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Monitoring and modelling of urban land use in Abuja Nigeria , using geospatial information technologies

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MONITORING AND MODELLING OF URBAN LAND USE IN ABUJA NIGERIA, USING GEOSPATIAL INFORMATION TECHNOLOGIES

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A thesis submitted in partial fulfilment of the University's requirements for the degree of Doctor of Philosophy

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Abstract

This thesis addresses three research gaps in published literature. These are, the absence of Object Based Image Analysis (OBIA) methods for urban Land Use and Land Cover (LULC) analysis in Nigeria; the inability to use Nigeriasat-1 satellite data for urban LULC analysis and monitoring urban growth in Nigeria with Shannon's Entropy Index.

Using Abuja as a case study, this research investigated the nature of land use/land cover change (LULCC). Specific objectives were: design of an object based classification method to extract urban LULC; validate a method to extract LULC in developing countries from multiple sources of remotely sensed data; apply the method to extract LULC data; use the outputs to validate an Urban Growth Model (UGM); optimise an UGM to represent patterns and trends and through this iterative process identify and prioritise the driving forces of urban change; and finally use the outputs of the land use maps to determine if planning has controlled land use development.

Landsat 7 ETM (2001), Nigeriasat-1 SLIM (2003) and SPOT 5 HRG (2006) sensor data were merged with land use cadastre in OBIA, to produce land use maps. Overall classification accuracies were 92%, 89% and 96% respectively. Post classification analysis of LULCC indicated 4.43% annual urban spread. Shannon's Entropy index for the study period were 0.804 (2001), 0.898 (2003) and 0.930 (2006). Cellular Automata/Markov analysis was also used to predict urban growth trend of 0.89% per annum.

For the first time OBIA has been used for LULC analysis in Nigeria. This research has established that Nigeriasat-1 data can contribute to urban studies using innovative OBIA methods. In addition, that Shannon's Entropy Index can be used to understand the nature of urban growth in Nigeria. Finally, the drivers of LULCC in Abuja are similar to those of planned capital cities in other developing economies.

Land use developments in Abuja can provide an insight into urban dynamics in a developing country's capital region. OBIA, Shannon's Entropy Index and UGM can aid urban administrators and provide information for sustainable urban planning and development.

Key words: Object Based Image Analysis (OBIA), Nigeriasat-1, Shannon's Entropy Index.

Dedication

To God the author and finisher of my fate

and my parents

Francis Onyema Chima (1926-1992)

Maria Onyekangaze Chima (1932-2004)

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In the course of my studies I have had the benefit of assistance from many individuals and departments in England and Nigeria. I will like to show my gratitude to all, particulary those mentioned below.

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List of Acronyms

AGIS: Abuja Geographic Information Systems

ASTP: Apollo-Soyuz Test Programme

AVHRR: Advanced Very High Resolution Radiometer

BFD: Brazilian Federal District

CA: Cellular Automata

CK: Conditional Kappa

CLUE: Conversion of Land use and Its Effects

CMSA: Consolidated Metropolitan Statistical Area

COHRE: Centre on Housing Rights and Evictions

DMC: Disaster Monitoring Constellation

EGO: Environment for Geoprocessing Objects

ERTS: Earth Resources Technology Satellite

ESIS: Extended Swatch Imaging System

ETM: Enhanced Thematic Mapper

FCDA: Federal Capital Development Authority

FCT: Federal Capital Territory

GCP: Ground Control Points

GLI: GLobal Imager

GOES: Geostationary Operational Environmental Satellites

HRG: High Resolution Geometric

IRS: Indian Remote Sensing

KIA: Kappa Index of Agreement

LCM: Land Cover Map

LSUM: Large Scale Urban Models

LUCAS: Land Use Change Analysis System

LULC: Land use and Land cover

LULCC: Land use and Land cover change

LULCC: Land use Land Cover Change

MODIS: Moderate Resolution Imaging Spectrometer

MS: Multi Resolution Segmentation

MSA: Metropolitan Statistical Area

NASA: National Aeronautics and Space Administration Space

NASRDA: National Space Research and Development Agency

NEMO: Naval Earth Map Observer

NOAA: National Oceanic and Atmospheric Administration

OA: Overall Accuracy

OASIS: Optimising Access to SPOT Infrastructure for Science

OBIA: Object Based Image Analysis

PA: Producer's Accuracy

SERAC: Social and Economic Rights Action Center

SLC: Scan-Line Corrector

SLIM: Surrey Linear IMager

SLIM: Surrey Linear Imager, the sensor on board the Disaster Monitoring Constellation of Satellites

SMSA: Standard Metropolitan Statistical Area

SP: Scale Parameter

SPOT: Satellite Probatoire l' Observation de la Terre

SSTL: Surrey Satellite Technology Ltd.

TIROS: Television and Infrared Observation satellite

TM: Thematic Mapper

UGM: Urban Growth Model

UNFPA: United Nations Population Fund

UTM: Universal Transverse Mercator

Chapter 1: Introduction

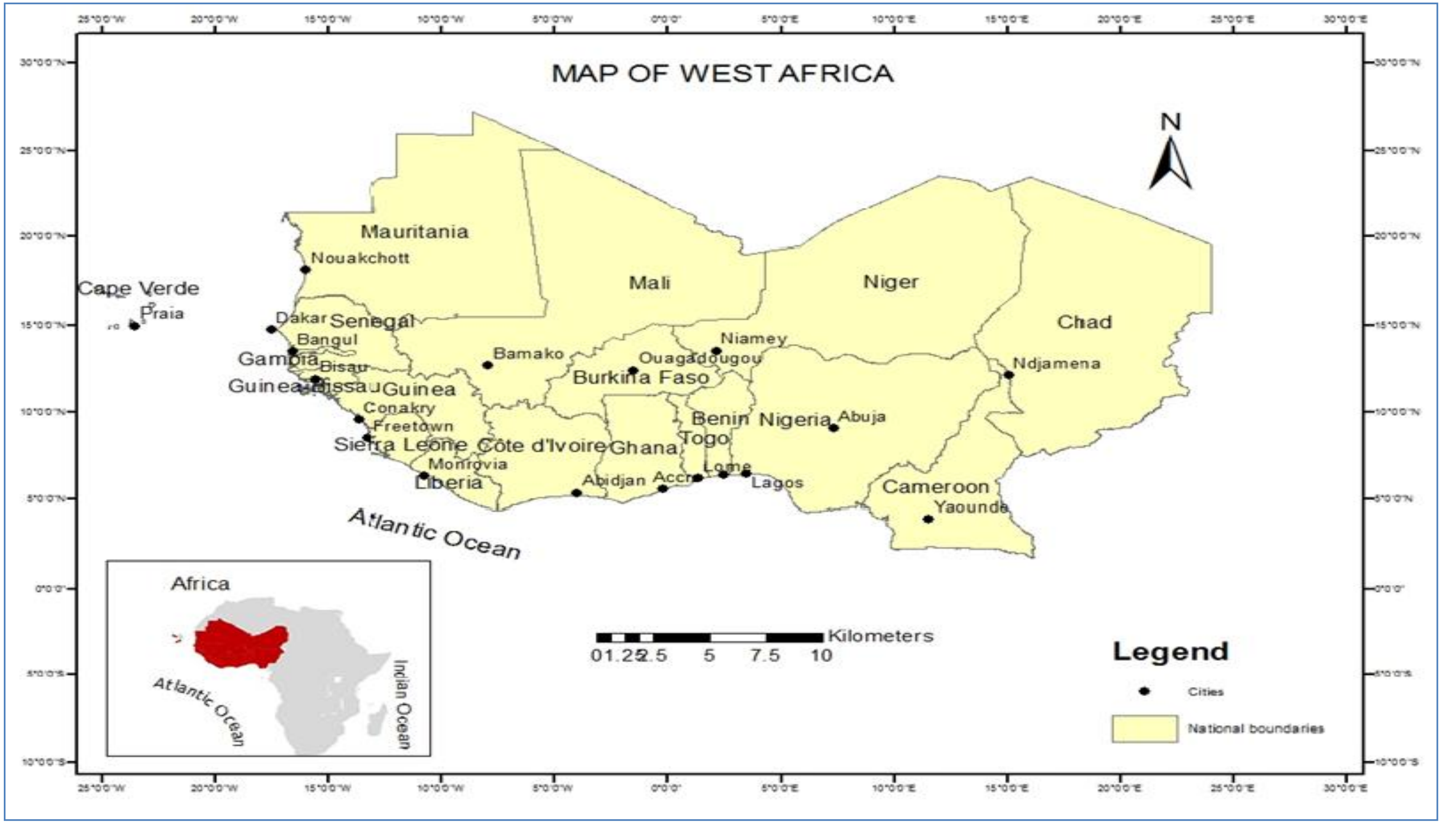
1.1Background

Urban areas contain half of the world's population (UNFPA 2011a) and more than a third of world urban population live in large cities (UNFPA 2011b, United Nations 2011a, Worldwatch Institute 2007). This makes cities places of primary concern to administrators because they harbour a large proportion of non-agricultural specialists. Cities contain a concentration of administrative, industrial and commercial activities (recreational and cultural). Over time cities have become places of economic strength for the surrounding regions as well as places of political and financial power, innovation and modern culture. They generate a larger proportion of national economic activity and provide greater employment opportunities and services due to their diversified economic base (Oyesiku 2010). This makes cities vehicles of national development and growth. The world's population currently living in cities has continued to grow, as more people are attracted to cities.

