is an outlet into the sea, surrounded by creeks and lagoons. The island is circled by a ring of highways (see plate 1.1), which is the main access to and from the island (Kumshe, 2010). Lagos Island is connected to the Lagos mainland by three large bridges, namely Carter bridge, Eko Bridge and the third-mainland bridge which cross the Lagos Lagoon to the district of Ebute Meta. The climate of Lagos Island is similar to that of the entire Lagos region. A tropical climate system that is largely controlled by two major prevailing winds, namely the tropical continental air mass from the Sahara and the tropical maritime from the Atlantic Ocean. The area experiences two significant periods of rainy seasons. The first is heaviest, falling from April to July and the second characterized by lesser rainfall between October and November.

Sedimentary rocks with rarely basement outcrop underlie the geology of Lagos Island. The highest point on Lagos Island is about 113 feet (34 metres) above sea level around Marina axis. The soil is made of rich alluvial and ferralitic red-yellow soil. The original vegetation made up of swamps and coarse type of grasses interspersed with clusters of a large tree on the Island had given way to the high concentration of human activities due to increased urbanization. The remnant at the fringes bordering the Lagos lagoon is presently being cleared and sand filled to provide land for other development (see plate 1.1).

Lagos Island Local Government Area has 19 spatial units called wards (see figure 1.1). It is made up of historical localities such as; Olowogbowo, Oluwole, Idumota, Oke Arin, Oko-Awo, Agarawu, Obadina, Isale Kakawa, Popo-Aguda, Anikantamo, Oko Faji, Eiyekole, Onikan, Sandgrouse, Epetedo, Lafiaji and Ebute-Elefun etc.

The choice of Lagos Island arises from three important reasons. First, the area occupies an important place in the urban history of Nigeria. It was a historical centre, a former capital of Lagos State, the former capital of the Federal Republic of Nigeria, a commercial core of the greater Lagos and the economic/commercial hub for the country. The area has witnessed a large-scale transformation in the recent past. The study of this area presents an opportunity to dig into and understand the urban history of Nigeria. It will help in comprehending and explaining the dynamics of the major axis of Lagos's historic growth. Second, Lagos Island covers one of the most dynamically evolving segments of Lagos's metropolitan fabric. It is the core and the most developed segment of the Lagos city.

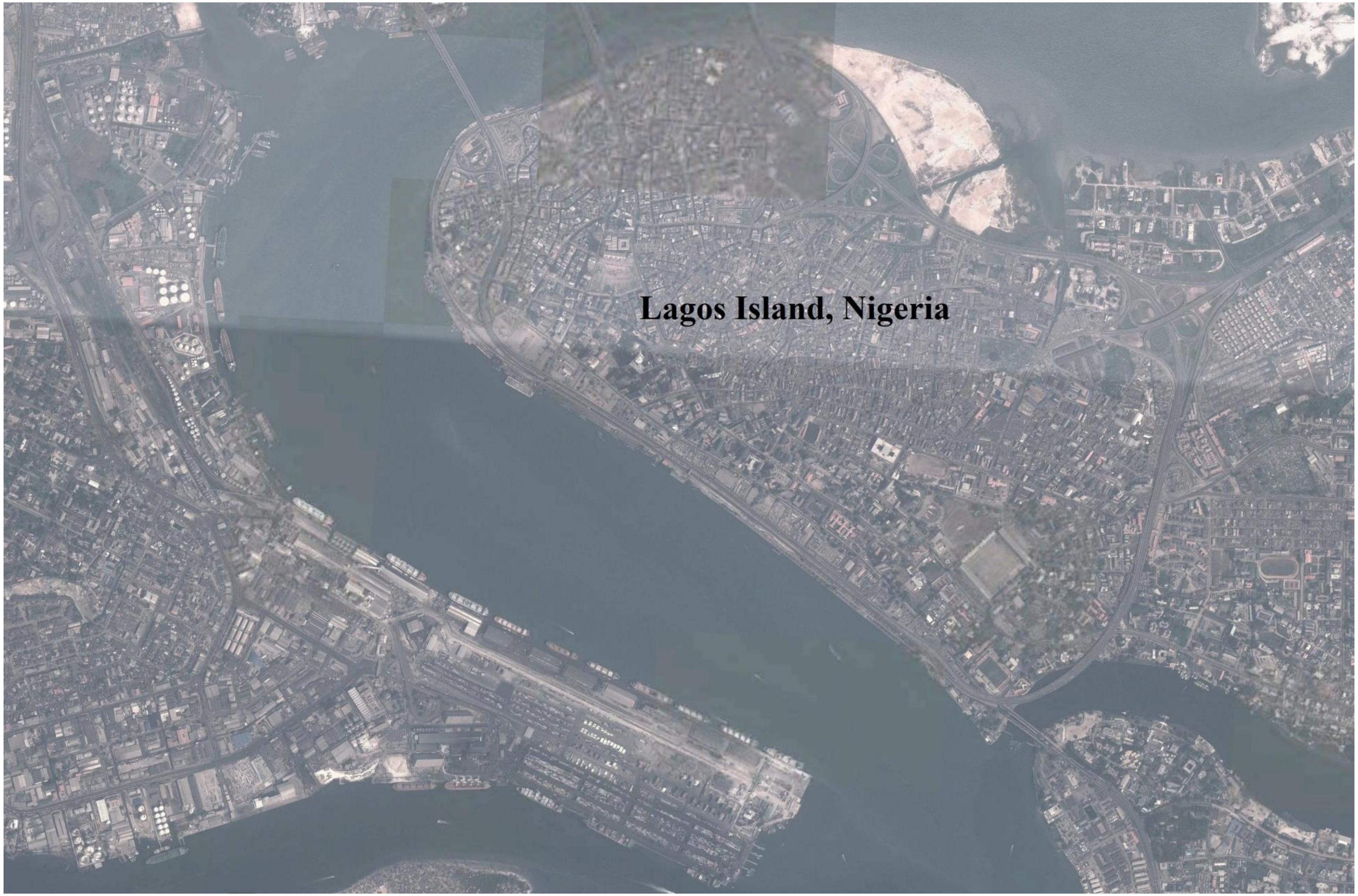


Plate 1.1. Lagos Island from IKONOS imagery 2013

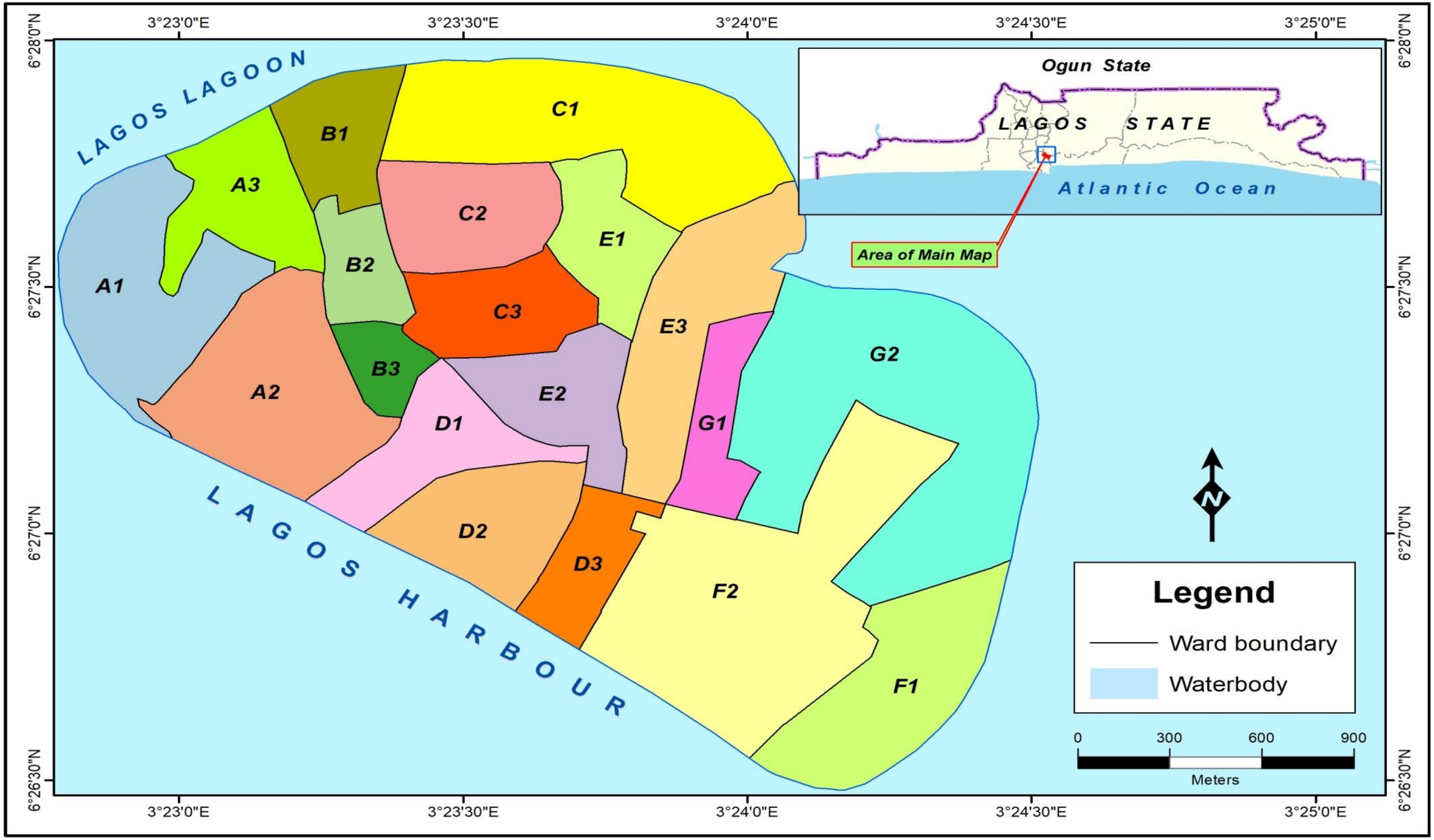


Figure 1.1. Lagos Island Administrative units (Wards)
Source: The Author, 2018

Although the whole of the Island had been reportedly built up by 1944 (Ayeni, 1981), yet the area is still expanding. Between 1991 and 2006 (a period of 15 years) the area was found to have expanded by 2.0 square kilometres. Within Lagos state and perhaps Nigeria at large, there is hardly any area that is undergoing continuous discernible structural and population changes like the Lagos Island area (see plate 1.1). As observed by Ayeni (1983), Nigeria provides a good situation for studying the dynamics of urbanisation process as well as for examining the social, economic and spatial responses to changing mechanism of urbanisation. Examination of mechanisms of growth in an area like Lagos Island will help urban planning strategies and policy development in the Lagos mega city and Nigeria as a whole.

Third, the main business district of the metropolitan Lagos occupies Lagos Island's Southwestern shore. High-rise buildings and many city wholesale market places characterize the area. It is an axis with high urban intensification. This no doubt qualifies the area for three-dimensional modelling exercise and analysis. Analysing urban growth from a three-dimensional perspective will enhance urban environmental planning and effective development control for beneficial urban growth.

Over the years, the northwestern tip of Lagos Island has been an urban planning challenge. The area is a slum, characterized by narrow streets, poor housing and overcrowding. There is an unauthorized change of use of land in the area, resulting in increased growth of blighted neighbourhoods, encroachment on drainage alignment and setbacks. Recently, emerging urban land uses like event centres, eateries, shopping plazas, private schools, places of worship, petrol filling stations, office complexes etc. are impeding traffic on major roads. Given this unhealthy physical development, the area has been listed as a major part of the urban redevelopment plan of Lagos State Government.

Presently, a notable urban re-development process in Lagos Island is Isale Gangan urban redevelopment scheme in Isale-gangan area. The scheme reportedly involves the development of 54 units of 11-storey building on the 2,500-square meters property which traversed Binuyo, Princess, Onala and Isale Agbede streets. This initiative will surely produce a significant effect on the urban system. Considering such an area for the present research would help to achieve better urban planning and sustainable urban environment.

1.6 Organization of the Thesis

The thesis divides into nine chapters. Chapter one provides a background to the research. It sets an agenda for the research in a clearly defined aim and measurable objectives. Chapter two focuses on the conceptual framework of the research. It gives details of supportive theories and concepts upon which the entire research was built and hypotheses tested. It also consists of a review of empirical findings on urban growth and urban growth modelling. Chapter three gives the details of the methodology of the research. Chapter four provides an in-depth evaluation of the growth of Lagos Island. In chapter five, measurement and analysis of complexity in urban growth were considered.

In chapter six, the modelling of urban growth processes was undertaken. Urban vertical growth and development in Lagos Island were discussed in chapter seven. Among many other things, the chapter expatiates on why cities grow vertically and examine variations in the vertical dimension of growth in various parts of the world. In chapter eight, an attempt was made at modelling the dynamics of urban vertical growth in Lagos Island. The chapter presents a 3D city model of the urban landscape developed in a GIS environment. Chapter nine concludes the thesis by highlighting the major findings of the research. The main thesis of the research was clearly stated and issues for future research were discussed.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2. 1 Introduction

This chapter presents the conceptual framework and the review of relevant literature for this research. It discusses important and relevant theories of urban growth. These frameworks were chosen because of the need to understand the spatial structure of the city, analyse patterns and processes of urban growth and identify the specific drivers of urban horizontal and vertical growth. The chapter has two broad sections. The first section provides a detailed description of the conceptual frameworks and their relevance to the research and the second provides a broad review of relevant literature on urban growth.

2. 2 Conceptual Framework

The classical theories of urban morphology (including Burgess (1925) concentric zone theory, Hoyt (1939) sector theory and Harris and Ullman (1945) multiple nuclei theory) complexity theory, the theory of urban land rent and urban population densities form the fulcrum upon which this study rests and turns. The details of these theories were discussed in the succeeding sections.

2. 2. 1 Classical Theories of Urban Growth

The earliest attempts at understanding and explaining urban growth patterns and processes were through classical theories of urban growth, that have their origin from the sociological school of thought, which emphasizes man-environment interaction. This body of theories include; concentric zone, sector and multiple nuclei models of urban land use. To date, this body of theories/models remains a reference point for urban analysis, particularly in understanding and explaining city growth and structure. The major concern of classical theories of urban growth is to explain the location of cities, their morphology and natural conditions that favoured their growth. The models emphasize how topography and other physical attributes influence the layout of streets and neighbourhoods as well as the direction of the city’s growth.

2.2.1.1 The concentric zone theory/model

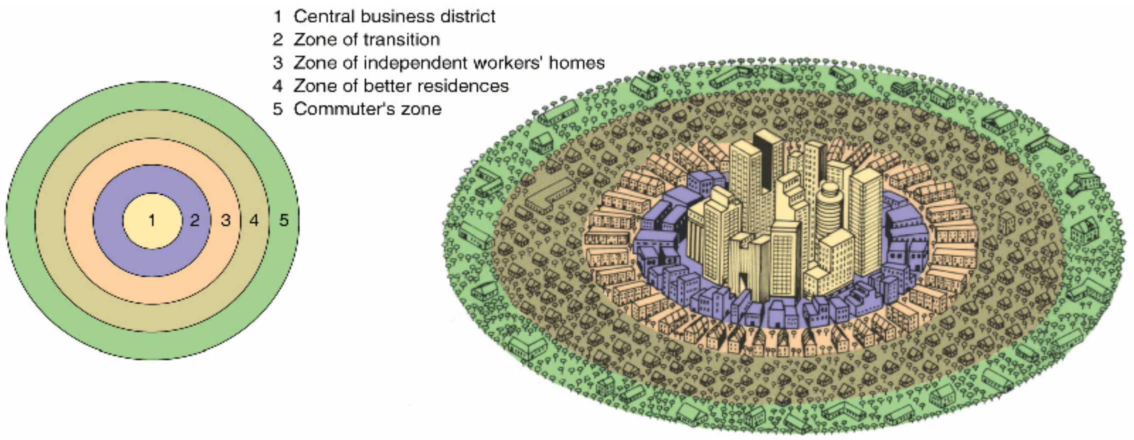
This model was developed by Burgess, a sociologist in 1925 from his study of the city of Chicago. The model stressed the importance of the interrelationship between growth and form and conceived the spatial organisation of the city as consisting of zones arranged concentrically from the city centre. The city structure grows by the expansion of zones and invasion of one zone by another (Winsborough, 1970). The model is monocentric suggesting an urban land use pattern arranged around a single centre which is usually called the central business district (CBD) (see figure 2.1a).

The CBD is usually the hub of urban activities including financial, economic, social and recreational functions and some light manufacturing towards the outer fringes (Ayeni, 1979). The zone following the CBD is the transition zone. It is a zone characterized by residential deterioration because of the encroachment of business and industrial activities from the CBD. The third zone is the zone of independent workers' home comprising residences of second generation migrant into the city. The fourth zone houses the middle class and the last zone called the commuter zone consists of encircling small cities, towns and hamlets, which serve as a dormitory suburb for the rich.

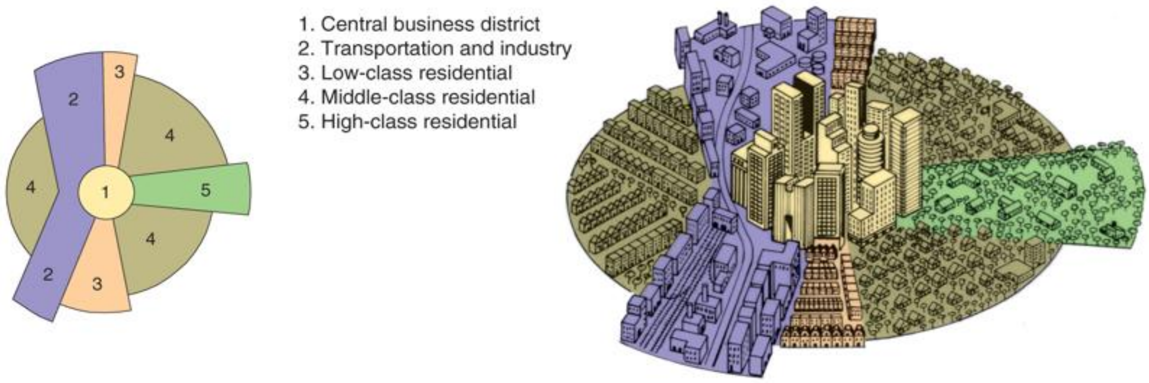
In Burgess's view, zones are products of the city's growth process. As the city grows, each zone extends to the next outer zone by the process of "invasion and succession." City expansion begins from the CBD and moves to the outer rings. However, the problem of the model lies in the fact that city growth was described, but why the city grows, the dynamics of its growth in time and space and the patterns emerging were not explained.

2.2.1.2 The Sector Model

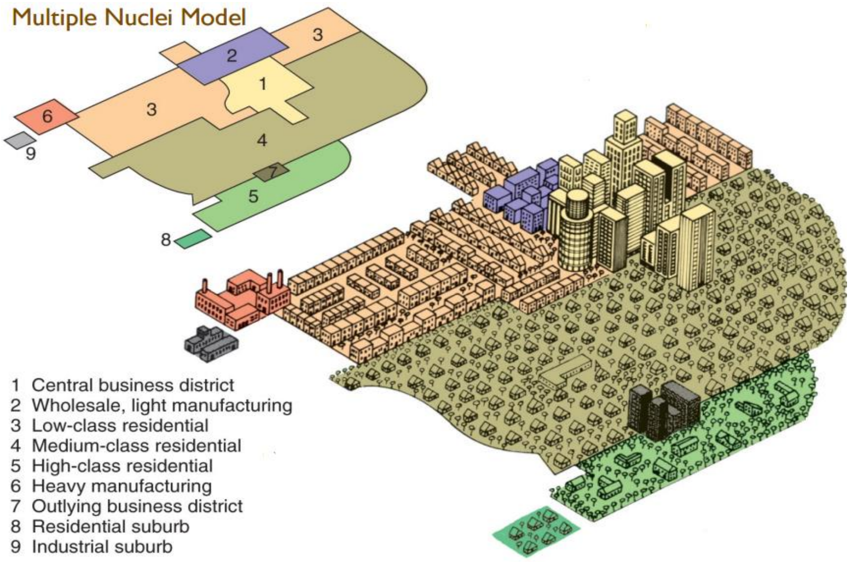
Implicit in concentric model of urban growth is the idea that transportation routes radiate from the city centre. Population and activities tend to follow transportation lines with residential use occurring on the interstices. The realization of these by Homer Hoyt, (1939) made him to described urban expansion as "axial growth pushing outward from the centre along transportation lines." Hoyt identified a relationship between urban growth, rent differential and ability of an urban function to bid for the city land, particularly in American cities. From his study, he observed that rent conforms to a pattern of sectors rather than concentric zonation and as a result define organization of city space. Thus, he concluded that a segmented pattern of land use seemed more appropriate than a pattern of concentric zonation as shown in figure 2.1b. The problem of sector theory of urban growth is similar to that of concentric zone theory. The idea of the monocentric urban centre is a fact hardly borne out in any part of the world (Ayeni, 1979).



(a) concentric zone theory/model



(b) The Sector Model



(c) Multiple Nuclei Model

Figure 2.1. A 3D rendering of the classical models of urban growth.
Source: Rubenstein, 2005: 445-447

2.2.1.3 The Multiple Nuclei Model

The inherent problem of monocentric assumption in the earlier two models necessitated the need to develop another model that could aptly describe the growth and form of cities. Chancy Harris and Edward Ullman formulated the multiple nuclei model in 1945 (see figure 2.1c) to address this problem. The model posits that the land use of a city is built around several discrete nuclei rather than one single nucleus. Such a nucleus may be residential, industrial, commercial, or political. Other nuclei may develop from different requirements of urban activities. Depending on the sizes of cities, the number of nuclei may vary from city to city. However, once a nucleus has been formed, the other types of land use are expected to develop around it.

The applicability of these models in countries outside North America where they are developed had been questioned. In a detailed analysis of the nature of Nigerian cities, Mabogunje (1968) applied these classical models. He concludes that the first two models deal with what may be defined as "natural growth process" of human population involving the slow, almost imperceptible change in the character and extent of functional areas in the city. The multiple – nuclei model assumes a relatively more dramatic growth that results from policy decisions and sometimes whims and caprices of urban administrators.

As observed by Ayeni (1979), at the very elementary stage the three classical models can be used to provide some basis for the analysis of the city. However, such an analysis may be too general, descriptive and devoid of all mathematical rigour and analysis. Understanding and explaining the dynamics of urban growth require that these theories be reconsidered in order to appropriately measure, analyse and model urban growth for sustainable urban development.

2.2.1.4 A Model of Sub-Saharan African City

The multiple nuclei model has a significant influence in the development of the dual-centred model of the growth of colonial cities. The dual-model is a form of the multiple –nuclei model whereby two centres result from the interaction between two histories of urbanization, pre-colonial and pre-industrial urbanization; and colonial quasi-industrial urbanization (Ayeni, 1979). This is what obtains in many African cities south of the Sahara (Mabogunje, 1968). De Blij (1968) created the Sub-Saharan African City Model to explain the dual and complex nature of Sub-Saharan African cities (see figure 2.2).

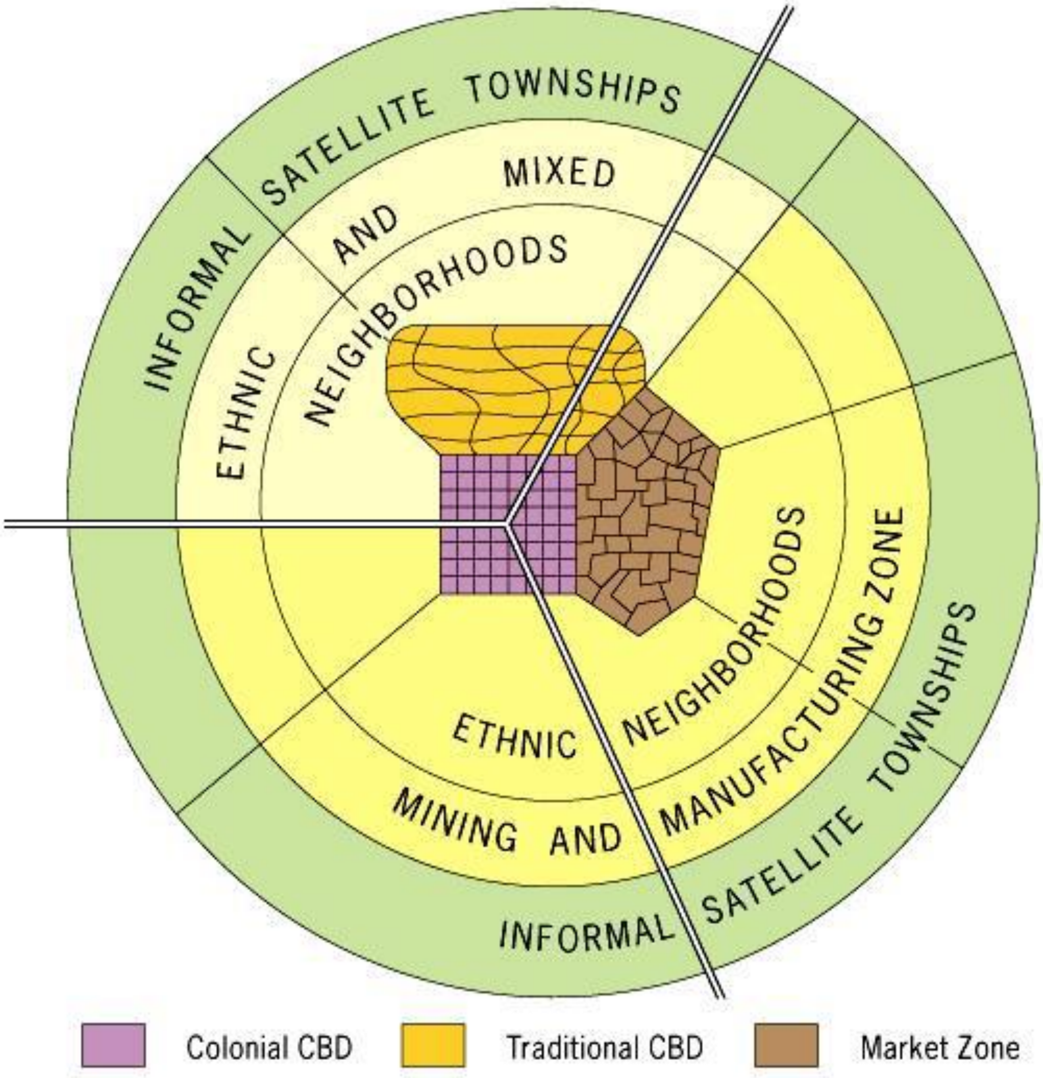


Fig. 2.2. A Model of Sub-Saharan African City

Source: De Blij, 1968.

The key elements of the model include; three CBDs: a remnant of the colonial CBD characterized by vertical development, a transitional business zone where commercial activities take place from the curbside or storefronts (usually single-story buildings with a touch of traditional architecture), and an informal and periodic market zone (usually open-air market). Sector development occurs along the encircling zone of ethnic and mixed neighbourhoods in which people have strong ethnic identities. Mining and manufacturing zones are found next to some parts of these ethnic neighbourhoods. On the outermost part of many African cities, there are informal satellite townships, which are squatter settlements. These squatter settlements consist of poor neighbourhoods, or shantytowns, in which people build anywhere possible or open, no matter if it is public or private.

Mabogunje (1968) who held that urban areas are polycentric in cities of developing countries also shared the idea of the dual centre. Both De Blij's (1968) and Mabogunje (1968) interpretation reflects the nature of Africa's development. In most cities of Africa, the quality of residences tends to get poorer as you move away from the city centre to the periphery. This is similar to what obtains in Latin America and Southeast Asia. Mining and manufacturing areas reflect the nature of the types of jobs found in some parts of Africa. The lack of elite, middle-class, or gentrification zones suggests a lack of development and the presence of ethnic neighbourhoods reflect the problem of tribalism in Africa. The informal satellite townships at the edge of the city reflect poverty in African cities. Usually, poor migrants occupy these satellite townships.

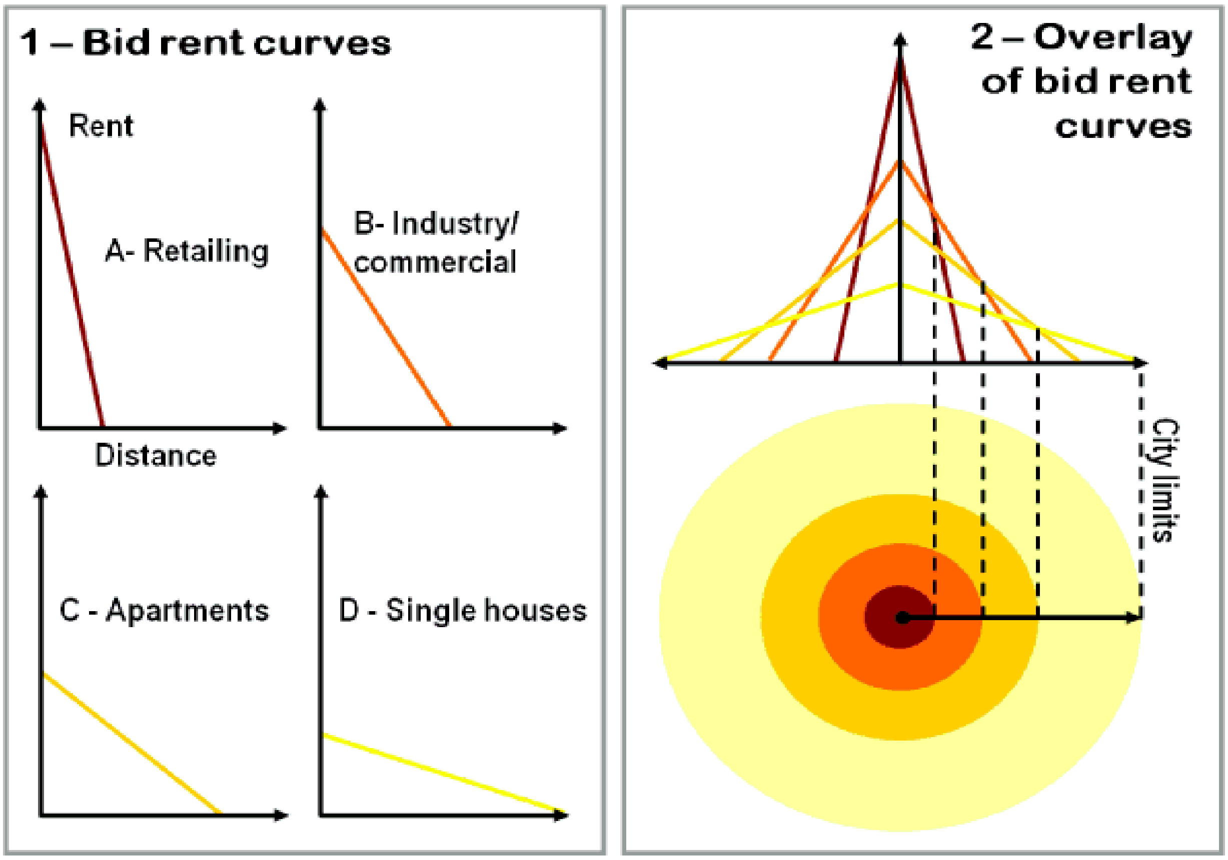
The classical urban land use theories laid the foundation for urban land rent theory. Section 2.2.2 discussed the central theme of urban land rent theory and reviewed scholarly views and findings on the bid rent function.

2.2.2 Urban Land Rent Theory

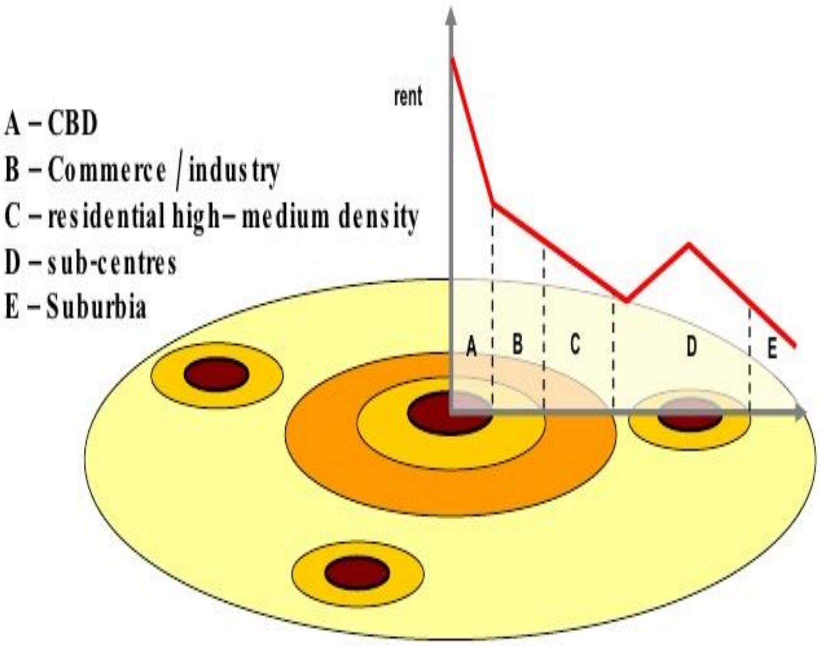
The Urban land rent theory had its roots in the work of von Thunen who traced "the variations in agricultural land rents to differences in fertility and location in a theoretically isolated community." The neo-classical economics theorists, including; Alonso, 1964; Mills, 1972; and Muth, 1969 later built on this to bring forth a theory of urban land differential rent. The assumptions of differential land rent state that, rent reflects differences in real productivity (lower unit costs of production/transportation) at various locations. The city centre is the most productive location in the urban area because of the high concentration of transport facilities. The rent falls to zero at the margins and the marginal locations are at the urban fringe. Firms and landowners are competitive price takers, there is no monopoly and the urban system is an atomistic market-exchange economy without government interference or social classes.

Although many of these assumptions had been questioned, however, they remain the basis upon which urban land values are explained. Figure 2.3 presents a schema of the urban land rent theory. Rent- a surplus (profit) resulting from some advantage such as capitalization and accessibility is highest in the city centre for retail because this activity is closely related to accessibility, while single-family housing has the lowest marginal cost. Rent gradient declines as distance increase from the city centre (see figure 2.3a). The rent gradient is related to the marginal cost of distance for each activity, which is how distance influences its bidding rent. The friction of space has an important impact on the rent gradient because with no friction all locations would be perfect locations. However, there may be high variations in rents in urban areas with multiple nuclei. Figure 2.3b presents a schematic representation of variations to bid rent theory. The emphasis on land rent theory is location and transportation. Considering the influence of location in urban rent, Marshall (1925) referred to the locational advantages of urban land as contributing "situation value." Chamberlain (1933), states that "the rent of urban land is explained wholly, that of agricultural land partly, by the factor of location.” Haig (1927) emphasized the influence of location upon land value by considering the relative accessibility advantages of different urban sites. Haig (1927) assumed an isolated city in which accessibility to the central core was the dominant aim. He also assumed that the primary objective of individuals and businesses in making locational decisions was to reduce the sum of site rentals and transportation costs (which he referred to as the costs of friction) to a minimum (Wendt, 1957).

Summarily Haig’s explanations on land rent in the city centre hinges on the fact that the centre of the city has the advantages of physical proximity or accessibility to all parts of the city. All activities will find the centre the most convenient point, as a result, location and rents in that sector will be the highest. Competition of uses will result in excluding certain uses that place a lower rental value upon central location and the owners of the relatively accessible sites will impose a rental charge equal to the saving on transportation costs, which the use of their sites makes possible.



(a)



(b)

Fig. 2.3. Bid rent curve function.
Source: Google images

Hurd (1903) conducted a comprehensive synthesis of the economic theory of urban land values with an empirical review of land value trends in the United States. He agreed that economic rent for urban sites is based upon the superiority of location. Estimated future prospects form the "mastering factor of all exchange values" and capitalization rates will tend to vary with the prospects for growth in different localities, being generally lower in larger cities where the ease of sale and stability of property in income are generally greater. Hurd pointed out that urban land values are influenced to such a degree by general financial and economic conditions, that values at times "represent, simply a condition of the public mind" (Wendt, 1957).

An abstract model that treated both firms and individual households as a consumer of space was developed by Alonso (1964) to explain patterns of urban land uses in urban areas. The model holds that the individual household or firm has a budget constraint on the type of goods it can buy, consequently, income would be spent in such a way that amount of space consumed, commuting costs and other expenditures are in equilibrium (Ayeni, 1979). Alonso (1964) defined the bid rent function of the household as;

$$Y = P_Z Z + P(x)q + k(x) \qquad (2.1)$$

Where ***y*** is the income, ***Pz*** is the price of the composite good, ***Z*** is the quantity of the goods, ***P(x)*** the price of land at distance ***(x)*** from the centre, q the amount of land purchased and ***k(x)*** are commuting costs. Alonso assumed household preferences for different locations in the city. He went further to define household satisfaction by giving a utility function in the form of;

$$U = u(z, q, x) \qquad (2.2)$$

The utility function plus the budget constraint (equation 2.1) defines the locational choice of the household or firm in the city (Ayeni, 1979). Alonso model is useful in analyzing land use and behaviour of firms in an urban setting. It offers insights into the relationship between urban spatial structure and market equilibrium.

The theory of urban land rent is relevant to the present research because the rent-paying ability of different economic functions largely determines changes and pattern of urban land use. Such economic functions include retailing, industry, residence etc. Generally, every activity would like to locate in the optimal location in the city, however, not all have the same capacity to afford it. Optimal location in the city is where accessibility is optimal, usually the central business district (CBD). Functions with the high rent paying ability locate in the CBD. As the city grows and more remote locations are being used, rent of the most accessible places increases, inducing higher densities and productivity. This generally occurs by "expulsing" some activities outside and attracting activities that are more productive. Thus the rent-paying ability of different economic functions becomes one of the major factors that account for cities growth and why growth is usually concentrated at the centre of the city.

The key assumption of urban land rent is that both land rent and residence density decline with the distance from the centre. In other words, rent and distance are power functions of distance. These two variables play significant roles in the growth of cities. In this next section (section 2.2.3), the relationship between population density and distance was examined. This is necessary because both rent and density have been established in the literature as important factors driving urban growth, particularly urban vertical growth at the centre of the city.

2.2.3 Urban Population Densities

The urban population represents one of the most important aspects of the city. Urban populations are made up of households, and a household is an important unit in understanding the behavioural characteristics of an urban population. The pattern of urban population distribution had been established to be the kind in which its densities decline exponentially from the city centre into the suburbs. More than half of a century ago, Clark (1951) demonstrated this quite clearly through his empirically derived equation expressed as;

$$d_x = d_o e^{-bx} \qquad (2.3)$$

Where $\boldsymbol{d_x}$, is population density d at distance $\boldsymbol{x}$ from the city centre, $\boldsymbol{d_o}$ is central density as extrapolated into the city's central business district; and $\boldsymbol{b}$ is the density gradient, a natural logarithm measuring the rate of change of density with distance. Equation (2.3) when transformed linearly becomes;

$$lnd_x = lnd_o{}^{-bx} \qquad (2.4)$$

The application of urban population densities theory is very essential and useful in urban growth analysis. In the first instance, it is useful in identifying the processes underlying urban population densities and growth. Second, it helps in relating various functions (Population, area, distance, distance-density curve) which are descriptive mechanisms of urban population densities not only to the sizes of urban centres but also to the growth of urban areas in different socio-cultural settings in the world. Since urban population depends on urban land for existence, urban man-land relations will no doubt become more and more strained in cities because of the population explosion. As a result, understanding, density-distance function in an urban setting is a sine-qua-non for effective urban planning.

The classical models of urban growth recognized vertical development in the city centre as obtained in some African, and in most European and American cities; however, the patterns and processes of urban vertical growth were not explained. Given this circumstance and, considering the importance of the examination of urban vertical growth in this research, section 2.2.4 was devoted to the theoretical explanation of urban vertical growth. The section explained the concept of a vertical city.

2.2.4 The concept of vertical cities

In the monocentric explanation of city structure, urban workers/residents commute between the city centre and their residencies for work. Since commuting is costly and increases with distance from the CBD, it is assumed that individuals or households would choose, other things being equal, to live closer to the city centre. As a result, housing density, housing price, rental price and land value, adjust to the market, thus land for housing becomes more expensive near the CBD. The high cost of land is a major reason why developers and investors economise on the use of land by increasing density and building upward at the location near the city centre. As a result, the city structure is characterised by a higher density and taller buildings close to the CBD, while the fringe areas have lower density and building heights (Alonso, 1964; and Mills, 1972). Thus, there is a negative exponential land-rent gradient between the central location and its hinterland.

The argument in support of urban vertical growth is premised on the increase in urban population growth and the need to meet the increasing demand for residential and commercial spaces within the city, particularly in places where the supply of land is limited for urban development. In this regard, building upward becomes a sustainable strategy. The process of building upward results in the vertical expansion of urban space and invariably the development of the vertical city.

The idea of vertical cities is theoretical in nature (Akristiniy and Boriskina, 2018), as a result, its conceptual explanation may be a bit challenging. However, a vertical city may be defined as an architectural system providing critical urban functions and or services different from that being provided in a multi-functional building. King and Wong (2015) defined the vertical city as a series of interlinking, environmentally friendly, self-sustaining, mega towers that extend as high as a mile skyward. A vertical city provides all necessary functions that a horizontal city typically possesses, including recreational spaces, free public spaces, social and governmental services, education, energy, and food production (Howell, 2016). Till date, no true vertical city exists, what obtains is the expansion of the city above the ground through many tall multi-functional buildings that at best, combined residential, restricted medical facilities, hotel and retail functions.

In terms of design, the idea of vertical cities as conceived today may have started by Le Corbusier (a Swiss-French architect and urban planner) in 1922. He proposed a plan for the "Ville Contemporaire" (contemporary city); a model city of three million people whose residents would live and work in a group of identical sixty-story tall apartment buildings surrounded by lower zig-zag apartment blocks and a large park (en.m.wikipedia.org, Le Corbusier, 1946 and 1947). Similar to the Le Corbusier idea, Frank Lloyd Wright, a contemporary of Le Corbusier in 1956 design a vertical city called "Illinois"- a 528 storey, mile-high skyscraper that has capacity to house 100,000 people, accommodates about 15,000 cars in its parking lot and has enough office spaces sufficient to house the state government (Frank Lloyd Wright Archives, 1994).

Thirteen years after the breathtaking attempt of Wright, Soleri (1969) design a vertical city plan called "Babels", which was proposed to house a population of 520,000 persons with facilities comprising industrial areas, parking lots, community centres, neighbourhoods etc. In recent times, several other designs of vertical city have emerged including; "Arcosanti" (Soleri, 1970); Japan "Hyper Building"(http://www.arcosanti.org, 2003) and the Sky City 1000 (Takenaka Corporation, 1989). Others are; "Holonic Tower" designed for Tokyo, Japan; "Millennium Tower" (www.fosterandpartners.com, 2003); "Ultima Tower" designed for San Francisco, California (Tsui Design and Research Inc., 1991) and "Bionic Tower"- a proposed vertical city designed by Celaya, Cervera and Gómez for the city of Shanghai. The proposed tall structure was designed to have a main tower of 1,228.2 meters (4,030feet) height and 300 storeys that could house approximately 100,000 people.

Recent advances in technology may be birthing into reality true vertical cities. Today we have great architectural designs across the world that qualifies as vertical cities. For example, China's Shanghai tower in Shanghai province is a 632 metres (2,073 feet) high spiralling trunk mega tall skyscraper having 128 storeys that have and stacks the amenities of the horizontal city block – homes, shops, offices, galleries, and multiplexes on a vertical plane. The plan of the building has a "sky gardens" that will display flora from around China, making it an ecologically compliant structure (The Guardian-International Edition, 2016). Similarly, the 828 metres high Burj Khalifa of the United Arab Emirate, has a residential space of about 1.85 million square feet, prime office space of over 300,000 square feet, hotel, luxurious recreational and leisure facilities and about 900 residences that spread over the 19th to the 108th floor of the tower (Fact Sheet - Burj Khalifa, 2010). Furthermore, the 1.6 kilometres high Jeddah Tower, presently under construction in the Kingdom of Saudi Arabia is an architectural masterpiece that will have optimum facilities similar to what obtains on the city surface when completed. Likewise, the recently proposed Cloud Citizen- a new high-rise futuristic design by Urban Future Organization and CR-Design, features a singular mega building complex that aims to create a hyper-dense urban centre that is environmentally friendly (Rawn, 2014). The proposed 680 meters tall, mega structure offers an alternative to the singular and unconnected high-rises found in most metropolitan areas. Cloud Citizen, when completed, will function as a "continuous metropolis" with public spaces suspended in the air and integrated into the structure itself.

Figure 2.4 gives an illustration of the factors influencing the appearance of the concept of vertical cities. Central to these factors is the high rate of population growth in cities occasioned by natural increase and migration. Then the need for sustainable solutions to housing the teeming population in the city, maximizing resources (land) at the centre, reducing the amount of the cost of land and protecting the environment, particularly in the city's suburbs led to the emergence of tall structures at the centre of the city. In some region of the world, particularly in Asia (Shanghai, Singapore and Hong Kong), the lack of resources (mainly land) for urban development is a major factor of urban vertical development.

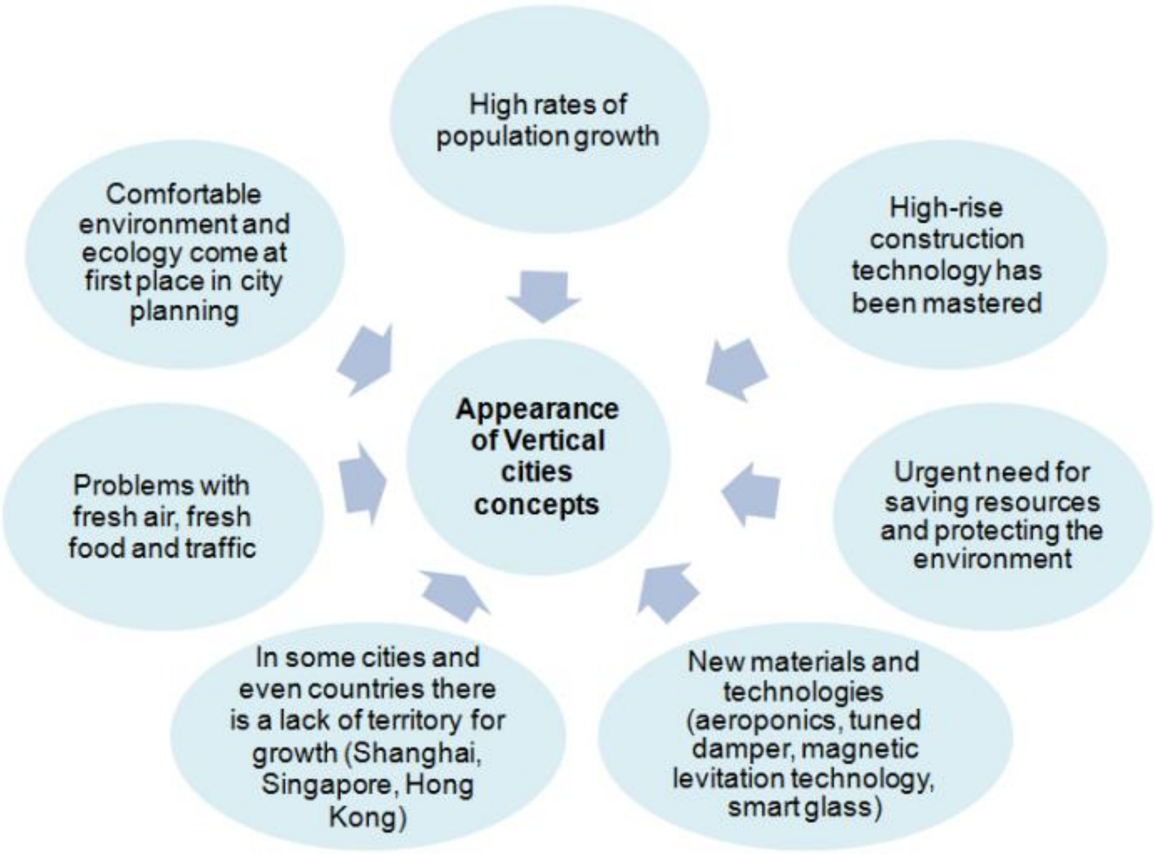


Fig. 2.4. Diagrammatic illustration of the appearance of vertical cities concept.

Source: Akristiniy and Boriskina, 2018.

Two major technological breakthroughs that contributed to the vertical development of cities were advancements in steel structures and vertical transportation. In particular, the development of the elevator by Elisha Graves Otis in 1852 made the construction of tall buildings a more feasible development. Today, advancements in steel structures, steel framed gravity system, improved reinforced and pre-stressed concrete coupled with improvements in the socioeconomic development of the countries of the world are accelerating the rate at which cities spaces expand vertically. As indicated in figure 2.4, modern technological advancement, including Aeroponics, smart glass, magnetic levitation technology and tuned damper are gradually transforming tall structures into a true vertical ecosystem where biological, physical and social systems interact to form complex entities as obtained on the horizontal city surface.

2.2.5 Complexity Theory

Complexity theory is a contemporary embodiment of general system theory (Batty, 2000). The general systems theory as a scientific paradigm was developed to explain the way distinct entities (systems) that are composed of lower order components organised themselves to become an ordered consistent whole that has pattern and order such that "the whole is greater than the sum of the parts" (Bertalanffy, 1972). The structure and behaviour of different systems were understood through feedbacks and hierarchical organisations that enable them to achieve certain stated goals. Cities and many other physical and social systems fit into the category of those entities; hence, the general systems theory became a generic logic for explaining structure, form and interaction in physical and social systems. From a general systems perspective, cities were conceptualised as sets of elements that are connected through various forms of interactions. Their structures explained to be in a state of equilibrium with a centralized form of control in a top-down pattern. Land use activities with their economic/functional linkages were the lens for the examination of cities.

Urban analysis from the general system theory perspectives was based on linear equations systems that lack spatial content (i.e not spatially explicit). Essentially, there was the development of series of disaggregate models based on utility maximizing and macro-models of spatial interaction based on the idea of entropy maximization to explain the structure and interaction in different entities (cities). However, mechanisms for quantitative descriptions of how systems developed from parts were actually missing. In addition, the understanding of the idea of disequilibrium and the explanation of the non-linear interaction in systems seem impossible.

Empirical investigations have shown that cities are never in equilibrium (Batty, 2008, 2007, 2004, 2003), that they are constantly changing, have positive feedback and are the product of human decisions and innovation. Cities are complex entities, their behaviour, though surprising and unpredictable yet could be understood adequately (Cheng, 2003). Cities are dynamical systems where actors or agents (people, communities, businesses, governments, etc.) are constantly interacting with one another and with objects (such as roads, buildings and parks) within a range of urban settings or contexts and are changing in response to each other. These interactions and changes create nonlinear feedback loops that either promote or deplete the life energy upon which their futures depend. Therefore, treating the city like simple or complicated machines as conceived in the general systems theory tends to limit our understanding of how the city works.

The raison d'être for complexity theory was the need to provide an alternative theory and concepts for exploring the nature and dynamics of complex systems, of which the city is archetypal. Complexity theory has its root in postmodern mathematics: dynamical systems theory, catastrophe theory, chaos theory, fractal geometry and fuzzy logic, which are purely new branches of mathematics spreading through all scientific disciplines in the 21st century. The theory developed during the last twenty years through various excursions into dynamics. It begins with catastrophe and bifurcation theory, with the application of non-linear approaches to biological systems, paralleled by work in deterministic dynamics leading to chaos theory. This has culminated in ideas about transition, order, and the edge-of-chaos, best seen in ideas about self-organized criticality (Batty, 2005).

Complexity theory is not about the study of complexity; rather it is concerned with the study of the behaviour of systems, particularly complex systems. Complex systems are systems that develop from the bottom up. They are those systems that evolve from their constituent parts. Such systems grow, change and manifest emergent behaviour. Emergent behaviour is a behaviour that arises out of the interactions between components of a system. Such behaviour cannot be simply inferred from the behaviour of the components (see figure 2.5), because the prediction or extrapolation of such behaviour from the behaviour of those individual parts is highly challenging.

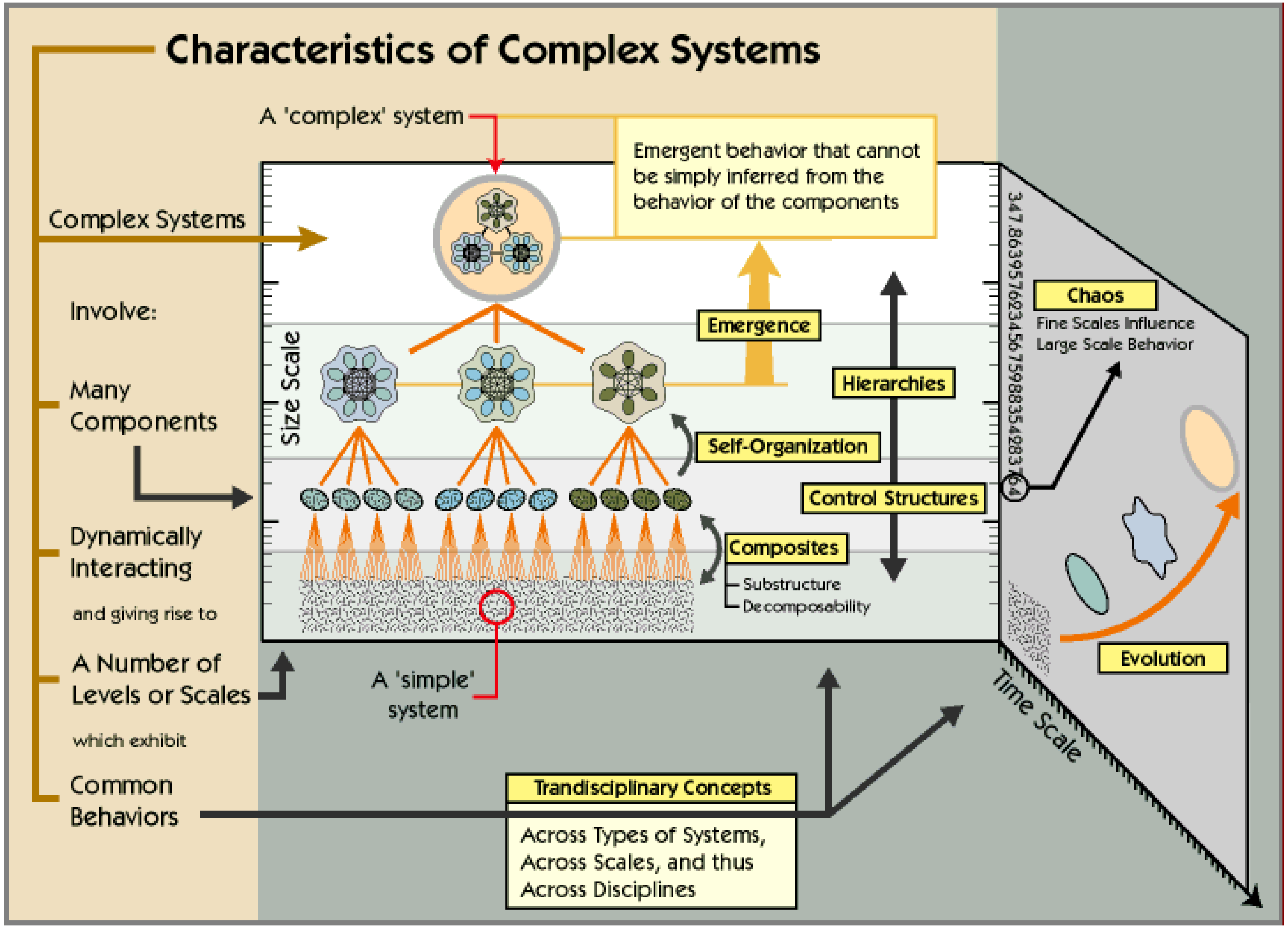


Fig. 2.5. Characteristics of complex systems

Source: Ferreira, 2001

The condition in complex systems is dependent on interacting individuals, which often result in unpredictability and path dependence. Path dependence suggests that the outcome of interaction in the system is a product of the path taken. The goal of complexity theory is to provide a generic logic with which we can understand complex systems. Figure 2.5 illustrates the characteristics of complex systems. First, they consist of many diverse components. These components interact dynamically and non-linearly, to bring about widespread information flow and feedback loops. Second, the interaction between the components takes place on a number of level or scale. Rules guiding each level in the system are consistent with those of a lower level (Crawford, 2016). It is possible to study complex systems by positioning oneself at one of these levels.

Third, complex systems are characterised by emergence- an emergent behaviour that cannot be inferred directly from the behaviour of the components. Fourth, they are self-organised systems. Self-organization results from the presence of attractors in the system. These attractors enable the system to evolve regardless of the initial conditions of the system. The idea of self-organization relates to spontaneous order that emerges from local system interactions. Although complex systems are hierarchically organised, yet autonomous agents in the system act locally without global control. In other words, bottom-up processes govern interactions among agents or actors. The hierarchical organization of subsystems in complex systems often results in evolution over time.

An important characteristic of complex systems is that they are usually in a non-equilibrium state. This condition may easily result in chaotic behaviour. Change within a complex system mainly occurs due to a change in the nature of interactions that link the parts together. In complex systems, cause and effect are subtle over time. Complex systems, therefore, are the kinds of systems with many different parts that, by a rather mysterious process of self-organisation, are more ordered and more informed than systems that operate in approximate thermodynamic equilibrium with their surrounding (Marshal and Batty, 2010 and Batty and Marshall, 2012).

Because complex systems are non-linear systems, and are usually under the influence of evolutionary dynamics, using linear mathematical models and equations to model them is inappropriate. Hence, the techniques of complexity theory are built on non-linear mathematical methods and spatial-temporal data of which developments in geographic information systems and remote sensing offer ample opportunities for analysis and modelling (Cheng, 2003).

Popular among the techniques of complexity theory are cellular automata (CA) and agent-based modelling (ABM). Cellular automata models are built on the principle of a collection of cells with defined finite states. The evolution of the system is modelled by updating the state of each cell based on pre-described rules (i.e. transition rules) which take into account the states of its immediate neighbours (Christakis, et al., 2010). Agent-based models (ABMs) are complementary to CA and utilize "agents" in order to resolve a system's behaviour. Agents are defined autonomously as behaving components whose states are updated by pre-described evolution rules (just like in CA), but which can learn from their environments and can thus respond by changing their behaviours (Christakis, 2010).

The application of complexity theory in social science research is just emerging; however, it has been widely embraced in the field of urban systems analysis and other disciplines. The wide applicability of complexity theory makes it promising. The theory offers much for urban research, particularly in understanding and explaining urban growth dynamics. Ideas and concepts in complexity theory provide a framework for modelling complex systems. They assist in providing nexus between modelling exercise and practical applications. Complexity theory offers a strong platform to understand and plan urban areas. It has the capacity to provide insight that could help in improving the present urban planning methods that are inadequate to address various evolving urban environmental challenges.

Given the developments in multi-temporal data collection and new modelling techniques, there is a renewed interest in understanding and modelling the complex nature of urban growth. The next section in this chapter attempts a review of the literature and empirical findings on cities as complex systems. It also reviews empirical findings on urban growth analysis and modelling. The section divides into two major parts. The first section discusses an empirical enquiry into the nature of cities as complex systems. The second focuses on the review of the literature on urban growth analysis and modelling.

2.3 Review of the Literature

2.3.1 Empirical findings on cities as complex systems

Cities are the most complex artefacts built by humans (Gallegos, 2017). Jane Jacobs (1961; 1969) was most probably the first to propose that the city was an example par excellence of organized complexity (Batty, 2005). She argued that complexity in cities emerged spontaneously and organically from the bottom up. In a similar vein, Alexander (1964, 1966) had recognized the bottom-up evolution of city systems and its implications for urban design. He observed the complexity in the inner nature and hierarchical ordering of cities. He noted that interaction within the city is a potential complexity that is often overlooked in planning. He, therefore, argued that planning and management approaches needed to be as organic as the city itself in order to be effective. In addition, the emergence of diverse kinds of cultural and economic sequestration in cities in recent years had been observed to be a confirmation of the emergent properties of cities (Portugali and Benenson, 1997), which is a byproduct of interactions at local and global levels between individuals and the city environment.

Extending the frontiers of the idea of cities as complex systems, Michael Batty in his several publications had demonstrated that cities are complex systems (See Batty 2008; 2008(cluster edition); 2007; 2005; 2004 and 2003). He proposed a change from centralized (top-down) approach to decentralized (bottom-up) approach in the study of cities and urban planning. He re-worked rank-size rule and explained the concept of hierarchy and urban dynamics from complexity perspective emphasizing scaling, self-similarity, and disequilibrium in urban systems.

Cities are not only complex systems; they are dually complex systems (Portugali, 2016). They are dually complex because; first, they are composed of material components and human components. As a set of material components, the city is an artefact and as such a simple system; as a set of human components (the urban agents) – the city is a complex system. The interaction among urban agents and between urban agents, between the city's material components and the environment, transformed the artefact city into a complex artificial urban system (Portugali, 2016).

