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ASSESSMENT OF URBAN SPRAWL IN *MOWE/IBAFO* AXIS OF OGUN STATE USING GIS CAPABILITIES

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Abstract

Urban Sprawl is one of the challenges to urban development in many nations. Different aspects of the phenomenon have been researched with a view to providing solutions to myriad of ills attributed to it. For any meaningful intervention, however, assessment of development to ascertain sprawl is essential. Despite this, its quantification and monitoring in environment with paucity of data remains a daunting task. Therefore, this thesis was designed to utilise GIS to assess urban sprawl in *Mowe/Ibafo* area of Ogun State.

The study classified Landsat data of 1987, 2000 and 2016 covering *Mowe/Ibafo* into water, vegetation and built-up areas and subjected them to post classification analysis. Digital Elevation Model and population data were used to examine factors of urban expansion and staff of Planning Offices interviewed to obtain data on development monitoring. The classified land cover map was divided into zones using centre of the towns and expressway. Shannon's Entropy and Relative Entropy were computed from the zones. Elevation layer was also overlaid on the classified land cover map to examine factors of expansion.

Overall Accuracy assessment for 1987, 2000 and 2016 classification were 88%, 90% and 86%. The classification showed that 1.69% (5.52 sq.km) of *Mowe/Ibafo* was built in 1987. This increased to 8.33% and 66.26% in 2000 and 2016 respectively. The results of a paired-samples t-test conducted revealed a significant difference between 1987 and 2016 land cover scores with an increase from 1987 ($M = 2.0115$, $SD = 0.14899$) to 2016 ($M = 2.3116$, $SD = 0.49023$), $t_{(362079)} = -36.801$, $p < .0005$). The results of Relative Entropy were very high and close to 1 confirming urban sprawl in *Mowe/Ibafo.* A comparison with Entropy values for the area within *Obafemi-Owode* (subset of the study area) produced a lower value, though close to 1, suggesting that the wider the coverage, the more the magnitude of sprawl. Pattern of development in the area was influenced by expressway and elevation as flat and stable (15 – 30 m) areas were most developed. The study revealed that there was inadequate local manpower, resources and government synergy to adequately monitor development in the area.

The government of Ogun and Lagos states should work together for orderly development of *Mowe/Ibafo axis.*

Keywords: Urban sprawl, Expansion, Assessment, Shannon's entropy, *Mowe/Ibafo*

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List of Abbreviations

ArcGIS	A patented Suite of GIS software developed by ESRI
DEM	Digital Elevation Model
df	Degrees of freedom
DN	Digital Numbers
DOS	Dark Object Subtraction
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic Mapper
GIS	Geographic information system
km	Kilometres
LG	Local Government
LUMA-GIS	Lund University Master's Program in Geographical Information Science
m	Metres
M	Mean
ML	Maximum Likelihood
MSS	Multispectral Scanners
NPC	National Population Commission
NASA	National Aeronautics and Space Administration
OLI	Operational Land Imager
QGIS	Quantum GIS – A free and open-source desktop GIS application
ROI	Region of Interest
SCP	Semi-Automatic Classification Plugin
SD	Standard deviation
Sig.	Significant
Sq.km	Square Kilometres
TM	Thematic Mapper
TOA	Top of Atmosphere
U.S.	United States
USGS	United States Geological Survey
ZTPO	Zonal Town Planning Office

Chapter 1: Background to the Study

1.1 Introduction

Lagos, a south-western coastal city was the former capital of Nigeria till 1991 and remains the commercial hub of the nation till date. The city has gradually grown from its farmstead status in the 15th Century AD to a metropolis, and with further population explosion, it has now reached a megacity. It is difficult to define the outer limits and exact population of megacities. Hence, megacity is not usually defined in term of spatial extent but as a conurbation with a threshold of ten million inhabitants (Ward 1990; UNDESA 2008; UN 2012). As noted by Sorensen and Okata, (2011), population figures are political boundary specific, while megacities have changing boundaries which are not conterminous with such political boundaries.

Administratively, Lagos megacity has been described to encompass the whole of Lagos state and parts of neighbouring Ogun state. The phenomenal population growth has resulted in corresponding areal expansion consisting of planned development, slums and urban sprawl. Mabogunje (2006) among others associated rapid population growth with the pressure leading to land-use conversion in Lagos. Oduwaye (2013) also found out that spatial coverage of metropolitan Lagos was largely influenced by population size and development needs.

The availability of cheaper land and accommodation for migrants in the suburb has continued to engender fast pace development of the metropolis into the outskirt, amidst inefficient development control by government agencies saddled with the responsibility (George, 2010). The metropolis expands, initially along major transport corridors, later to other areas and recently to *Mowe/Ibafo* axis of neighbouring *Ogun* state (Lawanson *et al.*, 2012). This suburbanization was identified in 2010 by the Lagos state government as one of the problems that necessitated the establishment of the Lagos Megacity Project.

A planning technique used in the 19th century to curb the growth of primatecity (a city that disproportionately dominates others both in size and influence) was the creation of satellite towns which are smaller towns located somewhat near to, but mostly independent of larger metropolitan areas. They are supposed to provide relief to larger metropolis by providing decent accommodation for people and facilities for vacation and relaxation. *Mowe* and *Ibafo*, like other peripheral settlements to Lagos, were not intentionally created as satellite towns to Lagos but they were existing villages that metamorphosed based on their proximity to Lagos. Their growth was not planned, thereby creating monotonous suburbs and unpleasant settlements (Adewale, 2010). In other words, Lagos population explosion premised on its antecedents and existence as a global city has rubbed on the growth of unplanned satellite towns from the existing surrounding villages. *Mowe* and *Ibafo* were originally two distinct settlements sandwiched between capitals of three states (*Ogun, Oyo, and Lagos*) and this location has not only favoured their growth but contributed to their neglect in term of planning and infrastructural provision.

Mowe and *Ibafo* have grown from rural settlements to major cities with little or no planning effort (Lawanson *et al*., 2012) and are still growing. The patterns of growth and other propelling forces, aside from population influx, however, remain undefined. One of the efforts made by the *Ogun* State government was the preparation of *Ogun* State Regional Plan (2005-2025) "*aimed at developing lagging and depressed regions of the State by purposefully concentrating developmental activities in few places in such a way that the growth impulses and economic advancement would radiate from the centres and trickle down or spread to the surrounding areas*" (Ogun State Government, 2008). Though the plan, which was the first of its kind for Ogun State since its creation in 1976, covers *Mowe/Ibafo* areas, its effect remains unfelt. Being a higher order plan, it saddled the 'Regional Plan Office' (an Agency for the plan implementation monitoring) '*to facilitate the preparation of sector-specific plans as necessary*. This, however, was not implemented. Another effort to accommodate the influx was the acquisition of land and laying out such for allocation. This was a piecemeal approach which did not match the rate of growth and demand for housing in the axis. Hence, the sprawling continues outside the acquired areas without following a pre-conceived pattern and approved plans as private developers and individuals dominate the development process. These cause for examination of the rate and direction of sprawling to determine the required manpower required for development control to checkmate the menace of urban sprawl and promote sustainable development of the area.

In order to achieve sustainable growth and management of a town, knowledge of its dynamics in term of population growth, spatial expansion is essential. Such analysis of changes is imperative for planning and management of city growth (Angel *et al*., 2005). However, there is dearth of historical data for such exercise in the *Mowe/Ibafo* area and manual monitoring cannot match the growth rate hence, the use of multi-temporal remote sensing data with Geographical Information System (GIS) capabilities to accomplish the task. Taubenböck *et al.* (2008) have described Remote sensing as a good source of data and useful techniques for urban areas mapping, and analysis of urban land cover change. They emphasised the independent and cost-effective nature of remote sensing data for spatiotemporal analysis. Landsat data was used because it satisfies the requirements for data as suggested by Radberger (2001) based on the following factors:

- *"Extent of the test sites*
- *Number of aimed land cover classes and their spatial differentiation potential*
- *Length of study period*
- *Requirements for accuracy of thematic classification"*

(Radberger, 2001).

The choice of *Mowe/Ibafo* was premised on the argument that there is a need for more local-level studies (Boyle, 2005) in medium and small cities to provide required information for planning and decision making at the local governments rather than in over-studied large and megacities (Redman and Jones, 2005). This is essential as it has been postulated that much of the future growth would be in the small to medium-size cities around the world (Thomas, 2003).

1.2 Research Problem Statement

Until recently, planning and monitoring of development in the suburb especially inter-urban areas have been a neglected issue (Pacione 2002; Egbe 2014). Attentions are usually focused on major cities at the expense of rural areas which usually depend on the cities (Pacione, 2002). Aside from the low capacity for the monitoring, there is lack of historical planning data to foster such action. However, increasing urban population has continued to populate the urban fringe with the attendant effects which contradict sustainability but central to urban planning achievement (Wellbank, 1994). Oduwaye (2009) attributed different vices to the proliferation of shantytowns resulting from unplanned urban expansion. He recommended, among others, empowerment of personnel and application of technology by planning practitioners to achieve sustainable development.

Studies using remote sensing with GIS capability to monitor urban growth have been on the increase (Besussi and Chin, 2003; Burchfield *et al*., 2006) as a result of increasing availability and quality of satellite imagery. In Nigeria, it includes the work of Oriye (2013) in the study of expansion of Ado-Ekiti in Ondo state and Dekolo *et al.* (2015) for the mapping of Ikorodu in Lagos. Eyoh *et al.* (2012) also used GIS to map development factors in Lagos metropolis. The focus of this study is on the *Mowe*/*Ibafo* axis which comprises small and hitherto isolated settlements often treated as an integral part of the metropolitan Lagos because of proximity. Administratively, however, the area is not part of Lagos. Whereas, Sorensen and Okata (2011) has identified building and management of infrastructure as one of the challenges in such location.

The purpose of the study, therefore, is to identify factors of development in the area, evaluate the processes against population increase and pattern of expansion for effective planning. The need for this study at this formative stage of the area is essential as Sorensen and Okata (2011) placed importance on emerging pattern during rural-urban transition. They argued that, such formed patterns might become difficult and costlier to revamp later. Hence, while the campaign for the improvement of deteriorating settlements persists, the rapid growth of areas of urban influence must be understood and monitored.

Questions addressed by the study include:

a) What is the characteristic of land cover composition of *Mowe*/*Ibafo* axis in Ogun state?
b) What is the rate of expansion between 1987 and 2016 and at different intervals?
c) What are the major zones of growth?
d) How have the major factors of expansion influence the pattern of development?
e) What is the development monitoring capacity in the *Mowe/Ibafo* axis?

Aim and Objectives

The study aims at utilising GIS methods to assess urban sprawl in *Mowe/Ibafo* axis of Ogun state between 1987 and 2016 with a view to improving management of urban expansion. Its objectives are to

a) Quantify land cover changes in *Mowe/Ibafo* axis from 1987 to 2016
b) Determine the rate and directions of expansion of *Mowe*/*Ibafo* settlements
c) Ascertain the major zones of growth
d) Determine the influence of factors of urban expansion on the emerging pattern
e) Examine the development monitoring capacity in the area

1.4 Research Hypothesis

This research hypothesised that the characteristic pattern of urban expansion in *Mowe/Ibafo* axis is a function of factors of expansion.

Specific hypothesis to be tested are:

i There is no statistical difference in land cover change in *Mowe*/*Ibafo* axis from 1987 to 2016

ii There is no relationship between pattern of urban expansion and factors of expansion

1.5 Study area

Nigeria operates a three-tier of government – federal, state and local. There are thirty-six states and a Federal Capital Territory, Abuja. At the third-tier level, the country has 774 Local government areas, comprising rural and urban settlements. *Mowe* and *Ibafo* are settlements located within Obafemi-Owode, a Local Government Area (LGA) with headquarters at Owode Egba (6°57′N 3°30′E) in Ogun state, Nigeria.

Obafemi-Owode Local Government, created in 1976, is still predominantly an agrarian area with 1,041.87 square kilometres of land. The Local Government shares boundaries with Odeda LGA and Oyo State in the North; Ifo (bounding Lagos State) and Sagamu Local Governments in the South; Abeokuta South and Ewekoro Local Governments in the West; and three other local governments (Remo North, Ikenne and Sagamu) in the East (Figure 1). It has a total population of 135,774 and 228,851as at 1991 and 2006 censuses respectively.

The study area (*Mowe*/*Ibafo* axis) is geographically located between Latitude $6^{o}44$’ North and Longitude $3^{o}22$’ East and Latitude $6^{o}54$’ North and Longitude 3^{0} 27’ East of the equator. Graphically it can be described as the tail of Obafemi-Owode LGA. *Ibafo* settlement, with 62,164 estimated populations projected from 1991 population of 25,415, is the largest within the study area and central to the region. Both *Mowe* and *Ibafo* were two hitherto separated settlements. However, they have merged overtime, hence the new nomenclature, *Mowe*/*Ibafo*, given to the axis. *Ibafo* is located just about 31km from the boundary of Lagos state; 20km North of Ikeja, the capital of Lagos state (and former capital of Nigeria); 45km southeast of Abeokuta (capital of Ogun state); and 90km southwest of Ibadan the capital of Oyo State (Figure 1). Both *Mowe* and *Ibafo* are linear settlements along Lagos – Ibadan expressway which traverses many settlements and links Lagos with other parts of the country. Other major linear settlements on the axis, absolving spill-over population from Lagos and other rural areas, include Loburo and Magboro.

The axis falls within the tropical zone. It experiences two seasons – raining and dry. The raining season lasts nine months (March to November) while the dry season lasts three months (December to February). Average temperature and humidity are 31^{o}C and 95% respectively with average annual rainfall (1991-1995) of 1115mm (Ogun State Government, 1998). The people of the area are predominantly farmers, cultivating arable and food crops while some engage in livestock farming and fishing (Oyesiku, 1992). Some of the inhabitants are into quarry business, artisan works and handcrafts, such as dye making and pottery.

The increasing population of Lagos state has induced important territorial changes, from anthropic processes, such as population migrations toward different areas including the *Mowe*/*Ibafo* axis, and the creation of new urban centres. The preference for this axis by major religious organisations in the country has also contributed greatly to the development of the study area as most of them have representation in the axis. These include the Redemption Camp of the Redeemed Christian Church (the largest church in Nigeria) at *Mowe*, and *Nasrul-Lahi-liFathi* (NASFAT) Society of Nigeria (a large Muslim prayer group). Other major land uses that have developed in the area include institutional (such as private universities) and residential estates. This transformation, going on in *Mowe*/*Ibafo* axis of Ogun state, informed the choice of the area. The growing awareness of how such processes are affecting the environment and continuous quest for innovative systems of decentralisedurbanisation justifies the quest.

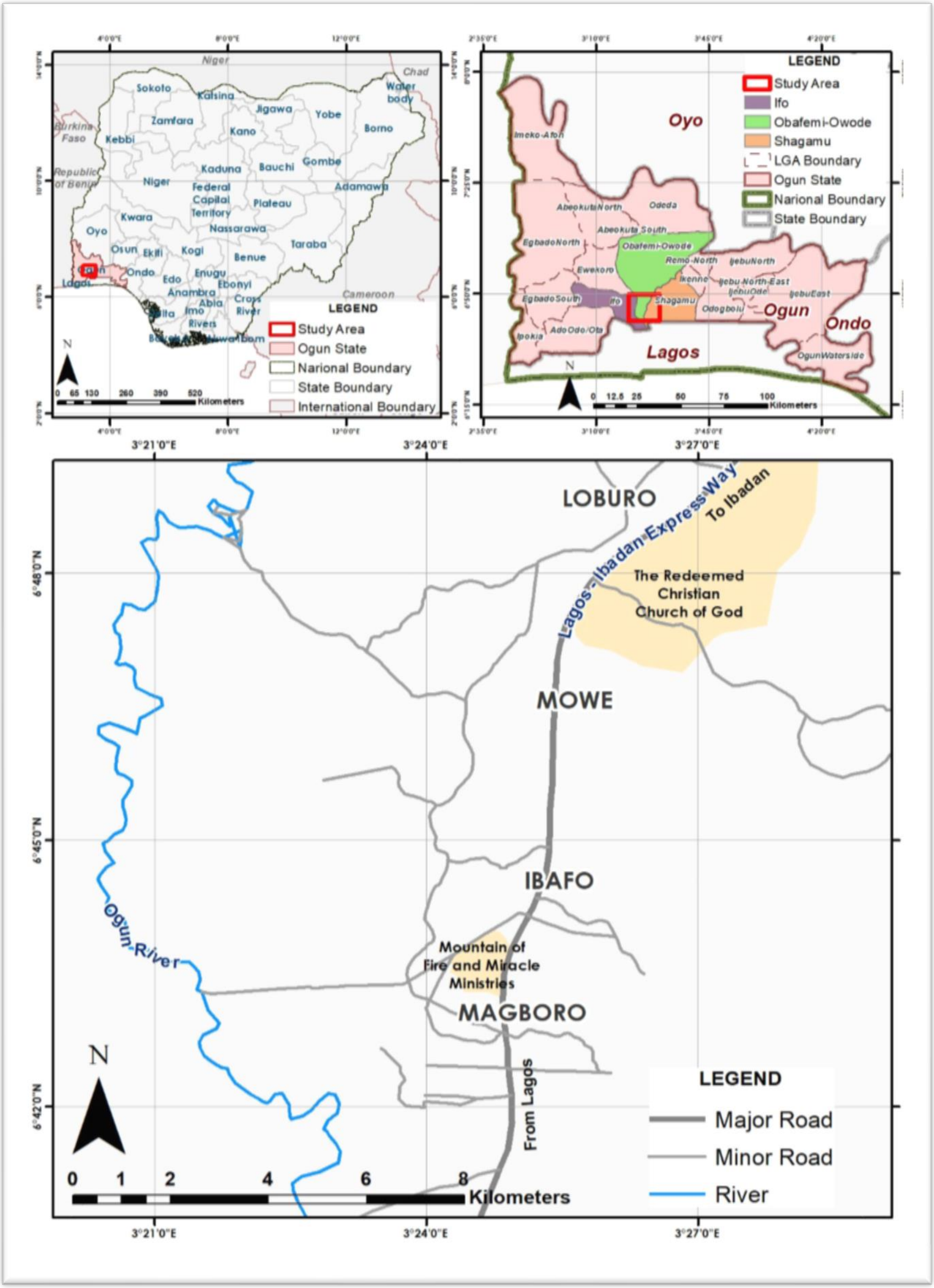


Figure 1.1: *Mowe/Ibafo* **within the Context of Nigeria**

1.6 **Project Plan**

The thesis is presented in six chapters. Chapter one, which is concluded here, is the general introduction, containing the background to the study and the study area, research questions, hypothesis, aim and objectives and the justification for the study

Chapter 2 is dedicated to literature review and explanation of concepts including urban sprawl, Geographical Information System (GIS), its application in urban planning and specifically urban sprawl, methodologies available for urban sprawl assessment among others.

Chapter 3 identifies sources of data for the study, justification for the choice of data and availability for the study area. The chapter also highlighted how each data contributed to the achievement of the objectives of the study; processing and pre-processing techniques were explained. Methods applied in combining data for the attainment of the goal of the study were explained in this chapter and the extent to which GIS was applied.

Chapter 4 presents the results of analyses and assessment of urban sprawl as performed using different methods explained in chapter 3. It graphically and textually present relationships among the studied variables.

Chapter 5 of the thesis discusses the findings from the analyses conducted. It relates the results to existing knowledge in literature with a view to ascertaining the agreement of the results with early findings and explained, in line with the factors considered, where difference exists. Contributions of the study to knowledge and policy development were discussed in this chapter.

Chapter six is a wrap-up of the thesis. It presents the entire report in a concise format Being the final part, recommendations were made to policy makers and areas for further study were suggested before the general concluding remarks.

Finally, the list of consulted materials was presented in reference and followed by appendices containing information which may aid in understanding some aspects of the thesis.

Chapter 2: Literature Review

2.1. Introduction

The study of urban sprawl has become a routine over the decades. Orenstein *et al.* (2014) associated this long interest in the study of urban sprawl with its implications for environmental quality, ecology, socio-economic equity, and sustainability. Other reasons include the desire to overcome or avoid its negative consequences. Despite this, urban sprawl, and associated methodologies for its measurement remains one of the most contentious issues in literature. This contentiousness, which ranges from ideological to empirical, has been raging for over two decades (Orenstein *et al.*, 2014). As human race continues to evolve, and population increases, the need for human habitation will remain a topical issue. Hence, phenomenon like urban sprawl will continue to receive attention especially that each city is a separate entity in which urban sprawl is manifesting in different ways (Pozoukidou and Ntriankos, 2017).

The negative conception of urban sprawl as undesirable development pattern has aroused global interest in curtailing it (Brueckner, 2000; Frenkel, 2004; Van Rij *et al.*, 2008). To achieve this anywhere, Orenstein *et al.* (2014) emphasised the role of reliable spatial data.

The recent spate of urbanization calls for measures aimed at improving the living conditions of people in the urban core and peripheries and make the city attractive to people. This can only be achieved with an understanding of the pattern of expansion across the urban area of influence. The knowledge of land cover provides information for planning and control of land use (Fischer-Stabel *et al.*, 2006).

2.2 Concept of Urban Sprawl

Urban sprawl has no consensual definition. Longley *et al.* (2002) observed that the term has-been generalised to cover wide range of urban forms. It lacks precise meaning (Longley *et al.*, 2002; Chin, 2002), and there are divergent opinions on its causes and effects. However, manifestation of the phenomenon on the fringe of growing cities is not contested (Longley *et al.*, 2002). Most authors (including Downs, 1998; Galster *et al.*, 2001, Squires, 2002; and Anas & Rhee, 2005) also agreed that, it is a low-density development. From this perspective, Squires (2002) described urban sprawl as low-density pattern of growth, on the outskirt of a city. Conceptually, Galster *et al.* (2001), defined eight measurable characteristic patterns of land use as "*density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity*". They categorised any pattern of development with low value on, at least one of, the indices as sprawl. Other similar definitions of sprawl that emphasised low-density include that of Downs (1998) which, also included ribbon commercial developments spreading into new areas, mostly outside the city as sprawl.

Peiser (2001) and Bhatta (2010) viewed sprawl from resource utilisation perspective. They described it as unplanned, wasteful horizontal expansion and inefficient utilisation of land resources.

From the foregoing, Chin (2002) categorised urban sprawl definitions into four. He based his classification on "*urban form, land use, impacts and density*", and acknowledged the advantages and disadvantages of each category of definition. In terms of urban form, all pattern of development aside from *"compact city*" qualifies as sprawl; Definitions based on land use are those that ascribed sprawl to segregation of land uses, monotonous development without mixed uses, among others. Based on impacts, definition of sprawl is premised on convenience among related land uses. Development patterns short of good accessibility are defined as sprawl. In term of density, areas with low concentration of houses per acre are described as urban sprawl.

Despite the plethora definitions of urban sprawl, a common component of the definitions is the extensive and progressive spreading of a city into its periphery. This is the conceptual understanding of sprawl in this thesis.