Worldwide, this continued growth of cities has generated some diseconomy as the large concentrations of people causes a huge demand for available resources, driving up rents and cost of land leading to sub urban development or sprawl. Also increased transportation costs as distances to work increase (Frank *et al.* 2000, O'Meara 1999). Other undesirable effects include congestion, pollution, poor welfare and health, increased social disorganisation, unemployment, economic stratification, and overcrowding (Pacione 2009). Additionally, cities in developing countries experience the following - primacy of growth, rural-urban migration, inadequacy and over utilisation of housing and basic services, and infrastructure, informal settlements, and lack of planning as most cities have grown from their traditional or pre-colonial setting (Ayeni 1981) and are struggling to adopt modern developments like motor-able roads, pipe borne water and well equipped health care facilities.

The situation in developing countries demands a close scrutiny because the pattern of public investments tends to favour few urban centres. Sometimes only the country's capital or primate city gets government attention (Kessides 2005). In virtually all of Africa, as in most other developing countries, rural poverty rates exceed urban poverty rates. This result would be expected, given that urban areas provide a wider and deeper labour market, permitting higher capacity to pay for services, and that density of settlement and proximity to centre of government allows provision of many services at lower per capita cost (Kessides 2005). This neglect of the rural areas means that cities will continue to grow to the detriment of other parts of the country (Richardson 2005). As more people migrate to cities which continue to grow formlessly beyond the planning limits and carrying capacity of infrastructure (Oyesiku 2010). Often solutions are sought to correct this anomaly and the role of cities as engines of national growth is restored over time.

The solution could be in the form of massive reconstruction, gentrification or even a decision to build a whole new City/town to take the pressure away from the existing urban centre. Some developing countries have adopted the strategy of building completely new capital cities because the old capital cities inherited from the colonial masters can no longer meet the countries' needs in terms of adequacy and accessibility from all parts of the country. Often these colonial capitals are by the coast for easy access from the sea. In West Africa, as shown in Fig.1.1 apart from the landlocked countries like Niger, Mali and Chad, the colonial capital cities (indicated with black dots) are located on the coast.



Source: Adapted from shapefile courtesy of Diva GIS: http://www.diva-gis.org/ (2012)

Fig. 1.1 Map of West Africa showing countries and capitals. Most of the capital cities are located on the Atlantic coast

The city may even be on an island with finite land space as is the case with Lagos in Nigeria. In Lagos, city expansion has spread to adjoining islands as well as a large and expanding mainland area. The city never seems to have enough bridges or arteries as constant traffic jam is a major feature of its life. The profusion of vehicles that came with the prosperity of the oil boom of the 1970s seemed often to be arranged in a massive standstill, and traffic jams are often the site for urban peddling of a variety of goods, as well as entertainment, exasperation, and occasionally crime (Metz 1991).

With the establishment of these new capitals, which are planned from inception, states can learn from, as well as avoid past mistakes, especially those of uncontrolled population growth and urban sprawl. How can these new cities be monitored to provide relevant and timely information to urban administrators? Why is there emphasis on these planned new cities in some developing countries? In this thesis, Abuja, Nigeria's new capital is used as a case study to understand urban land use dynamics in developing economies.

Land cover mapping from space since Landsat 1 in 1972 points to the use of satellite data images for the study of land use and land cover change. Since then satellite data /images have become readily available due to the launching of many earth observation satellites by various countries e.g. United States of America, France, China, Brazil, Japan, India, Russia, Turkey, Algeria and Nigeria. Moreover, data collection from satellites is rapid and repetitive, sometimes even available on a sub-daily basis.

The emphasis on developing countries arises from the paucity of data on the study of these new urban developments in these countries. The developing countries that have built new capital cities after political independence are shown in Table 1.1. Southern Sudan has also planned the relocation of its capital city from September 2011 and is expected to complete the movement in 2016.

Table 1.1 Countries with new capital cities in the developing countries

Country	**Old Capital City**	**New Capital City**	**Year of movement**	**Reasons for movement**
Brazil	Rio de Janaeiro	Brasilia	1960	Accessibility and regional development
Pakistan	Karachi	Islamabad	1960	National unity and defence
Tanzania	Dar-es-Salaam	Dodoma	1970	Regional development
Cote d'Ivoire	Abidjan	Yamoussoukro	1983	Regional development
Nigeria	Lagos	Abuja	1991	Neutral territory, accessibility and regional development, Inadequacy of old capital
Kazakhstan	Almaty	Aqmola	1991	Earthquake and national security
Myanmar	Rangoon	Naypyidaw,	2005	National defence and political
South Sudan	Juba	Ramiciel	2011-2016 (expected)	Neutral territory

1.2 Research Gaps

The use of remote sensing to study urban areas in Nigeria dates back to the use of sequential aerial photographs. The availability of data determined the decision whether to use remote sensing techniques or not. Prominent among these works are studies that investigated and mapped the rates of urban and peri-urban land use and land cover change in Ibadan (Areola 1982, Oyelese 1968) and Lagos (Adeniyi 1980, Adeniyi 1986, Grenzebach 1978). The decision to utilise the remote sensing was due to cost effectiveness of the method over the traditional ad hoc sample surveys (Adeniyi 1986). Other studies that have utilised these methods include the study of patterns of land use in pre-colonial Benin (Ikhuoria 1987). When satellite images became available studies, which utilised them, were done in combination with sequential aerial photographs to map spatial-temporal urban land use and land cover change. SPOT XS imagery was combined with sequential aerial photographs in the study of peri-urban spread in Ilesha, Southwestern Nigeria (Odeyemi 1999). The same data combination was used to study patterns of land use in Ile-Ife campus of Obafemi Awolowo University (Tsolocto 1996) and Ikeja, Lagos (Chima 2002). One of the earliest to use wholly satellite image techniques utilised SPOT XS to study the growth of Ile-Ife (Ikhuoria 1999). Since then different combinations of satellite datasets have been used for urban studies in various parts of Nigeria. SPOT XS data was used to document urban land use conversion in FESTAC town, a predominantly residential suburb of Lagos that is losing its aesthetic appeal, due to in filling of open spaces with commercial and residential developments (Omojola and Fasona 2004). Urban land use dynamics in greater Lagos was the focus of a study that used Landsat TM, Landsat ETM and SPOT PAN data for change detection over 18 years (Adepoju, Millington and Tansey 2006). These studies indicate that remote sensing methods are gaining currency for the study of urban areas in Nigeria.

However, the studies have all concentrated on the use of visual image interpretation techniques for the analysis of aerial photographs and pixel based approaches for the analysis of satellite images. The review of available literature indicates that there is no published work on Object Based Image Analysis (OBIA) in Nigeria. None of the studies have utilised OBIA for the classification of the satellite imagery. This study hopes to add to the body of knowledge by utilising OBIA for the analysis of urban land use and land cover in Nigeria

Another research gap this study hopes to fill is the use of Nigeriasat-1 satellite data for urban studies. Published work on Nigeriasat-1 indicates that it is only useful for synoptic area coverage (Omojola 2004) (see literature review in Chapter 2: Section 2.9). This study will help to establish the usefulness of Nigeriansat-1 for urban studies by combining it with Landsat and SPOT satellite images which are regarded as the ‘workhorses’ of satellite remote sensing and GIS studies (Blaschke 2010).

Lastly, urban growth in Nigeria has been monitored and quantified in various studies within Nigeria, but there is no published literature to indicate that Shannon's Entropy index has been used to measure and quantify or measure urban sprawl in Abuja and environs.

1.3 Research questions

With detailed planning, it is expected that spontaneous developments similar to what happens in unplanned urban areas will not happen in planned cities like Abuja. This leads to the first research question.

1 Does spontaneous and unplanned growth happen around planned cities?

If this growth exists despite the planned nature of the city and can be monitored, then the second research question is

2 What factors are responsible for this unplanned growth?

The answers will give useful indication about urban management in developing countries and an indication as to how these growth patterns occur. This will hopefully be useful information for urban managers and planners and possibly help to establish the driving forces of urban growth in developing countries.

To answer the research questions we need information on urban Land use and Land cover (LULC) and new missions (such as Nigeriasat-1) which offer the possibility of more frequent (and higher likelihood of cloud-free) coverage. However, per-pixel image classification of Nigeriasat1 and other Earth Observer missions (e.g. Landsat TM/ETM+ and SPOT HRG) is unlikely to generate useful urban land cover products (as mentioned in the literature review Section 2.8) and so new techniques of OBIA will be tested to see if they can generate the information required. With OBIA methods, is it possible to extract image objects from DMC and other satellite data? This leads to the third and fourth research questions.

3 Is OBIA able to support urban studies in developing countries?
4 Can Nigeriasat-1 data contribute to urban LULC analysis?