Secondly, the complex artificial city created, influence the behaviour of urban agents, it develops into a complex artificial environment (Portugali, 2011) for a large-scale collective and complex artefact that interacts with the environment on one hand, while on the other it is an environment for the millions of people that live and act in cities. Thirdly, cities are dually complex systems because of the complex interaction between internal and external representations of the artefact city. The internal representation of the artefact city is in the form of ideas, intentions and memories, thoughts that originate and reside in the mind/brain of urban agents, while the external representation of the artefact city is in the form of texts, cities, buildings or roads that reside in the world. Obviously, cities are like living organisms. They are dynamic, complex systems that comprised of independent and often smaller, more understandable sub-components that relate with one another. Growth is a product of the relationship between various subsystems of urban systems. Understanding this has been a major focus of urban analysis and urban growth modelling activities.

In the characterisation of cities, four levels of complexity have been identified in the literature. First, there is definitional complexity. Defining a city is a complex adventure due to variations in standards adopted in the settlement classification across the world. Population threshold, a generally accepted standard for classifying settlement is fraught with lots of complexity, as nations differ in the population standard for urban areas. A city is therefore what it is, based on theoretical definitions and according to the point of view, which is chosen to define it; whether anthropological, cultural, economic, geographical, political, religious, demographical, morphological, social or legal.

Second, there is spatial complexity. The Christaller's central place theory demonstrates this aptly as it explains the city as existing within a network of cities (Christaller, 1933, Getis and Getis, 1966). As a result, a city cannot be conceived as an isolated entity, rather it is "a system within systems of cities" (Berry, 1964). Similarly, the distribution of cities in term of size and scale, as enunciated in Zipf's scaling law had been explained by Batty (2008) as evidence of spatial complexity in the distribution of cities in an urban system. Scaling law is like a fractal (an object that displays self-regularity or self-similarity on multiple scales). It is an algebraic function that does not change form when its scale is changed. For example, if x transform to $2x$, the function of x changes from $f(x)$ to $2f(x)$. In other words;

$f(x) = 2f(x)$…………………………………………………………………… (2.5)

Similarly, $2f(x)$ can be transformed into $f(2x)$, such that;

$2f(x) = f(2x)$ ………………………………………………………………... (2.6)

Equation 2.6 is similar to the power law given as;

$$f(x) = 1/x \quad (2.7)$$

In addition, it had been established in the literature that cities follow the law of allometry (Cebrat and Sobczyński, 2016; Chen and Feng, 2017 and Li et al., 2015). They change in scale and size. Based on Zipf's rule, as they grow, they get bigger and become less in terms of size. The number of possible connections between them increases as the square of the population. Similarly, the average time of intraurban travel and density increases. Density increases at the centre and fall towards the peripheral areas. All these are evidence that both scale and size are related. They are functions of distance and are the underlying factors of the spatial complexity in cities.

Third, there is the temporal complexity of the city. The multiplicity of time scales at which event occurs in the city defines its complex structure. Differences in the time scales of the components of an urban entity cause severe dysfunctioning in the day-to-day life of cities and make the description of the dynamics of the urban systems very difficult. Lastly, there is taxonomic complexity. Due to the changing social and economic contents of cities and their importance in time and space, different generations of towns and cities emerge. As a result, the systems of cities are not amenable to a stable taxonomic description. Therefore, cities need to be characterized differently and according to their morphological aspect as well as to their urban functions (Pumain, 1998). This usually creates taxonomic complexity in urban systems.

Given the foregoing, it is obvious that cities are highly complex. However, our conceptualization and thinking about cities are far away from that. It is no longer reasonable to conceive the city as a simple machine that can be controlled in a top-down fashion by the imposition of rules and regulations. Cities behaviours are far away from such; as a result, their management becomes a daunting task given such perspective. As a result, there is a need to change the way we conceptualise and design our cities. We need methods that allow an understanding of the whole city's system rather than the parts. Complexity theory offers opportunities for understanding the complex nature of cities and designing them in such a way as to function optimally. The theory allows urban decision-makers, designers and community to understand the complex nature of cities. In the next section, empirical findings on urban growth analysis and modelling particularly from the perspective of complex systems theory were considered.

2.3.2 Empirical findings on urban growth analysis and modelling

Two aspects of urban growth that have caught the attention of urban geographers and planners over the years are; the demographic and spatial aspects of urbanization. While the former relates mainly to the proportion of people dwelling in urban areas, the latter is concerned with the organization of urban space as a product of demographic growth and city size distributions (Geyer, 2003; Gwebu, 2006; Gwebu, 2012). Urban growth concerns the pattern of land development and the process of attaining a form influenced by various factors. It is a process whereby non-urban activities and spaces transit into urban through a series of processes. In the language of complexity theory, urban growth is an archetypal self-organized system consisting of three interrelated defined sub-systems viz; developed urban system, natural non-urban system and planned urban system (Clark and Gaydos 1998). Urban growth is a spatial system that is spatially heterogeneous, considerably complex and varies in time and space. It involves various agents, exhibiting different patterns of behaviour, that has significant implications for humans and other ecological components in urban areas.

Studying the dynamics of urban growth involves understanding and modelling individual subsystems (various land uses) and their behaviours in cities. It involves analysing and understanding the patterns, processes and drivers (causes) of growth in urban areas. This three must be clearly distinguished, understood and analysed using appropriate techniques (Galster et al., 2001). The pattern is closely related to process, however, the two differs. The process creates, modifies and maintains the pattern, but pattern constraints, promotes or neutralises process (Li and Wu, 2004). While the pattern of urban growth had been explained to mean the spatial arrangement of land uses in cities, the process of city growth concerns its spatial expansion and its attributes (Galster et al. 2001).

The spatial expansion of the city had been likened to the movement of an advancing wave on a beach and land in the fringe, be it farmland, grassland or forest (Bryant et al., 1982: 34) cited in Sebego and Gwebu, 2013). The advance of the built-up edge of a city is a process, like a wave breaking on a rocky shore, irregular patches of urban and urban-associated land use, develop well beyond the built-up edge of a city with ribbons of development (Greene and Pick (2006) cited in Sebego and Gwebu, 2013).

Several theoretical explanations had been provided in an attempt at explaining the patterns and processes of urban growth. The modernist theories including; central place theory, monocentric models of urban growth, microeconomic theories, and polycentric model argued that urban growth patterns and processes are functions of socio-economic variables, among which are land use type, population density, transportation, location, bid rent function, housing rent, land and housing values, economic clustering and agglomeration. The post-modernist perspectives on urbanisation as exemplified by Harvey (1973, 1985, 1989 and 2003) believe that urban growth is a product of the crisis of Fordism, de-industrialization, class and racial conflict, demographic shift and hyper-mobile capital.

A theoretical explanation of urban growth patterns and processes in the cities of less developed countries was provided by Mabogunje (1961, 1962a, and 1962b). He undertook the ecological analysis of Lagos and the growth of residential districts in Ibadan metropolis, by identifying and classifying major residential districts in these cities. He found that growth processes in most cities of less developed countries are products of fission, occasioned by whim and caprices of urban administrators.

In his efforts at explaining urbanisation in Nigeria, Mabogunje (1968) provides an in-depth analysis of processes of urban growth in Nigeria. He observed that causes, processes and consequences of urban growth varied from place to place. He showed that understanding urban growth should proceed from an examination of the processes of urbanization and the unique environment within which these processes played out. He identified three stages in the urban growth of Nigeria namely; pre-colonial, colonial and post-colonial stages. Essentially, he observed that there is both spatial and economic duality in most cities in Nigeria. Spatial duality concerns the presence of traditional and modern centres and economic duality is all about the presence of formal and informal sectors. Spatial duality has significant effects on the growth and development of cities in Nigeria.

The study of the trend in the development of built-up areas of the city of Jos was undertaken by Ayeni (1974). He established the fact that the spatial structure of the city of Jos was the outcome of two interdependent elements; first, the location of housing stock and second the location of economic activities. Based on data collected he developed a residential location model, which he proposed as a general framework for the planning of Jos metropolis. Salami (1997) studied the growth of Ibadan region. He identified population increase, the nature of urban land uses and landscape configuration, the location of the development scheme/government policy and pattern of route development as forces influencing urban growth.

Seto and Fragkias (2005) using the method of landscape ecology, studied the process of land use change in the cities of Guangdong Province in China between 1988 and 1999. They discovered that there is a similarity in the expansion and speed patterns of the cities that make up the province, despite different economic and social background. The factor of urban growth in China was examined by Fan (1999). He found that the major factors that contributed to China's urban growth and shaped its current urban spatial structure were social and political factors rather than an economic factor. The pattern of urban horizontal expansion in China had been reported to be similar to that in the U. S and Europe (Shi, et al., 2009)

Several studies had considered the characteristics and driving mechanism of the urban expansion process in Europe and North America (Aguilar, 1999). For example, Alig et al. (2004) reported an increase of 34% in urban land construction in the U. S between 1982 and 1997. He identified the conversion of arable and forest land to urban land as the predominant factor influencing land use change. He also noted that the driving forces of urban growth are mainly population density and personal income. Between 2000 and 2006 urban land use increased by 3.4%. More than an estimated quarter of European Union territories were directly affected by urban land use. Economic factors (including globalisation, European integration, rising living standards, land prices, national policies), demographic factors, housing preferences, social aspects, transportation and regulatory frameworks are found to be the main drivers of urban expansion in Europe (European, Environment Agency, 2011).

In urban research, significant attention had been given to patterns and processes of urban horizontal growth, while the vertical dimension of urban growth had received little attention. As observed by Weizman (2002) "the cartographic, top-down aerial gaze had long dominated both mainstream and critical geopolitical discourses. To him, this had worked to flatten spatial imaginaries. Geopolitics he said is a flat discourse that largely ignores the vertical dimension and tends to look across rather than to cut through the landscape. This was the cartographic imagination inherited from the military and political spatialities of the modern state' (Weizman, 2002: 3). To date, similar flattening of discourses and imaginaries tends still to dominate critical urban research in the Anglophone world (Graham and Hewitt, 2012), as a result relatively little attention is paid to the process of vertical expansion in cities (Shi, et al, 2009).

Urban vertical growth in cities may have started with the construction of multi-storey buildings by the Roman Empire. However, around the 16th century, a number of mud brick tower houses of five to eight storeys, built to protect the inhabitants from Bedouin attacks were found to have been existing in the Yemeni city of Shibam. In the later parts of the 19th century, social, economic and technological developments led to the construction of modern high-rise buildings in the North American cities of New York and Chicago. Within the last few decades, extraordinary vertical extensions of built-up space both upwards and downwards are ongoing in the Middle East, Asia, and South East Asia. However, adequate attention has not been given to this development in urban empirical research.

A survey of current literature on urban vertical growth showed that attention is mainly on the structural characteristics of tall buildings/high-rise apartments in the urban landscape. The understanding of the pattern of urban vertical growth and its associated drivers is limited. A major challenge in this regard is the unavailability of time series data that is able to capture the vertical and volumetric dimensions of urban growth. However, researches conducted so far has shown the need to focus attention on the vertical dimension of growth, as recent development has suggested that vertical city is going to dominate 21st-century urban discourse and may be a solution for sustainable urban development.

Urban vertical growth is an important aspect of general urban growth. It is a product of urban compactness, population growth (Fan 1999), and change in residential lifestyle (Lin et al. 2014). Comparing the rate of urban horizontal growth to that of vertical growth in the city, Al-Gabbani (1991) investigated the expansion of the built-up areas of the city of Riyadh, Kingdom of Saudi Arabia (KSA), He found that Riyadh city is expanding both horizontally and vertically, but it's horizontal expansion far outweigh its vertical expansion. The process of horizontal expansion in the KSA is producing a considerable decrease in density over space.

Shi, et al. (2009), examined the driving forces of urban vertical growth in Shanghai, China. They developed a three-dimensional spatial index (an index that expresses a proportional relationship between urban vertical and horizontal expansion), and velocity variation index to delimit the stages of urban spatial growth and describe the three-dimensional spatial variation in Shanghai using Shanghai's statistical data. The vertical and horizontal space was represented by the average high-rise building's height and urban built-up area respectively. Changes in urban three-dimensional space were analysed and the study found a transition from fast horizontal growth to slow vertical expansion. However, the spatial expansion process was found to be primarily dominated by horizontal expansion. The city's horizontal expansion is being influenced by urbanization process, while, improvement in the industrial structure was the main driver of urban vertical expansion.

Batty et al. (2008) using data for the Greater London region investigated scaling relationships and power laws based on geometric properties of buildings. The research established allometric relationships between properties of buildings. Frenkel (2007) examined the spatial aspects of the distribution of high-rise buildings in Tel Aviv, Israel. He found that the spatial distribution of high-rise buildings matches the spatial development and sprawl of all the metropolitan areas following Hall (1971) urban stage model. Suburbanization processes in the direction of the outer rings of the metropolis peripheral areas lead to an increased probability of the appearance of high-rise buildings. Re-urbanization processes lead to the re-concentration of high-rise buildings in the city’s core. Alfred (1890), using diminishing marginal return and land rent, analysed building heights, Wright (1971) considered the layout structure of tall buildings while Hoch (1968) examined the environmental effects of the vertical expansion of urban areas.

Fan (1999) examined the vertical and horizontal urban growth in China. He noted that urban expansion has taken place vertically through population growth and horizontally through the addition of new cities to China’s urban system. The Chinese cities' distinct feature of vertical expansion had been linked to huge population pressure that occasioned residency in tall buildings (Shi, et al, 2009). Institutional factor rather than scale factor or agglomeration economies were the principal factors of vertical and horizontal urban expansion in China.

A GIS-based cellular automata model for analysing and modelling the vertical complexities of urban growth was developed by Lin et al., (2014) for Guangzhou city, China (2001-2010). Using several variables including; accessibility, building and population density, etc., they effectively model and analyze building distribution patterns. They found that the fringe area tends to construct high-rise buildings, while the hinterland zone had witnessed a significant increase in low-rise buildings. They showed that urban vertical growth patterns can be effectively modelled using GIS-based cellular automata modelling technique. The model developed showed an outward spread of low-rise buildings, a compact development of high-rise buildings, phase transition from a mono-centre to a bi-centre and the development of co-developed low moderate and high-state buildings that are beginning to constitute an important feature of the urban and smart growth landscape of Guangzhou city.

Saleem (2016) examines the drawbacks of vertical growth in the light of challenges it poses to urban dwellers in relation to the individual and community health, the historicity of metropolitan, safety and upkeep of the urban environment among many others. Population growth, agglomeration, land prices, land consumption, human aspirations, symbolism and ego were identified by A-Kodmany (2012) as major drivers of urban vertical growth.

Using remote sensing technique, Zhang et al. (2017) studied urban growth in Guangzhou city, China. They found that Guangzhou city had undergone both horizontal and vertical urban growth from 1993 to 2013. Analysis indicated that vertical urban growth followed horizontal urban growth successively. Factors influencing urban horizontal and vertical growth were found to be; increase in population density, real GDP, and fixed investment. While population density was the major driving force of horizontal urban expansion, fixed investment was the major driving force of vertical urban expansion.

Given the foregoing, it is obvious that growth in urban areas happens both horizontally and vertically. However, the understanding of growth in cities will be limited without exploring the nature of urban growth both in two dimensions and in three dimensions. This will enhances the analysis of urban systems and ultimately help in understanding and addressing numerous urban planning challenges. Understanding the nature of urban growth has occupied the hearts of urban geographers for several decades. Major research efforts directed towards achieving this is the simulation and modelling of urban areas. Forrester (1969) may have been the first to develop the first coherent dynamic systems model of a city with feedbacks. Using many important variables including residential population, housing, employment, land use, transportation, and governance he provided an explanation about the growth of the city of Boston. Urban growth in the Detroit region of the United States was simulated by Tobler

(1970) using computer movie simulation. His urban simulation attempt was most probably the foundation for more spatially specific models that emphasized temporal feedbacks.

Using catastrophe theory, Amson (1975) explored the usefulness of the idea of catastrophe in urban systems modelling. He developed the cusp catastrophe model to explained urban density as a function of rent and "opulence". Casti and Swain (1975) applied the concept of cusp catastrophe to the analysis of developmental patterns of functions provided to the population by cities. He also used butterfly catastrophe, which is one of the more complex elementary catastrophes to explain the issue of equilibrium residential property prices in urban land markets. Mees (1975) modelled the revival of cities in medieval Europe using the five-dimensional "butterfly" catastrophes. Wilson (1976) reviewed some elementary ideas underlying catastrophe theory and showed clearly that the cusp catastrophe can be used in the theory of binary choice. He specifically applied catastrophe theory to the explanation of modal transport choice within an urban setting emphasizing its usefulness in urban modelling. Wilson (1981) using catastrophe and bifurcation theory developed models that demonstrated how new kinds of activity and infrastructure could emerge spontaneously and quite rapidly in unexpected locations and change the growth pattern in urban settings.

Related to Wilson's (1981) work is Allen's (1997) who may probably be the first to develop complexity theories of cities from the self-organization perspective. Based on self-organised principle, he developed models that demonstrated effectively, how new kinds of activity and infrastructure could emerge spontaneously and quite rapidly in unexpected locations. Mustapha Ben Hamouche, (2009) applied chaos theory to explain complexity in urban fabric using a traditional Muslim settlement. The study demonstrated the ability of chaos theory to provide better instruments for the analysis and understanding of the traditional urban fabric in old Muslim cities that have paradoxically long been considered as lacking order and thus chaotic.

Haken and Portugali (1995) examined the self-organization ability of cities and settlement based on the synergetic theory of cities. They developed mathematical models to explain the change of population by migration and change of profession within the urban system. Pulselli et al. (2006) from the perspective of the theory of dissipative cities examined complexity in urban systems by studying mobility in urban space. Dynamic patterns of urban mobility were investigated to demonstrate that cities behave like complex self-adapting systems. Sun and

Liu (2013) analysed the city ecological system based on dissipative structure characteristics to explain the process forming dissipative structure. They developed an entropy-evaluated model to explain the city's levels of ecology system. Wilson (1970, 1981, 2007 and 2008) developed a series of entropy maximizing models developed from ideas from statistical thermodynamics and information theory, to describe analogies between cities and other social systems. His efforts showed that information or entropy is a measure of system complexity and that cities are open complex systems that exhibit all the properties of natural complex systems.

Many of the modelling attempts discussed above were based on linear mathematical equations that lack capacities to effectively explain the logistic trend in urban systems. Urban growth is a logistic function that requires spatial and temporal data and non-linear mathematical techniques for its analysis, interpretation and explanation. Developments in geographic information systems and remote sensing provided many opportunities to obtain timely repetitive data that are suitable for analysing non-linear functions. Remote sensing data provide an inductive, bottom-up perspective to understanding urban patterns and processes. It incorporates "real world" remote sensing-based measurements of urban form and dynamics rather than generalized consideration, as are commonly used in traditional spatial theories and models of urban spatial structure and change (Herold, et al. 2002, 2003 and 2005).

An aspect of urban modelling that has benefitted immensely in the use of remote sensing and GIS is Cellular Automata modelling (CA Modelling). Cellular automata models (CA-Models) offer innovative thinking and methods for comprehending and modelling the inherent complexity underlying urban growth in space and time. It offers the opportunity of reproducing complex phenomena like urban growth (Wolfram 1994). Cellular automata models represent open systems that are capable of self-organisation. Developing automata models that are more complex in their internal processing and in their behaviour, leads to a different world of modelling activities known as agent-based modelling, multi-agent systems or simulation. Such automata are called agents. While there is no accepted definition of what an agent is, the term often signifies an autonomous, intelligent entity that can interact or communicate with other autonomous agent or intelligent entities. Agent-based simulations can provide valuable information about the dynamics of the real world(s) that they emulate. They are powerful tools for "what if" scenario analysis.

In addition, CA models have the capabilities of being used as laboratories for testing urban theories, particularly those fundamental urban theories including; Losch theory of urban settlement distribution theory, von Thünen location theory, Burgess urban land use model, and Christaller's central place theory. Generally, when CA models are applied to urban studies, they become urban cellular automata models (UCAMs). UCAMs are built on the principle of fractal geometry and are very useful in modelling a variety of complex, dynamic, socio-economic and environmental phenomena in urban systems. There are generally three types of UCAMs. The first are those that test ideas and assumptions related to urban theories (see Batty et al. 1999; Couclelis 1997; Webster and Wu 1999; Wu 2000). The second are those that attempt the simulation of real cities (Batty and Xie 1994, Clark and Gaydos 1994). The third are those that use cellular automata technique to develop normative planning models to simulate different urban scenarios based on specific planning objectives (Li and Yeh 2000, Ward et al. 2000, Yeh and Li 2001).

The capacity of cellular automata technique for modelling complexity in urban growth had been emphasized in the literature (see Anthonia, 2007; Batty, 1997a, 1998, and 1999; Demirel and Cetin, 2010; Torrens, 2000 and Torrens and O'Sullivan, 2001). Researches had shown that cellular automata technique could be combined with multi-agent methods to model spatial and temporal complexity in urban growth based on the idea of self-organization (Li and Yeh, 2002). Similarly, cellular automata technique could also be used in studying urban evolution (Schweitzer and Steinbrink, 1998, Haken and Portugali, 1995). Batty (1998) argued that based on the concept of self-organized criticality, cellular automata technique can be used to explain the temporal urban development pattern.

Unlike most conventional urban models that focus more or less on the spatial patterns of urban growth, cellular automata based models (CA-Models) pay more attention to simulating the dynamic processes of urban development and defining the factors or rules driving the development by applying different transition rules. Improvement in CA-based models has led to the development of fuzzy constrained CA-Models of urban development. A fuzzy logic-controlled cellular automata model of urban development attempt to simulate the complexity in urban systems behaviour through transition rules based on fuzzy set theory (Liu and Phinn 2003; Wu 1996; White and Engelen 1993). Urban development is a product of physical constraints and human decisions that are both uncertain and fuzzy in nature. The applications of the fuzzy set theory and fuzzy logic control would help in defining the rules controlling urban developments and provide a deeper understanding of the nature of an urban system. A number of studies on the application of fuzzy set and fuzzy logic in cellular automata-based urban modelling can be identified in the literature, few among them are; Mandelas, Hatzichristos, and Prastacos, (2007); Dragicevic (2004); Liu and Phinn (2003) and Wu (1998b), following the pioneering attempt by Wu (1996).

A major research problem in the study of urban growth is how to quantify urban growth patterns and processes. Currently, this problem is being addressed, through a body of techniques built on data and methods in remote sensing and GIS, known as landscape metrics or spatial metrics (Herold, Liu, and Clarke, 2003). Spatial metrics are quantitative indices calculated using categorical, patch-based models of the landscape. They are built on information theoretic measures (Shannon and Weaver 1949 and 1964) and the fractal geometry (Mandelbrot 1983, Goodchild and Mark 1987, De Cola and Lam 1993, Xia and Clarke 1997). Because they are obtained through the digital processing and interpretation of thematic-categorical raster data (maps) that are spatially heterogeneous in resolution and scale (Herold, et al., 2005), they are very useful in describing the pattern and dynamics of a landscape O'Neil et al. 1988; MacGarigal, 2015).

Several studies had applied spatial metrics to the study of landscape. For example, Luck and Wu (2000) examined the pattern of the urban landscape in the Phoenix metropolitan region, Arizona, the USA using gradient analysis and landscape metrics. They demonstrated that urban growth pattern could be measured and analysed using landscape metrics. Herold and Menz (2000) employed landscape metrics to quantitatively measure and describe structural changes in urban land use of Santa Barbara, CA region. Herold, Liu and Clarke (2003) evaluated the use of texture measurements and spatial metrics as quantitative discriminators of urban spatial characteristics for the mapping of urban land uses. Using a mosaic of seven multispectral IKONOS images that completely cover the urban areas of Santa Barbara South Coast Region of California suggested that the region-based method exploiting spatial metrics and texture measurements is a potential new avenue to extract detailed urban land-use information from high-resolution multi-temporal satellite data

Zamyatin and Cabral (2011) explored the effectiveness of the combined use of cellular automata (CA) modelling and advanced spatial metrics in analysing the dynamics of land use/land cover. They found that modelling with spatial metrics produced a better model performance when compared to the others. Sheknar (2016) using spatial metrics and multi-temporal data attempted an analysis of the extent and rate of the growth of Gulbarga city in India. He found that urban growth is occurring in a patchy and fragmented way in Gulbarga city.

Analysing the spatial and temporal urban growth patterns in Greater Cairo Region (GCR), Megahed, et al., (2015) computed eight spatial metrics and found an occurrence of dense urbanization, as well as dispersed and fragmented landscape due to the individual urban establishment in the GCR. Ramachandra et al. (2012) investigated trends in urban land use changes in Mysore, a rapidly urbanizing traditional region of Karnataka, India. Combining spatial metrics with the method of gradient analysis, they found a coalescence of urban patches, resulting in clumped growth at the centre and dispersed growth in the boundary region with a complex pattern. Using Urban Atlas (a dataset that provides information on land use for all cities in Europe) Prastacos, Chrysoulakis and Kochilakis (2012) estimated various landscape metric indicators for several cities in Greece and found that spatial metrics provide an adequate comparison of the structure and the form of the cities studied. Others who have used spatial metrics in studying urban growth patterns and processes are; Dasgupta, Kumar, and Ramachandra (2010); Bekalo (2009); Oduro, Ocloo and Peprah (2014) and Kabba and Li (2011).

Modelling the patterns and dynamical processes of urban growth has become an important research agenda for urban systems analysis in recent time. This is because urban growth and decline are spatially conditioned processes that operate at different temporal scales and resolutions. There are two major approaches to the spatial modelling of patterns and processes of urban growth; first, there is prescriptive modelling of urban growth that aimed at the determination of the optimum land-use patterns that satisfies a set of goals and objectives (Braimoh and Onishi, 2007). This approach is built on the utility-maximization function that does not always apply to human socio and economic processes. Second, there is descriptive modelling that aimed at the simulation of current and near-future urban land-use patterns (Braimoh and Onishi, 2007). Descriptive modelling approach focuses on the complex nature of the urban landscape. It explains how the interaction between different agents brings about the emergent pattern.

Under descriptive modelling approach, two essential modelling techniques can be identified; first, there is the spatial/statistical regression-based modelling and the second is the modelling technique based on deterministic/probabilistic transition rules. The latter is relatively very recent and relies on Markov chain and/or stochastic cellular automaton principles (Zhou and Liebhold 1995). The spatial/statistical regression approach tries to the established relationship between a wide range of predictive variables and the probabilities of the transition of the urban area (or a cell) from a non-urban category to an urban category to enable a quantitative description of typical urban growth patterns. The approach involved generation of multi-temporal land-cover maps, multivariate modelling of drivers of land cover change and the prediction of land cover transition. The capacity of this approach in modelling and understanding urban growth pattern and processes has been emphasized in the literature. Given its flexibility, it has been the most widely used in land use change modelling.

Wilson et al. (2003) identified, described and modelled different categories of urban growth. Three specific categories of urban growth including; infill, expansion, and outlying growth were identified to characterise urban growth patterns. An "infill growth" was described as a condition where at least forty per cent (40%) of the existing developed pixels encompassed a pixel that transformed from non-developed to a developed state. In this case, urban land cover surrounds the development of a small tract of land. For example, the development of vacant land within a built-up area is an example of an infill growth. "Expansion growth" occurs when a pixel transformed from non-developed to a developed state and is encompassed by no more than forty per cent (40%) of the existing developed pixels. In this case, existing urban patches are being extended particularly along the metropolitan fringe. Outlying growth occurs when development moves to the outer regions of an existing developed area. Outlying growth comes in different forms. It may be an isolated growth, linear branch, or clustered branch type of growth (see Wilson et al., 2003 for details).

In an attempt at measuring urban sprawl a negative form of urban growth, Galster et al. (2001) offered eight conceptually distinct, the objective dimension of land use that can be used in measuring urban growth patterns. These include;

i. Density- This describes the average number of residential units per square mile of developable land.
ii. Continuity- Expresses the degree to which developable land has been built upon at urban densities in an unbroken fashion.

iii. Concentration- Describes the degree to which development is located disproportionately in relatively few square miles of the total urbanised area.
iv. Clustering- Illustrates the degree to which development has been tightly bunched to minimize the amount of land in each square mile of developable land occupied by residential or non-residential uses.
v. Centrality- This is the degree to which residential or non-residential development (or both) is located close to the central business district (CBD).
vi. Nuclearity- Describes the extent to which the pattern of development of a particular urban area is monocentric or polycentric in nature.
vii. Mixed uses- The degree to which two different land uses commonly exist within the same small area, and this is common across urbanised areas.
viii. Proximity- The degree of the nearness of different land uses to each other across urbanised areas.

Using spatial regression method to model urban growth processes, Hu and Lo (2007) found that despite logistic regression's lack of temporal dynamics, the method is spatially explicit and suitable for the analysis of multi-scale data. Deeper understanding and adequate insight into the workings of urban growth processes may be gained using logistic regression. Corroborating Hu and Lo (2007), Nong and Qingyun (2011) applied logistic regression method to model urban growth in the Jiayu county of Hubei province, China and show that the logistic regression model is suitable for urban growth modelling.

Studying urban growth pattern in Africa, Vermeiren, et al., (2012) examined the urban growth of Kampala, Uganda. Using LANDSAT images of 1989, 1995, 2003 and 2010 they mapped the urban growth of Uganda and developed a spatially explicit logistic regression model to analyse the pattern and scenario development of Kampala. Building three alternative scenarios for future urban growth of Kampala by 2030, they showed that the alternative policy options on the urban growth of Kampala would result in contrasting future urban sprawl patterns with a significant impact on the local quality of life. Linard, Tatem and Gilbert (2013) used boosted regression tree models (BRTMs) to model the pattern of urban growth in African cities. Mohammady and Delavar (2014) used the Logistic Regression method to model urban expansion pattern in Tehran Metropolis and found that distance to the residential areas was the significant variable influencing urban development in Tehran. Mundia and Murayama (2010) using the CA-Markov chain modelling technique, modelled the spatial processes of urban growth in Nairobi City. They found that the CA-Markov chain modelling technique is suitable for spatiotemporal modelling of processes of urban growth.

Braimoh and Onishi (2007) examined the spatial factors influencing urban land use change in the city of Lagos, Nigeria using multi-temporal satellite data and binary logistic regression. They found that changes in land use were functions of spatially explicit independent variables that include accessibility, neighbourhood interactions and spatial policy. However, Barredo and Demicheli (2003) hinted that rural to urban migration is the major factor influencing the monumental increase in population and the built-up areas of the Lagos city. Thapa and Murayama (2010) examined the driving factors of urban growth in Kathmandu Valley using the analytic hierarchy process. Among several factors considered; population growth in the fringe, economic opportunities at the city's core and the political conditions in the rural areas were discovered to be the most significant factors influencing urban growth. These factors were used to develop a representative model to illustrate and explain the overall association between drivers of the urban growth process in Kathmandu Valley.

Similarly, Aguayo et al. (2007) investigated the drivers of urban growth patterns in the Mid-Cities of Los Ángeles, Chile. Using multi-temporal satellite images, they developed several sets of models to characterise the changing pattern of land-use. They found that density of the urban road system, distance to access roads, the density of urbanized area at various scales and soil types were important predictors of the urban growth pattern. Their research effort showed that combining spatial modelling tools and GIS provides a good understanding of the urban growth patterns that could help urban planning and management.

Studying the growth pattern of Washington, D.C. area in the US, Masek, Lindsay and Goward (2000) using Landsat data, relate satellite-derived estimates of urban growth to economic and demographic drivers. They found that the built-up areas surrounding Washington DC have expanded considerably, with notably higher growth during the late 1980s. Relating satellite-derived estimates with census data; they found that the physical growth of the urban plan observable from the space could be reasonably correlated with regional and national economic patterns.

Eniolorunda and Dankani (2012) attempted an assessment of urban growth pattern in Sokoto metropolis in Nigeria using multi-temporal satellite data. They showed that the growth pattern of Sokoto metropolis follows a sporadic pattern and that the city may double its 2005 size by the year 2020. Lopez et al. (2001) examined the processes of land use and land cover transition in Morelia, Mexico (1960-2000) from aerial photographs. Using the combination of Markov chain and regression methods, they found that there is a significant relationship between urban growth, landscape change and population growth. Migration from rural areas following the drop in prices of agricultural produce was found to be the primary cause of urban expansion.

Evident from the foregoing is that significant improvements have been made in the aspects of measuring and understanding the growth and the spatial structure of the city. In addition, significant attempts have also been made at modelling urban growth and its associated drivers. However, it is obvious that researches have focused more on the urban horizontal growth dynamics, and discussions largely based on the experiences of cities in developed countries of the world. The review had also shown that the application of complexity theory to the understanding of the spatiotemporal patterns and processes of urban growth is relatively new. Its applications to the study of growth patterns and processes in the cities of less developed countries are limited, particularly in Africa.

Three critical issues requiring research attention had been identified by the review. First, is the understanding, analysis and modelling of urban growth patterns and processes in cities of less developed countries from a complex systems perspective, using the non-linear method. This, if achieved, will be an important contribution to the body of literature on urban research. Second, the review showed the paucity of research on the third dimension of growth in the city. The knowledge of the dynamics of urban vertical growth is limited. Hence this research holds the view that investigating the dynamics of urban vertical growth is a new frontier in urban geographical research that worth exploration. Lastly, the possibility and adequacy of combining time-dependent data with socio-economic data in modelling urban growth are worth examining. This will open a new horizon of understanding of urban dynamics and move urban research away from relying solely on theoretical abstraction and hypothesis with non-spatial statistical data. Given this backdrop and couple with a number of issues raised in the background to the study and the research problem, section 2.4 presents the hypotheses of the research. These hypotheses bear a direct relationship with the research objectives stated in section 1.3.

2.4 Research Hypotheses

Based on the research problem and the choice of conceptual frameworks, seven research hypotheses were postulated to explain and model the dynamics of urban growth in Lagos Island. They are stated as follows;

1. There is no significant spatiotemporal variation in the spatial expansion of Lagos Island.
2. The pattern of urban growth is significantly correlated with net population change and population density.
3. The urban spatial expansion is a function of physical variables (distance, building lot size and building height) and socio-economic variables (population growth, housing stock and housing demand).
4. The vertical expansion of built-up space is a function of economic (Number of finance /Insurance companies, land value and rental value), density (population density), physical (contiguity with water bodies, building lot area) and accessibility (Average road width) variables.'
5. The spatial distribution of high-rise buildings is significantly random.
6. The probability of change in urban growth (spatial expansion) is a function of physical variables (Contiguity to a water body, distance and building lot size) and social economic variables (trading activities, net population change, the rate of change in both housing stock and the city's built-up areas).
7. The probability of change in the urban vertical expansion is a function of physical factors (distance to water bodies), and socio-economic factors (rental value, the degree of concentration (building density), land use type, population income and household size).

Operationalisation of variables for these hypotheses and their calibrations are discussed in chapter three and other relevant section of the thesis.

2.5 Conclusion

In this chapter, the review of the literature on urban growth theories and empirical findings from urban growth research had been undertaken. Details of supportive theories and concepts upon which this research was built and hypotheses tested were explained. Principally, the review of relevant literature showed that cities can be best understood from a complexity theory perspective and that complexity theory offers an innovative approach to urban planning. The applications of complexity theory to the analysis and modelling of urban growth were examined. Consequently, complexity theory was explained as a new paradigm for urban growth analysis, and research hypotheses were developed. The techniques of testing and analysing these hypotheses were discussed in the next chapter, which focused on the methodology of the research.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

In the first and second chapter of this thesis, the aim, specific objectives and the hypotheses of this research were stated. The conceptual framework that formed the foundation upon which this research was built was discussed and relevant literature reviewed. In this, chapter methodologies employed in collecting, processing, analysing, and presenting data to achieve the aim and objectives of the research were discussed. Methods and techniques, by which research hypotheses were tested and analysed were discussed. Significantly, the chapter gives the details of the database for the research, the calibration of variables, method of data collection- sample size, sampling procedure, the processes of questionnaire administration, and various techniques of analysis.

3.2 Research Method, Design and Data

3.2.1 The database for the study

Since urban growth involves population and structural changes in urban areas, a very detailed database consisting of both primary and secondary data that capture these two aspects is required. It is believed that since patterns and processes of urban growth (both horizontal and vertical) can be significantly explained by specific physical and socio-economic variables, extensive spatial data sets and socio-economic data at aggregate and disaggregate levels are indispensable. This will enable the creation of a comprehensive spatial database from the integration of up-to-date information from satellite imagery with demographic and socio-economic data which hitherto, had been rarely employed in social sciences research until the recent times. Satellite imageries, aerial photographs, topographical map, and land use data are some spatial data sets used. Socio-economic data for the research include data on land value, rental value, income, household size etc.

3.2.2 Primary Sources of Data

The primary sources of data for the research include questionnaire administration, interview, personal observational study, focus group discussion, field measurement and remote sensing data. Questionnaire surveys were conducted in the nineteen wards that made up the study area.

3.2.2.1 Questionnaire Surveys

Questionnaire surveys were carried out in the study area in fieldwork activities that spanned six months. The surveys used two questionnaires (see Appendix I and II) to obtain information on urban residents, urban growth and factors that drive patterns and processes of urban growth in Lagos Island. The first questionnaire was designed to capture detailed information on urban households from household heads. It was divided into four sections. Section one provided general information on urban household composition. Particularly information on family systems and structure were sought for. Section two focused on the nature and type of house in the study area. Information obtained in this regard are partly observational data and includes; building type, geometry (height, plot area, distance to road etc.) and age. Others are plot size, land price, building use, number of floors, rooms occupied by household, rent per month, infrastructure in the building among many others.

The third section dealt with the issue of the quality of the environment and urban growth, urban life and health. Using a devised Likert-type scale (Likert, Rensis, 1932), respondents were asked to rank the impact of urban growth. This was done to determine the effect of urban growth on consumption of land area, loss of wetland, loss of soil permeability, loss of biodiversity, impairment of small watershed, high noise level, air pollution, traffic congestion, public transport network, social economic division, social interaction, quality neighbourhood, sand filling for building and changing pattern of land use. Section four probed respondents' perception of urban growth and future planning measures for the area. A Likert scale was also developed to investigate the effect of urban growth on the housing quality, the need to develop long term integrated plans to promote sustainable urban growth, the involvement of public-private partnership in urban growth management and the need for coordination between various levels of government in achieving sustainable urban renewal and growth.

The second questionnaire was used in the survey of a high-rise building (a building that is about 75 feet (23 meters) above the ground or having a minimum of seven storeys. See section 3.2.2.3 for details). It was aimed at taking some observational data and other valuable information on urban vertical growth. Urban vertical growth concerns upward expansion in urban areas. The principal targets here are owners, building users/tenants, estate/property managers, developers, real estate property management agencies and property management office of corporations, government ministries etc. Section one of the questionnaire sought for general information on high-rise buildings including type of high-rise building (whether it is a proposed or an existing development), location of the building, factors influencing the choice of the location, age of the building, number of floors in the building, structure displaced by the building, building ownership etc.

Section two focused on rent in high-rise buildings. Questions in this section were drafted to investigate the relationship between land use type and rent structure. Monthly rent per room, flat, floor and office complexes was sought for to understand rent dynamics and differentials in a high-rise building. Information on the average population per floor, the number of families per floor, number of persons per room and floor area was also obtained. Section three dealt with facilities in a high-rise building. Section four dealt with various activities occupying space in the high-rise building. It sought information on percentage occupiable space (used space) and vanity height (non-occupiable space) to understand the dynamics of space use in high-rise buildings. In addition, information on the average travel time from ground level to the middle floor and the upper floor was sought to determine the efficiency of vertical transportation within a high-rise structure. Similarly, information on accessibility to various high-rise buildings with other transport services; private car, public transport and train were obtained together with the cost of maintaining the building. The last section dealt with respondents' preferences for high-rise building and environmental conditions within the buildings.

3.2.2.2 Personal Interviews and Observational study

Personal interviews and observational study were conducted to complement the household survey. Selected individual heads of household were interviewed on issues ranging from the history of the area under study to factors influencing its growth both horizontally and vertically. Direct observation was equally used to study and record information on land use type, economic activities and functional areas within the study area, housing types, social and spatial interaction and special landmarks that provided information about the study area.

3.2.2.3 Field Measurement

Since one of the principal objectives of this study is to examine urban vertical dimension, direct field measurement was carried out to determine the height of buildings, most especially, high-rise buildings. Definition of high-rise or tall building varies across countries. For example, the German regulation defined tall buildings as buildings higher than 22meters

(72ft) with rooms for the permanent accommodations of people (Ross, 2004). The ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Technical Committee for Tall Buildings defines tall buildings as buildings higher than 91m (330ft) (Ellis and Torcellini, 2005). The Emporis Standard Committee defines a high-rise building as a multi-storey structure between 35-100 meters tall, or building of unknown height from 12-39 floors (ESC, 2011), skyscraper, (a multi-storey building whose architectural height is at least 100 meters (ESC, 2011), towers (extremely high building for habitation and non-habitation purposes). The International Building Code specified that tall buildings are buildings having occupied floors located more than 22,860 mm (75 feet) above the lowest level of fire department vehicle access (IBC, 2003). The Israeli Planning and Building Act 1965 defines a high-rise as "a building exceeding 27 meters above the entrance level", which is equivalent to a building of 10 stories or more.

For the purpose of this research, the cut-off point for tall building/high-rise buildings is seven storeys. If stated in terms of linear height (feet or meters), a high-rise structure in respect of the study area is considered to be one that extends higher than the maximum reach of available fire-fighting equipment. In absolute numbers, this has been set variously between 75 feet (23 meters) and 100 feet (30 meters), " or about seven to ten stories- depending on the slab-to-slab distance between floors (Knoke, 2006). The Council for Tall Building and Urban Habitat CTBUH standard was adopted in estimating building height for each category of buildings on Lagos Island. The buildings, having seven storeys and above are classified as high-rise.

Other measurements taken directly on the field are; the distance between buildings and major highways and between the building and access roads. These were measured using 50 metres long steel/synthetic measuring tape. Areas occupied by buildings, plot size and average street width in each ward were determined by direct measurement. Measurements in respect of buildings that are not accessible were estimated, while proximity to the city centre and of a particular spatial unit (ward) to other features e.g. water bodies were determined in GIS using ArcGIS. The housing stock in different spatial wards that made up the study area was obtained through satellite counts, this was complemented by field visit and secondary data sourced from government publications.

3.2.2.4 Sampling and Sample size

Samples used for the research were drawn from the combination of the household population, the number of electoral areas and the number of housing units. The 2006 National Population Commission census provided data on the number of housing units by types and regular household in Lagos Island. The number of housing units provided by NPC was complemented by satellite counts of houses, field visits and personal survey to arrive at the number of houses in various wards of Lagos Island.

A preliminary investigation revealed that houses and households in the study area vary significantly in their composition. The local government area had a population of 165,996 inhabitants in 1991. It increased to 209,437 in 2006 consisting of 108, 057 males and 101, 380 females, indicating about a 26% increase in growth. There are about 47, 447 households occupying about 8,217 houses. To determine the sample size, several criteria were considered. Applying a ten per cent (10%) sampling rule would mean interviewing about 4,745 heads of households in about 818 houses. Give the time constraint, this is not feasible. If Bruton (1975) rule of thumb of 1% for a population under 50,000 is applied, a sample of 475 heads of households would be needed. That will be a non-probability method and subject to high error(s). Therefore, a better method that minimizes error margin is therefore needed to arrive at a fairly representative sample of the population of interest.

To achieve a representative sample of the population of interest, Neumann (2014), proposed two methods. The first is the probability method, which he referred to as the “gold standard” for representative samples (Neumann, 2014). With a probability sampling strategy, an accurate representative sample that has mathematically predictable errors (i.e., precisely known chances of being “off-target”) can be taken (Neumann, 2014). The method involves making an assumption about the population of interest and using statistical equations to determine the degree of confidence (or margin of errors) that is acceptable and in variance with the population. Though the method is complex, however, it is reliable. The second method is known as a non-probability sampling method. It is less accurate, less rigorous statistically and depended on the rule of thumb. Though convenient, the method may be misleading, and thereby results in a total misrepresentation of the entire population.

Using Neumann (2014) probability method for a representative sample, a sample, based on 95% confidence limit with a Z-score of 1.96 and a percentage value of 0.5 at $\pm$3% margin of error was selected using equation 3.1 as provided by SurveyMonkey (2019);

$$S = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + (\frac{z^2 \times p(1-p)}{e^2 N}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where S is the sample size, N = population size, e = the margin of error (0.03), z is the confidence level (Z score = 1.96 at 95%) and p is a percentage value (0.5). Using equation 3.1, 1,200 heads of households (about 2.53% of the entire households) in about 368 houses (about 5% of the total estimated number of houses) in Lagos Island was derived. Through this method, it was believed that the level of precision in the sampling process had been improved. In addition, the likely risks of errors that would have been incurred in the sampling process must have been reduced to about 5%.

The allocation of the 368 houses to spatial wards to select 1, 200 heads of households was done using the method of proportional allocation. In proportional allocation, the stratum sample is selected such that the size of the sample is proportional to the number of units in each stratum such that (n_k) varies directly as (N_k) or (n_f) varies directly as (W_k). If the total sample that is to be allocated is (n), then the stratum sample is given as;

$$n_k = \frac{n}{N} \times N_k = nW_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where n_k = Stratum sample size (sample size of each ward).

n = Total number of sample to be allocated as n varies across wards.

N_k= Units or stratum of the anticipated population.

N = Observed total population (estimated population of the study area).

Therefore 1,200 heads of household were selected proportionally based on the number of households by ward as presented in table 3.1.

Table 3.1. Summary of the Sample Size and Questionnaire Administered

S/N	Ward Code	Area	Estimated Total Population based on 2006 Census	Estimated number of houses in wards	Number of Households in the ward	Total Household Sampled by ward	Number of Questionnaire Retrieved
1	A1	Olowogbowo/Elegbata	9859	607.00	4112	104	102
2	A2	Oluwole	7221	398.00	1349	34	29
3	A3	Idumota/Oke Arin	13904	430.00	2192	55	35
4	B1	Oju- Oto	8655	248.00	1566	40	30
5	B2	Oko-Awo	10960	280.00	1605	41	41
6	B3	Agarawu/Obadina	6299	554.00	2023	51	35
7	C1	Iduntafa	14135	662.00	4014	102	67
8	C2	Ilupesi	16900	387.00	1715	43	33
9	C3	Isale Agbede	15492	554.00	2705	68	60
10	D1	Olosun	11139	152.00	851	22	22
11	D2	Olushi/Kakawa	3841	130.00	667	17	17
12	D3	Popo-Aguda	3278	458.00	1709	43	31
13	E1	Anikantamo	3073	122.00	760	19	19
14	E2	Oko Faji	23993	284.00	1574	40	40
15	E3	Eiyekole	17617	690.00	6914	175	150
16	F1	Onikan	11677	437.00	2076	53	43
17	F2	Sandgrouse	14135	340.00	1560	39	39
18	G1	Epetedo	10140	939.00	7513	190	160
19	G2	Lafiaji/Ebute-Elefun	7119	545.00	2542	64	52
Total			**209437**	**8217.00**	**47447**	**1200**	**1005**

Source: Fieldwork 2013/2014

The second survey was an enumeration of all high-rise buildings. As earlier stated, a high rise building is taken to be a building greater than 75 feet (23 m) in height where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story (Moore, 2004). In Lagos Island, average floor height was found to be 3.5 metres, implying that a high-rise building would have a minimum of seven (7) floors. A preliminary investigation indicated that there were about 100 high-rise buildings in Lagos Island. A total survey of the entire buildings was considered, however, about 64 per cent of the questionnaire administered on the buildings was recovered.

The selection of the spatial unit of data collection is a key issue in urban studies (Salvati and Carlucci, 2014). As observed by Garcia and Riera (2003), Muñiz, Galindo, and Angel Garcia, (2003) and Tsai (2005), quantitative research, usually relies on administrative boundaries often used as the denominator for land use and socio-demographic analysis. Although it is an arbitrary spatial unit with regard to the urban landscape, however, it provides a detailed and meaningful unit of analysis for both statistical and planning purposes. Since this research focused on household heads for all socio-economic data, the choice of household heads was done at the household level. However, for spatial data, political ward and cell (patch) in satellite images were the lowest units at which data was collected.

The administration of the two questionnaires was achieved with the help of colleagues and about ten field assistants in fieldwork that spanned about six months. Systematic sampling technique was employed in the selection of housing units and target respondents based on the identification of major lanes, streets and roads in each ward. The sampling interval was determined using equation 3.3 given as;

$$I = \frac{N}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where, I = sampling interval, N = total population of interest and n = the sample size. The sampling interval for household heads was ~ 40 and for houses/buildings ~ 22. The selection of the first house and household head was done randomly, such that where K is a random starting point; the other members of the sample are selected by $K + i, K + 2i; K + 3i$ etc. on either side of the specific street where samples were being taken. Wherever the male head of the household was not around, the wife was interviewed; this was based on the assumption that the wife can assume the position of the head of household in the absence of male head or on occasion of death.

3.2.2.5 Remote Sensing/Satellite Data

The ability of the modern remote sensing technologies to continuously acquired data, with a synoptic view and present such in a digital format amenable for computer processing has made it possible to achieve accurate urban growth analysis. Remotely sensed imageries, including; Advanced Very High-Resolution Radiometer (AVHRR), Landsat imagery data from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+ sensors, IKONOS, RADAR and SPOT (Satellite Probatoire d'Observation de la Terre) are main primary data sources for change detection analysis and urban growth monitoring in recent times. Change detection is the application of remotely sensed datasets of different time scales to observe and analyse different time states of the phenomenon. It involves differentiating the state of an object or a phenomenon at different dates through careful and systematic observation (Singh, 1989).

For the purpose of this research Landsat TM of 1984, Landsat ETM+ 2000, and 2015 were the basic multi-temporal datasets obtained. Earth Science Data Interface (ESDI) hosted by the University of Maryland, USA provided the datasets freely. IKONOS 2013 image and Google Earth imageries were obtained to complement the Landsat data. Google Earth satellite data are available in a free version or in licensed versions for commercial use. Many large cities including Lagos are available in a resolution high enough to see individual buildings, houses, and even cars. The degree of resolution available is based somewhat on the points of interest, but most places are available at least at 15 metres resolution. That seems reasonable for some level of urban growth analysis. Table 3.2 shows the detail characteristics of the selected satellite sensor of data used in this research.

Due to the problem of data availability, urban growth analysis in this research was divided into two epochs; 1984-2000 and 2000-2015, indicating a period of thirty-one years. Remote sensing data obtained were used to analyze and determine the extent of urban growth and to monitor changes that have taken place over the years. Variables such as distance to water bodies, CBD (modern), major highways and major access roads were extracted from satellite imageries by calculating the Euclidean distance from ward centroids to the respective features.

Table 3.2. Characteristics of selected satellite sensor

Data Product	Provider	Spatial Resolution (m)	Swath Width (Km)	Operation period	Specific year	Spectral Coverage (µm)
TM (Landsat 4, 5)	NASA, USA	30 (MS) 120 (TIR)	185	Since 1982	1984	0.45–2.35
Landsat 7 ETM+	NASA/USGS	15(PAN) 30(MS) 60(TIR)	183	Since April 15, 1999	2000, 2006 & 2011	0.450–2.35, 10.4–12.5
Landsat 8 ETM+	NASA/USGS	15 m- 100 m	185	Since February 11, 2013	2013 & 2015	B1: 0.433–12.5µm
IKONOS	Geoeye/Digital Globe	PAN0.82–1 m (32–39 in); MS: 3.2–4 m (130–160 in)	Nadir (11.3 km) Off-Nadir (13.8 km at 26°)	Since 1999	1999 - 2015	11-bits per pixel

NB: ETM+, Enhanced Thematic Mapper plus; MS, Multi-Spectral; MSS, Multi-Spectral Scanner; NIR, Near Infrared; PAN, Panchromatic and TIR, Thermal Infrared.

Source: Rogan and Chen, 2004 and Wikipedia

The height of each location above the sea level and location data (x and y coordinate values) of all buildings were obtained using Garmin GPS. Due to the unavailability of aerial photos of the study area, cartographic sources, including 1885 and 1964 maps and political ward map sourced from the local government and Federal Survey Department served as the base data sources. All these maps were processed and transformed to a suitable digital format for the purposes intended.

Because of differences in coordinates, the Landsat images obtained could not be overlaid to evaluate urban growth; hence, all images were transformed from geographic coordinates to UTM coordinates, WGS84, Zone 31 using the ArcMap 10.3 software. The extent of spatial growth in the study area was obtained by clipping out the study area by year from all the satellite data, using heads-up digitizing methods in the ArcGIS software. The images obtained were classified with the help of ENVI (raster-based GIS software) using supervised classification method. Overlay operations in GIS were performed on the digitized and classified maps to undertake change detection analysis and to determine the spatial and temporal changes in urban growth between 1984 and 2015. IKONOS 2013 high-resolution image and data from Google Earth were used for the 3D city modelling of the urban landscape. Other data sources used in this research, particularly secondary sources were discussed in the next section.

3.3 Secondary data sources

The decennial census and other housing data routinely collected by government agencies were the principal sources of secondary data used in this research. Population, housing and amenities data were obtained from 1991 and 2006 censuses. Total number of educational and health facilities, banks, hotels, markets, recreational parks, plan of properties processed etc., were obtained from the publications of different government ministries and agencies. Administrative and land use maps were obtained from the City Engineer Department, Lagos Island Local Government and the Lagos State Urban Development Planning Department. Plan of the town of Lagos West Coast of Africa with a scale of 1:100 feet prepared in December 1885 and corrected to June 1887 was obtained from Federal Survey, Lagos. Similarly, topographical map of Lagos on a scale 1:25,000 and a cadastral map of Lagos Island at a scale of 1:5, 000 were also obtained from Federal Survey, Lagos Nigeria.

Data on urban residential density, government reservation area, government acquisition area for barracks, commercial and other purposes, Institutional area, recreational area, industrial area, open space etc., were obtained from Lagos State Urban Development Planning Department and Lagos GIS Department. Internet website, technical reports, magazine, academic journals and other periodic publications of Lagos State that contain historical development of Lagos Island Local Government provided rich information that are helpful for the analysis of the function and services that contribute in one way or the other to the economic prosperity, population growth and spatial expansion of Lagos Island.

The next section discusses the measurement of variables used in this research. Techniques of analysis used in testing research hypotheses, methods used in measuring complexity in urban growth and technique of modelling the vertical landscape of the built environment of Lagos Island were also discussed.

3.4 Measurement of variables and techniques of analysis

3.4.1 Measurement of variables

Operationalisation of variables concerns representation of variables in an objectively measurable form. This is a fundamental step towards the evaluation of research aim and objectives. It is also important for a successful test of research hypotheses. Given this backdrop, the variables used in this research are categorized into;

i. **Urban growth variables**- These includes the number of built-up pixels, built-up area by wards, the areal extent of spatial units (wards), and rate of change in the urban land area, among many others.

ii. **Housing/Building variables-** Including the number of houses by wards, housing type, age, height, density and rent. It also includes the annual rate of change in housing stock by ward and average lot size.

iii. **Distance variables-**Euclidean distance to CBD (the CBD was the area designated as Lagos Island Central Business District by the Lagos State government. The area extends from the foot of Carter Bridge westwards, through Adeniji Adele Road to inner and outer Marina, Tafawa Balewa Square, back to Broad Street, Tinubu Square, Nnamdi Azikiwe Street, Idumota and to Carter Bridge.). Other distance variable considered includes distance to major highways, access road and water bodies.

iv. **Transport variables**- Road density, sum length of all roads, number of access roads, road width etc.

v. **Land variables**- Land rent/value,

i. **Environmental variables**- height above sea level and proximity to water bodies.

vi. **Planning/policy variables**-Number of properties processed for land use charge, number of building plan approved, land use types

vii. **Socio-economic variables-**Household head characteristics including; age, household size, occupancy rate and average monthly/annual income among many others. For mapping and spatial data analysis, the mean value of relevant socioeconomic variables by wards was used.

viii. **Variables related to economic activities-**Number employed in formal and informal sector, number of local markets, retail shops, manufacturing industries, hotels/motels, restaurants, construction and allied company, financial and related industries, hospitals/maternity/primary health care centres, public schools (primary, secondary and tertiary) and shopping mall in each ward.

ix. **Density variables-**Population and housing density.

The descriptions and calibration of these variables were discussed in the relevant sections of the thesis.

3.4.2 Techniques of Analysis

Information obtained from questionnaire surveys, field observation and measurements were subjected to various statistical techniques and GIS analysis. These are discussed as follows;

3.4.2.1: Testing research hypotheses

The first hypothesis that states that ‘There is no significant spatial and temporal variation in the spatial expansion of Lagos Islands was tested using analysis of variance (ANOVA). Changes in the areal extent of each spatial unit, making up Lagos Island were calculated using ArcGIS and afterwards analysed to determine the level of variability over time and space

The test of the second hypothesis that states that ‘Pattern of urban growth is significantly correlated with net population change and population density.’ was achieved using Pearson Product Moment Correlation model. Details of the model were presented in chapter six of this thesis.

The third hypothesis seeks to understand and explain the driving factors of the horizontal dynamics of urban growth in Lagos Island. To this end, the hypothesis that states that 'Urban spatial expansion process is a function of physical variables (distance, building lot size and building height) and socio-economic variables (population growth, housing stock and housing demand),' was also tested using the spatial regression method (spatial lag model).

The fourth hypothesis seeks to examine the factors influencing the vertical growth of urban areas. To do this the hypothesis that states that; 'the vertical expansion of built-up space is a function of economic (Number of finance/Insurance companies, land value and rental value), density (population density), physical (contiguity with water bodies, building lot area) and accessibility (Average road width) variables' was tested using the standard ordinary least square regression method in SPSS.

The fifth hypothesis seeks to examine the spatial distribution of high-rise building and pattern of height in urban space. This is very fundamental to this research since a major focus of this research is to understand the dynamics of vertical growth of the city. The hypothesis that stated that; 'The spatial distribution of high-rise buildings is significantly random.' was tested using the Nearest Neighbour Index (NNI) and spatial autocorrelation statistics (Moran's I).

Predictive modelling of the future horizontal expansion of Lagos Island was attempted by testing the sixth hypothesis using the binary logistic regression. The hypothesis states that; 'The probability of change in urban growth (spatial expansion) is a function of physical variables (Contiguity to water bodies, distance and building lot size) and socio-economic variables (including trading activities, net population change, the rate of change in housing stock and in built-up areas).' Similarly hypothesis seven that states that 'the probability of change in urban vertical expansion is a function of physical factors (distance to water body), and socio-economic factors (rental value, degree of concentration (building density), land use type, population income and household size)' was tested using binary logistic regression in order to determine the future vertical expansion of Lagos Island.

Critical to this research is the measurement of complexity in urban growth, particularly the determination and understanding of the pattern and processes of urban growth. In addition, the research has the aim of modelling of the vertical landscape of the city in a GIS environment. Respective techniques employed in achieving all these were explained in subsequent sections.

3.4.2.2 Measuring complexity in urban growth

Urban growth and form take on several features of scaling invariance (Chen, 2010). This scaling invariance is a major feature that characterised fractals. Fractals are examples of complex systems. They are geometric objects manifesting self-similarity and fractional dimensionality. Fractal geometry is used in explaining patterns generated by complex systems (Batty, 2005 and Batty and Longley, 1994). As observed by Lee De Cola and Sui-Ngan Lam, (1993), fractal dimension index is useful in determining the complexity of curves and surfaces.

Urban growth is a dynamic process that manifests self-similarity. As a result, processes and pattern of urban growth can be characterised and determined using fractal dimensions (Batty, Fotheringham and Longley, 1993, Chen, 2010, 2012, Tuček and Janoška, 2013). Methods of computing the fractal dimension are many, however, the most commonly used method is the box-counting method given by Barabàsi and Stanley, (1995) as;

$$D_b = \lim_{l_b \to o} \frac{\log_{10} N_b(l_b)}{\log_{10} l_b} \dots\dots\dots\dots\dots (3.4)$$

Where l_b is the length of boxes, D_b is the fractal dimension and it corresponds to the slope of the plot $\log_{10} N_b(l_b)$ against $\log_{10} l_b$ and $N_b(l_b)$ is the number of boxes needed to completely cover the structure of interest. The fractal dimension value of urban form based on the box-counting method ranges from $D = 0$ to $D = 2$, depending on the measurement centre of the fractal body. In this research, the fractal dimension of the city was computed using Fragstas software version 4.2. Classified remotely sensed images of the study area were imported into the software to compute the fractal dimension in order to examine complexity in urban growth in space and time. The description and calibration of the fractal dimension index are provided in chapter six of this thesis

3.4.2.3 Quantitative measurement of patterns and processes of urban growth

The issue of the identification and measurement of the pattern and process of urban growth is critical to this research. While pattern relates to the spatial configuration of the landscapes

(Galster et al. 2001, Gustafon, 1998, Pijanowskia et al. 2002), process relates to the spatial and temporal sequences of change (Cheng, 2003). While a sequence of change in space is a spatial process, temporal process refers to the sequence of change in time. These are different from socio-economic processes driving the physical and functional growth of the city.