2.3. **Causes and Effects of Urban Sprawl**

The quest to satisfy the increasing need of the growing population mostly result in land utilisation. In addition to the natural increase in population, uneven distribution of opportunities has continued to force the rural inhabitants to move to the city, thereby increasing city population. This generates increasing demands for housing and Longley, *et al.* (2002) have observed that, people would find accommodation elsewhere as solution to deficiency of housing in the central cities. Similarly, where land supply for housing is geographically constrained, demand would be met in other places or locations, especially where there is surplus.

Audirac, *et al*. (1990) identified individual preferences among the factors promoting sprawl to the suburb. Such preferences include the tendency to own house in quality neighbourhood, penchants for certain types of environmental qualities suitable for raising a family, privacy, and others. In addition, Mathema (2008) identified land and building regulations which promote low-density sprawl and put all land under State control among the factors.

Contrary to the primary purposes of providing housing for the people and willingness of individuals to live in sprawling suburbs (Torrens, 2008), suburbanization is mostly perceived in a negative light. It is believed (Pichler-Milanović, 2007), that unrestrained expansion of cities impacts negatively on urban environment and the economy due to loss of productive land. Consumption of land is attributed to highly inefficient urban form, which characterises urban sprawl. According to Mitchell (2001), Seventy million Americans lived in 34,000square kilometresurbanised areas in 1950.The population increased threefold by 2001, when the metropolitan area was more than fifty times larger. In Lagos metropolis, 665,246 people occupied 70.50km^2 in 1963; when the population increased to 12 times (7,937932) in 2006, the space occupied increased by 14 times to 999.60km^2 (Aluko, 2010). Sudhira & Ramachandra (2007) identified land-use/land-cover change as a direct effect of sprawl.

Economic effects of sprawl include the high cost of extending infrastructure and services to new areas (Burchell and Mukherji, 2003). This, in most cases, accounts for poor infrastructure in some newly extended areas of cities in developing countries. Urban sprawl has also been associated with social and health effects. Arbury (2005) enumerated the social effects to include reduced social equity and segregation while health effects were highlighted by Kelly-Schwartz *et al.* (2004) to include life-threaten diseases such as hypertension.

From the above, the adverse effects of urban sprawl are contrary to the concept of sustainability. This agrees with the position of Elkin *et al.* (1991) that urbanism fundamentally conflicts with sustainability. However, since most of the impacts are debatable, research on the subject will linger for a while.

2.4 GIS Capabilities in Assessing Urban Sprawl

Like the concept of urban sprawl, research abounds on the methods of assessing urban sprawl across the globe (Galster*et al.*, 2001; Tian et al. 20017). Among the commonly used indices by these researchers to measure or assess sprawl are land consumption rate, densities, spatial pattern; Gross Domestic Product (GDP), floor area ratio (e.g. Pendall, 1999, Bhatta, 2010)

Resulting from inability to obtain sufficient and related data for measurement, most of the techniques used in developed countries are not readily applicable in developing countries. Jiang *et al*. (2007), for instance, attempted thirteen 'geospatial indices', to produce an integrated urban sprawl index, to measure urban sprawl in Beijing. As robust as the method might be, Bhatta (2010) argued that it is fraught with extensive data which are hardly available in developing countries. Hence such index is difficult to derive. This limitation cut across most of the methodologies commonly applied in urban sprawl assessment and therefore necessitate the need to judiciously use the available data.

Remotely sensed data is a widely recognised primary source for urban growth monitoring and is relatively available. Using the remote sense data, urban studies have applied GIS techniques to explore spatiotemporal growth of cities (Tian et al. (2017). LULC change analysis using GIS has been considered as one of the current strategies for monitoring environmental changes (Hegazy and Kaloop, 2015). These GIS capabilities have widely been employed to study different aspects of urban sprawl (e.g. Yeh and Xia, 2001). It has also been used to forecast urban development and to monitors regional urban sprawl (Imhanfidon *et al*., 2016).With the availability of data, the capabilities have been employed in growth monitoring, at lower cost compared to the use of traditional methods (Hegazy & Kaloop, 2015)such as paper maps and surveying,

2.4.1 Applications of GIS Techniques in Assessing Urban Sprawl

The use of GIS in assessing urban sprawl includes image classification, visualisation, Multi-criteria analysis, integration of statistical methods such as logistic regression and Shannon's entropy.

In their review of literature on urban sprawl in Iran, bin Ibrahim and Sarvestani (2009) identified studies where GIS capabilities have been explored to include Sudhira *et al.* (2004), Weber and Puissant (2003), Liu and Zhou (2005). All the studies agreed on the suitability and reliability of the technique.

Eyoh *et al. (2012)* applied GIS in modelling future expansion of Lagos. Ten proximity variables, presumably driving land use, were considered in the study which covered 1984 to 2005. The study revealed that Lagos expanded by 56.90% from 1984-2000 and by 64.04% from 1984-2005. It predicted an urban expansion of 129.49% between 1984 and 2030 based on the 1984-2000 calibrated model.

Ewing *et al.* (2002) used multi-criteria analysis (MCA) in their study:

"Measuring Sprawl and Its Impact". The study was an attempt to measure sprawl in all its dimensions and analyse related impacts. They used four common descriptors of urban sprawl namely "*residential density; neighbourhood mix; activity centres and downtowns; and accessibility of the street network"* (Ewing *et al.*, 2002) as criteria. The overall Four Factor Sprawl Index was computed, from the used criteria, to rank the level of sprawling of the metropolitan areas. Among the impacts of sprawl found by the research are long distance driving and pollution of the ozone. Ewing *et al.* (2002) concluded the study by advocating sprawl reduction through "smart growth" to improve quality of life. The study was an indication that sprawl is real and measurable

The benefit of the MCA method is the opportunity to study the sprawling pattern of individual regions and availability of benchmark to judge their sustainability. Banerji (2013) however, identiied difficulty in reaching consencus as demerit of using MCA in decision making.

The weakness of MCA can be addressed by employing Shannon's entropy in GIS analysis, as Yeh and Li (2001) affirmed that, the application of Entropy requires no consensus; the higher the entropy, the more the sprawl. Yeh and Li (2001) demonstrated the use of Shannon's entropy with GIS capabilities in measuring and differentiating types of sprawl in the Pearl River Delta in China. They concluded that the method is effective for change detection and quantifying urban sprawl in developing areas. **"**Simplicity and easy integration with GIS" were cited by Yeh and Li (2001) as the advantages of entropy method.

In his study of urban sprawl pattern in Lokoja, Nigeria, Alabi (2009) used GIS techniques with Shannon's entropy. Mohammady and Delavar (2016) also employed Shannon's Entropy in the assessment of Tehran Metropolitan urban sprawl for 1988, 1999 and 2010 using Landsat data from TM and ETM sensors. The results revealed that the city was experiencing sprawl at an increasing rate as the Shannon's entropy values increased between the two periods considered (1988–1999 and 1999–2010). Other researchers (including Li and Yeh, 2004; Sudhira *et al*., 2004; and Bhatta, 2009), who have utilised Shannon's entropy to study sprawl, acknowledged its acceptability as a useful technique for assessment of the phenomenon; hence the use of this method for the *Mowe*/*Ibafo*axis of Ogun State, Nigeria.

Giving the proximity of *Mowe*/*Ibafo* towns to Lagos, whose population is ever increasing over the years and expected to reach about 21million based on the UN projection by 2050, the growth of the towns is inevitable, however, it must be regulated

(Glaeser, *et. al.*, 2006) to reap the advantages of urbanisation. This can only be achieved with the knowledge of the settlements and their expansion patterns. One of the questions is whether the rate of expansion can be categorised as sprawl that is, whether the land expansion is commensurate with population increase in the areas or not. In addition, Alves and Skole (1996) observed that land cover changes have local, regional and global environmental effects. Hence, the need to determine the effects of land LULC change on terrestrial ecosystem and formulation of sustainable land use planning were identified, by Muttitanon and Tripathi (2005),among the necessitating factors for examining LULC change. Since urban expansion is a land use component, a closer assessment, using GIS capabilities is expected to accomplish this feat.

2.5 **Data**

The most commonly used and available data for urban sprawl assessment in literature are those from remote sensing. Lu & Weng, 2007 identified factors to be considered in selecting suitable remote sensing data to include *scale of study area, availability of image data, cost and time constraints.* In term of scale and cost, Lu & Weng (2007) recognized Landsat among the frequently used medium spatial resolution data at regional level. Taubenböck *et al.* (2008) adjudged Landsat data as an independent and cost-effective data source for spatiotemporal analysis. It has wide temporal and spatial coverage and its spatial resolution of 10-100m is sufficient for the purpose of sprawl detection. It satisfies the technical requirements for data, as suggested by Radberger (2001), earlier quoted in chapter one.

Therefore, the study utilised Landsat data of 1987, 2000 and 2016.The use of Landsat data, starting from 1987 was premised on the level of data availability for the study area and the stages of growth of the communities. This is in line with the position of Longley and Mesev (2000) that *"data quality and quantity clearly prescribe the scope of spatially extensive urban analysis*". The project was set out to observe development in the axis at regular interval for relatively long period of 30 years. Giving the prior knowledge of the movement of people to *Mowe/Ibafo,* influence and proximity of Lagos State to the study area, the study aimed at starting with a period that is coterminous with the expired Lagos State Regional Plan (1980-2000) to a recent year. However, of all the speculated years (1980, 1990, 2000, 2010), only 2000 Landsat data was available (in term of quality) for the area. Hence, the first available Landsat data, after

1980, was chosen as the base year (1987) while 2016 was chosen as the third year after adopting year 2000 as the midyear. The three images from the three years identified were considered sufficient because using three images is a common practice in change detection studies (and has not been proved to have any known effect), even in studies that span two to three centuries as seen in the work of Ardö and Olsson (2003). Rather than the number of the available data, Eikvil (2005) placed emphasis on characteristics (temporal, spatial and spectral) of remote sensing data, and availability of data at the initial and final years of analysis in land use detection analysis.

The data used were not at regular intervals, but this is common where there is paucity of data (e.g. Enaruvbe and Atedhor, 2015). Giving the dearth of data and having established that the use of three years at two intervals (regular or irregular) is a common practice in many change-detection studies (including urban sprawl analyses), the available years (1987, 2000 and 2016) were used. The use of Landsat data to identify and assess sprawl in *Mowe/Ibafo* area from 1987 to 2016 enabled detection of temporal and spatial expansion, and exploration of the emerging pattern (including rate) of the sprawl.

Physical characteristics of the study area, in relation to pattern of growth, were explored using Digital Elevation Model (DEM).

To establish the major zones of growth as well as the emerging suburban land uses, the map of the wards (smaller units into which local governments are divided in Nigeria) in the study area was preferred. However, wards in the area are only named for election purposes without physical delineations. Therefore, in lieu of ward map, the study area was divided into regular interval of 500 metres width starting from the major road and town centres.

In addition to the Landsat data, the most recent (1991 and 2006) population data of the study area, were obtained from the National Population Census. Although population census is supposed to be at an interval of ten years, this has not been regular in Nigeria as a whole, hence, population projection was used to augment the available data. The population density in relation to urban expansion rate was attempted in determining rate of land use consumption.

Data on the available human capacity to monitor development and available Planning Officers was obtained from *Isheri/Ibafo* and *Mowe/Ofada* Zonal Planning Offices.

Chapter 3: Methodology

3.1 Introduction

This chapter highlights the steps taken to achieve the aim and objectives of the thesis. It includes sources of data and methods of data collection, data processing and analyses. Software used was mentioned and the methods adopted for the measurement of urban sprawl were described.

3.2 Data acquisition

The study utilised remotely sensed data of the study area to obtain spatiotemporal information of land cover. Landsat data of different sensors and periods (Thematic Mapper (TM) 1987, Enhanced Thematic Mapper (ETM+) 2000, and Operational Land Imager (OLI) 2016) were used to analyse the urban sprawl pattern. The imageries were downloaded from the USGS and National Aeronautics and Space Administration (NASA) website (See Table 3.1). They were subjected to land cover classification process and analysis conducted to examine the pattern of expansion in *Mowe/Ibafo*.

Table 3.1: Satellite Imageries utilised

Satellites	Image ID	Acquisition Date	Spatial Resolution	Projection
Landsat 5 TM	"LT51910551987057AAA02"	26/02/1987	30	WGS84 UTM ZONE 31
Landsat 7 ETM+	"LE71910552000037EDC00"	06/02/2000	30	WGS84 UTM ZONE 31
Landsat 8 OLI	"LC81910552016361LGN01"	26/12/2016	30	WGS84 UTM ZONE 31

Source: US Geological Survey, 2016

Two factors (elevation and population) of urban expansion were considered. Li *et al*. (2019) grouped determinants of urban expansion into natural (elevation, geological conditions, slope and climate) and socio-economic (population growth, economy growth, social process, infrastructure and transport, national policies and institutions) factors. The first group is related to the physical characteristics of an area and Li *et al*. argued that they are “fundamental for urban development” and functions as suitability determinants of any area, while the socio-economic factors are main driving forces. From the first group, elevation was considered because the study area is characterised with different elevation levels (including wide areas with low elevation), while population was considered from the second group (socio-economics). Elevation of an area can be used to determine its suitability e.g. flood risk level among others. Floodable areas and areas below MSL are usually avoided during development, especially where there is inadequate fund and or inappropriate technology/technical know-how. They are generally riskier and more expensive to build. There are different reports on the rate of human occupation of such areas. For instance, McGranahan, Balk and Anderson (2007) reported that the low elevation coastal zone (less than 10 metres above sea level) represents 2 per cent of the world's land area but contains 13 per cent of its urban population. This percentage of urban population living in the low elevation coastal zone however varies from as low as 9% in Sub-Sahara Africa to more than 33% in South-Eastern Asia (McGranahan, Balk and Anderson, 2007). With the growing campaigns to factor disaster risk into urban development (United Nations Office for Disaster Risk Reduction (UNISDR), 2013), the choice of elevation, as an urban expansion determinant, doubled as a measure of the consciousness of developers to risk in an organically developing suburb.

A Digital Elevation Model (DEM), which represents the relief of a surface, was used to classify and assess elevation of the study area with a view to determining the extent to which pattern of urban expansion was influenced by this physical characteristic. Shuttle Radar Topography Mission (SRTM) DEM data (n06_e003_1arc_v3.tif), available in 30 meter resolution - 1 arc second, was obtained from USGS's Earth Explorer site for this purpose. It has the same projection (WGS84 UTM ZONE 31) as the Landsat images used. The classified DEM was overlaid on the classified Landsat data layer of the final year (2016) to evaluate the effect of elevation on the emerging patterns.

From the second group (socio-economic), population, which represents the number and distribution of people occupying the area, was considered. Population growth in relation to rate of expansion is one of the criteria for measuring development pattern. For data on the number of people residing in the study area, census data for analytical purposes were sourced from the National Population Commission (2006). This was augmented with information from the Ogun State Regional Plan (2005-2025) report and projected for the periods of study. The 2006 population census was the most recent in the study area. It has figure for the national (the entire country), state and local governments, but unlike the 1991 census, was not disaggregated into lowest units (wards) or settlements level; hence references were made to earlier census of 1991 and other sources from literature.

3.3 Clipping of the study area

The study area is contained within a single tile (Path191/Row055). To save processing time, it was clipped from the Landsat and DEM data obtained. However, rather than using the site-specific boundary, a rectangular area covering the study settlements (*Mowe/Ibafo)* and a little beyond was used because the study area lacks definitive boundaries. The use of this methodology however is advantageous to the study as Bowyer (2015) claimed that this method eliminates edge effects (distortion of pattern of interaction across bounded region) that may arise if strictly clipped to the territorial boundary. To ascertain the effect of coverage on the phenomenon of sprawl, the shapefile of *Obafemi-Owode* local government (LG) area was used to clip portion of the study area (subset) within the boundary of *Obafemi-Owode* LG.

3.4 Image processing

The Landsat data was processed using both ArcGIS and Quantum GIS (QGIS). Data processing was done in three stages of pre-processing, processing and post-classification processing. A chart of the process is displayed in Figure 3.1

3.4.1 Pre- Processing

To enhance land cover classification, the three years Landsat imageries for the project (1987, 2000 and 2016) were subjected to pre-processing since they were acquired with Multispectral Scanners of different characteristics. The Pre-processing was done to ensures that the three images have the same spatial parameters and reference system (projection, cell size, spatial extent, spatial resolution and rows and columns). The pre-processing included the conversion of raster bands. Converting the images to Top of Atmosphere (TOA) reflectance from Digital Numbers (DN) eliminates the problems of comparing data with different levels of quantization (MSS data acquired with a 6-bit system and TM / ETM+ and OLI data acquired in an 8-bit system). Atmospheric scattering correction removes likely contaminations (Hadjimitsis *et al.*, 2008).

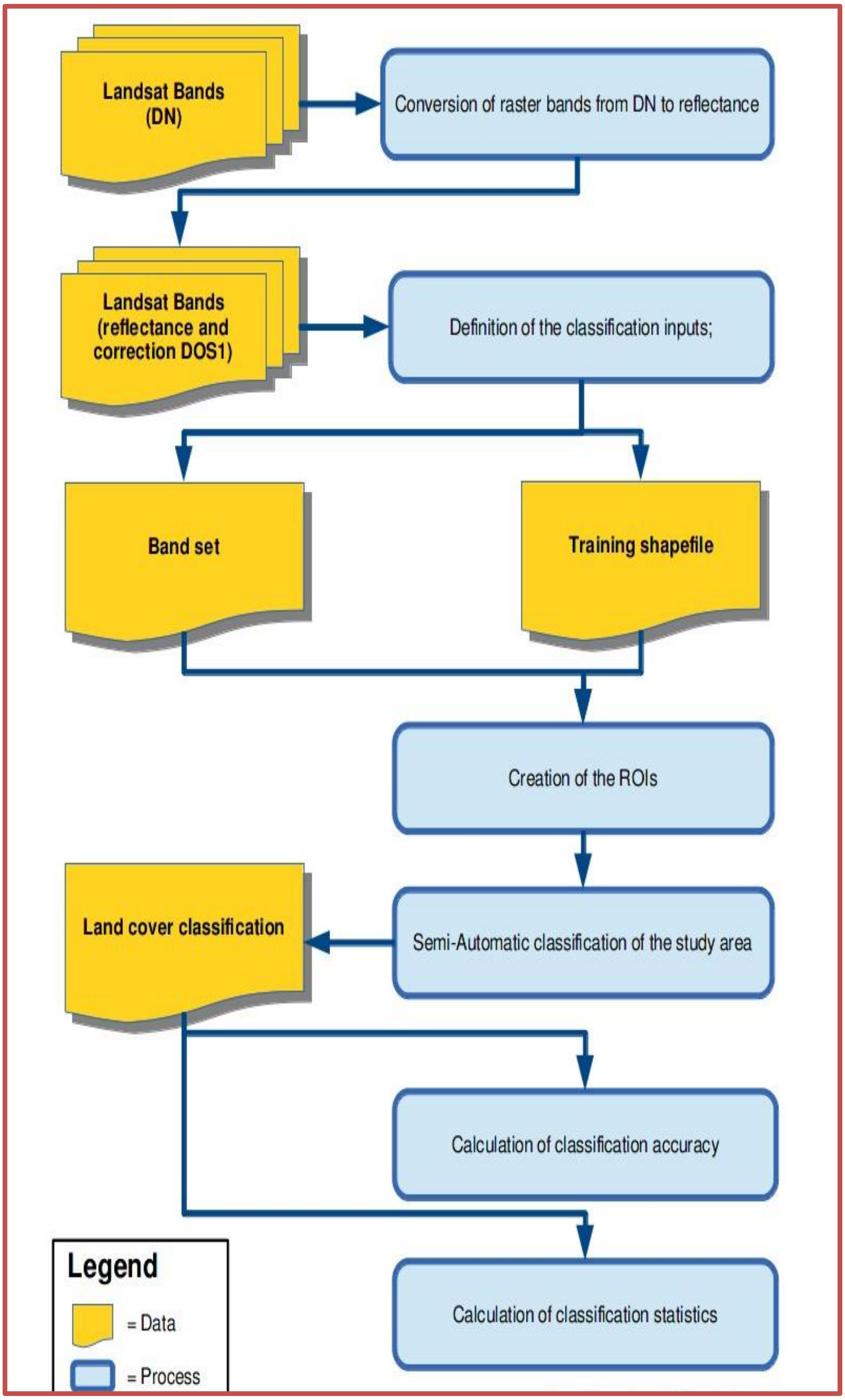


Figure 3.1: **Image Processing Workflow -Semi-Automatic Classification**

Source: Congedo, 2014

3.4.2 **Image Classification**

The land cover classification was conducted with the aim of identifying rate and pattern of sprawl and subsequently measure the phenomenon over the study period. The essence of classification is to cluster similar objects and determining the required classes is one of the steps in classification. Axis Maps (2017) argued that '*there is no ideal number of classes for a map*' but suggested *'3–7 data classes'* depending on the goals of classification, available data and acceptable level of generalisation. More classes reduce data generalisation but increases complexity of classification and confusion. Di Gregorio (2005) recommended that when strictly considering land cover, it should be restricted to '*vegetation and man-made features'*. He however, pointed out the dispute on the genuineness of water surface being *'real land cover'*. From the foregoing, and for the avoidance of the controversy of water being real land cover or not, the classification singled out water bodies as a class and classified the rest into vegetation and man-made features (built-up). Accordingly, as water body is usually considered as constraint to development (Sim and Mesev, 2014) its separation from other land cover class makes it possible to assess its influence as a factor of development. Therefore, three classes were used to attain the goal. These are:

1. Water body (including all river, stream, ponds and any other water surfaces);
2. Vegetation (all forms of vegetation including forest, shrub, grassland etc.);
3. Built-up (all artificially developed areas such as buildings, roads and areas awaiting development (bare land);

Generally, image classification is divided into unsupervised and supervised. Bhattacharya (2017) pronounced the superiority of supervised classification over unsupervised classification in the presence of quality training data. Therefore, supervised classification was used in this study. The choice of classification methods depends on algorithms available with the image processing software employed and experience. Unsupervised and supervised methods are automated processes while there are also manual, and hybrid approaches. Automated process uses an algorithm to assign pixels to one class. It has been established that both supervised and unsupervised classification approaches are reliable but supervised classification has more varieties of algorithms (De Gregorio, 2005). Also, the result of supervised classification is a land cover map with pixels labelled as a cover type. Unsupervised algorithm is limited to using only the pixel values and it results in output image with many unlabelled clusters (as may be specified) that requires further labelling into appropriate land cover. In classification, where only two or three classes are considered, inspecting and labelling each of the classes (which may be 25 or more) may sometimes create difficulty as some of the classes may contain more than one land cover type (De Gregorio, 2005). This challenge also influenced the use of supervised classification in this study.

Several algorithms are available for supervised land cover classification. They include Maximum Likelihood (ML), Minimum Distance Classifiers, Mahalanobis Classifier and Parallelepiped Classification. ML was used for the classification. ML classification algorithm had been adjudged as a good source of satisfactory LULC classification results in a variety of urban area studies using Landsat data (Rogen& Chen, 2004; Yuan *et al*., 2005; Afify, 2011). However, Richards and Jia (2005) have noted that maximum likelihood classification is slow. Despite that, ML remains preferable as the minimum distance algorithm, which is a faster technique, is not as flexible as ML (Richards and Jia, 2005).