1.1 Aim and objectives

The aim of this research is to investigate the nature of land use/land cover change (LULCC) in Abuja, Nigeria from 1991 to 2006. In order to achieve this aim, the six specific objectives are to:

1) Design an object based classification method to extract urban land cover and land use,
2) Validate a method to extract LULC in developing countries from multiple sources of remotely sensed data,
3) Apply the method to extract LULC data of Abuja for 1991 to 2006,
4) Use the outputs to validate an Urban Growth Model (UGM) for the period 1991 to 2006,
5) Optimise an UGM to represent patterns and trends and through this iterative process identify and prioritise the driving forces of urban change, and
6) Use the outputs of the land use maps to determine if planning has controlled land use development in Abuja.

1.2 Thesis Structure

This thesis comprises six chapters. Chapter 1 sets out the research problem including the aims and objectives of the research. Chapter 2 reviews existing literature on the three major themes of the research, and Chapter 3 deals with the methodology of analysing urban land use with remotely sensed data. Chapters 4 and 5 analyse and discuss the results. Finally, chapter 6 concludes by summarising the major findings of the research.

Chapter 1 introduces the general overview of the research. This includes the problems occasioned by unplanned growth of urban areas in developing countries, the relevance of the research and the research aim and objectives.

Chapter 2 provides a literature review on three major themes of the research namely, remote sensing of urban areas in developing countries, methods of satellite data analysis and modelling of urban land use. It introduces the key concepts of urbanisation and the factors that drive urban growth and appraised the monitoring of urban areas with earth observation satellites. Methods of satellite data analysis are also previewed. The chapter ends by analysing the spatial-temporal growth of Abuja, Nigeria as a case study of urban growth in developing countries using remotely sensed data. It traces the origins of modern urban development in Nigeria to help understand the context in which Abuja was conceived.

Chapter 3 deals with the GIS and remote sensing methodology. The results are presented and analysed in Chapter 4. This analysis sets the tone for the discussions in Chapter 5 and a comparison of developments in Abuja with other capital cities in similar socio-economic circumstances in South America (Brazil) and Asia (Pakistan). Chapter 6 draws a conclusion from this research and presents the major findings and suggestions for further studies. A flowchart of the thesis structure is presented in Fig. 1.2.

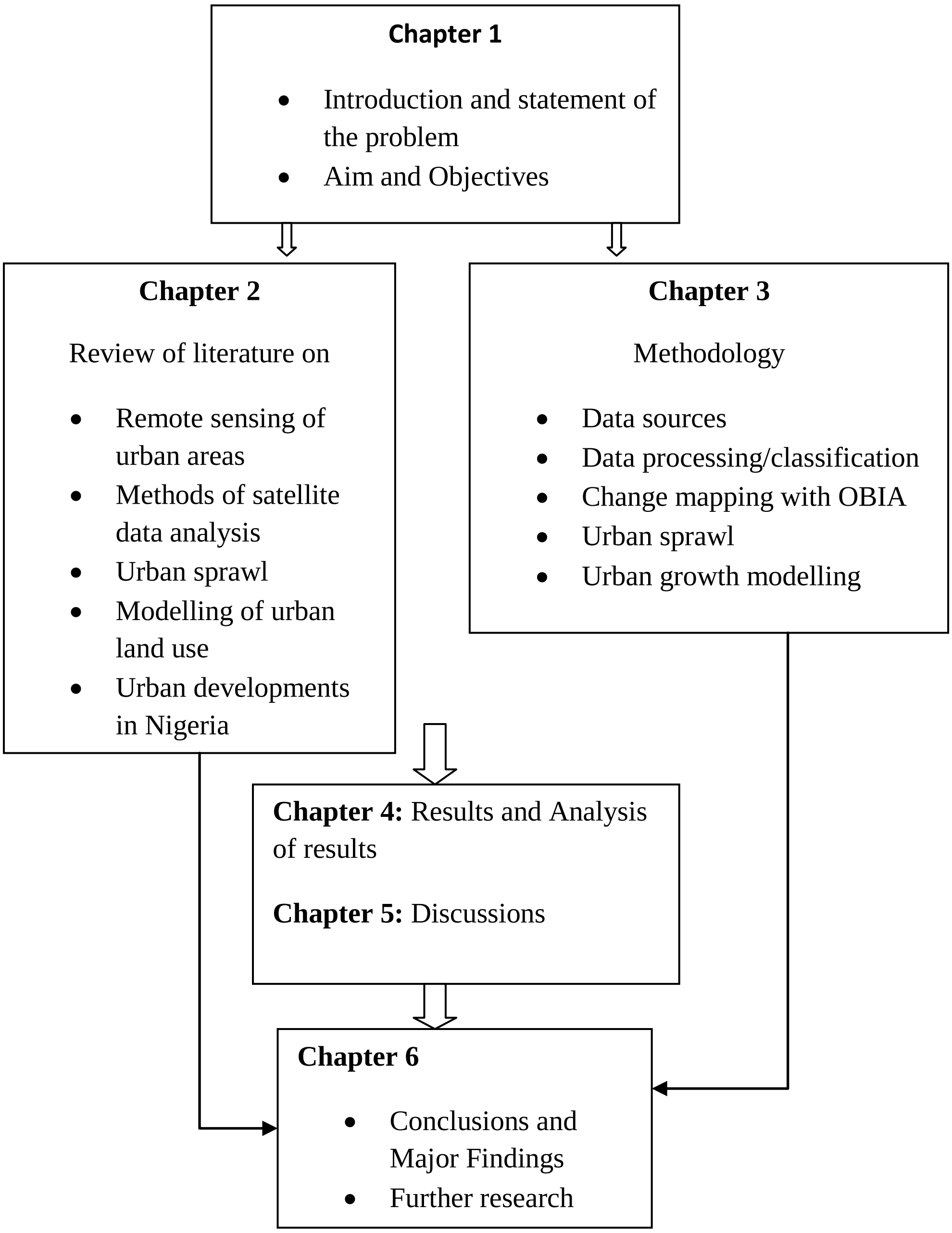


Fig. 1.2 Flow chart of thesis structure.

Chapter 2: Remote sensing of urban areas

Remote sensing has been used to study urban areas since the advent of aerial photography and earth observation satellites. This method is particularly useful because remote sensing provides synoptic views of urban areas. Remote sensing can also provide regular cloud free images that can help accurate documentation of temporal or multi-temporal urban land use and land cover dynamics. This chapter reviews the literature on the study of urban areas with remotely sensed data and the methods used to analyse the data. Finally, the conception of Abuja in the context of modern urban developments in Nigeria is reviewed.

2.1 Urban areas defined

There is no single definition of urban areas. Definitions differ between disciplines, countries and from one period to another. Among the disciplines, practitioners tend to emphasise only aspects that are of primary interest to them. However, census bodies at national and international levels and scholars in various disciplines have evolved four broad criteria in arriving at their definitions.

2.1.1 Population size

Very often in many parts of the world, a minimum population threshold that a place must have to be called an urban area is specified. This varies depending on the country concerned. In practice this threshold also varies over time and space (Pacione 2009). In Sweden and Norway, a settlement of more than 200 inhabitants is classified as urban in the national census. In the United States of America this threshold is 2,500 and rises to 10,000 in Switzerland and Portugal. In Japan this figure is 30,000. In densely populated countries like Japan (with a population of more than 127million), a low threshold of 200 like Sweden would mean that virtually everywhere in the country would be classed as urban. However, this is adequate for Sweden because of its sparse population (Cohen 2004, Lang 1986, Onokerhoraye and Omuta 1995, Oyesiku 2010, Pacione 2009).

A common problem associated with the use of population thresholds to define urban areas is how to define boundaries between what is urban and rural. This method does not use official or legal boundaries of administrative divisions, but uses other criteria. These may be in terms of persons, housing units, percentage of land covered by buildings, employment per given area, traffic generation (Donnay, Barnsley and Longley 2005, Lang 1986, Pacione 2009). A minimum threshold can be set for each of the above criteria as a basis for urban or city limits. In addition, the presence of certain institutional services like schools, markets and hospitals may be used for urban delimitation (Onokerhoraye and Omuta 1995, Pacione 2009).

In many developing countries, there is the problem of data, which may be used to define urban limits. Often the only consistent archive of data available is demographic. As a result, demographically based definition is the only criteria used to distinguish urban areas (Onokerhoraye and Omuta 1995). In view of this, most researchers in Africa use the United Nations Economic Commission for Africa definition, which classifies any cluster of 20,000 people or more as an urban locality. This threshold figure is useful for international comparison since it is the one used by the United Nations organisation. For census purposes, an urban locality should be defined as a distinct population cluster (also designated as inhabited place, populated centre, settlement and so forth) in which the inhabitants live in neighbouring sets of living quarters and has a name or a locally recognized status (United Nations 2011b).