Both process and pattern are inter-related. The process creates and modifies the pattern, but patterns constrained process. Understanding the processes of urban growth is a fundamental step towards land use modelling. It provides adequate working knowledge about urban growth for planning and sustainability. Hence, the combination of a set of spatial metrics and cellular automata-Markov (CA-Markov) in modelling land use change in order to identify and analyse patterns and processes of urban growth in Lagos Island. The CA-Markov chain modelling technique was employed in modelling the processes of land use/land cover transitions The technique is a combination of cellular automata principle and Markov process. A Markov process is a simple discrete-time stochastic process$\{X_n\}$ in which the future development of states is completely determined by the present state and is independent of the way in which the present state has developed such that;

$$Pr\{X_{n+1} = j|X_o = k_{o,} \ldots . X_{n-1} = k_{n-1,}X_n = i\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

$$= \Pr\{X_{n+1} = j|\, X_n = i\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.5)}$$

Equation 3.4 is the transition probabilities. For every $i.J, k_o \ldots \ldots .. k_{n-1}$ and every n, discrete time means $n = \in N = \{0, 1, 2 \ldots .\}$.

Cellular Automata consist of a collection of agents (cells or pixels in raster data), of an arbitrary shape, arranged in a grid-like structure, interacting dynamically according to some rules applied at a regular discrete time interval. The cells behaviour, usually in the binary state is determined by the possible combination of states in its neighbourhood.

In Markov processes, the cell under consideration is assumed to be independent of the states of the neighbouring cells surrounding it (Feller, 1968), hence proximity, pattern and direction are not adequately accounted for. In geographical research, proximity is fundamental in the analysis of any given spatial system. Because proximity is not well considered in the traditional Markov chain processes, prediction of spatial systems is difficult. Hence, there is a need for a technique that has time series and spatial prediction capabilities. Cellular automata models are powerful in simulating dynamic systems. The combination of Markov processes and cellular automata (CA) in a GIS environment produce CA–Markov models that can be used to simulate spatial and temporal processes. Apart from helping in simulating the spatial and temporal processes, the combination of cellular automata with Markov processes increased our ability to understand the complex systems of spaces and landscape prediction with accuracy. This is further expatiated on in the sixth chapter of this thesis.

Spatial metrics are mathematical expressions of patch characteristics (area, perimeter, geometry (shape), position etc.). Patches are the basic dynamic units of the landscape and are based on land cover. They are discrete, relatively homogeneous areas that differ from their surroundings at a particular scale. They have a definite shape and spatial configuration. Spatial metrics are useful in measuring landscape characteristics and are usually calculated using a fixed neighbourhood. The specificity of the spatial configuration of urban landscape and processes of urban growth can be captured using spatial metrics. For the purpose of this research, metrics used in describing and measuring the pattern of urban growth include; Number of patches (NP), Edge Density (ED) and Fractal Dimension Index (FRAC). Others are the Largest Patch Index (LPI), Patch Area (AREA), Percentage of landscape (PLAND), Clumpiness Index (CLUMPY), Contagion index (CONTAG), Patch density (PD) and Patch Richness (PR). The research also used Shannon's Diversity Index (SHDI), Simpson Evenness Index (SIEI), Total (Class) Area (CA), and Patch cohesion index (COH) were used to determine the urban growth process. The descriptions and equations for the calculation of these metrics were given by McGarigal (2015) and are presented in chapter five and appendix II.

3.4.2.4 Modelling the vertical landscape of the built environment

One of the objectives of this research is to model the vertical landscape of the built environment in the city. In this research 3D, GIS was employed to provide a detail representation and visualization of the complex urban landscape in Lagos Island. A method employed is a 3D City modelling technique. 3D city modelling varies and involved several steps depending on the level of detail to be included in the model. Level of Detail (LoD) defines the degree of abstraction of real-world objects. It determines the number of details of the real-world objects to be included in the model based on the user's needs, the computational ability of the available technology and economic capacity. Five levels of details can be identified in a multi-scale 3D modelling approach. These are; LoD 0 (a 2.5D digital terrain model, used as a regional model), LoD 1 (a block model having no roof structures), LoD 2 (a city model having roof structures with optional textures). LoD 3 (commonly used in the detailed architectural design as site model) and LoD 4 (the model used in modelling walk-able interior spaces). LoD1 was adopted as a level of detail for this research. LoD1 is a well-known block model showing prismatic buildings with flat roof structures. This level is used in modelling the landscape of Lagos Island.

Software used in achieving all analysis stated above includes IBM Statistical Packages for Social Sciences (SPSS) version 20.0, ArcMap 10.3, Fragstas version 4.0, and IDRISI Land Change Modeller in TerrSet Geospatial Monitoring and Modelling System. SPSS was used to run both descriptive and inferential statistical analysis. ArcMap was used in modelling spatial relationship and building 3D City model. Fragstas was used in identifying and analysing patterns and processes in urban growth and Land Change Modeller in IDRISI was used in modelling land transition processes and prediction. The foregoing showed that this research used both qualitative and quantitative approaches in achieving its stated aim and objectives.

3.5 Conclusion

This chapter had presented the methodology of the research. It discussed the database for the research and the sources of data including primary and secondary sources. The primary sources of data include; questionnaire administration, field observation and measurement and remote sensing data. Two questionnaire surveys conducted were discussed in this chapter. The variables used in the analysis of data were described and discussed. Similarly, techniques of analysis employed in analyzing data obtained from the field and in testing hypotheses were explained. Succeeding chapters were devoted to the analysis of data and discussion of the results of data analysis. The immediate chapter following this attempts an evaluation of population change and urban growth in Lagos Island. Essentially the chapter discusses urban growth in Lagos Island both in space and in time. It investigates changes in the spatial structure of the city from different perspectives to provide a deeper understanding of the spatial and temporal changes in the structure of Lagos Island. Figure 3.1 showed the schematic representation of the research methodology. Among many things, it showed the interrelationship between each stage of the research.

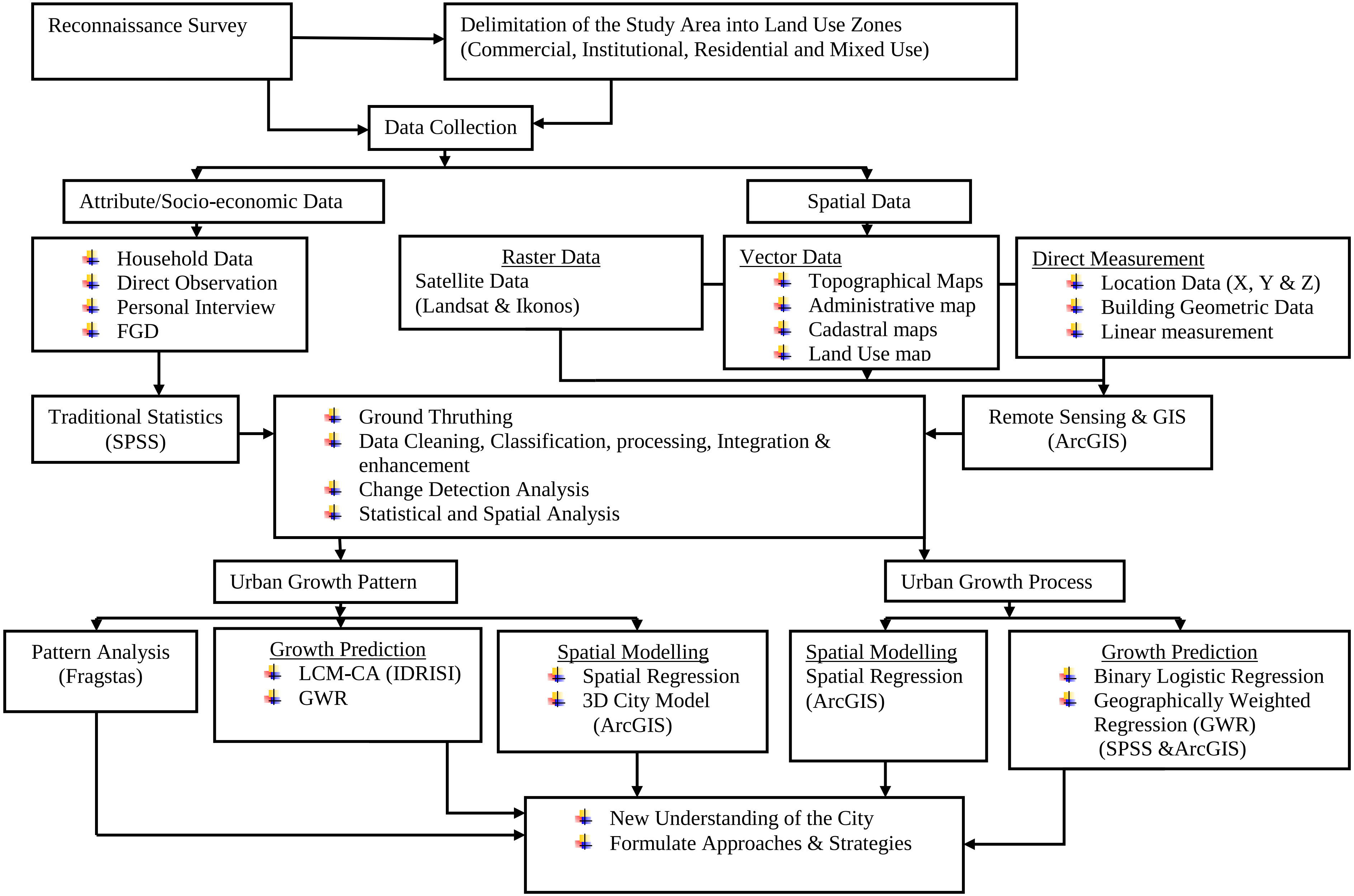


Fig. 3.1. Schematic presentation of the research methodology.

CHAPTER FOUR

EVALUATING POPULATION CHANGE AND URBAN GROWTH IN LAGOS ISLAND

4.1 Introduction

So far, regarding its urban spatial and temporal growth, Lagos Island has not been systematically studied from the geospatial perspective; rather research attention has been generally focused on the entire metropolitan Lagos. In addition, the evaluation of the population change, household structure and their impacts on urban spatial expansion have not been considered in recent time. In this chapter, analysis and evaluation of the urban growth of Lagos Island between 1984 and 2015 were undertaken. The chapter has four broad sections. Following the introduction, the second section examines population change, its driving factors and relationship to urban growth. Section three considers the structure and characteristics of households in Lagos Island. This provides a general understanding of households that made up the population of the Island and provide background information for the evaluation of its population growth. The final section of the chapter attempts a systematic evaluation of urban growth in Lagos Island.

4. 2 Population structure and change in Lagos Island (1984-2015)

The population of Lagos Island is a rapidly growing population. Table 4.1 showed Intercensal change in the population of Lagos Island between 1991 and 2015. Between 1991 and 2006 the population of Lagos Island grew by 43, 441 persons indicating a 26% increase with a mean annual net change of 2896.07 persons. Between 2006 and 2015, the population increased by 68,644 persons indicating a 33% increase in 9 years with the mean annual net change of 7627.11 persons.

4.2.1 Age-sex structure in Lagos Island.

Information on age and sex distribution is very important in understanding the structure and growth of the urban population over a period. Age and sex structure of a given population is an indication of its reproductive capabilities and the likelihood of its continuation. It has implications for future growth, economic development and social policy. Trends in the sex ratio of Lagos Island between 1991 and 2015 are presented in table 4.2. In 1991, there were 83,276 males and 82, 720 females, indicating a male-female ratio of 1.01 males to 1 female.

Table 4.1. Intercensal change in the population of Lagos Island (1991 – 2015)

	Population		
	Census		**Projection**
	1991	**2006**	**2015**
Total Population	165996	209437	278081
Household Population	29728	47447	62998
	Net change (total population)		
		Period	
		1991-2006	**2006-2015**
Total Net change	--------	43441	68644
Mean annual net change	--------	2896.07	7627.11

Source: Author's analysis

Table 4.2. Trends in the sex ratio of Lagos Island Population 1991-2015

Year	Total Population	% Male	%Female	Male/Female
1991*	165996	50.2	49.8	1.01
2006*	209437	51.6	48.4	1.1
2007**	887364	53.7	46.3	1.2
2008**	915760	53.7	46.3	1.2
2009**	945064	53.7	46.3	1.2
2010**	975306	53.7	46.3	1.2
2011**	1006516	53.7	46.3	1.2
2012**	1038724	53.7	46.3	1.2
2013**	1071963	53.7	46.3	1.2
2014**	1106266	53.7	46.3	1.2
2015**	1141667	53.7	46.3	1.2

Source: Author's analysis

By 2006 there were about 108, 057 males and 101, 380 females in the population, indicating a male-female ratio of 1.1 males to 1 female.

Going by the 2006 Lagos state population survey, there were 461,830 males and 398,019 females on Lagos Island, giving a male-female ratio of 1.2 males to 1.0 female. Using the data on age-Sex characteristics of Lagos Island in 2013 as presented in table 4.3, the age-sex composition in Lagos Island was examined. From the table, there is evidence of increasing male-female ratio from the age group 20-24 (1.03) to age group 55-59 (1.43). The highest ratio was recorded in the age group 55-59. The increasing proportion of a large number of male indicates that the population comprises of a large number of adults, of which greater proportion are migrants that may have been attracted by economic advantages available in Lagos Island. Also, it is obvious from the table that Lagos Island is made up of a large percentage of the active population. About 32 per cent of the population were children (0-14 age group). Adults, 15-59 years representing the working population, account for about 64 per cent of the entire population, while those above 60 years are only 4 per cent.

A graphical plot of the data in table 4.3 produced the population pyramid of Lagos Island for the year 2013 as presented in figure 4.1. Among many other things, the pyramid showed the percentage population of male and female in the population of Lagos Island. It reveals a near balance between both sexes in the population. The pyramid shows that infants of age 0-4 were about 13% of the entire population. Pre-reproductive age (Age group 5-14) constitute about 20% of the population in the year 2013. Significantly, the pyramid shows that the area has a very sexually active population. The highly active reproductive age 15-39 made up about 50% of the population, with this it is expected that more children will be born into the population, thereby increasing the rate of natural increase.

Information on birth and death rate, the number of immigrant and ethnicity in the population of Lagos Island is not available. However, birth dynamics in Lagos Island may be inferred from the number of pupils registered in public primary schools. Enrollment in public primary schools was reported to have increased by 5.5% in 2010/2011 session, but by 2011/2012, it jumped to 29.75%. The implication is that the proportion of children in the population is increasing considerably, indicating an upward trend in the population growth of Lagos Island. There is a diverse ethnic nationality in Lagos Island; however, the Yorubas are still the dominant ethnic nationality in the area.

Table 4.3. Age-Sex characteristics of Lagos Island in 2013

Age	Population	%	Male	Female	Male/Female Ratio
0-4	135484	12.63	68023	67461	1.00
05-09	112680	10.51	56543	56137	1.00
10-14	99124	9.24	48186	50938	0.94
15-19	101802	9.49	49759	52043	0.95
20-24	128490	11.98	65220	63270	1.03
25-29	131784	12.29	67905	63879	1.06
30-34	98365	9.17	52808	45558	1.15
35-39	76910	7.17	42751	34159	1.25
40-44	56143	5.23	31398	24745	1.26
45-49	42249	3.94	24559	17690	1.38
50-54	30825	2.87	17094	13731	1.24
55-59	19166	1.78	11282	7884	1.43
60-64	14455	1.34	7710	6745	1.14
65-69	8436	0.78	4563	3873	1.17
70-74	6189	0.57	3095	3094	1.00
75-79	3290	0.30	1578	1713	0.92
80-84	3282	0.30	1366	1916	0.71
85+	3290	0.30	1438	1852	0.77
TOTAL	**1071964**	**100**	**555277**	**516686**	**1.07**

Source: Lagos State Bureau of Statistics, 2012

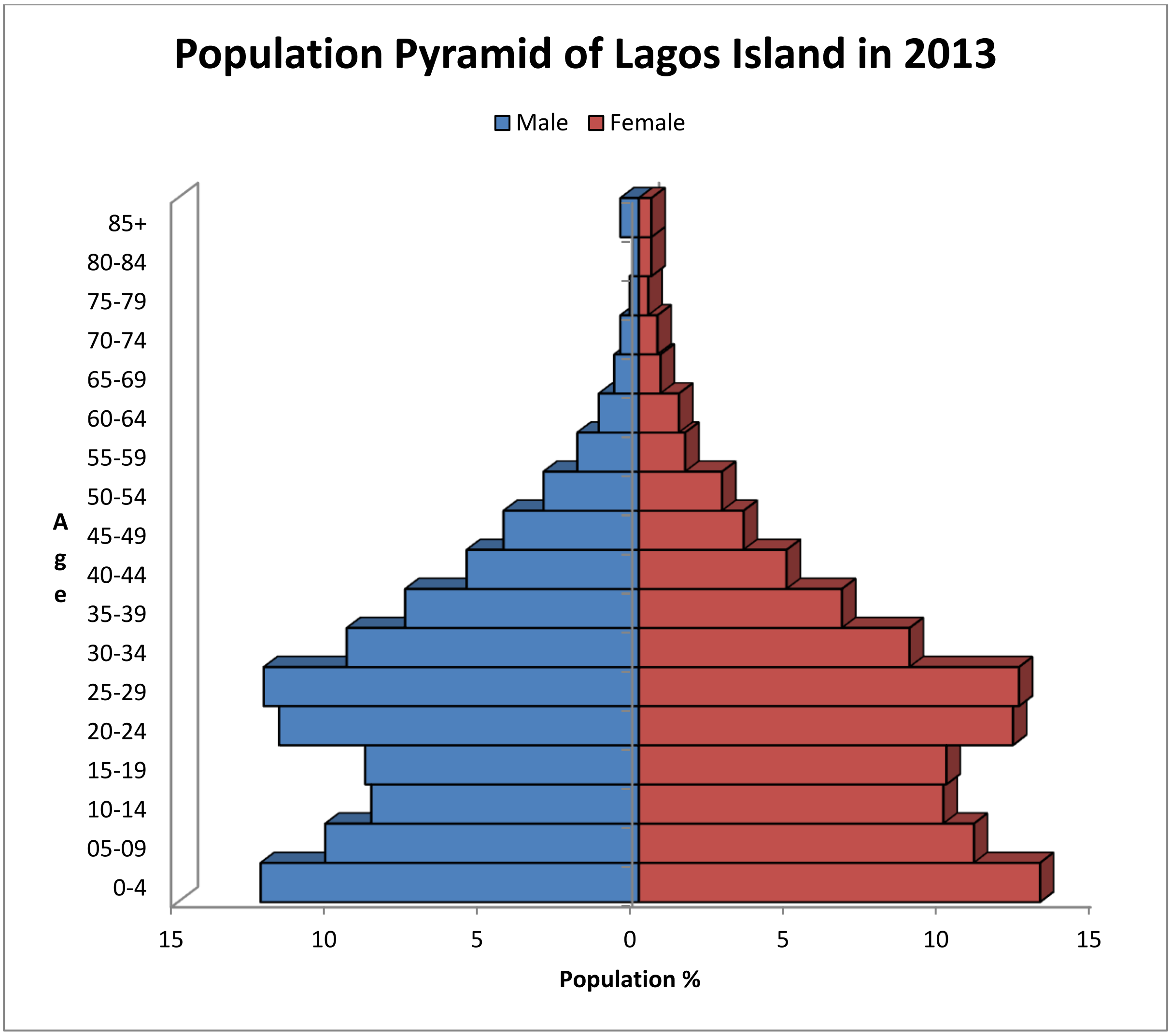


Fig. 4.1. Population pyramid of Lagos Island for the year 2013

Source: Author's analysis

4.2.2 Urban growth and Population change in Lagos Island

Since changes in the urban population is an important aspect of urban growth dynamics, changes in total population vis-a-vis household population, housing stock and the urban land area from 1984 to 2015 were examined to establish the association between changes in population and urban spatial expansion. Table 4.4 showed changes in total population, household population, population density, urban land area and housing stock in Lagos Island. Between 1984 and 2015 the total population increased by 145%, the household population increased by 217%, population density by 90,8%, urban land area by 29%, housing stock by 39% and built-up area by 24%. Total net change in population between 1984 and 2000 is 60, 014 persons with mean net population change of 3, 751 persons, between 2000 and 2015 the total net change in the population increased to 104, 710 persons with mean net population change of 6, 981 persons. Given the foregoing, it is very safe to say that as population increases with increasing density and built up area in Lagos Island, consequently, there is a continuous expansion of the land area. A graphical plot of the relationship between total population and urban land area gives an R^2 value of 0.92, and a correlation coefficient of R = 0.95, indicating a high positive relationship.

Table 4.4. Total population, household population, housing and urban land area (1984-2015)

Variables	Years			% change
	1984	**2000**	**2015**	**1984-2015**
Total Population	113357	173371	278081	145
Household Population	19902	36707	62998	217
Population density	26990	36119	51496	90.8
Housing stock	5927	7021	8217	39
Urban land area (km^2)	4.2	4.8	5.4	29
Built-up area (km^2)	3.82	4.53	4.73	24
Total net population change	--------	60014	104710	
Mean net population change	--------	3751	6981	

Source: Author's analysis, 2018

4.2.3 The driving factors of urban population change in Lagos Island

Population change may be explained by several factors. However, nine variables were selected for the purpose of this research based on data availability and the observations on the socio-economic conditions of the population in Lagos Island. The natural log of net population change between 1984 and 2015 was obtained and used as the dependent variable (Y). The driving factors were a set of explanatory variables selected systematically based on ideas from the literature on population dynamics, frameworks of human ecology and environmental research. The factors are categorized into;

i. Demographics- Percentage change in the number of household and
ii. Industrialisation/employment in the formal sector- Number of manufacturing companies.
iii. Urban Growth/Development- Built up area in kilometre square.
iv. Transportation Accessibility- Distance to CBD in kilometre and Road Density and
v. Livability- Average monthly income, Car ownership, Occupancy rate and Net change in the housing stock.

The operational definitions of the variables are presented in table 4.5. The complex interactions between population change and its driving factors in Lagos Island were determined by developing an ordinary least square (OLS) multiple regression model of the factors. A correlation matrix for the variables was developed to ensure that there is no multicollinearity (see table 1 Appendix II). Any variable with a correlation coefficient higher than 0.5 was removed from the model. Results from the model, as presented in the table 4.6 showed that there is a significant positive relationship between population change and demography, industrialization, urban growth, transportation accessibility and livability (R=0.94, F =7.74 at $P \leq 0.05$). The explanatory variables accounted for 89% variation in net population change between 1984 and 2015 (R^2 = 0.89). A detailed analysis of the result in table 4.6 showed that the percentage change in the number of households by ward contributes most significantly to the model (($\beta = 0.60$) significant at $P \leq 0.01$. This indicates that the higher the percentage change in the number of households, the higher the net change in the population in Lagos Island. A significant positive correlation was also obtained between net change in population and occupancy rate ($\beta = 0.49$), distance to CBD ($\beta = 0.41$), the built-up areas in kilometres ($\beta = 0.43$) and the number of manufacturing industries ($\beta = 0.33$).

Table 4.5. Operational definition of variables for regression modelling of the driving factors of population change

Variables	Title	Operational definitions	Measurement
	Dependent variable		
Y	$\boldsymbol{LogNPC_i}$	Log of net population change	Continues
	Independent variables		
	Transportation Accessibility		
X_1	$\boldsymbol{ED_i}$	Euclidean distance to CBD from ward centroid	Continuous
X_2	$\boldsymbol{RD_i}$	Road density by ward	Continuous
	Livability		
X_3	$\boldsymbol{AI_i}$	Average population income by ward	Continuous
X_4	$\boldsymbol{CAR_i}$	Car Ownership by ward	Discrete
X_5	$\boldsymbol{NHSG_i}$	Net change in housing stock by ward	
X_6	$\boldsymbol{OCC_r}$	Occupancy rate	Continuous
	Demographic Characteristics		
X_7	$\boldsymbol{CHH_i}$	Percentage change in the number of the household by ward	Discrete
	Industrialisation/Employment in the formal sector		
X_8	$\boldsymbol{NMFD_i}$	Number of manufacturing industries by ward	Continuous
	Urban Growth/Development		
X_9	$\boldsymbol{BUT_i}$	Built-up areas in km^2 by ward	Continuous

Source: Author's analysis, 2018

Table 4.6. The driving factors of population change in Lagos Island

Variables	Std. Coeff. (β)	Std. Error	t	P value
Constant	5.73	0.87	6.62	0.00
Average monthly Income	-0.01	0.00	-0.09	0.93
Percentage change in Household number	0.60	0.00	4.96	0.00
Distance to CBD in Kilometer	0.41	0.19	2.92	0.02
Occupancy rate	0.49	0.14	3.57	0.01
Built up area in Kilometer in 2015	0.43	0.57	2.79	0.02
Number of Manufacturing Industries	0.33	0.01	2.56	0.03
Number of car owners by ward	-0.18	0.02	-1.17	0.27
Net change in housing stock	0.26	0.00	1.93	0.09
Road Density	0.01	15.59	0.08	0.94
R	0.94			
R^2	0.89			
F	7.74			0.00

Dependent Variable: Natural log of net population change (1984-2015)

Source: Author's analysis, 2018.

That occupancy rate is significantly related to population change is an indication of livability problem. It suggests the presence of slum(s) and inadequate housing. It suggests that common housing type in Lagos Island is multiple dwelling units and that occupancy rate tends to be higher in multiple dwelling housing units than in single-family dwelling units. Most probably, this is serious evidence of livability problems on the Island. In addition, the positive relationship between built-up areas and population change indicate the continuous transition of non- urban land to urban, most probably for commercial and residential purposes. Undoubtedly, this has resulted in significant changes in land use pattern of Lagos Island from 1984 to date. That population change increases with increasing distance to CBD suggests that there is an increasing concentration of people on the Island in all directions. It also indicates that accessibility is an important predictor of urban population change in Lagos Island. In addition, the positive relationship between the number of manufacturing industries and population change is reiterating the importance of industrialization in urban population change.

Although population income, represented by average monthly income and car ownership represented by the average number of car owners were found to be negatively and inversely related to population change, however, the results point to the problem of livability on the Island. It indicates that population change is higher in the areas of low-income dwellers and where car ownership is very low. Positive but insignificant relationship obtained for population change and net change in housing stock is an indication of rising demand for housing. A positive, but insignificant relationship between population change and road density emphasizes the role of accessibility in population change. Accessibility to CBD increases the number of urban residents.

Given the foregoing, it can be concluded that both spatial and socio-economic processes drive population change. It’s also safe to conclude that household pattern and its distribution are manifestations of urban land use and economic status. Representing the variables in table 4.5 in a regression equation produced equation 4.1 expressed thus;

$$LogNPC_i = \alpha + \beta_1 ED_i + \beta_2 RD_1 + \beta_3 AI_i + \beta_4 CAR_i + \beta_5 NHSG_i + \beta_6 OCC_r + \beta_7 CHH_I + \beta_8 NMFD_i + \beta_9 BUT_i + \varepsilon \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (4.1)$$

From the result in table 4.6, equation 4.1 was developed into a population growth model for Lagos Island. It is expressed in the form of;

$$LogNPC_i = \alpha + 0.41\,ED_i + 0.01RD_1 - 0.01\,AI_i - 0.18\,CAR_i + 0.26\,NHSG_i + 0.49\,OCC_r + 0.60\,CHH_I + 0.33\,NMFD_i + 0.43\,BUT_i + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4.2)$$

Equation 4.2 expresses the dynamics of urban population growth in Lagos Island. It can provide help for planners and policymakers, particularly when considering developing future sustainable planning strategies for densely populated areas like Lagos Island. It could also help in developing a model plan for a sustainable habitable environment.

4. 3 The structure and characteristics of households in Lagos Island

The household is an important component of the city. Its structure and characteristics define the city and largely influences the rate and dimension of urban growth. Detailed analyses of data collected during the fieldwork provided information on the structure and socio-economic characteristics of households in Lagos Island. Discussion of the data and analyses follows in the succeeding sections.

4.3.1 The structure of households in Lagos Island

The results of the analysis of the structure of households in Lagos Island were presented in table 4.1. The results showed that most of the residents of Lagos Island are relatively young people with a mean age of 39.92 years. The relatively large standard deviation of 12.48 indicates high variability in the age distribution of head of households and the existence of a significant number of old men and women who are probably indigenes. The mean length of stay in Lagos Island as indicated in table 4.1 is 27.24 years. This suggests that most heads of households were born in Lagos Island; however, the standard deviation of 16.91 indicates high variability and probability of some of the heads being recent migrants.

The average household size is 4.92 persons. About 70% of the household heads interviewed have <5 members in their household, 28% of the household heads have between 6-10 household sizes and the remaining 2% have a household size above 10. The standard deviation of 2.38 for household size indicates that there is high variability in household sizes and the existence of very large and very small household in Lagos Island. It is therefore obvious why population growth in Lagos Island is phenomenal over the years. Average monthly income is about sixty-six thousand, four hundred and sixty-eight thousand Naira (₦66, 468.43) with a standard variation of ₦33798.96, suggesting a high level of variability in income.

Household heads in Lagos Island are mostly men (66%), implying female constitute a significant proportion of household heads (34%). It is unusual that a woman will head a household unless an occasion of household head absence or death. Results in table 4.7 provided us with an insight into the contribution of the household to the city workforce. The average of 1.09 relatives living with household heads suggests that for a house head there will be an average of one relative living along with him. This most probably suggests that households who are migrants bring in their relatives to live with them. Certainly, this will be true of most migrants who usually bring in their relatives to train in commercial skills in order to be economically dependent, after which they bring in other relatives. To a house head, there is an average of 1.29 children and 1.11 relatives who are workers. This suggests that forty out of the relatives are workers in Lagos Island.

4.3.2 Spatial Variation in Characteristics of Household

Characteristics of households by wards in Lagos Island are shown in table 4.8. The table clearly showed strong spatial variations of the household characteristics among the wards. One way analysis of variance of the spatial variation of the socio-economic characteristics of households presented in table 4.9 supported the observed variation. Ward E3 comprising prominent locations like Adams, Oke-popo, Inabere and Igbosere has the highest mean age of 50.92, with an average household size of 5.12 crammed into an average of 1.48 rooms. Mean age is also high in ward A2 and D2. These wards comprise areas around Abibu Oki, Alli Balogun, Campbell, Olushi and Marina. Wards A3, B2, B3, C1 C2 and C3 that falls into the densely populated Northern part of the Island and ward G2 in the eastern portion of the Island close to Obalende also have high mean age. In all the wards stated above, the average mean age is higher than the value for the entire Lagos Island area (39.92). Analysis of variance test for the age of head of households shows a significant variation at the 0.00 level of significance.

Table 4.7. The structure of households in Lagos Island

S/N	Variable	Mean	Standard Deviation
1	Age	39.92	12.48
2	Average monthly income in naira	₦66,468.43	₦ 33,798.96
3	Household size	4.92	2.38
4	Number of children living with a household head	2.79	1.418
5	Number of household head children who are working	2.09	1.287
6	Number of household head children who are in school	2.59	1.166
7	Number of relative staying with the household head	1.56	1.093
8	Number of household head relatives who are in school	1.13	0.927
9	Number of household head relatives who are working	1.51	1.110
10	Length of stay in Lagos Island	27.24	16.91
11	Length of stay in the residential building	15.38	14.27

Source: Author's analysis, 2018

Table 4.8. Spatial Variation of the characteristics of households in Lagos Island

S/N	Ward	Major Streets	Age of Head	Average Income	Length of stay in Lagos Island	Length of stay in a residential house	Numbers of rooms occupied	Household size
1	**A1**	Breadfruit, Bankole, Olowogbowo, Apongbon	32.60	83957.45	19.72	10.87	1.35	4.53
2	**A2**	Namdi Azikiwe, Broad Street, Marina	43.89	81878.05	38.24	23.27	2.26	4.50
3	**A3**	Oke Arin, Kosoko, Ereko	40.40	75817.65	33.47	14.09	2.24	4.81
4	**B1**	Idumota, Ashogbon, Idumagbo	36.79	73745.19	29.12	9.67	2.26	4.47
5	**B2**	Agarawu, Mosalasi	40.35	79943.40	29.80	14.92	2.32	4.45
6	**B3**	Obadina, Wahab Folawiyo, Nnamdi Azikiwe	41.56	33934.21	23.15	13.49	2.39	7.45
7	**C1**	Erelu, Onilegbale, Egun Iga	46.07	73535.71	30.92	19.50	3.08	5.12
8	**C2**	Iga Iduganran, Ojo Giwa, Jankara	46.24	88535.09	26.01	17.80	2.70	5.21
9	**C3**	Aroloya, Isale Igangan	39.80	25536.59	19.41	10.34	3.02	6.05
10	**D1**	Tinubu, Bamgbose, Kakawa	38.68	77812.50	19.88	11.75	2.62	4.78
11	**D2**	Odunlami, Campbell, Ajele	41.19	55263.16	17.13	9.72	2.45	7.31
12	**D3**	Catholic Mission, Glover	35.36	65281.25	21.43	13.37	2.31	5.50
13	**E1**	Faji, Atiku	31.35	86941.86	18.74	13.90	2.03	4.18
14	**E2**	Olusi, Odunfa	37.87	84194.12	30.66	18.76	3.91	4.88
15	**E3**	Oke Popo, Igbosere	50.92	38025.64	35.39	25.63	1.48	4.06
16	**F1**	King George, Onikan, Mcarthy	37.48	31785.71	18.72	9.22	2.27	4.53
17	**F2**	TBS, Okesuna, Igbosere	35.00	36513.51	19.64	17.10	1.61	3.69
18	**G1**	Tapa, Oshodi, Tokunboh	34.53	69684.21	18.18	7.13	1.53	5.20
19	**G2**	Strachan. Lewis, Moloney	40.44	23345.24	33.84	22.95	3.46	4.52
	Total		**39.92**	**66468.43**	**27.24**	**15.38**	**2.46**	**4.92**

Source: Author's Fieldwork 2013/2014

Table 4.9. One-Way analysis of variance of the spatial variation of the socio-economic characteristics of households

		Sum of Squares	df	Mean Square	F	Sig.
Age	Between Groups	22376.94	18	1243.16	9.21	.000
	Within Groups	127684.54	946	134.97		
	Total	150061.48	964			
Length of Stay in Lagos Island	Between Groups	39581.54	18	2198.97	8.80	.000
	Within Groups	237335.93	950	249.83		
	Total	276917.46	968			
Length of stay in a residential house	Between Groups	26159.34	18	1453.29	8.09	.000
	Within Groups	166901.17	929	179.66		
	Total	193060.51	947			
Number of rooms occupied	Between Groups	467.50	18	25.97	3.36	.000
	Within Groups	7117.88	921	7.73		
	Total	7585.38	939			
Average monthly income	Between Groups	422475537909.18	18	23470863217	34.38	.000
	Within Groups	592583958051.03	868	682700413		
	Total	1015059495960.1	886			
Respondent's household size	Between Groups	563.80	18	31.32	6.65	.000
	Within Groups	3285.57	697	4.71		
	Total	3849.37	715			

Source: Author’s analysis, 2018.

Average income varies significantly across wards. The maximum income is about N105, 000.00 and the minimum income is N14, 500.00. A significant proportion of the sampled household (20%) earns N14, 500.00 monthly. This implies that a significant number of households in Lagos Island live below the national monthly minimum wage of N18, 000.00. The lowest mean income (N23, 345.24) is found in ward G2 comprising areas such as Strachan. Lewis, Moloney etc. The highest income (N88, 535.09) is found in Ward C2, particularly in areas around Iga Iduganran Street, Ojo Giwa and Jankara market. The result of a one-way analysis of variance test on variation in average monthly income across wards as presented in table 4.9 shows a significant variation (F= 34.38 at P = 0.00).

In terms of length of stay, the shortest length of stay in Lagos Island is 17.31 years and was observed in ward D2, particularly in areas around Odunlami, Campbell and Ajele. The highest is 38.24 years and was observed in ward A2 that comprises areas around Broad Street and Marina in Lagos Island Central Business District. Analysis of variance of spatial variation in the length of stay of residents in Lagos Island is statistically significant at the 0.00 level of significance. This suggests that most household heads are natives of Lagos Island. However, the standard deviation of 16.91 indicates the existence of significant proportions of household heads that are migrants, who most probably are traders found on Broad Street, Marina within Lagos Island Business District.

Household size varies significantly in Lagos Island (F=6.179 at P = 0.00) and is very high. The highest household size is 7.45 and was observed in ward B3 comprising areas such as Obadina, Wahab Folawiyo and Nnamdi Azikiwe Street. Household sizes are above the general household size of Lagos Island in ward C1 (5.12), C2 (5.21), C3 (6.05), D2 (7.31), D3 (5.50) and G1 (5.20). The lowest household size was found in ward F2 in areas around Tafawa Balewa Square (TBS), Okesuna and Igbosere. The large household sizes found in most of these wards are an indication of the presence of extended family and many migrants' households having relatives living with them. Large household size has an implication for future population growth of Lagos Island. It also has an implication for the quality of life of urban residents.

The average number of rooms occupied by a household as shown in table 4.8 showed that living condition is poor in most localities in Lagos Island. For example, households with seven members in wards B3 and D2 are crammed into an average of 2 rooms. The situation is worst in ward G1 (Tapa, Oshodi, Epe, Cow-lane, Tokunboh etc.) where households containing 5.20 persons are crammed into 1.53 rooms. This situation calls for the development of a sustainable and affordable housing plan for the residents of Lagos Island.

Education is a major determinant of the quality of life of individuals. It has a significant influence on health practices and attitudes. It is also very critical to entrepreneurship, innovation, city growth and sustainable development. Table 4.10 shows a cross-tabulation of the educational status of household heads and their sex. The table shows that male household heads are more educated than female household heads. Female heads without formal education are more than male heads without formal education.

Among household heads that have basic/primary education, the male heads account for about 59%. Among those with secondary education, male heads account for 53.3%, of the sampled heads, the same also is true for those in the tertiary education category. Over 52% of the inhabitants of Lagos Island are traders. About 13% are artisans and 14% are public servants and those in private companies/corporation. The rest 21% cut across those in self-employment. The unemployment situation in Lagos Island is very high. The 2010 household survey done by the Lagos state government reported that 36% of the 381 household heads sampled are unemployed. 46% of the household head are self-employed and only 20% work for wages. Urban unemployment is a serious problem in Nigeria and the situation is worst in the city of Lagos because of the false impression that most migrants have jobs. Until present most migrants believe that jobs are readily available in Lagos.

4.3.3 Housing stock and characteristics in Lagos Island

Housing is an integral part of the urban household. If forms the important socio-economic aspect of urban growth. Investment in housing increases the size of the built environment. It swells up the amount of space used for residential activities. Direct counting of houses via satellite data was done to determine the number of houses in Lagos Island. This was validated by information from the Lagos state bureau of statistics. A total of 8, 217 houses were found in Lagos Island. Based on land use zones, about 33% of the housing stock was found in the traditional/native areas, 31% of the housing stock was found in the low-class residential area, 21.97% is in LICBD and 13.9% of the entire housing stock was found in the institutional zone.

Table 4.10. Educational Status and Gender in Lagos Island

Variables			Sex Female	Male	Total Female
Educ. Status	No Formal Education	Count	12	8	20
		% within Educational Status	60.0%	40.0%	100.0%
	Basic/Pry	Count	87	126	213
		% within Educational Status	40.8%	59.2%	100.0%
	Schl. Cert.	Count	156	350	506
		% within Educational Status	30.8%	69.2%	100.0%
	Diploma/Cert	Count	27	69	96
		% within Educational Status	28.1%	71.9%	100.0%
	Degree	Count	35	77	112
		% within Educational Status	31.3%	68.8%	100.0%
Total		Count	317	630	947
		% within Educational Status	33.5%	66.5%	100.0%

Source: Author's analysis, 2018

Classification of housing stock based on ownership shows that the majority of the residents in Lagos Island live in rented houses. Public and private rented houses accounted for about 86% of the total housing stock. The percentage of owner-occupied houses were only 14.2%. Taken together, the percentage of owner-occupied houses were much higher in traditional/native areas and low-class residential areas than in other parts of the Island, but most houses in Institutional area and LICBD are owned by public authorities and private corporations.

About 69% of household head interviewed in the course of this research have their families dwelling in multiple dwelling units, consisting of two or three storey apartment. Mean building age across Lagos Island is 31.86 years. The minimum building age is one year and the maximum age is 128 years. This shows that most of the houses on the Island are relatively recent and might have displaced a particular structure. Information gathered in the course of this research shows that most structures displaced are old type multiple dwelling bungalows and/or one storey apartment, which are replaced by either three or more storeys. In some cases, high-rise buildings that are used for mixed purposes replace them.

Apart from building type and age, other housing characteristics examined in this research in respect of Lagos Island include number of rooms, number of rooms used for commercial and residential purposes and the number of households living in a building. A one-way analysis of variance of housing characteristics is shown in table 4.10. Mean number of rooms in a building on Lagos Island is 15.41, and this varies significantly ($F = 6.127$ at $P = 0.000$).

The mean number of rooms used for residential purposes in a building is 12.40 rooms, this also varies significantly ($F = 7.777$ at $P = 0.000$). Similarly, the mean number of rooms used for commercial purposes in a building is 4.52, ($F = 6.606$ at $P = 0.000$) and the mean number of households living in a building is about 7.60, ($F = 8.194$ at $P = 0.000$). A correlation coefficient of 0.79 significant at $P \leq 0.05$ was obtained for the relationship between the number of households and built up areas, Similarly, a correlation coefficient of 0.98 significant at the 0.05 level was also obtained for the relationship between the number of households and urban land area for the period of 1984-2015. These results indicate that as the household number increases, so also is the extension of the land and built up areas of Lagos Island. Therefore, it may be safe to conclude that households play a significant role in urban the growth process in Lagos Island.

Table 4.11. One-way Analysis of variance of housing characteristics in Lagos Island

	Mean		Sum of Squares	df	Mean Square	F	P-value
No of households in buildings	7.60	Between Groups	3730.12	18	207.229	8.19	.000
		Within Groups	17070.52	675	25.290		
		Total	20800.64	693			
No of rooms in the building	15.41	Between Groups	8337.29	18	463.183	6.13	.000
		Within Groups	62519.19	827	75.598		
		Total	70856.49	845			
No of rooms used for residential purposes	12.40	Between Groups	7922.44	18	440.135	7.78	.000
		Within Groups	45782.64	809	56.592		
		Total	53705.08	827			
No of rooms used for commercial purposes	4.52	Between Groups	1495.56	18	83.087	6.61	.000
		Within Groups	9344.65	743	12.577		
		Total	10840.21	761			

Source: Author’s analysis, 2018

4.4 Monitoring and evaluating urban growth in Lagos Island (1984-2015)

4.4.1 The Spatial and Temporal Growth of Lagos Island

Based on the first objective, a detailed examination of the spatiotemporal trend in the growth of Lagos Island was considered. Figure 4.2 shows temporal trends in the expansion of Lagos Island between 1885 and 2015. An estimate of the spatial extent for 1885 was included in the temporal analysis to show the pre-independence growth era. Due to data unavailability, the value for 1968 was included to show the independence era. Estimates of growth for 1984, 2000 and 2015 represent the post-independence era.

Within a space of 130 years, the Island experiences about 80% increase in its land area. Between 1885 and 1968 (83 years) the land area increased by 33%, from 3.0 Km^2 to 4.0 Km^2. Between 1968 and 1984 (a space of sixteen years) the island expanded by 5% (about 4.20 Km^2). By 2000 the land area expanded by 14.29% and increased to 4.8 Km^2. Between 2000 and 2015, the land area increased by 12.50%. The rate of expansion between 1984 and 2000 was very high compared to what was witnessed between 2000 and 2015. Figure 4.7 shows the composite map of Lagos Island as of 2015. The bright green boundary on the image represents the expanded land area of the Island as of 2015.

Growth by spatial units (wards) that made up the Island was estimated by overlaying the administrative map of the Island on the satellite images (see figure 4.3). The choice of the year 1984, 2000 and 2015 for the spatial analysis was based on a number of reasons; first, there were no useful available aerial photograph or satellite data that can be used for change detection and spatiotemporal analysis of land cover dynamics between 1885 and 1968. Secondly, between the year 1984 and 2015, the city of Lagos experienced rapid population growth and economic transformation (Braimoh and Onishi, 2007). In addition, in 1989 Lagos Island was divided into 19 spatial units called wards; as a result, it was believed that there will be no much difference in the spatial configuration of the Island between 1984 and 1989.

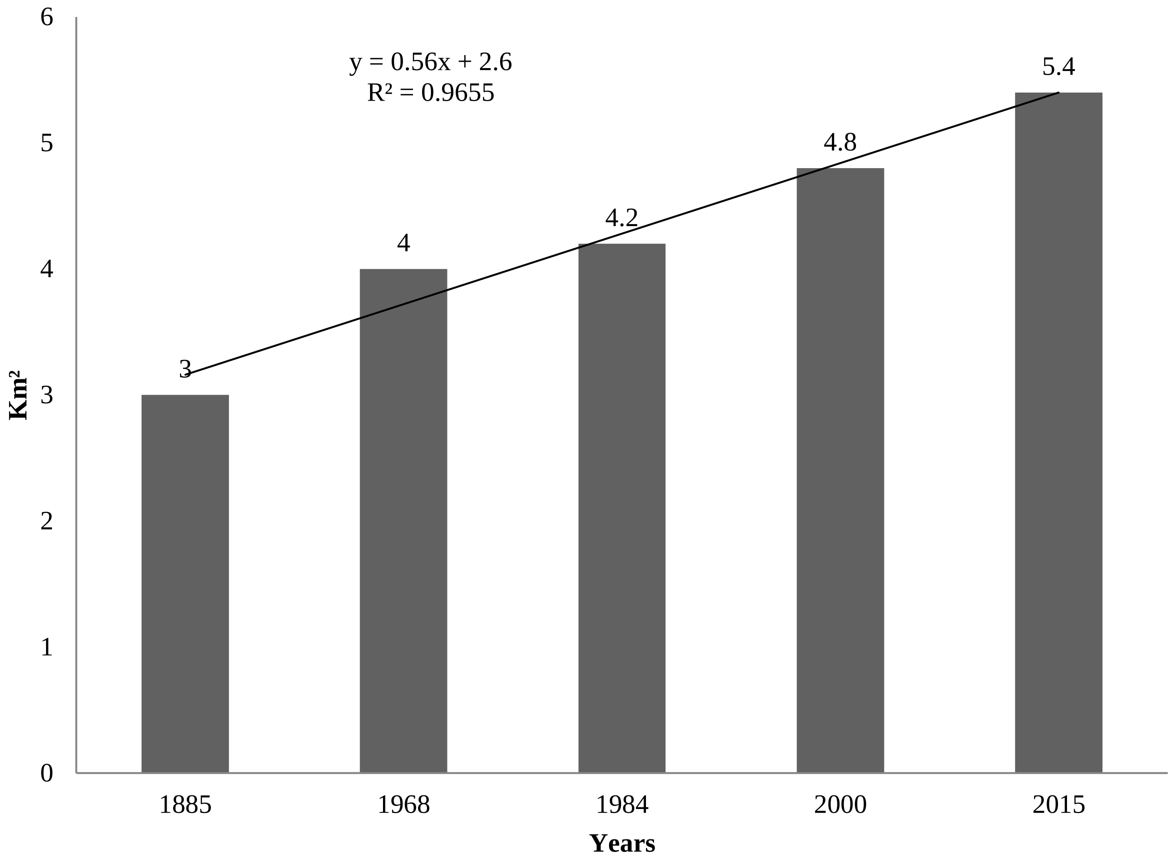


Fig. 4.2. Temporal trend in the expansion of Lagos Island

Source: Author's analysis, 2018

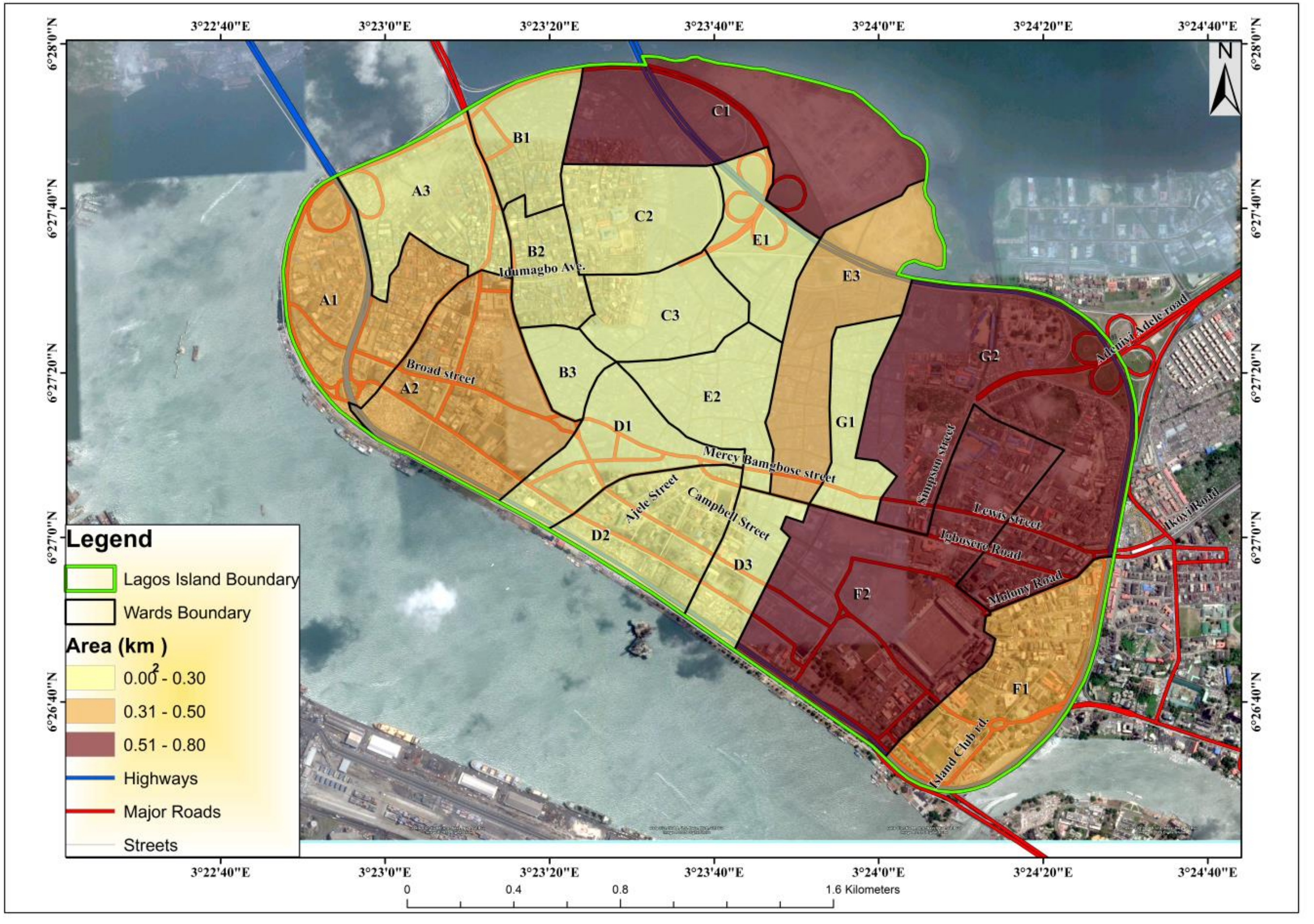


Fig. 4.3. Overlay of the ward boundary map on the composite map of Lagos Island

Source: Derived from Google Earth image, 2015 by the author.

The estimates of the land area of each spatial unit as obtained for 1984, 2000 and 2015 were shown in table 4.12. The table showed the spatial units that had changed over the years and by how much they had expanded during the period under consideration. Between 1984 and 2015, twelve (12) wards, including; ward, A2, B1, C1, D1, D2, D3, E1, E3, F1, F2, and G2 experience changes in their land areas. These are wards that share boundaries with Lagos lagoon and the Lagos harbour. Three wards experienced unprecedented changes in their urban land area. Ward C1 experienced 95.45% change in its land area, ward E3 experienced 77.78% change in its land area and ward D3 has its land area increased by 60.33%. Other wards that experienced changes are ward G2 (48.15%), ward F1 and F2 (about 33% each), and ward B1 having its land area increased by 23.07%. Changes in ward B1, C1, E3 and G2 can be explained by recent reclamation on the fairly shallow portion of the Lagos lagoon at Ilubinrin, a settlement on the northern fringe of Lagos Island (see plate 4.1). However, changes in ward D3, F1 and F2 can be attributed to reclamation along the Lagos harbour at the southern fringe of Lagos Island.

A detailed examination of plate 4.1 showed that serious development, particularly vertical development had commenced in the reclaimed land areas at Ilubinrin. It also showed that there is a serious incursion into the sea. While this development is laudable, yet there is the need for caution, to avoid future disaster of monumental proportion particularly in this era of climate change.

Using the data on estimates of urban land areas by ward from satellite imageries in table 4.12, a test of analysis of variance was conducted to confirm hypothesis 1 which states that 'there is no significant spatial and temporal variation in the spatial expansion of Lagos Island.' Table 4.12 shows the results of the ANOVA test of the variation in urban spatial expansion of Lagos Island between 1984 and 2000. Given an F-value of 3.79, 5.71 and 11.75 significant at 0.05 level, the results show that there are significant temporal variations in the spatial expansion of Lagos Island between 1984 and 2015. The observed variations in the temporal growth of Lagos Island would have a significant relationship with increasing demand for space, for both residential and commercial activities. This shall be examined in the succeeding chapter(s). However the result in table 4.13 established the fact that significant growth processes are ongoing in Lagos Island, an area concluded to be fully built-up by Ayeni (1981).

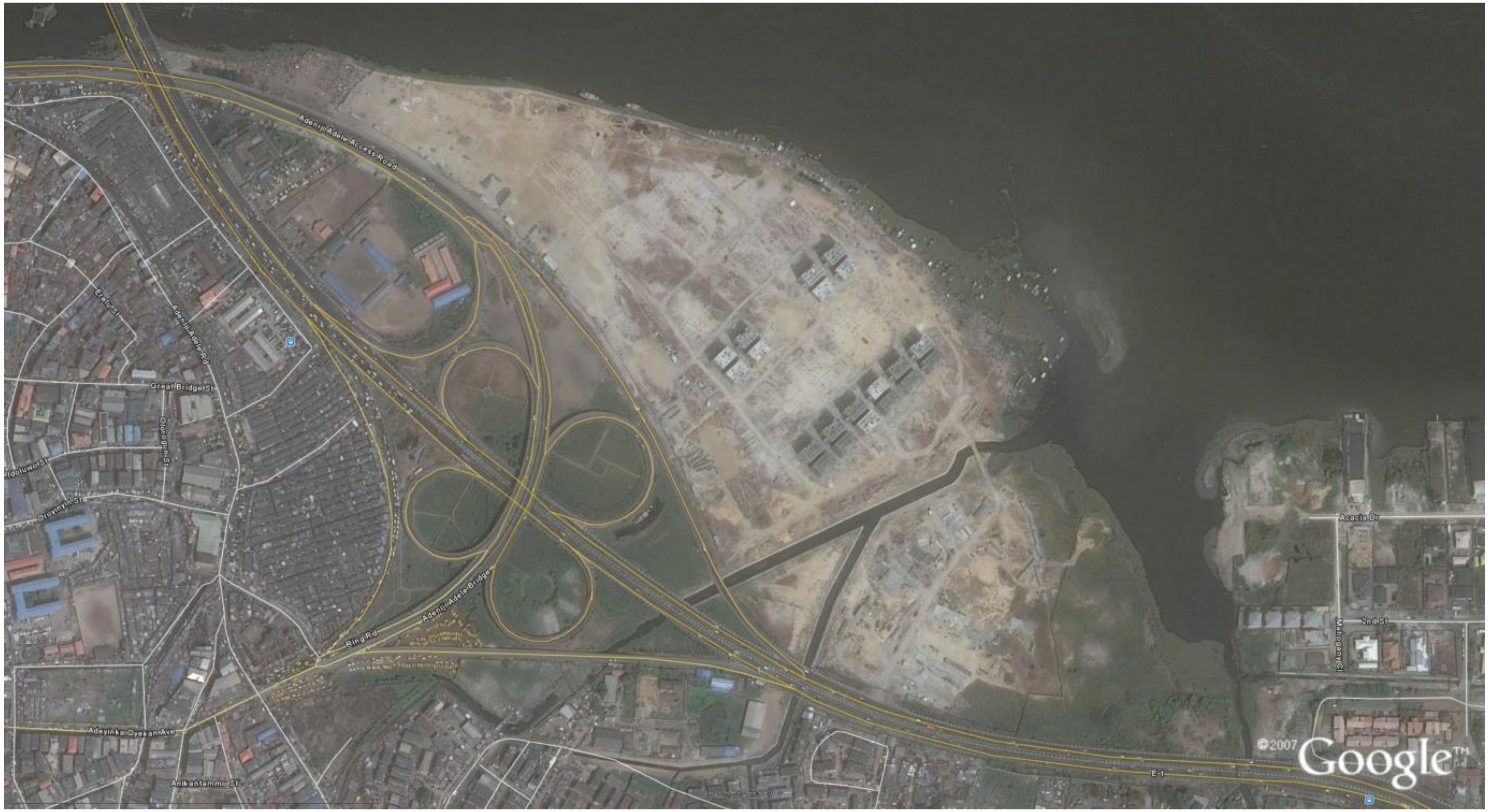


Plate 4.1. Land reclamation at Ilubinrin settlement, December 2015.

Source: Google Earth

Table 4.12. Spatial and temporal trends in the expansion of Lagos Island 1984-2015

Wards	Total area in Km² [1984]	Total area in Km² [2000]	Total area in Km² [2015]	Gain	Lose	% Change
A1	0.31	0.34	0.34	0.03	-	9.68
A2	0.32	0.34	0.34	0.02	-	6.25
A3	0.19	0.19	0.19	-	-	-
B1	0.13	0.16	0.16	0.03	-	23.07
B2	0.11	0.11	0.11	-	-	-
B3	0.12	0.12	0.12		-	-
C1	0.44	0.53	0.86	0.42	-	95.45
C2	0.18	0.18	0.18		-	-
C3	0.31	0.31	0.31		-	-
D1	0.19	0.21	0.21	0.02	-	1.05
D2	0.22	0.28	0.28	0.04	-	18.18
D3	0.05	0.06	0.08	0.03	-	60.00
E1	0.19	0.23	0.23	0.04	-	21.05
E2	0.18	0.18	0.18	-	-	-
E3	0.18	0.21	0.32	0.14	-	77.78
F1	0.18	0.24	0.24	0.06	-	33.33
F2	0.27	0.36	0.36	0.09	-	33.33
G1	0.08	0.08	0.08	-	-	-
G2	0.54	0.67	0.8	0.26	-	48.15
Total	**4.19**	**4.79**	**5.39**	**1.2**	**-**	**28.33**

Source: Estimated by the Author using remote sensing data and GIS.

Table 4.13. Variation in the urban spatial expansion of Lagos Island (1984 -2015)

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Urban extent in kilometer (1984)	Between Groups	.23	11	.02	3.79	.04**
	Within Groups	.04	7	.01		
	Total	.27	18			
Urban extent in kilometer (2000)	Between Groups	.37	11	.03	5.71	.02**
	Within Groups	.04	7	.01		
	Total	.41	18			
Urban extent in kilometer (2015)	Between Groups	.77	11	.07	11.75	.00**
	Within Groups	.04	7	.01		
	Total	.81	18			

Note: ** Values significant at the 0.01 level
Source: Author's analysis, 2018

4.4.2 Urban Land use and land cover dynamics in Lagos Island

A systematic and most widely recognized way of monitoring urban growth is primarily by remotely sensed imagery (Cheng, 2004). Remote sensing data provides the opportunity for timely, repetitive and multi-date data that are useful in monitoring and evaluating changes in urban land cover/land use pattern (Herold, et al., 2006). There is a thin margin of difference between land cover and land use. While the observed physical cover on the earth's surface is the land cover (Di Gregorio and Jansen, 1998), land-use is the functional role of land in terms of economic activities (Campbell, 1983). These two terms are indispensable in landscape analysis. Urban land cover, or urban extent, is typically measured by the total built-up areas of cities, sometimes including the open (non-developed) spaces captured by their built-up areas and the open (non-developed) spaces on the urban fringe affected by urban development (Angel, 2013). Monitoring urban growth in Lagos Island was done by taking the inventory of types and analysing the dynamics of its land cover and land use. This was achieved through four integrated stages namely; data preparation, processing, classification of land cover, and post-classification analysis.

4.4.2.1 Data pre-processing, classification and Post classification

The Global Land Cover Facility (GLCF) provided the three Landsat (TM and ETM+, 30m × 30 m spatial resolution) imageries used to examine land cover dynamics in Lagos Island. GLCF archives Landsat imageries that have proved sufficient for a synoptic view of urban development. Their spatial resolution and spectral range are sufficient to capture the characteristic scales of human development and to detect changes in land cover. Three years datasets (1984, 2000 and 2015) were selected for this study. These datasets were selected based on data availability, but they also represent significant periods.