3.4.2.1 **Image Classification Process**

The classification involved creation of multiband raster for each of the three images (1987, 2000 and 2016), production of training samples from known locations of desired classes, developing a signature file, viewing and editing signature file, and finally, the classification. Composite bands were produced for the classification. False colour composites aided easy identification of features during the classification. Adequate training samples were created for the three classes (water, vegetation and built-up,). With the creation of the training shapefile for the Region of Interest (ROI) collection, the signature list file was created. From this, the spectral signatures were calculated for the classification

The classification results were previewed, based on visual impression and local knowledge of the study area, thereafter the entire image classified when the outputs were considered satisfactory.

3.4.3 **Accuracy assessment**

Short (2003) defined accuracy assessment as the degree of correspondence between observations and reality. Map accuracy assessment provides opportunity to examine “sources of error and weakness of a classification strategy” (Powell *et al.,* 2004). It is usually judged by comparison against existing maps, aerial photography or field assessments i.e. sources of reference data include aerial photo, ground truth with Global Positioning Systems (GPS) and Google Earth image. As ground collected data is expensive and labour intense (FAO, 2016), the use of satellite imagery or aerial photography is common, especially when quantifying changes in time and space (Lund University GIS Centre, 2004).

Accuracy assessment was done for the three resulted classification images through a comparison of map data (classified dataset) and the ground truth data points (reference) from high-resolution Google Earth imagery (Virginia Geospatial Extension, 2013; Tilahun and Teferie, 2015). Google Earth has historical data, making it possible and robust to observe a location at different times (e.g. 1987, 2000 and 2016). Physical ground-truthing can only capture existing situation but not the past (which might have changed over time).

Overall Accuracy, which is the sum of correctly classified points divided by the total number of pixels in the classification (Liu *et al.*, 2007), was computed for the three years thus:

$$\text{Overall accuracy} = \frac{\text{Sum of correctly mapped points}}{\text{Total number of points in the sample}} \text{ X } 100$$

In addition, User and Producer accuracies were computed for each of the classes for the three years.

$$\text{User accuracy} = \frac{\text{Correctly classified pixel of a class}}{\text{Total number of pixel chosen for that class in the classified image}} \text{ X } 100$$

Producer's accuracy is the correctly classified pixels of each class divided by the total number of pixels of the class in the reference image i.e.

$$\text{Producer accuracy} = \frac{\text{Number of correctly classified points in a class}}{\text{Total number of points for that class in the reference image}} \text{ X } 100$$

The Accuracies were computed from Error/Confusion Matrix derived from the classification maps and ground truth/reference image (see Appendix 1 for the classification result/ground truth table and the Error Matrices).

Kappa-coefficient of agreement was also considered. It measures agreement between predictions and reality (Congalton, 1991). The overall Kappa provides information on the quality of maps. It was computed using the equation:

$K = \frac{N\sum_{i=1}^{n} x_{ii} - \sum_{i=1}^{n}(x_{i+} X x_{+i})}{N^2 - \sum_{i=1}^{n}(x_{i+} X x_{+i})}$---------------------------------Eqn. 1

where;

n = rows in the matrix

N = number of cells in the matrix

x_{ii} = correctly classified cells in a class

x_{i+} =sum of row *i* values

x_{+i} =sum of column *i*values

(Jensen, 1996)

Kappa value ranges between -1and 1. A Kappa value of –1 indicates that the map does not correspond to the ground truth at all (Lund University GIS Centre, 2004); 0 is expected agreement from random chance, while 1 denotes perfect agreement between the classification map and reference map

The classified maps of 1987, 2000 and 2016 were evaluated against high-resolution Google Earth imagery (resolution ranges from 15 meters to 15 centimetres).In selecting the reference data points, efforts were made to be practical while following common rule of thumb regarding number of points as detailed by Lund University GIS Centre (2004); and Congalton and Green (2009).While there are many procedures for selecting the assessment units, the simple random selection protocol, which is widely recommended (Lund University GIS Centre, 2004 and FAO, 2016), was used to generate a total of 1,500 points for each of the studied years (1987, 2000 and 2016). The points were relatively much and concentrated on some classes, especially the vegetation, because of its size, while few points were found on water class. Resulting from this, the first 50 points were selected for classes in excess of 50 points while the entire points were used where the resulting points were not more than 50. Congalton and Green (2009) recommends minimum of 20 to 100 samples per class, while Lund University GIS Centre considered 30 points adequate.

The points were used to extract class values from the classified maps for identification. They were converted to KML file in ArcGIS and opened in Google Earth

(Virginia Geospatial Extension, 2013). Land cover types were verified by zooming into each of the points to examine the land cover in Google Earth at exact point locations (Figures 3.2 - 3.5).The land cover types in the image were recorded against the class value in the classification map and used to construct confusion matrix for the computation of accuracies and Kappa coefficient (see Appendix 1). The process was repeated for the studied years with the aid of time slider (used to switch from 1987 to 2000 and 2016 images) in Google Earth.

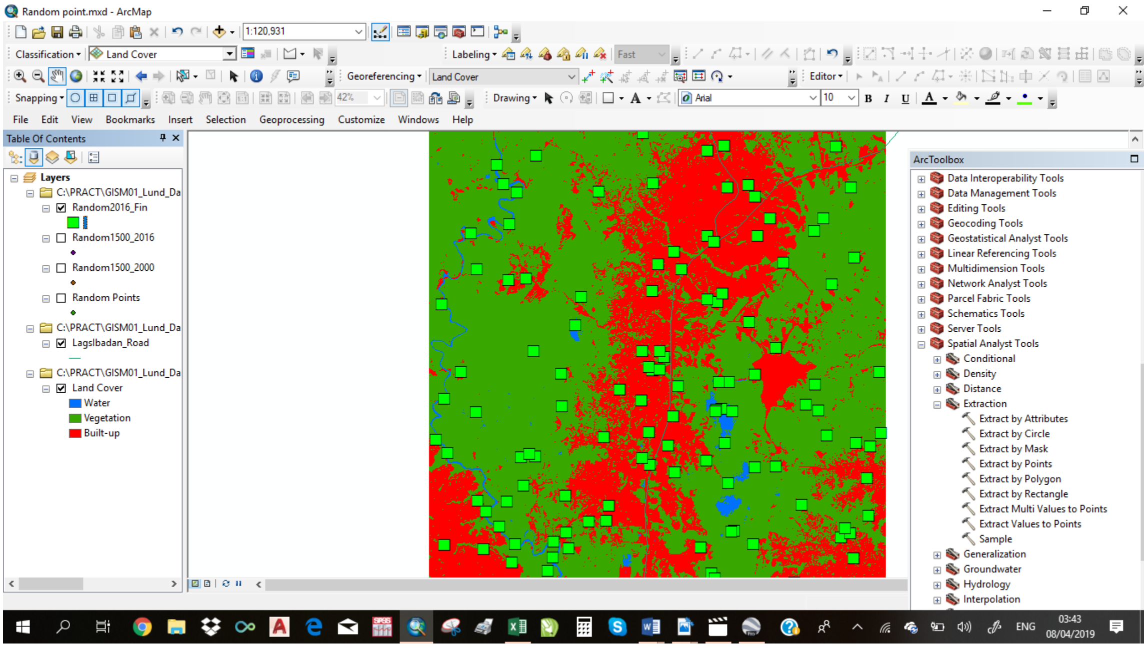


Figure 3.2: A Screen Dump of the Random Points in ArcGIS

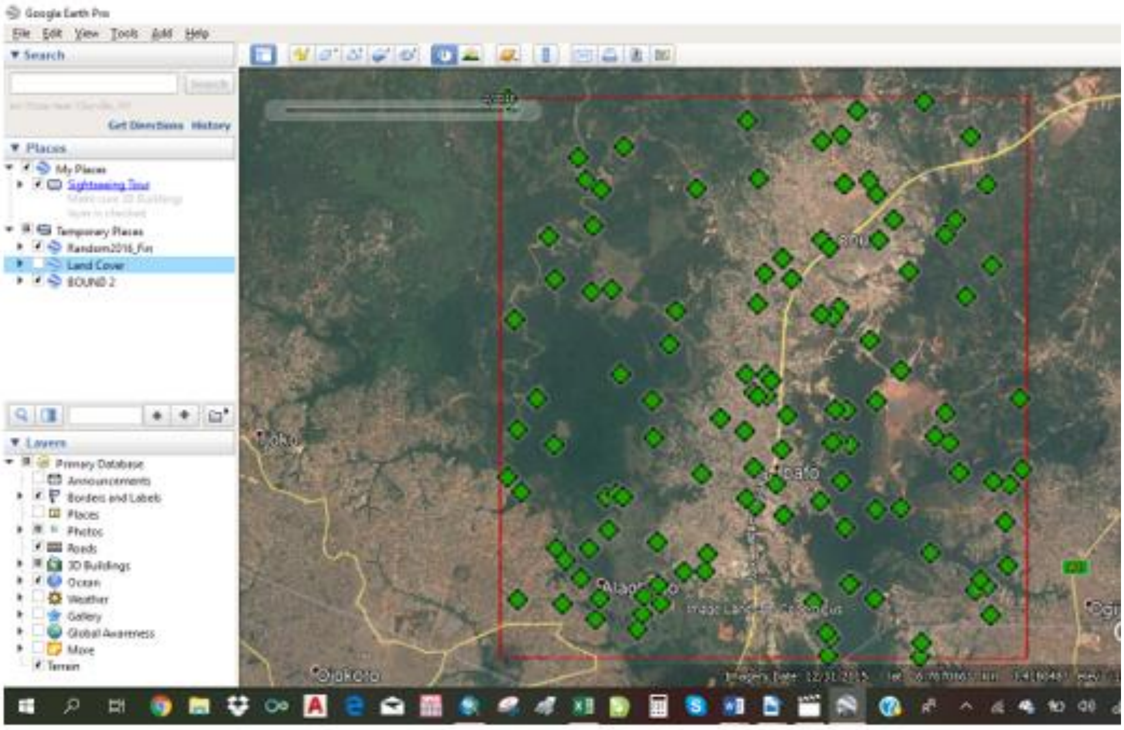
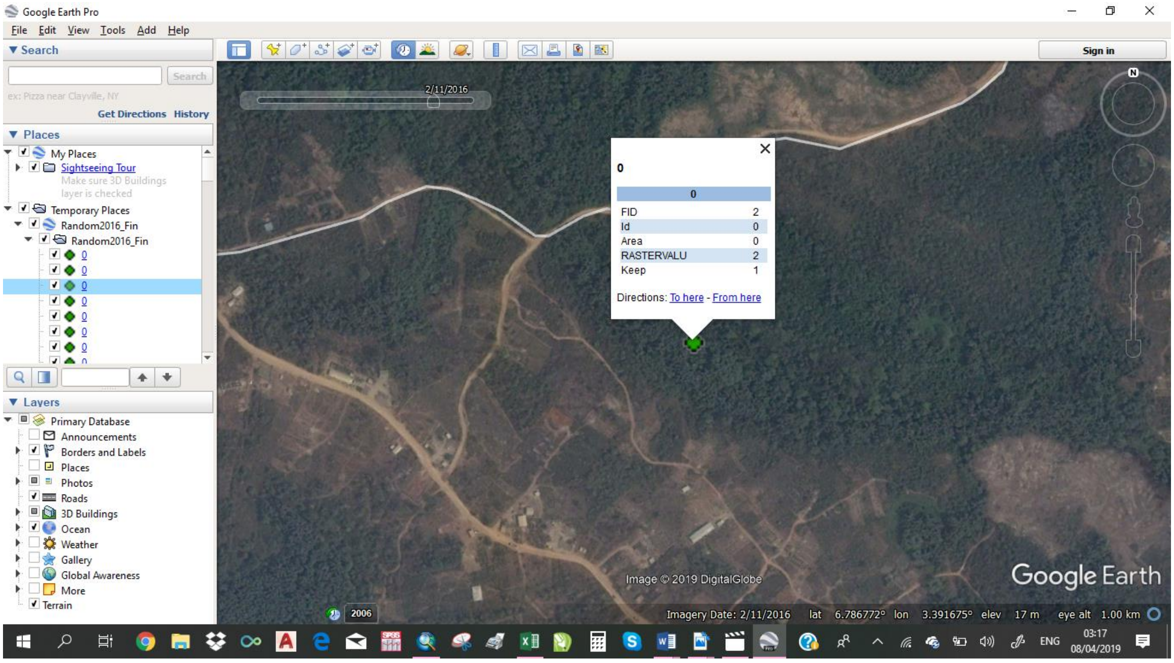


Figure 3.3: Screen Dump of the reference Points in Google Earth

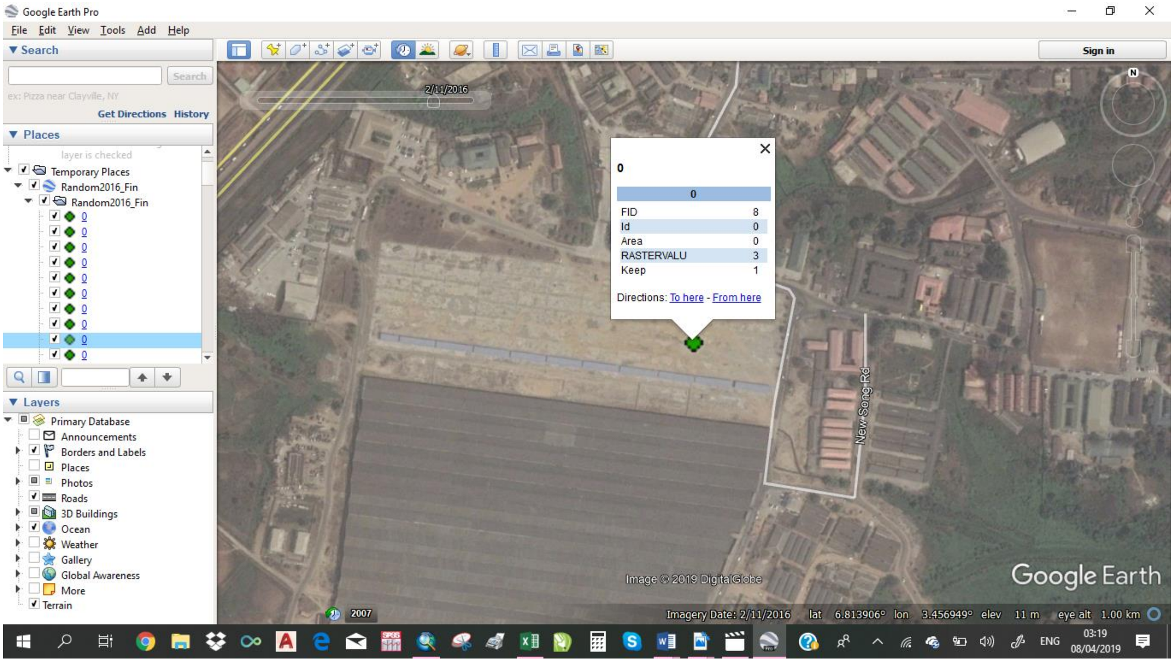


0

0	
FID	2
Id	0
Area	0
RASTERVALU	2
Keep	1

Directions: To here - From here

Figure 3.4: Identifying a vegetated area in Google Earth



0

0	
FID	8
Id	0
Area	0
RASTERVALU	3
Keep	1

Directions: To here - From here

Figure 3.5: Identifying a Built-up area in Google Earth

3.5 Post Classification Assessment

There are many techniques for mapping land cover change (Afify, 2011). The popular ones have been identified (Afify, 2011; El-Hattab, 2016) as ”post-classificationcomparison, image rationing, image differencing and principal component analysis”. Afify (2011), however, singled out post classification technique as the best in terms of accuracy. Therefore, post-classificationcomparison technique was adopted.

The results of the classifications (for years 1987, 2000 and 2016) were subjected to post-classification comparison (using visual and statistical interpretations) to detect transitions in land cover in different years. Changes were detected by comparing the three classified images to establish transitional changes and where urban growth occurred. Total coverage (and percentage) of each of the land covers (water, vegetation and built-up) were computed in sq.km for each of the years based on the number of pixels and pixel size of 30 metre by 30 metre. These were then computed to determine increases or decrease from year to year.

3.5.1 Rates of change

Land cover change for 1987-2000, 1987-2016 and 2000-2016 were computed from the resulting classifications using equation 2. Furthermore, annual rates of change were estimated as the average of percent change (Straight-Line Growth Rates) with equation 3

$$= \frac{d}{t1} * 100 \text{ -- Eqn. 2}$$

$$R = \frac{\left[\left(\frac{d}{t1}\right) * 100\right]}{y2 - y1} \text{ ------------------------------------ Eqn. 3}$$

where

d = difference in coverage between the two reference years

t_1 = area covered at the initial year

y_1= base year

y_2 = final year

(Enaruvbe and Atedhor. 2015)

The analysis was done at micro and macro level. The micro was the study area within the boundary of *Obafemi-Owode* Local Government (Obafemi-*Owode*Local Government tail end) while the macro was the rectangular study area which may be referred to as the area of influence of *Mowe/Ibafo*. The area within the confine of *Obafemi-Owode* covers 140.8158 square kilometres while the area of influence measures 325.872 square kilometres.

3.6 Measuring urban sprawl

The study employed Shannon’s Entropy to compute sprawl index of *Mowe/Ibafo*, using the classification results. It was used to explore the pattern of expansion and magnitude of sprawl. Li and Yeh (2004), among others, have described Shannon’s Entropy as a useful method for measuring compactness of urban growth. The formula for computing Shannon’s Entropy was given by Yeh and Li (2001) as:

$$H_n = -\sum_{i=1}^{n} P_i \, log_e(P_i) \qquad \text{--------------------------------------- Eqn. 4}$$

i.e. (-sum (P_i*ln(P_i)

where:

Pi = Proportion of phenomena (built-up area) within *ith* (each) zone;

n = Number of zones.

e.g. for twenty zone computation the equation will be

$H = -((P1*\text{Ln } P1)+(P2*\text{Ln } P2)+(P3*\text{Ln}P3)+\text{-------------}(P20*\text{Ln}P20))$

Yeh and Li (2001) used buffers to define the zones from city centres and roads, then computed the entropy from the density of land development in each of the buffer zones. The use of Shannon's Entropy can establish major zones of growth and the magnitude of change of urban sprawl over the period of study (Yeh and Li, 2001).

A raster algebra statement can be applied to calculate the entropy (H).

H = -1*((lc1 * Ln(lc1) + (lc2 * Ln(lc2) + ...)

Where: lc is land cover

Alternatively, it can be computed in excel sheet (Goepel, 2013). This method was adopted in this study (See Appendix 2).

Shannon's Entropy values range from 0 to $\log_e(n)$; where:

0 is very dense urban areas;

values close to $\log(n)$indicate urban sprawl (Yeh and Li, 2001).

$\text{Log}_e(n)$ or Ln(n) (Maximum Diversity) (Goepel, 2013) depends on the number of outcomes or zones, hence the value of Shannon Entropy may be more than 1. The equation for calculating the range of Entropy as provided by Wang (2011) is:

$0 \leq \text{Entropy} \leq \log(n)$,

where n is number of outcomes or zones.

However, for easy comparison, the Shannon Entropy value can be scaled into a value between 0 to 1using Relative Entropy (Thomas, 1981) or Shannon's equitability, with the following equation:

$$H'n = \sum_{i}^{n} Pi\ \log(1/Pi)/\log(n) \qquad \text{--------------------} \text{ Eqn. 5}$$

i.e. computed entropy divided by Maximum diversity index Ln(N):

$H'n$ =H/Ln(N), where N is the number of proportions or class

If the obtained value is closer to 1 (perfect equitability), it shows that the area is really dispersed but when closer to 0, the pattern is compact.

3.6.1 Shannon’s entropy Computation

Shannon’s Entropy was calculated for the study area over three different periods, using the extracted built-up area from the classified land cover data (Appendix 2). Entropy served as independent variable to measure the dispersion of land cover across the study area. The process usually involves division of study areas into zones using different criteria. Chong (2017) observed that, most earlier studies (Yeh and Li, 2001; Deka *et al*., 2012; and Dadras *et al*., 2014) that used Shannon's Entropy for urban sprawl measurement used buffer zones of diverse shapes. Such buffers are created using city centre as the starting point (to create concentric shapes about the town centre) while others use major roads to create linear buffers. For instance, Dadras *et al*. (2014) and Deka *et al.* (2012) employed circles and squares respectively in creating their concentric buffers. Based on the observed pattern of development in the study area, and the work of Yeh and Li (2001), this study used a combination of concentric circles (buffers) from assumed centres of the towns and linear buffer along Lagos - Ibadan Expressway that traverses the study area.

In conceding to the use of town centres and major road, existing models of urban land use, such as the ‘Chicago School of Urbanism (Burgess, 1925; Hoyt, 1939; and Harris and Ullma, 1945), were relied upon. They recognised the development of settlements from a Central Business District (CBD) or centre. Burgess postulates that city radiates about a single CBD and density is a function of distance to the centre (i.e. density decreases towards outside zones). Hoyt agreed to the development from the CBD but emphasised expansion in wedges along major transportation routes rather than concentric form, while Harris and Ullma believes that development is about multiple city centres (as the city becomes larger over time, smaller centres grow throughout the city). It is also the postulation of diffusion theory that the farther a place is to the city centre the less developed it would be. Therefore, this study considered the city centre (CBD) and major transportation route in dividing *Mowe/Ibafo* axis into zones to examine the pattern of development.

Bhatta (2010) argues that the “size, shape, and number of the buffer zones” are immaterial in computing entropy. This position was further affirmed by Chong (2017) who conducted sensitivity analysis on the Shannon's Entropy metric using different numbers of buffer zones and sizes. Relative entropy, which rescales Shannon's Entropy value from 0 - 1, is also not affected by number of zones (Thomas, 1981). While Rahman (2016) and Chong (2017) used buffer width of 500m and 1610m (1 mile) respectively, Yeh and Li (2001) used 250m buffer width. This study adopted 500m width buffer. Although, earlier researches (quoted above) did not establish sensitivities relating to sizes and numbers of buffers, 1000m width buffer was further used in the research to verify the sensitivity or otherwise of entropy computation to size of the zones.

The entire study area was divided into 20 zones (500-metre multiple ring buffer) from the centre of *Mowe*/*Ibafo* towns and equally from the Lagos - Ibadan Expressway (Figure 3.6). Seventeen of the zones were within the boundary of *Obafemi-Owode* local government. The buffer zones were overlaid on the built-up areas, obtained from the land classification maps. Values of developed areas within each zone were extracted into the buffers, with *Zonal Statistics Tool* in ArcGIS, to compute the density across the study area. The built-up (developed) area within each of the zones was divided by the entire zonal buffer area to compute density of land development, which was subsequently used to calculate the entropy and relative entropy for the studied years. These were used to compare the magnitude of urban sprawl (See Appendix 2 for details). For comparison and sensitivity analysis, the total study area was divided into 10 zones of 1000m multiple ring buffer (See Appendix 3).