2.1.2 Legal and administrative

Legal and administrative definitions are derived from the laws of a given country. In this respect, the urban areas acquire their status from laws or byelaws set out by the government within whose jurisdiction they are located (Onokerhoraye and Omuta 1995). The basis of such legal recognition may be some minimum facilities and services or functional thresholds that are used to determine the boundaries of the urban areas. Sometimes minimum thresholds are not set, but by law certain areas are defined as urban areas and the required minimum facilities and services required are provided to bring such areas up to urban standards. The usefulness of this approach will depend on how often the laws are reviewed considering the rapid population growth in developing countries (Onokerhoraye and Omuta 1995). This is because, sometimes, the built up areas extend beyond the administrative boundaries set by the initial charter establishing the urban boundaries, a condition known as under bounding. If the boundaries are not reviewed this may cause fiscal difficulties for urban administrators who will not be able to extend tax regimes to commuters who reside outside the legal limits (Pacione 2009) of the urban areas. The 'problem' is that these commuters use the city's services, which are maintained by taxpayers.

2.1.3 Functional

To address the problem of under bounding (and its converse over bounding) some urban scholars have devised a concept of ‘functional urban regions’ which reflect the real extent of urban areas (Pacione 2009). The United States Bureau of Census introduced this concept of extending the urban area to include all built up areas around the city in 1910. It was then developed into Standard Metropolitan

Statistical Area (SMSA) in 1960 and since 1983 has been known as Metropolitan Statistical Area (MSA) and Consolidated Metropolitan Statistical Area (CMSA) if it covers two or more MSAs. Two main principles of this concept are a settlement form based on the population size of a central core city and functional integration between core city and outlaying districts reflected in journeys to work (Pacione 2009).

2.1.4 Economic base

Population size can also be combined with other criteria like the percentage of people engaged in non-agricultural pursuits. For example in India, a settlement must have more than 75% of the adult males in non-agricultural employment to be classified as urban (Pacione 2009).

Synopsis: Urban areas are places, with a high proportion of its residents in non-agricultural employment, having a population of at least 20,000.

2.2 Land use vs. Land cover

Land cover is defined as the attributes of the earth's surface and immediate subsurface, including biota, soil, topography, surface and ground water, and human structures (Lambin, Geist and Lepers 2003). Land use is the human employment of the land cover type (Skole 1994). Natural scientists define land use in terms of human activities such as agriculture, forestry and building construction that modify land surface processes including biogeochemistry, hydrology and biodiversity. Social scientists and land managers characterize land use more broadly to include the social and economic purposes and contexts within which lands are managed (or left unmanaged), such as subsistence versus commercial agriculture, commercial vs. residential, or private vs. public land (Ellis and Pontius 2007).

2.3 Urban land use / land cover change in developing economies

In the context of this study, the term developing economies represents countries in economic transition from producers of raw materials to industrial processing of those materials. The difference between developed and developing countries arises from unevenness in economic development (Knox and Marston 2007).

Land use and land cover change is a major driver of global change (Vitousek 1992). Urban growth and, by implication, urban land use and land cover change in developing countries is associated with natural population growth, rural-urban migration, convergence in rural-urban lifestyles, economic and political processes (Cohen 2004). Urban expansion usurps agricultural land and forests (Vincent, Baquero and Levine 2002), uncontrolled urban spread also leads to fragmentation of landscapes, destruction of wildlife habitat, and reduction (or loss) in biodiversity (Braimoh and Onishi 2007).

Remote sensing and GIS methods have been used to study LULCC in developing countries. Most studies have used aerial photographs and pixel based methods to perform satellite data analysis (Adeniyi and Omojola 1999, Adepoju, Millington and Tansey 2006, Bhatta, Saraswati and Bandyopadhyay 2010, Dwivedi, Sreenivas and Ramana 2005, Maktav and Erbek 2005, Ojiji 2006, Omojola 2004, Osunmadewa and Enokela 2011, Yeh and Li 2001).

2.4 Land use and land cover change detection: Determining the areas of change from satellite images

Change detection is the process of identifying variations in the state of an object or phenomenon by observing it at different times. Basically, it involves the ability to quantify temporal effects using multi-temporal data sets (Singh 1989). Timely and accurate change detection of land use or land cover is necessary to understand human interactions with the earth's features and can inform better policy decisions (Lambin *et al.* 2001, Lu *et al.* 2004, Verburg *et al.* 2006). Change detection methods from digital imagery can be broadly divided into spectral (change vector analysis, image differencing, image rationing, change vs. no change binary mask) and post classification change detection methods (Lunetta and Elvidge 1999). According to Singh (1989), there are two basic approaches for change detection. These are: (1) comparative analysis of independently produced classifications for different dates and (2) simultaneous analysis of multi-temporal data. The post classification change detection method was considered the most suited option for this study because of the different data sensors and spatial resolutions of the images used in this study.

2.5 Causes of land use and land cover change

Human exploitation of land cover determines the land use. The decision to utilize land for specific purposes is dependent on a myriad of interlinked factors. These can range from political and socioeconomic which can be global or local. There are immediate (direct) and underlying (indirect or root) causes (Geist and Lambin 2002) of land use change. The direct causes of land use change are human activities that arise from the purpose for which land use is intended, this in turn directly affects land cover (Robson and Berkes 2011). These causal factors operate at the local and individual levels

(Serneels and Lambin 2001). This includes the physical action of the humans on existing land cover. The root causes of land use change represent a complex mix of political, socioeconomic, demographic, technological, cultural and biophysical variables that form the initial pre change condition and are systemic (Lambin *et al.* 2001) in nature with all the factors intertwined. The root causes of land use change are initiated outside the local communities and cannot always be controlled from within. Sometimes the decisions that affect land use change at local level are the results of some macro level decisions made at the global or national level (Niroula and Thapa 2005). Understanding the causes of land use change from global to local level requires different study approaches. Land cover change can be understood by a comparison of successive land cover maps. On the other hand, understanding subtle changes in the form of land cover modifications will require very close scrutiny, which might require remote sensing data of high temporal frequency (Lackner and Conway 2008, Long *et al.* 2007, Osunmadewa and Enokela 2011). The overall picture of causes of land use and land cover change can best be understood using place based research and comparative analyses of case studies of land use dynamics (Lambin *et al.* 2001).

2.6 Drivers of land use and land cover change in the developing world

Multiple factors (or forces) operating temporally and spatially drive land use change. These forces may differ from place to place, but some common denominators can be found in all areas. Namely, population/income, technology, political, socio-economic and cultural factors (Lambin, Geist and Lepers 2003). These factors acting jointly or individually have environmental effects with eventual impact on land use and land cover (Anifowose *et al.* 2011). The level of interaction between the driving forces determines the rate of urbanisation (Geist and Lambin 2002, Lambin *et al.* 2001). While the driving forces of change in developed economies are a complex mix of all factors with technology being at the core (Lambin *et al.* 2001), the situation in developing economies seems to be population driven (Knox and Marston 2007, Ujoh, Kwabe and Ifatimehin 2010). Of the estimated 7 billion people in the world, the developing countries of Africa, Asia, Latin America and the Caribbean have a combined percentage of 82% (Population Reference Bureau 2009). According to the United Nations, between 2007 and 2050, Asia is projected to see its urban population increase by 1.8 billion, Africa by 0.9 billion, and Latin America and the Caribbean by 0.2 billion. Population growth is therefore becoming largely an urban phenomenon concentrated in the developing world (UNFPA 2011a).

2. 7 Planned cities as a strategy to control urbanisation

Planned new cities are considered as a strategy of urban deconcentration, decentralisation, and internal migration policy (Palen 1995). In developing countries, the new towns are considered as a strategy of establishing intermediate cities and simultaneously inducing growth and development of rural areas (Oyesiku 2010).

Across the world, countries have relocated their capital cities for reasons such as ease of accessibility from various parts of the country, overcrowding of former capitals, national unity and regional development of the country's interior. The former capitals still remain centres of high commercial activity and demographic concentration despite the development and designation of new cities as capitals. These planned capital cities are designed to avoid the lapses of their predecessors. They are also centres of national pride meant to project the right image of the countries in the committee of nations (Jatau 2007).

2.8 Development of remote sensing analysis as strategy for urban studies

Remote sensing techniques have been used to study urban areas since the use of aerial photographs during World War 1 (1914-1918) and the advent of Landsat satellite in 1972 (Maktav, Erbek and Jurgens 2005). Since then, technical improvements have led to the second generation of earth observation satellites such as the subsequent Landsat satellites, SPOT, IRS, Envisat etc. and third generation satellites with very high spatial resolution of under 5 meters like IKONOS, Quickbird, and WorldView (Lillesand, Kiefer and Chipman 2008). These improvements in spatial resolution have also been accompanied by increased revisit times, as many of the third generation satellites have a capacity for daily revisits of same locations on earth.

With the advent of daily temporal/high spatial resolution imagery and more capable techniques, urban remote sensing is rapidly gaining interest within the remote sensing community (Melesse *et al.* 2007, Weng and Quattrochi 2006) and has uses in many urban applications since the requirements regarding the level of detail can be fulfilled either by aerial or satellite based sensor systems (Maktav, Erbek and Jurgens 2005). Aerial photographs and satellite imagery are sometimes complimentary. They have been the principal means of land use and land cover observation, recording and quantification (Khorram, Brochaus and Gerachi 1991), especially in developing countries where other ways to monitor urban changes from a ground level, like ad hoc sample surveys are expensive and time consuming (Adeniyi and Omojola 1999, Ikhuoria 1988).