The dataset for the year 1984 is Landsat Thematic Mapper (TM) image. It covers an area of about 170 km at the north-south axis and 183 km at the east-west axis (106 mi by 114 mi). Landsat imagery data have seven spectral bands. Bands 1 to 5 and 7 have 30 meters resolution. Band 6 (thermal infrared) has 120 meters resolution, however, this had been resampled to 30-meter pixels. The dataset for 1984 represents the period of early economic prosperity in Nigeria. The dataset for the year 2000 is Landsat Enhanced Thematic Mapper Plus (ETM+) that covers about 170 km north-south and 183 km east-west scene size. The dataset has eight spectral bands. Bands 1 to 7 has a spatial resolution of 30 meters. Band 8 is a panchromatic image with 15 meters spatial resolution. The data for the year 2000 is very central to this research. The year represents the beginning of the current political dispensation in Nigeria. The dispensation came with renewed efforts at rejuvenating urban centres in Nigeria through a series of urban renewal programmes, particularly Lagos State.

The dataset for the year 2015 is Landsat 8 from Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The dataset has nine spectral bands covering approximately 170km north-south and 183 east-west scene size. Bands 1 to 7 and 9 have 30 meters spatial resolution. However, band 8 is a panchromatic image having 15 meters resolution. The dataset for the year 2015 was chosen to represent, analyse and monitor the current urban growth situation in Lagos Island.

Geometric and radiometric corrections were made on all images used. They were also projected and register to the 1984 World Geodetic System (WGS) and Universal Transverse Mercator (UTM) Zone 31N coordinate system respectively. Linear enhancing, filtering and resetting of the brightness and contrast of all imageries was performed to enhance the visual display of the imageries. ENVI 5.3 raster-based GIS software was used to perform the supervised classification on the imageries using maximum likelihood method. The method of Maximum likelihood, clusters pixels in a dataset into classes based on user-defined training data and the statistical assumption of normality for each class in each band to calculate the probability that a given pixel belongs to a particular class. Each pixel was assigned to the class that has the highest probability.

Four classes namely; built-up (including all paved surfaces such as office blocks, commercial structures, educational centres, hospitals, residential apartment, industrial buildings, roads and parking lots etc.), water (including, ponds, lagoons, marsh and wetlands),vegetation (including park, open field, reserved areas, urban farm and other vegetated surfaces) and open surface (including undeveloped urban space) were created. The reference training sites for each land cover type was collected in order to generate training signatures. Training sites for each cover class were delimited by means of visual interpretation of true and false colour composites of Landsat imageries, multi-temporal very high-resolution imagery available through Google Earth, Lagos Island boundary map for the year 2000 and direct observations from the field.

The “confusion matrix” and “Kappa Statistics (coefficients)” were calculated to evaluate the classification procedures and the accuracies of the derived classified land cover maps. Kappa statistic considers a measure of the overall accuracy of image classification and individual category accuracy as a means of an actual agreement between classification and observation. The value of Kappa lies between 0 and 1, where 0 represents agreement due to chance only, 1 represents the complete agreement between the two data sets (Ismail and Josef, 2008). The overall accuracy of the classifications for the three images were 79.5% (1984), 78.4% (2000) and 84.6% (2015), with a standard deviation of $\pm$10.3 per cent. The Kappa statistics value of 0.72, 0.82 and 0.86 were obtained respectively for the three images. Figure 4.4 to 4.6 was the derived classified images/maps of Lagos Island. These were transformed into “shape files” and brought into ArcMap 10.3 for more detailed analysis.

4.4.2.2 Change detection

Change detection is an important process in the analysis of urban growth. It involves a comparison of sequential land-cover maps of an area derived from remote-sensing data or other sources (Lambin, 1997), calculation and analysis of the area of each land cover class (in this case built-up, vegetation, water and open surfaces). Estimates of land cover/land use change and change rates for Lagos Island was derived using descriptive statistics (frequency and summary statistics) in ArcMap 10.3. The result is presented in table 4.14.

For the three years (1984, 2000 and 2015), the built-up category dominates the land cover. In 1984 it accounted for about 70% of the land cover (2.93 km^2), by 2000 it increased to 84.36% (4.04 km^2), but decreased to 81.77% (4.4km^2) in 2015 due to the expansion of the Island in the northwestern corner. Open surface increased from 0.26km^2 (6.22%) in 1984, 0.31 km^2 (6.54%) in the year 2000 and 0.5km^2 (9.3%) in 2015. The overall spatial change in the total urban land areas from 1984 to 2015 for Lagos Island was 22.3%, indicating 1.2 km^2 of 5.39 km^2 land area (see table 4.11). However, this overall change masks the variability in changes among various feature classes. To take care of this, Loveland and Acevedo (2016) recommended that both net and gross change statistics should be taken into account when considering land change amounts.

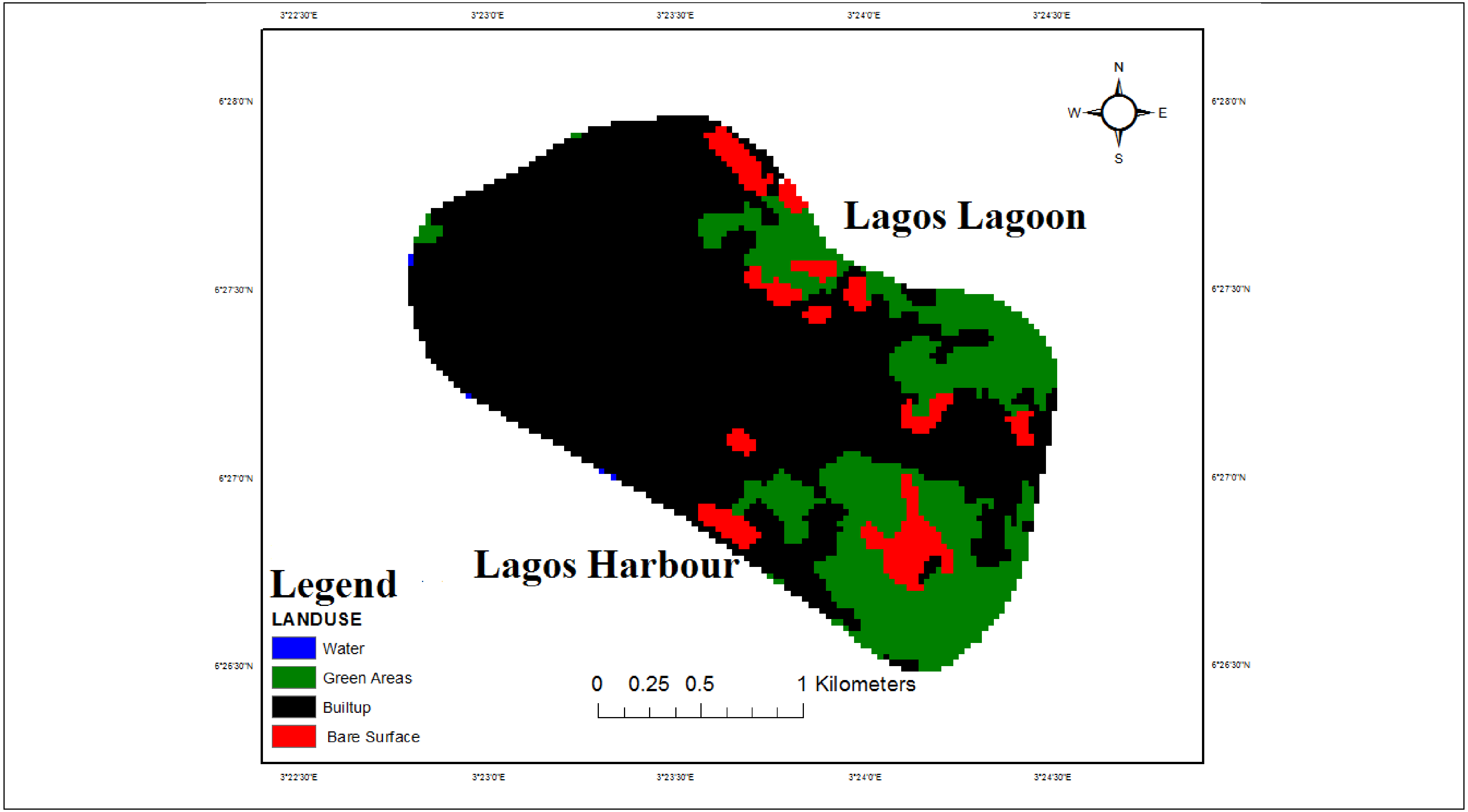


Fig. 4.4. Classified Landsat imageries of Lagos Island, 1984
Source: Author's GIS analysis.

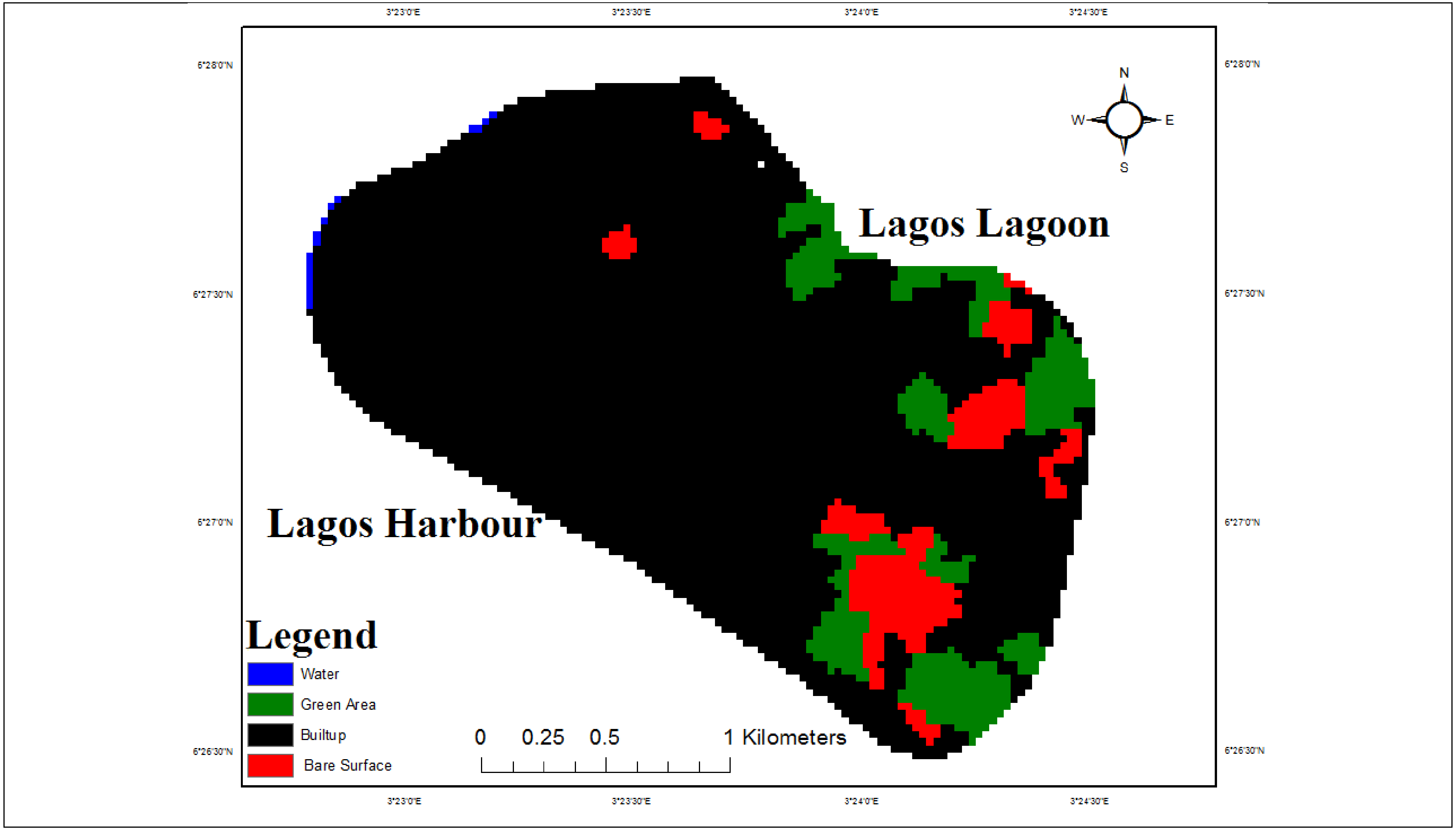


Fig. 4.5. Classified Landsat imageries of Lagos Island, 2000
Source: Author's GIS analysis.

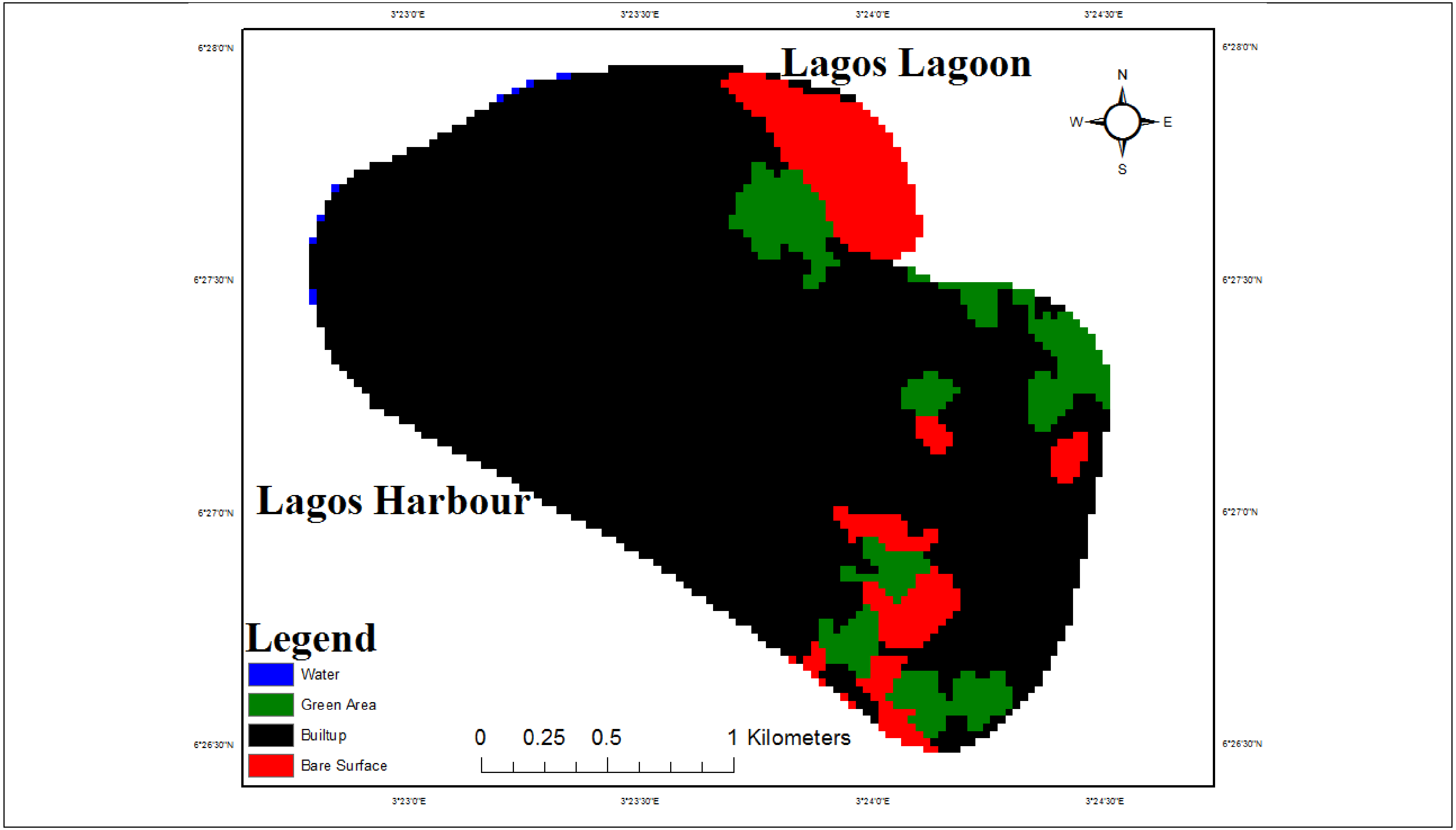


Fig. 4.6. Classified Landsat imageries of Lagos Island, 2015
Source: Author's GIS analysis.

Table 4.14. Land Cover change statistics for Lagos Island

Feature Class	1984		2000		2015		1984-2000	2000-2015	1984-2015		
	Area in km^2	% of Total	Area in km^2	% of Total	Area in km^2	% of Total	Gains/ Losses	Gains/ Losses (%)	Net Change ($\pm km^2$)	Gross Change (km^2)	Rate of Change
Built-up	2.93	69.98	4.04	84.36	4.41	81.8	1.11	0.34	0.77	1.45	1.63
Open Surface	0.26	6.22	0.31	6.54	0.5	9.3	0.05	0.19	0.14	0.24	2.98
Vegetation	0.99	23.73	0.42	8.75	0.46	8.59	-0.57	0.04	0.61	-0.53	-1.73
Water bodies	0.003	0.07	0.02	0.35	0.02	0.34	0.02	0.00	0.02	0.02	18.3

Source: Author’s analysis, 2018.

The net change in a given land cover category results from the gains and losses in a particular cover type between two periods, it represents the differences in the gain and losses of a particular land cover type between specific points in time. Gains represent the amount of areas that convert into given classes between two dates, irrespective of the amount of areas lost, Losses represent the amount of areas that convert out of given classes between two dates, irrespective of the amount of areas gained.

Gross change represents the total areas modified between two periods or the sum of all gains and losses in a class, between two dates. It provides a clear indication of the overall amount of change activity that affected specific land cover sectors and clear evidence of the overall amount of land change experienced rather than the actual availability of specific land cover (Loveland and Acevedo, 2016, Sleeter, et al., 2012).

Table 4.14 shows net change and gross change in land cover classes. The rate of change in different land cover classes was also presented. Of all the four land cover classes identified in Lagos Island, the built-up category changed most with about an increase of 1.5 km^2. This indicates that about 27.5 per cent of the total land area of Lagos Island experienced a conversion either to or from built-up land cover class. A value of ±0.77 km^2 for net changes in the built-up class indicate that about 13.7% of the Land area of Lagos Island is converted from built-up category to other uses or added due to land expansion for other purposes.

For the built-up category, the rate of change is 1.63% for the period under consideration. A Gross change of ±0.24 km^2 in open surface class, with a net change of 0.14 km^2 and the rate of change of 2.98% may be attributed to the ongoing expansion process in the northwestern corner of Lagos Island at Ilubinrin. The vegetation class is the most negatively affected. It experienced a decline of about 0.53km^2 in its size, with a net change of 0.61 km^2. The net change experience in vegetation class can be attributed to the urban renewal efforts of state government and reclamation processes going on the Island. The water class has a gross change of 0.02 km^2, with a net change of ±0.02 km^2. It has the highest rate of change (18.3%). Gross changes noticed in water class (0.02 km^2), with a net change of ±0.02 km^2 though very small, suggests that about 0.4% of Lagos Island areas convert to or from water class either through the process of coastal erosion or sand filling for reclamation exercise. This indicates the need to pay closer attention to environmental changes in Lagos Island, in order to forestall future negative environmental occurrences that can bring untold damages to human lives and properties.

Data in table 4.14 mask variability in both net and gross changes and rate of change in various spatial units that made up Lagos Island. Figure 4.7, 4.8 and 4.9 showed the net and gross changes and the rate of change in built-up class in various wards that made up Lagos Island. Both net and gross change and rate of change are highest in ward C1, but no changes were observed in ward B2 and B3.

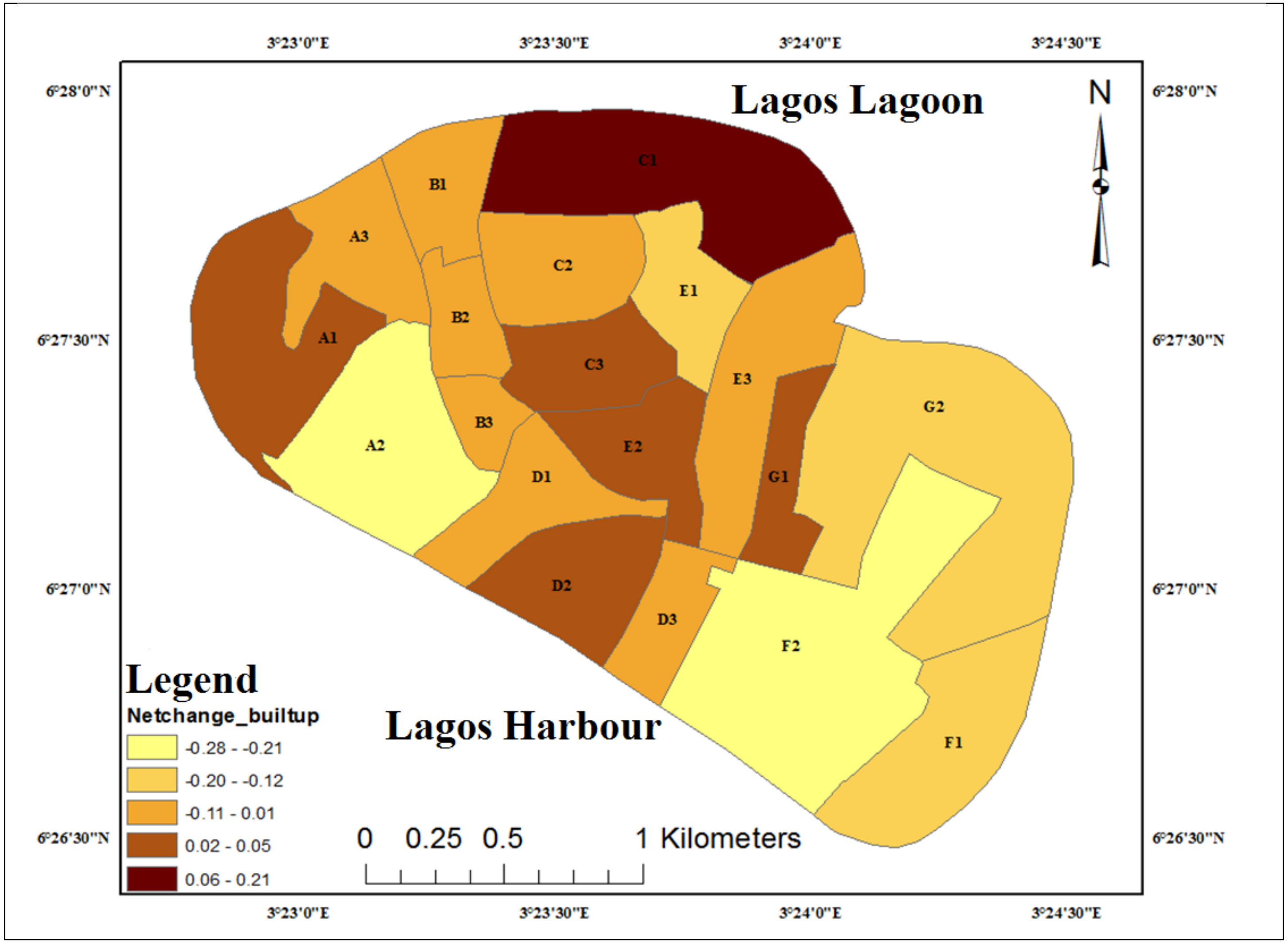


Fig. 4.7. Net change in built-up area by ward
Source: Author's analysis, 2018

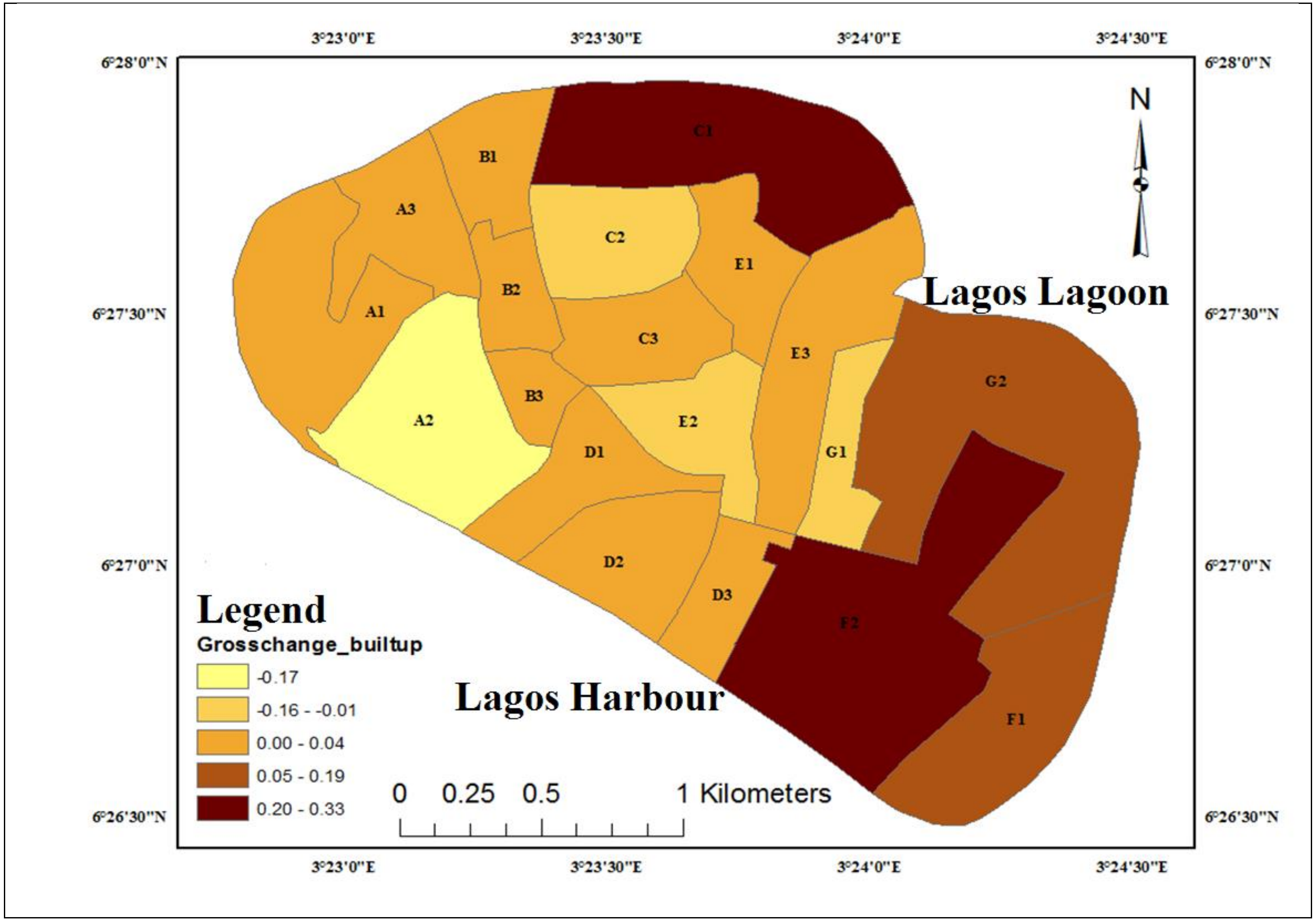


Fig. 4.8. Gross change in built-up area by ward
Source: Author's analysis, 2018.

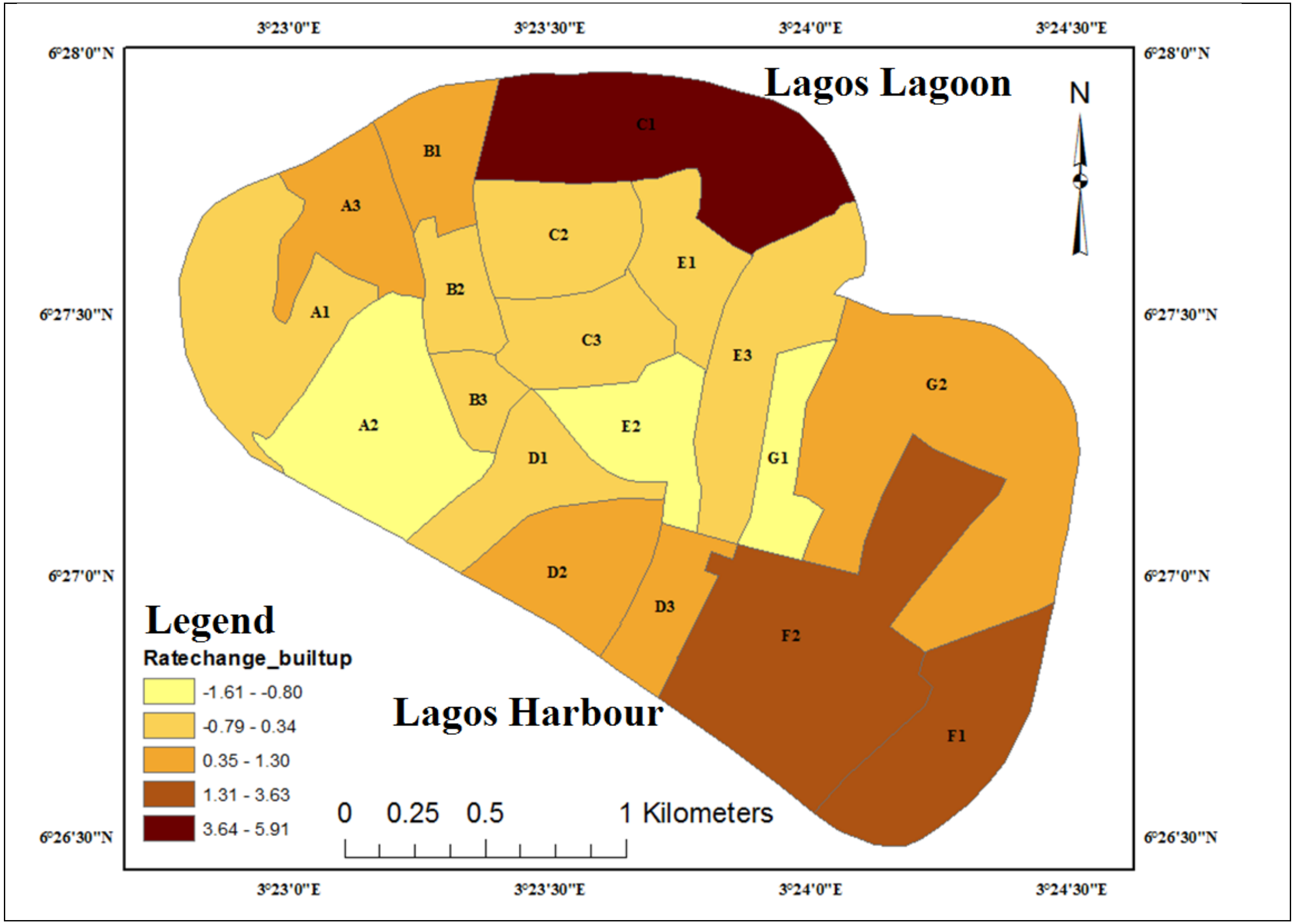


Fig. 4.9. Rate of change in built-up area by ward
Source: Author's analysis, 2018

The changes, observed in ward C1 is principally due to reclamation and development that is ongoing in Ilubinrin. A negative change in net values for the built-up class was obtained for ward A2, A3, D1, D3, E1, E3, F1, F2 and ward G2. Similarly, negative values were obtained for gross changes in built-up class for ward A2, C2, E2 and G1. Rate of change is lowest in ward C2. The implication of this is that the intensity and rate of change in built-up areas vary across wards. The result presented in figure 4.7 to 4.9 is invaluable for monitoring the development process in Lagos Island. It affords planners and decision makers to focus on specific spatial units that require spatial interventions. In wards where intensity and rate of development are high, there is the need for new development control plan and implementation strategies that will ensure safe habitation.

4.3 Analysis of the urban morphology of Lagos Island (1984-2015)

Morphological analysis of urban areas involves the examination of changes and trends in urban spatial structure in time and space, particularly from the perspectives of the classical theories of urban land use. The classical theories viewed urban morphology from a primarily static viewpoint. Analysis from this perspective depended heavily on socio-economic data; as a result, they are inadequate in analyzing the very complex urban spatial evolution (Cheng, 2003). The morphological analysis of the spatial structure of Lagos Island proceeded in two levels. First, the land use structure of the Island is described from the urban classical theories perspectives and a map of land use pattern was developed. Second a more spatially depended method called the method of clusters of urban built-up pixels from remote sensing data was used in evaluating changes in the spatial structure of Lagos Island.

4.3.1 Measuring Temporal changes in the urban spatial structure

The research examined temporal changes in the spatial structure of Lagos Island from 1984 to 2015 using R^2 statistics. Hackwort (2013) had demonstrated that rent, income, housing value and population distance gradient could provide deep insight into the structure of cities. He showed that an R-square value of 0 in a distance gradient scatterplot would suggest complete statistical randomness, whereas a value of 1 would imply that the type of the trend line used in the distance gradient plot explains all variability in the city. He stated that multinodality tends to register high r-square value when represented by polynomial lines (Hackwort, 2013: 85). Given this backdrop, R^2 statistics was used to measure temporal changes in the spatial structure of Lagos Island.

Figure 4.10 presents a graphical plot of the relationship between distance and land value using a polynomial function of the second degree. The plot produced an r-square value of 0.65. The result indicates greater variability in the absolute location of land value. It showed that distance account for about 60 per cent of the variation in land value. It also suggests that the structure of the city is polycentric. The polynomial function obtained for the distance-land value relationship is similar to Stewart (1947) postulation of a lineal relationship between density and distance in which density-distance function take the form of;

$$D(x) = D_o + bx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5.3),$$

and Newling (1971) possibilities of an intrinsically lineal functional form of urban density through a polynomial function in the form of;

$$D(x) = D_o + bx + cx^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (5.4).}$$

with $D_o > 0$, $b \neq 0$ and $c < 0$.

Both equation 5.3 and 5.4 supports Clark (1951) second assumption on urban density that states that in most cities, as time passes, density decreases in the central areas and increases in the suburbs, thus producing a territorial expansion of the city and emergence of new centres (Martori and Surinach, 2001).

Polycentricity in Lagos Island in respect of land market is not impossible, given the fact that land values in major urban centres of Nigeria vary due to the influence of market forces of supply and demand that govern availability, accessibility and affordability of land and housing. Therefore, it can be concluded that land value is one of the major factor influencing the spatial expansion of cities, particularly Lagos Island. However, relying on land value data alone to explain the structure of Lagos Island may not be very safe. This is because the land market is not regulated in Nigeria; hence, there is a possibility of volatility in values within the city. To ascertain the true form of Lagos Island, graphical plots of the distance-density gradient for population density using quadratic polynomial functions were obtained for the year 1984, 2000 and 2015. This provided the opportunity to quantify the city form and to examine the spatial dynamics of the urban form.

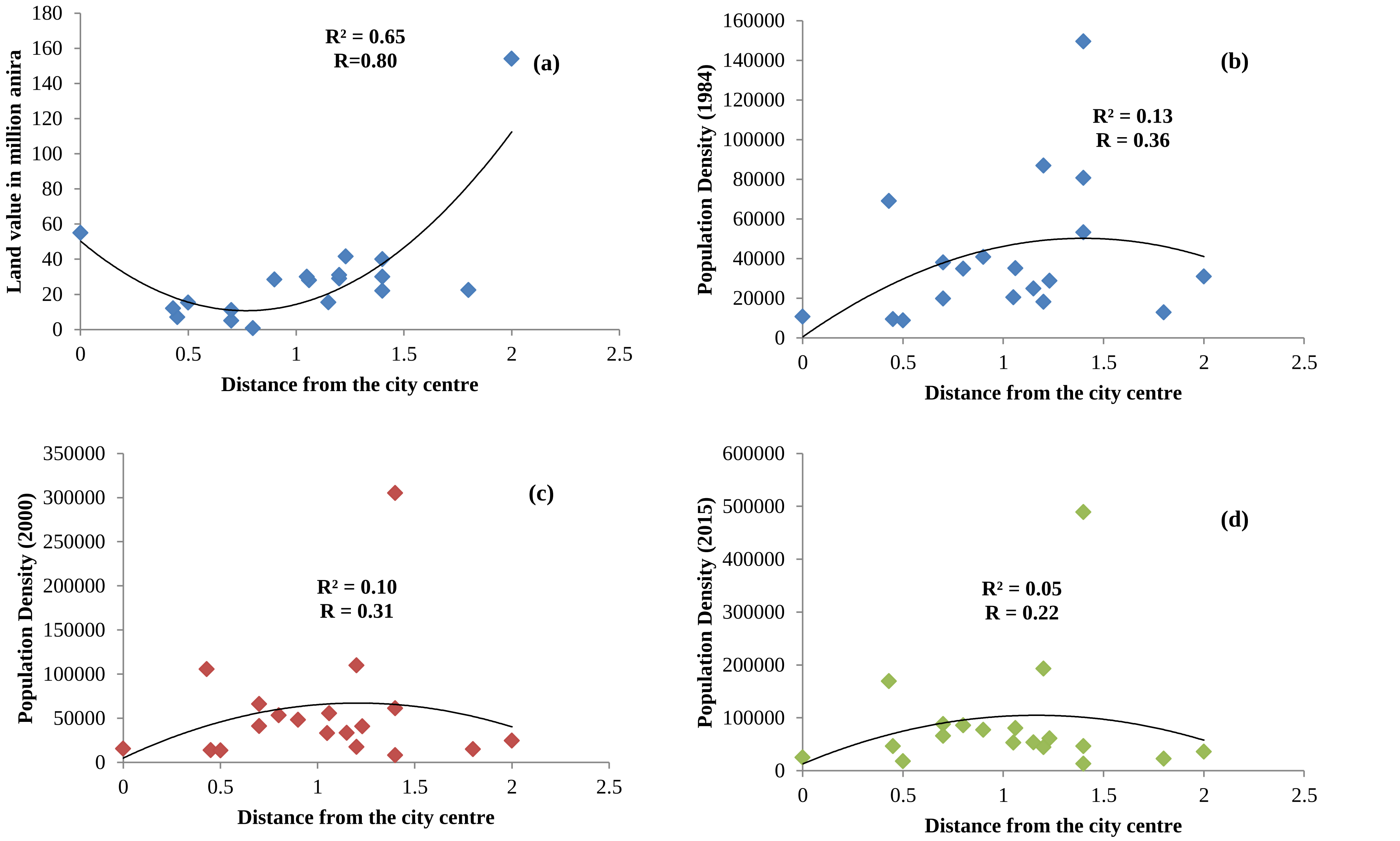


Fig. 4.10. Land value and Population density gradient in Lagos Island
Source: Author's analysis, 2018

From the perspective of multi-nuclei theory, two major centres can be identified in Lagos Island. The first is the commercial land use zone at the southwestern edge through the southeastern corner of the Island, known as the Lagos Island Central Business District (LICBD) as shown in plate 4.2. The second is the traditional core of Lagos Island, comprising the area behind the LICBD, similar to what Burgess (1925) referred to as the zone in transition. The traditional core is the main traditional residential zone of Lagos Island. A new wave of invasion is currently taking place in areas around the Tafawa Balewa Square. The area officially designated for public use is being currently reinvented into a shopping complex, thus becoming another major nucleus in Lagos Island. Similarly, Onikan is gradually becoming a commercial complex.

The polynomial functions obtained in figure 4.10b-d give R^2 values of 0.13, 0.1, 0.05 for 1984, 2000 and 2015 respectively. The plots suggest that Lagos Island is a dense area without an extremely dense core. The R-square value for 1984 in figure 4.10b suggests a tendency towards variability rather than randomness, thereby indicating the element of polycentricity. However, the decreasing low r-square values for the later years (2000 and 2015) showed that there is randomness in the absolute location of high-population density zones, indicating discontiguous urban form and expansion of urban space. As observed by Rodriguez-Bachiller (1986), "physical discontiguity can result from a multinucleated pattern of employment-points, either as a generalization of the two-worker household extension of the basic microeconomic model or as a derivation of classical Central Place Theory and a trend towards a more balanced (lognormal) distribution of nuclei". Discontiguity in urban growth had been associated with cities under fast urbanisation particularly in developing countries (Rodriguez-Bachiller, 1986).

Results in figure 4.10b-d lend credence to Clark (1951) general hypothesis. That in all cities, excluding a business and commercial area, there are densely populated areas. which decrease when moving away from the centre (a negative density function) but as time passes density decreases in the central areas and increases in the suburbs, thus producing a territorial expansion of the city (Martori and Surinach, 2001).

Plate 4.2. Lagos Island Central Business District

Source: Lagos State Ministry of Physical Planning and Urban Development

One-way analysis of variance in population density across the ward from the centre of the city gives an F value of ~0.2 not significant at 5% level. Spatial autocorrelation analysis of the spatial pattern of population density for Lagos Island showed a random pattern with Moran's I values of 0.03 for 2015, 0.02 for 2000 and -0.04 for 1984 at $P > 0.05$. The random patterns observed suggest a widely spread population density across space. That population density spread across space is an indication that Lagos Island is spreading out in its physical extent, yet because of its geographic constraint, it maintains a compact spatial morphology. Therefore, the growth process in Lagos Island may be concluded to be a process of leapfrogging. The growth does not follow a low-density discontiguous process, rather a high-density sprawling process similar to what Fulton, et al. (2001) called "dense sprawl".

4.3.2 Evaluating the structure of Lagos Island using the classification of built-up pixels

The earlier attempts at understanding and quantifying the spatial structure of the city is through a statistical approach that is heavily dependent on socio-economic variables. Principally, data on rent, income, density and distance are heavily relied upon. While this approach gave a useful insight into population distribution, location of economic activities and households, yet there is the need for a more spatially dependent method that can reveal the spatial and temporal dimensions of urban spatial structure. A relatively new way of understanding and analysing urban spatial structure is to consider the classifications of built up pixels as revealed by land cover/land use map of the city (Angel et al., 2005).

Using the classified land cover/land use maps of Lagos Island presented in figure 4.6, 4.7 and 4.8, a three order cluster of urban built-up pixels was developed. It was believed that if there were no centres at all, there would be no contiguous clusters of built-up pixels that are larger than, a 10-block area (about 10 hectares) (Angel, et al., 2005). The distributions of the cluster sizes of different orders of magnitude for Lagos Island both in space and time is presented in table 4.15. The first-order cluster has a cluster size class of 50 to 100+ hectares; the second has a cluster size of 10 to 49 hectares (second order) and the third less than 9 hectares (third order). In 1984, 21% of the land area of Lagos Island was fragmented. This reduced to 10.5 per cent in the year 2000 and 2015 respectively. In 1984 and 2000 10.5% and 5.3% of the built-up areas are in the first-order (highest) cluster and 68.4% and 84.2% are in the second-order cluster class, indicating the presence of centres and sub-centres (polycentricity).

Table 4.15. The distribution of the built-up area among clusters of different Size

Cluster Size Class (Hectares)			**1984**		**2000**		**2015**	
Class	**From**	**To**	**Units**	**%**	**Units**	**%**	**Units**	**%**
3	1	9	4	21.1	2	10.5	2	10.5
2	10	49	13	68.4	16	84.2	17	89.5
1	50	100+	2	10.5	1	5.3	0	0
Total			19	100	19	100	19	100

Source: Derived after Angel et al., (2005) The absence of the first-order cluster class in 2015 and about 10.5% of the area not clustered suggest a shift to mono-centricity. Advantages of using the classifications of built-up pixels in the city to measure urban spatial structure are many. First, it can help in observing the differences in the urban spatial structure of the city in time and space. Secondly, it can help in developing other measures for describing the spatial structure of the city. For example, contiguity index and compactness index can be developed and calculated from the classification of built-up pixels for different periods to describe the geometrical form of the city.

4. 6 Conclusion

A major highlight of chapter four is that population increases with increase in population density and built up area of Lagos Island. Important determinants of population change in Lagos Island are found to be demography, industrialization (essentially small-scale industries), urban growth, transportation accessibility and livability. Number of households contributed significantly to the urban growth process in Lagos Island, as there is a significant positive relationship between numbers of household, sizes of built-up area and urban land areas for the period of 1984-2015. Spatiotemporal analysis of urban growth in Lagos Island indicated a significant variation in the spatial expansion of Lagos Island between 1984 and 2015. The observed variation was related to increasing demand for space, both for residential and commercial activities. Built up category of the derived land cover classes, dominated the urban landscape. The spatial structure of the Island follows a monocentric pattern.

Result and discussion in chapter four established the fact that significant growth processes are ongoing in Lagos Island. These processes are accompanied by various planning challenges that the traditional top-down city planning approach being practiced in the past had proved insufficient. Sustainable planning interventions to manage and monitor the processes of growth in this iconic area are necessary and required. Lagos Island is a major core with lots of investment opportunities. There is the need for strategies to transform Lagos Island into a twenty-first-century business precinct comparable to other core of the major cities of the world. To this effect, a balanced approach to planning that involved a democratised and inclusive citizen engagement combined with a more centralized planning effort is needed in managing and making Lagos Island a healthy, liveable, environmentally friendly and rich area.

CHAPTER FIVE

MEASURING THE COMPLEXITY OF URBAN GROWTH IN LAGOS ISLAND

5. 1 Introduction

In the last chapter, population change and urban growth in Lagos Island were evaluated. The physical extent and form of the city were analysed from land cover dynamics, however, dynamical processes of growth in the city were not emphasized. The subject of this chapter is to measure and examine the complexity of urban growth. The issue of complexity had been extensively discussed in chapter two of this thesis. It refers to the higher-order phenomena produced because of interaction between various connected system's subcomponents. Complexity describes both the dynamics (i.e., processes) and the structure (i.e., patterns and configurations) of a particular system (Batty 2005 and Boeing, 2018). The structure of a city relates to its physical pattern or form. This also relates to the discernible regularity observed in the city landscape. Regularity in space defines the complexity of the city landscape.

The physical pattern of cities is a product of dynamical processes, which are the sequences of actions producing a change in the state of a system. Change in space is a spatial process and in time a temporal process. Therefore, the spatial process may be conceived as the operation of the temporal process in a spatial context (Harvey, 1968). Process herein does not refer to the socio-economic processes, which are regarded as the main drivers of urban spatial and functional growth.

Chapter six proceeds in two levels; first, the examination of the pattern of distribution of urban growth in Lagos Island was considered and thereafter the analysis of the dynamical patterns and processes of urban growth in Lagos Island using spatial metrics. These metrics provide an opportunity to measure and explain the dynamics of urban growth and its complexity.

5. 2 The spatial distribution of urban growth in Lagos Island

There are many methods for assessing the spatial patterns of urban growth. However, most popularly used are the spatial auto-correlation methods. The application of the spatial autocorrelation methods is relatively recent in urban analysis. However, their uses are based on the hypothesis that urban growth and decline are spatially conditioned processes, of which the outcome at one location is partially affected by events at other locations (Pàez and Scott, 2004). The most widely used among spatial autocorrelation methods are; Moran's I including Anselin's LISA (Local Indicator of Spatial Autocorrelation), Geary's C, and the Getis and Ord family of G_i *(d)* statistics (Getis and Ord, 1993; Ord and Getis, 1995, 2001). These statistics measured the spatial weights matrix that reflects the intensity of the geographic relationship between observations in a neighbourhood. They also compared the spatial weights to the covariance relationship at pairs of locations.

Empirical investigations have demonstrated that Moran's I statistics can be used in the analysis of the spatial pattern of urban growth (Fan and Myint, 2014; Li et al., 2017; Malpezi and Guo, 2001; Musakwa and Niekerk, 2014 and Tsai, 2005). Moran's I provide an opportunity to evaluate the level of compactness in urban growth. A positive Moran's index (I = +1) indicates spatial clustering of values across geographic space; while the significant negative index (I= -1) indicates a random or dispersed pattern.

Since the important objective of this study is to determine urban growth pattern in Lagos Island, spatial pattern analysis of urban growth was achieved following two integrated levels. First, using ArcMap 10.3, the total built-up pixels in each ward were calculated and mapped. The average pixel size was 28.41m × 28.41m. Then the hypothesis that states that 'there is no statistically significant spatial clustering of built up pixels in Lagos Island' was tested by Moran's I statistics (Global and Local Moran's I), using row-standardized weights matrix with the spatial statistics tool in ArcMap. The global Moran index states;

$$I = \frac{n}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j wij\ (x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x}\,)^2}$$

$$= \frac{n}{\sum_i \sum_j w_{ij}} \frac{\sum \sum w_{ij} \hat{x}_i \hat{x}_j}{\sum_i \hat{x}_i^{\,2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.1)}$$

where $\bar{x}$ is the mean of variable vector x, $\hat{x}_{i,j}$ are deviations from the mean and w_{ij} are the elements of a spatial lag operator (**W**) standardized by measures of total variation ($\sum_i \hat{x}_i^{\,2}$) and connectivity in the system ($\sum_i \sum_j w_{ij}$) (P´aez and Scott, 2004). The Anselin local Moran statistics (Anselin, 1995) for an observation is given as;

$$I_i = z_i \sum_j w_{ij}\, z_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5.2)$$

where, analogous to the global Moran's I, the observation $z_{i,} z_j$ are in deviations from the mean, and the summation over j is such that only neighbouring values $j \in J_i$ are included, the weights w_{ij} may be in row-standardized form and by convention is equal to 0 (Anselin, 1995). Four patterns of local spatial association are observable;

1) High-high association- when the value of x_i is above the mean and the values of x_j at 'neighbouring' zones as in equation 5.1 (i.e.,$\sum_j w_{ij}\, \hat{x}_j$) are generally above the mean, the statistic is positive;
2) Low-low association- when both values are below the mean, the statistic is positive;
3) High-low association- when the value at $\boldsymbol{i}$ is above the mean and the values at neighbouring zones are, in general, below the mean, this gives a negative $\boldsymbol{I_i}$; and
4) Low-high association- when the value at $\boldsymbol{i}$ is below the mean and the weighted average is above the mean, $\boldsymbol{I_i}$ is negative (P´aez and Scott, 2004).

Equation 5.1 is global in the sense that the overall pattern in the data is summarized into a single value indicating different spatial relationships for a given subset of data, but 5.2 is local because it measures the correlation between the value for a given area and that for its neighbours.

The values of I obtained for the respective years under consideration (1984, 2000 and 2015) were shown in Table 5.1 together with their associated Z- scores and the P-values. Given I = 0.29 (Z = 1.76), significant at p > 0.05 in 1984, there is a less than 10% likelihood that the clustered pattern of the built-up cluster could be the result of random chance. However, given I = 0.53 (Z = 3.08), significant at p ≤ 0.05 in 2000, and I = 0.39 (Z = 2.22), significant at $p \leq 0.05$, in 2015, the results showed that there is significant spatial clustering of built-up pixels in the landscape. This is an indication of a clustered pattern of urban growth. The clustered urban landscape is a higher-order phenomenon produced as a result of self-organisation.

Table 5.1. Global Moran's Index for Lagos Island (1984-2015)

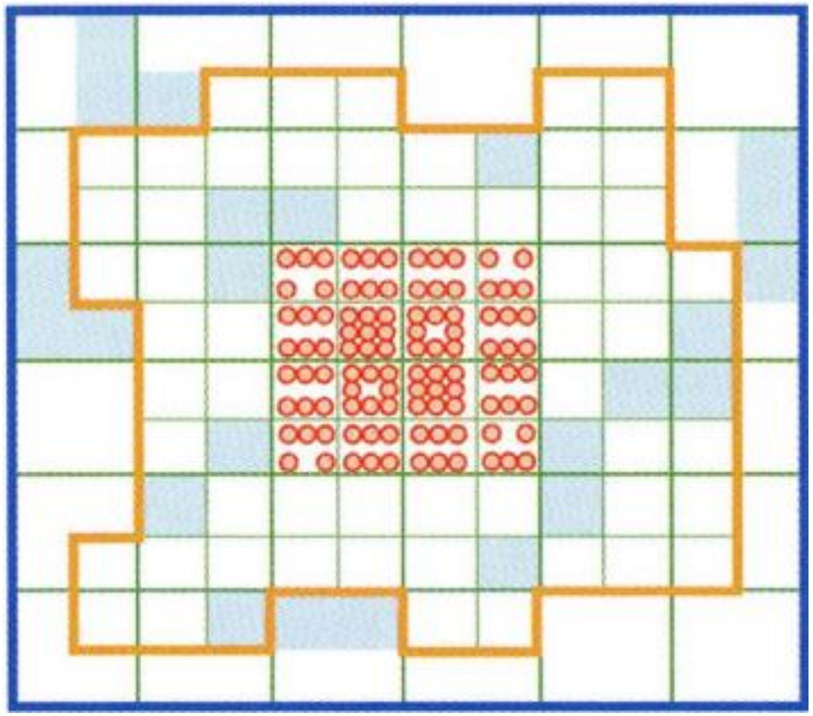
Year	Moran's Index	Expected index	Variance	Z-Score	P-Value
2015	0.28	-0.06	0.039	2.22	0.026
2000	0.53	-0.06	0.036	3.08	0.002
1984	0.29	-0.06	0.038	1.76	0.077

Source: Author's analysis

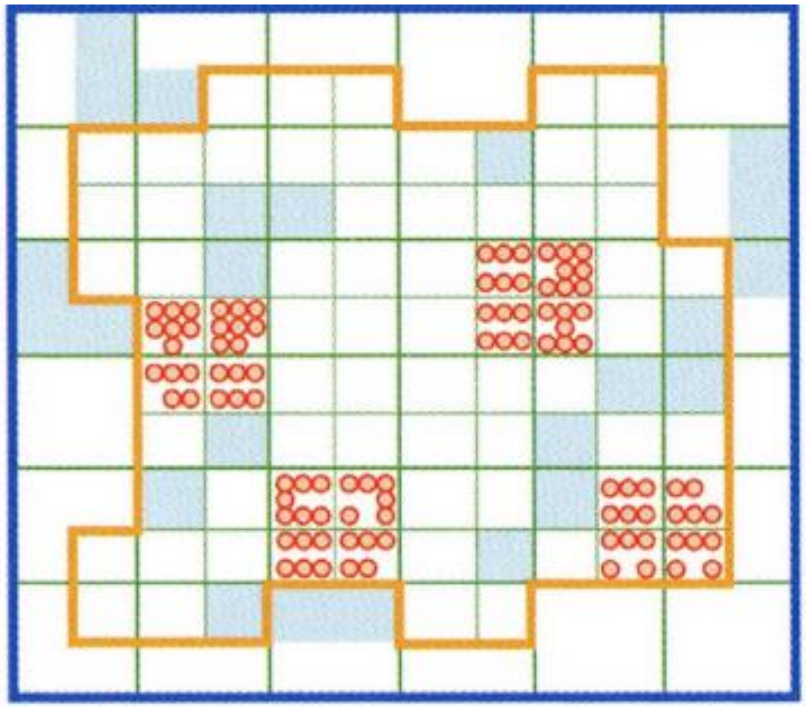
A clustered urban growth pattern symbolises an urban growth type that is neither linear nor dispersed. It is a compact and dense development that may be related to an infill process (a process where development of remaining small lots sets in after a city has reached the peak of its spatial development) or leapfrogging (a discontiguous process associated with urban clusters). Two possible clustered pattern of urban growth are presented in Figure 5.1. Figure 5.1a presented a monocentric compact development that results because of an infill process. A polynucleated development that results due to the formation of several urban clusters through discontiguous growth is presented in figure 5.1b.

Considering the results in table 5.1 in relation to figure 5.1, it is obvious that there has been spatial clustering of development in Lagos Island. This development suggests a non-spontaneous, but rather a self-organised process characteristic of a complex system, adopted intuitively to minimize the amount of land in each square meter of developable land occupied by residential or non-residential uses. This established the fact that urban growth system undergoes the self-organisation process (Allen, 1997b). It also corroborates Cheng (2003), Salvati, and Carlucci (2014) who noted that the spatial clustering of urban development is a self-organizing process characteristic of orderly and efficient land use in a complex urban system.

The built-up parcels in Lagos Island for 1984, 2000 and 2015 are presented in figure 5.2. A detailed examination of the figure showed that first, there was a spatial clustering of urban built-up parcels. The clustered pattern resulted from the coalescence of neighbouring clusters of built-up parcels. This development constitutes a serious planning challenge, particularly in the areas of infrastructural and service provision, management and maintenance. Second, the built landscape was perforated with some undeveloped land parcels that become a potential platform for leapfrogging in urban development. Three degraded built up pixels could be noticed at the southeastern tip of Lagos Island in the year 2000. Degradation of built-up pixels may be a product of planning and policy intervention of the government towards the regeneration of Lagos Island. The result in table 5.1 shows that Moran’s index for Lagos Island increased by 83% between 1984 and 2000, but decreased by 47% between the year 2000 and 2015, an indication that urban growth was more contiguous between 1984 and 2000 than between 2000 and 2015. These changes in the pattern of growth may be explained by the process of expansion at the fringe area through the process of sand filling for land reclamation.



(a)Compact Development (Concentric zone, sector models)



(b)Polynucleated Development (Multi-nuclei model)

Fig. 5.1. Clustered urban growth pattern
Source: Galster et al, 2001

Fig. 5.2. Coalesced urban built-up parcels in Lagos Island

Source: Author’s analysis, 2018

The results in table 5.1 obscured the growth pattern at local levels. As a result, a cluster outlier analysis of urban growth pattern was conducted using Anselin's Local Moran's I. The results were presented in table 5.2. For each observation, (I_i) evidence of significant spatial clustering of dissimilar values of urban built-up pixels (High-low association) at local levels was observed. The results showed that ward A2 with $I_i = -1.11, \text{significant at } p \leq 0.05$ has a high spatial clustering of built up pixels and is surrounded primarily by wards with a low number of built-up pixels. However, in 2000 and 2015 the location of the outlier changed to Ward G2 with the value of $I_i = -2.06, \text{at } p = 0.03$ in 2000 and $I_i = -2.20 \text{ at } p = 0.02$ in 2015. Results in table 5.2 showed evidence of spatial heterogeneity in the distribution of urban growth in Lagos Island. The results presented in Table 5.2 produced a number of spatial autocorrelation maps called LISA cluster maps for Lagos Island presented in figure 5.3. The maps showed the location of high-low spatial clustering of built-up pixels.

Graphical plots of the relationship between distance from the city centre and the Local Moran's Indexes for the built-up class for each year were presented in figure 5.4a-c. The figures enable a deeper understanding of the dynamics of urban growth in Lagos Island. Declining values of R^2 from 0.34 in 1984 to 0.20 in 2015 and low positive autocorrelation values observed closed to the city centre indicated a mono-centric structure, moderately altered by fragmentation of the landscape. It also indicates the diffusion of urban development through the process of land expansion at the fringe of the Island. The results showed that urban growth in Lagos Island is a product of self-organisation, an indication of complexity in the structure of the landscape of Lagos Island.

The application of Moran's I statistics to the analysis of urban growth pattern provides a good opportunity to measure and explain compactness or nuclearity in urban growth. However, an inherent problem associated with the technique is that it is difficult to determine the specific dynamical processes influencing urban growth pattern. In the next section, attention is focused on the quantitative description of urban growth patterns and processes using spatial metrics. Spatial metrics are potent tools in determining the specific spatial and temporal complexity inherent in urban growth. They are useful tools in understanding the urban structure and developing measures for urban planning and design.