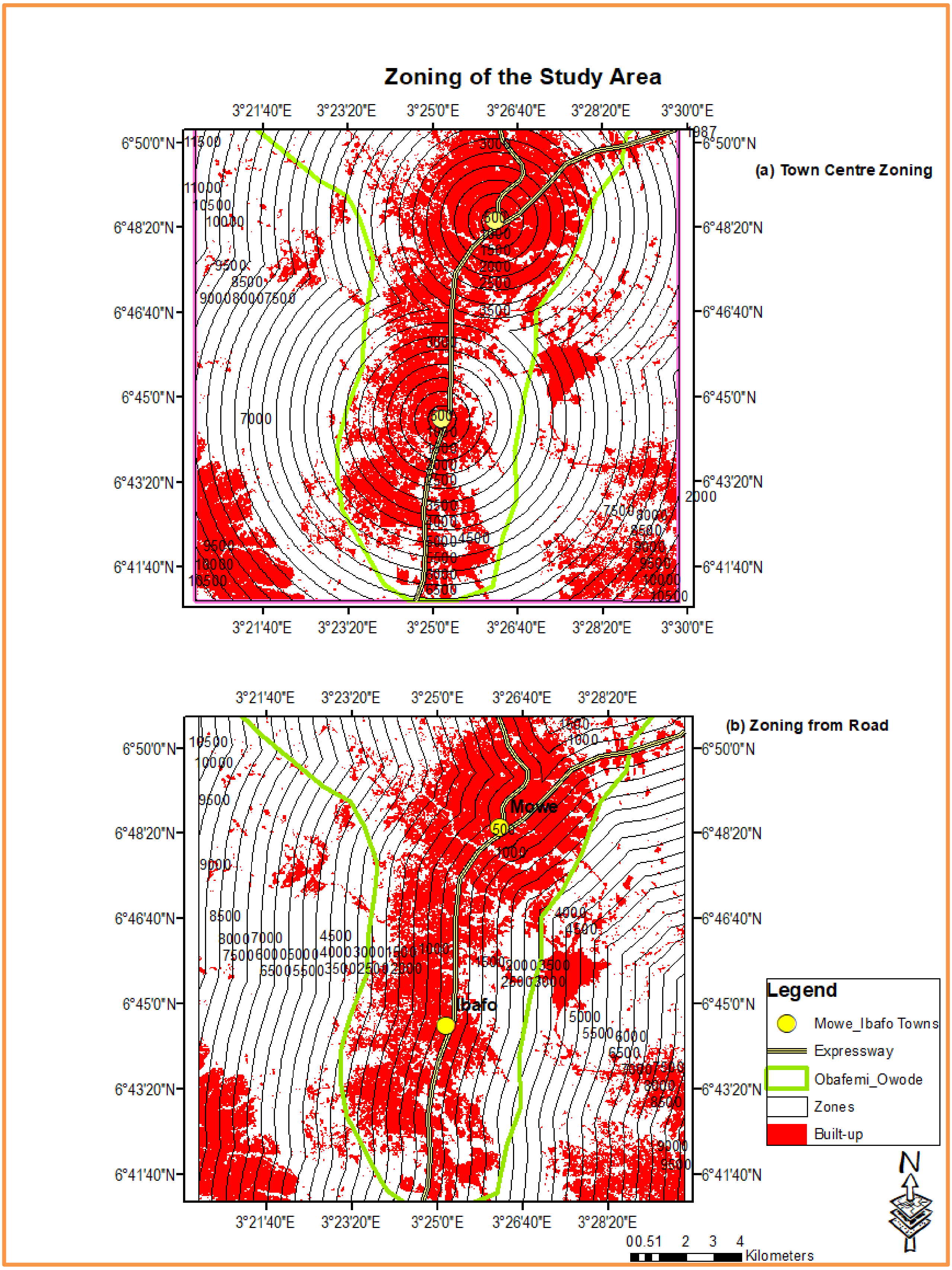


Figure 3.6: Zoning of the Study area for Entropy Computation

3.7 Factors of expansion in the study area

3.7.1 *Physical Characteristics*

The physical characteristics of an area and distance to facilities/infrastructure have been identified in literature (Braimoh and Onishi, 2007) among factors for pattern of urban sprawl. To this end, the digital elevation model (DEM) was processed to evaluate the elevation of the study area in relation to the evolving settlement. The elevation, which ranges between -10 and 108 m, was classified into five at a relative interval of 15 m and total land area within each class was computed. Classified built-up layer of the area was extracted into the elevation layer and the built-up area within each class was also computed. These were used for analysis and contrasting of urban expansion among the different elevation zones

3.7.2 *Population* of the Study Area

The most recent official population figures for Nigeria are 1991 and 2006 censuses. The population of *Obafemi-Owode* as a local government was 135,774 in 1991 and 235,071 in 2006. In 1991, the population of *Ibafo* was 25,415 (National Population Commission (NPC), 1991), which was about 19% of the population of the local government. Population figure of *Mowe* was not available, as most settlements had no registered census figures for 1991. Similarly, 2006 population was not broken down to unit beyond local government. However, *Mowe*/*Ibafo* was identified among the corridors along the Lagos-Ogun State borders that have experienced the highest population pressure and under the intense pressure of physical growth (Lagos State Government, 2004). Premised on this, the Ogun State Government (2008), projected the population of Obafemi-Owode for 2025, in the Ogun State Regional Plan (2005-2025), to be 2,000,000 and that of *Ibafo* and *Mowe* at 400,000 and 200,000 respectively. In as much as *Ibafo* maintains 20 percent of the total population (close to the 19% in 1991 census), the figure (which is about 8.23% annual growth rate) appears ambitious and far from the NPC (1998) suggested population growth rate of 2.75% for the area.

The above was reconciled by using the intercensal growth rate of 1991 and 2006 censuses (3.65%) and Exponential Growth and Decay formula to project the population figure for the study years 1987, 2000 and 2016 (Table 3.2). It was assumed that the population of the study area within the coverage of Obafemi-Owode is 30% of the total population of the local government as inferred from the 1991 census and Ogun State projection of 2008. Computation of the wider coverage area was not feasible as it could not be properly situated within other local governments.

Table 3.2: Estimated Population of the Study Area within Obafemi-Owode Local Government

Year	Estimated Population
1987	32 944
2000	52 639
2016	93 415
2025	128986

3.8 Development Control in the study area

Data on development and its control in the study area was obtained through interview of selected Planning Officials from the two Zonal Town Planning Offices (ZTPOs) monitoring development in the area. Questions on the number of available staffs within the ZTPOs and their qualifications, available monitoring instruments (such as plans), equipment and facilities among others were probed. Methodology for monitoring development was also explored.

Chapter 4: Results

4.1 Introduction

This chapter presents the results of the project at micro and macro level. The micro depicts study areas within the boundary of *Obafemi-Owode* Local Government while the macro covers the rectangular study area (entire study area) which may be referred to as the area of influence of *Mowe/Ibafo*. The area within the confine of *Obafemi-Owode* covers 140.8158 square kilometres while the area of influence measures 325.872 square kilometres. Land cover composition for the years 1987, 2000 and 2016, accuracy assessment, pattern of expansion, as analysed and affected by the factors of urban expansion, were presented in different sections of the chapter.

4.2 Land-cover classification of the study Area

The classifications of land cover for 1987, 2000 and 2016 years are shown in Figure 4.1. There was gradual increase in the built-up area over the years. As further revealed in Figure 4.2, only 5.52 (1.69%) of the 325.87 sq.km of the study area was built-up in 1987 while 318.60 sq.km (97.77%) and 1.76 sq.km (0.54%) were vegetation and water body respectively. The portion of *Ogun* River that traverse the study area in the west constituted the major water body. Built-up area increased by 8.33% between 1987 and 2000. Major growth was in the city centres, along the expressway, and in the extreme southwest with expansion from Lagos. Water body increased to 0.81% while vegetation reduced to 90.86%. The pattern was maintained between 2000 and 2016 as water body and built-up increased to 1.29% and 66.26% respectively while vegetation decreased to 32.45%.

Jurisdictionally, out of the total land area covered in this study, 140.816 sq.km is within the boundary of *Obafemi-Owode* local government. Land cover classifications of the portion for the year1987, 2000 and 2016 were equally depicted in Figure 4.1. By 1987, only 3.54 square kilometre (2.51%) of the 140.816 sq.km that make up the portion within *Obafemi-Owode* was built-up while 97.35% was vegetation of different types and 0.14% was water body (mainly a portion of *Ogun* River to the extreme left of the study area). The built-up area increased to 17.56 sq.km (12.47%) and 70.15 (49.82%) in 2000 and 2016 respectively (Figure 3). Similarly, water body increased to 0.70 sq.km. Contrarily, vegetation decreased from 137.08 sq.km (35%) in 1987 to 122.56 sq.km (87.03%) in 2000 and 69.17 sq.km (49.12%) in 2016.

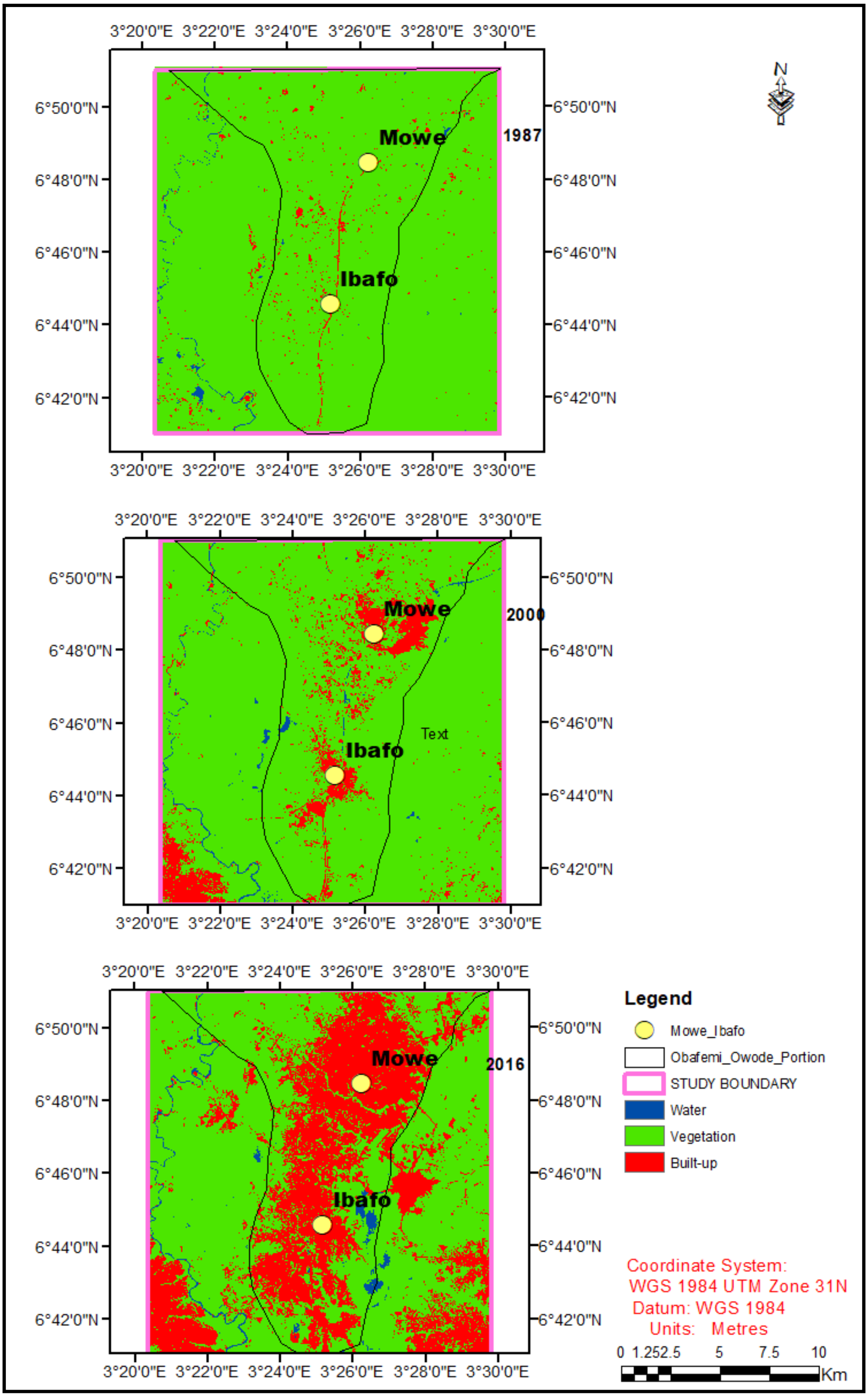


Figure 4.1: Land cover classification maps of the Study Area for 1987, 2000 and 2016

Figure 4.2: Land Classification of the Entire Study Area

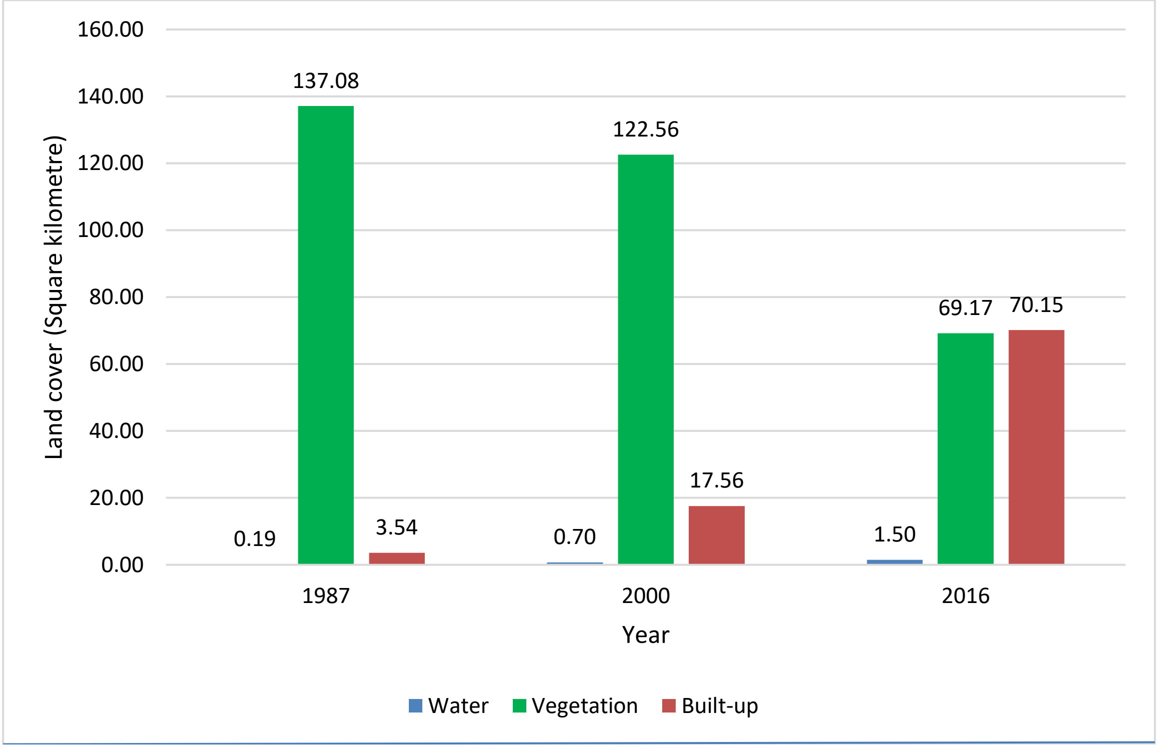


Figure 4.3: Classification of Study area within *Obafemi-Owode* LGA

4.2.1 **Hypothesis Testing**

The first hypothesis of the study is that *there is no statistical difference in land cover change in Mowe/Ibafo axis from 1987 to 2016.*

Therefore, the above classification result was subjected to Paired Samples *t* Test. Among other things, it tests ‘Statistical difference between two time points.’ The variable used in the test is called dependent variable. In this case, it is the land cover of the entire study area, measured in 1987 and 2016 at pixel level (Table 4.1).

The results of the paired-samples t-test conducted is shown in Table 4.2. There was a significant difference between 1987 and 2016 land cover scores with an increase from 1987 ($M = 2.0115$, $SD = 0.14899$) to 2016 ($M = 2.3116$, $SD = 0.49023$), $t_{(362079)} = -36.801$, $p < .0005$ two-tailed). The mean increase in landcover scores was 0.3001 with a 95% confidence interval ranging from -30168 to -29844. The eta squared statistics (.2666), computed below indicated a large effect size.

Table 4.1 Paired Samples Statistics

		Mean	Number of Pixels (N)	Std. Deviation	Std. Error Mean
Pair 1	Land1987	2.0115	362080	.14899	.00025
	Land2016	2.3116	362080	.49023	.00081

Table 4.2: Pair Samples Test

	Paired Differences							
				95% Confidence Interval of the Difference				
Pair	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	Df	Sig.
Landcover1987-Landcover2016	-.30006	.49767	.00083	-.30168	-.29844	-362.801	362079	.000

The result above shows statistical significant different in the land cover results of 1987 and 2016. The magnitude of the effect is revealed by the value of eta squared calculated as:

$$\frac{t^2}{t^2+(N-1)} \quad \text{----------------------------------- Eqn. 6}$$

where,

t = t-value, which is -362.801 in table 4.2

N = Total sample, which is 362080 in Table 4.1

$$\frac{-362.801^2}{-362.801^2 + (362080 - 1)}$$

$$\frac{131624.565601}{131624.565601 + 362079}$$

$$= \quad 0.2666$$

With the calculated value of 0.2666 and based on Cohen’s (1988) interpretation of the Eta squared value (.01 is small effect, .06 is moderate effect; and .14 is large effect), it was concluded that there was a large effect, with a substantial difference in the land cover score of 1987 and 2016

4.3 Land Cover Classification Accuracy

The results of accuracy assessments are displayed in the matrices in Table 4.2 and calculations shown in Appendix 1. The assessment was done using Overall, User’s and Producer’s accuracies. Overall accuracy, which measures the percentage of correctly classified data for each classification, was 88%, 90% and 86%for 1987, 2000 and 2016 respectively. Both the Producer’s and User’s accuracies were also assessed for individual classes. Aside from the water class, User’s Accuracy values of all other classes were between 72% and 100%. The results of Kappa coefficient, in Table 4.3, also revealed a substantial agreement between the classified and ground truth (reference) data for 1987 and 2016 (0.77 and 0.78 respectively) and a perfect agreement (0.84) between the classification map and reference map for 2000 classification (Appendix 1).

Table 4.3: Accuracy Assessment of the Land Cover Classifications

1987 Land Cover Classification Matrix

Ground Truth

	Class	Water	Vegetation	Built-up	Total	**User's Accuracy**
	Water	7	1	1	9	**78%**
Map Data	Vegetation	0	49	1	50	**98%**
	Built-up	1	6	18	25	**72%**
	Total	8	56	20	84	
Producer's Accuracy		**88%**	**88%**	**90%**		

Overall Accuracy = 88%

KAPPA = 0.77

2000 Land Cover Classification Matrix

Ground Truth

	Class	Water	Vegetation	Built-up	Total	**User's Accuracy**
	Water	9	5	1	15	**60%**
Map Data	Vegetation	0	48	2	50	**96%**
	Built-up	1	2	47	50	**94%**
	Total	10	55	50	115	
Producer's Accuracy		**90%**	**87%**	**94%**		

Overall Accuracy = 90%

KAPPA = 0.84

2016 Land Cover Classification Matrix

Ground Truth

	Class	Water	Vegetation	Built-up	Total	**User's Accuracy**
	Water	16	8	0	24	**67%**
Map Data	Vegetation	0	45	5	50	**90%**
	Built-up	0	4	46	50	**92%**
	Total	16	57	51	124	
Producer's Accuracy		**100%**	**79%**	**90%**		

Overall Accuracy = 86%

KAPPA = 0.78

4.4 Built-up Density and Entropy

The results from the two methods (buffer from the town centre and from the expressway) for the 2016 land classification revealed a slight difference in density of land development across the zones as shown in Figure 4.4. The density decreased sharply with distance from the expressway, rose slightly at 3500 metre zone to 8000 metre zone and again dropped sharply. On the contrary, the results from the town centres' zoning produced a curve with two crests. The density of land development increased gradually from the town centres (zone 1) to the 7th zone (3500 metres buffer), then decreased progressively to 6500 metre zone where it rose again and peaked at 9000 metre before decreasing to the last zone. It could be inferred that the development along the road was more uniform and consistent within each zone while that was not the situation with the city centre where some sectors (within zone) or wedge were denser than the others. Furthermore, the road had a major influence on the expansion of the settlements, and this informed the linear pattern of the settlements. The creation of crests supports multi-nucleic development rather than a mono-concentric form. As observed in the classification map, other settlements (nuclei), mainly from Lagos state were also expanding from the southwest and southeast of the study area towards the *Mowe/Ibafo* axis. The pattern was similar for the three studied years (Figure 4.4a)