Despite these improvements in resolution, the heterogeneous composition of urban landscapes (buildings, paved roads, glass, water, asbestos, grass, soil, parking lots etc.) poses a major challenge to urban remote sensing feature extraction (Oke 1982). Satellite data with very high spatial resolution like Landsat and SPOT were seen as having potentials for identification and classification of urban land cover and land use (Weber 2001). Due to the fine resolution, each pixel is more likely to contain a single land cover type (Forster 1985) and the high spatial resolution will increase the potential range of any signal and hence the spectral variability of each land cover type (Weber 2001). These recent advances in spatial resolution have not brought about improved classification accuracy because several land cover/land use types are contained in one pixel (Mather 1999, Welch 1982). For example, a pixel can contain houses, fields and roads, which have different spectral reflectance. This problem known as the mixed pixel problem has been seen as the reason responsible for low classification accuracies of urban land use and land cover classifications which are rarely above 80% for per pixel classification or hard classification approaches (Mather 1999). To overcome the pixel problem, soft classifiers (also known as fuzzy classifiers) (Lillesand, Kiefer and Chipman 2008) have been applied. In this method, each pixel is assigned to a class membership of a land use type rather than a single label (Wang 1990).

Despite these attempts to solve the urban mapping problems, there have been studies, which suggest that hard and soft classifications are not the appropriate tool for the analysis of heterogeneous urban landscape (Mather 1999, Ridd 1995). These studies have called for a three-pronged method of identification/description/quantification rather than classification in order to provide a better understanding of the diversity and process of the urban landscape.

To understand the dynamics of patterns and processes and their interactions in heterogeneous landscapes such as urban areas, a methodology must be able to accurately quantify the spatial pattern of the landscape and its temporal changes (Wu *et al.* 2000). Ridd (1995) had earlier proposed ways to achieve this. He posited that it is necessary: (a) to have a standardized method to define these component surfaces, and (b) to detect and map them in repetitive and consistent ways, so that a global model of urban morphology may be developed and as such monitoring and modelling their changes over time is possible.

2.8.1 Strengths and limitations of remote sensing for urban monitoring

The strengths of remote sensing for urban mapping lie with its capacity for synoptic overview which permits independent, rapid, up-to-date, and relatively cost-effective transformation of data (or images) into information (Taubenbock, Esch and Roth 2006); it makes use of a vast amount of methodologies

- e.g. visual, statistical, pixel based, neural, fuzzy and object based classifiers – for automatic information extraction from particular data sets. It can also be used for historical monitoring and temporal change detection given the vast archive of data that has been accumulated through aerial and satellite based sensors (Forster 1985, Taubenbock, Esch and Roth 2006).

However, historical (or long-term) monitoring using remotely sensed data is limited to the available data source. Thus, monitoring for the past 20 years has relied on medium resolution data from sensors such as Landsat, SPOT or IRS. With these, the limited geometric resolution does not allow for too much thematic detail, but provides enough information to analyse spatial urban growth on regional level, differentiating between urbanized and non-urbanized areas (Taubenbock, Esch and Roth 2006).

Using a pixel-based post-classification change detection, spatial urban growth can be identified. It enables the detection of the spatial dimension of sprawl and its dynamics over time. Added to that, processes such as re-densification (infilling), leap frog development as well as growth patterns such as axial, mono-centric or polycentric structures or satellite town evolution, can be identified and analysed. More detailed analysis can be achieved with very high resolution images (Aplin 2003) and (or) other sophisticated means of classification.

Spatial resolution requirements for urban area classification should be determined based on the context of the study (Aplin 2003). For instance, requirements for land use/ land cover change detection will vary from that of resource planning and allocation. The latter will require higher spatial resolution. While it may be possible to utilise existing pixel based classification algorithms to produce land cover maps of urban areas from high resolution images, deriving information on land use is much more challenging (Barnsley and Barr 2000, Eyton 1993). This is because the concept of land use is abstract. It is a combination of economic, social, and cultural factors defined by functions and not physical form (Donnay, Barnsley and Longley 2005).

The integration of remote sensing and ancillary data like socio-economic data and geocoded cadastral information will help to characterise land use and give proper interpretation. Identification of complex urban features is one of the human photo-interpretation techniques that has developed with time. If this process can be formalised into a means of digitally measuring features and patterns in remote sensing, then it may be possible to evolve an automated or semi-automated system for urban land use mapping (Barnsley and Barr 2000).

With the advent of high resolution satellite sensors in the last decade, urban monitoring approaches can now be undertaken at a higher thematic and geometric level (Maktav, Erbek and Jurgens 2005, Taubenbock, Esch and Roth 2006). However, with pixel sizes becoming smaller than the imaged objects, object-oriented classification methodologies came into focus (Benz *et al.* 2004, Blaschke and Strobl 2001, Blaschke *et al.* 2000, Blaschke 2010).

2.8.2 Improvements of satellite Image resolution and frequency of coverage

The initial images acquired from satellite systems were coarse because the satellites were primarily launched for other purposes than image acquisition. However, the coarse nature of the images helped provide insight into the possibilities of improved image resolution from satellite platforms. From 1960, various satellite missions were commissioned into orbit for other missions but they were able to also acquire photographic images. The earliest of the programmes are Television and Infrared Observation Satellite (TIROS-1) (1960), Corona programme of US military (1960), Mercury (1961, 1962), Gemini (1962), Apollo (1969), Skylab (1973) and Apollo-Soyuz test programme (ASTP) (1975). These programmes acquired panchromatic images with the exception being the Apollo reconnaissance mission prior to the moon landing which acquired multispectral images (Lillesand, Kiefer and Chipman 2008).

These developments led to conceptualisation of The Earth Observation mission coordinated by National Aeronautics and Space Administration (NASA) of United States of America (USA). The earth observation programme included the Earth Resources Technology Satellite (ERTS), which later changed to Landsat earth observation satellite. The first Landsat earth observer mission was launched on 23rd January 1972. Since then five other Landsat satellites (2, 3, 4, 5 and 7) have been successfully launched, the exception being Landsat 6, which failed to reach orbit. The first and second Landsat missions acquired multispectral images at resolutions of between 79-82 meter resolutions. Improvements in resolution were made in subsequent missions, which were able to acquire images in 15 and 30 meters. The current mission Landsat 7 was launched on 15th April 1999. Its on-board imaging instrument is the Enhanced Thematic Mapper (ETM). It acquires 30 m data in three visible bands (blue, green and red), two infrared (near and mid), one thermal (60m) and one panchromatic band (15m). It has swath width of 185km at nadir and a sun synchronous orbit at an inclination of 98.2°. It has a 16 day revisit period (Adeniyi and Omojola 1999, Lillesand, Kiefer and Chipman 2008). Landsat 7 ETM suffered a serious malfunction in 2003 (the scan-line corrector (SLC) failed) leading to the loss of 22% of data. Unsuccessful attempts were made to remotely repair the SLC. Landsat 7 continues to acquire data in this mode. Data products are available with the missing data optionally filled in using other Landsat 7 data selected by the user (Wulder *et al.* 2008).

Other satellite missions dedicated to earth observation have been developed. With the advent of these new satellite missions, efforts were made to improve the image resolution and also the frequency of coverage. Prominent among the later satellites are Terra/Aqua (ASTER, ALI sensors), four IRS satellites from Indian Remote Sensing programme and Satellite Probatoire l' Observation de la Terre (SPOT) developed by France. The SPOT mission has successfully launched five satellites into orbit. SPOT missions 1, 2 and 3 have 20 meter image resolution with 26 day repeat cycle. Improvements in frequency of coverage were made with later SPOT missions. SPOT 5 launched in 1999 has a repeat cycle of 2-3 days and had a 5m and 10m ground resolution (Lillesand, Kiefer and Chipman 2008).

Various other satellite missions have since been developed for use by various agencies and government organisations. Most of these satellites are dedicated to specific uses. Some of these are mentioned below.

1, Meteorological satellites, which are designed to specifically monitor and predict weather, these include National Oceanic and Atmospheric Administration (NOAA) satellites and Geostationary Operational Environmental Satellites (GOES). The NOAA satellites number about 15 missions. The sixth to fifteenth missions have on board Advanced Very High Resolution Radiometer (AVHRR) sensor. The Satellites had daily revisit and 4km ground coverage. This wide coverage made them very useful for monitoring various environmental phenomena like snow cover, regional vegetation, regional soil moisture analysis, wild fire monitoring and various geologic applications.

2, Hyperspectral satellites designed to collect data in many narrow and continuous spectral bands. Spectral bands of 26 and 36 are common in this category of satellites and can be as much as 384 bands on the Clark satellite, which was launched by NASA in 1997, though it never reached operational status due to control, and communication problems that occurred after launch. Other satellites in this category are Moderate Resolution Imaging Spectrometer (MODIS), Global Imager (GLI), ORBIMAGE Orbview-4, and Naval EarthMap Observer (NEMO).

3, Disaster Monitoring Constellation (DMC). These are a group of 7 equally spaced satellites designed to monitor disasters as they occur anywhere on the earth. In combination, these satellites have a daily coverage of every location in the world. The satellites have typical resolutions of 32m. There is more information on this group of satellites in Section 2.9.