Table 5.2. Urban growth patterns at local levels (wards) in Lagos Island

Ward	1984			2000			2015		
	I_i	ZI_i	P_v	I_i	ZI_i	P_v	I_i	ZI_i	P_v
A1	0.34	0.41	0.68	-0.15	-0.11	0.91	-0.20	-0.16	0.88
A2	-1.11	-1.96	0.05*	-1.01	-1.88	0.06	-1.04	-1.90	0.06
A3	0.04	0.19	0.85	0.01	0.14	0.89	0.04	0.18	0.86
B1	0.02	0.17	0.86	0.11	0.39	0.70	0.26	0.61	0.54
B2	-0.05	0.03	0.98	0.16	0.67	0.51	0.28	1.00	0.32
B3	-0.43	-0.85	0.40	-0.19	-0.33	0.74	0.11	0.37	0.71
C1	-0.01	0.07	0.94	-0.09	-0.05	0.96	-0.17	-0.17	0.86
C2	-0.02	0.10	0.92	0.02	0.22	0.83	0.07	0.32	0.75
C3	-0.06	-0.01	1.00	0.11	0.45	0.65	0.26	0.85	0.39
D1	-0.02	0.09	0.93	-0.01	0.12	0.91	0.05	0.25	0.80
D2	-0.19	-0.25	0.80	-0.04	0.03	0.97	0.01	0.13	0.90
D3	-0.32	-0.27	0.79	-0.12	-0.07	0.94	0.02	0.08	0.93
E1	-0.02	0.06	0.95	0.01	0.12	0.90	0.06	0.26	0.79
E2	0.00	0.15	0.88	0.02	0.19	0.85	0.10	0.43	0.67
E3	0.07	0.23	0.82	-0.05	0.02	0.99	0.02	0.14	0.89
F1	-1.16	-1.15	0.25	-0.32	-0.30	0.77	-0.02	0.03	0.97
F2	-1.16	-1.15	0.25	-0.32	-0.30	0.77	-0.02	0.03	0.97
G1	-0.04	0.03	0.98	-0.52	-0.89	0.37	-0.52	-0.89	0.37
G2	-0.96	-0.94	0.35	-2.06	-2.23	0.03*	-2.20	-2.31	0.02*

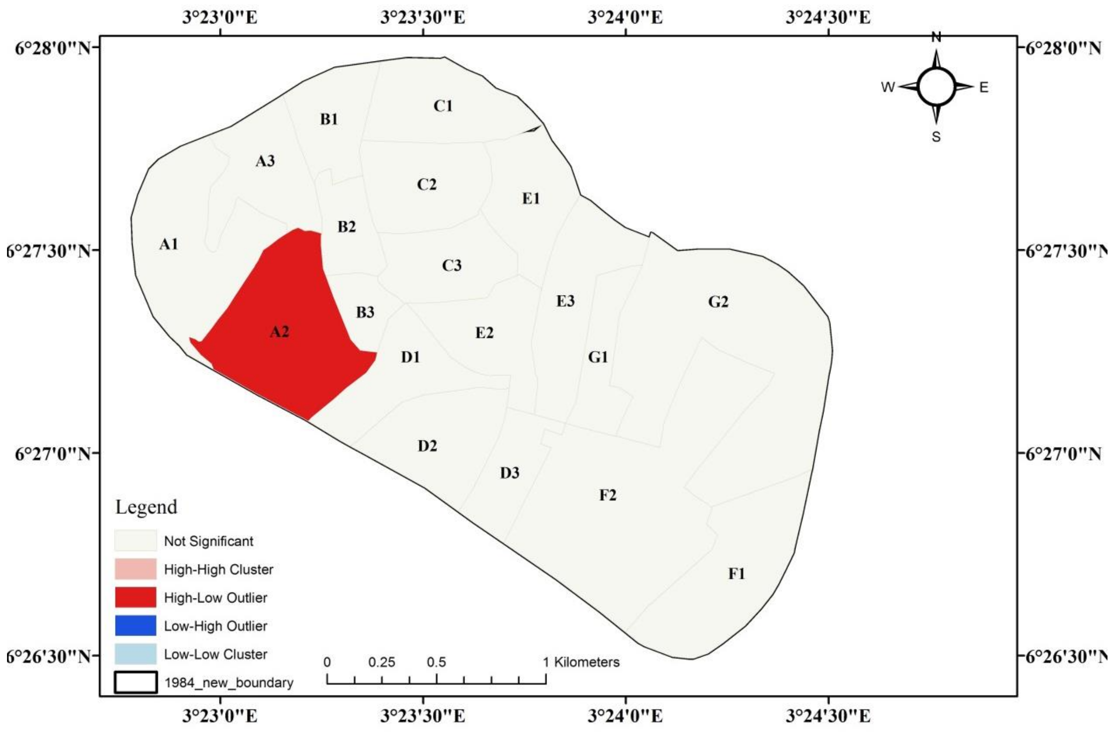
Source: Author's analysis, 2018

Note:

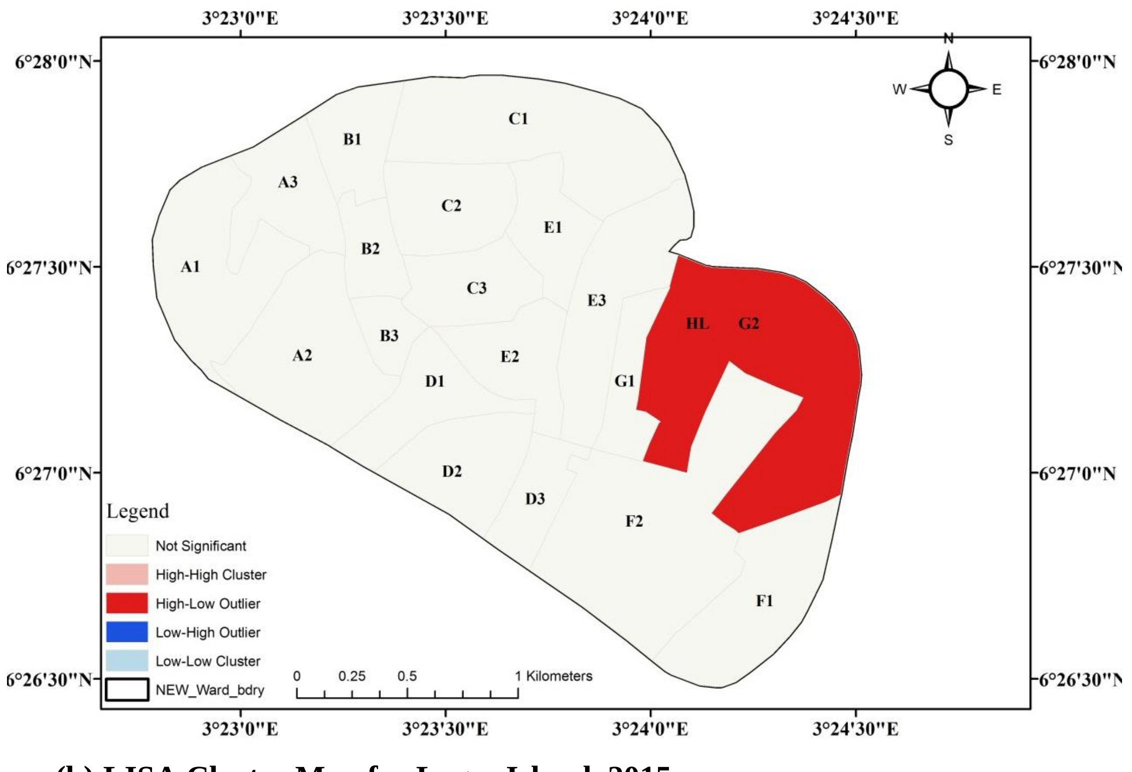
I_i = Moran's Index

ZI_i = Z score.

P_v = P value (Significance level at 0.05 percent)

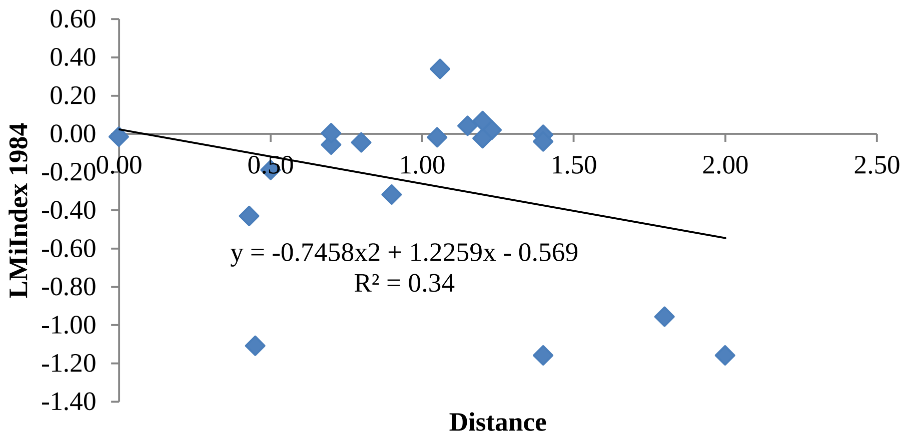


(a) LISA Cluster Map for Lagos Island, 1984

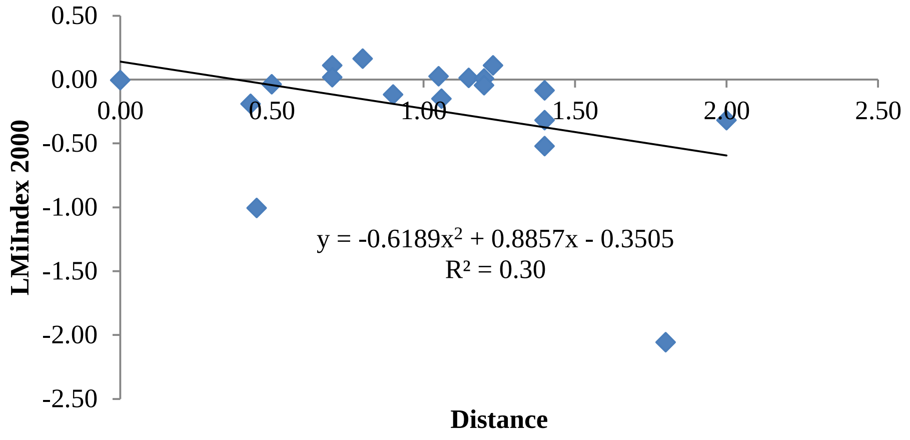


(b) LISA Cluster Map for Lagos Island, 2015

Fig. 5.3. LISA Cluster Map for Lagos Island
Source; Author's analysis.



(a)



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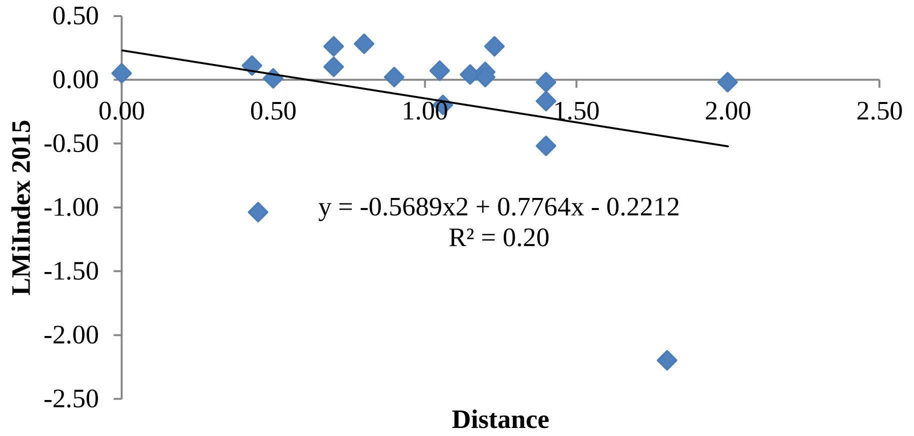


(c)

Fig. 5.4. The relationship between the local Moran's index for the built-up class and distance
Source: Author's analysis

5. 3 The Indicators of complexity in urban growth

There are several dimensions of complexity in urban growth. In chapter two, four dimensions of complexity in cities were discussed. These include definitional, spatial, temporal and taxonomic complexity. However, Boeing (2018) provided more comprehensive dimensions of the complexity of urban growth, including; temporal, visual, spatial and structural complexity. Temporal complexity relates to how processes and behaviour change over time and in space. Visual complexity in urban growth concerns the human perception of the built environment. Spatial complexity relates to the physical patterns of the landscape in terms of diversity and dispersion. Structural complexity relates to the fractal structure and network pattern in the urban landscape. Fractal refers to the roughness and/or self-similarity of some object, and how its detail relates to the scale at which it is observed. Network complexity refers to the city's internal organization, connectedness and circulation.

Decision-making complexity is another dimension of complexity identified in urban growth. Decision making complexity relates to the components, processes and agents involved in decision-making (Cheng, 2003). Visual complexity and complexity in decision-making are difficult to measure due to the complex patterns of behaviour manifested by various actors in the urban landscape.

The indicator of urban growth complexity refers to the particular indices used in evaluating various dimensions of complexity. Usually, they are referred to as spatial or landscape metrics. Herold, Clarke and Liu (2003) defined spatial metrics as "quantitative indices calculated from a categorical, patch-based representation of the landscape from the digital analysis of thematic-categorical maps." These metrics are powerful in quantifying urban dynamics spatiotemporally (Aithal and Sanna, 2012). They are useful in explaining the structures of urban built-up areas (Herold, Scepan and Clarke, 2002), identifying the driving forces of urban growth and understanding the spatial structure of land cover change (De Cola and Lam, 1993; Mandelbrot, 1983; and Xia and Clarke, 1997). Various researches including; Aburas et al. (2016); Ramachandra et al., (2012); Prastacos, Chrysoulakis and Kochilakis, (2012); Triantakonstantis and Stathakis, (2015); and Kim and Batty, (2011) are among the few that had successfully used spatial metrics in explaining urban growth patterns and processes.

The analysis of the patterns and processes of urban growth in Lagos Island was further extended by conducting spatial analysis in GIS using FRAGSTAS (Version 4.2.1) FRAGSTAS is public domain software that is specifically developed for spatial pattern analysis and for the quantification of the landscape configuration. The data sets used to derive the spatial metrics were the classified Landsat TM imageries presented in chapter four. The imageries consist of four land-cover types namely; built-up areas, open surface, vegetation/green areas and water bodies (see pages 104-106). In FRAGSTATS, metrics were grouped according to the aspect of landscape pattern measured. There are essentially six groups of metrics namely; area and edge, aggregation, core area, contrast, shape and diversity metrics. Within each of these groups, metrics were further grouped into patch, class, and landscape metrics.

The basic unit of analysis for spatial metrics is a patch. Discrete areas of similar environmental conditions are referred to as patches (McGarigal, 2004, 2013). They are classified based on the land cover or land use types. The patch dynamics (the spatiotemporal changes within and among patches) make up a landscape. Three possible states in which a patch can exist are the potential, active or degraded state. The potential state can be transformed into active patches through colonization of the patch by other active or degrading patches. Patches transformed to the degraded state when it is abandoned, but may be revived through the recovery process. The development process in the urban landscape may link or separate a patch from other patches.

In this research, temporal, spatial and structural complexity of urban growth were evaluated and discussed. Both visual and decision-making complexities were not considered due to the inherent difficulties involved in measuring them, and that is not limited to this research. There are more than one hundred spatial metrics for measuring complexity in the urban landscape, however, the selection of metrics for this research was guided by their purposes and proven capabilities in quantifying specific landscape characteristics as identified in previous researches. Full descriptions and calibration of each variable were provided by McGarigal (2015) and are presented in table 5.3 and Appendix II. Their applications to the explanation of urban dynamical patterns and processes were discussed in the subsequent relevant sections.

Table 5.3. Measures of Complexity in Urban Growth

S/N	Metric	Abbreviation	Description and uses
1	Patch Area	AREA	The areas of each patch comprising a landscape mosaic.
2	Class Area	CA	A measure of landscape composition
3	Percentage of landscape	PLAND	Measure the proportional copiousness of each patch type in the landscape.
4	Number of patches	NP	A measure of landscape fragmentation
5	Patch Density	PD	Assist in differentiating landscapes of varying size.
6	Patch Richness	PR	The number of patch types (classes) in the landscape.
7	Simpson's Evenness Index	SIEI	Quantifies the dominance of a particular patch type
8	Clumpiness Index	CLUMPY	Measures patch aggregation.
9	Largest Patch Index	LPI	Used in identifying and measuring dominant patch types and the level of aggregation
10	Edge Density	ED	A measure of shape complexity of the patches or geometry of the patches
11	Shannon's Diversity index	SHDI	Used in determining the proportional abundance of each patch type.
12	Shannon Evenness Index	SHEI	Quantifies landscape fragmentation
13	Contagion Index	CONTAG	Measures aggregation of patches.
14	Patch Cohesion Index	COHESION	Measure and describes the level of the physical connectedness (aggregation or fragmentation) of the corresponding patch type in the landscape.
15	Fractal Dimension Index	FRAC	A measure of complexity in the urban landscape.
16	Area-weighted MPFD	FRAC-AM	Determines the area-weighted mean value of the fractal dimension values of all patches in a land cover class.
17	Perimeter-Area FRAC	PAFRAC	A measure of complexity in the landscape.

Source: MacGarigal, 2015

5. 3. 1 Evaluating spatial complexity in Lagos Island

Spatial complexity relates to the structural composition or physical pattern of the landscape. Several measures of spatial complexity in urban growth have been identified in the literature, however the most relevant ones include; Number of patches (NP), Patch Area (AREA), Percentage of landscape (PLAND), Patch density (PD), Patch Richness (PR), Simpson's Evenness Index (SIEI) and the Total (Class) Area (CA). These metrics were grouped into patch, class and landscape levels for accurate and convenient analysis of the landscape (table 5.3 and appendix II for full description and analysis).

Table 5.4, 5.5 and 5.6, present the result of the analysis of spatial complexity in the growth of Lagos Island. Number of Patches (NP) measures the level of urbanization. The lower the number of patches the higher the level of urbanization and consequently the higher the complexity in the landscape. When there is only one patch of the corresponding patch type in the landscape, NP = 1, indicating that the landscape has a contiguous pattern. At the patch level (see table 5.4), the built-up class has six patches in 1984, a single patch in 2000 and five patches in 2015. This implies that in the year 2000 there is continuity in the urban fabric, suggesting a contiguous or compact pattern of development. Growth pattern between 2000 and 2015 is discontinuous and less complex as the number of patches increased to five. At the landscape level, (see table 5.6) the numbers of patches decreased in 2000 by 17.39% and increased by 26.09% in 2015.

Similarly, at the class level, the area of built-up class as shown in table 5.5 increased by 23.26% in 2000 and by 6.31% in 2015. This shows that the rate of urban expansion between 1984 and 2000 is higher than between 2000 and 2015. Expansion of urban area increases the level of complexity in urban growth, as more actors are brought on board in the development process. Further analysis of table 5.4 shows that open surface increased by 53.86% between 1984 and 2015, green areas decreases by 61.79% and the water class increased by 242.5% between 1984 and 2000 but decreased by 35.77% between 2000 and 2015. The increase in open surface class and the decrease in green area class were because of continuous land reclamation process at the fringe of Lagos Island. Increase in the areas of water class between 1984 and 2000 may be due to the activities of coastal erosion, however as land reclamation through sand filling for urban development increases rapidly, the water class is gradually given way for other class, most especially built-up class.

Table 5. 4. Urban Landscape Structure in Lagos Island (Patch level, 1984-2015)

	Patch Areas		
No of patches (NP)	**1984**	**2000**	**2015**
1	350.51	438.43	437.72
2	2.02	-	0.18
3	1.29	-	28.24
4	0.32	-	0.18
5	0.81	-	0.09
6	0.73	-	-
Total	**355.68**	**438.43**	**466.41**

Source: Author's analysis, 2018.

Table 5.5. Urban landscape structure in Lagos Island (Class level, 1984-2015)

YEAR	CLASS	Class Area (CA)	PLAND	NP	PD
1984	**Built up**	355.68	70.10	6.00	1.18
	Open Surface	32.12	6.33	11.00	2.17
	Green areas	119.20	23.49	6.00	1.18
	Water	0.40	0.08	4.00	0.79
2000	**Built up**	438.43	83.74	1.00	0.19
	Open Surface	33.66	6.43	9.00	1.72
	Green areas	50.12	9.57	8.00	1.53
	Water	1.37	0.26	5.00	0.96
2015	**Built up**	466.41	82.17	5.00	0.93
	Open Surface	49.42	0.19	9.00	1.67
	Green areas	45.54	8.47	7.00	1.30
	Water	0.88	0.16	8.00	1.49

Source: Author’s analysis, 2018.

Table 5. 6. Urban landscape structure in Lagos Island (Landscape level, 1984-2015)

Year	TA	ED	NP	PD	PR	SIEI
1984	507.41	47.87	27.00	5.32	4.00	0.56
2000	523.58	33.70	23.00	4.39	4.00	0.60
2015	537.53	30.51	29.00	5.40	4.00	0.41

Source: Author’s analysis, 2018

Similar to the total class area (TA) is the percentage of landscape (PLAND) that measures the proportional abundance of each patch type in the landscape. PLAND is a relative measure of landscape composition useful for comparing landscapes of varying sizes. For built-up class, the PLAND is 70.10% in 1984, 83.74% in 2000 and 82.17% in 2015, indicating both significant changes in the built landscape and its dominance in Lagos Island. Increase in the values of PLAND from 1984 to 2015 evidently revealed a more fragmented landscape of Lagos Island. The Patch density is a measure of fragmentation in the urbanized area (Prastacos, Chrysoulaki and Kochilakis, 2012). Decreasing values of PD implies fewer patches. It also indicates the land use continuity. However, a higher value indicates more patches, spatial dispersion and discontinuity in the urban landscape. The results showed that patch density (PD) for built-up class decreases by 83.89% between 1984 and 2000 and increased by 389.47% between 2000 and 2015. The values of PD obtained showed a contiguous pattern between 1984 and 2000, but a discontinuous pattern of growth between 2000 and 2015.

Boeing (2018) had shown that Simpson Evenness Index (SIEI) is also a good measure of spatial complexity. Simpson's Evenness Index (SIEI) is a measure of diversity to determine the urban landscape physical composition rather than the shape. It determines the level of dominance of a particular class on the landscape. The values of SIEI are usually between 0 and 1. The less diverse or evenness the landscape is, the lower the index. For Lagos Island, the value of SIEI in 1984 is 0.57. It increased to 0.60 in 2000 and decreased to 0.41 in 2015. This result suggests that the landscape is more diverse, contiguous and complex between 1984 and 2000 than between 2000 and 2015.

In the next section, attention is turned to the determination of the temporal complexity in urban growth. Temporal complexity relates to the dynamical processes influencing growth in the urban landscape.

5. 3. 2 Measuring temporal complexity of urban growth in Lagos Island

Urban growth is dynamic and a product of the combination of different processes. In landscape ecology, the analysis of temporal processes, i.e. the operation of the temporal process in a spatial context may be achieved in two levels; first at the global (landscape) level and second, at the local (class or patch) level. At the landscape level, the analysis takes into account the entire area of interest, however, at the local level, the neighbourhood is the focus of the analysis. Fragmentation, perforation, diversification, aggregation and simplification are some of the processes that operate at the landscape level. At the local (class level), contraction, domination, invasion, stability and succession are major processes f growth. These processes are highly dynamical in space and time.

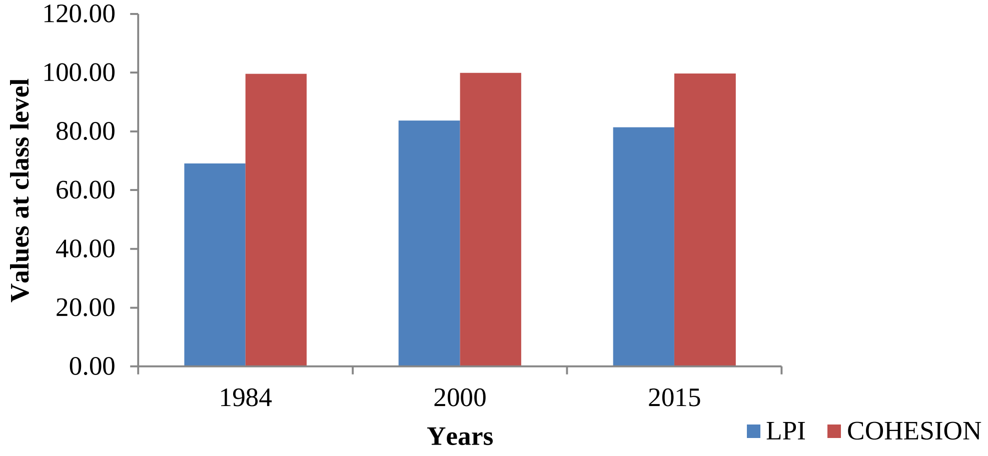
Measures of temporal complexity in urban growth are derived from information theory propounded by Shannon (1948). The theory emphasizes that the more types of things there are and equal each type's proportional abundance is, the less predictable the type of any single object will be. Entropy is lowest when the system is highly ordered and thus completely predictable. It is highest when the system's disorder is maximized (Boeing, 2018).

Metrics developed from Shannon's entropy; particularly Shannon's Diversity (SHDI) and Shannon's Evenness (SHEI) indexes have been recommended as measures of temporal complexity in urban growth (Boeing, 2018). Apart from these two, other related metrics useful in determining spatial processes in the urban landscape are; Clumpiness Index (CLUMPY), Contagion index (CONTAG), Edge Density (ED), Largest Patch Index (LPI) and Patch cohesion index(COH) (See table 5.3 and appendix II for their description and calibration). All these were deployed to analysed and explain the spatiotemporal processes influencing urban growth in Lagos Island.

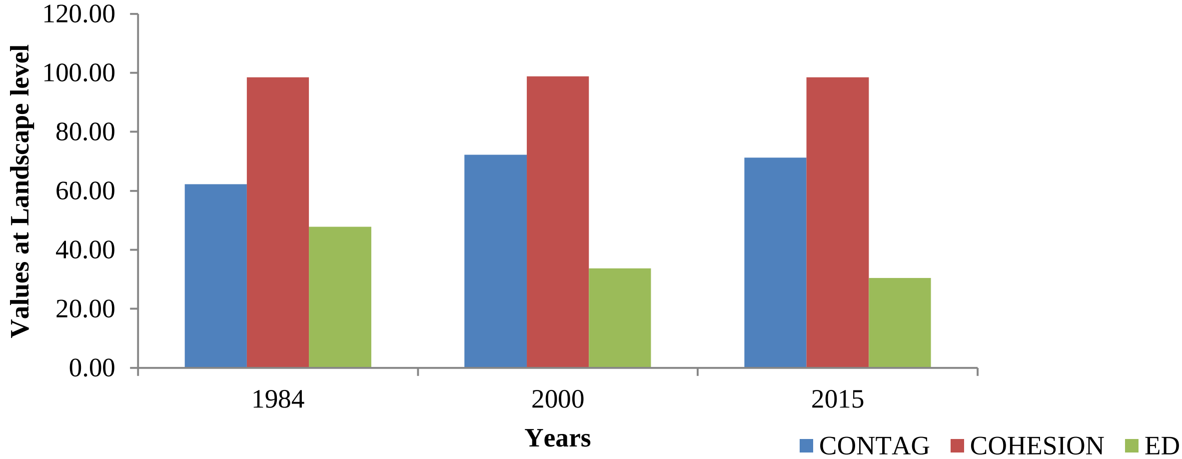
Figure 5.5a-c present the result of the analysis of the temporal complexity in the landscape of Lagos Island. The largest patch index (LPI) has been identified as a measure of aggregation and fragmentation (Pham and Yamaguchi, 2011; Reis, Silva and Pinho, 2015 and Wu and David, 2002). The LPI for the built-up class is presented in figure 5.5a, the figure showed that there was an increase in the value of LPI from 69.08 in 1984 to 81.43 in 2015. It also showed that the built-up class dominates the urban landscape between 1984 and 2015. The rate of change in LPI for the built-up class is higher between 1984 and 2000 (an increase of 21.22%) than between 2000 and 2015 (a decrease of 2.75%). This is an indication that the level of aggregation is higher between 1984 and 2000 than between 2000 and 2015. It also showed that while aggregation was the process of urban growth between 1984 and 2015, fragmentation was the process driving urban growth between 2000 and 2015. The fragmentation of the landscape cannot be dissociated from the continuous effort to expand land areas at the fringe areas. The result is similar at the landscape level.

The contagion index (CONTAG) is calculated based on the assumption of the random and conditional probabilities that a pixel of a patch class *i* is adjacent to another patch class *k*. The index described the fragmentation of the landscape. As a result, it is useful in determining the level of aggregation or clustering of patches in the landscape (O'Neill et al, 1988). Complete disaggregation of the landscape occurs when CONTAG = 0, however when CONTAG reaches 100 the landscape becomes totally aggregated. Given an increase in CONTAG by 16.14% in 2000 and a decrease of 1.43% in 2015 as shown in figure 5.4b, it may be safe to say that the landscape is more aggregated between 1984 and 2000, than between 2000 and 2015.

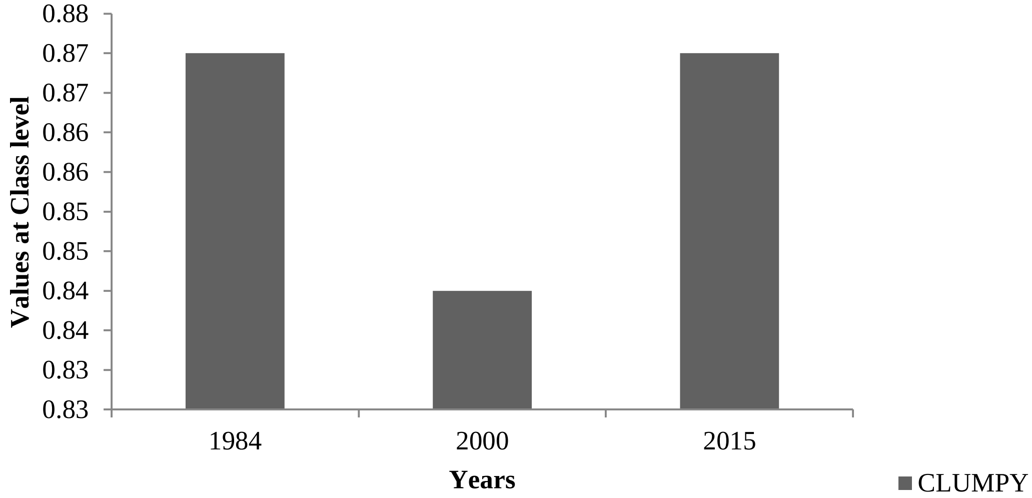
Edge density (ED) measures the spatial distribution of land use by considering the size and complexity of the shape/geometry of the patches. For Lagos Island, ED decreases from 47.87 in 1984 to 30.51 in 2015, suggesting a more compact development through a process of aggregation of built-up patches. The Clumpiness index (CLUMPY) is a measure of patch aggregation (see appendix II for full description). CLUMPY values at landscape level shown in figure 5.4c indicated that the built-up area is maximally aggregated. This corroborates the results obtained for CONTAG and ED. In the same vein, Patch cohesion index (COHESION) (a metric that measures physical connectedness of patches) obtained for Lagos Island were very high. At class level COHESION= 99.55 in 1984, 99.88 in 2000 and 99.70 in 2015 (see figure 5.5b). The result is not different at the landscape level. The implication of this is that processes of aggregation of built-up patches were higher between 1984 and 2000 than between 2000 and 2015. This undoubtedly was so because by the year 2008 land reclamation processes had commenced in the northwestern corner of Lagos Island at Ilubinrin to extend the reach of the urbanised area.



(a) **Largest Patch and Cohesion Index**



(b) **Edge Density, Contagion and Cohesion Index**



(c) **Clumpiness Index**

Fig. 5.5. Measures of spatial processes of urban growth in Lagos Island
Source: Field survey 2013/2014

The extension of the urbanised area resulted in the creation of more spaces for new development, which triggered off the process of fragmentation although at a minimal level. SHDI and SHEI are all measures of dominance. SHDI = 0 when the landscape is less diverse or contains only 1 patch type. When the number of different patch types increases or the proportional and equitable distribution of areas among patch types increases (MacGarigal, 2015), the value of SHDI is equal to or greater than 1. This also increases the patch richness of the landscape. When the value of SHDI and SHEI approaches 1, the landscape becomes more diverse and complex. The value of SHDI and SHEI for Lagos Island is shown in figure 5.6. SHDI decreased by 25.97% in 1984 and 2000 and increased by 5.26% between 2000 and 2015. Similarly, the value of SHEI decreased by 31.67% between 1984 and 2000 and increased by 4.88% between 2000 and 2015. Increased value of SIEI indicates urban expansion. The landscape is more diverse and complex between 2000 and 2015 than between 1984 and 2000.

Given the foregoing, it can be concluded that at the later time (2000-2015), the built landscape of Lagos Island was more fragmented than between 1984 and 2000. Fragmentation results in discontiguous (scattered development) urban growth pattern. Discontiguous development is related to leapfrogging. Leapfrogging is a form of scattered urban growth in disjointed patches of urban land uses, interspersed with green areas or open surfaces. It is a process of urban intensification whereby developed land leapfrog over undeveloped land. It is a condition whereby development occurs at the remaining small lots after a city has reached its peak of development in an infill process. Fragmentation processes caused landscape change and affect both the structure and function of the landscape. It breaks the landscape elements into smaller pieces. It is a feature of outlying growth or peripheral growth.

Outlying growth is a land transformation process involving the extension of the city boundary. Three types of outlying growth may be identified in the city namely; isolated, linear branch, and clustered branch. The development of a single or many non-developed built-up pixels (s) in a position in space away from an existing developed built-up pixel(s) results in isolated growth. This usually occurs in an urban landscape where little or no developed land surrounds a new residential housing structure or related development.

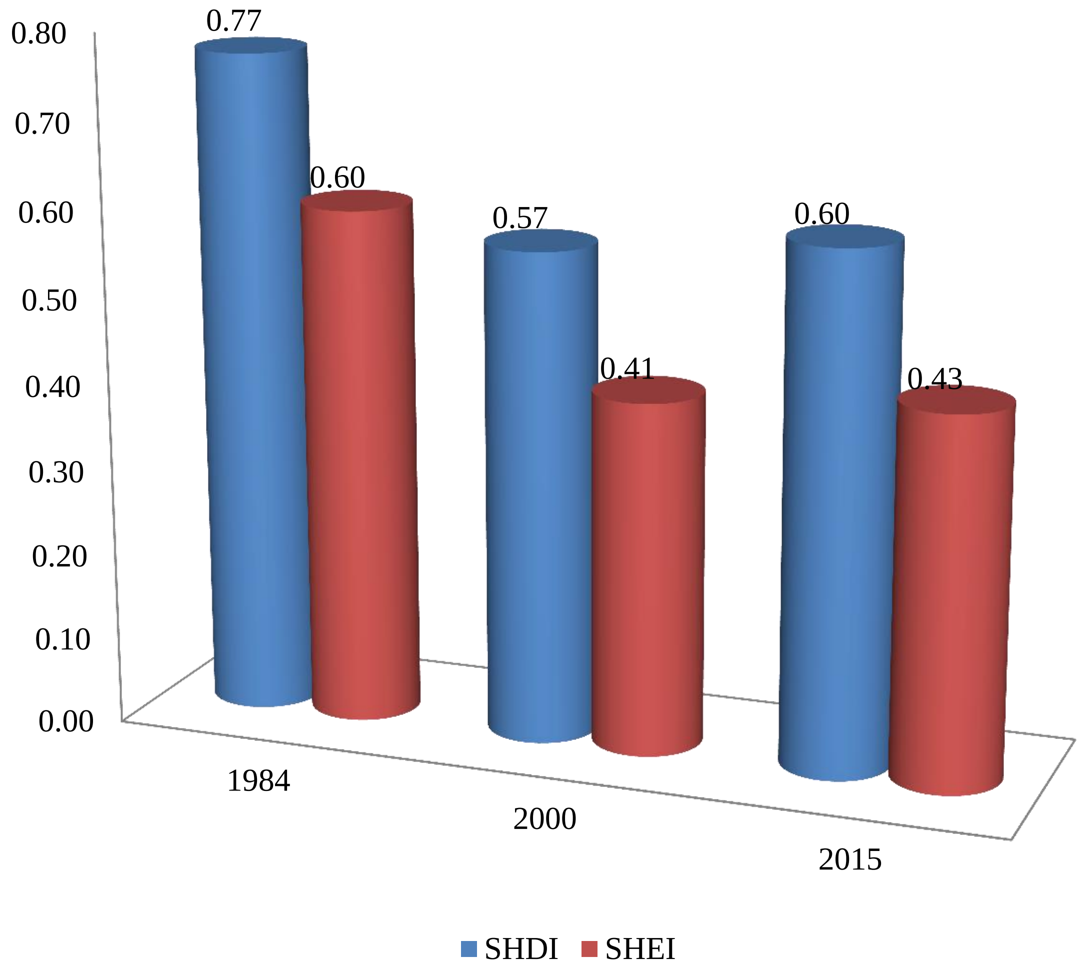


Fig. 5.6. Shannon's Diversity Index (SHDI) and Shannon's Evenness Index (SHEI) for Lagos Island

Source: Author's Analysis, 2018

Development along a new road or any other similar development that is generally surrounded by non-developed land in a location far away from the existing developed land results in linear branch type of growth. This is also referred to as ribbon development, resulting from the compaction of segments that extend along a particular axis leaving the interstices undeveloped (Harvey and Clark, 1965). The clustered branch is characteristic of urban expansion process in originally compact and dense cities.

The urban growth process in Lagos Island follows the cluster branch type. Cluster growth pattern as identified in section 5.2 and 5.3 have fractal pattern and are results of self-organization. Fractal relates to the shape and physical configuration of a system and is perhaps the most applicable measures of the complexity of complex systems. In the next section, the fractal nature of the landscape of Lagos Island was examined for the different time considered in this research to determine the specific spatial and temporal complexity of urban growth.

5. 4 The fractal nature of the urban form

The use of fractal in the urban analysis is relatively recent; however, it has gained prominence in describing the spatial pattern of urban growth and morphology of the city. Cities display complex order, characteristic of a fractal structure. Fractals are objects that are independent of scale and are self-similar at all scales. The analysis of the fractal nature of urban form provides a synthetic measure of complexity in the urban landscape. It proves that the city has self-similarity. The presence of self-similarity indicates that there are unseen hands (hidden processes) that operate at different time and scales to generate self-similarity. The most popular way of analysing fractal structure is the derivation of the fractal dimension index.

Fractal dimension index is a space-filling extent measure. The description of the fractal dimension index and various methods of obtaining it had been discussed in chapter three, section 3.4.2.2 of this thesis. An object with a straight-line property would have FRAC = 1. A 2 dimensional or planar object will have FRAC value > 1 and < 2. A three-dimensional structure would have FRAC > 2 (Tuček and Janõska, 2013). When FRAC = 2 for any city, the city will fill up the whole plane (Tuček and Janõska, 2013).

Fractal Dimension Indexes (FRAC) were estimated for Lagos Island using FRAGSTAS and land cover maps presented in pages 104-106. Other indices derived from fractal dimension including Area-weighted mean patch fractal dimension (FRAC-AM) and Perimeter-Area Fractal Dimension (PAFRAC) were added to explain the fractal nature of urban form in Lagos Island. The description and calibrations of these metrics as run by FRAGSTAS were presented in appendix II. The fractal dimension indexes for Lagos Island were presented in figure 5.7. At the patch level (figure 5.7a), fractal dimension (FRAC) for the built-up class was > 1.00, indicating that the built environment in Lagos Island for the years under consideration have shapes that are highly convoluted and plane filling. This is suggesting increasing complexity in the urban landscape. The weighted mean patch fractal dimension (FRAC_AM) both at class and landscape level as shown in figure 5.7b also shows that the landscape is highly complex as FRAC_AM for all the three years (1984, 2000, 2014) are > 1.0. Similarly, the perimeter-area fractal dimension (PAFRAC) reveals the inherent complexity in the shape of the landscape. Because there are less than 10 patches at the class level for some of the years considered, PAFRAC is returned zero (0). However, for the built-up class at the landscape level as indicated in figure 5.7c, PAFRAC was found to be > 1. This is an indication of a convoluted built-up landscape in Lagos Island.

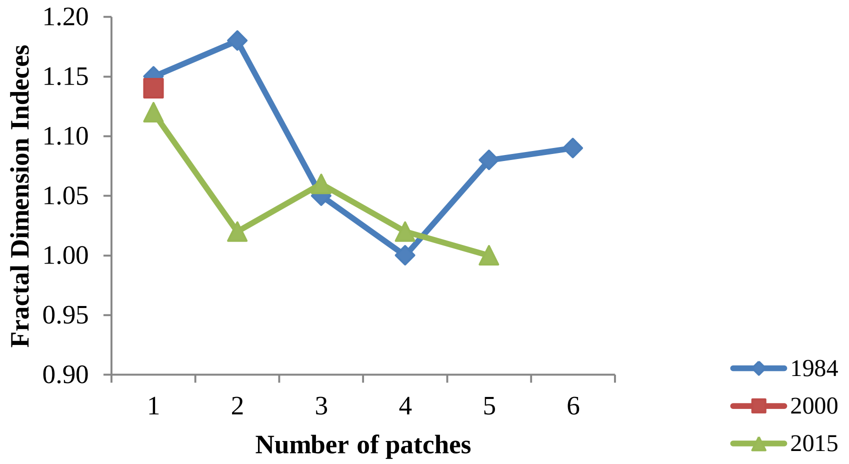
An ordinary mean value of fractal dimension index at the patch level gives FRAC = 1.09 in 1984, 1.14 in 2000 and 1.09 in 2015. These results showed that the perimeter of the built landscape in Lagos Island increased between 1984 and 2000. It was more complex and aggregated than between 2000 and 2015. Increasing fractal dimension is a reflection of the systematic and reproducible compact sprawling process. A further look at the results in figure 5.7b showed that FRAC_AM values at class and landscape levels decreased by 2.6% between 1984 and 2015. PAFRAC values decreased between 1984 and 2000 by 9.02% and increased by 0.82% between 2000 and 2015. The decrease in FRAC_AM though small and increase in PAFRAC between 2000 and 2015 suggests a small-scale fragmentation of a disorganized built-up pattern in a highly dense urban landscape.

The changing number of patches, patch area sizes coupled with the varying fractal dimension over years indicates spatiotemporal dynamics in the pattern of the urban landscape and increasing complexity of the landscape of Lagos Island. The result of edge densities (ED) obtained for all the years under consideration in section 5. 3. 2 attested to this fact. ED is an index of land fragmentation that measures the spatial distribution of the land use by considering the size and the complexity of the shape or geometry of the patches. A low-value ED indicated fewer patches and compact shape, whereas large values indicate the presence of many patches with simpler shapes. The compact shape is characteristics of a complex system that is non-fragmentable.

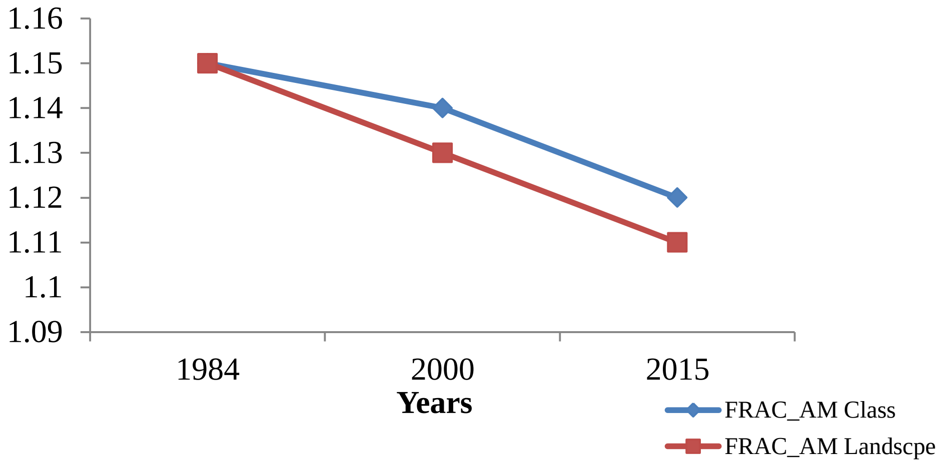
The relationship between fractal dimension, area and time were examined to further examine the change in the complex nature of the urban landscape of Lagos Island. A graphical plot of the relationship between fractal dimension values and the areal extent of Lagos Island is shown in figure 5.8a. The plot shows a perfect linear relationship between the weighted mean patch fractal dimension and areal extent given an R^2 value of 1.00 and R= -1.00 significant at $p \leq 0.05$. This indicates that the fractal dimension decreases significantly with the increasing size of the urban landscape. The result corroborates the assertion of Tuček and Janõska (2013) who stated that the relation between area and its fractal dimension is assumed strictly linear.

A graphical plot of the relationship between fractal dimension index and the area is presented in figure 5.8a. The result shows that as land area increases, the built-up area becomes less complex. The relationship between fractal dimension and time is presented in figure 5.8b. The figure showed a dynamic spatial and temporal trend in fractal dimension index of the urban landscape in Lagos Island. The R^2 value of 1.00 and R= -1.00 at p-value ≤ 0.05 showed that complexity in the landscape decreases significantly over time. As the city built–up space increases and its borders expand, the land area becomes more fragmented and discontiguous. Figure 5.8c showed the graphical plot of the relationship between area and time. The relationship is perfect and positively linear with R^2 value = 1.00 and R = +1.00 at p-value ≤ 0.05.

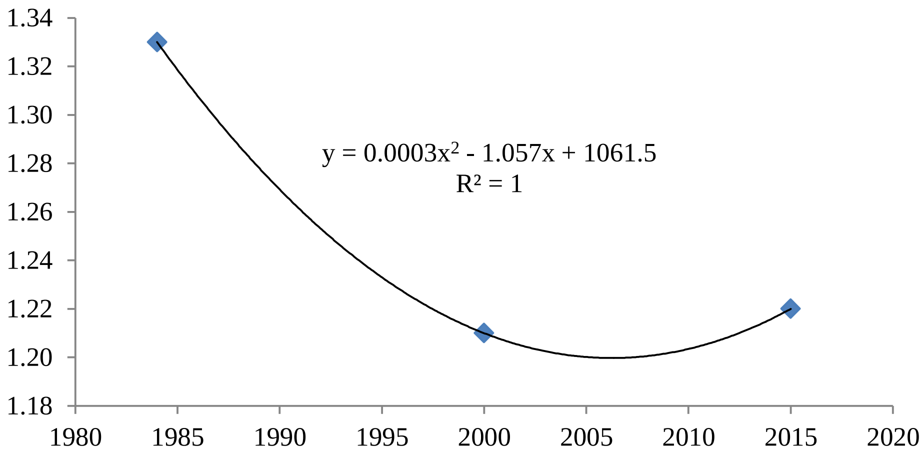
Results presented in figure 5.8 indicate the continuous expansion of the highly dense and compact land area of Lagos Island. It also showed that the fractal dimension index could be used not only to examine the growth of the city in the past but as a tool to predict the future development of the city. In the next section, the correlates of built-up land area changes and the spatial pattern of urban growth in Lagos Island was examined. This is in line with the research objective three that aimed at relating the satellite-derived estimates of changes in urban growth to the physical and socio-economic drivers of growth.



(a) Fractal Dimension Index for built-up class at the patch level

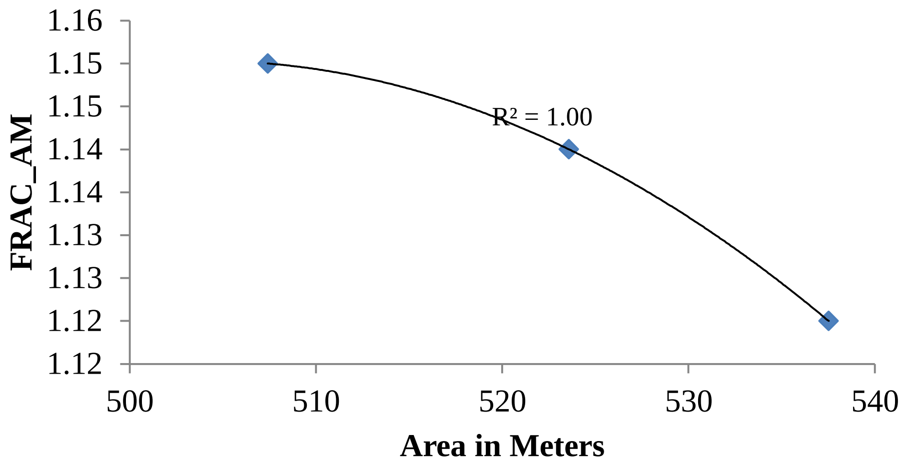


(b) The weighted mean patch fractal dimension of the built-up class

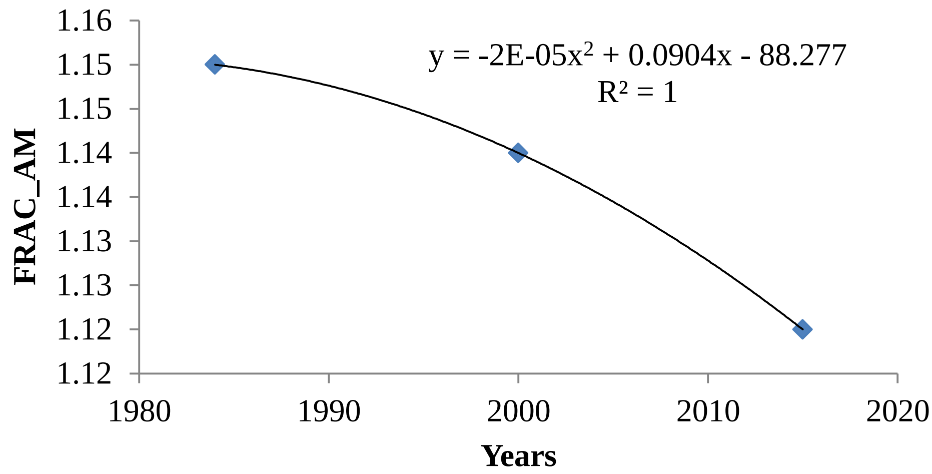


(c) Perimeter-area fractal dimension (PAFRAC) of the built-up class

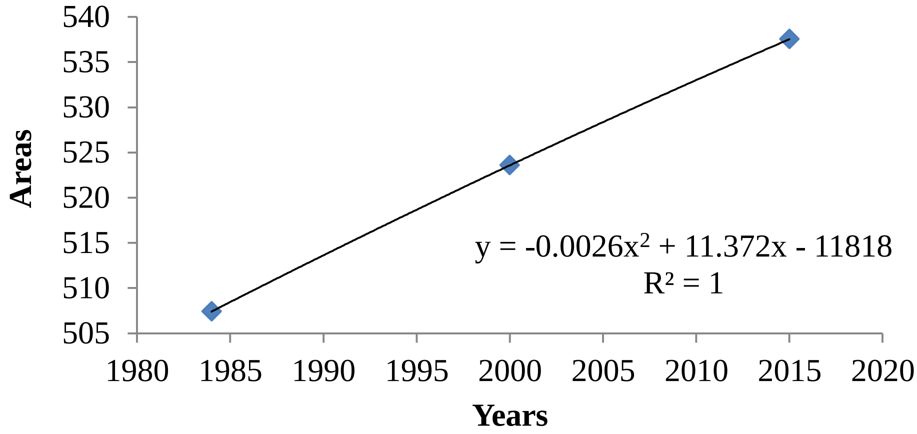
Fig. 5.7. Measuring Complexity in urban growth
Source: Author’s analysis, 2018



(a) The relation between area and fractal dimension



(b) The relation between time and fractal dimension



(c) Relationship between area and time

Fig. 5.8. Relationship between fractal dimension, area and time.
Source: Authors analysis, 2018

5. 5 Correlates of Pattern of Urban Growth in Lagos Island

A general survey of recent literature in urban analysis and planning showed that most studies are concerned with the quantification of the spatial structure or physical pattern of cities, with little attention given to the correlates of the observed spatial patterns. This research examines the correlates of patterns of urban growth in order to identify the specific factors influencing the regularity or irregularity observed in the urban landscape.

The determination of the correlates of the spatial pattern of urban growth in Lagos Island was done on two levels. First, a zero-order correlation matrix was developed using Pearson product moment correlation method in SPSS (See table 5.7). Urban growth pattern represented by the local Moran's index (LISA) obtained for 2015 was used as the dependent variable and land value, net population change, population density, road density, population size, trading activities represented by the number of whole and retail businesses and distance were used as independent variables. Thereafter a stepwise regression analysis was performed to determine the most important socio-economic process driven urban growth pattern.

The zero-order correlation matrix presented in table 5.7 showed that among all the selected independent variables the most significant correlates of urban growth pattern were net population change, the number of whole and retail businesses and population density. Significant negative relationship found between Local Moran's index and net population change, number of wholesale and retail businesses and population density as indicated in table 5.7 suggests that depending on the locality, urban growth may be more or less randomly distributed or more or less spatially clustered with increasing population density, trading activities and net population change.

The result of stepwise regression presented in table 5.8 showed that the most important factors influencing the pattern of urban growth in Lagos Island were trading activities and net population change. The stepwise regression model indicated a significant positive relationship between these three variables ($R = 0.66$ at $P \leq 0.05$). It shows that the joint contribution of trading activities and net population change to the explanation of the physical pattern of Lagos Island is about 44%.

Table 5.7. Correlates of the spatial pattern of urban growth in Lagos Island

Variables	LMi	NPOP	POPDENS	TRADE
Local Moran's Index (LMi)	1.00	-.47*	-.48*	-.48*
Net population change (NPOP)	-.47*	1.00	.67**	-0.05
Population density by ward (POPDENS)	-.48*	.67**	1.00	0.05
Number of wholesale and retail businesses (TRADE)	-.48*	-0.05	0.05	1.00
N	19	19	19	19

**. Result significant at $p \leq 0.05$ level (2-tailed).*

***. Result significant at $p \leq 0.01$ level (2-tailed).*

Source: Author's analysis, 2018

Table 5.8. Summary of Stepwise regression model of factors of urban growth pattern

Variables	**Std. Error**	**Standardized β**	**t**	**P-value**
Constant	0.49	0.59	1.19	0.25
Net population change 1984-2015	0	-0.46	-2.43	0.03
Number of wholesale and retail businesses	0	-0.53	-2.82	0.01
R	0.66			
R^2	0.44			
F	6.29			0.01
DF -Regression	2			
Residual	16			

Dependent Variable: Local Moran's Index
Source: Author's analysis, 2018

The stepwise regression result in table 5.8 was developed into urban growth pattern equation in the form of;

$$P_G = 0.59 - 0.46NPOP - 0.53TRADE + \varepsilon \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. (5.3)$$

Where P_G is pattern of growth, NPOP is net population change, TRADE is number of wholesale and retail businesses and ε stochastic error.

5. 6 Conclusion

In this chapter, an effort had been made to consistently measure and analyse the complexity of urban growth in Lagos Island by using univariate statistics (Moran's I) and spatial metrics. Among many other things, it had been established that aggregation and fragmentation were the major processes driving urban growth in Lagos Island. The pattern of growth was found to be a compact urban development produced through a coalescence of urban built-up patches. The examination of spatial heterogeneity in the pattern of urban growth provided an opportunity to identify areas of urban development constraints intensively in need of urgent planning interventions.

The quantitative analysis of urban growth patterns, dynamical processes and correlates of urban growth has enabled a better comprehension and representation of urban growth dynamics. It had been demonstrated in this chapter that in complex urban areas like Lagos Island, where development is difficult to monitor and manage, the application of spatial metrics for planning interventions will produce effective monitoring of the landscape and help in developing strategies and policy interventions capable of providing sustainable solutions. Since urban growth is a dynamical process, efforts were directed at modelling the processes of urban growth in the next chapter.

CHAPTER SIX

MODELLING THE SPATIAL AND TEMPORAL PROCESSES OF URBAN GROWTH

6. 1 Introduction

In chapter six, dynamical processes of urban growth were analysed using spatial metrics. However, the processes of land use transition were not considered. Processes in this context refer to the sequences of change in urban land that occurred through complex spatiotemporal interactions between various land cover/land use types. Understanding land-use transition in the urban area involves explicit modelling of land cover/land-use changes. This is crucial for effective urban planning, as it offers the opportunity of the possibility of developing scenario, predicting the future and based on the outcome of the scenarios developed, provide urban policies for sustainable urban growth management. This chapter sets out to achieve two purposes. First to achieve the objective concerning relating satellite-derived estimates of changes in urban growth to physical and socio-economic drivers, and second to test the research hypothesis that states that urban spatial expansion process is a function of physical variables (distance, building lot size and building height) and socio-economic variables (population growth, housing stock and housing demand).

6. 2 Modelling processes of land use transition in Lagos Island

Land-use transition modelling attempts to abstract the processes of conversion of one land-cover type to another. Particularly it involves modelling and analysing the conversion of non-developed land to urban land. The conversion from non-developed to urban land usually increases the extent of the built-up area of the city. This often results in urban fringe development or development of a complex higher order phenomenon characteristic of a compact or clustered urban development.

There are several approaches to modelling the urban land use transition. However, the most commonly used are; Agent-Based Modelling (ABM), cellular automata modelling (Grinblat, Gilichinsky and Benenson, 2016; Li and Yeh, 2000; Wu and Webster, 1998) and Markov chain stochastic modelling (Bell, 1974; Cabral and Zamyatin, 2009; Kumar, Radhakrishnan and Mathew, 2014; Petit et al., 2001; Rozario, Oduor, Kotchman and Kangas, 2017; Weng, 2002). Others are the Multi-Agent-Based modelling techniques and the combination of Cellular Automata and Markov probability model (CA-Markov). This research adopted the

CA-Markov, modelling techniques for the spatiotemporal modelling of urban growth processes. CA-Markov model is based on cells and transition rules. It has the capacity to represents a complex system given a set of rules and states with spatiotemporal behaviour. It focuses on the spatial interaction among cells to produce several land cover/land use categories. The technique is based on the assumption that the landscape change can be measured and predicted for time $t + 1$, once the system state at time t is known. The state of the system if stated as a vector at time *t* may be expressed as;

$$x_t = x_1 x_2 x_3 \dots \dots \dots \dots \dots x_n \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (6.1)$$

where x_i is the proportion of cells in type *i* at time *t*. If equation 6.1 is projected to time $t + 1$, the state vector is post multiplied by the transition matrix and then becomes;

$$x_{t+1} = x_t P \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (6.2)$$

The state of the system can be projected into the future time $t + k$ by iteration through the manipulation of the matrix into a vector state;

$$x_{t+k} = x_t P^k \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (6.3)$$

To model the processes of land use change in Lagos Island, the classified land cover maps presented in chapter four (pages 104-106) was imported into IDRISI GIS. The stochastic matrix, matrixes of transition areas, expected transition areas were calculated and the modelling was carried out based on the classified images for the year 1984 and 2000. The image for the year 2015 was used for ground truthing. The number of iterations for the modelling exercise was set to 16, with iteration for each year under the prediction period (2015 to 2031). Kappa Index of Agreement (KIA), a measure to evaluate the accuracy of the model obtained is 0.82, indicating that the model is accurate. The results were presented in table 6.1 and 6.2. Table 6.1 is a square transition matrix describing the chances of a particular land cover transiting from one probable state to another. The older land cover classes are in the row, while the newer classes are indicated in the column. Thus, the rows show the probabilities of moving from the state represented by that row, to the other states. The sum of all values in each row equals 1 such that;

$$x_i = [x_1 + x_2 + x_3 \dots\dots\dots\dots. x_n] = 1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6.4)$$

The transition probability matrix shows that the probability that the built-up class will remain unchanged is 0.79. The probability that built-up class will change to vegetation is 0.04 and to open surface is 0.15. The probability that the vegetation class will transit to built-up class is 0.16, and to open surface is 0.48. The probability that open surface will change to built-up class is 0.09 and to vegetation is 0.07. The probability that water class will change to built-up class is 0.66 and to open surface is 0.22. The predicted results, as presented in table 6.1 show that the future land use transitions will mainly include built-up class transiting to vegetation and open surface, vegetation transiting to built-up class and open surface, open surface transiting to built-up, vegetation, water to built-up and open surfaces. 4.8% of the built-up class will transit to vegetation and 15.49% of the built-up class will transit to open surface. About 17% of vegetation class will change to built-up class and there is a probability that 49% of vegetation class will change to open surface. About 9% of the current open surface will change to built-up and 7% of it will change to vegetation. There is a probability that about 67% of water class may change to built-up and 22% change to open surface.

The states of the current (2015) land cover/land use pattern and the predicted pattern (2031) were presented in table 6.2. Results show that the built-up class will lose about 12.49% of its current land area to other land use classes by 2031, amounting to about 0.55Km^2. Vegetation class will gain 11.04% of its current size (about 0,05km^2) and the open surface will gain 103.13% of its current size (about 0.49km^2). Figure 6.1 shows the predicted land cover map of Lagos Island and figure 6.2 shows gain and losses by land cover/land use categories. Although it is evident in figure 6.1 that the land cover categories will experience changes, however, the land cover pattern may not be significantly different from what it is presently, given the fact that built-up class will still dominate the land cover/land use categories. The result indicates that the built-up class will cover about 71.49% of the land area in 2031. Summarily, the major processes of urban growth in Lagos Island are processes of land transition, particularly change from non-urban to urban land use type.