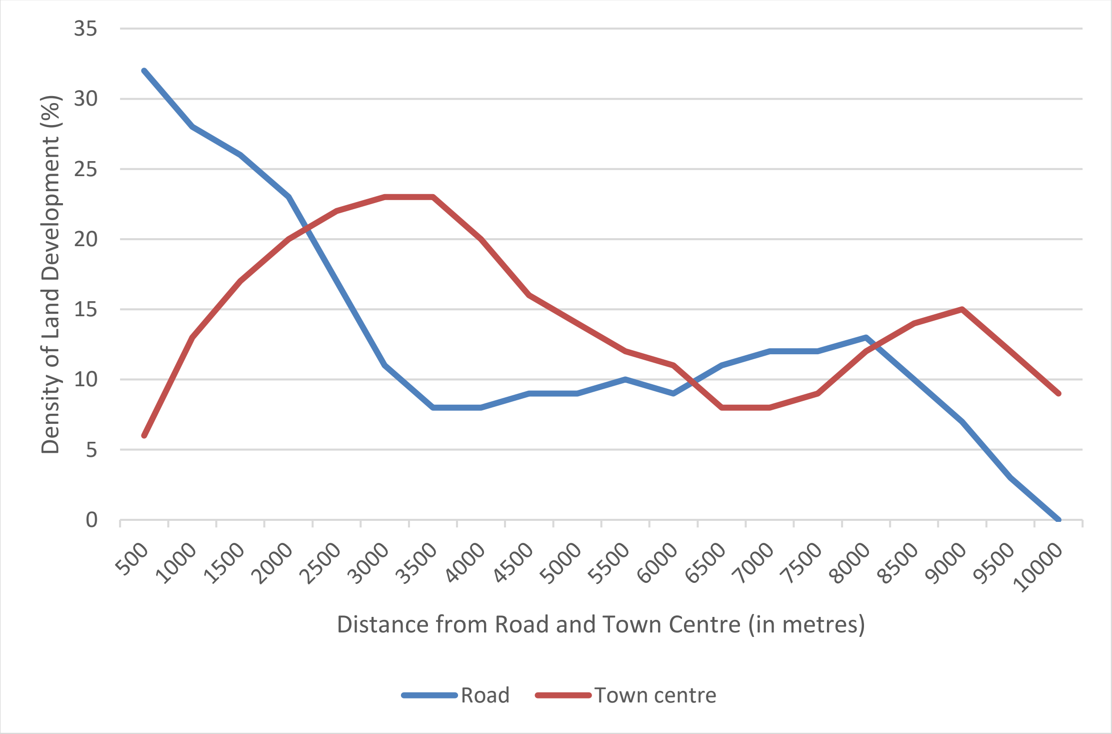


Figure 4.4: Built-up Density Progression from town centre and major road

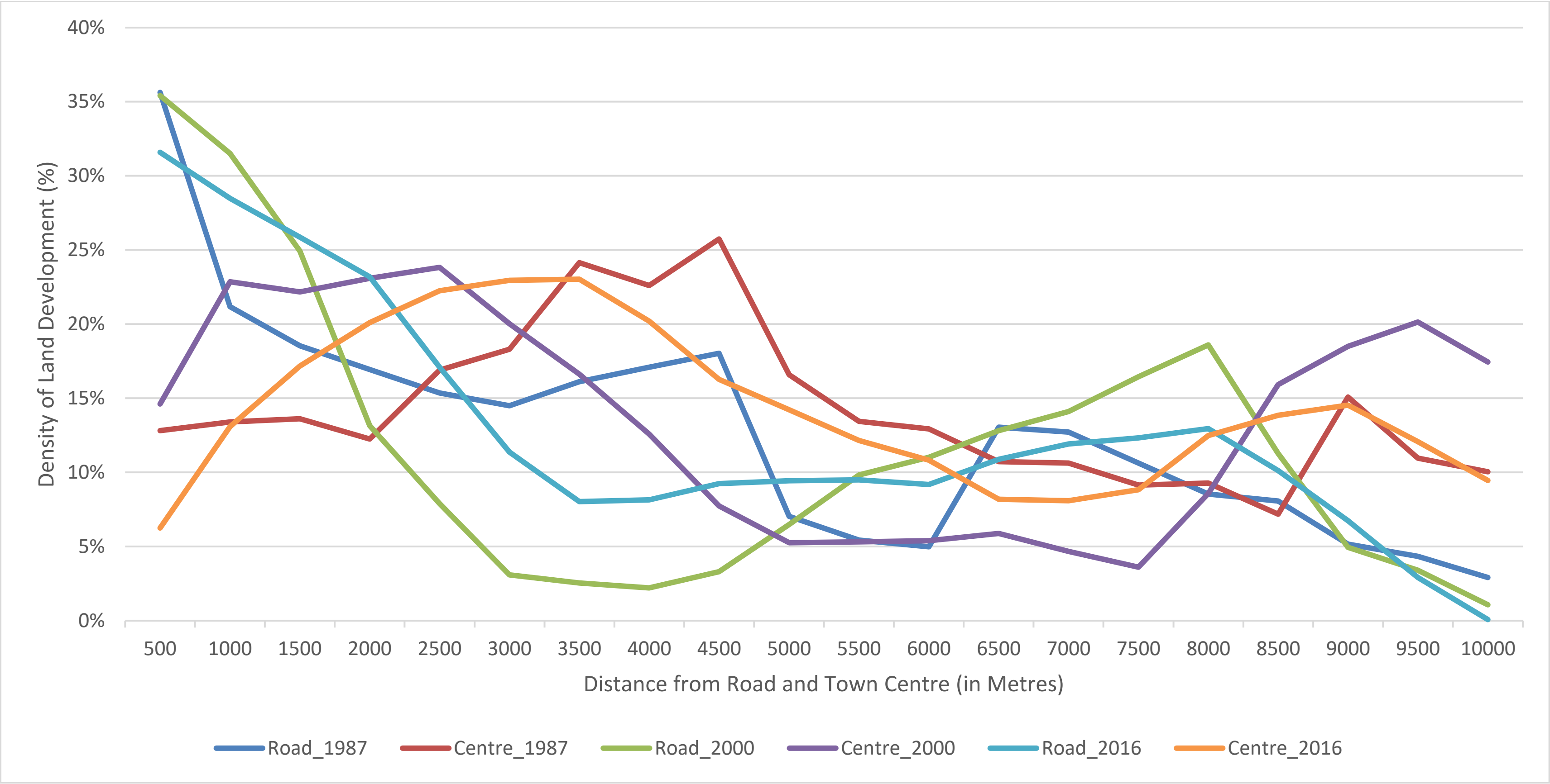


Figure 4.4a: Comparison of Built-up Density Progression from town centre and major road for the three years

Table 4.4 presents the summary of computed entropy indices for the three studied years (See Appendix 2 for details). Entropy was calculated based on the zonings from the town centres and from the major road. The values from zoning based on the town centres are higher than the results from the road zoning for the three years, however, the two methods displayed a similar pattern, decreasing from 1987 to 2000 and increasing to 2016 (Figure 4.5). Year 2000 had the lowest entropy (2.742) while 2016 had the highest (2.860). The entropy values were very close to Log (n) value and the relative entropy values were also very close to 1, indicating that developments in the area are dispersed i.e. sprawls. In comparing the years, the results indicated that the area was sparsely developed as at 1987 and tends towards compaction in 2000 but this was reversed in 2016.

Table 4.4: Shannon's entropy indices of *Mowe/Ibafo*

Year	Entropy (H)	Ln(n)	Relative Entropy (H'n)
	From City Centres		
1987	2.858	2.996	0.9539
2000	2.742	2.996	0.9152
2016	2.860	2.996	0.9546
	From the major road		
1987	2.562	2.996	0.8551
2000	2.542	2.996	0.8485
2016	2.591	2.996	0.8648

The values show that the area is really dispersed (sprawl pattern) as the relative entropy values are closer to 1 which is perfect equitability

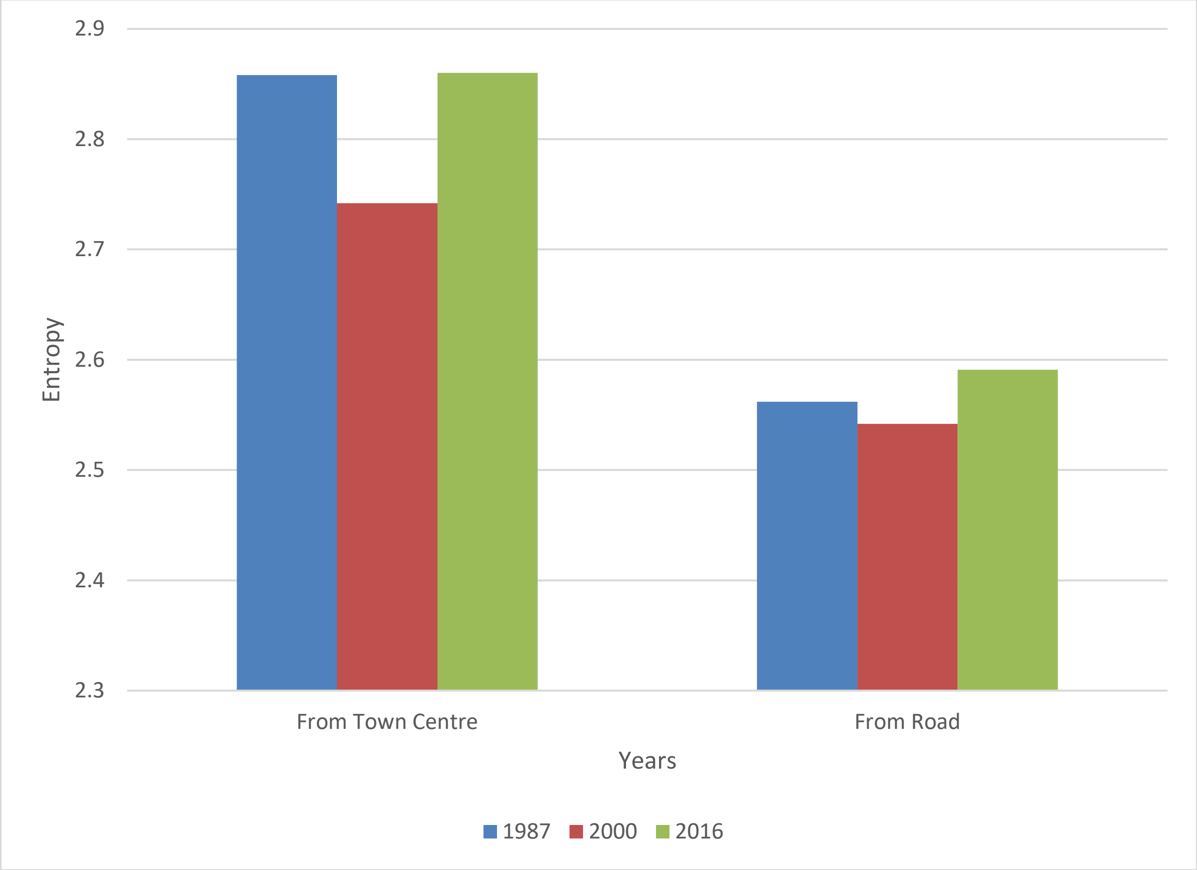


Figure 4.5: Entropy Values from 1987-2016 based on zoning from the town centre and expressway

Entropy was also computed for the study area within the confine of *Obafemi-Owode* to assess the effects of area coverage on the values of entropy vis-a-vis urban sprawl. The results (Table 4.5) produced lower values for the three years compared to the entire area values in Table 4.4. This implies that the wider the coverage, the more the degree of sprawl. However, it displayed the same pattern with that of the entire study area in Figure 4.6. The entropy values from the city centre zoning were higher than those from the major road's zoning; the value was higher in 1987 for the two methods, decreased in 2000 and increased again in 2016. Although the values for the computation of area within *Obafemi-Owode* Local Government (LG) was not as high as the values for the entire study area, all the Entropy values were high, and the Relative Entropy values were closer to 1 than 0 which portrayed sprawling (Figure 4.7). As in the larger area, a comparison of the year 2016 entropy values with 2000 shows a higher sprawled development.

Table 4.5: Shannon's entropy indices of *Mowe/Ibafo*
(Area within Obafemi-Owode)

Year	Entropy	Ln(n)	Relative Entropy
	From City Centres		
1987	2.555	2.833	0.9019
2000	2.335	2.833	0.8242
2016	2.368	2.833	0.8359
	From the road		
1987	1.993	2.833	0.7035
2000	1.490	2.833	0.5259
2016	1.805	2.833	0.6371

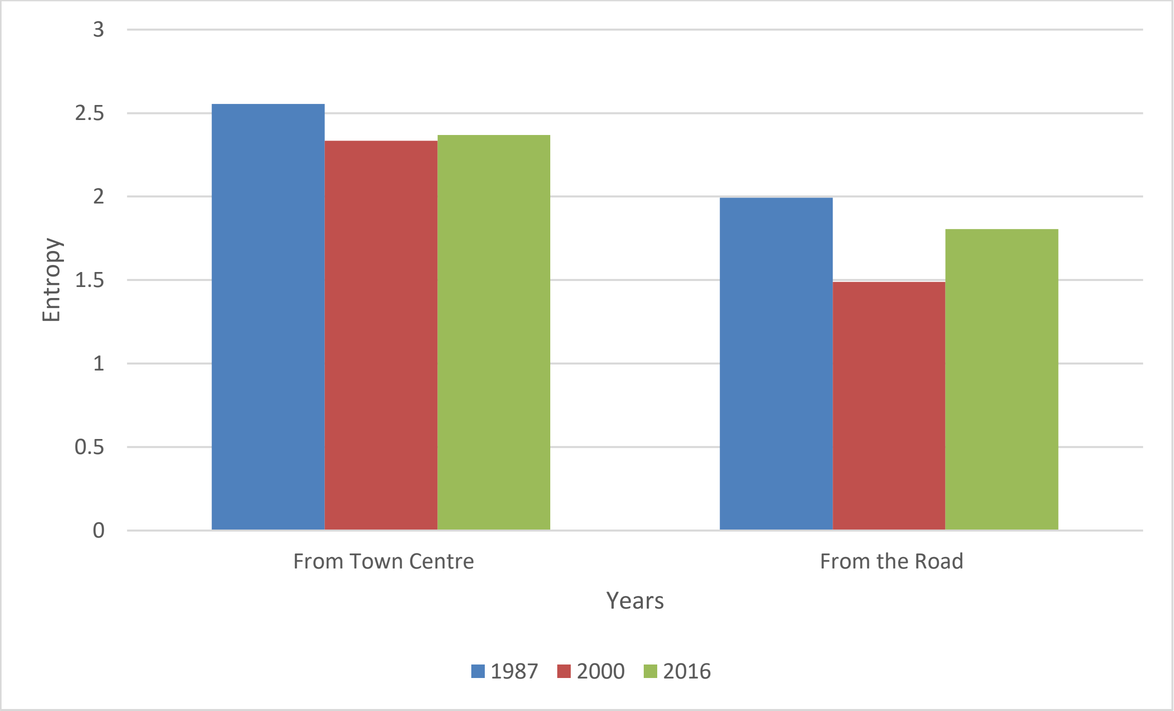
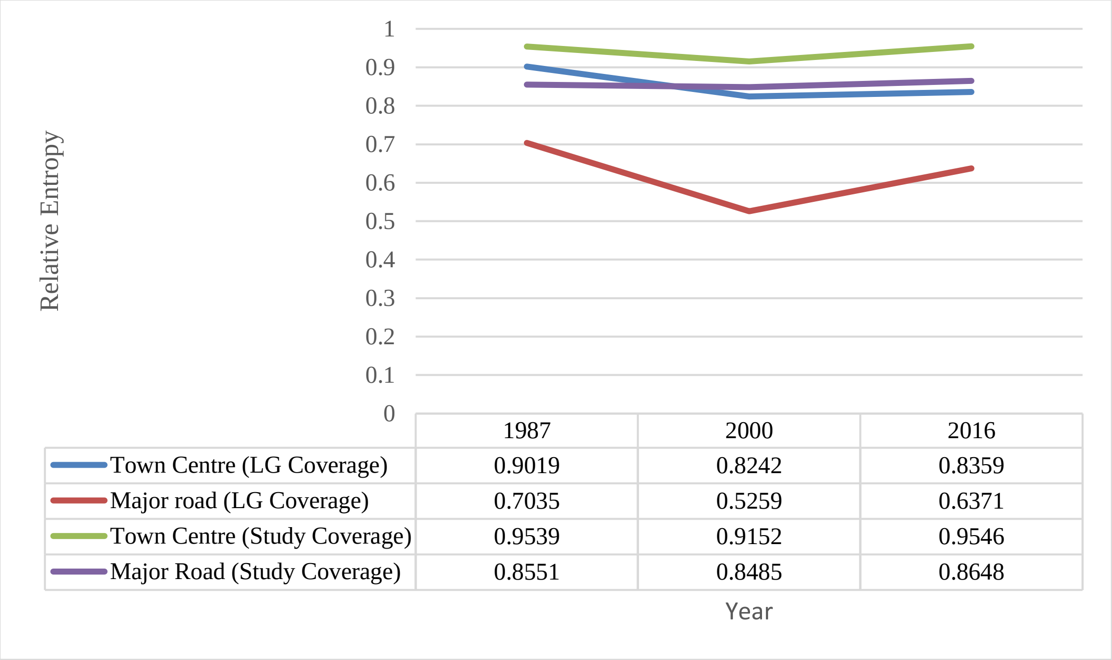


Figure 4.6: Built-up Density Progression from town centre and major road



	1987	2000	2016
Town Centre (LG Coverage)	0.9019	0.8242	0.8359
Major road (LG Coverage)	0.7035	0.5259	0.6371
Town Centre (Study Coverage)	0.9539	0.9152	0.9546
Major Road (Study Coverage)	0.8551	0.8485	0.8648

Figure 4.7: Relative Entropy trends for the Obafemi-Owode LG coverage and the entire study area using the town centre and the major road

To test the size effect and the number of buffer zones on the entropy value, the entropy computation was subjected to sensitivity analysis. Using 1000 metre multiple buffer rings, the study area was divided into 10 zones (instead of 500 metre buffer and 20 zones earlier used). The results are shown in Table 4.6 and the complete computation in appendix 3 (Tables A17-A22). As shown in the table, all the Entropy values (column 2) are close to Ln values (column 3) and Relative Entropies (column 4) are closer to 1 than zero thereby agreeing with the 500m buffer results that the study area sprawls. Although the values are lower when compared to 500m buffer values, they share the same pattern.

Table 4.6: Analysis of Shannon's Entropy Sensitivity using 1000m buffer zones

Year	Entropy (H)	Ln(n)	Relative Entropy (H'n)
	From City Centres		
1987	2.186	2.303	0.9491
2000	2.070	2.303	0.8988
2016	2.179	2.303	0.9464
	From the major road		
1987	1.941	2.303	0.8430
2000	1.687	2.303	0.7328
2016	1.911	2.303	0.8298

4.5 Rate and directions of expansion of *Mowe/Ibafo* settlements

The entire study area witnessed a tremendous growth between 1987 and 2016. As shown in Table 4.7, the built-up area increased by 392% and 290% during 1987-2000 and 2000 - 2016 respectively while the overall growth (1987 – 2016) was 1815%. These resulted in an increase from 5.521 sq.km in 1987 to 105.751sq.km in 2016. The average annual change or expansion was estimated as 63%. The percentage growth for different periods were a little higher for the area within the limit of *Obafemi-Owode* [1987-2000 was 396% while 2000-2016 was 299% and the overall (1987 - 2016) was 1883%] with an average annual change of 65%.

The early developments (1987-2000) in the area were at the city centres along the Lagos Ibadan – Expressway and in the southwest parts, mostly in Lagos State. The major direction of expansion of *Mowe/Ibafo* is towards the north and south along Lagos - Ibadan Expressway and northwest along *Mowe-Ofada* Road. While there is concentration along the expressway, the settlements are spreading outward into other areas to create low density dispersed settlements across the area. There are also increase and concentration of development in the extreme southwest and south-east direction of the study area. These developments, as observed in Figure 4.8 are from settlements in Lagos state spreading towards *Ibafo* in the north, which may likely merge over time except for influence of the Ogun River (in the west) and floodable plains separating the settlements from the boundary of *Obafemi-Owode* Local Government.

Table 4.7: Rate of Expansion in *Mowe/Ibafo*

Land cover	**Years**			***Change (%)**			****Average**
	Within the entire study area						
	1987	**2000**	**2016**	**1987-2000**	**2000-2016**	**1987-2016**	**1987-2016**
	Sq.km	**Sq.km**	**Sq.km**	**%**	**%**	**%**	**%**
Water	1.757	2.654	4.207	51	59	139	5
Vegetation	318.595	296.077	215.915	-7	-27	-32	-1
Built-up	5.521	27.141	105.751	392	290	1815	63
Total	**325.872**	**325.872**	**325.872**				
	Within the Coverage of Obafemi-Owode Local Government						
	1987	**2000**	**2016**	**1987-2000**	**2000-2016**	**1987-2016**	****Average 1987 – 2016**
	Sq.km	**Sq.km**	**Sq.km**	**%**	**%**	**%**	**%**
Water	0.194	0.695	1.499	258	116	673	23
Vegetation	137.084	122.558	69.166	-11	-44	-50	-2
Built-up	3.538	17.564	70.151	396	299	1883	65
Total	**140.816**	**140.816**	**140.816**				

**Cover Change was computed as difference in land cover coverage between the initial and final year divided by land coverage at the initial year*

***Rate was calculated as average per annum (i.e. change divided by period of study.*

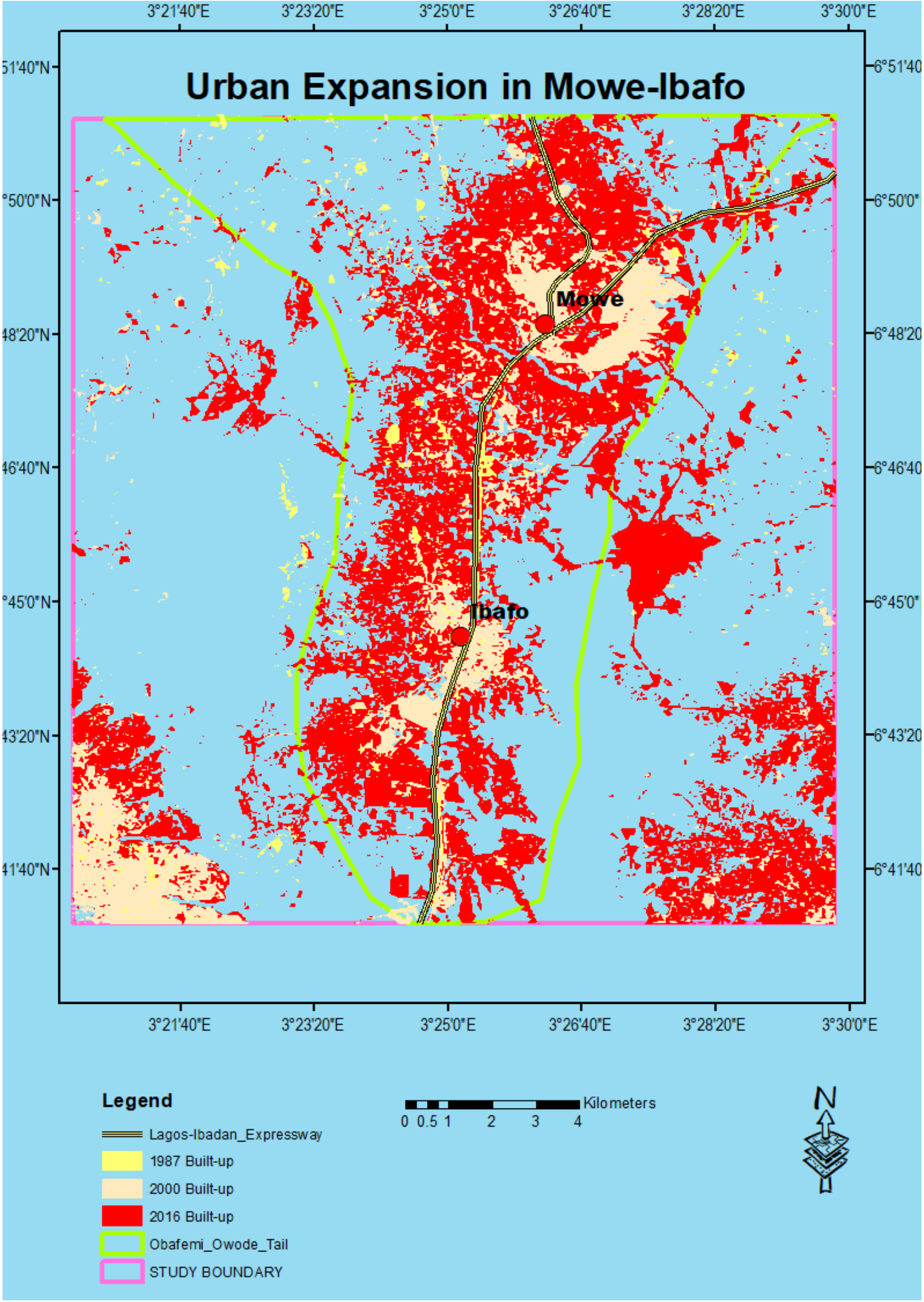


Figure 4.8: Direction of Expansion in *Mowe/Ibafo* Area

4.6 Factors influencing Pattern of expansion in the study area

4.6.1 Population Growth and Urban Expansion

Population is one of the criteria for determining pattern of urban expansion. In most cases, urban land increases to accommodate increasing population. In other words, increasing population will usually requires additional land to develop for different purposes thereby necessitating expansion. When the rate of land expansion is higher than the rate of population increase, the evolving pattern is sprawl.