4, Very High Spatial Resolution satellites. These satellites lay emphasis on achieving very high ground resolution typically below 5m. Most of the images in this category are produced for military and commercial purposes. For this reason, they have frequent revisit periods and as well very high spatial resolution. Some of the satellites in this category are SPIN-2 (1.56m), IKONOS (1m Panchromatic-Pan and 4m multispectral-MS) with 11 day revisit period, DigitalGlobe Quickbird (2-4-2-8m Pan and 60-70cm MS and WorldView1 (50cm) / WorldView 2 (1.8m MS and 0.5m Pan) with 1-7 day revisit period, OrbView-3 (Im Pan and 4m MS) with less than 3 day revisit period. EROS A (1.8m Pan) with a 7 day revisit period.

2.9 Disaster Monitoring Constellation Satellites for land use and land cover analysis

One of the satellite images used in this research is a product of Nigeriasat-1 satellite. It was used as a test case to establish the usefulness of the Disaster Monitoring Constellation (DMC) for urban land use and land cover analysis. The satellite is one of the satellites, which form part of the DMC designed and built by Surrey Satellite Technology Ltd. (SSTL). Working together, these equally spaced satellites provide data for disaster and environmental monitoring.

At the onset, it was recognized that radiometric calibration would be key to providing a long-term reliable data source for a range of applications. Consequently, the DMC imagers were each radiometrically calibrated prior to launch at the Surrey Space Centre. Plans were also made for the regular re-calibration of the instruments in orbit, recognizing that instruments can change their characteristics in the space environment. The method chosen was equivalent to that used for the AVHRR instrument on the NOAA satellites – which is a mixture of absolute calibrations using ground targets measured by ground instruments simultaneously with imaging during an overpass, and by imaging flat-field targets - such as the Antarctic ice sheets - for relative inter-calibration. Absolute calibration with the same ground targets ensures that all the DMC image data are radiometrically "identical" and therefore interchangeable for applications that require precise radiometry and daily revisit (Underwood *et al.* 2005).

The DMC satellites launched on or before 2003 are now referred to as first generation satellites, while those launched after that date are regarded as second generation. The second generation of satellites are designed to eliminate data artefacts like low-level horizontal banding and low-level residual vertical stripping noticeable on images acquired with first generation satellites. They will also replace the first generation of satellites when they complete their missions (SSTL 2011). See Table 2.1 for details.

Table 2.1: Disaster Monitoring Constellation of satellites and their characteristics

Country: Satellite	Sensor Type	Spatial resolution	Temporal resolution	Swatch width	Launch date	Mission end date
First generation of DMC Satellites (launched on or before 2003)						
Algeria: Alsat-1	DMC	32m Multi spectral	Daily	600Km	8/11/02	08/2010
UK: UK-DMC	DMC	32m Multi spectral	Daily	600Km	27/09/03	08/2010
Nigeria:Nigeriasat-1	DMC	32m Multi spectral	Daily	600Km	20/09/03	
Turkey: Bilsat-1	DMC	26m Multi spectral/12m Panchromatic	Daily	600Km/25km	27/09/03	
Second generation of DMC Satellites (launched after 2003)						
China: Beijing-1	DMC	32m Multi spectral/4 m Panchromatic	Daily	600Km /24km	27/10/05	
Spain: Deimos-1	DMC	22m Multispectral	Daily	600km	29/07/2009	
UK: UK DMC 2	DMC	22m Multispectral	Daily	660Km	29/07/2009	
Nigeria: Nigeriasat-2	DMC	5m Multispectral/ 2.5m panchromatic	Daily	20km	17/08/2011	
Nigeria: Nigeriasat-X	DMC	22m Multispectral	Daily	600km	17/08/2011	

Source: Surrey Satellite Technology Ltd. (2011)

The DMC are owned by six countries namely Nigeria, China, Turkey, United Kingdom Algeria and Spain (International New Town Institute 2009). Two of the satellites owned by UK and Algeria completed their missions in 2010 (see Table 2.1 for details) and only seven of the missions are currently operational. Launched between 2002 and 2011, the satellites are in sun synchronous orbit with an inclination of 98%. They operate from an altitude of 686km with an overpass of 10.30 am local time. All the satellites carry a Surrey Linear IMager (SLIM) which is an Extended Swatch Imaging System (ESIS). The SLIM sensor is a nadir-viewing push broom, three-band multispectral scanner, which scans in green, red and near infrared bands. The satellites have a 6 lens linear CCD-array-based imager at a medium resolution of 22 meters or 32 meters (the only exceptions being the Bilsat-1, Beijing-1 and Nigeriasat-2). The Bilsat-1, Beijing-1 and Nigeriasat-2 satellites carry additional Panchromatic Camera and mapping telescope which have spatial resolution of 12m, 4m and 2.5m respectively. Nigeriasat-2 is designed for high resolution data capture. It has sensors with spatial resolution of 5 meter multispectral and 2.5 panchromatic cameras. On board data are stored in solid-state data recorders, and downloaded via an 8 Mbps S-band Link (SSTL 2011)

Specifically, Nigeriasat-1 is a 98kg micro-satellite, jointly designed and built by a team of engineers from SSTL and National Space Research Development Agency (NASRDA). It was launched into 686km sun synchronous orbit on 27th of September 2003 at 7.07 GMT on board a Cosmos launch vehicle in Plestek, Russia. A 3.7m dish Mission Control Ground Station manned by Nigerians is installed in Abuja for the telemetry, telecontrol and command of the spacecraft. Image download is processed in low-level data (bits and bytes) and made available to users in soft copy (Boroffice 2007).

Nigeriasat-1 captures data in the near infrared, red and green bands of the electromagnetic spectrum. An evaluation of the equivalent bands from Landsat ETM$^+$, which has been successfully used for land cover studies, shows that there is saturation in the near infrared and green bands, which means the response of the DMC to signal is poor from DN values of 235 and therefore not sensitive to higher reflectance (Ogunbadewa 2008). The outcome of this comparison suggests that there is more work to be done in the calibration and atmospheric corrections on the sensor on board the Nigeriasat-1 satellite.

Nigeriasat-1 has been used to monitor disaster scenes. Notably, it was the first satellite to acquire images of the havoc caused by hurricane Katrina soon after the incident on 2nd September 2005. Fig 2.1 shows Nigeriasat-1 image of United States coastline post hurricane Katrina.

Fig. 2.1 Nigeriasat 1 image of the coast of Louisiana, USA after hurricane Katrina September 2, 2005. The affected parts are highlighted in Yellow. 1- Represents the coastal areas and 2- represents the perimeter of New Orleans. Source: Google images (2011)

Nigeiasat-1 data has also been used to study rural and urban environments in Nigeria. Initial land cover studies with Nigeriasat-1 data were carried out by researchers at the behest of NASRDA to ascertain the potentials of the imagery from the satellite.

Omojola (2004) evaluated the potentials of the datasets for rural and urban land cover mapping in Ekiti state, southwest Nigeria. The research concluded that mapping of observable urban areas in the state from Nigeriasat-1 was limited to mere outline or extent detection as the internal structure of the towns were virtually unobservable. In the case of the rural landscape, the coarse resolution of the data tended to average together separate components of the landscape thereby making it difficult to map specific classes in a complex mosaic of the rural landscape.

In a separate study (Olaleye, Sangodina and Hamid-Mosaku 2004) also in southwestern Nigeria, the potentials of Nigerisat-1 for mapping transportation networks were tested. The results show that errors of between 0.4 - 2% were present in the route location maps compiled from Nigeriasat-1. This was blamed on the low tonal variation, which leads to low contrast of the image features, noting that image enhancement methods are of limited success when image quality is poor.

The potential of Nigeriasat-1 data to assess water resources was also carried out and the result showed that water bodies could be easily identified, but the study noted that it was difficult to identify settlements, as there was spectral confusion with other features like hills and irrigated farmlands; these ambiguities were cleared during the field trip. In addition, the study showed that broad land cover like water bodies could be mapped from the Nigeriasat-1 data (Ibrahim 2004).

In the identification of potential tourism sites, the limitations of Nigeriasat-1 data included the low spatial resolution and poor visibility due to cloud cover within the study area. In addition, it was noted that ancillary data was required to identify features because spectral signatures for some land cover types, were similar in several bands (Ayeni, Uluocha and Saka 2004).

For the purposes of broad land cover mapping the Nigeriasat-1 imagery was able to compare with Landsat TM. However, some artefacts in the Nigeriasat-1 imagery like alternating striping and smooth surfaces across the imagery meant that linear features like minor roads and minor waterways could not be identified (Oyinloye, Agbo and Aliyu 2004).

2.10 Methods of satellite data analysis to map urban land cover and land use

Image analysis and classification is the process of assigning pixels to user defined land use or land cover classes (or informational classes of interest) (Campbell and Wynne 2011). The classification process uses a classifier to identify and map the patterns associated with each pixel position in an image in terms of characteristics of the objects or materials present at the location on the Earth when the image was captured. Classifier refers to a computer program that implements a specific procedure for image classification (Campbell 2002).