Table 6.1. Markov Transition Probabilities

Class	Built-up	Vegetation	Open Surface	Water
Built-up	0.7962	0.0483	0.1549	0.0006
Vegetation	0.1679	0.3431	0.4891	0.0000
Open Surface	0.0966	0.0763	0.8271	0.0000
Water	0.6667	0.0000	0.2222	0.1111

Source: Author’s analysis, 2018

Table 6.2. Current and Predicted land use pattern for Lagos Island by 2031

	Areas in (Km²)					
Class	**2015**	**Percent**	**2031**	**Percent**	**%Gain**	**%Loss**
Built-up	4.396	81.69	3.847	71.49	------	-12.49
Vegetation	0.498	9.25	0.553	10.27	11.04	-------
Open Surface	0.479	8.91	0.973	18.09	103.13	-------
Water	0.008	0.15	0.008	0.15	--------	-------
Total	5.381	100	5.382	100		

Source: Author's analysis, 2018

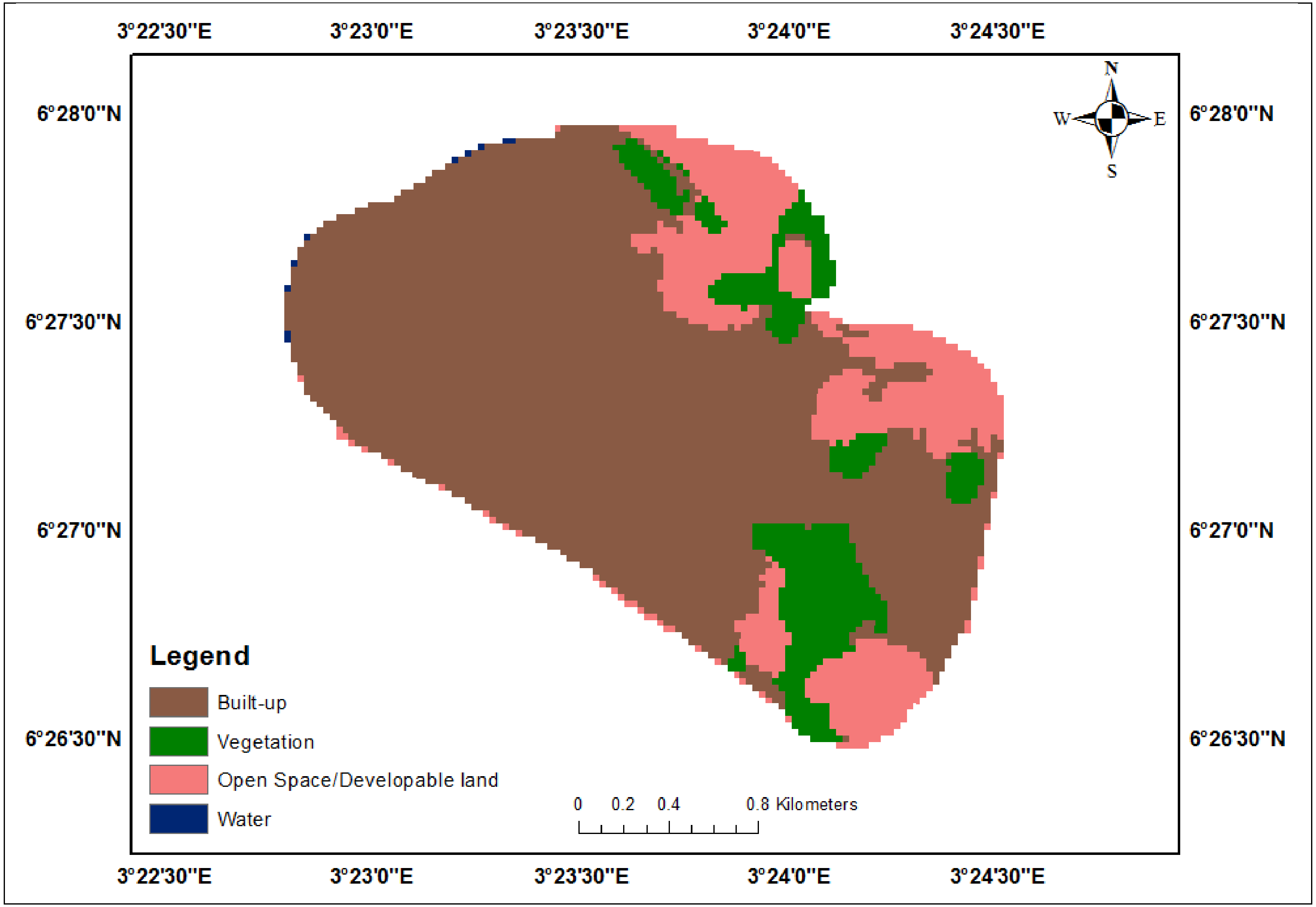


Fig. 6.1. Predicted land cover map for Lagos Island (2031)
Source: Author's analysis, 2018.

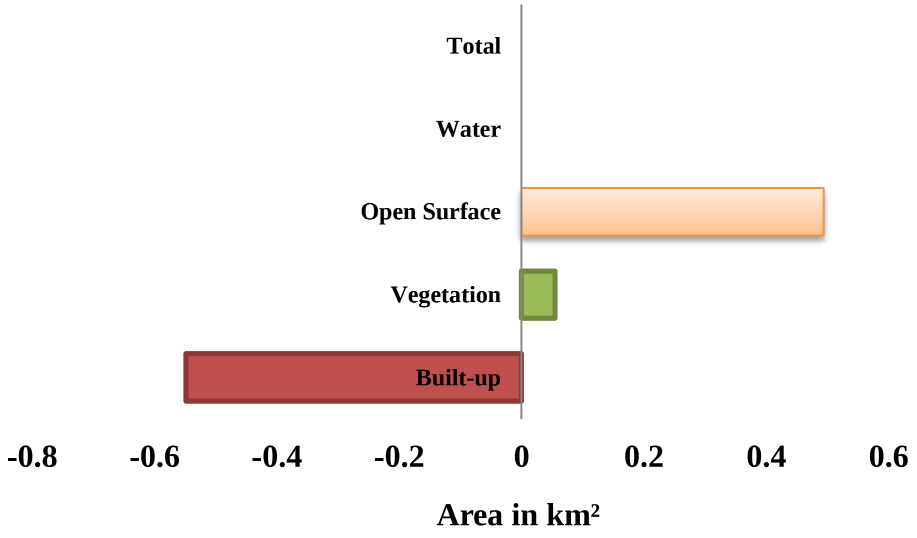


Fig. 6.2. Gains and Losses of Land Cover classes in Lagos Island

Source: Author's analysis, 2018.

6.2.1 Modelling the drivers of urban spatial (horizontal) expansion

The intensity of urban expansion, its pattern and direction are useful indicators that reveal the characteristics of urban growth. It provides important information for policy development and planning. Different physical and socio-economic drivers are driving urban expansion in cities. However, measuring the expansion of the city in order to determine its associated drivers may be a bit challenging. A critical issue in this regard is what constitutes the area of the city (Wolman et al. 2005; Parr, 2007), the administrative or the built-up areas of the city? The built areas of the city have been observed to be a much more precise, consistent, and comparable measure of its area (Angel, et al. 2005). Therefore, the physical/spatial expansion of the built-up areas of the city is considered as urban expansion in this research following Angel (2005).

The determination of the drivers of urban spatial expansion followed two stages. First, the administrative boundaries of the Island for the years 1984, 2000, and 2015 were delimited and mapped respectively. Overlays of the administrative boundary map on land cover maps were performed to estimate changes in the built-up area of Lagos Island. The urban expansion between 1984 and 2015 was estimated using;

$$UE = \frac{X_2 - X_1}{T_2 - T_1} \times 100\% \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6.5)$$

Where UE is urban expansion over a specific period, $X_2$is a built-up land area at a latter time, X_1 is a built-up land area at the initial period, T_2 is the year at the latter period and T_1 is the year at the initial period. Spatial regression analysis in ArcMap to model the relationship between the identified drivers of growth later followed. The review of the literature, the conceptual framework of the research and data availability guided the selection of all variables used for the spatial regression model. Table 6.3 shows the operational definition of variables used. Specifically, the dependent variable is the extent of urban expansion between 1984 and 2015. The explanatory variables are; physical variables (including; distance from the CBD, building lot areas in meter square and average building height) and socio-economic variables (including; demographic variable represented by population growth, housing variables represented by housing stock and average number of rooms used by households to represent the demand for space).

Table 6.3. Operational definition of variables for spatial regression modelling of urban growth drivers

Variables	Title	Operational Definition	Measurement
Independent variable			
$\boldsymbol{Y}$	UE	The extent of urban spatial expansion	Continuous
Explanatory variables			
Physical variables $(\boldsymbol{P_v})$			
$\boldsymbol{X_1}$	BLT_a	Building lot area (m²)	Continuous
$\boldsymbol{X_2}$	BLD_h	Average building height	Continuous
$\boldsymbol{X_3}$	ED_i	Distance from the CBD in metres	Continuous
Socio-economic variables $(\boldsymbol{SEC_v})$			
Demographic Variables			
$\boldsymbol{X_4}$	PG_i	Population increase	Discrete
Housing Variables			
$\boldsymbol{X_5}$	AR_n	Average number of room used by household by ward	Discrete
$\boldsymbol{X_6}$	HST_i	Housing stock by ward	Discrete

Source: Author/s analysis, 2018

The variables in table 6.3 was stated as regression equation and expressed as

$$UE = \alpha + b_i(BLD_a + BLD_h + ED_l) + b_j(PG_i + AR_n + HST_i) + \varepsilon \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6.6)$$

where; UE= the extent of urban expansion,b_i, b_j = regression coefficients and ε = stochastic error term.

Table 6.4 showed the model summary of the spatial regression analysis. A detailed examination of the table showed that the main driver of urban growth in Lagos Island is population growth ($\beta = 0.98 \text{ at p} \leq 0.01$). This indicates that as population increases, land consumption also increases and consequently the expansion of urban land. The results also showed that urban expansion also responds positively to the demand for space ($\beta = 0.22 \text{at P} \leq 0.01$). It suggests that an increase in the demand for room by households will result in more use of urban space and consequently increase in urban land areas. Similarly, a low but positive relationship was obtained between urban expansion and housing stock ($\beta = 0.0003 \text{ at P} \leq 0.05$), indicating an increase in the rate of urban expansion as housing stock increases.

Besides population growth, housing stock and average number of rooms used by households, the model showed that urban expansion is inversely related to building lot area ($\beta = -0.04 \text{ at P} \leq 0.01$). This suggests that where building lot areas increases, urban expansion decreases. This is possible in areas inhabited by the rich who build on a relatively large expanse of land.

Although other variables were found not statistically insignificant, however, they provide understanding about urban growth process in Lagos Island. A positive but insignificant relationship between average building height, distance to the CBD and the extent of urban expansion suggest a possibility of horizontal expansion accompanied by a vertical expansion in the nearest future. That urban expansion increases with increasing distance from the CBD suggests that urban expansion is occurring at the fringe area, particularly in areas that shared a boundary with the sea.

Table 6.4. Drivers of urban spatial expansion in Lagos Island

Variable	Coeff. [a]	Std. Error	t-Stat	Prob. [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	-1.621	0.196	-8.273	0.00**	0.17	-9.33	0.00**	-------
Average building height	0.001	0.001	0.87	0.40	0.00	1.16	0.27	1.13
Building lot area (m^2)	-0.04	0.01	-3.95	0.00**	0.01	-5.66	0.00**	1.67
Housing stock by ward	0.0003	0.0002	1.83	0.09	0.00	2.26	0.04*	1.26
Distance from the CBD in metres	0.00004	0.00008	0.54	0.59	0.00	0.64	0.54	1.52
Population growth	0.98	0.12	8.21	0.00**	0.15	6.68	0.00**	1.29
Average No of room used by households	0.22	0.05	4.35	0.00**	0.05	4.79	0.00**	1.18

*AICc = -2.53, Joint F-Statistics = 19.95** and Wald Statistics = 143.69*

*Dependent variable: Urban expansion intensity * Significant at 0.05 level*

Source: Author's analysis, 2018

Given the foregoing, it may be safe to conclude that the most significant drivers of urban spatial expansion in Lagos Island are socio-economic processes, which are principally outcomes of human decisions that resulted into emergent properties of the urban landscape. Results presented in Table 6.4 were developed into a model of urban growth drivers for Lagos Island in the form of;

$$UE = -1.621 + 0.001BLD_h - 0.043BLT_a + 0.00004ED_i + 0.98PG_i + 0.21AR_n + 0.0003HST_i + \varepsilon \ldots (6.7)$$

The result of the OLS diagnostic for the spatial regression model indicated that the adjusted R-Squared is = 0.86 and Akaike's Information Criterion (AICc) = -2.53 with Joint F and Wald Statistics of 19.95 and 143.69 at $p \leq 0.01$. This indicates that the model is statistically significant and is perfectly fit.

A critical view of the result presented in table 6.4 showed the influence of physical and socio-economic processes of urban growth at the macro scale. However, the effect of locality on the strength and intensity of each process of growth was not examined. The increasing attention being paid to the role of locality in urban growth analysis in recent times necessitates the need to give considerable attention to spatial heterogeneity in modelling and predicting urban growth. Therefore, in the next section, the issue of spatial heterogeneity in urban growth was considered. The aim is to discover and determine the specific socio-economic processes of growth operating at local levels in Lagos Island.

6. 2. 2 Modelling spatial heterogeneity in urban growth

Urban processes often exhibit patterns of spatial heterogeneity (Páez and Scott, 2004). Li and Reynolds (1994) defined spatial heterogeneity as "the complexity and variability of a system property in space." It represents the condition in which the structure of the processes being modelled varies across space. Fotheringham et al., (2002) called it spatial non-stationarity. Several spatial statistical methods had been developed to examine and model spatial heterogeneity in urban analysis. However, one of the most recent and popular is the Geographically Weighted Regression technique (GWR).

GWR is a statistical technique proposed by Brunsdon et al. (1996) to model complex spatial variation at the smallest unit (local level) of spatial analysis. The technique assigns weights to individual observations based on their geographical distance from a central location (0), based on the concept of distance-decay. The GWR model takes the form of;

$$y_o = \sum_{k=1}^{K} x_{ok} \beta_{k(C_o)} + \varepsilon_o \text{ ………………………………………………………….. (6.8)}$$

where sub-index 0 indicates a focal point (city centre) that needs not correspond to an actual observation of y (Páez and Scott, 2004). The error terms assume the usual conditions of independence and constant variance (Páez and Scott, 2004).

Equation 7.8 can also be written as;

$$y_i = \beta_o(u_{i,} v_i) + \sum_k \beta_k(u_{i,} v_i) x_{i,k} + \varepsilon_i \text{ … … … … … … … … … … … … … … … … … … … (6.9)}$$

Where $\beta_o(u_{i,} v_i)$ equals the coordinates of *ith* point in space and $\beta_k(u_{i,} v_i)$ indicates the existence of the continuous function at point I (Fortheringham et al., 1998). The existence of continuous surface of parameter values enables the measurements of the surface at certain points to denote the spatial variability of the surface (Murayama, 2012). GWR model predicts the dependent variable at *i* with the local coefficients $\beta(u_i, v_i)$ that are specific to the same point. The prediction using local regression coefficients take the form of;

$$\hat{y}_i = \sum_k \hat{\beta}_k (u_{i,} v_i) x_{i,k}$$

$$= (1, x_{i,1,} x_{i,2} \dots \dots \dots \dots ..)(\hat{\beta}_o(u_{i,} v_i), \hat{\beta}_1(u_i, v_i)^i, \hat{\beta}_o(u_{i,} v_i), \dots \dots \dots ..)^i,$$

$$= X_i(X^i W_i X)^{-1} X^i W_i y \text{ …………………………………………………………........... (6.10)}$$

where X_i is the *ith* row vector of *X*. In the vector-matrix notation, the GWR prediction may be written as;

$$\hat{y} = H_y \text{ ……………………………………………………………………………….. (6.11)}$$

where the *ith* row of matrix $H(h_i)$ is expressed as;

$$h_i = x_i(X^i W_i X)^{-1} X^i W_j \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (6.12).$$

The matrix transforming the observations into predictions is referred to as the hat matrix (Karen, 2008).

The use of geographically weighted regression (GWR) is a relatively new development in urban growth analysis. GWR make an observation at a given neighbourhood, to provide parameter estimates for every regression point (local levels). This makes it an indispensable tool in understanding urban growth processes at local levels. It had been noted that the parameter estimates produced by GWR model if characteristically mapped can highlight spatial variation (Mennis, 2006), produce maps that are didactic to assist policymakers, and useful for summarizing a large amount of data generated by GWR modelling procedure (Cho et al., 2009). Partridge et al. (2008) had used geographically weighted regression (GWR) to investigate geographic diversity in urban and regional growth. It has been used to model urban spatial structure (Noresha and Rainis, 2009), the probability of urban land expansion (Luo and Wei, 2009) and urban land use changes (Noresha, Gairola and Talib, 2010)

To model local variations of processes of urban growth in Lagos Island, GWR models were estimated in the ArcGIS environment using all variables presented in table 6.3. For the modelling exercise, adaptive kernel type and a bandwidth method of Akaike Information Criterion were chosen. It was believed that the GWR model with a smaller bandwidth kernel effectively fits the data than those with a larger bandwidth kernel (Karen, 2008). Monte Carlo tests (Fotheringham et. al., 2002) were also done to determine the significance of the spatial variability in the local parameter estimates. The results, including the model summary and the location-specific parameter estimates for processes of urban growth, were presented in table 6.5.

A detail examination and comparison of the results of the ordinary least square spatial regression model presented in table 6.4 and that of GWR models presented in table 6.5 showed that the use of GWR has increased the strength of the relationship among the variables used. The goodness-of-fit statistics (R^2), Adjusted R^2 value and AICc improved significantly. The GWR model produced an R^2 value of 0.93 and adjusted R^2 value of 0.85, which make the model more statistically fit and more robust for the explanation of urban growth processes in Lagos Island.

The Akaike information criterion (AICc) measures the relative quality of a statistical model for a given set of data. It provides a relative estimate of the information lost when a given model is used to represent a certain process that generates data used in the modelling process, thereby dealing with the trade-off between the complexity of the model and its goodness of fit. AICc is not an absolute measure of goodness of fit but it is useful for comparing models with different explanatory variables as long as they apply to the same dependent variable. The AICc is expressed as;

$$AICc = -2SupL + 2q + 2\frac{q(q+1)}{N-q-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.13)}$$

where *SupL* is the log-likelihood of the model representing its degree of fit (if the model fit better,*-2SupL* becomes smaller), q represents the model total parameters and *N* represents the sample size (Karen, 2008). AICc value of 39.05 obtained for the GWR model indicated a better model than the OLS model. A randomly distributed residuals obtained, indicated that the residuals were not spatially autocorrelated, as a result, the model can be adjudged statistically fit. Similarly, a Monte Carlo test of the GWR model shows that four of the six variables used in modelling drivers of urban growth demonstrated statistically significant spatial non-stationarity, at $P \leq 0.05$.

The intercept/constant parameter in the GWR model determines the basic level of urban growth change without the effects of all the factors considered across the study area (Huang and Leung, 2002). In table 6.5, the intercept value is negative and higher in ward E2 (-1.68) and lowest in ward C3 (-0.74), these are the basic level of changes in urban spatial expansion in Lagos Island. The local R^2 is higher in ward E2 (0.915) and lowest in ward C2 (0.804). The local regression model obtained for drivers of urban growth in ward E2 may be expressed as;

$$Y = -1.68 + 0.00BLD_h - 0.03BLT_a + 0.00ED_i + 1.01PG_i + 0.21AR_n + 0.00HST_i + \ldots\ldots \text{(6.14)}$$

Thus, the GWR models provide an opportunity to examine and explain drivers of urban growth from the local dimension.

Table 6.5. Local Processes of urban growth in Lagos Island

Ward	Observed	Intercept	Local R2	Predicted
A1	0	-1.41	0.86	0.01
A2	0	-1.51	0.88	-0.05
A3	0	-1.51	0.88	-0.02
B1	0.1	-1.57	0.89	0.18
B2	0	-1.59	0.89	0.05
B3	0.1	-1.43	0.87	0.01
C1	0.06	-1.33	0.84	0.05
C2	0.06	-1.17	0.80	0.07
C3	0.2	-0.74	0.82	0.19
D1	0.1	-1.23	0.87	0.13
D2	0.3	-1.46	0.90	0.24
D3	0.19	-1.49	0.91	0.33
E1	0	-1.41	0.85	-0.14
E2	1.35	-1.68	0.92	1.17
E3	0	-1.53	0.88	0.14
F1	0.13	-1.65	0.91	0.10
F2	0	-1.54	0.91	-0.06
G1	0.45	-1.62	0.91	0.58
G2	0.84	-1.59	0.92	0.82

$R^2 = 0.93$, R^2 Adjusted = 0.85, AICc = 39.05

Source: Author’s analysis, 2018

The parameter estimates (coefficients) of the OLS model obtained in sections 6.2.2 indicated the strength and weakness of all socio-economic processes that drive urban growth in Lagos Island. However, areas, where they exert influences, were not indicated. A better understanding of urban growth dynamics will be gained if local processes of urban growth could be identified and explained. Modelling urban growth using geographically weighted regression method enables the identification of the local processes of urban growth through locational-dependent data usually generated by the model.

The local parameter estimates (regression coefficient values by each spatial unit in the model) are important locational–dependent data generated by GWR. This set of data is useful in explaining local urban growth. As observed by Mennis (2006), maps generated from the data provide a reliable means of exploring and interpreting local spatial non-stationarity (Mennis, 2006). The parameter estimates from the geographically weighted regression model for drivers of urban growth in Lagos Island are presented in figure 6.3-6.8. Higher parameter estimate means that the effect of a particular variable is higher in the corresponding locality compared to other localities within the study area (Huang and Leung, 2002).

Detail examinations of the figures show that there is variation in the way each of the variables exerts influence on urban growth in Lagos Island. Some variables have a wider influence than others does. For example housing stock, population, distance to CBD and an average number of rooms used by households have a wider influence on urban growth in all spatial units that made up Lagos Island. However, a closer examination reveals that housing stock has more influence in ward C1, B1, A3 and B3 than in any other ward. Population increase has more influence in ward A2, A3, B1, B2, E2 and F1. Average number of rooms per household has great influence in ward E2, G1, G2 and F1 and distance to CBD play a dominant role in explaining urban growth process in ward A1, D1, G1, D3 and F2. Building lot area exerts more influence in the traditional areas (areas occupied by indigenes) and significant parts of LICBD than in any other areas; however, its influence is very high in ward C3 than any other ward. The influence of building height is more felt in ward D1, D2 and D3.

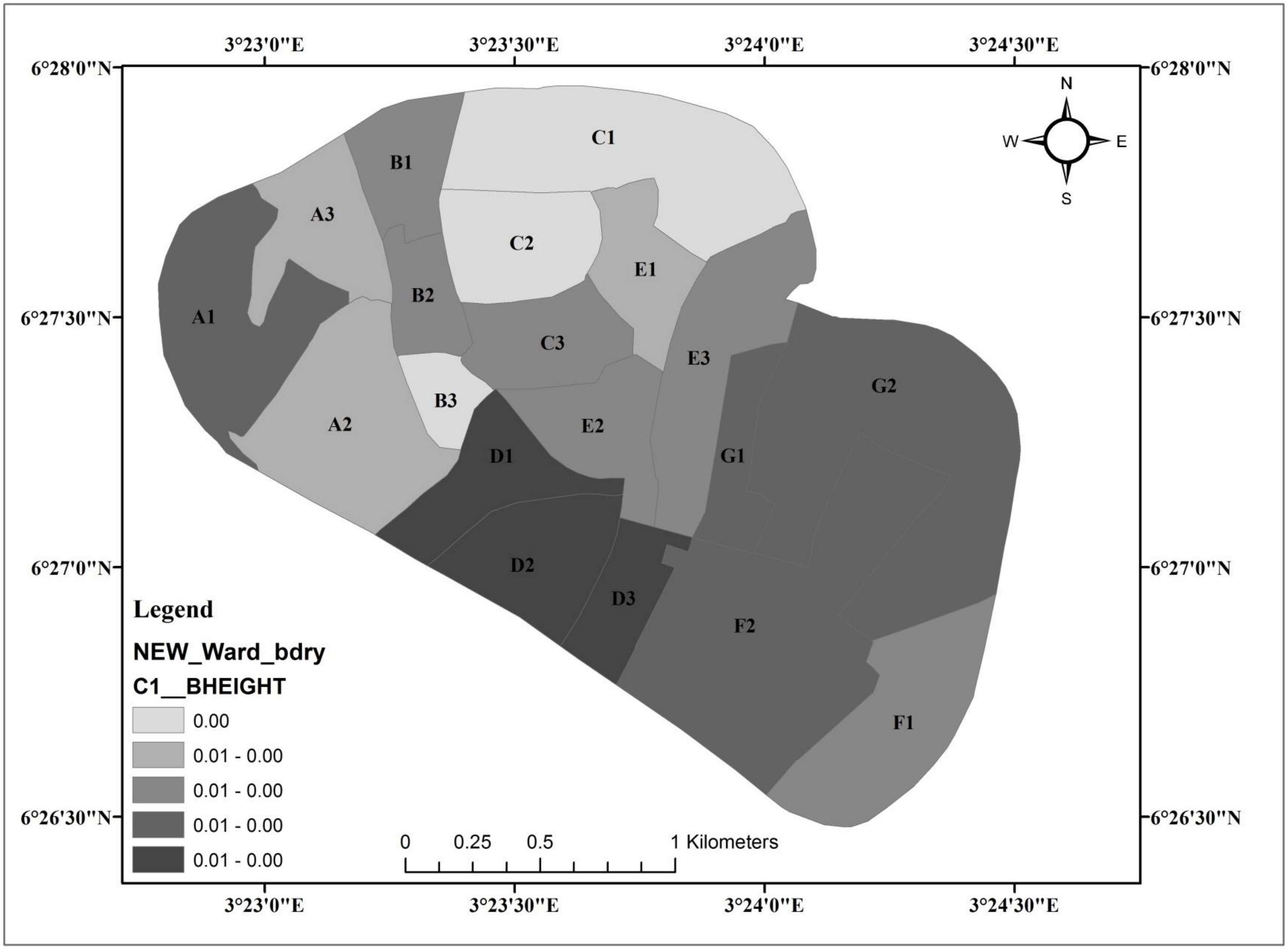


Fig. 6.3. Local influence of building height on urban growth in Lagos Island
Source: Authors analysis, 2018

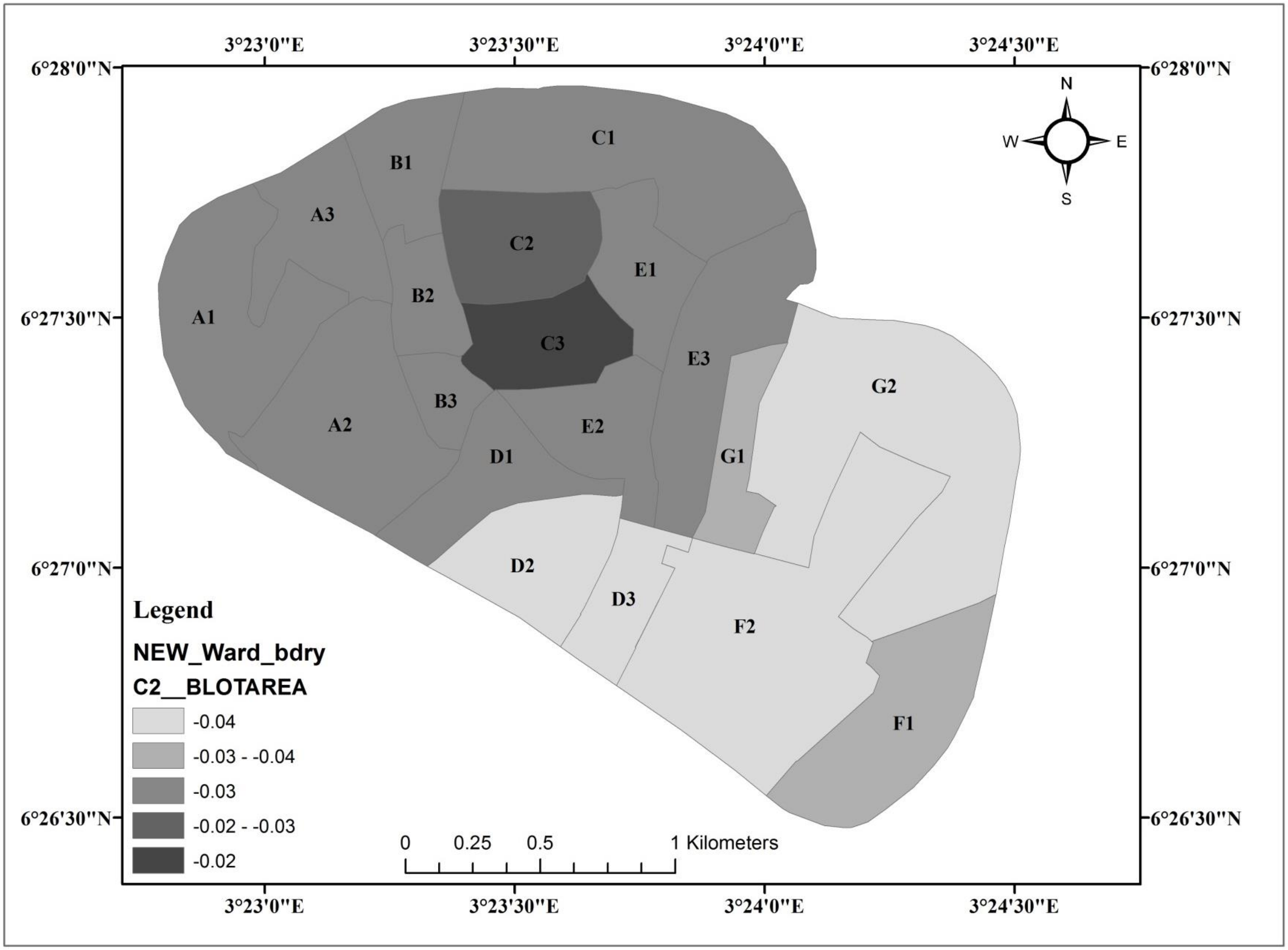


Fig. 6.4. Local influence of building lot area on urban growth in Lagos Island
Source: Authors analysis, 2018

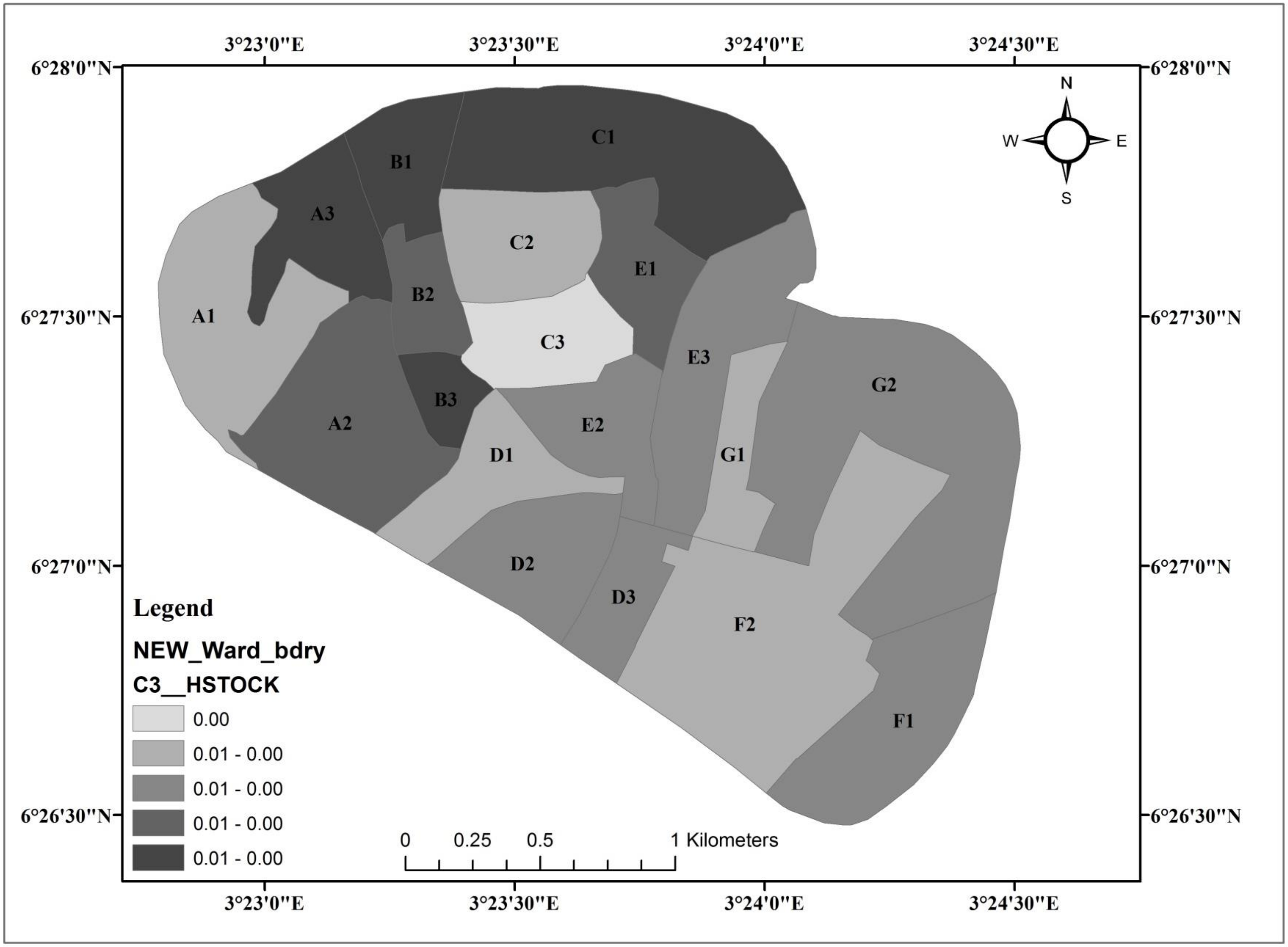


Fig. 6.5. Local influence of housing stock on urban growth in Lagos Island
Source: Authors analysis, 2018

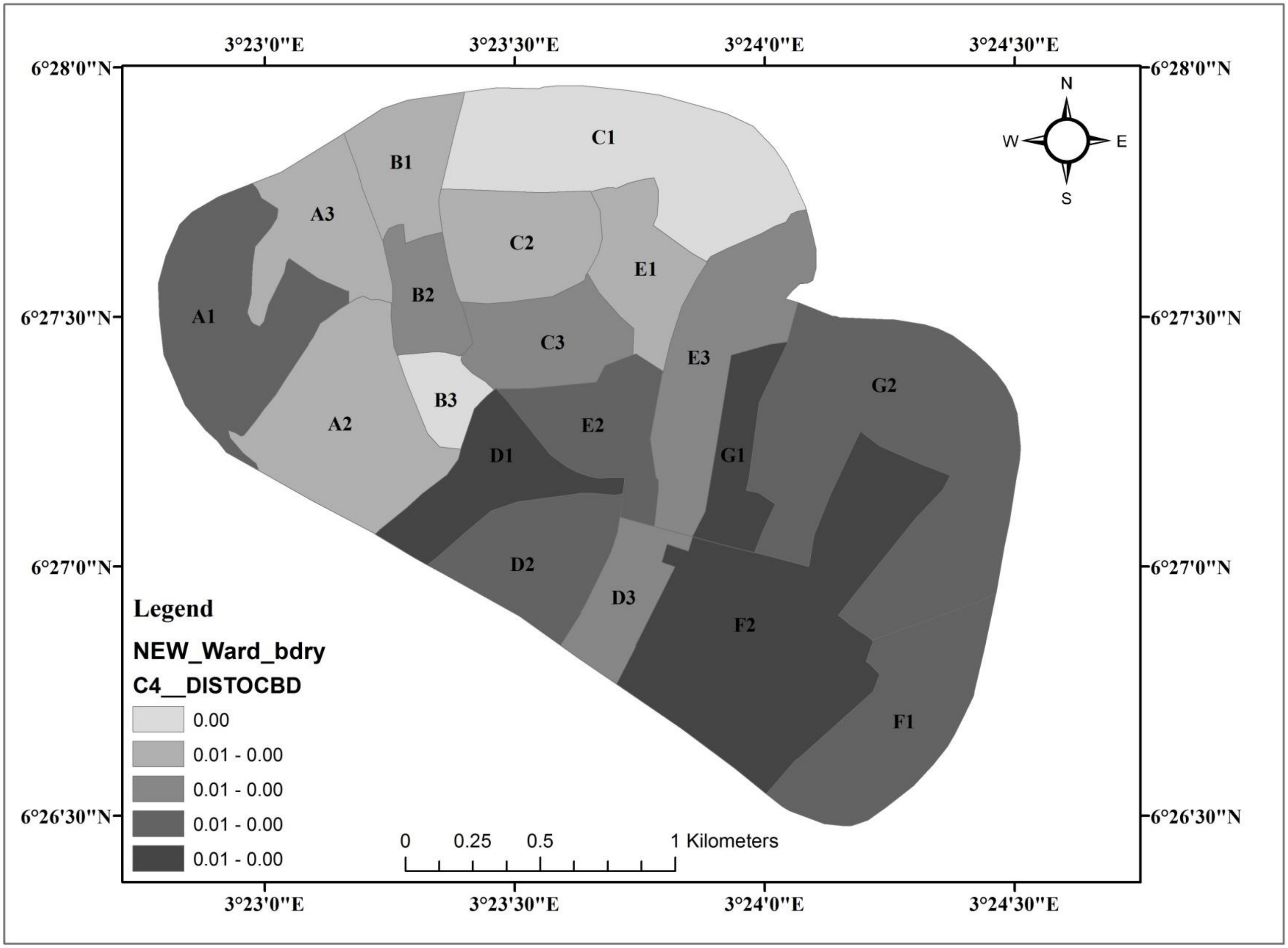


Fig. 6.6. Local influence of distance on urban growth in Lagos Island
Source: Authors analysis, 2018

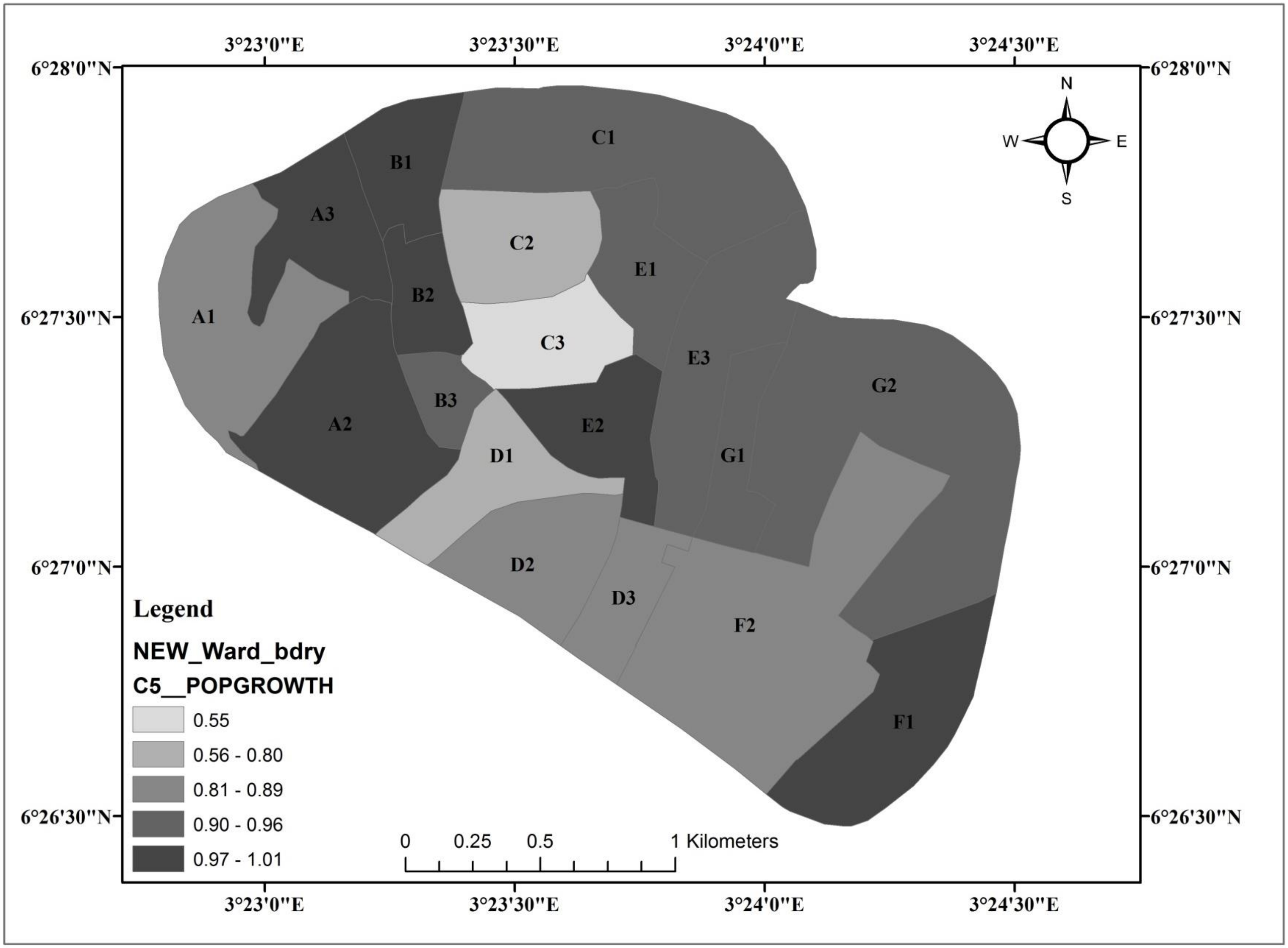


Fig. 6.7. Local influence of population growth on urban growth in Lagos Island
Source: Authors analysis, 2018

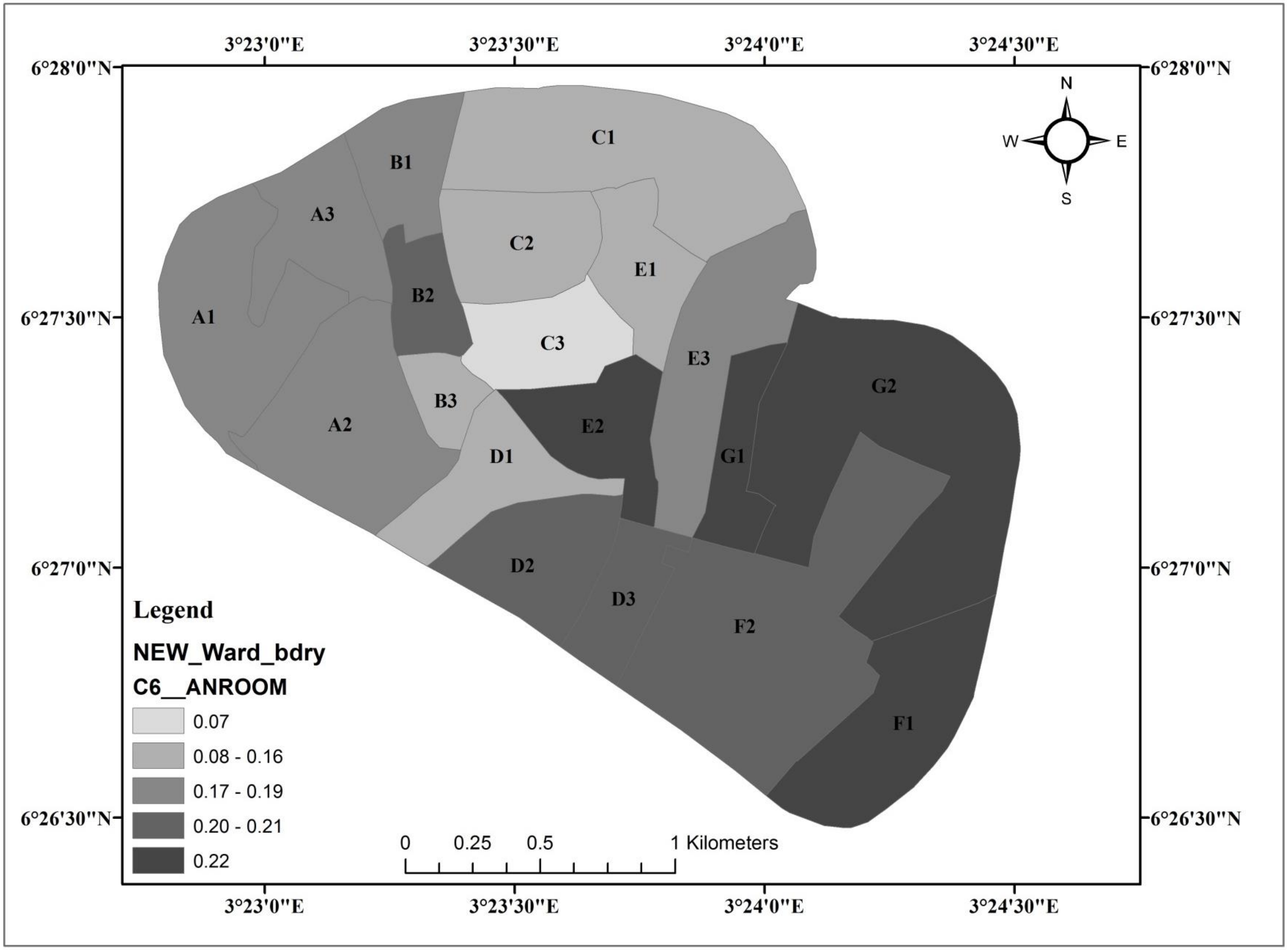


Fig. 6.8. Local influence of demand for space on urban growth in Lagos Island
Source: Authors analysis, 2018

The mapping of local parameter estimates as presented in figure 6.3 to 6.8 is very useful in locating areas that require planning interventions. It offers opportunities for sustainable growth management, as factors operating at different local levels may be quickly identified for urgent planning intervention.

6.2.3 Predicting local urban growth pattern in Lagos Island

Future local urban growth patterns in Lagos Island were indicated in the predicted results presented in table 6.6. The results showed that there would be future variability in growth pattern across space. Apart from ward A2, A3, E1 and F2 who are likely to experience a decline in their spatial extent, future expansion will be experienced virtually in all other wards. However, a significant expansion will be recorded in ward E2 as the predicted rate of change in its extent is the highest (1.17). Similarly, the future rate of expansion in ward G1 and G2 will be $\sim$ 1.0.

The implication of the above is that significant portions of Lagos Island may be inundated with water in no distant future, particularly in this era of climate change and global warming. It, therefore, becomes pertinent that precaution must be taken considering the rate of incursion into the sea and the Lagoon, for land reclamation. Lagos Island, being almost surrounded by water is highly vulnerable to pluvial and coastal flooding; hence it is advised that government, planning agencies, developers and individuals must adhere strictly to environmental planning regulations to avoid future disaster and to ensure environmental and human safety.

6.2.4 Spatial logistic regression modelling of urban growth in Lagos Island

A cardinal objective of this study is an assessment of the future growth of Lagos Island, in order to suggest appropriate planning strategies for the future. Prediction of future urban growth trend and pattern is crucial for urban planning. However because urban growth is a complex spatial and social-economic phenomenon, its distribution follows a logistic function. In logistic regression models, dichotomous/binary variables are used as a dependent variable, while the independent variables can be a mixture of binary and continuous variables. Given the nature of urban growth, the most appropriate technique for its analysis is logistic regression. Logistic regression estimates a multiple linear regression function defined as;

$$ln\left(\frac{P}{1-P}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n \text{ .... (6.15)}$$

Where p, is the probability of an event occurring (in this case urban expansion). If probabilities of urban growth at each spatial unit (ward) are to be predicted then the logistic regression equation becomes;

$$P = \frac{\exp(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n)}{1+\exp(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n)}, 0 < p < 1 \text{ .... (6.16)}$$

A logistic regression model was developed for Lagos Island by testing the sixth hypothesis of the research. The hypothesis states that the probability of change in urban growth (spatial expansion) is a function of physical variables (proximity to water bodies, distance and building lot size) and social economic variables (trading activities, net population change, rate of change in housing stock and built-up area), a logistic regression model was obtained using SPSS. The dependent variable; change in urban spatial extent was obtained by converting the velocity variation rate into dichotomous variables, taking two values such that $\{Y \in [0,1]\}$ with $Y = 1$ if there is a change in spatial extent and $Y = 0$ if there is no change. The block model of the logistic regression was obtained using proximity to water bodies as the only variable. The model produces;

$$ln\left(\frac{P}{1-P}\right) = \alpha = 0.539 \text{ .... (6.17)}$$

which in turn produces an odd ratio $[Exp(\beta)]$ of 1.714 indicating that if any of the spatial unit (ward) in Lagos Island is randomly chosen, it is 1.71 times more likely to experience growth than not. The probability of growth occurring is estimated by the model given as;

$$P(probability\ of\ growth) = \frac{Exp(0.539)}{1+Exp(0.539)} = 0.632 \text{ .... (6.18),}$$

indicating that 63.2% of the wards were correctly classified and the classification from the null model is 63.2% accurate.

Table 6.6. Operational definition of variables for logistic regression modelling of urban growth

Variables	Title	Operational Definition	Measurement
Dependent variable			
$\boldsymbol{Y}$	$PURB_{gr}$	Probability of change in urban growth	Categorical
Explanatory variables			
Physical variables $(\boldsymbol{P_v})$			
$\boldsymbol{X_1}$	$CONT_i$	Proximity to the water bodies	Categorical
$\boldsymbol{X_2}$	BLD_a	Building lot area (m^2)	Continuous
$\boldsymbol{X_3}$	ED_i	Distance from the CBD in metres	Continuous
Socio-economic variables $(\boldsymbol{SEC_v})$			
$\boldsymbol{X_4}$	WR_t	Number of whole and retail business	Discrete
$\boldsymbol{X_5}$	NPC_i	Net population change	Discrete
$\boldsymbol{X_6}$	HSG_i	Rate of change in housing stock	Continuous
$\boldsymbol{X_6}$	$RBUT_i$	Rate of change in the built-up areas	Continuous

Source: Authors analysis, 2018

Table 6.7. Summary of the logistic regression model for urban growth

							95% C.I. for Exp (β)	
Variables	**Coeff. (β)**	**Std. Error**	**Wald**	**df**	**P-value**	**Exp(β)**	**Lower**	**Upper**
Proximity to water bodies (1)	4.11	1.92	4.6	1	0.03	60.74	1.43	2589.91
No of whole and retail business	0.002	0.02	0.02	1	0.88	1.002	0.97	1.04
Building lot area	0.00	0.001	0.01	1	0.92	1.00	0.99	1.00
Distance to CBD	2.01	3.37	0.36	1	0.55	7.47	0.01	5540.66
Net population change	0.00	0.00	0.18	1	0.67	1.00	1.00	1.00
Rate of change in housing stock	-0.50	1.16	0.19	1	0.67	0.61	0.06	5.91
Rate of change in built-up area	0.69	1.15	0.36	1	0.55	1.99	0.21	18.97
Constant	-2.77	3.90	0.51	1	0.48	0.06		

Omnibus Test (LR) (X^2) = 14.66**, -2 Log likelihood = 10.35, Cox & Snell R^2 = 0.54 and Nagelkerke R^2 = 0.74

Source: Author's analysis, 2018

The performance of the logistic regression model can be ascertained if the percentage of the accuracy of the classification increases with the addition of more explanatory variables. Therefore, the explanatory variables listed in Table 6.6 were included in the logistic regression model. Table 6.7 gives a summary of the logistic regression model. The Likelihood Ratio (LR) also called the omnibus test of the model coefficients that show whether the inclusion of the independent variables contributes significantly to the model fit gives a p-value of less than 0.05. This indicates a significant improvement in the null model. The pseudo R^2 values (Cox & Snell R^2 and Nagelkerke R^2) which measure how much variation in Y may be explained by the model indicated that the model gives between 54% and 73.5% of the explanation on the variation in urban growth. The correct classification rate increased to 89.5%. That the Hosmer & Lemeshow goodness-of-fit is not statistically significant suggests that the model is highly reliable.

A detailed examination of the model coefficient shows that the most significant variable predicting growth is proximity to water bodies ($\beta = 4.11$ at alpha ≤ 0.05). The odds ratio comparing the likelihood of ward sharing boundary with water bodies to experience growth is higher than those that do not. Wards sharing a boundary with water bodies were 60.74 times more likely to experience a change in urban extent than others. The odds of a ward that does not share a boundary with water bodies to experience a change in its spatial extent over a ward that share boundary with water bodies is $1/60.74$ = 0.02, indicating that the likelihood of ward notsharing a boundary with water to increase in spatial extent is ~ 0.

Although the coefficients of other variables in the model are not statistically significant, however a detail examination of the result provides important insight into the growth process in Lagos Island. The model showed that the number of wholesale and retail business by ward has a positive influence on urban growth. The odd of change (1.00) in urban growth increases with the number of wholesale and retail businesses. This implies that the numbers of whole and retail businesses are an important predictor of urban growth. Therefore, an increase in the numbers of whole and retail businesses will correspondingly result in the increase in the spatial extent of Lagos Island. In a similar way, urban growth increases with an increase in building lot areas per square meter. However, for distance, an odd ratio of 7.47 suggests that a unit increase in distance away from the CBD indicate a probability of change in spatial extent by seven times. The same applies to the net population change (odd ratio =1.00) and the rate of change in built-up areas (odd ratio =1.99).

However, given an inverse relationship between change in urban growth and rate of change in the housing stock ($\beta = -0.50$) with odd ratio = 0.61, areas, where the rate of change in housing stock is lower are more likely to experience a change in their spatial extent. Figure 6.9, shows the rate of change in housing stock by ward in Lagos Island. Rate of change is very low mostly in ward D1, D2 and E3. It is very low in ward E3 because it is one of the wards bordering Lagos Lagoon and that is experiencing a rapid expansion of their sizes in the recent time.

Given the foregoing, it is not out of order to say that closeness to water body plays a predominant role in the spatial expansion process of any given Island. Triantakonstantis (2012) and many others had observed that the interface between land and water is very crucial to the growth of an island. Water physically and symbolically connects islands and separates them from other places (Picornell, 2014). The dynamics of separation and connectedness produced by different patterns of land-water spatiality can profoundly affect island urbanization processes (Pons et al., 2014; McElroy and Lucas, 2014; Grydehøj and Hayward, 2014 all cited in Grydehøj, 2015).

Since about 58% of the spatial units (wards) that made up Lagos Island share boundary with water bodies (Lagos Lagoon and Lagos harbour), it may be safe to conclude that geography will play a dominant role in the urban growth process of Lagos Island now and in the future. The result in table 7.7 was expressed in the form of an equation to produce a logistic regression model of the urban growth process for Lagos Island as;

$$ln\left(\frac{P}{1-P}\right) = -2.774 + 4.107CONT_i + 0.00BLD_a + 2.011ED_i + 0.002WR_t + 0.00NPC_i - 0.50HSG_i + 0.687RBUT_i + \varepsilon \quad \text{(6.19)}$$

The logistic regression equation shows that Island cities tend to exhibit a distinctive pattern of expansion. In any area where the city remains substantially restricted to either the island or the archipelago, land scarcity mitigates against sprawl, favouring instead piecemeal accretions to the existing urban fabric or the decisive establishment of dense satellite cities on nearby landmasses. As common to Island cities, as Lagos Island grows in population, socio-economic and political importance, it grows out over years into the water too.

The probability that wards sharing a boundary with water bodies in Lagos Island are more likely to experience an increase in their extent is a signal that *ceteris paribus* there will be a further extension of the land area into the Lagoon and the harbour. This occurrence will undoubtedly result in further fragmentation of the urban land. Therefore, there is the need for a proactive policy and planning strategies that will manage future urban development such that there will be synergy between transportation systems, the built environment and other ecological components. This will ensure sustainable settlement and human security particularly in this era of global warming, and changes in climatic variables that often resulted in large scale flooding in urban coastal areas. Lagos Island is notable for regular occurrences of pluvial flooding and coastal erosion. Future development must be guided in such a way that the interaction between man and the environment is beneficially harmonious.

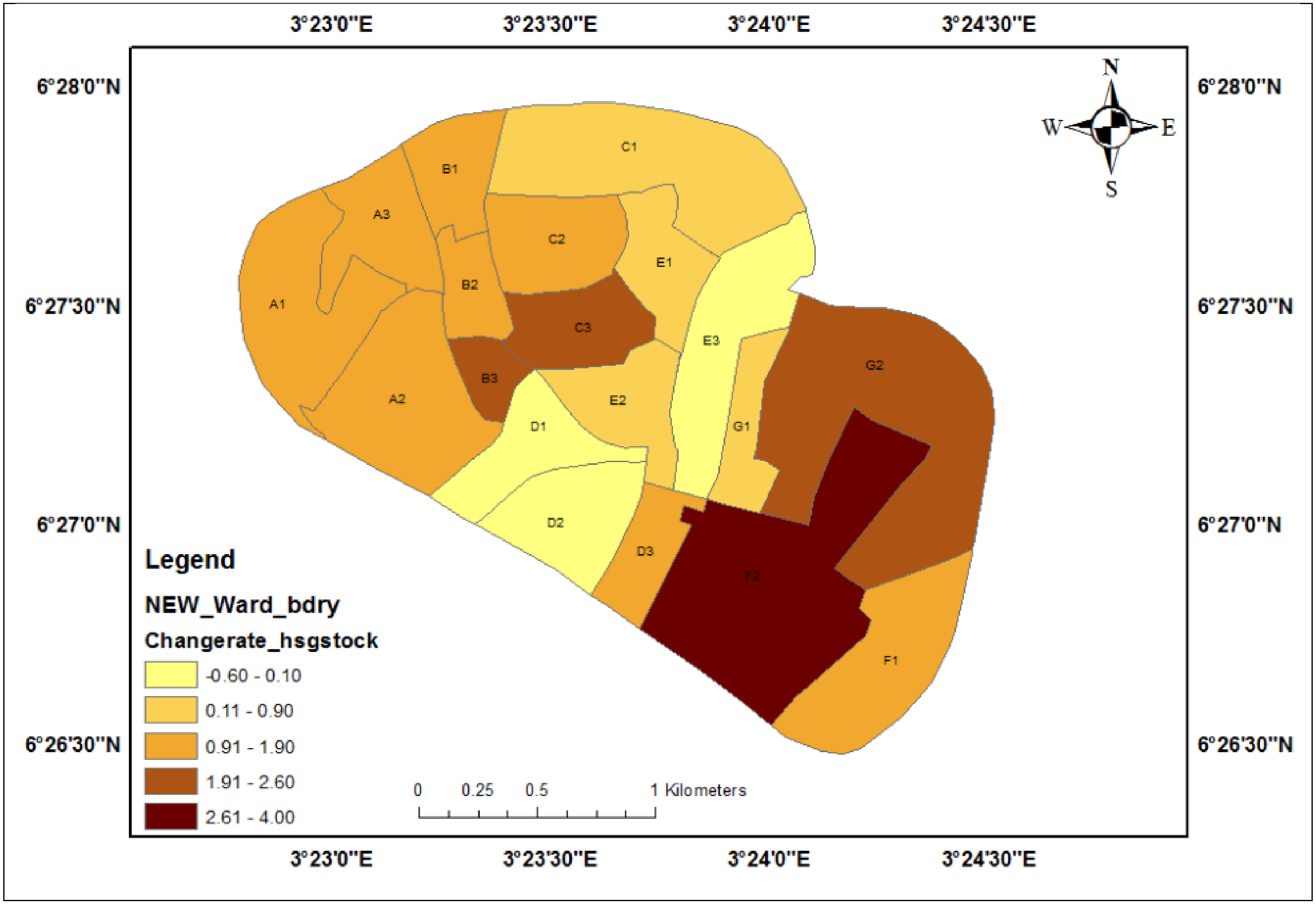


Fig. 6.9. Rate of change in housing stock

Source: Author's analysis, 2018.

6. 3: Conclusion

A fundamental achievement of this chapter is the understanding and modelling of the spatial and temporal processes of land use change in Lagos Island. Employing CA-Markov modelling technique in the GIS environment, it was found that land conversion processes, particularly the transition from non-urban to urban land are the major processes of urban land use change and consequently spatial expansion in Lagos Island. The examination of the various land cover categories and their inter-relationship confirmed, that “city behaves like a living organism and respond to the behaviour of individual independent and often smaller, more understandable sub-components that relate with one another to produce emergent structure” (Herold, Couclesis and Clarke, 2005). The driving factors of urban land use change in Lagos Island were principally socio-economic processes, particularly the increase in population and demand for space. In this chapter, it had been demonstrated that the geographically weighted regression model (GWR) could help planners in discovering specific locality in the city, where urgent planning interventions would be needed. Prediction using logistic regression showed that proximity to water bodies would be the most important factor that will shape the future growth of Lagos Island. Since occurrences of pluvial flooding and coastal erosion had become regular occurrences in Lagos Island, it is important to put in place proactive measures that will ensure that the interaction between man and the environment is beneficially harmonious in order to achieve sustainable security of humans and settlement.

CHAPTER SEVEN

URBAN VERTICAL GROWTH IN LAGOS ISLAND

7. 1 Introduction

The last three chapters were devoted to the understanding, quantification, analysis and modelling of the spatiotemporal dynamics of horizontal (2Dimensional) growth in the city. Urban growth is a complex spatiotemporal process that involves both horizontal and vertical growth. Vertical urban growth is related to the vertical building growth (Lin et al., 2014). Vertical building growth extends the urban built-up space upward through the construction of tall or high-rise buildings. A tall building is a huge volume of built-up space on a small footprint that may extend to several hectares above the city surface. A city's functions, its form and building height are three critical variables that define its spatial order (Almagor, Benenson and Alfasi, 2016). As a result, an examination of the vertical growth of the city becomes crucial for a deeper understanding of urban growth dynamics. This chapter began with the examination of the historical trajectory of urban vertical development in Lagos Island. It then proceeds to examine and explain the geographical distribution of high-rise buildings and the pattern of building heights in Lagos Island.

7. 2 Historical trajectory of urban vertical development in Lagos Island

In the West-African sub-region, there is nowhere vertical urban development is more pronounced than the Lagos Island. Many high-rise buildings used as offices by both public and private organizations distinctively define the skyline of Lagos Island. Three significant eras can be identified in the vertical development of Lagos Island, they are the pre-independence (1800-1950), independence (1950-1960) and post-independence era (1960-Present). The pre-independence era has two phases namely post-slave trade phase (1800-1900) and the colonial administration phase (1900-1950).

The post-slave trade phase was characterised by the Brazilian architecture brought by the returnee slaves from Europe and America who are of Brazilian descent. The Brazilian-style buildings were usually made of two storey houses of brick with wide windows, bright pastel colours with balcony grills, dormers, attic spaces and gardens. The windows were large with a pointed Gothic shape. At the same period, the Sierra Leoneans living in Olowogbowo and environs introduced row houses and built two storey buildings often with a shop on the ground floor. The houses were distinguished by their whitewashed stucco inside or outside and by large wooden windows in both the front and back of the house. The second phase was the period of colonial administration. At this period, the British colonial architecture prevailed. Structures were mainly wide-roofed British colonial homes made of high pointed windows and attic space. Housing structure at this period was similar to the 18th-century houses of the English countryside or prefabricated constructions with deep verandas and overhanging eaves. The tallest building at the time was a six storeys building located behind the prison on Brooke Street.