A comparison of population growth and urban expansion is presented in Table 4.8. Due to the unavailability of breakdown population figure for the entire study area, the analysis was limited to the section within Obafemi-Owode LG. The population of *Mowe*/*Ibafo* in 1987, 2000 and 2016 and the corresponding built-up area are presented in the table. Between 1987 and 2016, the population of the settlements increased from 32,944 to 93,415 while the built-up area increased from 3.54 km^2 to 70.15 km$^{2.}$The population growth rate between the periods are 4.6%, 4.84% and 6.33% for 1987 – 2000, 2000 - 2016, and 1987 -2016 respectively. In response, the built-up area increased at the rate of 30.50% between 1987 and 2000; 18.71% between 2000 and 2016, with overall growth rate of 64.92% between 1987 and 2016.

Table 4.8 Population growth and Urban Expansion Rate between 1987 and 2016

	Years			**Rate (%)**		
	1987	2000	2016	1987-2000	2000-2016	1987-2016
Population	32944	52639	93415	4.60	4.84	6.33
Built-up	3.54 km^2	17.56 km^2	70.15 km^2	30.50	18.71	64.92

A look at the grapy of population and built-up area (Figure 4.9) shows the sharp increase in the rate of expansion of the built-up compared to the population growth rate, thereby tending towards a merge with the population curve. This high rate of built-up expansion against population also confirm sprawl earlier identified using entropy.

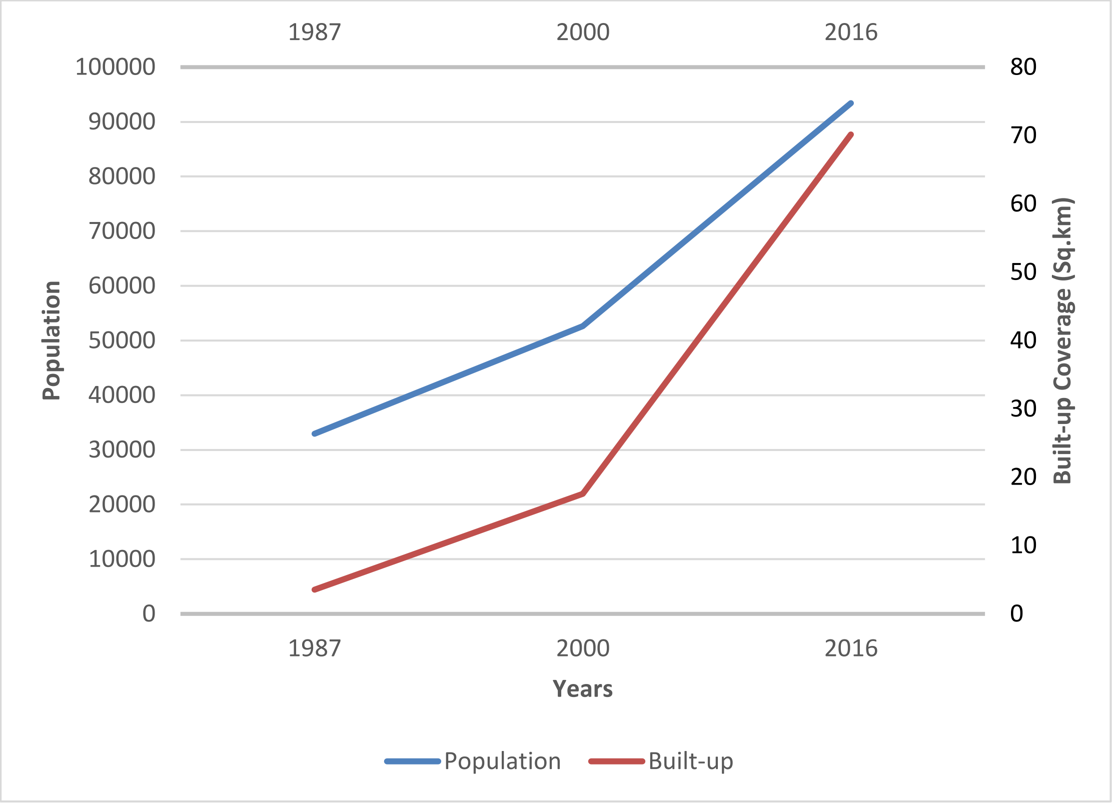


Figure 4.9: Population and Built-up expansion

4.6.2 Elevation and Urban Expansion Pattern

Figure 4.10 shows the classification result of the elevation in the study area, while Figure 4.11 shows the analysis in comparison with built-up within each elevation zone. An analysis of the classification revealed that the largest coverage of 139.45 sq.km was within the lowest elevation zone while the least was in the highest zone (Figure 4.11). An assessment of the development across the zones, from the result of the built-up overlay on the elevation, however, revealed that the most developed portion (51.47 sq.km) was in the second zone of 15.01 – 30 m.

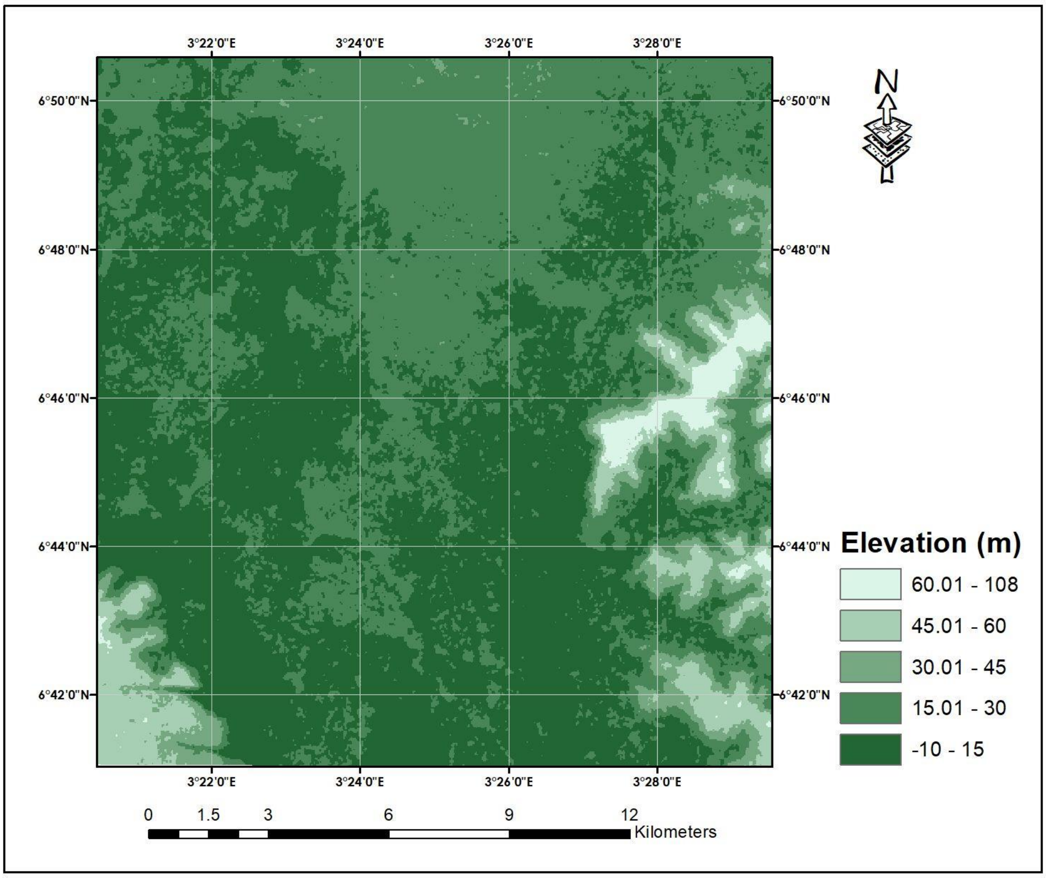


Figure 4.10: Elevation of the Study Area

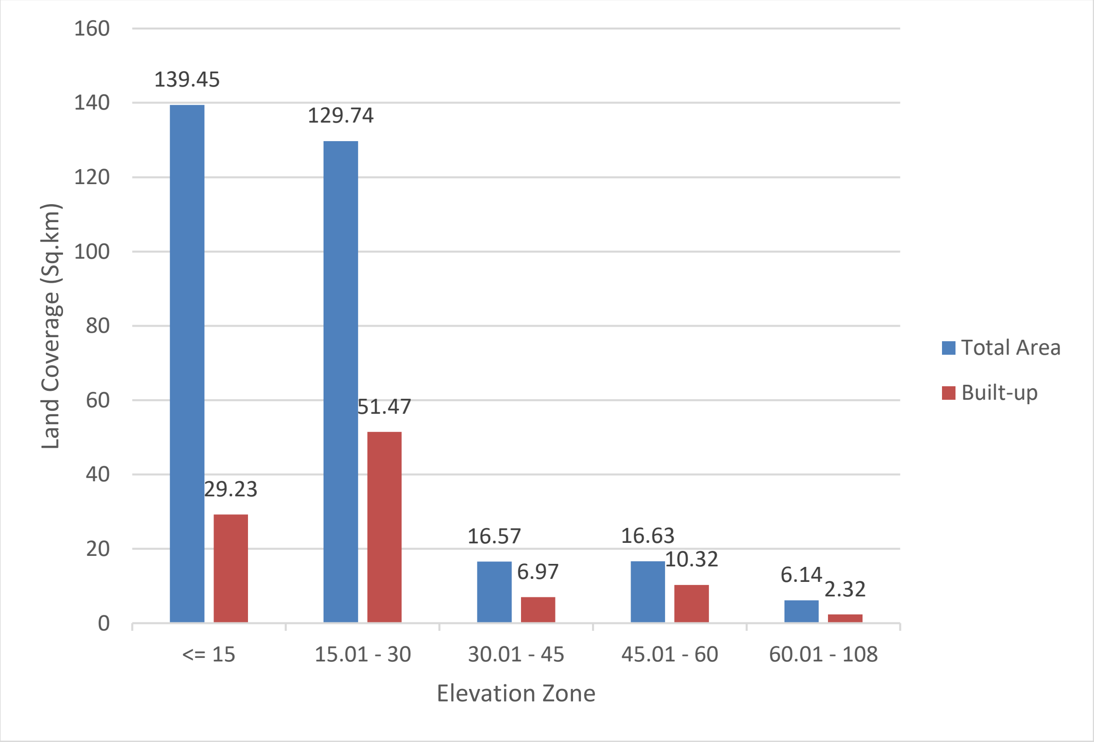


Figure 4.11: Coverage /Built-up areas within different Elevation Zones

4.7 Human capacity for Monitoring development in *Mowe/Ibafo*

Ogun State has twenty local government areas, similarly, the state was divided into twenty Zonal Planning Offices for development control. However, the results of the interview conducted revealed that the division was not local government based but premised on growth axis. Accordingly, the *Mowe/Ibafo* axis was controlled by two of the zonal planning offices namely: *Mowe/Ofada* Zonal Planning Office located in *Mowe* (*Mowe* Bus Stop) and *Isheri/Ibafo* Zonal Planning Office at *Warewa*. The *Isheri/Ibafo* Office covers areas within Obafemi-Owode and some boundary towns within *Ifo* Local government area. *Mowe* zone also covers parts of Obafemi-Owode and sections of *Shagamu* local government. For easy operation, *Isheri/Ibafo* and *Mowe/Ofada* zones were further divided into 10 and 12 sectors respectively.

In term of staffing, *Isheri/Ibafo* Zonal Office has two administrative and twelve Technical staff. The Administrative Officer 1 was responsible for correspondences, filling and stamping of approved drawings while the Administrative Officer 2 was the Accountant from the state Ministry of Finance whose duty was to collect fees and issue receipts for processing of building plans. The Technical Officers comprises the Chief Executive Officer (CEO), responsible for the overall coordination of the zonal office and issuance of development permit. He was assisted by a Deputy CEO and had an Assessment Officer who evaluates development plans and raises development permit bill for government payments. According to the interviewees, there were nine field officers referred to as recommendation officers (graduates with more than one-year experiences) and Inspectorate Officers (graduates with less than one-year experience). Two of the staff were professional Urban Planners and none of them had knowledge of the application of Geographic Information Systems (GIS). The structure was similar at the *Mowe/Ofada* Zonal Planning Office, but with 11 registered planners and twelve sectors.

All their activities were manual. Monitoring was limited to physical contact and only one Hilux van was available to each of the zones. Except for standalone individual or organisation layouts, there were no schemes for monitoring of developments. (Table 4.9)

Table 4.9: Existing Manpower Capacity for Monitoring Development in *Mowe/Ibafo (2017)*

Zonal Planning Office	**No. of Sectors**	**Required Staff**	**Available Staff**				**Qualified Professionals**	**Staff with GIS Experience**	**Monitoring Vehicle**
			Administrative	Technical		Total			
				Executives	Field Inspectorate				
Isheri/Ibafo	10	15	2	3	9	14	2	none	1
Mowe/Ofada	12	15	2	3	11	16	11	none	1

Chapter 5: Discussion

5.1 Introduction

GIS with remote sensing application allow long-term assessment of urban sprawl and landscape composition in diverse environments, including those affected by paucity of data. Assessment of urban sprawl might seem quite straightforward, however, truly identifying strategy and data to use may not be as easy as expected. While this was confirmed in the study, concerted efforts were made to achieve meaningful results. The results and their relationships to findings in literature, are discussed in this chapter.

5.2 Characteristic of Land Cover Composition of *Mowe/Ibafo* axis in Ogun State

Significant changes occurred in the land cover composition of *Mowe*/*Ibafo* between 1987 and 2016, with vegetation mostly replaced by built-up and water body. The composition was on the constant change as a result of urban expansion. A paired t-test conducted on the Landsat data of 1987 and 2016 confirmed a statistically significant difference in land cover between the two periods. Built-up area increased, and vegetation was decreasing. Contrary to many findings however, water body was also increasing in the area. This was ascertained to be unconnected with the period of image capturing as all Landsat data used were within the dry season in the study area (December to February). This may call for management and proper monitoring as there was history of perennial flooding in parts of the study area.

5.3 The pattern of expansion between 1987 and 2006 and the zones of growth

Mowe and *Ibafo* settlements are located along interstate expressway. The entire study area witnessed a tremendous growth rate between 1987 and 2016. Built-up area increased by 392% and 290% for 1987-2000 and 2000 - 2016 respectively while the overall (1987-2016) annual growth rate of built-up area was 63%. This resulted in an increase from 5.521 sq.km in 1987 to 105.751 sq.km in 2016. The major direction of expansion was towards the north and south along Lagos - Ibadan Expressway and northwest along *Mowe-Ofada* Road. Though with concentrated city centres, the development of the towns was linear, and the density decreased away from the expressway. Leapfrog development also characterised some areas resulting in different densities within the same concentric zones from the city centres. As observed in the classification map, other settlements, totally disconnected from *Mowe*/*Ibafo*, were also expanding from the southwest and southeast of the study area. Patches of other isolated development were also emerging across the area.

The values of entropy, which were very close to one (1), for the computations, from town centres and expressway confirmed a sprawl development throughout the study years. There was tendency for compaction towards year 2000 but this was reversed by 2016 with higher entropy values resulting from development away from the centre. For the three years, 2000 had the lowest entropy while 2016 had the highest. The effect of area coverage on the magnitude of urban sprawl was verified by comparing the entire study area with the study area within the portion of Obafemi-Owode LG. Although the resulted entropy values indicated sprawling, the lower values for the three years compared to the entropy values for the entire area implies that the wider the coverage, the more the degree of sprawl.

5.4 The major factors of expansion in the areas

The major factors of urban expansion and pattern of expansion described in section 4.2 above is the population explosion, mainly from Lagos state which has proximity (about 20km North of Ikeja, Lagos State Capital) to the study areas. Many people work in Lagos state and reside in *Mowe*/*Ibafo* for different reasons ranging from affordability of housing. *Mowe*/*Ibafo* axis is one of the populated areas in Obafemi-Owode local government area and one of the bourgeoning areas surrounding Lagos. The Lagos state government (2004) recognised this fact and classified the area among the corridors along the Lagos-Ogun State borders that have experienced the highest population pressure.

Although breakdown of the population of the entire study area was not available, a comparison of population increase and urban expansion within the section of Obafemi-Owode LGfrom 1987 – 2016 revealed that the population increased from 32,944 to 93,415 while the built-up area increased from 3.54 km^{2} to 70.15 km$^{2.;}$ an increase of 183.56% and 1882.79% respectively. The higher rate of urban expansion to population growth further confirmed sprawl based on the postulation that ‘sprawl growth is when the urban construction growth is greater than the population growth’

(Barnes *et al.*, 2001).The increasing population, largely attributed to migration from the neighbouring Lagos, no doubt, is a major factor in the expansion of the area. This is in line with the work of Lawanson (2012) that settlements that are closer to the Lagos Megacity have a higher propensity to grow demographically and spatially than those that are not. It also attunes with the finding of Oduwaye (2013) and Mabogunje (2006) among others that rapid population growth is one of the major factors responsible for the physical forms and pressure leading to the conversion of one land-use class to another. The increase in population resulted in building of additional houses for accommodation, large expanse of religious places and industrial development.

The Lagos-Ibadan Expressway was among the factors that contributed to the emerging pattern of development as earlier discussed. There was concentration along the express and it informed the linear pattern especially at the early stage of the development.

Elevation influenced the development of patches as difficult terrain such as excessive low and high elevation areas were avoided. Although the -10 to 15 m zone had the largest coverage (139.45 sq.km which is about 45% of total coverage), it was less developed (only 21%) compared to 15-30 metre zone and other higher elevation zones (where built-up ranges from 38 to 62%) because it contains water bodies and swamplands. This include the *Ogun* River channel to the left of the study area. Such areas and their surroundings, which are floodable, were relatively avoided, and this created the wide undeveloped gap between the development from the Lagos and *Mowe/Ibafo* boundary and towards the western zone. The perennial flooding of communities along the plains of the *Ogun* River, resulting from recurrent discharge of water from Oyan Dam, being managed by the *Ogun-Osun* River Basin Development Authority, was also identified as disincentive to development along the *Ogun* River. The central part of *Mowe/Ibafo* that range between 15 m and 45m coincides with the area with the densest development as those areas are less costly to develop and saver. This physical characteristic of the study area contributed to the variation in density across the area and the emerging pattern of development. Braimoh & Onishi (2007) among others have described elevation as a restrictive factor to urban expansion in areas with poor natural conditions and Li. *et al*. (2018) also argued that the presence of river restricts urban expansion.

5.5 Capa**city for Monitoring development in *Mowe/Ibafo***

One of the findings of this study was that there is no adequate local manpower to monitor urban expansion in *Mowe*/*Ibafo* axis of Ogun state. This study revealed that inadequate human capacity was among the challenges facing physical development control in *Mowe*/*Ibafo*. The division of the entire Ogun state into twenty Zonal Planning Offices for development control was not premised on the local governments but based on growth axis. This at times caused overlapping and jurisdictional problems among the monitoring agencies, as revealed by the officers. The *Isheri/Ibafo* Office covers areas within Obafemi-Owode and other boundary towns within Ifo Local government area which include *Ibafo, Magboro, Oke-Afa* (opposite *Magboro*), *AlagboleAkute, Ishashi, Denro, Warewa, Gaun, Makogi, Arepo,* Christ Embassy, and *Sefu Elelede*. The settlements are scattered and at distances to each other. The staff of the *Isheri/Ibafo* Zonal Office comprises two administrative and twelve Technical staff. The Technical Officers comprises the Chief Executive Officer (CEO), responsible for the overall coordination of the zonal office and issues development permit. He is assisted by a Deputy CEO and has an Assessment Officer who evaluates development plans and raises development permit bills for government payments. There are nine field officers referred to as recommendation officers (those with more than one-year experiences) and Inspectorate Officers (with less than one-year experience).

The available field officers that were responsible for monitoring development were not commensurate with the zones in each of the Zonal Planning Offices, nine and eleven for *Isheri/Ibafo* and *Mowe* respectively. The staff were further challenged in terms of skills, and resources required for effective control of the area. It was revealed that a minimum of fifteen field officers was required, therefore, the available staff were overburdened due to their area of coverage and could not provide the required control resulting from the rate of development.

A study by Wrike (2016), as quoted by Longelin (2017) revealed that there was an increase in workload of people across sectors. He identified the consequences of such situation are ‘staff burnout, need to hire more employees or lose of efficiency. However, to avert such consequences, Longelin (2017), among other things, suggested ‘more efficient ways’ of doing things. One efficient way of monitoring urban expansion is the use of GIS technology, unfortunately, only two of the staff at *Isheri/Ibafo* Office were professional Urban Planners and none of them had knowledge of the application of Geographic Information Systems (GIS). Manual operations and reliance on physical contact for monitoring, in the absence of adequate resources, incapacitated the field officers and made it difficult to efficiently map and monitor physical development. Lack of schemes or development guides for monitoring of urban expansion subjected judgments on developments to the whims and caprices of the CEO. Therefore, the leapfrog developments and conflicting land use could not be efficiently controlled.

Based on the foregoing, the results of this study revealed that development in *Mowe*/*Ibafo* axis is with little or no control. This has resulted in plan-less and leapfrogged sprawling development in the area. Speculators kept acquiring large piece of lands for different uses ranging from residentials (single use to estate) to industrial. There was increasing development of incompatibles uses with intermingling of industrial, residential and religious land uses. Since land in the area is largely in the hands of individuals, allocation for various uses was neither controlled nor zoned. A State (*Ogun*) regulation puts all land within two kilometres from Lagos – Ibadan Expressway under government acquisition but this has not really deterred development within the zone since there was limited control. Rather than strict control, the government introduced ‘ratification’ (a process of legally transferring ownership of government’s land to individual or group who hitherto possessed it illegally) to accommodate illegality and raise funds. While some developers embraced this ratification process, others developed without recourse to government. Development is guided by the need of individuals people rather than any development goal for the area. Since the area has no official development guide, development permits, where requested, are granted at the discretion of the planning officials.

The increasing population with diverse development goals, leading to the expansion of unplanned settlements, coupled with lack of instrument and enforcement of development control regulations, has contributed to the unguided sprawl development in the study area.