Several methods have been developed and used for image analysis and pattern recognition of remotely sensed images (Campbell and Wynne 2011, Lillesand, Kiefer and Chipman 2008). All the methods are based on two forms of digital image classification namely- (a) classification based on individual pixels which is also known as spectral or point classification (Campbell and Wynne 2011) or per point or per-pixel classification based on spectral information contained in the image (Mather 1999); and (b) classification based on a group of pixels also known as spatial or neighbourhood classifiers which examine areas within the image using both spectral and textural information to classify homogenous areas within the image (Lillesand, Kiefer and Chipman 2008).

Of the various approaches to image classification per pixel approaches are more commonly used since pixels are the native format in which satellite image data are captured and stored (Blaschke *et al.* 2000). Alongside this, they are less expensive and less difficult to program than spatial classifiers (Campbell 2002). The per pixel classification process can be supervised or unsupervised. The supervised classification process involves the guidance of an analyst to identify and assign the different land cover or land use categories into a pre-determined classes. On the other hand, the unsupervised classification proceeds with minimal interaction of the human analyst. In this case, a computer algorithm identifies and clusters areas with similar spectral properties. The analyst will then decide what land cover/land use type these clusters represent. The task of the remote sensing analysis is to identify informational classes of interest and the supervised classification process will allow a trained analyst to achieve this. The process of supervised image classification outlined below is adapted from Campbell (2002).

1) Acquisition of digital images to be classified.
2) Acquisition of ancillary or other supporting data that may help with the identification of features and informational classes on the images.
3) Field reconnaissance to become familiar with different informational classes to be mapped.
4) Preliminary examination of the digital images scenes to determine land marks that may be useful for the identification of informational classes.
5) Identification and delineation of representative areas of each informational class that will be used as training areas for the classification process.
6) Choose a classification algorithm and classify the image.

Some of the commonly used classification algorithms used for supervised classification are Parallel-piped, Maximum Likelihood, Minimum-distance-to-means. (Campbell and Wynne 2011, Eastman 2009, Lillesand, Kiefer and Chipman 2008).

Parallel-piped classification undertakes a parallel classification of remotely-sensed data based on the information contained in a set of signature files. The parallel-piped classification is based on a set of lower and upper threshold reflectance determined for a signature on each band. To be assigned to a particular class, a pixel must exhibit reflectance within this reflectance range for every band considered. The parallel-piped procedure is the fastest of the classification routines. It is also potentially the least accurate (Eastman 2009).

The Maximum Likelihood Classification is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class based on a comparison of the probability that it belongs to each of the signatures being considered. It is also known as a Bayesian classifier since it has the ability to incorporate prior knowledge using Bayes' Theorem (Eastman 2009). Prior knowledge is expressed as a prior probability that each class exists. It can be specified as a single value applicable to all pixels, or as an image expressing different prior probabilities for each pixel.

Minimum Distance to Means classifier undertakes a classification of remotely sensed data based on the information contained in a set of signature files. The Minimum Distance to Means classification is based on the mean reflectance of each band for a signature. Pixels are assigned to the class with the mean closest to the value of that pixel (Eastman 2009). It is slower than the parallel-piped classification procedure, and faster than the Maximum Likelihood Classification. It is commonly applied when the number of pixels used to define signatures is very small or when training sites are not well defined. (Eastman 2009).

After image classification, the quality of the output is usually assessed to determine if the map produced meets the standard required. The process of determining the map quality is known as classification accuracy assessment.

2.11 Classification accuracy assessment

Classification accuracy is the degree to which image classification agrees with ground reference data (Campbell and Wynne 2011). Classification accuracy can be assessed to provide an overall measure of the quality of a map, to form the basis of an evaluation of different algorithms or to help gain an understanding of errors (Congalton *et al.* 1998, Foody 2002). A classification error results when there is a discrepancy between the classified data and the ground reference or ‘truth’ (Foody 2008).

According to Campbell (2011) the standard form of reporting classification accuracy (or error) is the error matrix (also known as the confusion matrix or contingency table). The error matrix compares, on category by category basis, the relationship between known reference data and the corresponding results of an automated classification. Such matrices are square with the number of rows and columns equal to the number of land cover or land use categories being assessed. All the categories that are properly classified are located along the major diagonal. The non diagonal entries in the error matrix represent errors of omission (non diagonal column entries) or commission (non diagonal row entries), see Table 2.2.

Table 2.2. An example of error matrix used for classification accuracy assessment of maps derived from remotely sensed data

Source: Congalton and Green (1999)

Several other measures of determining classification accuracy can be derived from the error matrix (Congalton 2001, Foody 2002, Foody 2008) depending on the intentions of the user. It is recommended that the raw confusion matrix be presented and that it must not be normalised (Foody 2002), so that accuracy measures can be computed as appropriate by users (Congalton and Green 1999). According to Congalton and Green, some of the accuracy statistics, which can be measured from the error matrix, are Overall Accuracy (OA), Producer's Accuracy (PA), User's Accuracy (UA), Kappa Index of Agreement (KIA) and Conditional Kappa (CK).

Overall Accuracy calculates number of correctly classified pixels by the total number of reference pixels. Producer's Accuracy indicates how well training set areas in the image are classified and User's Accuracy is a measure of commission errors, which, indicate the probability that a pixel classified into a given category actually represents that category on the ground (Congalton and Green

1999). Kappa Index of Agreement expressed as *k* (*KHAT*) is a measure of how well the remotely sensed classification from the automated classifier agrees with the reference data and Conditional Kappa is measure of how well individual land categories are classified in the error matrix. Kappa values are measured on a scale of 0-1, such that 0.80 (i.e. 80%) represents strong agreement, 0.40 and 0.80 (i.e. 40–80%) represents moderate agreement and a value below 0.40 (i.e. 40%) represents poor agreement (Congalton 2001, Landis and Koch 1977). The other accuracy statistics mentioned above are measured in percentages.

The higher the classification accuracy of the map the more useful it is for land administrators and land use planners, but the use of pixel based analysis presents problems commonly known as the mixed pixel problem which has been mentioned in Section 2.8 of this literature review (Mather 1999).

2.12 Object Based Image Analysis

Pixel based classification techniques have been extensively used to extract land cover information from satellite data. These traditional land cover classification techniques rely on determination of broad land cover groupings to analyse images (Blaschke and Strobl 2001, Blaschke 2010). Extraction of image objects presents an alternative approach. The strong motivation to develop techniques for the extraction of image objects stems from the fact that most image data exhibit characteristic texture, which is not considered in common classifications (Blaschke *et al.* 2000, Haralick, Shanmugan and Dinstein 1973, Haralick and Shapiro 1985, Haralick and Shapiro 1992). Image texture can be defined across the spectrum from coarse to smooth appearance (Lillesand, Kiefer and Chipman 2004).

Identification of spatially homogenous regions in satellite images was made possible with the advent of image segmentation (Benz *et al.* 2004, Blaschke, Burnett and Pekkarinen 2004, Lang 2008, Liu *et al.* 2001). Image segments are regions which are generated by one or more criteria of homogeneity in one or more dimensions; this means that segments have more spectral information compared to pixels and, more importantly, additional spatial information (Blaschke 2010). Image segmentation clusters pixels into meaningful image regions, which correspond to single objects or spatially homogenous regions (Stow *et al.* 2007). Image segmentation has its origins in industrial image processing and has been used in geospatial applications since the 1980s (Sijmons 1986, Blaschke, Burnett and Pekkarinen 2004).

There are four algorithms used for image segmentation: edge based, point based, region based and combined (Schiewe 2002). Edge based approaches describe the segments by their outlines. Point based approaches search for homogeneous elements within the entire image by applying global threshold operations, which combine points that show similar intensity or value. In region based methods, the image is partitioned into connected regions by grouping neighbouring pixels of similar intensity levels. Adjacent regions are then merged under some criterion involving perhaps homogeneity or sharpness of region boundaries. Combined as the name suggests incorporates any of the three aforementioned algorithms.

Whichever algorithm is used, the bottom line is that image segmentation provides the building blocks for object based analysis. Based on user defined criteria, satellite data can be segmented into homogenous units (Haralick and Shapiro 1992) or objects, which can later be assigned to various classes. Sometimes, however, spectral information contained within images is not enough to segment them and in these situations, cadastre data can be integrated with the image to aid segmentation (Sun, Forsythe and Waters 2007).

OBIA has been successfully used to classify high and medium resolution satellite data across the world. For example, in British Columbia, Canada, high resolution imagery was used to distinguish riparian forest structural classes to aid riparian forest restoration planning in an area of disturbed forest (Gergel *et al.* 2007). Urban land use polygons was delineated from high resolution IKONOS data in Ontario, Canada, with Overall Accuracy of 86% and 90% for two land use maps produced from the study (Lackner and Conway 2008). A review of published literature shows that no known study has been done with OBIA in Nigeria; indeed its application within Nigeria represents part of this study's novelty. However, in nearby Ghana, OBIA was used to determine socio-economic status for health care delivery by delineating residential land use polygons, from high resolution Quick Bird multispectral data. The presence of vegetation within the polygon was used as an indicator of economic status. The study noted that the socio-economic characteristics of districts will allow more reliable estimates of population distributions most in need of public health interventions (Stow *et al.* 2007). OBIA has been adopted as the standard method of mapping land cover at the national scale in the United Kingdom. The UK Land Cover Map (LCM) 1990 and 2000 were drawn using OBIA (Wallis 2002). In addition, image segmentation using the cadastral boundaries is considered the preferred approach. For example, the UK LCM for 2007 was segmented with cadastral data before image objects were extracted (Wallis 2002).