The independence era (1950-1960) sets the stage for rapid vertical development in Lagos Island. The opening of Western House (18 storeys building) in 1958, Investment house, LAPAL (Lagos Paris and London) house and the Independence house at independence marked the beginning of vertical growth of Lagos Island. The construction of independence building was significant because it was bequeathed to the country by the colonial administration to mark Nigeria independence from colonial rule. The Western House was situated at Broad Street and has a shopping mall, a huge office complex and residential quarters at the top. The development marked a departure from the kind of housing structure formerly in existence and signalled the dawn of a modern Central Business District in the city of Lagos. Other tall buildings that appeared in the late 1950s are Shell building (now National House) and Co-op Bank house (Prucnal-Ogunsote, 2015).

The post-independence period is characterised by two phases. The first is the early independence period (1960s-1980s) and the second is the period between the 1990s and the present time. At the early independence period, Lagos Island witnessed a rapid increase in the number of tall buildings. Within the first two decades after independence, there was an upsurge in the number of high-rise buildings on the Island. Virtually all government ministries, major financial institutions, corporate organizations and large multinational organizations either have high-rise apartment or occupy space in most of the skyscrapers in Lagos Island.

Table 7.1: Tall buildings and their characteristics in Lagos Island

Rank	Name	Year Constructed	Use	No of Floor	Height (Mts.)	Average floor height (Mts.)
1	NECOM Building	1979	Public	32	160	4.0
2	Union Bank Building	1991	Commercial	28	124	4.0
3	Independence Building	1960	Public	23	103	4.0
4	CBN Building 2	2013	Commercial	19	100	4.0
5	SEC Building	------	Commercial	22	83	4.0
6	National Oil	1984	Commercial	23	83	4.0
7	Energy House	1990	Mixed	25	80	3.0
8	UBA Building	------	Commercial	20	80	4.0
9	African Reinsurance	2000	Commercial	15	74	4.0
10	WEMA Bank Building		Commercial	20	73	4.0
11	Zenith Height	2006	Commercial	17	73	4.0
12	Freeman	------	Admin	18	70	4.0
13	Sterling Building	------	Commercial	18	66	4.0
14	Unity House	------	Commercial	18	63	3.5
15	Mamman Kotangora	------	Mixed	15	63	4.0
16	Savannah Bank	------	Commercial	15	63	4.0
17	Bookshop	------	Commercial	15	62	3.5
18	Fernandez Tower	1974	Mixed	16	60	3.5
19	Elephant House	------	Commercial	16	58	4.2
20	ST Nicholas	1984	Medical	15	60	3.8
21	First Bank Building	1990	Commercial	14	53	4.0
22	Abibu-Oki Court	1990	Mixed	14	52	3.5
23	NEPA Building	1964	Public	14	52	4.0
24	Stallion	------	Commercial	13	52	3.8
25	LAPAL House	1978	Mixed	13	52	4.0
26	Federal Secretariat	------	Public	13	52	4.0
27	BOI Building	------	Commercial	11	50	4.0

Source: Author’s analysis, 2018

The construction of tall buildings and high-rise office buildings at this period was because of rapid industrialization, administrative function of the city of Lagos as the federal capital of the Republic of Nigeria and accelerated rural-urban migration to the city. By the late 1970s to 1980s the skyline of Lagos Island had changed, being dotted with skyscrapers. Between the 1990s and the present time, numbers of tall buildings/high-rise apartment have increased tremendously.

Data collected from the field showed that forty-five per cent (45%) of the tall structures found in Lagos Island was constructed between 1960s and 1970s. In the 1980s about thirty per cent were constructed and between 1990s and the present period, twenty-five per cent (25%) of the structures were constructed. One significant change witnessed during the second phase of the post-independence era is the addition of more skyscrapers into the housing market in Lagos Island. Field data showed that about 8% of tall structures in Lagos Island are skyscrapers. Table 7.1 shows important tall buildings in Lagos Island and their major characteristics.

Apart from the construction of more tall structures, another important process that influenced the vertical development of Lagos Island during the early post-independence period until the present is vertical phasing and redevelopment. Vertical phasing is a process whereby developers construct first a shorter building and then add significant expansion later by increasing the building's height. Vertical phasing is an important practice in real estate development. It is a real options strategy for corporate real estate.

Further analysis of the field data showed that more than 70% of high-rise buildings in Lagos Island are not original occupants of their present space. About seventeen per cent (17%) of the high-rise was found to have displaced bungalow, while fifty-five per cent (55%) of the buildings either displaced low rise building (a structure having less than seven storeys) or were converted to high-rise through vertical phasing. Figure 7.1 shows the vertical transformations of some major streets in Lagos Island. Streets like Broad Street, Marina, Tinubu Square, Oil Mill and places like Epetedo who were once characterised by low-rise building had been vertically transformed. Majority of the tall structures found in Lagos Island are located in this area.

THEN	NOW

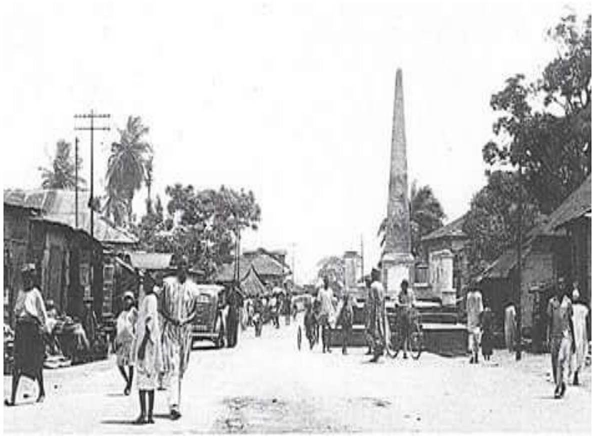
(a) Broad Street

(b) Marina

(c) Tinubu square

Fig. 7.1a-c. The vertical transformation of Lagos Island.

Source: http://life.cdn.guardian.ng; https://titiswanderlust.wordpress.com; http://venturesafrica.com; http://buzznigeria.com; www.goggle.com; https://www.google.com/culturalinstitute/beta/exhibit/ARivCwds

THEN	NOW
	

(d) Epetedo

(e) Oil Mill Street

(f) Bank of British West Africa (Now First Bank)

Fig. 7.1d-f. The vertical transformation of Lagos Island

Source:http://life.cdn.guardian.ng;https://titiswanderlust.wordpress.com; http://venturesafrica.com;http://buzznigeria.com;www.goggle.comhttps://www.google.com/culturalinstitute/beta/exhibit/ARivCwds

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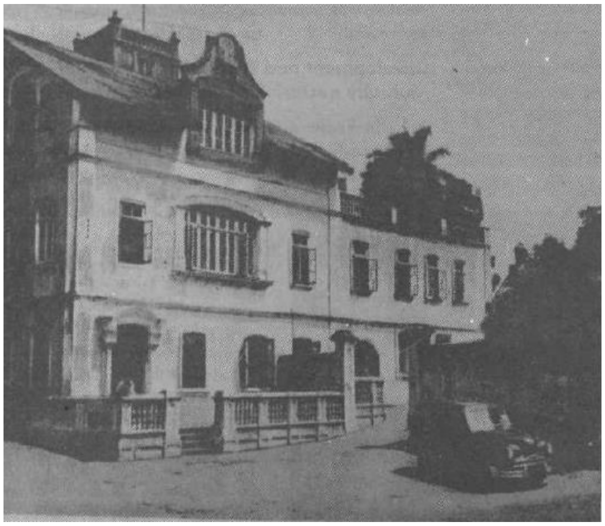
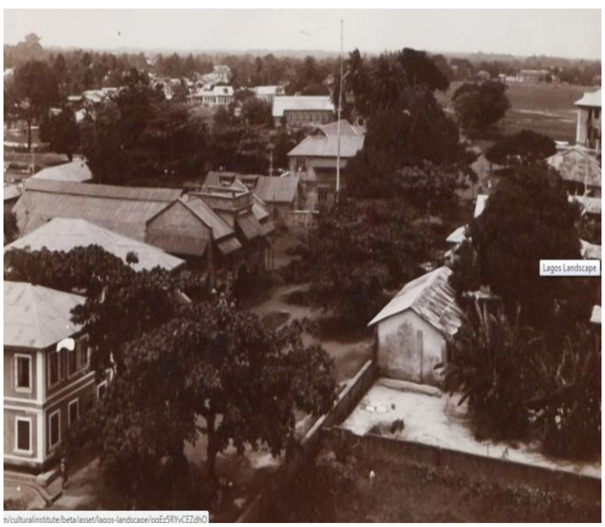


(g) Elephant house, Marina
Source: www.google.com



(h) Bird eye view of Lagos Island, 1920

Source: https://www.google.com/culturalinstitute/beta/exhibit/ARivCwds

Bird eye view of Lagos Island, 2016

Source: gettyimages.com

Fig. 7.1g-h. The Vertical Transformation of Lagos Island

A good example of vertical development through redevelopment is the transformation of one story building housing Bank of British West Africa in the Colonial period to the present fourteen-floor structure situated at Broad Marina (see figure 8.1f). Similarly, Elephant house, a sixteen-floor structure replaced a story building once located at Broad Street/Olowogbowo Street (see figure 8.1g). The bird eye view of Lagos Island in the 1920s and 2016 are shown in figure 8.1h. The figure showed a radical vertical transformation of urban space in Lagos Island.

7. 3 The Spatial distribution of high-rise building Lagos Island

The understanding of the spatial distribution of high-rise buildings is very important for a number of reasons; first, it is important for the spatial pattern analysis and identifying specific processes of urban vertical growth. Second, the measurement of the extent of the vertical growth of the city is significantly tied to the distribution of high-rise buildings. Lastly, the design and the socio-economic attributes associated with high-rise buildings provide vital information that can assist in understanding the dynamics of the city's growth. The analysis of the spatial distribution of high-rise building in Lagos Islands began with the examination of the distribution of the high-rise building types by location. This was followed by the description of the distribution of building group based on the number of floors by location.

The classification of a high-rise building by types and location in Lagos Island is shown in Table 7.2. High-rise buildings in Lagos Island were classified into four namely; existing, abandoned, under construction and under renovation. High-rise buildings classified as existing are structures that their construction is complete and has the potential for use. Those under construction are high-rise structures that their structural components are being assembled permanently on-site. High-rise buildings classified as under-renovation are completed structures that have been in use but are now undergoing renovation. Those classified as abandoned are those buildings that are not in use currently due to many reasons.

Table 7.2. Classification of a high-rise building by types and location in Lagos Island

Ward		Type of High-rise building				Total
		Existing	Abandoned	Under Construction	Under Renovation	
A1	Count	3	1	0	0	4
	%	75.00%	25.00%	0.00%	0.00%	100.00%
A2	Count	17	5	0	1	23
	%	73.90%	21.70%	0.00%	4.30%	100.00%
B3	Count	1	0	0	0	1
	%	100.00%	0.00%	0.00%	0.00%	100.00%
C3	Count	0	0	1	0	1
	%	0.00%	0.00%	100.00%	0.00%	100.00%
D1	Count	3	1	0	0	4
	%	75.00%	25.00%	0.00%	0.00%	100.00%
D2	Count	7	1	0	0	8
	%	87.50%	12.50%	0.00%	0.00%	100.00%
D3	Count	2	0	0	0	2
	%	100.00%	0.00%	0.00%	0.00%	100.00%
F1	Count	12	0	0	0	12
	%	100.00%	0.00%	0.00%	0.00%	100.00%
F2	Count	5	0	0	1	6
	%	83.30%	0.00%	0.00%	16.70%	100.00%
G2	Count	3	0	0	0	3
	%	100.00%	0.00%	0.00%	0.00%	100.00%
Total	Count	53	8	1	2	64
	%	82.80%	12.50%	1.60%	3.10%	100.00%

Pearson Chi-Square Test

Variables	Value	df	Asymp. Sig. (2-sided)
Chi Square Test	75.19	27	0.03
Likelihood Ratio	23.2	27	0.674
Linear-by-Linear Assoc.	1.98	1	0.159
No of valid Cases	64		

Source: Author's analysis, 2018

Detailed examination of table 7.2 showed that about 82.80% of the sampled high-rise buildings are existing structures, 12.50% are abandoned buildings, 1.60% is under construction and 3.10% are under renovation. Ward A2 comprising areas around Marina and Broad Street has about 36% of the sampled tall buildings. About 18.75% of these buildings were found in Ward F1, most especially in areas around King George, Onikan and Mcarthy. About 12.50% of the sampled buildings were found in Ward D2 in areas around Odunlami, Campbell and Ajele. About 9.38% of these building were found in Ward F2, particularly in areas around Tafawa Balewa Square, Okesuna and Igbosere. Others are scattered across Ward A1 (6.25%), D1 (6.25%), G2 (4.69%), D3 (3.13%), B3 (1.56%) and C3 (1.56%). Within wards, there are variations in the type of high-rise buildings. For example, in ward A2, of all the twenty-three high-rise building observed during fieldwork, 17 are existing, 5 are abandoned and 1 is under construction. In this ward, we have the highest number of abandoned high-rise buildings.

The distribution of high-rise building by group is presented in figure 7.2. High-rise buildings were grouped based on their number of floors into; (I) 7-12 floors, (II) 13-24 floors and (III) 24-49 floors. While the group I (7-12 floors) were classified as a medium-rise group, group II (13-24 floors) were classified as tall structures and group III (24-49 floors) are classified as skyscrapers. However, all building groups are generally taken as a high-rise structure based on the United States Fire Department recommendations (Moore, 2004).

Skyscrapers were found mainly in ward A2 and F2as indicated in figure 7.2. Buildings in this group are NECOM (32 floors), Union Bank Building (Stallion House) (28 floors) and Energy House (25 floors). Tall structures (a group of 13-24) were mainly found in ward A1, A2, D1, D2, D3, F1, F2 and G2. Medium-rise is a common phenomenon in Lagos Island. A Pearson Chi-square test of the relationship between the row and column produces $\chi^2 = 23.83$ at alpha > 0.05, suggesting that there is no significant relationship between location and building group.

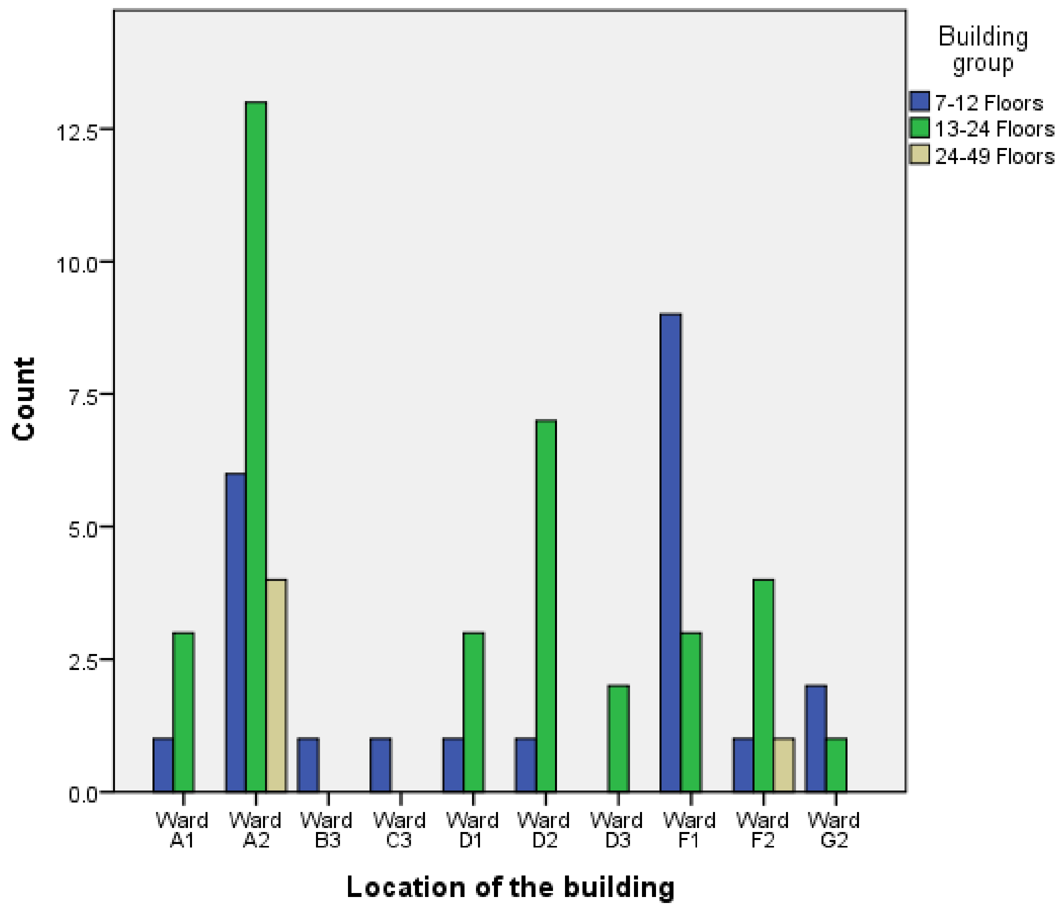


Fig. 7.2. Location of High-rise buildings by building group

Source: Author's analysis, 2018

The pattern of distribution of high-rise buildings in Lagos Island was examined in order to determine the pattern of urban vertical growth and to test the fifth hypothesis of this research that states that 'The spatial distribution of high-rise buildings is significantly random.' Average Nearest Neighbour statistics (ANN) also known as Nearest Neighbour Index (NNI) in spatial analysis extension of ArcMap 10.3 was used to test the fifth hypothesis. NNI is given as;

$$R_n = 2\bar{d}\sqrt{\frac{n}{A}} \quad \text{………………………………………………………………………} (7.1)$$

Where R_n is the description of the pattern of distribution, $\bar{d}$ is the mean distance between nearest neighbours (km), n is the number of points (high-rise buildings) and A is the area under study. The summary of the result of the nearest neighbour analysis presented in figure 7.3 showed that the spatial distribution of high-rise buildings is significantly clustered given $R_n = 0.52$ with $Z = -8.96$ and $P \leq 0.01$. Therefore, the fifth hypothesis of this research was rejected.

A detailed examination of figure 7.3 showed that high-rise buildings (indicated in red points) are clustered around the Lagos Island Central Business District (LICBD), particularly along Marina/Broad Street axis of the LICBD. Given the nucleation of points in figure 7.3, it may be safe to conclude that the vertical built-up space is compact. However, this does not have a quantitative basis because the result in figure 7.3 only showed the distribution of high-rise buildings. As a result, in the next section, attention is turned to the examination of the pattern and the spatial structure of building heights in order to measure appropriately and gain a full understanding of the urban vertical form in the city.

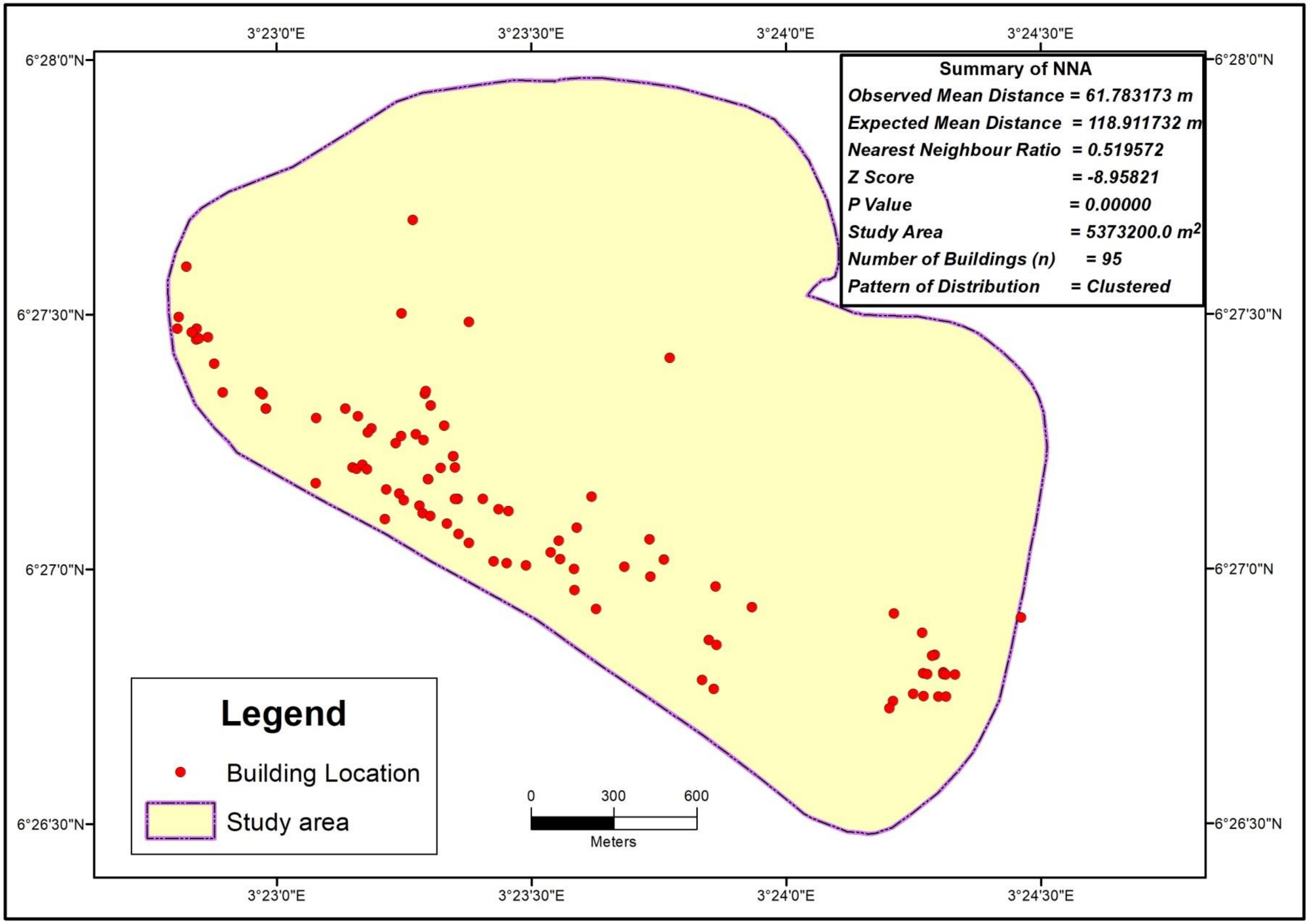


Fig. 7.3. The Pattern of distribution of high-rise buildings in Lagos Island.

Source: Author's analysis, 2018

7. 4 Pattern and structure of building heights in Lagos Island

The determination of the height of buildings in Lagos Island was achieved through direct measurement on the field. Building heights were measured from the ground up to the architectural top as recommended by the Council on Tall Buildings and Urban Habitat (CTBUH) for different types of tall buildings (see heightcalculator.ctbuh.org). This approach provides a diagnostic measurement that ignores any antennae, masts or flagpoles. The spatial distribution of buildings height by wards in Lagos Island was presented in figure 7.4. The highest mean height (63.50 metres above the ground) was found in ward A2, located within the Lagos Island Central business district (LICBD). The lowest mean height values are mainly recorded in the traditional/ low-income neighbourhood.

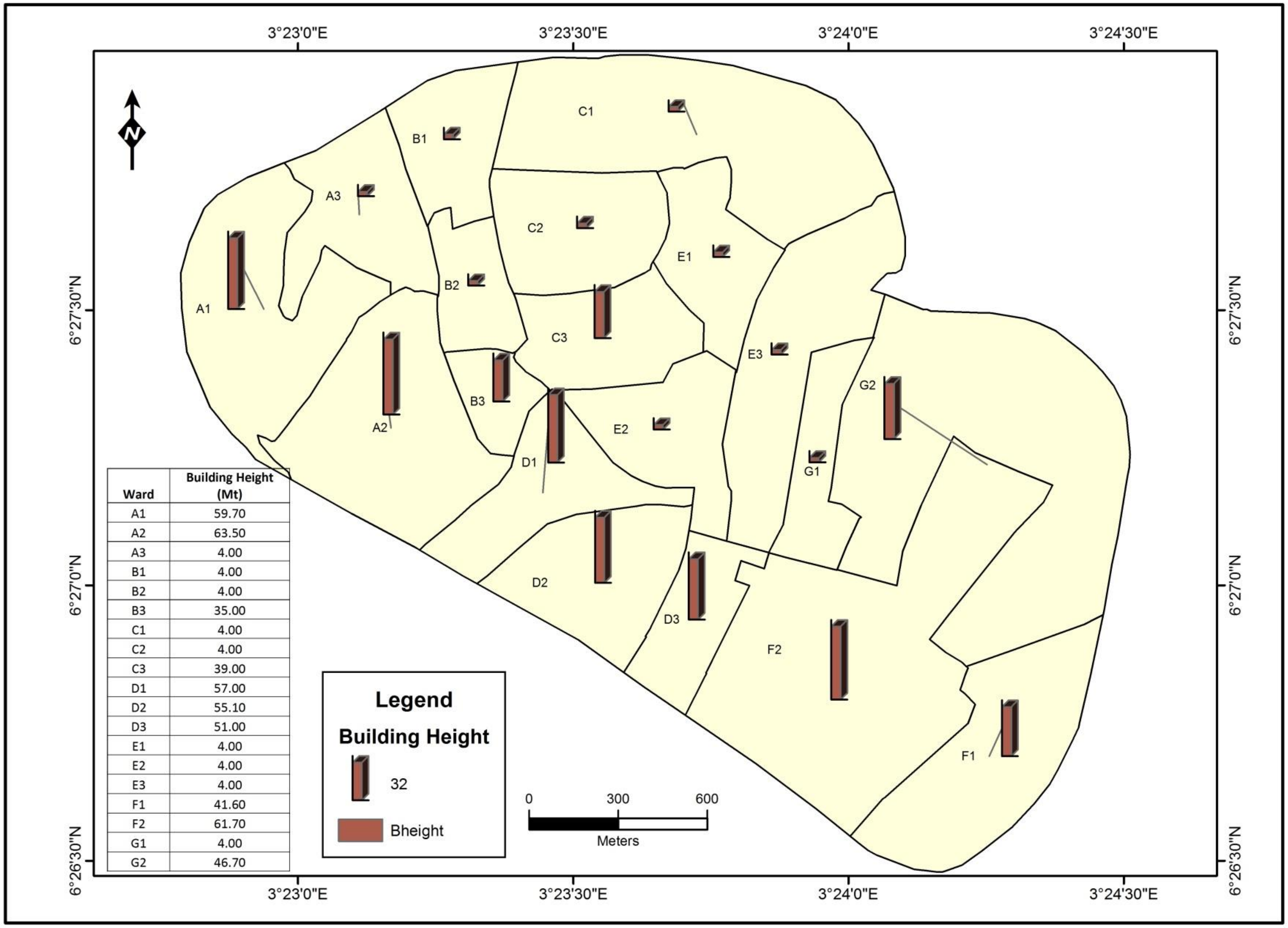
The spatial pattern of heights was determined by testing the hypothesis that states that 'In the city, building heights exhibit a significant tendency towards a clustered distribution'. The testing of the hypothesis proceeds on two levels. First, average high-rise building heights by ward were mapped in ArcGIS. The result is what was presented in figure 7.4. Subsequently, spatial autocorrelation analysis was perform using global Moran's I statistics in spatial analysis extension of ArcMap 10.4. Given a Moran's index of $I = 0.36$ with Z–score = 1.99 at $P \leq 0.05$, the result showed that the distribution of buildings heights is significantly clustered in Lagos Island. The result implied a clustered pattern of the vertical built-up space. The clustered pattern suggests a distance-decay effect in the distribution of building height. This is convincing evidence that vertical growth is concentrated in the centre of the city, but decline as distance increases away from the city centre.

The form of the city at the two-dimensional level may be monocentric or polycentric from the perspectives of classical models of urban growth. However, this has not been confirmed for the three-dimensional growth in the city. Given this backdrop, an attempt was made to determine how monocentric or polycentric the city is vertically. The classical assumption of distance gradient was examined for height and distance. The ground level is taken as the centre of the city and distances (heights) measured from the ground level to any location above the ground. A graphical plot of the relationship between average height and distance in Lagos Island was obtained, the result as presented in figure 7.5a showed a negative relationship between average height and distance with an R^2 value of 0.1. The implication is that height is concentrated at the centre and decreases with an increasing distance from the centre (LICBD). Thus, the result is in line with the view held by the classical models of urban spatial structure, that the city centre is a strategic location with economic benefits of agglomeration and strong market. The city centre attracts more activities and the presence of more economic agents that generate spatial competition. Ability and willingness to pay for land cause competition among bidders, this, in turn, raise land values. The effect is the intensive use of land through the construction of taller buildings on the more expensive land. The graph in figure 7.5a with R^2 value of 0.1, with no outlier nor evidence of a logistic trend, suggests a vertical monocentric form. Therefore, given the foregoing, it may be safe to conclude that Lagos Island has a vertical monocentric form.

Extending the analysis further, the rent-distance function was obtained by plotting the relationship between average height and land value as presented in figure 7.5b. A positive linear relationship with a correlation coefficient of 0.14 and an R^2 value of 0.02 was obtained. The plot showed that average height increases with increasing land value. Comparison of figure 7.5a and 7.5b reveals that land value exerts a positive influence on urban vertical growth. It suggests that land value is the chief driver of urban vertical growth in Lagos Island.

Considering population-height function and density-height function, a graphical plot of the relationship between total population, population density and average building height were obtained as shown in figure 7.5c and d. An R^2 value of 0.1 (R= -0.32 at $p \geq 0.05$) was obtained for population-height function. R^2 = 0.2 (R = -0.48 at $P \leq 0.05$) was obtained for population density-height function. These results indicated that both the total population and population density decreases with increasing height. Two important conclusions may be drawn from this; first, from the three-dimensional plane, it suggests that population and population density is very high at the lower floors of high-rise buildings and decreases with increasing height of the floor. This is similar to Clark (1951) hypothesis that population distribution and density decreases as distance increases away from the city centre. However, this conclusion may not be very reliable since the research did not consider population size within high-rise buildings. That may be considered for future research.

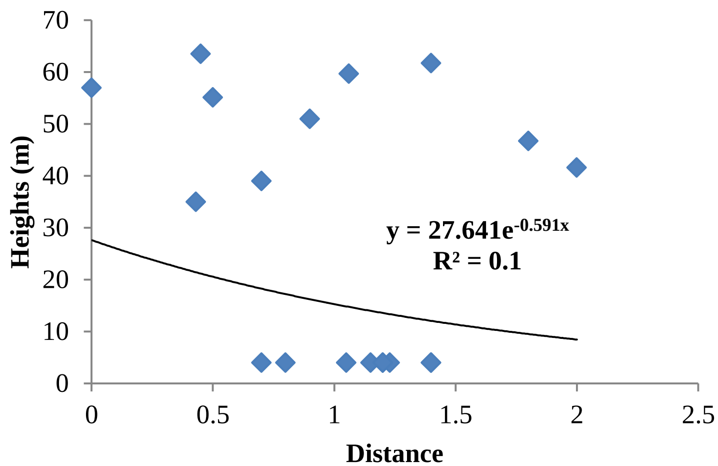
Second, the results suggest that population and population density are very low in areas where high-rise buildings are concentrated. This could not be far from the truth because the majority of the high-rise buildings in LICBD are mainly office spaces. Besides, the high rental price attached to office space at the centre tends to have a negative effect on residential function, as a result, residential activity is limited by rent. The limitation placed on residential function by rent reduces population size in areas around high-rise buildings compared to what obtained at the low-income residential neighbourhood around the city centre. Given the foregoing, It may be safe to conclude that the vertical form of the city exhibit a compact pattern, characteristics of monocentric urban form in a two-dimensional plane.



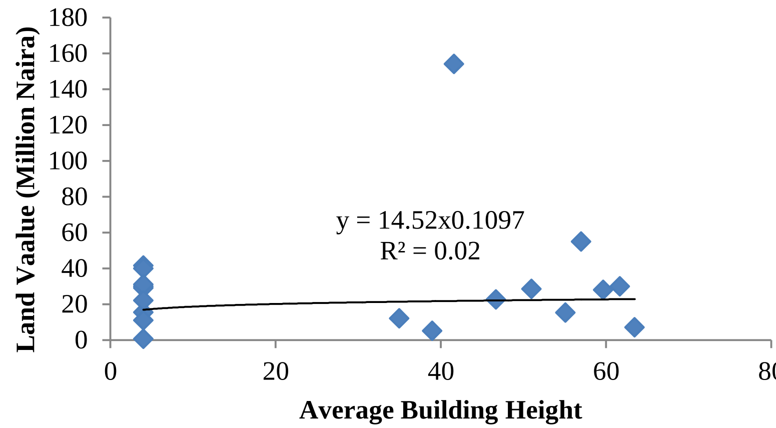
Ward	Building Height (Mt)
A1	59.70
A2	63.50
A3	4.00
B1	4.00
B2	4.00
B3	35.00
C1	4.00
C2	4.00
C3	39.00
D1	57.00
D2	55.10
D3	51.00
E1	4.00
E2	4.00
E3	4.00
F1	41.60
F2	61.70
G1	4.00
G2	46.70

Fig. 7.4. The Spatial distribution of heights in Lagos Island

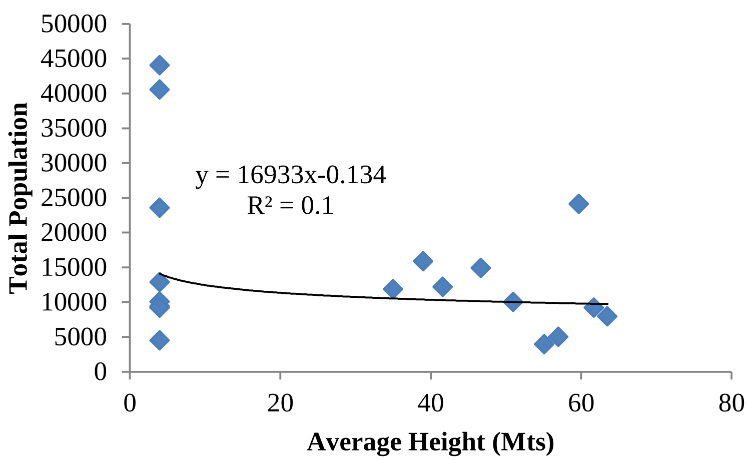
Source: Author’s analysis, 2018



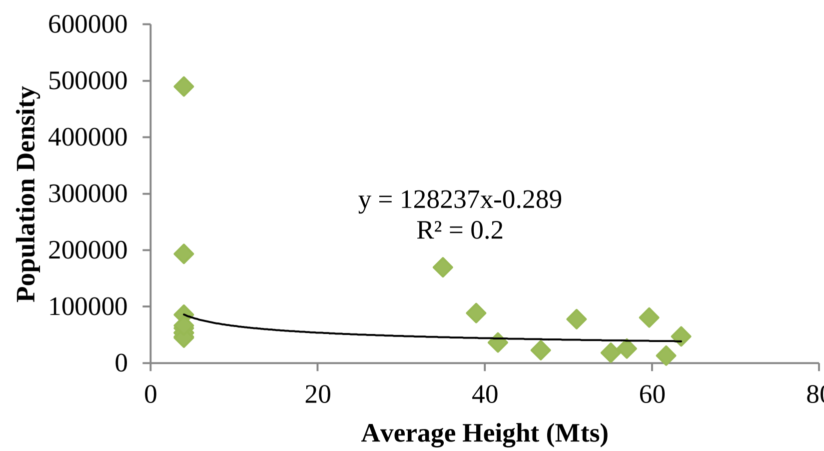
(a): Distribution of heights by distance from the CBD



(b): Average Building height by land value



(c): Height distribution by population



(d): Height distribution by population density

Fig. 7.5. The spatial structure of heights in Lagos Island

7. 5 Conclusion

Chapter seven examines the vertical transformation of the landscape of Lagos Island. During the pre-independence and the early independence period, major factors that accounted for the vertical growth of Lagos Island were found to be rapid industrialization, the administrative function of the city of Lagos as the federal capital of the Republic of Nigeria and the accelerated rural-urban migration that increased the demand for space in Lagos Island area. During the post-independence era (an era extending from the late 1970s till present), the research identified vertical phasing as the major process driven urban growth. Vertical phasing is a process whereby developers construct first a shorter building and then add significant expansion later by increasing the building's height. Vertical phasing is an important practice in real estate development.

Considering the pattern of distribution of high-rise buildings, the research found that the spatial distribution of high-rise buildings is significantly clustered. It also found that buildings height clustered in space and decreases as distance increases away from the CBD. This gives convincing evidence that vertical growth is concentrated in the centre of the city and that the built-up space above the surface is compact.

Examining the density-height relationship as a measure of the vertical form of the city, the study observed a negative linear relationship between population density and height. Two things are implicit in this; first, it suggests that population density is very high at the lower floors of high-rise buildings and decreases with increasing height of the floor. This look similar to Clark (1951) hypothesis that population distribution and density decreases as distance increases away from the city centre. Second, it suggests that population and population density are very low in areas where high-rise buildings are concentrated. This could not be far from the truth because the majority of high-rise buildings in LICBD are mainly office spaces.

A better quantitative measure of the form of the vertical city is needed to properly measure patterns and processes of urban vertical form. Therefore, in the next chapter attention is turned to the dynamical processes of urban vertical growth. This is very essential to determine the specific processes influencing the vertical growth of the city in time and in space.

CHAPTER EIGHT

MODELLING THE DYNAMICS OF URBAN VERTICAL GROWTH IN LAGOS ISLAND

8. 1 Introduction

In the last chapter, the historical trajectory of urban vertical growth in Lagos Island was examined. The pattern of distribution of high-rise buildings and the structure of building heights was also examined to describe the vertical form of urban growth. A simple measure of urban form such as density-height function was used to quantify and explain the form of urban vertical growth. However, the dynamical processes of urban vertical growth were not examined. The concern of this chapter is to quantify and explain the spatial patterns and temporal processes of urban vertical growth in Lagos Island. The chapter proceeds in four levels; first, the vertical expansion of built space in Lagos Island was measured using three-dimensional spatial index developed by Shi et al. (2009). Second, vertical entropy was calculated to quantitatively describe the physical pattern of the vertical growth of the city built space. Three the determinants or drivers of urban vertical growth were analysed and modelled using multiple regression method and lastly, a 3D model was developed to represent the transformation of the urban vertical landscape in Lagos Island.

8. 2 Determination of the urban vertical expansion in Lagos Island

The determination of the vertical expansion of Lagos Island was achieved using a three-dimension spatial index developed by Shi, *et al,* (2009). The index expressed a proportional relationship between urban vertical expansion and horizontal expansion, and is given as;

$$C = \frac{(1000 \times H)^2}{A} \quad \text{(8.1)}$$

where

$$H = \frac{\sum_{i=1}^{n}(h_i - N_i)}{\sum_{i=1}^{n} N_i} \quad \text{(8.2)}$$

Where ***C*** is a three-dimension spatial index, *H* is the average high-rise building height in metres; ***A*** is the built-up area (km²), *hi* is the height of the building with *i* stories in metre (for Lagos Island average height of a storey is 4metres). *Ni* is the quantity of buildings with *i* stories and *n* is the number of the highest story in a certain area (Shi, *et al.*, 2009). Within a given period, if the value of C increases, the direction of urban growth is vertical, but if the value of C decreases, urban growth takes a lateral dimension.

The trend of change in urban vertical expansion of Lagos Island as measured by a three-dimensional spatial index is shown in figure 8.1 and 8.2. Between the year 1984 and 2000, the mean three dimensional spatial index decreased by 11.30%, indicating a decline in the urban vertical expansion of Lagos Island and an increase in horizontal expansion. However, between the year 2000 and 2015, the mean three-dimension spatial index increased by 4.74%, indicating an increase in vertical expansion. Generally, there were local variations and fluctuating trends in the three-dimensional expansion of Lagos Island between 1984 and 2000 and between 2000 and 2015. For example between 1984 and 2000 the value of **C** increased in ward A1, C2, E2, and G1, indicating an increase in urban vertical expansion. In ward A2, A3, B1, C1, D1, E1, E3, F1, F2, and G2 horizontal expansion process increased as the value of **C** decreased. The value of **C** in ward B2, B3 and D2 remain constant.

Between the year 2000 and 2015, changes were observed in the vertical expansion process. The value of **C** in ward A2, E1, and E3 increased, indicating an increase in urban vertical expansion. However, in ward A1, B1, C1, C3, D2, F1 and G2 the values of **C** decreased, indicating an increase in horizontal expansion. In the remaining wards, the value of **C** remains constant. A captivating feature of urban vertical growth in Lagos Island as shown in figure 8.1 and 8.2 is that horizontal expansion characterises urban growth process in wards sharing a boundary with water bodies, while in wards that are mostly “landlocked”, it is a vertical expansion of urban space.

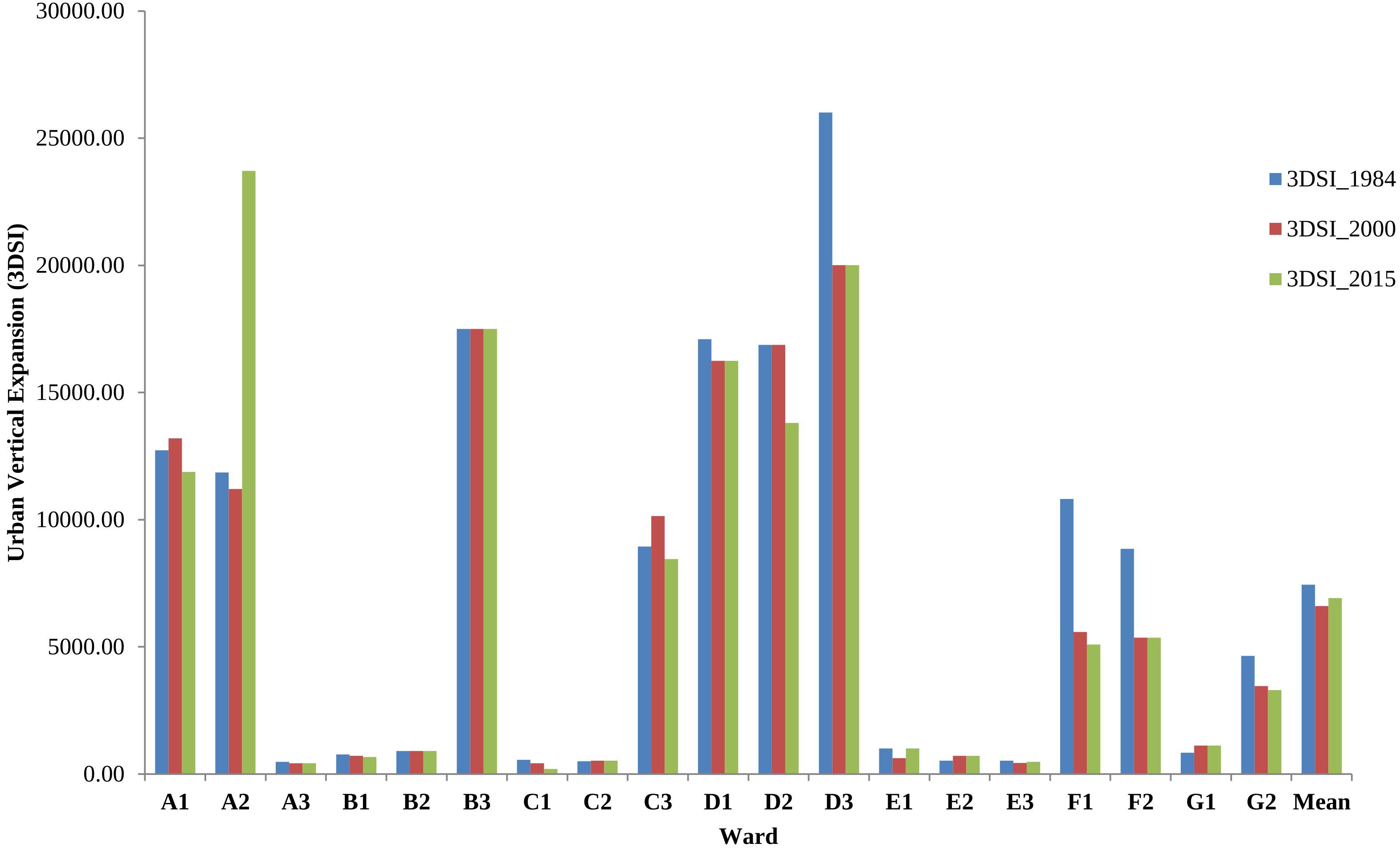


Fig. 8.1. Three-dimensional spatial index (1984-2015)

Source: Author’s analysis, 2018

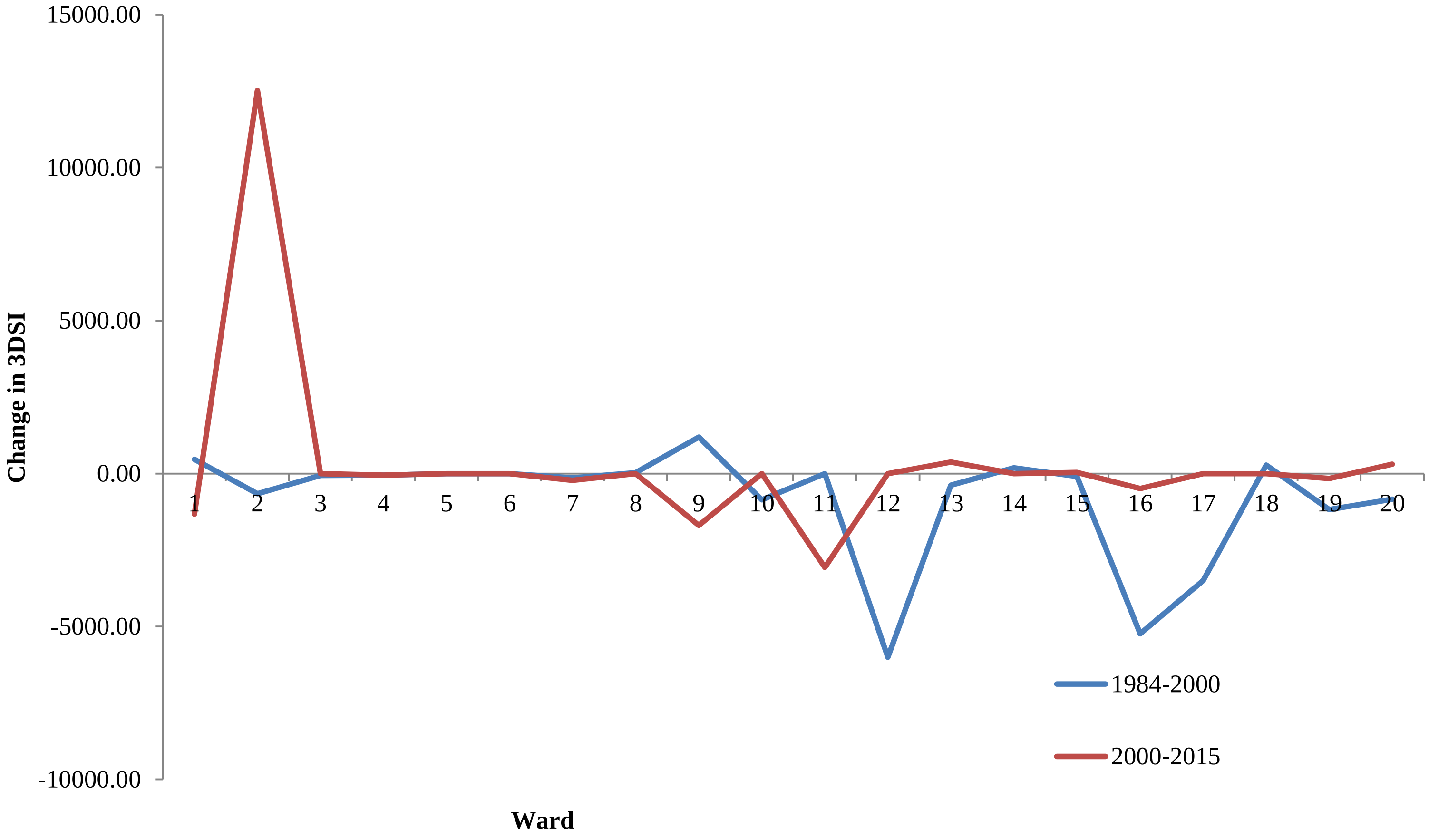


Fig. 8.2. Change in three dimension spatial index (1984-2015)

Source: Author's analysis, 2018

8.3 The complexity of urban vertical growth in Lagos Island

As noted in chapter six of this thesis, complexity refers to the higher-order phenomena produced because of interaction between various connected system's subcomponents. It describes both the dynamics (i.e., processes) and the structure (i.e., patterns and configurations) of a particular system (Batty 2005 and Boeing, 2018). The determination of the pattern and process of urban vertical growth in Lagos Island was done by investigating vertical entropy in the urban landscape. Vertical entropy is a measure developed from Shannon's (1948) theory of information entropy. Entropy measures the degree of order or disorder in a system. It is lowest when the system is highly ordered and predictable, but highest when the system's disorder is maximized (Verzosa and Gonzalez, 2010). Vertical entropy is expressed as;

$$H_n = \sum_{i}^{n} P_i \log\left(\frac{1}{P_i}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (8.3)$$

Where P_i denotes the probability of the existence of a phenomenon in the *ith* spatial unit out of *n* units. P_i is given by:

$$P_i = X_i / \sum_{i}^{n} x_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \quad (8.4)$$

Where the built-up area at time $\boldsymbol{t}$ is $\boldsymbol{X_i}$, the aggregated floor area of the built-up area is $\boldsymbol{x_i}$ and is given as;

$$x_i = N_f \times A_{bf} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \quad (8.5),$$

where N_f is the number of floors and A_{bf} is the area of the building footprint. The growth pattern is concentrated if vertical entropy approaches 0, but dispersed when entropy reaches a maximum value of log *n* (Verzosa and Gonzalez, 2010).

The built-up areas of Lagos Island in metres square, the total number of floors by year, areas of building footprints calculated from the combination of direct measurement taken from the field and from the satellite image (IKONOS) of Lagos Island were presented in table 8.1. The aggregated floor area of the built-up space and vertical entropy was obtained using equation 8.3, 8.4 and 8.5. Vertical entropy value of $\sim$0.1 was obtained for the year 1984, 2000 and 2015. The results indicated a concentrated or compact pattern of urban vertical development. Indicating a less diverse and contiguous pattern.

Table 8.1. Vertical Entropy in Lagos Island

YEAR	**Built Area in Mt^2**	**Total Number of floor**	**Area of building footprints (Mt^2)**	**The aggregated floor area of the built-up (Mt^2)**	**Vertical Entropy**
2015	4, 720,000.00	127	131,057.00	129, 091,145.00	0.06
2000	4, 550,000.00	209	27,808.03	5, 811, 878.27	0.08
1984	3, 840,000.00	985	36,724.50	4, 664,011.50	0.09

Source: Author’s analysis, 2018

Although the values of entropy for all the years were approximately 0.1, however, the value for each year differs and decreased over time. Vertical entropy decreased by 11.11% between 1984 and 2000, and by 25% between 2000 and 2015. Between 1984 and 2015 the value of vertical entropy decreased by 33.33%. The decreasing value of vertical entropy indicates that the vertical landscape is becoming less fragmented and homogenously covered. It suggests the possibility of dense vertical development in the future. Given the value of vertical entropy obtained, it may be safe to conclude that aggregation is the major temporal process driven urban vertical change in Lagos Island. Aggregation of urban vertical space occur through vertical phasing- a process whereby developers construct first a shorter building and then add significant expansion later by increasing the building's height and displacement of the existing structure by new development. The compact pattern of urban vertical development is an indication of a self-organising process and increasing complexity in the urban landscape.

The results above showed that entropy is a good measure, useful in determining the pattern of urban vertical and horizontal growth. It offers urban planners and analysts the opportunities of quantifying and describing pattern and processes of urban growth accurately. It could guide policy formulation for planning intervention. In the next section both the physical factors and socio-economic drivers influencing the vertical expansion of urban space in the city, particularly Lagos Island were examined.

8.4 Processes of urban vertical growth in Lagos Island

Processes of urban growth in this context relate to the physical and socio-economic factors driving vertical urban growth. Several factors including; population growth, demography, rural-urban migration, economic opportunities, availability and accessibility to transportation networks, social and environmental services, land use designations, land scarcity, increasing demand for business and residential space, technological advancements, innovations in structural systems, desire for aesthetics in urban areas, cultural significance and globalization have been identified as drivers of urban vertical expansion.

The identification of the specific processes influencing the vertical growth of Lagos Island was achieved by testing the fourth hypothesis of this research. The hypothesis states that 'The vertical expansion of built-up space is a function of economic (Financial sector, represented by the number of financial/insurance companies, land value and rental value), density (population density), physical (proximity to water bodies, building lot areas) and accessibility

(Average road width) variables.' Traditional OLS regression technique in SPSS was employed to analyze and model the drivers of urban vertical growth. The dependent variable for the model is the rate of change in the three-dimension spatial index. The summary of all explanatory variables used for the modelling process and their calibration is presented in table 8.2. The variables were used to develop regression equation expressed as;

$$VG = \alpha + \beta_i ECO + \beta_k PHY + \beta_\mu DEN + \beta_j ACC + \varepsilon \quad (8.6)$$

Where VG is urban vertical growth, ECO represents economic variables, PHY represents physical variables, DEN represents density variables, ACC represents accessibility variables, $\beta_i \ldots \ldots \beta_j$ are regression coefficient and ε is the stochastic error. Equation 8.6 was expanded to become;

$$VG = \alpha + \beta_i(FIN_i + LND_v + RT_i) + \beta_k(CW_T + BLT_a) + \beta_\mu(PD_i) + \beta_j(RD_w) + \varepsilon \quad (8.7)$$

The zero-order correlations for all the variables as a test of multicollinearity were presented in table 8.3. None of the correlation coefficients is greater than 0.5, as a result, the assumption of no multi-collinearity was taken. The summary of the regression model for the urban vertical growth in Lagos Island is presented in table 8.4. Detail examination of the table shows that the coefficient of relationship (R) between all the variables (both dependent and independent) is 0.81, indicating a perfect positive relationship. The coefficient of determination (R^2) is 0.66, indicating that the model provides 66% explanation about urban vertical growth in Lagos Island. The overall fitness of the model is established by the F-test value of 3.09 significant at $p \leq 0.05$.

Given $\beta = +0.68$ at $p \leq 0.05$, the result showed that the financial sector represented by the number of finance and insurance companies in different localities is the most significant variable explaining urban vertical growth in Lagos Island. Majority of the high-rise buildings in Lagos Island were found to be the corporate offices of major financial institutions in Nigeria.

Table 8.2. Summary of variables for regression modelling of urban vertical expansion

Variable No	Operational code	Description	Measurement
Dependent variable			
Y	URB_v	3Dimensional spatial index	Continuous
Explanatory variables			
$\boldsymbol{X_1}$	RD_w	Average Road width by ward	Continuous
$\boldsymbol{X_2}$	BLT_a	Building lot Area by ward	Continuous
$\boldsymbol{X_3}$	FIN_I	The financial sector (Number of finance and insurance companies by ward	Continuous
$\boldsymbol{X_4}$	CW_T	Contiguity with water	Categorical(Wards sharing a boundary with water bodies 1, otherwise 0)
$\boldsymbol{X_5}$	RT_I	Average rental price by ward	Continuous
	LND_V	Land Value by ward	Continuous
$\boldsymbol{X_6}$	PD_i	Population density by ward	Continuous

Source: Author's analysis, 2018.

Table 8.3. Relationship between physical and socio-economic processes of urban vertical growth

Variables	RD_w	BLT_a	FIN_i	CW_T	RT_i	LND_v	PD_i
Average Road width (RD_w)	1.00	-0.08	0.37	0.29	0.006	-0.11	-0.02
Building lot Area (BLT_a)	-0.08	1.00	0.29	-0.13	0.004	0.11	0.10
Number of finance/insurance Institution (FIN_I)	0.37	0.29	1.00	0.46*	-0.083	0.25	-0.16
Contiguity with water (CW_T)	0.29	-0.13	0.46*	1.00	0.275	0.51*	-0.31
Average rental price (RT_I)	0.01	0.00	-0.08	0.28	1.00	0.01	-0.12
Land Value (LND_V)	-0.11	0.11	0.25	0.51*	0.01	1.00	-0.03
Population density (PD_i)	-0.02	0.10	-0.16	-0.31	-0.12	-0.03	1.00
N	19	19	19	19	19	19	19

**** Correlation coefficient is significant at the 0.05 level (2-tailed).***

Source: Author’s analysis, 2018

Table 8.4. Summary of a regression model of urban vertical growth in Lagos Island

Variables	Unstandardized Coeff. (B)	Std. Error	Standardized Coeff. (β)	t	P-value
Constant	-6.11	3.07		-1.99	0.07
Average Road width	1.25	1.14	0.23	1.10	0.30
Building lot Area	-0.41	0.30	-0.28	-1.37	0.20
Average rent	0.57	0.24	0.46	2.33	0.04*
Financial sector	0.66	0.23	0.68	2.87	0.02*
Contiguity with water	-1.46	0.67	-0.63	-2.18	0.05*
Land Value	-0.25	0.24	-0.24	-1.02	0.33
Population density	0.00	0.01	0.11	0.58	0.57

R = 0.81

R^2 = 0.66

Adjusted R^2 = 0.45

Std. Error = 0.85

F = 3.09*

DF (Regression) = 7

DF (Residual) = 11

Total = 18

*Significant at $p \leq 0.05$

Source: Author's analysis, 2018.

The Marina/Broad Street axis starting from the foot of Carter Bridge down to the NECOM house is lined with high-rise buildings belonging to banks, insurance companies, and corporate offices of public and private organizations. Few of these buildings are used for residential function. Behind this axis, we have pockets of high-rise structure used for residential function and others for mixed uses. The positive relationship between a number of finance/insurance companies and urban vertical growth suggests that growth will continue to take upward dimension in Lagos Island as demands for office space keep increasing.

Furthermore, the result in table 8.4 also showed that average rent contributed significantly to the regression model. Given $\beta = +0.46$ at p ≤ 0.05, rent is higher where vertical growth is higher. Incidentally, the number of high-rise buildings is highest in the city centre (LICBD) where commercial activities are at the highest. Commercial activities are principal drivers of rent in the city. It may, therefore, be safe to conclude that the higher the rent, the higher the rate of urban vertical expansion in Lagos Island. Considering the contiguity factor, a significant inverse relationship between urban vertical growth and distance to water bodies($\beta = -0.63$ at p ≤ 0.05) was obtained. This result suggests that in wards sharing a boundary with water bodies, two-dimensional growth (horizontal expansion) is the dominant process.

Although other variables used in the model were not statistically significant, however, they provide a useful explanation on urban vertical development in Lagos Island. A positive relationship between urban vertical growth and accessibility as represented by average road width suggests that urban space expands upward where accessibility is very high. The inverse relationship between average land value and urban vertical growth suggests that where land value is high the speed of urban vertical expansion will be very slow. In an actual sense this does not totally invalidate the tenet of the classical theory of urban growth that says that investors will intensify the use of land by building up where land value is very high, rather it suggests that if resources are not available, vertical growth tends to go at low speed.

The negative relationship between urban vertical growth and building lot area indicated that vertical development takes place on a relatively small piece of land compared to other locations where low-rise building are constructed on a large piece of land. The population density was found to be positively related to urban vertical growth, indicating that density is higher in areas where vertical growth is intense. Cities grow upward to concentrate population and density in a relatively small space in order to maximize resources, in this case, land resources. The foregoing implies that physical and socio-economic processes are the main drivers of urban vertical expansion in cities, particularly Lagos Island.

Based on the result in table 8.3 and 8.4, equation 8.7 was developed into a model of urban vertical growth for Lagos Island, and thus expressed in the form of;

$$VG = \alpha - 6.11 + 0.68FIN_i - 0.24LND_v 0.46RT_i - 0.63CW_T - 0.28BLT_a + 0.11PD_i + 0.23RD_w + \varepsilon \quad (8.8)$$

Urban vertical growth model presented in equation 8.8 is useful for planning and policy decisions. It offers an opportunity for local planners to predict future urban vertical growth given the interplay of all processes factored into the model.

What is the probability of change in urban vertical growth in Lagos Island and how can it be determined? Using dichotomous variables, the research attempt the evaluation of future urban vertical growth in Lagos Island using binary logistic regression. This is the focus of the next section.

8. 5 Logistic regression modelling of future urban vertical growth in Lagos Island

A critical issue of concern for this research is what the implications of the present pattern and processes of urban growth in Lagos Island will be in the future, and what can or should be done about the future? This research assesses the future urban vertical growth of Lagos Island, by testing the seventh hypothesis of the research. The hypothesis states that 'the probability of change in urban vertical growth is a function of physical (distance to water bodies) and socio-economic variables (including; economic variables (population income, land use type and rental value), density variables (degree of concentration-represented by building density) and demographic variable (household size)'.