While the closeness to Lagos state makes it dormitory for people working in Lagos thereby easing housing problem in Lagos state, infrastructure was not extended to the area as it is outside Lagos jurisdiction. Similarly, the Ogun State government focused the state’s resources on the capital towns and ignored *Mowe*/*Ibafo* and similar border towns as the distance from the state capital did not make it attractive to Ogun state government.

Unless the expansion of the area is adequately guided and controlled, present conditions of human health, sanitation, and haphazard development may worsen and provision of basic social infrastructure amenities like access roads, schools, hospitals, markets and utilities may be costlier at the long run, when demolition of buildings would be required to make provision for such infrastructure.

5.6. The Methodology and possible errors or flaws with the methods.

The use of GIS capabilities and entropy methods for the investigation of urban sprawl become handy in the context of this research where there is paucity of data for urban expansion monitoring. The fact that the finding of the entropy followed the same direction of confirming sprawl in the study area, with the use of population density, is an attestation to the robustness of the method.

Although, many studies have concluded that the radii of concentric circle in the computation of entropy have no influence on the result, it is worth of further investigation, especially that the curves from the road and the city centre computations did not completely corroborate each other.

Finally, while it may be reasonable to allow for reasonable length of time in conducting evaluation studies, such as change detection, where computation of rates of expansion is involved, the use of yearly population census data and Landsat Data will be worthy of further evaluation, subject to availability.

Chapter 6: Summary of Findings and Conclusion

6.1 Introduction

The study explored the capabilities of GIS in assessing urban sprawl in *Mowe/Ibafo* axis of Ogun state between 1987 and 2016. To achieve the goal, pattern and rate of urban expansion were computed from classified land cover and entropy values determined, factors of expansion were identified and their influences on the emerging pattern were discussed while the existing human capacity for monitoring of development was also explored. This chapter summarises the findings of the study, presents limitations and recommended areas of further research.

6.2 **Findings**

6.2.1 Land Cover composition

The first question that this study set out to answer was the land cover composition of the area over the study period. This was limited to water body, vegetation and built-up area. There was a progression in the quantity of built-up area and water body over the study period while vegetation decreased. The post-classification change detection of Landsat imagery revealed that at by 1987, water body formed 0.54% while vegetation and built-up area accounted for 97.77% and 1.69% respectively. By 2016, water body increased to 1.29% while vegetation and built-up were 66.26% and 32.45% respectively. The increase in built-up area was attributed to the increase in population (largely from Lagos overflow), which resulted in building of additional houses for accommodation, religious and industrial purposes. This invariably resulted in depletion of vegetation. The increase in water body however calls for attention of the Authority and further research.

6.2.2 ***Pattern of expansion***

There was difference in density of development across the zones in year 2016 based on the zoning methods used. It decreased with distance from the expressway. On the contrary, the density from the city centres produced a curve with two crests. It increased gradually from the town centres (zone 1) to the 7th zone (3500 metres buffer), then decreased progressively to 6500 metre zone where it rose again and peaked at 9000 metre before decreasing to the last zone. This revealed the non-uniformity of development and leapfrogging across the area as some sector were more densely developed than others. The second crest accounted for the concentrated development adjacent to Lagos boundary

Development pattern may be compact or sprawl, this was confirmed in the study area based on Entropy model that the higher the entropy value, the more an area sprawls. Area with relative entropy closer to zero is compact while those closer to 1 is sprawl. All the results revealed that the area sprawls and was sparsely developed. The result also revealed that coverage has effect on the degree of sprawl as area within the confine of *Obafemi-Owode* local government in the study area had lower entropy value than the larger study area. Hence, the degree of sprawling is a function of area covered.

6.2.3 Factors of expansion

Different factors contributed to the expansion of *Mowe/Ibafo.* The proximity of the area to the metropolitan Lagos qualified the axis as dwelling place to the increasing number of people who work in Lagos. The location of the settlements along Lagos – Ibadan Expressway also contributed to the development and pattern of the evolved development in the corridor and this informed the linear pattern of the settlements rather than a concentric form.

The physical characteristics of the area, naturally low land with the availability of watercourse (river), also influenced the expansion and development pattern in the study area. Settlements expanding from the Lagos end were being prevented from merging with those from the *Ibafo* end because of the difficult terrain or low elevation, thereby creating leapfrogging development which characterises urban sprawl.

6.2.4 Capacity to monitor development

The study revealed inadequate local capacity for monitoring development of the area as presented by the interviewee. The available staff for monitoring was not commensurate with the rate of development. The workers pointed out that minimum of fifteen field officers was required while only nine and eleven were employed at the *Isheri/Ibafo* and *Mowe/Ofada* zonal offices respectively. Therefore, the available staff reported that they were overburdened and could not provide the required control resulting from the rate of development. The effects of this include haphazard development pattern within the area, which partly characterises sprawl. Unplanned urban development, according to Bhatta (2010), is one of the generally agreed characterises of sprawl.

The study hypothesised that the characteristic pattern of territorial expansion is a function of administrative framework in any setting. This was proved right because, despite the closeness to Lagos state, infrastructure was not extended to the areas it is outside Lagos jurisdiction. Similarly, the Ogun State government focused the state's resources on the capital towns and ignored *Mowe*/*Ibafo* and similar border towns as the distance from the state capital makes it less attractive to Ogun state government. The area lacks in major amenities such as electricity and water. The increasing population has begun to impact on the volume of traffic on Lagos-Ibadan expressway that serve as connector between the settlements and Lagos state.

6.3 Limitation of the Study

Data limitation is a great challenge in the application of GIS in developing countries and this was not totally overcome in this study. The study set out to observe urban expansion in the study area over a period of thirty years from 1986. The use of Landsat Satellite imagery was adopted because of its availability, free cost and long history of existence. However, the quality of 1986 image of the study area was not fit for the study, hence the use of the nearest year, 1987. Fortunately, as shown in Figure 5.1, though 75% of the image was cloud covered, the study area was 100% cloud-free. Although the substitute sufficed for the study, due to the closeness of the date of its acquisition to 1986 (26thFebruary,1987), the thirty years period may still be questioned.

The use of Entropy for the study of sprawl is robust. However, most studies combined it with population growth and density. This was not fully achievable due to lack of reliable and lower level (town/settlement by settlement) population data.

Reliance on three-year data (1987, 2000 and 2016) limited the determination of year-to-year growth rate in the study area to computation of average annual growth rate, which portrayed an unrealistic linear rate for the study years.

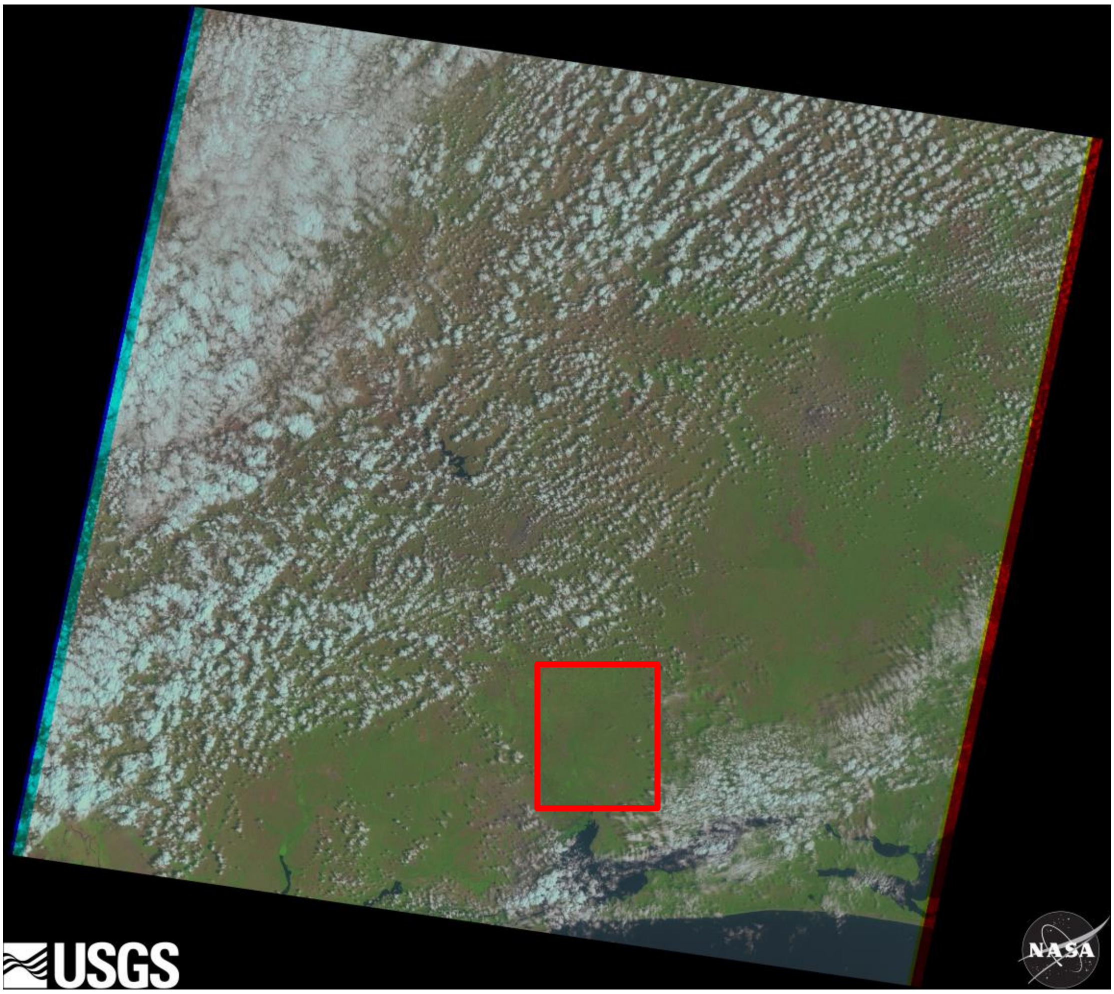


Figure 6.1: Study Area within Cloud-Covered 1987 Satellite Image

6.4 Area for Further Research

It is believed that this research can be refined with a further study highlighting detailed composition of development in the area, their degree of mix and contribution to sprawl development.

Similarly, studies with imageries at regular and shorter intervals will be of interest.

Finally, other methods aimed at the same goal can be embarked upon for comparison.

6.5 Conclusion

Urban sprawl measurement is key to monitoring urban development. However, availability of data has made it a difficult task, especially in developing countries. Remote sensed data, especially, free Landsat and application of GIS techniques have emerged as a solution to this challenge over the time.

The study assessed sprawl and determined the type, amount, and location of land conversion and urban growth. It identified the pattern of growth, and capacity required for development control. The hypothesis that there is no statistical difference in land cover change in *Mowe/Ibafo* axis from 1987 to 2016 was rejected; computed entropy was high, and rate of urban expansion was more than population increase. Hence it was concluded that *Mowe/Ibafo* axis is sprawling.

Therefore, with the acceptance of the proposition that there is inadequate local manpower to monitor urban expansion in the zone, this study recommends that more priority should be placed on its development. Synergy should be formed between Lagos and Ogun State governments to develop the zone for the benefit of the two parties and residents.

The study opened a new vista for the proper management of *Mowe*/*Ibafo* axis for sustainable development while advancing the knowledge of the application of GIS.

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Appendices

APPENDIX 1: ACCURACY ASSESSMENT OF THE LAND COVER CLASSIFICATIONS

Table A1: 1987 Map and Ground Truth Sample Points and Coordinates

FID	POINT_X	POINT_Y	GROUND TRUTH	MAP DATA
0	541519.8	744072.4	2	2
1	554755	744986.8	2	3
2	543280.6	750194.9	2	2
3	546788.2	745632.6	2	2
4	539239	745787.6	2	2
5	551499.7	757109.3	2	2
6	548062	743936.5	2	2
7	548483.1	750000.8	2	2
8	550490.7	753200.8	2	2
9	551712.3	742233.8	2	2
10	546849.1	743468.2	2	2
11	553205.1	740993.5	2	2
12	548100.5	752547.1	3	2
13	549700.4	749230.9	2	2
14	540965.3	744054.9	2	2
15	543946.1	754223.9	2	3
16	537696.9	757167.2	2	2
17	552351.1	745854.9	2	2
18	540789.2	754189.6	2	2
19	545637.2	756467.6	2	2
20	550731	743714.6	2	2
21	546965.7	746764.4	2	2
22	552203.8	752726	2	2
23	551373.4	738808.6	2	2
24	554275.3	741813.9	2	2
25	543553.8	741592.4	2	2
26	549906.1	743661.6	2	2
27	540617.5	740034.1	2	2
28	540403.4	742368.4	2	2
29	551427.8	739266.7	2	2
30	542696.4	741170	2	2
31	554345.2	744480	2	2
32	549869.6	740718.2	2	2
33	542657.4	742580	2	2
34	538027.6	740684.4	3	3
35	546808.7	751926.2	2	2
36	542487.7	747247.5	2	2
37	542543.7	746010.8	2	2
38	545974.4	750429.8	2	2
39	539521.6	740541.9	2	2
40	552210.9	746842.8	2	2

41	549273.9	756793	2	2
42	552543.2	753206	2	2
43	551863.1	746081	2	2
44	548751	756000.6	2	2
45	545555.2	746236.5	2	2
46	549921.1	747220.8	2	2
47	553582.3	741127.1	2	2
48	548857.6	754385.3	2	2
49	549669.7	754497.7	2	2
50	553585.1	754372	2	2
51	544322.8	742189.4	2	2
52	539257.8	751236.9	2	2
53	542220.1	740806.7	2	3
54	547113.1	751244.6	3	3
55	547375.4	751267.5	3	3
56	548463.5	752342.1	3	3
57	545819.1	741798.4	3	3
58	546870.3	749451	3	3
59	538287.6	739671.3	3	3
60	542321	748704.9	2	3
61	539918.9	740755.4	3	1
62	537780.6	746124.8	1	1
63	545271.6	747829.4	3	3
64	551354.8	754073.7	3	3
65	542220.7	748516.3	2	3
66	542172.6	740211.7	1	1
67	542859.6	746768.3	2	1
68	540279.3	754504.1	1	3
69	545462.9	754977.5	3	3
70	546305.3	744065	3	3
71	538216.3	740695.6	3	3
72	540132.1	741385.4	1	1
73	542849.7	746676	1	1
74	539673	741073.8	1	1
75	546108.1	744275	3	3
76	543792.4	748084.7	2	3
77	546052.5	744054.9	3	3
78	539818.7	740516.1	1	1
79	554281.7	739786	3	3
80	546289.3	744632	3	3
81	546823.9	748424.1	3	3
82	539618.9	741966.1	1	1
83	543971.1	756139.1	2	3

Table A2: 1987 Land Cover Classifications Matrix

		Ground Truth			
	Class	Water (W)	Vegetation (V)	Built-up (B)	Total
Map Data	Water (w)	7	1	1	$\sum \text{w} = 9$
	Vegetation (v)	0	49	1	$\sum \text{v} = 50$
	Built-up (b)	1	6	18	$\sum \text{b} = 25$
	Total	$\sum \text{W} = 8$	$\sum \text{V} = 56$	$\sum \text{B} = 20$	N = 84

$$\text{Overall accuracy} = \frac{\text{Sum of correctly mapped points (diagonal pixels)}}{\text{Total number of points in the sample (N)}} \text{ X } 100$$

$$= \frac{(\text{wW}+\text{vV}+\text{bB})}{\text{N}} \text{ X } 100$$

$$\text{Overall accuracy} = \frac{(7+49+18)}{84} \text{ X } 100 = 88.09 \ = \qquad \mathbf{88\%}$$

$$\text{User accuracy} = \frac{\text{Correctly classified pixel of a class}}{\text{Total number of pixel chosen for that class in the classified image}} \text{ X } 100$$

$$\text{User accuracy (Water)} = \frac{\text{wW}}{\sum \text{w}} \text{ X } 100 \quad \text{i.e.} \ = \frac{7}{9} \text{ X } 100 = 77.7\%$$

$$\text{User accuracy (Vegetation)} = \frac{\text{vV}}{\sum \text{v}} \text{ X } 100 \quad \text{i.e.} \ = \frac{49}{50} \text{ X } 100 = 98\%$$

$$\text{User accuracy (Built-up)} = \frac{\text{bB}}{\sum \text{b}} \text{ X } 100 \quad \text{i.e.} \ = \frac{18}{25} \text{ X } 100 = 72\%$$

$$\text{Producer accuracy} = \frac{\text{Number of correctly classified points in a class}}{\text{Total number of points for that class in the reference image}} \text{ X } 100$$

$$\text{Producer accuracy (Water)} = \frac{\text{wW}}{\sum \text{W}} \text{ X } 100 \quad \text{i.e.} \ = \frac{7}{8} \text{ X } 100 = 87.5\%$$

$$\text{Producer accuracy (Vegetation)} = \frac{\text{vV}}{\sum \text{V}} \text{ X } 100 \quad \text{i.e.} \ = \frac{49}{56} \text{ X } 100 = 87.5\%$$

$$\text{Producer accuracy (Built-up)} = \frac{\text{bB}}{\sum \text{B}} \text{ X } 100 \quad \text{i.e.} \ = \frac{18}{20} \text{ X } 100 = 90\%$$

$$\textit{Kappa coefficient} = \frac{N\sum_{i=1}^{n} x_{ii} - \sum_{i=1}^{n}(x_{i+} X x_{+i})}{N^2 - \sum_{i=1}^{n}(x_{i+} X x_{+i})}$$

$$\textit{Kappa coefficient} = \frac{\text{N}* \ (\text{wW}+\text{vV}+\text{bB}) - ((\sum \text{W} * \sum \text{w}) + (\sum \text{V} * \sum \text{v}) + (\sum \text{B} * \sum \text{b}))}{\text{N}^2 - ((\sum \text{W} * \sum \text{w}) + (\sum \text{V} * \sum \text{v}) + (\sum \text{B} * \sum \text{b}))}$$

$$\textit{Kappa coefficient} = \frac{84* \ (7+49+18) - ((8*9)+(56*50)+(20*25))}{84^2 - ((8*9)+(56*50)+(20*25))}$$

$$\textit{Kappa coefficient} = \frac{2844}{3684} =)\ 0.77$$

Table A3: 2000 Land Cover Classifications Matrix

		Ground Truth			
	Class	Water (W)	Vegetation (V)	Built-up (B)	Total
Map Data	Water (w)	9	5	1	$\sum w = 15$
	Vegetation (v)	0	48	2	$\sum v = 50$
	Built-up (b)	1	2	47	$\sum b = 50$
	Total	$\sum W = 10$	$\sum V = 55$	$\sum B = 50$	N = 115

$$\text{Overall accuracy} = \frac{\text{Sum of correctly mapped points (diagonal pixels)}}{\text{Total number of points in the sample (N)}} \text{ X } 100$$

$$= \frac{(\text{wW+vV+bB})}{\text{N}} \text{ X } 100$$

Overall accuracy = $\frac{(9+48+47)}{115}$ X 100 = 90.4 = **90%**

$$\text{User accuracy} = \frac{\text{Correctly classified pixel of a class}}{\text{Total number of pixel chosen for that class in the classified image}} \text{ X } 100$$

User accuracy (Water) = $\frac{\text{wW}}{\sum \text{w}}$ X 100 i.e. = $\frac{9}{15}$ X 100 = 60%

User accuracy (Vegetation) = $\frac{\text{vV}}{\sum \text{v}}$ X 100 i.e. = $\frac{48}{50}$ X 100 = 96%

User accuracy (Built-up) = $\frac{\text{bB}}{\sum \text{b}}$ X 100 i.e. = $\frac{47}{50}$ X 100 = 94%

$$\text{Producer accuracy} = \frac{\text{Number of correctly classified points in a class}}{\text{Total number of points for that class in the reference image}} \text{ X } 100$$

Producer accuracy (Water) = $\frac{\text{wW}}{\sum \text{W}}$ X 100 i.e. = $\frac{9}{10}$ X 100 = 90%

Producer accuracy (Vegetation) = $\frac{\text{vV}}{\sum \text{V}}$ X 100 i.e. = $\frac{48}{55}$ X 100 = 87%

Producer accuracy (Built-up) = $\frac{\text{bB}}{\sum \text{bB}}$ X 100 i.e. = $\frac{47}{50}$ X 100 = 94%

$$Kappa\ coefficient = \frac{N\sum_{i=1}^{n} x_{ii} - \sum_{i=1}^{n}(x_{i+}Xx_{+i})}{N^2 - \sum_{i=1}^{n}(x_{i+}Xx_{+i})}$$

$$Kappa\ coefficient = \frac{\text{N}*\ (\text{wW+vV+bB}) - ((\sum \text{W}*\sum \text{w}) + (\sum \text{V}*\sum \text{v}) + (\sum \text{B}*\sum \text{b}))}{\text{N}^2 - ((\sum \text{W}*\sum \text{w}) + (\sum \text{V}*\sum \text{v}) + (\sum \text{B}*\sum \text{b}))}$$

$$Kappa\ coefficient = \frac{115*\ (9+48+47) - ((10*15)+(55*50)+(50*50))}{115^2 - ((10*15)+(55*50)+(50*50))}$$

$$Kappa\ coefficient = \frac{6560}{7825} = 0.84$$

Table A4: 2016Land Cover Classifications Matrix

		Ground Truth			
Map Data	**Class**	Water (W)	Vegetation (V)	Built-up (B)	Total
	Water (w)	16	8	0	$\sum w = 24$
	Vegetation (v)	0	45	5	$\sum v = 50$
	Built-up (b)	0	4	46	$\sum b = 50$
	Total	$\sum W = 16$	$\sum V = 57$	$\sum B = 51$	N = 124

$$\text{Overall accuracy} = \frac{\text{Sum of correctly mapped points (diagonal pixels)}}{\text{Total number of points in the sample (N)}} \text{ X } 100$$

$$= \frac{(wW+vV+bB)}{N} \text{ X } 100$$

$$\text{Overall accuracy} = \frac{(16+45+46)}{124} \text{ X } 100 = 90.4 = \qquad 86\%$$

$$\text{User accuracy} = \frac{\text{Correctly classified pixel of a class}}{\text{Total number of pixel chosen for that class in the classified image}} \text{ X } 100$$

$$\text{User accuracy (Water)} = \frac{wW}{\sum w} \text{ X } 100 \quad \text{i.e.} \quad = \frac{16}{24} \text{ X } 100 = 67\%$$

$$\text{User accuracy (Vegetation)} = \frac{vV}{\sum v} \text{ X } 100 \quad \text{i.e.} \quad = \frac{45}{50} \text{ X } 100 = 90\%$$

$$\text{User accuracy (Built-up)} = \frac{bB}{\sum b} \text{ X } 100 \quad \text{i.e.} \quad = \frac{46}{50} \text{ X } 100 = 92\%$$

$$\text{Producer accuracy} = \frac{\text{Number of correctly classified points in a class}}{\text{Total number of points for that class in the reference image}} \text{ X } 100$$

$$\text{Producer accuracy (Water)} = \frac{wW}{\sum W} \text{ X } 100 \quad \text{i.e.} \quad = \frac{16}{16} \text{ X } 100 = 100\%$$

$$\text{Producer accuracy (Vegetation)} = \frac{vV}{\sum V} \text{ X } 100 \quad \text{i.e.} \quad = \frac{45}{57} \text{ X } 100 = 79\%$$

$$\text{Producer accuracy (Built-up)} = \frac{bB}{\sum bB} \text{ X } 100 \quad \text{i.e.} \quad = \frac{46}{51} \text{ X } 100 = 90\%$$

$$\textit{Kappa coefficient} = \frac{N\sum_{i=1}^{n} x_{ii} - \sum_{i=1}^{n}(x_{i+} X x_{+i})}{N^2 - \sum_{i=1}^{n}(x_{i+} X x_{+i})}$$

$$\textit{Kappa coefficient} = \frac{N*\ (wW+vV+bB) - ((\sum W * \sum w) + (\sum V * \sum v) + (\sum B * \sum b))}{N^2 - ((\sum W * \sum w) + (\sum V * \sum v) + (\sum B * \sum b))}$$

$$\textit{Kappa coefficient} = \frac{124*\ (16+45+46) - ((16*24) + (57*50) + (51*50))}{124^2 - ((16*24) + (57*50) + (51*50))}$$

$$\textit{Kappa coefficient} = \frac{7484}{9592} = 0.78$$

APPENDIX 2: ENTROPY COMPUTATIONS

Shannon's Entropy (H_n) $= -\sum_{i=1}^{n} P_i \, log_e(P_i)$

i.e. (-sum (P_i*ln(P_i)

Hn= - ((P1*LnP1)+(P2*LnP2)+(P3*LnP3)+---------(P20*LnP20))

e.g. for 1987 (See Table A5)

Hn = -((0.039717267*-3.22597) + (0.042409963*-3.16037) + (0.043419724*-3.13684) +-----------------(0.028105015*-3.57181))

Because of the lengthy computation, excel was used and the resulting tables are presented below.
In the tables, the **Built-up** column represents the developed area within each zone and the total is shown at the end of the column.