A logistic regression model was obtained using SPSS. The dependent variable; the probability of change in urban vertical growth was obtained by converting the three-dimension spatial index into dichotomous variables. The block model of the logistic regression was obtained using land use type as the only variable. The model produced;

$ln\left(\frac{P}{1-P}\right) = \alpha = -0.318$ ……………………………………………………........... (8.9)

which in turn produced an odd ratio $[Exp(\beta)]$ of 0.727 indicating that if any of the spatial unit (ward) in Lagos Island is randomly chosen, it is 0.73 times more likely to experience vertical expansion than not. The probability of growth occurring is estimated by the logistic model given as;

$P(probability\ of\ vertical\ growth) = \frac{Exp(-0.318)}{1+Exp(-0.318)} = 0.42$ ……………….…………. (8.10),

Equation 8.10 indicated that 42.0% of the wards were correctly classified and the classification from the null model is 59.7% accurate. The performance of the logistic regression model can be ascertained if the percentage of the accuracy of the classification increases with the addition of more explanatory variables, as a result, the explanatory variables stated above were included in the model. Their operational definitions had been indicated in table 8.5 and the model summary is presented in table 8.6.

From the summary of the logistic regression model in table 8.5, the omnibus tests of the model coefficients (the Likelihood Ratio (LR) test) gives a p-value (sig.) of 0.05, indicating a significant improvement of the null model. The pseudo R^2 values (Cox & Snell R^2 and Nagelkerke R^2) which measure how much variation in Y is explained by the model indicated that between 48% and 65% of the variation in urban vertical growth can be explained by the model. The correct classification rate increased to 89.5%. The Hosmer & Lemeshow goodness-of-fit that was found to be statistically insignificant suggests that the model is highly reliable. Detail examination of the model coefficients shows that the most significant variable predicting urban vertical growth in Lagos Island is the distance to the water bodies ($\beta = 0.01$ at P ≤ 0.05). The odds ratio comparing the likelihood of a ward located far away to water bodies to experience vertical growth is higher than those that do not. Ward located far away to the lagoon or harbour is more likely to experience a change in urban vertical extent by 1 unit.

Table 8.5. Operational definition of variables for logistic regression modelling of urban growth

Variables	Title	Operational Definition	Measurement
Dependent variable			
$\boldsymbol{Y}$	$PURB_v$	The probability of change in urban vertical growth	Categorical
Explanatory variables			
Physical variables $(\boldsymbol{P_v})$			
$\boldsymbol{X_1}$	$DIST_w$	Distance to water bodies	Continuous
Socio-economic variables $(\boldsymbol{SEC_v})$			
Economic variables			
$\boldsymbol{X_2}$	$AINC_p$	Average population income by ward	Continuous
$\boldsymbol{X_3}$	RT_i	Average rental price by ward	Continuous
$\boldsymbol{X_4}$	$LUSE_t$	Land use type	Categorical
Density variables			
$\boldsymbol{X_5}$	BLD_d	Building density by ward	Continuous
Demographic variables			
$\boldsymbol{X_6}$	$AHHZ_i$	Average household size by ward	Discrete

Source: Author's analysis, 2018

Table 8.6. Summary of the urban growth logistic model for Lagos Island

Variables	*B*	*S.E.*	*Wald*	*df*	*P-value*	*Exp(B)*	*95.0% C.I. for EXP(B)*	
							Lower	***Upper***
Land use type (1)	-1.12	2.58	0.19	1.00	0.67	0.33	0.00	51.82
Distance to water body (Lagoon and Harbour)	0.01	0.01	4.52	1.00	0.03	1.01	1.00	1.02
Average rental price	0.05	0.11	0.21	1.00	0.64	1.05	0.84	1.32
Building density	0.61	0.57	1.14	1.00	0.29	1.84	0.60	5.62
Average population income	0.07	0.10	0.39	1.00	0.53	1.07	0.87	1.31
Average household size	0.16	0.47	0.11	1.00	0.74	1.17	0.46	2.95
Constant	-10.72	7.08	2.29	1.00	0.13	0.00		

Omnibus Test (LR) =14.05*; -2 Log likelihood= 13.43; Cox & Snell= R^2, 0.48 and Nagelkerke R^2= 0.65

*Significant at P = 0.05

Source: Author's analysis, 2018

Although the coefficients of other variables in the model are not statistically significant, however detail examinations of the result provide important insight into the urban vertical growth process in Lagos Island. The model showed that average rental price by ward has a positive influence on urban vertical growth. The likelihood of change in urban vertical growth increases with an increase in the rental price. This suggests that high rent areas are likely to increase vertically with 1 unit of increase in the rental price. This also applies to the degree of concentration (building density), income and average household size. An inverse relationship between change in urban vertical expansion and land use ($\beta = -1.12$) with odd ratio = 0.33, indicated that areas that fall into land use zone different from commercial land use were more likely to experience a change in urban vertical expansion by 1 unit of increase in land use for commercial purposes

The result in table 8.6 is stated in equation form to form a logistic regression model for urban vertical growth in Lagos as;

$$ln\left(\frac{P}{1-P}\right) = -10.72 + 0.01DIST_w + 0.07AINC_P + 0.05RT_i + 0.61BLD_d + 0.16AHHZ_i - 1.12LUSE_t + \varepsilon \quad (9.14)$$

Given the foregoing, It may be safe to conclude that Island cities do exhibit a distinctive pattern of expansion. The result above affirmed the fact that in any area where the city remains substantially restricted to the island or other geographical phenomena, land scarcity mitigates against sprawl, favouring instead piecemeal accretions to the existing urban fabric. It also shows that growth takes a three-dimensional form where geography constrained physical expansion. Given these observations, there is the need for planning strategies that will control and guide vertical development in a way that will make Lagos Island become more habitable, comfortable and at the same time productive. A bottom-up approach planning strategy that promotes synergy among actors in urban development is the key.

8. 6 3D modelling of Lagos Island

The 3D city model is a technique for measuring, evaluating and presenting the city third dimension. In 3D city models, heterogeneous geoinformation is visually integrated within a single framework to create and manage complex urban information spaces. A major academic relevance of 3D city model is its ability to generate data for urban analysis.

Building, road and terrain information can be generated from 3D city models. A spatial query can be performed on a 3D city model to locate areas or specific building that requires planning intervention. Urban planners and designers can use the 3D city model as a tool to assess urban form. 3D city model is useful for planning urban revitalization and renewal, emergency response strategies, security and developing sustainable plans for the future. It is a useful tool for comparison of different urban design. It is also useful in the visualization of planning decisions outcomes.

In order to achieve the sixth objective of this research that aimed at modelling the vertical landscape of the built environment in Lagos Island. A 3D city model of Lagos Island was developed. For model development, socio-economic data was combined with spatial data. The spatial data used include; the coordinates of high-rise buildings and other important buildings in Lagos Island. IKONOS imagery 2013, Google Earth imagery of November 13 2000, October 7, 2008, and October 10, 2015, for Lagos Island were important satellite data used. The attribute data used include road length and width, the height of high-rise buildings and building lot area (m^2) obtained from field survey.

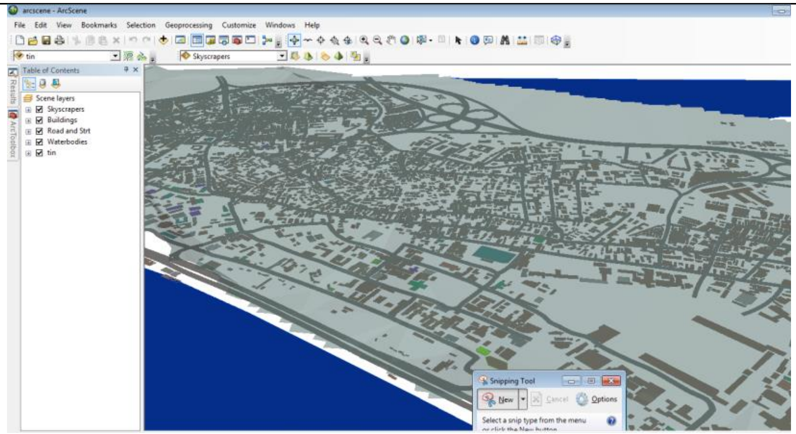
ArcGIS software 10.3 was used in building the model. Both spatial and socio-economic data were stored and arranged in a format that the software could easily recognize. Data processing follows all the sequence of image geometric and atmospheric correction, spatial and spectral enhancement and the conversion of the primary spatial data into ESRI shapefile and geodatabase. Integrity check was done using satellite imageries of the year 2000 and 2008 on that of the year 2013 and 2015. 2D image of Lagos Island was first obtained by digitizing the satellite imagery of the area, creating shapefiles and geodatabase for all the data in the ArcGIS environment (see figure 8.3a). This was done to enable the creation of 3D features. Data on road width obtained was used to create a buffer around roads, streets and buildings. The heights of buildings were used to convert the 2D features into 3D features. This gives way for the pre-model operation. The pre-model operation is essentially concerned with the creation of the triangular irregular network (TIN) for the area under consideration using shuttle radar transmission (SRTM) data of 30 meters resolution in place of X, Y and Z values.

The TIN was obtained to provide a spatial surface upon which the buildings and roads were to be constructed. The modelling then proceeded on the platform of ArcScene 10.3 and

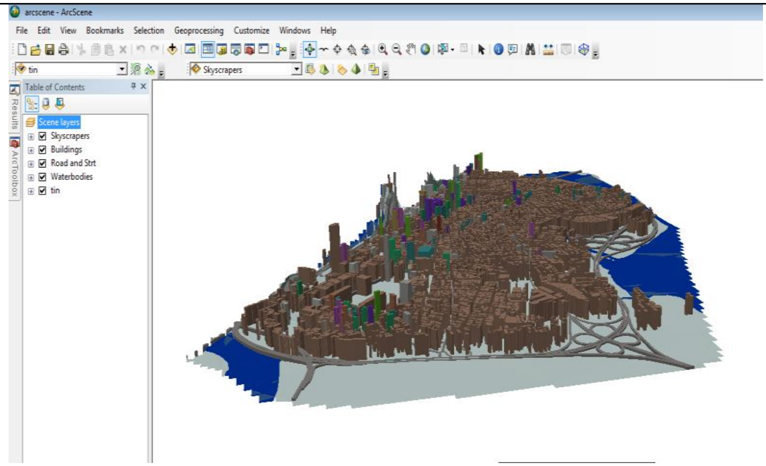
Arcglobe 10.3, where buildings and roads were drapped on the TIN with the vertical exaggeration of 41.5 meters. The buildings base heights were obtained from the TIN and the buildings were extruded using their heights (see figure 8.3b and c). Traditionally this involved checking and adjusting the light intensity on the features, the shadow smooth, the sun's angle of elevation and 3D transparent effects in ArcScene. The resultant model is a LoD1 3D city model of Lagos Island (see figure 8.3d and 8.4).

Looking closely at the model presented in figure 8.4, at the foreground is Marina/Broad Street axis, which is the major high-rise buildings corridor in Lagos Island. The open space at the south eastern edge of the Island is the race course area at Tafawa Balewa Square (TBS). Figure 8.4 showed a complex urban vertical landscape. It may be used as a measure of visual complexity in the urban landscape. Visual complexity relates to human perception of the built environment's visual coherence, scale, interest, order, legibility, and detail (Boeing, 2018). As observed by Ewing and Clemente (2013) good visual complexity in urban design depends on variety: types of buildings, design details, street furniture, signage, human activity, sunlight patterns, and the rich textural details in the urban landscape. Poor complexity exists when urban design elements are too few, too similar and predictable, or too disordered to be comprehensible (Boeing, 2018). Figure 8.4 showed a nucleated pattern of vertical development.

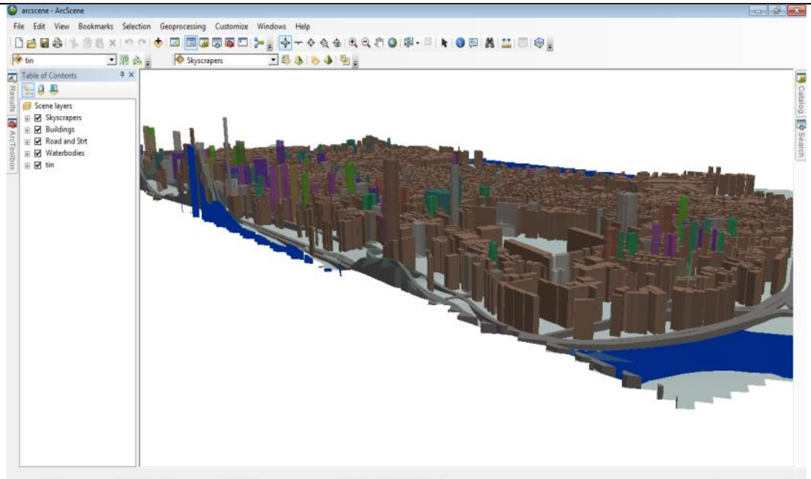
A further attempt was made at projecting into the future, by looking at what the pattern of urban landscape will be if all the buildings on the island were to be high-rise. The heights of all buildings used in the model were increased by 20 metres to convert all the low-rise buildings to high-rise buildings. The result is presented in figure 8.5. The figure showed a highly dense vertical landscape.



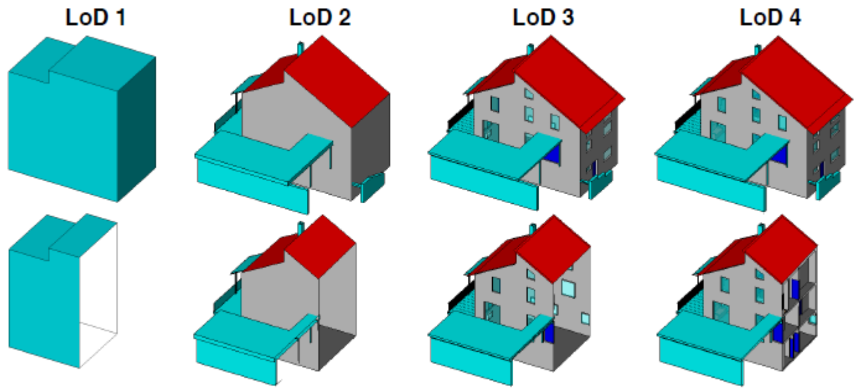
(a) Draping of 2D features on TIN



(b) Extrusion and vertical exaggeration of features



(c) 3D effect on the extruded features



(d)Level of Detail in 3D modelling

Source: Biljecki (2013)

Fig. 8.3. Stages in constructing 3D model of Lagos Island
Source: Author’s analysis, 2018.

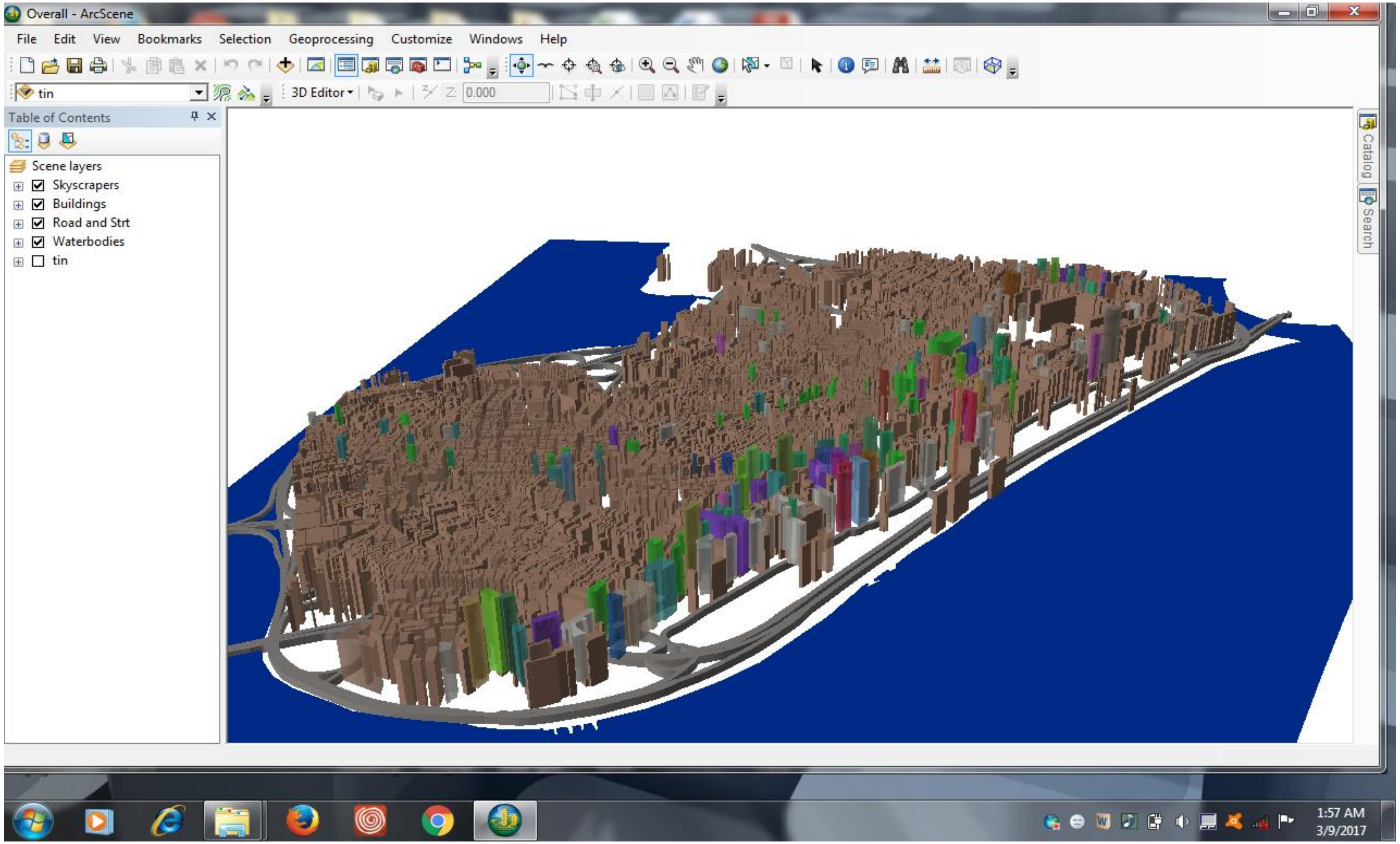


Fig. 8.4: 3D City model of Lagos Island

Source: Author's analysis, 2018.

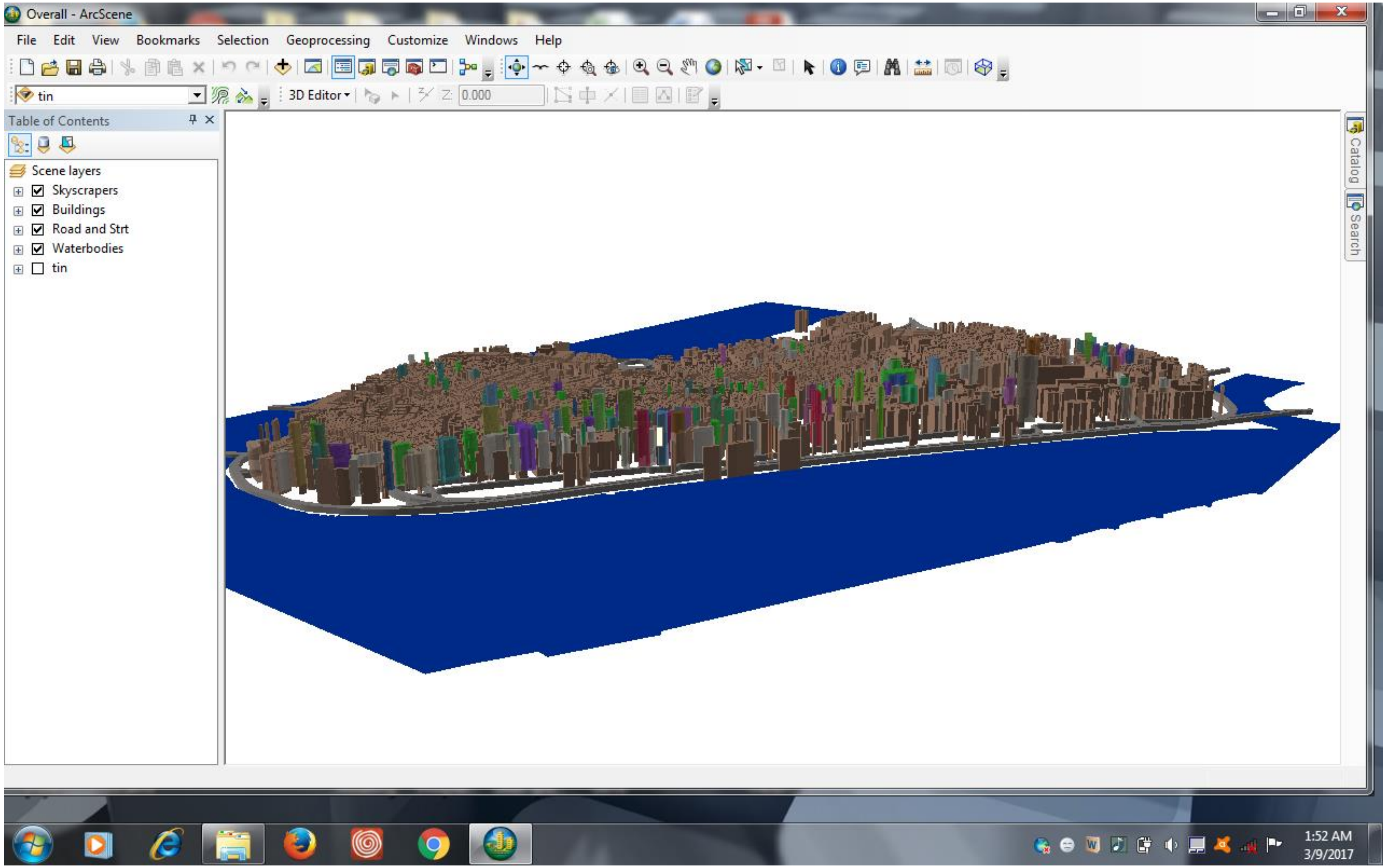


Fig. 8.5. Projected 3D City Model of Lagos Island

Source; Author's analysis, 2018.

Given the rate of vertical phasing, and the current plan by the government to encourage and build more high-rise buildings in the city of Lagos, urban growth in Lagos Island and in some other parts of Lagos city may take the form of densely populated cities in Asia and the Middle East where vertical growth occurs in an inefficient manner through vertical sprawl. Vertical sprawl is a condition of growth in an urban area that often resulted in streets lined endlessly with high-rise buildings, with the same problem of traffic congestion, inadequate parking space, poor housing conditions, inadequate infrastructure and lack of community interaction characteristic of suburban sprawl. The 3D model presented in figure 8.5 indicated the need for planning precaution and appropriate planning strategies to control vertical development in Lagos Island to avoid the development of a vertical slum.

No doubt, with an increasing population, high-rise buildings will feature prominently in the future growth of Lagos Island. Vertical expansion of urban space in Lagos Island will undoubtedly be an option for accommodating the growing population on the Island in the face of daunting challenges of inadequate land for development. Strategic real estate development through investment in high-density high-rise buildings would help in the management of scarce resources, as well as meet the demand for housing by the populace. To achieve sustainable vertical development, there is the need to create a standard for high-density vertical buildings and establish safety factors for their development. This research posits that *ceteris paribus*, Lagos Island may be developed into a container for a functionally differentiated urban development with long-term transportation planning, urban revitalisation and renewal agenda, socio-economic transformation and tourism development.

8.7 The relationship between vertical and horizontal urban growth

In line with the fifth objective of this research, the relationship between horizontal and vertical urban growth was examined. The hypothesis that states that there is a significant relationship between the horizontal and vertical urban growth was tested using the Pearson product moment correlation test in SPSS. The horizontal growth was represented by a Net change in the built-up area of the city and vertical growth was represented by the number of high-rise buildings in different localities in Lagos Island. The result gives a correlation coefficient of $R = -0.54$ at $P \leq 0.05$, indicating that outward expansion of the city will decrease with the increasing vertical expansion of the city built space through the construction of high-rise buildings.

8.7 Conclusion

In chapter eight, elaborate explanation on the third dimension of urban growth had been provided, particularly in respect of Lagos Island. A compact pattern of urban vertical growth was observed. The main process of urban vertical growth was found to be an aggregation of built vertical space through the process of vertical phasing. An important finding in this chapter is that both physical and socio-economic processes particularly number of finance and insurance companies, rental value and distance to water bodies were major drivers of urban vertical growth in Lagos Island. A highpoint in this chapter is the development of a 3D model of Lagos Island and the projection of vertical growth of the Island via the 3D City model. The model outcome showed that urban growth in Lagos Island may take the form of densely populated cities in Asia and the Middle East where vertical growth occurs in an inefficient manner through vertical sprawl.

Analysis and explanation in this chapter had shown that Lagos Island of the future might become a 3D city in which vertical and horizontal architectural urban forms merge to create a new urban form. However effective planning efforts need to be put in place to make the area a vibrant urban nucleus for socio-economic transformation of the entire Lagos city. The present top-down urban planning method fraught with inappropriate regulations and opaque policies need to be replaced by adaptable strategies to address future demand and growth.

CHAPTER NINE

SUMMARY AND CONCLUSIONS

9.1 Introduction

Major findings of this research were presented in this chapter. The research had made concerted efforts at analysing and explaining the dynamics of urban growth in Lagos Island. This was done with the view to understand and explain urban growth patterns and processes in the city. The chapter is divided into four sections; the first section summarises the findings in this research. The second section examines the conceptual and theoretical contribution of the research. The third section examines the planning and policy implications of the research. The chapter ended by discussing the direction for future research.

9.2 Review of major research findings

Findings in this research have led to some significant understanding of changes that had occurred in Lagos Island in the past three decades. In the first instance, the research assessed population change in Lagos Island and found that population increases, with increasing density and expansion of built-up areas. Important determinants of population change were found to be demography (represented by percentage change in the number of household), industrialization and employment in formal sector (represented by number of manufacturing industries), urban growth (represented by built-up areas in kilometer square), transportation accessibility (represented by Euclidean distance to the CBD), livability (represented by average monthly income), car ownership, occupancy rate and net change in housing stock. Number of households contributed significantly to the urban growth process in Lagos Island, as there is a significant positive relationship between numbers of household, sizes of the built up area and urban land area for the period of 1984-2015.

The research found that there is an increasing trend in the spatial growth of Lagos Island despite its dense built-up status. The total land area of the island estimated from Landsat satellite data was found 4.2 km² in 1984. Estimate for the year 2000 was 4.8 km² indicating an increase of 19% from what it was in 1984. The land areas increased to about 5.39km² in 2015. Spatiotemporal analysis of urban growth indicated a significant variation in the spatial expansion of Lagos Island between 1984 and 2015. The observed variation is related to increasing demand for space, for both residential and commercial activities. Built up category of the land cover classes, dominated the urban landscape. The spatial structure of the Island indicated a monocentric form. The research established the fact that significant growth processes is ongoing in Lagos Island that had been hitherto concluded to have been fully built-up.

Further, the study provided a basis for understanding and monitoring urban growth in cities of less developed countries. It emphasized the spatiotemporal analysis of patterns and processes of urban growth as the *sine qua non* for understanding and explaining urban growth dynamics. Patterns of urban growth relate to changes in the land cover/land use elements of the city and processes relate to sequences of spatial events in time. The examination of urban growth patterns and processes in Lagos Island had helped in understanding and analysing the urban spatial structure and dynamical processes influencing it. The research observed spatial clustering of built-up land parcels, indicating a compact pattern of urban development. Aggregation and fragmentation were found to be the major dynamical processes of urban growth in Lagos Island.

Population growth, housing, demand for space and building lots sizes were found to be the major socio-economic processes driving urban horizontal growth. However, proximity to water bodies, rent, commercial activities, and the number of financial and insurance companies were major drivers of vertical urban growth in Lagos Island. The identification of these socio-economic processes provided a means of understanding, modelling and predicting the future growth of Lagos Island.

The study modelled the spatial and temporal processes of urban growth in Lagos Island using Land Change Modeler (LCM) in IDRIS GIS. The urban system was divided into three subsystems comprising of developed (built-up areas), non-urban (including vegetation and water bodies) and developable (Open surface) urban systems. The study found that urban growth is a conditioned process involving the process of change from non-urban to urban land use. The probability that vegetation will transit to built-up class was found to be 0.16, open surface is 0.1 probable to change to built-up class and the probability that water class will transit to built-up class is 0.66. The implication is that Lagos Island will continue to experience a slow but steady increase in extent spatiotemporally.

Though the land use transition model from GIS predicted a decline in built-up areas of Lagos Island by 2031, the model indicated that the built-up class will still dominate the urban landscape. The model projected that Lagos Island may lose about 12.49% of its present built-up areas by 2031, translating to about 0.55 km² of its built-up space. This suggests a possibility of an effect of natural factors such as flooding and or coastal erosion that may affect the built environment negatively resulting in urban decline. Similarly, future planning and policy actions toward urban revitalization, regeneration and renewal may also result in loss of some proportion of built-up areas.

Substantiating the above claim, the logistic regression model of urban growth showed that proximity to water bodies ($\beta = 4.107$ at $\mathrm{p} \leq 0.05$) is a significant predictor of future urban horizontal expansion. The odds ratio comparing the likelihood of ward sharing a boundary with water body to experience growth is higher than those that do not. Wards sharing a boundary with water body were 60.74 times more likely to experience a change in their extent. The probability of wards at a distant location to water bodies to experience change (positive or negative) in their spatial extent is not up to 1.00.

An important finding in this study is the presence of spatial heterogeneity in the spatial and temporal growth of Lagos Island. Spatial heterogeneity in urban growth concerns local differences in urban growth experiences at various spatial units (wards) of the urban system. The study using geographically weighted regression (GWR) generated parameter estimates of growth factors for every ward in Lagos Island. The parameters generated were mapped to show where each factor holds a strong influence on urban growth. This helped in advancing the understanding of urban growth processes at the local levels.

Considering the dynamics of urban growth in Lagos Island, the study found that between 1984 and 2000, the rate and dimension of horizontal expansion was higher, but between 2000 and 2015, the vertical expansion of urban space increased. The analysis of the distribution of high-rise buildings and heights in Lagos Island using nearest Neighbour statistics and method of spatial autocorrelation showed that high-rise buildings and height clustered in space. This suggests a compact pattern of urban vertical development. Similarly, given a vertical entropy value of ~ 0.1 for all the years under consideration, urban vertical growth in Lagos Island was found to be less diverse, as a result, compact in nature. A 3D city model of Lagos Island was developed in GIS to model the built landscape. The result showed a very complex vertical landscape. Projecting the vertical landscape, the research found the possibility of development of vertical sprawl in the future growth of Lagos Island.

Finally, the research examined the relationship between horizontal and vertical urban growth. The number of high-rise buildings by wards represented vertical urban growth and horizontal growth was represented by the net change in built-up areas. A test of relationship using Pearson product moment correlation showed a significant negative relationship between horizontal and vertical growth. This result suggests that the outward expansion of the city will decrease with the increasing vertical expansion of the city. Generally, the study provided a conceptual basis for the analysis of urban growth and its associated problems in the city. Its contribution has conceptual and theoretical relevance. It also has planning and policy design implications, hence these are considered in the subsequent sections.

9.3 Conceptual and Theoretical contribution

The study examined the dynamics of urban growth from the perspectives of complexity theory and classical theories of urban growth. Complexity theory hypothesizes that systems having a large number of seemingly independent agents can spontaneously order themselves into a coherent system. Put in other words, pattern manifested by a complex system may be explained by the self-organising outcomes of local interactions between several elements that made up the system under the influence of global factors. The interaction between multiple entities of the urban system is guided by bottom-up processes rather than top-down decision-making processes. Unlike the static classical theories that assume equilibrium in the city's system, the city is a non-equilibrium and ever-developing system in the perspective of complexity theory.

The study viewed urban growth as a system, made up three sub-systems including developed (built-up class), non-developed (vegetation and water class) and developable (reclaimed land and other open surfaces) urban systems. Each of these systems is made up of several patches (discrete areas of homogeneous environmental conditions). Interactions between these subsystems result into the transition from one states another. This transition is a bottom-up process characteristic of a complex system.

The emergent behaviour arising from the interaction among several subsystems of the urban landscape is what is referred to as complexity. This applies to both the processes and patterns/configurations of the landscape. The study explained the clustered or compact pattern of urban development in Lagos Island as a higher order phenomenon produced by interactions among various subcomponents of the urban system. Clustered development is a global spatial pattern arising from the coalescence of urban built-up clusters. The study measured and analysed temporal, spatial and structural complexities in urban growth using several measures, particularly those developed from Shannon's (1948) information theory including Shannon's diversity index (SHDI) and Shannon's Evenness index (SHEI) used in measuring spatial complexity, and vertical entropy used in measuring complexity in urban vertical growth. The concept of fractal and fractal dimension index was applied to determine and explain the dynamics of urban form in Lagos Island. Given the fractal dimension index of > 1.00, the study described Lagos Island as having a highly convoluted urban form, indicating a highly complex urban shape.

The application of complexity theory to the explanation of urban growth in this study is considered a modest contribution to the global discourse on the capacity of complexity theory to provide a sound theoretical basis for the explanation of urban systems. The study posits that complexity theory represents a paradigm shift in the study of urban growth. It is an indispensable approach in urban systems analysis and urban planning and design.

Finding from this study corroborates the views of the classical theories of urban growth. The concentric and sector theories viewed the growth and spatial structure of the city from the monocentric perspective. However, the multi-nucleation theory viewed city growth and structure from a polycentric perspective. Applying the concentric and sector theories, the study identified three distinct districts in the urban land use structure of Lagos Island. The first district is the commercial centre that runs North-West to Southeast along Marina and Broad Street. The second district consists of the civic and old merchant areas of Bamgbose, Igbosere (where the High and the Supreme courts are situated) and Tafawa Balewa Square (the old race course) that housed major social institutions located in Lagos Island. The third district is the traditional residential area of the city towards the North of the Island, around the Oba's palace. The third district is more of mixed-used consisting of commercial and residential land use with the latter accounting for more than 70 per cent of the land use. The study found an uncompromising and multi-dimensional layered land use pattern that epitomises the complexities, contradictions, creativeness and cultural dynamism of Lagos Island.

Deficiencies in classical urban land use theory are their over-simplicity and lack of mathematical rigour in the analysis of the urban spatial structure. To address this problem, the study used the method of the classification of the clusters of urban built-up pixels (the smallest item of information in an image as regard built-up areas) as suggested by Angel, (2005) to describe the spatial structure of Lagos Island. The result indicates a shift to mono-centricity, emphasizing the relevance of classical theories of urban spatial structure.

The study considered the issue of spatial local heterogeneity in urban growth. Spatial local heterogeneity refers to a condition in which the value of an attribute at one unit is different from that of its surrounding. It is a way of conceptualizing and understanding local variations in the distribution of geographical processes. The issue of spatial heterogeneity in urban growth has not received serious attention in urban systems analysis until the recent advancement in the techniques of GIS and remote sensing. Using geographically weighted regression, the present study examined spatial heterogeneity in urban growth in Lagos Island and showed that urban growth is spatially dependent, that the rate of growth in one location is strongly influenced by values in the neighbouring spatial units. The presence of local spatial heterogeneity is an indication that the urban system is complex. It is, therefore, necessary that urban planning and design should take cognizance of this spatial property of urban growth when providing model plans for cities.

The examination of the vertical dimension of urban growth is considered a high point of this research. Urban research has focused too much on the horizontal dynamics, neglecting the vertical dimension of urban growth. The study looked at the pattern of urban vertical growth and found a compact pattern of urban development in Lagos Island. Specific drivers of urban vertical growth were identified and model of urban vertical growth that may be useful in understanding the dynamics of urban growth was developed. A 3D city model of the urban landscape was also developed to represent the built landscape and to demonstrate visual complexity in the urban landscape.

Finally, the study makes its modest input into the gamut of researches that focus on the integration of remote sensing and socio-economic data in land use change model application for urban environments. The study showed that the analysis of specific socio-economic indicators of urban growth can complement land-use change detection analysis (Pontius et al., 2013) and thereby expand the frontier of spatial analysis.

9.4 Planning and policy implications of the research

Findings from this research have implications for planning and policy. The ultimate goal of urban planning is to provide immediate and long term solutions to various problems of the city. This requires proper identification of the planning problems and a strong methodology to cope with the problems identified. In this regard, some pertinent planning questions were asked. First, is Lagos Island growing spatially? Second, how is Lagos Island growing and what is the nature of this growth? Third, in what ways can urban growth in Lagos Island be monitored and managed? Lastly what specific urban planning strategy is suitable for conceptualising and monitoring the future pattern of urban growth?

The first question relates to the spatial expansion of Lagos Island. Using the methodology of GIS and remote sensing, the present study had demonstrated that Lagos Island is expanding its urbanised area; hence, the unconfirmed speculation and questions about the supposed static nature of Lagos Island had been answered. The second question relates to the patterns and processes of urban growth. Two major planning problems have been identified with regards to this. First, there is disproportionality between structural growth and population growth due to the topographical constraint that limits horizontal urban expansion. Usually approach often used by the government to address this problem is to create more land by piecemeal accretion through the reclamation process. In this way, development is forced into vulnerable areas, particularly areas closer to Lagos lagoon and the sea. A good example is an on-going reclamation at Ilubinrin settlement at the north-western corner of Lagos Island. Land reclamation results in fragmentation and increased development in the urban landscape. Increased development in Lagos Island had resulted into a compact high-density sprawl with concomitant problems of poor housing standard, poor environmental condition, difficulties in achieving and maintaining normal traffic flow or circulation and perennial pluvial and coastal flooding.

The second is the increased vertical expansion of urban space. The built environment has been expanding upward through vertical phasing and construction of more high-rise buildings, of which their management, uses and maintenance pose threat to urban sustainability. Vertical phasing is a corporate real estate strategy by which the addition of five or more stories are made to an existing development (Guma, et al, 2009). Vertical phasing and the construction of high-rise buildings had been on-going for years without proper monitoring and evaluation. This has often resulted in incidences of collapse building with attendant loss of life and properties. Generally, the growth and development of Lagos Island over the years had occurred without adequate attention given to planning and proactive management. The Island had witnessed years of neglect, abuse and abandonment that have turned it into a dirty, poor, unhealthy, crime-ridden, expensive and environmentally unfriendly area due to poor public policy, government inactions and effect of market forces.

With continuous urban population growth and dwindling land resources in Lagos Island, the increasing rate of vertical development is inevitable. This invariably calls for a new approach to planning and urban management. The traditional top-down city planning approach being practised in the years past had proved insufficient. A balanced approach to planning that involved a democratised and inclusive citizen engagement combined with a more centralized planning effort will help in managing and making Lagos Island a healthy, liveable, environmentally friendly and rich area. Complexity holds the key to achieving this balanced approach to planning.

The third planning question concerns the appropriate planning methodology for monitoring and managing urban growth. The present study conceptualises urban growth within the framework of complexity theory. Complexity theory has significant implications for urban planning. It provides a more radical and rigorous conceptualisation of planning. This conceptualisation involves detailed analysis and full appreciation of the interrelationship between various subcomponents of urban systems. Land cover classes, government, firms, planning organisations, estate developers, property owners, household and individuals are actors in the urban landscape. The interrelationship between these various actors will undoubtedly result in the emergent property of the landscape with feedback loops.

Ideas from complexity theory were found useful in gaining insight into the design of the urban system as a whole. It can help in developing bottom-up model plans. Results from the application of spatial metrics to the analysis of urban growth in this study have shown that spatial metrics provide working tools for urban planners and designers in assessing complexity in the urban landscape. They are useful in assessing urban performance, resilience, adaptability, connectedness, and liveability. Similarly, the analysis of local spatial heterogeneity in urban growth in Lagos Island revealed a complex interplay of processes of urban growth in various local autonomous spatial units that made up Lagos Island.

Complexity theory offers two possible approaches to urban planning problems. First is the urban development strategy that is based on the application of simple spatial laws. In this approach, for example, government set laws and regulations that guide the behaviour of actors in the urban sector, but not necessarily over-regulates. Agents or actors are allowed to make decisions and actualise their own urban plans within the framework of the spatial rules or standards set by the government.

The second approach is a participative, collaborative approach to urban development. The approach is essentially built on the principle that no one actor has the capacity to control the system outcomes, as a result, collaborative efforts of urban actors will ensure a beneficial evolutionary development of the city (Crawford, 2016). All actors are involved in urban planning objectives and shared a commitment to actualising the objectives of urban development. They also have a similar understanding of development in the urban system through feedback loops. The foregoing showed that urban systems analysis and planning can be enriched with complex systems thinking. It can help in the assessment of urban environmental performance and supports inform decision-making processes as regards urban development.

The fourth question concerns the planning approach for the future development of the city. Since planning is all about managing the growth of towns and cities for future sustainable development, the study believes that it is high time to shift spatial planning and policy to vertical urban development in Lagos Island. This will help in accommodating the growing urban population not only in Lagos Island but in the entire city of Lagos. Currently, the government of Lagos State has started thinking towards that direction. The Isale Igangan urban renewal effort in Lagos Island and Eko Atlantic city in Eti-Osa local government is a case on point here. Eko Atlantic city is a planned vertical development that is being constructed on a reclaimed expanse of Land in an area around the Atlantic Ocean. The government also has the plan to turn Ikoyi, Victoria Island and other notable localities in Lagos State to high-rise axes. If this is going to be realized, there is the need for the review of the present planning approaches adopted by the government

The goal of this study is not to propose a specific development plan for Lagos Island. That is beyond the scope of this research. However, it is advised that given the rapid rate of incursion into the surrounding Lagoon, the ocean and wetland in Lagos, environmental planning regulations and housing design strategy that meets the carrying capacity of the land area must be put in place to avoid future disaster. Government, planning agencies, developers and individuals have the responsibility of adhering to planning standards to ensure environmental and human safety in Lagos Island. Specifically, planning strategies that will achieve the right balance between horizontal and vertical growth is needed. A combination of strong urban containment policy to discourage development into vulnerable areas and promote vertical growth through the construction of tall buildings and the greening on urban buildings is what is needed to be put in place.

Although going vertical is not being suggested here as a utopian ideal to solving planning problems, however, the basic fact is that if we can achieve more vertical growth, there will be less need for horizontal growth and much of the problems that city administrators and government are grappling with will be resolved. Vertical development requires an advance strategy. It must be approached with caution less there is the development of vertical sprawl and slum in Lagos Island and other cities of Nigeria.

Finally, it is hoped that this study will serve as a suitable reference for researchers, data analysts and students who are interested in urban growth research. It is also hoped that this study will give decision-makers better information from which to implement good urban growth policy not only for the large metropolitan area but the inner cities that are suffering from continual neglect by policymakers and administrators.

9.5 Conclusion and direction for future research

Important areas for future research may be identified in this study. First, complexity theory as a generalised universal systematic philosophy is relatively an emerging science which its applications in the fields of urban planning and management have not received adequate attention (Cheng, 2003, Crawford, 2016). The applications of complexity theory in urban system analysis, ecology, economics and other disciplines of social sciences research have made great progress in the developed world. Researches had shown that complexity theory and its related methods have great potential for urban growth planning and management.

Application of complexity theory to different aspects of urban systems analysis need to be explored extensively in developing countries. Limitations to this abound, particularly in the aspect of a data challenge, however, this can be surmounted with a concerted effort on the part of both the academic community and the government. Secondly, the dynamics of the population within high-rise in Lagos Island need to be studied. This will enable a clearer understanding of the level of densification process in Lagos Island. Also, the within the building condition in high-rise building need an examination to investigate, the appropriateness of high-rise building and how well they can serve an urban population.

Given the outcome of this study, the thesis of this research is thus stated as follows; 'In highly built-up metropolitan areas, where geographical constraints limit horizontal development, both horizontal and vertical growths occur simultaneously. However, land scarcity mitigates against low-density sprawl, favouring instead piecemeal accretions through the process of land reclamation that often result in the fragmentation of the urban landscape, thereby producing a compact high-density sprawl.'

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APPENDIX I

Table 1. ZERO-ORDER CORRELATION FOR THE DRIVING FACTORS OF POPULATION CHANGE IN LAGOS ISLAND

	$LogNPC_i$	AI_i	CHH_i	ED_i	OCC_r	BUT_i	$NMFD_i$	CAR_i	$NHSG_i$	RD_i
Log of Net Change in Population ($LogNPC_i$)	1.00	0.06	0.38	0.45	0.33	0.19	0.18	-0.25	0.50*	-0.18
Average monthly Income		1.00	-0.04	-0.31	0.13	0.15	0.43	-0.08	-0.25	0.39
% change in Household number (CHH_i)			1.00	-0.07	-0.12	-0.23	-0.09	0.09	-0.02	0.00
Distance to CBD in Km (ED_i)				1.00	-0.11	0.11	-0.19	-0.28	0.37*	-0.40
Occupancy rate (OCC_r)					1.00	-0.33	0.04	-0.27	0.13	0.26
Built up area in Km² (BUT_i)						1.00	0.00	0.27	0.22	-0.24
No of Manuf. Industries ($NMFD_i$)							1.00	-0.04	-0.16*	0.08
No of car owners by ward (CAR_i)								1.00	0.06	0.28
Net change in housing stock ($NHSG_i$)									1.00	-.11*
Road Density (RD_i)										1.00

*. The correlation coefficient is significant at the 0.05 level (2-tailed).

Source: Author's Analysis, 2018

Table 2. ZERO-ORDER CORRELATIONS OF DRIVERS OF URBAN GROWTH

Variables	**BHT**	**BLOT**	**HSTOCK**	**DIST**	**POPGROWTH**	**ANROOMS**
Average Building Height (BHT)	1.00	0.11	-0.14	-0.25	-0.01	-0.11
Building lot Area (BLOT)		1.00	-0.01	-0.17	0.13	0.26
Housing Stock in 2015 (HSTOCK)			1.00	0.39	0.23	-0.24
Distance from CBD in meters (DIST)				1.00	0.42	-0.14
Population growth in Lagos Island (POPGROWTH)					1.00	-0.01
Average number of rooms used by households (ANROOMS)						1.00
N						19

Source: Author's Analysis, 2018

APPENDIX II

TABLE 3: MEASURES OF COMPLEXITY IN URBAN GROWTH

S/N	METRICS	EQUATIONS	DESCRIPTIONS AND USES
1	AREA	$AREA = a_{ij}\left(\frac{1}{1000}\right)$	**Patch Area-** The area of each patch comprising a landscape mosaic.
2	CA	$CA = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{10{,}000}\right)$	**Class Area-** A measure of landscape composition used in computing many of the class and landscape metrics. It is an excellent way of analysing and comparing the development and change extent of the built and non-built-up landscape.
3	PLAND	$PLAND = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	**Percentage of the landscape** – It is a metric used in assessing the proportional copiousness of each patch type in the landscape.
4	NP	$NP = n_i$	**Number of patches-** a measure of landscape fragmentation
5	PD	$PD = \frac{n_i}{A}(10{,}000) * (100)$	**Patch Density** A measure of landscape pattern.
6	PR	$PR = m$	**Patch Richness-** Determines rich the landscape in terms of patch types (classes) present.
7	SIEI	$SIEI = \frac{1-\sum_{i=1}^{m} p_i^2}{1-\left(\frac{1}{m}\right)}$	**Simpson's Evenness Index -** A measure of the dominance of patch types. When SIEI = 0 the landscape is composed of a single patch, as a result, no diversity. SIEI approaches 0 when there is inequity in the distribution of area among the different patch types. SIEI = 1 when

			there equitable distribution (proportional distribution) of the area among patch types
8	CLUMPY	$Given G_I = \left(\frac{g_{ii}}{\sum_{k=1}^{m} g_{ik}} \right)$ $CLUMPY = \left[\begin{matrix} \frac{G_i - P_i}{1 - P_i} \; for G_i \geq P_i \\ g \\ \frac{G_i - P_i}{1 - P_i} \; for G_i < P_i; P_i \geq .5 \\ \frac{P_i - G_i}{1 - P_i} \; for G_i < P_i; P_i \geq .5 \end{matrix} \right]$	**Clumpiness Index-** A measure of patch aggregation. When CLUMPY = 1, the focal patch type is completely disaggregated; If CLUMPY= 0, then the distribution of the focal patch type is random, and approaches 1 when the patch type is maximally aggregated. CLUMPY = 1 for the landscape consisting of a single patch and has a border comprised of the focal class
9	LPI		**Largest Patch Index** – A measure of dominance and aggregation. When LPI = 100 the landscape is composed of a single patch
10	ED	$ED = \frac{E}{A}(10{,}000)$	**Edge Density**- Measures the spatial distribution of land use by considering the size and the complexity of the shape/geometry of the patches. Low values imply fewer patches and compact shape, whereas large values denote many patches with simpler shapes.
11	SHDI	$SHDI = -\sum_{i=1}^{n} (P_i{}^e \ln P_i)$	**Shannon's Diversity index** Measure abundance of each patch type in the landscape.

12	SHEI	$$SHEI = \frac{\sum_{i=1}^{m}(P_i * lnP_i)}{\ln m}$$	**Shannon Evenness Index**- A measure of landscape fragmentation
13	CONTAG	$$CONTAG = \left[1 \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[p_i * \frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right] * \left[\ln\left(p_i * \frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)}\right](100)$$	**Contagion Index**- A measure of aggregation. CONTAG approaches 0 when the landscape is completely disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions of all pairwise adjacencies). CONTAG = 100 when all patch types are maximally aggregated
14	COHESION	$$COHESION = \left[1 - \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} p_{ij}^{*}}{\sum_{i=1}^{m}\sum_{j=1}^{n} p_{ij}^{*}\sqrt{a_{ij}^{*}}}\right] * \left[1 - \frac{1}{\sqrt{z}}\right]^{-1} * (100)$$	**Patch Cohesion Index**- Measures the physical connectedness of the corresponding patch type. It describes the level of aggregation and fragmentation in the urban landscape.
15	FRAC	$$FRAC = \frac{2\ln(.25\, p_{ij})}{\ln a_{ij}}$$	**Fractal Dimension Index**- A measure of complexity in the urban landscape. If > 1 for a 2-dimensional patch shape complexity increases indicating a deviation from Euclidean geometry. FRAC ~ 1 for simple shapes e.g squares and ~ 2 for complex (highly convoluted and plane-filling) shapes.
16	FRAC-AM	$$FRAC-AM = \frac{2 * \ln p_{ij}}{\ln a_{ij}}$$	**Area-weighted mean patch fractal dimension** – Used in determining the complexity of the landscape

17	PAFRAC	$$PAFRAC = \frac{2}{\dfrac{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\ln p_{ij} * \ln a_{ij}\right) - \left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\right]\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]}{\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^{2}\right) - \left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)^{2}}}$$	**Perimeter-Area Fractal Dimension-** A measure of complexity in landscape

Source: MacGarigal, 2015

APPENDIX III

UNIVERSITY OF IBADAN
FACULTY OF THE SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY

URBAN HOUSEHOLD SURVEY

Serial No				

Dear Sir/Ma,
We are investigating the horizontal and vertical growth of Lagos Island over time and space in order to predict future growth for planning purposes. This survey has nothing to do with the government or the local planning agencies, nor does it has anything to do with taxation. It is purely an academic exercise. We would, therefore, appreciate your cooperation in supplying the information requested below. We assured you that any information supplied shall be treated as confidential.

……………………………….
H.D Olaniran
23 February 2013.

All household head should answer

(A) GENERAL INFORMATION

1. Location/Ward ………………………………………………………………………
2. Sex: Male ( ) Female ( )
3. How old are you now? …………………………………………………………..
4. Could you tell us how long you have been living in Lagos Island? ……………….
5. How long have you lived in this house?...
6. Do you own or rent this house?...
7. How much is the rent per month if you are paying rent?..
8. How many rooms altogether does your household occupy in this building?............
9. What is your level of education?...
10. What is your occupation?..
11. Please tell us your average monthly income? ……………………………………
12. From which ethnic group are you?...
13. What is your marital status? Tick appropriately; Married ( ), Single ( ), Divorced ( ), Separated ( ) Others ( )

14. If you are married how many wives do you have? ………………………………
15. What is the size of your family?...
16. What is/are age(s) of wife/wives?........ (1)……………(2)……………….(3)……..
17. What is their level of education? (1)………… (2)………… (3)………………
18. What is their occupation? (1)…….. (2) ………… (3)……………………………..
19. How many of your children are living with you? ………………………………….
20. How many of them are workers? ……………………………………………………..
21. How many of them attend school? …………………………………………………
22. How many of your relatives live with you? ………………………………………..
23. How many of them are workers? ……………………………………………………..
24. How many of them attend school? …………………………………………………
25. If you own a car, how many do you have? ………………………………………
26. How many hours of electricity do you have in a day? ……………………………
27. What is the source of your domestic water needs? ………………………………..
28. Kindly give an estimate of the average quantity of water you use at home on a daily basis? ………………………………………………………………………………….
29. How much do you spend on transportation weekly?..
30. How would you rate your access to health care facilities in this area?......................
31. What is the average distance between your residence and workplace? ……………

(B) NATURE AND TYPE OF HOUSE

1. Kindly identify your house type;
    - i. Single dwelling flat…………………………
    - ii. Single unit dwelling bungalow……………..
    - iii. Multiple unit dwelling storey building………………….
    - iv. Multiple unit dwelling high-rise…………………………
    - v. Duplex……………………………………………………
    - vi. Others…………………………………………………….
2. When was this house built? ………………………………………………………
3. This house was built on how many plots of land?...

4. What is the land price when you bought your land? ……………………………..
5. What is the average land price now in this area? …………………………………
6. If your house type is a multiple dwelling unit, how many households reside in the building? ………………………………………………………………………………..
7. How many storeys is there in the building? ………………………………………
8. How many rooms altogether are in the building?...
9. How many kitchens are in the house? ……………………………………………
10. If your house displaces an existing structure, what type of structure it is? ………....
11. What form of energy do you employ in cooking?..
12. How many rooms altogether are being used for residential purposes in this building? ………………………………………………………………………………...
13. How many rooms altogether are being used for commercial purposes in this building? ………………………………………………………………………………...

(C) THE QUALITY OF URBAN ENVIRONMENT, LIFE AND HEALTH IN RELATION TO URBAN GROWTH

Give a score to the relevance of the following physical and socio-economic impact connected to urban vertical and horizontal growth **(1=Very low, 2= Low, 3= Medium, 4= High, 5= Very High)**

S/N	**EFFECTS**	**SCORE**				
		1	2	3	4	5
1	Consumption of land					
2	Loss of wetland					
3	Loss of soil permeability					
4	Loss of biodiversity					
5	Impairment of small watershed					
6	High noise level					
7	Increase air pollution					
8	Increased poor air circulation					
9	Traffic congestion					
10	Insufficient public transport network					
11	Increased social economic development					
12	Less social interaction					
13	Improvement in quality of the neighbourhood					
14	Increased rate of sand filling for building					
15	Changing pattern of Land use					

(D) PERCEPTION ON VERTICAL GROWTH AND FUTURE PLANNING MEASURES

Rate your perception on urban vertical growth and future planning measures as follows **(1=Agree, 2=Strongly Agree, 3= Disagree, 4= Don't know)**

S/N	**PERCEPTION**	**SCORE**				
		1	2	3	4	5
1	Vertical growth of Lagos Island will ease housing problems					
2	Increased vertical growth will increase the rate of building collapse					
3	Development of long term integrated plans to promote sustainable vertical growth of Lagos Island is needed					
4	Public-private partnership is needed in achieving a sustainable urban vertical growth in Lagos Island					
5	There is a need for coordination between the various level of government and community for sustainable urban vertical growth management					
6	Urgent urban renewal is needed in Lagos Island					

Thank you.

APPENDIX IV

UNIVERSITY OF IBADAN
FACULTY OF THE SOCIAL SCIENCES
DEPARTMENT OF GEOGRAPHY

Serial No				

Survey on urban vertical growth

Sir/Ma,
We are interested in investigating the horizontal and vertical growth of Lagos Island over time and space in order to predict future growth for planning purposes. This survey has nothing to do with the government or the local planning agency, nor does it has anything to do with taxation. It is purely an academic exercise. We would, therefore, appreciate your cooperation in supplying the information requested below. We assured you that any information supplied shall be treated as confidential.

………………
H.D Olaniran
22 January 2014

1. Type of high-rise building (Please tick as appropriate)
   Proposed new high-rise [ ]
   Existing high-rise [ ]
2. Location of the building…………………………………………………………………......
3. Why was this location chosen for the construction of this building?.................................
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   …………
4. Which was this structure/building constructed?...
5. What informed the decision to construct this building as a high rise?.....................................
   a) High land value
   b) Increased demand for a housing unit
   c) The consumer preferences
   d) Others (specify)………………………………………………………………………..

6. How many floors are there in the building?..
7. If this building displaced any existing structure, what type of structure was it?
    a) Bungalow
    b) Storey building
    c) Warehouse
    d) Industrial complex
8. Who owns the building?
    a) Private developers
    b) Corporate organisation
    c) Government
    d) Family/Community
9. Kindly indicate the group to which this building belongs

Group	1	2	3
Number of floors	7-16	17-24	25 & Above

10. What is the land-use type in this area?
    a) Commercial land use
    b) Mixed land use 9mainly commercial and residential)
    c) Residential
    d) Public
11. What is the average monthly rent paid here per room? ₦………………………………….
12. What is the average monthly rent paid here per flat? ₦ …………………………………...
13. What is the average monthly rent paid here per office complex ₦ ………………………..
14. If you pay rent per square metres, how much do you pay? ₦ ………………………………
15. Kindly indicate an estimate of rent paid per square meter or by room over time;

Year	**1st Quarter (Jan-March)**	**2nd Quarter (April-June)**	**3rd Quarter (July-Sept)**	**4th Quarter (Oct-Dec)**
1970-1979				
1980-1989				
1990-1999				
2000-2009				
2010-2014				

16. Is there rent differential in this building? **YES** [ ] **NO** [ ]
17. If yes in 16, how much is being paid as indicated below

Floors	**Rent in Naira (₦)**
1-6	
7-12	
12-17	
18-23	
23 & Above	

18. What is the average population in this building per floor? ………………………………...
19. What is the average number of family per floor? ………………………………………….
20. What is the average person per room? …………………………………………………..
21. What is the average floor area per person? ………………………………………………...
22. Kindly indicate YES or NO if these facilities are available and functional in this building,

S/N	Facilities	YES	NO
1	Elevator/Lift		
2	Fire detector equipment		
3	Wet pipe sprinkler		
4	Fire resistive equipment		
5	Automatic extinguishing equipment		
6	Enclosed mall		
7	Restaurants		
8	Parking space		
9	Public space		
10	Emergence voice communication system		
11	Standby power supply		
12	Stairway Door Operation		
13	Smoke proof exit enclosure		
14	Emergency escape and rescue operation		

23. Indicate if this building is being used for any of the activities listed below

S/N	Activities	YES	NO
1	Medical services		
2	Office complexes		
3	Residential		
4	Business		
5	Industrial		
6	Education (School, Advancement centre etc.)		
7	Urban farming		
8	Commercial (Row of store)		
9	Worship/Religion (Church, Fellowship etc.)		
10	Enclosed mall		
11	Civic/cultural/recreation		

24. What is the percentage of occupiable space (used space) in this building? …………………
25. What is the percentage vanity height (non-occupiable space) in this building? …………..

26. What is the average travel time from ground level to the middle floor? …………………..
27. What is the average travel time from the ground level to the upper floor?................................
28. Indicate if this building is accessible by any of the transport services listed below;
    a) Private Car YES [ ] NO [ ]
    b) Public Transport YES [ ] NO [ ]
    c) Train YES [ ] NO [ ]

29. Kindly provide the following cost information with respect to this building;

S/N	Cost Type	Amount
1	Land cost	
2	Maintenance cost per annum	
3	Insuring cost	
4	Monthly service cost (electricity, water, security etc.)	
5		
6		

30. Given a choice, would you prefer to live in a high-rise building? …………………………..
31. What is your preferred floor level? ………………………………………………………...
32. From the factors listed in the table below, kindly indicate your preference for high-rise building as follows (1=Not attractive, 2= Fairly attractive, 3=very fairly attractive, 4= Attractive, 5= Very Attractive.

Categories	Preference factors	1	2	3	4	5
Pull Factors	Better view					
	Fresh air					
	Windier					
	Quiet environment					
	Better housing					
	High-rise living as a lifestyle					
Push Factors	Safety of the building structure					
	Ease of escaping in an emergency situation					
	Longer waiting time for the elevator					
	Lack of community interaction					
	Insufficient supporting infrastructure					
	Personal fear for height					

33. Could you identify some social effects of living in a high-rise building? …………………
    a) …………………………………………………………………………………….
    b) …………………………………………………………………………………….

c) …………………………………………………………………………………….

d) …………………………………………………………………………………….

34. If there are there plans to rebuild or increase the number of floors in this building in the nearest future, how many floors are being proposed?..
35. Why would the numbers of the floors be increased? ………………………………………
36. Kindly indicate the state of the within the building environment by floor as follows; 1= Poor, 2= Fair, 3= Very fair, 4= Good, 5= Very Good.

S/N	**Environmental Factors**	**1**	**2**	**3**	**4**	**5**
1	Temperature/ Heat					
2	Fresh air					
3	Solar exposition					
4	Pedestrian comfort (ability to move around within the building at a walking pace					
5	Exterior space					
6	Shadow					

Thank you.