Pi column is the proportion of built-up within each zone in relation to the total built-up in the year; computed as coverage per zone divided by the sum of the built-up.

LnPi is the 'natural logarithm' of each of the proportions computed.

P*LnPi column multiplied proportion per zone (P) by the logarithm value (LnP) of the P, the resulting values were summed up.

H (Shannon's Entropy) column is the negative of sum of Ln*P i.e. (-sum (P_i*ln (P_i)

i.e. computed entropy divided by Maximum diversity index Ln(N):

Shannon's Entropy values range from 0 to $\log_e$ (n) *or* Ln(N), 0 is very dense urban area and values close to log(n)indicate urban sprawl

Shannon Entropy may be more than 1 because Ln(n) depends on the number of outcomes or zones.

.

Relative Entropy H’n was used to scale the value to between 0 and 1

It was computed as Shannon’s Entropy **(H)** divided by Maximum diversity index **Ln(N)** i.e.

$$\frac{\text{Shannon's Entropy values } (\mathbf{H})}{\text{Maximum diversity index } \mathbf{Ln}(\mathbf{N})}$$

where **N** is the number of zones.

In computation covering the entire study area (e.g. Table A5) there are 20 zones therefore N is 20 while it is 17 for the core.

e.g. in 1987 from centre of town (20 zones) (Table A5)

Relative Entropy (H’n) =H/Ln(N),

Shannon’s Entropy (2.857756) divided by Ln(20)

$$= \frac{2.857756}{2.995732}$$

= 0.953942

e.g. in 1987 from centre of town (17 core zones) (Table A5)

H’n =H/Ln(N),

Shannon’s Entropy (1.917283) divided by Ln(17)

$$= \frac{1.917283}{2.833213}$$

Relative Entropy = 0.676717

Computation of Entropy Values for the Entire Study Area using the Town centre as Reference (500m buffer)

Table A5: 1987-Town centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	212400	0.039717267	-3.22597	-0.12813	2.857756	2.995732	0.953942
2	226800	0.042409963	-3.16037	-0.13403			
3	232200	0.043419724	-3.13684	-0.1362			
4	198900	0.037192864	-3.29164	-0.12243			
5	321300	0.060080781	-2.81207	-0.16895			
6	364500	0.068158869	-2.68591	-0.18307			
7	582300	0.108885897	-2.21745	-0.24145			
8	517500	0.096768765	-2.33543	-0.226			
9	656100	0.122685964	-2.09813	-0.25741			
10	312300	0.058397846	-2.84048	-0.16588			
11	227700	0.042578256	-3.15641	-0.13439			
12	215100	0.040222147	-3.21334	-0.12925			
13	164700	0.030797711	-3.48031	-0.10719			
14	162900	0.030461124	-3.4913	-0.10635			
15	132300	0.024739145	-3.69937	-0.09152			
16	135000	0.025244026	-3.67917	-0.09288			
17	95400	0.017839111	-4.02636	-0.07183			
18	270000	0.050488051	-2.98602	-0.15076			
19	170100	0.031807472	-3.44805	-0.10967			
20	150300	0.028105015	-3.57181	-0.10039			
Total	**5347800**			**-2.85776**			

Table A6: 2000-From Town centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1222200	0.048150906	-3.03342	-0.14606	2.742378	2.995732	0.915428
2	2506500	0.09874836	-2.31518	-0.22862			
3	2375100	0.093571606	-2.36903	-0.22167			
4	2552400	0.100556678	-2.29703	-0.23098			
5	2698200	0.106300748	-2.24148	-0.23827			
6	1999800	0.078785945	-2.54102	-0.2002			
7	1486800	0.058575329	-2.83744	-0.1662			
8	982800	0.038719285	-3.25142	-0.12589			
9	499500	0.019678758	-3.92822	-0.0773			
10	301500	0.011878169	-4.43305	-0.05266			
11	305100	0.012019998	-4.42118	-0.05314			
12	311400	0.012268198	-4.40074	-0.05399			
13	347400	0.013686487	-4.29135	-0.05873			
14	258300	0.010176222	-4.5877	-0.04669			
15	186300	0.007339645	-4.91446	-0.03607			
16	575100	0.022657164	-3.78728	-0.08581			
17	1393200	0.054887778	-2.90246	-0.15931			
18	1758600	0.06928341	-2.66955	-0.18496			
19	2020500	0.079601461	-2.53072	-0.20145			
20	1602000	0.063113853	-2.76281	-0.17437			
Total	**25382700**			**-2.74238**			

Table A7: 2016-From Town centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1534500	0.014844417	-4.21013	-0.0625	2.860166	2.995732	0.954747
2	4238100	0.04099845	-3.19422	-0.13096			
3	6366600	0.061589093	-2.78727	-0.17167			
4	8198100	0.079306622	-2.53443	-0.201			
5	9736200	0.094185864	-2.36249	-0.22251			
6	10282500	0.099470651	-2.30789	-0.22957			
7	10341000	0.100036567	-2.30222	-0.23031			
8	8267400	0.079977015	-2.52602	-0.20202			
9	5862600	0.056713507	-2.86974	-0.16275			
10	4785300	0.046291943	-3.07279	-0.14225			
11	3807900	0.03683679	-3.30126	-0.12161			
12	3224700	0.031195041	-3.4675	-0.10817			
13	2196900	0.021252329	-3.85129	-0.08185			
14	2159100	0.02088666	-3.86864	-0.0808			
15	2436300	0.023568232	-3.74786	-0.08833			
16	3950100	0.038212401	-3.2646	-0.12475			
17	4597200	0.044472305	-3.11289	-0.13844			
18	4944600	0.047832976	-3.04004	-0.14541			
19	3769200	0.036462414	-3.31147	-0.12074			
20	2673900	0.025866722	-3.6548	-0.09454			
Total	**103372200**			**-2.86017**			

Computation of Entropy Values for the Entire Study Area using the Major road as Reference (500m buffer)

Table A8: 1987-Road centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1521900	0.279411765	-1.27507	-0.35627	2.562254	2.995732	0.855302
2	471600	0.086582948	-2.44665	-0.21184			
3	378900	0.069563781	-2.66551	-0.18542			
4	328500	0.060310641	-2.80825	-0.16937			
5	282600	0.051883675	-2.95875	-0.15351			
6	259200	0.047587574	-3.04518	-0.14491			
7	304200	0.055849306	-2.8851	-0.16113			
8	333000	0.061136814	-2.79464	-0.17086			
9	362700	0.066589557	-2.70921	-0.1804			
10	94500	0.017349636	-4.05418	-0.07034			
11	67500	0.012392597	-4.39066	-0.05441			
12	60300	0.01107072	-4.50345	-0.04986			
13	222300	0.040812954	-3.19876	-0.13055			
14	214200	0.039325843	-3.23587	-0.12725			
15	165600	0.030403173	-3.49321	-0.1062			
16	122400	0.02247191	-3.79549	-0.08529			
17	113400	0.020819564	-3.87186	-0.08061			
18	63000	0.011566424	-4.45965	-0.05158			
19	50400	0.009253139	-4.68279	-0.04333			
20	30600	0.005617978	-5.18178	-0.02911			
Total	**5446800**			**-2.56225**			

Table A9: 2000-From Road centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	7304400	0.272065972	-1.30171	-0.35415	2.340222	2.995732	0.781185
2	5081400	0.1892662	-1.6646	-0.31505			
3	3098700	0.115416848	-2.1592	-0.24921			
4	1107000	0.041232275	-3.18853	-0.13147			
5	542700	0.020213871	-3.90139	-0.07886			
6	162900	0.006067514	-5.10481	-0.03097			
7	127800	0.004760149	-5.34748	-0.02545			
8	108000	0.004022661	-5.51581	-0.02219			
9	176400	0.006570346	-5.02519	-0.03302			
10	418500	0.015587811	-4.16127	-0.06487			
11	731700	0.027253528	-3.60257	-0.09818			
12	860400	0.032047199	-3.44055	-0.11026			
13	1065600	0.039690255	-3.22665	-0.12807			
14	1227600	0.045724247	-3.08513	-0.14107			
15	1548900	0.057691663	-2.85264	-0.16457			
16	1876500	0.069893735	-2.66078	-0.18597			
17	887400	0.033052864	-3.40965	-0.1127			
18	293400	0.010928229	-4.51641	-0.04936			
19	183600	0.006838524	-4.98518	-0.03409			
20	45000	0.001676109	-6.39128	-0.01071			
Total	**26847900**			**-2.34022**			

Table A10: 2016- From Road centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	20038500	0.190523866	-1.65798	-0.31588	2.590708	2.995732	0.8648
2	15815700	0.150373945	-1.89463	-0.2849			
3	13023000	0.123821259	-2.08892	-0.25865			
4	10657800	0.101333196	-2.28934	-0.23199			
5	6437700	0.061208947	-2.79346	-0.17098			
6	3521700	0.033483938	-3.39669	-0.11373			
7	2181600	0.020742414	-3.87557	-0.08039			
8	2220300	0.021110369	-3.85799	-0.08144			
9	2637900	0.025080865	-3.68565	-0.09244			
10	2712600	0.025791104	-3.65773	-0.09434			
11	2740500	0.026056374	-3.64749	-0.09504			
12	2612700	0.024841266	-3.69525	-0.09179			
13	3305700	0.031430234	-3.45998	-0.10875			
14	3767400	0.035820027	-3.32925	-0.11925			
15	3947400	0.037531447	-3.28258	-0.1232			
16	4246200	0.040372405	-3.20961	-0.12958			
17	2987100	0.02840102	-3.56133	-0.10115			
18	1723500	0.016386849	-4.11128	-0.06737			
19	590400	0.005613459	-5.18259	-0.02909			
20	8100	7.70139E-05	-9.47152	-0.00073			
Total	**105175800**			**-2.59071**			

Computation of Entropy Values for the Study Area within the Confine of Obafemi/Owode Local Government Area using the Town centre as Reference (500m buffer)

Table A11: 1987-From Town centre Entropy Computation (within LG)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	212400	0.060950413	-2.79769	-0.17052	2.514002	2.833213	0.887333
2	226800	0.065082645	-2.7321	-0.17781			
3	232200	0.066632231	-2.70857	-0.18048			
4	198900	0.057076446	-2.86336	-0.16343			
5	321300	0.092200413	-2.38379	-0.21979			
6	364500	0.104597107	-2.25764	-0.23614			
7	567900	0.162964876	-1.81422	-0.29565			
8	447300	0.128357438	-2.05294	-0.26351			
9	355500	0.102014463	-2.28264	-0.23286			
10	188100	0.053977273	-2.91919	-0.15757			
11	99900	0.028667355	-3.552	-0.10183			
12	96300	0.027634298	-3.5887	-0.09917			
13	51300	0.014721074	-4.21848	-0.0621			
14	73800	0.021177686	-3.85481	-0.08164			
15	18900	0.005423554	-5.217	-0.02829			
16	27000	0.007747934	-4.86033	-0.03766			
17	2700	0.000774793	-7.16291	-0.00555			
Total	**3484800**			**-2.514**			

Table A12: 2000-Town centre Entropy Computation (within LG)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1222200	0.069694637	-2.66363	-0.18564	2.32649	2.833213	0.821149
2	2506500	0.142930459	-1.9454	-0.27806			
3	2375100	0.135437516	-1.99924	-0.27077			
4	2552400	0.145547857	-1.92725	-0.28051			
5	2698200	0.153861945	-1.8717	-0.28798			
6	1999800	0.114036438	-2.17124	-0.2476			
7	1481400	0.084475237	-2.4713	-0.20876			
8	972000	0.055427252	-2.89268	-0.16033			
9	486900	0.027764947	-3.58398	-0.09951			
10	265500	0.015139851	-4.19042	-0.06344			
11	287100	0.016371568	-4.11221	-0.06732			
12	275400	0.015704388	-4.15382	-0.06523			
13	289800	0.016525532	-4.10285	-0.0678			
14	62100	0.003541186	-5.64329	-0.01998			
15	33300	0.001898897	-6.26648	-0.0119			
16	11700	0.00066718	-7.31245	-0.00488			
17	17100	0.000975109	-6.93296	-0.00676			
Total	**17536500**			**-2.32649**			

Table A13: 2016-Town centre Entropy Computation (with LG)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1534500	0.021885911	-3.82191	-0.08365	2.364511	2.833213	0.834568
2	4238100	0.06044619	-2.806	-0.16961			
3	6366600	0.090804067	-2.39905	-0.21784			
4	8198100	0.11692596	-2.14621	-0.25095			
5	9736200	0.138863216	-1.97427	-0.27415			
6	10282500	0.146654857	-1.91967	-0.28153			
7	10177200	0.145153009	-1.92997	-0.28014			
8	7782300	0.110995584	-2.19826	-0.244			
9	4464900	0.063680941	-2.75387	-0.17537			
10	2898000	0.041332923	-3.1861	-0.13169			
11	1934100	0.027585233	-3.59047	-0.09904			
12	1361700	0.019421339	-3.94138	-0.07655			
13	866700	0.012361368	-4.39318	-0.05431			
14	139500	0.001989628	-6.21981	-0.01238			
15	98100	0.001399158	-6.57188	-0.0092			
16	24300	0.00034658	-7.9674	-0.00276			
17	10800	0.000154036	-8.77833	-0.00135			
Total	**70113600**			**-2.36451**			

Computation of Entropy Values for the Study Area within the Confine of Obafemi/Owode Local Government Area using the Major Road as Reference (500m buffer zones)

Table A14: 1987-From Road Entropy Computation (with LG)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1449900	0.409819384	-0.89204	-0.36557	1.993066	2.833213	0.703465
2	440100	0.124395828	-2.08429	-0.25928			
3	374400	0.10582549	-2.24596	-0.23768			
4	322200	0.091070974	-2.39612	-0.21822			
5	251100	0.070974307	-2.64544	-0.18776			
6	191700	0.054184686	-2.91536	-0.15797			
7	135900	0.038412618	-3.25937	-0.1252			
8	72900	0.020605444	-3.8822	-0.07999			
9	91800	0.025947596	-3.65168	-0.09475			
10	50400	0.014245739	-4.2513	-0.06056			
11	24300	0.006868481	-4.98081	-0.03421			
12	3600	0.001017553	-6.89035	-0.00701			
13	51300	0.014500127	-4.2336	-0.06139			
14	21600	0.006105317	-5.0986	-0.03113			
15	51300	0.014500127	-4.2336	-0.06139			
16	2700	0.000763165	-7.17804	-0.00548			
17	2700	0.000763165	-7.17804	-0.00548			
Total	**3537900**			**-1.99307**			

Table A15: 2000-Road centre Entropy Computation (with LG)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	7240500	0.412246989	-0.88613	-0.36531	1.490201	2.833213	0.525975
2	5019300	0.285780169	-1.25253	-0.35795			
3	3084300	0.175608506	-1.7395	-0.30547			
4	1103400	0.062823469	-2.76743	-0.17386			
5	538200	0.030643095	-3.48535	-0.1068			
6	160200	0.009121189	-4.69716	-0.04284			
7	95400	0.005431719	-5.2155	-0.02833			
8	67500	0.003843198	-5.56145	-0.02137			
9	72900	0.004150653	-5.48449	-0.02276			
10	55800	0.003177043	-5.7518	-0.01827			
11	54000	0.003074558	-5.78459	-0.01779			
12	5400	0.000307456	-8.08718	-0.00249			
13	8100	0.000461184	-7.68171	-0.00354			
14	13500	0.00076864	-7.17089	-0.00551			
15	7200	0.000409941	-7.7995	-0.0032			
16	19800	0.001127338	-6.7879	-0.00765			
17	18000	0.001024853	-6.88321	-0.00705			
Total	**17563500**			**-1.4902**			

Table A16: 2016-Road centre Entropy Computation (with LG)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	19199700	0.273703523	-1.29571	-0.35464	1.80465	2.8332	0.63696
2	15615900	0.222614252	-1.50231	-0.33444			
3	12965400	0.184829745	-1.68832	-0.31205			
4	10568700	0.150663314	-1.89271	-0.28516			
5	6335100	0.090310744	-2.4045	-0.21715			
6	3238200	0.046162531	-3.07559	-0.14198			
7	1139400	0.016242847	-4.1201	-0.06692			
8	268200	0.003823356	-5.56663	-0.02128			
9	210600	0.003002232	-5.8084	-0.01744			
10	205200	0.002925252	-5.83437	-0.01707			
11	266400	0.003797696	-5.57336	-0.02117			
12	30600	0.000436222	-7.73736	-0.00338			
13	36900	0.000526032	-7.55015	-0.00397			
14	15300	0.000218111	-8.43051	-0.00184			
15	18000	0.000256601	-8.26799	-0.00212			
16	13500	0.000192451	-8.55567	-0.00165			
17	20700	0.000295091	-8.12823	-0.0024			
Total	**70147800**			**-1.80465**			

APPENDIX 3: SENSITIVITY ANALYSIS OF ENTROPY WITH 1000M MULTIPLE BUFFER RINGS AND 10 ZONES

Table A17: Year 1987-Town centre Entropy Computation (1000m)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	439200	0.082127	-2.49949	-0.20528	2.18545	2.302585	0.949129
2	431100	0.080613	-2.5181	-0.20299			
3	685800	0.12824	-2.05385	-0.26339			
4	1099800	0.205655	-1.58156	-0.32525			
5	968400	0.181084	-1.7088	-0.30944			
6	442800	0.0828	-2.49132	-0.20628			
7	327600	0.061259	-2.79265	-0.17107			
8	267300	0.049983	-2.99607	-0.14975			
9	365400	0.068327	-2.68345	-0.18335			
10	320400	0.059912	-2.81487	-0.16865			
Total	5347800	1		-2.18545			

Table A18: Year 2000-From Town centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	3728700	0.146899	-1.91801	-0.28175	2.069472	2.302585	0.89876
2	4927500	0.194128	-1.63924	-0.31822			
3	4698000	0.185087	-1.68693	-0.31223			
4	2469600	0.097295	-2.33001	-0.2267			
5	801000	0.031557	-3.45596	-0.10906			
6	616500	0.024288	-3.71776	-0.0903			
7	605700	0.023863	-3.73544	-0.08914			
8	761400	0.029997	-3.50666	-0.10519			
9	3151800	0.124171	-2.08609	-0.25903			
10	3622500	0.142715	-1.9469	-0.27785			
Total	25382700	1		-2.06947			

Table A19: Year 2016-From Town centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	5772600	0.055843	-2.88521	-0.16112	2.179181	2.302585	0.946406
2	14564700	0.140896	-1.95974	-0.27612			
3	20018700	0.193657	-1.64167	-0.31792			
4	18608400	0.180014	-1.71472	-0.30867			
5	10647900	0.103005	-2.27297	-0.23413			
6	7032600	0.068032	-2.68778	-0.18285			
7	4356000	0.042139	-3.16678	-0.13344			
8	6386400	0.061781	-2.78417	-0.17201			
9	9541800	0.092305	-2.38265	-0.21993			
10	6443100	0.062329	-2.77533	-0.17298			
Total	103372200	1		-2.17918			

Table A20: Year 1987-Road centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	1993500	0.365995	-1.00514	-0.36787	1.940954	2.302585	0.842946
2	707400	0.129874	-2.04119	-0.2651			
3	541800	0.099471	-2.30789	-0.22957			
4	637200	0.116986	-2.1457	-0.25102			
5	457200	0.083939	-2.47766	-0.20797			
6	127800	0.023463	-3.75232	-0.08804			
7	436500	0.080139	-2.524	-0.20227			
8	288000	0.052875	-2.93982	-0.15544			
9	176400	0.032386	-3.43003	-0.11108			
10	81000	0.014871	-4.20833	-0.06258			
Total	5446800	1		-1.94095			

Table A21: Year 2000-From Road centre Entropy Computation

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	12385800	0.461332	-0.77364	-0.3569	1.68727	2.302585	0.732772
2	4205700	0.156649	-1.85375	-0.29039			
3	705600	0.026281	-3.63889	-0.09564			
4	235800	0.008783	-4.73496	-0.04159			
5	594900	0.022158	-3.80955	-0.08441			
6	1592100	0.059301	-2.82513	-0.16753			
7	2293200	0.085415	-2.46024	-0.21014			
8	3425400	0.127585	-2.05897	-0.26269			
9	1180800	0.043981	-3.124	-0.1374			
10	228600	0.008515	-4.76597	-0.04058			
Total	26847900	1		-1.68727			

Table A22: Year 2016- From Road centre Entropy Computation (1000m buffer)

Zones	Built-up	Proportion (Pi)	LnPi	Pi*LnPi	H	Ln(N)	H'n
1	35854200	0.340898	-1.07617	-0.36686	1.910559	2.302585	0.829745
2	23680800	0.225154	-1.49097	-0.3357			
3	9959400	0.094693	-2.35712	-0.2232			
4	4401900	0.041853	-3.1736	-0.13282			
5	5350500	0.050872	-2.97844	-0.15152			
6	5353200	0.050898	-2.97794	-0.15157			
7	7073100	0.06725	-2.69933	-0.18153			
8	8193600	0.077904	-2.55228	-0.19883			
9	4710600	0.044788	-3.10582	-0.1391			
10	598500	0.00569	-5.16896	-0.02941			
Total	105175800	1		-1.91056			

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