The adoption of the OBIA method will hopefully provide multi-temporal land use maps that can be used to have a detailed look at the study area. If there is rapid uncontrolled development within the city limits, this can lead to compacted growth. If the development is outside the city then it can result in a phenomenon known as urban sprawl. Future urban growth can be predicted by the use of Urban Growth Models to create a scenario of what the urban areas would look like in the future. This modelling should help urban planners (Adu-Poku, Drummond and Li 2011) to combat any unwanted growth or sprawl. Urban planners can also use multi-temporal land use maps in a GIS environment to determine if there is urban sprawl (Bhatta 2010, Bhatta, Saraswati and Bandyopadhyay 2010, Yeh and Li 2001).

According to Bhatta (2010) one of the major effects of rapid urban growth is sprawl, which increases traffic, saps local resources, and destroys open space. Urban sprawl is responsible for changes in the physical environment, and in the form and spatial structure of cities. In many countries including the developed countries like the United States, poorly planned urban development is threatening the environment, health, and quality of life. In communities across the world, sprawl is taking a serious toll. The concept of urban sprawl is discussed in the next section.

2.13 Urban sprawl

2.13.1 What is urban sprawl?

Urban sprawl is a complex phenomenon, which has social and environmental impacts (Barnes *et al.* 2001, Bhatta, Saraswati and Bandyopadhyay 2010, Luther 2005, Sun, Forsythe and Waters 2007). Due to its complexity, there is no specific, measurable, and generally accepted definition of urban sprawl (Franz, Maier and Schröck 2011, Sutton 2003). Although accurate definition is debated, a general consensus is that urban sprawl is characterized by unplanned and uneven pattern of growth, driven by multitude of processes and leading to inefficient resource utilization (Bhatta, Saraswati and Bandyopadhyay 2010). In another study, it was referred to as irresponsible, and often poorly planned development that destroys green space, increases traffic, contributes to air pollution, leads to congestion with crowding and does not contribute significantly to revenue (Sudhira, Karthik and Sanjeev 2011).

The nature of urban sprawl has become topical and studied in developed countries like Canada, United States of America and United Kingdom (Batty, Xie and Sun 1999, Bengston *et al.* 2005, Frank *et al.* 2000, Hanham and Spiker 2005, Sun, Forsythe and Waters 2007), and in developing countries such as India, Malaysia, China and Nigeria (Alabi 2009, Bhatta 2010, Griffiths *et al.* 2010, Kumar, Garg and Khare 2008, Maktav, Erbek and Jurgens 2005, Noor and Hashim 2010, Rahman *et al.* 2011, Ujoh, Kwabe and Ifatimehin 2010, Yeh and Li 2001).

2.13.2 Patterns of sprawl

Sprawl development consists of three basic spatial forms: low density continuous sprawl, ribbon sprawl, and leapfrog development sprawl (Harvey and Clark 1971 cited in Clarke *et al.* 2001). Low density sprawl is the urban consumption of land along the fringes of existing metropolitan areas. This type of sprawl is supported by piecemeal provision of basic urban infrastructures such as water, sewer, power, and roads. Ribbon sprawl is growth that follows major transportation routes outward from urban cores. Lands adjacent to transport corridors are developed, but those without direct access remain in rural uses/covers. Over time, these nearby lands may be converted to urban uses as land values increase and infrastructure is extended perpendicularly from the major roads and lines. Leapfrog development sprawl is a discontinuous pattern of urbanization, with areas of developed lands that are widely separated from each other. Leapfrog development sprawl is caused by various factors. Physical geography such as rugged terrain, wetlands, mineral lands, or water bodies may prevent continuous development or make it prohibitively expensive. Other factors encouraging leapfrog sprawl are not necessarily physical: restrictive land-use policies in one political jurisdiction may lead development to “jump” to one that is favourably disposed toward development or is less able to prevent or control it (Barnes *et al.* 2001).

2.13.3 Causes of sprawl

The causes of urban growth are quite similar with those of sprawl. In most of the instances, they cannot be discriminated since urban growth and sprawl are highly interlinked. However, it is important to realise that urban growth may be observed without the occurrence of sprawl, but sprawl must induce growth in urban area. Some of the causes, for example, population growth, may result in coordinated compact growth or uncoordinated sprawled growth (Bhatta 2009, Bhatta 2010).

From the literature, the main causes of urban sprawl are rapid population increase, transportation and lack of strict planning policies (Adesina 2005, Bhatta 2010, Rahman *et al.* 2011, Ujoh, Kwabe and Ifatimehin 2010). Population increase can result from natural causes or migration to urban areas (Bhatta 2010). This increase can result in people seeking accommodation in affordable locations, which can be found away from city centres where land rents are usually expensive. Improvements in transportation, which allow people to commute to work, will also encourage people to live in any location where rents are affordable. These locations can be at the rural outskirts of the city. Absence of strict planning policies can also be responsible for sprawl development. Even when a city has a master plan, if the details of the master plan are not fully implemented it can lead to sprawl development when corrupt land officials allocate land without due process (Akingbade, Navarra and Georgiadou 2010).

2.13.4 Consequences of urban growth or sprawl development

The consequences of urban growth may have both positive (Bhatta 2010) and negative impacts (Luther 2005). The negative impacts are generally more highlighted because this growth is often uncontrolled or uncoordinated leading to sprawl. However, the positive implications of urban growth outside the urban limits include higher economic production, opportunities for the underemployed and unemployed, and also, better services. Urban growth can extend better basic services (such as transportation, sewer, and water) as well as other specialist services (such as better educational and health care facilities) to more people (Bhatta 2010). However, in many instances, urban growth is uncontrolled and uncoordinated resulting in sprawl (Sudhira, Karthik and Sanjeev 2011). As a result, the positive impacts disappear leaving the negative impacts.

Luther (2005) lists the negative effects of urban sprawl as:

1) Increased community costs for maintaining roads, school bus routes, sewers, and other services needed when businesses and residences are spread out.
2) Loss of natural habitats and biodiversity.
3) On-going increases in property taxes to meet growing need for services, which may pressure rural landowners to sell to developers.
4) Increased need for automobiles; increased noise, traffic, pollution; reduced potential for bicycling and walking.
5) Isolation of the young, poor, and elderly who cannot drive or lack access to cars.
6) Increased cost and difficulty of providing public transportation.
7) Increased time needed for transportation reduces time available to spend with family and friends or contributing to the community.
8) Loss of agricultural and forested lands, and associated jobs, and traditional land practices.
9) Reduction of rural character or community sense of place.
10) Increased ordinances that regulate logging, noise, or odours.

2.13.5 Measurement of urban sprawl

The physical manifestation and patterns of sprawl on landscapes can be detected, mapped, and analysed using remote sensing and geographical information system (GIS) technologies (Barnes *et al.* 2001 cited in Bhatta, 2009). The patterns of sprawl can be described using a variety of metrics, through visual interpretation techniques, or with the aid of software and other application programs (Sudhira, Ramachandra and Jagadish 2004).

Attempts to measure urban sprawl have relied on the percentage of an area covered by impervious surfaces and concrete as a straightforward measure of urban development (Sun, Forsythe and Waters, 2007). Sprawl is quantified by considering the impervious or the built-up area as the key feature of sprawl (Yeh and Li 2001). Based on this idea, the Shannon's Entropy, which reflects the concentration or dispersion of a spatial variable in a specified area, has been used to measure and differentiate types of sprawl. This measure is based on the notion that landscape entropy, or disorganisation, increases with sprawl. Urban land uses are viewed as interrupting and fragmenting previously homogenous rural landscapes, thereby increasing landscape disorganisation.

According to Bhatta *et al.* (2010), a number of metrics have been proposed by several researchers, for the measurement of sprawl, but the entropy method has proved to be the most stringent measurement tool among the available sprawl measurement techniques. Using Shannon's Entropy, spatial patterns of urban sprawl over different time periods can be systematically mapped, monitored and accurately assessed from satellite data along with conventional ground data (Lata *et al.* 2001). When integrated in a GIS, Shannon's Entropy has proved to be a simple, but efficient approach for the measurement of urban sprawl from remote sensing data (Sun, Forsythe and Waters 2007).

With GIS it is possible to use multi-temporal land use/land cover maps derived from satellite data to retrospectively measure urban sprawl. In order to make the results of the land cover maps comparable, relative entropy, which returns values ranging from 0-1, can be used to measure sprawl. It is expected that a good understanding of urban sprawl trends would help to plan properly and combat the effects of sprawl. Future trends can also be predicted using Urban Growth Models.

2.14 Models of Urban Growth

Land use change models support the analysis of the causes and consequences of land use dynamics. Scenario analysis with land use models can support land use planning and policy (Verburg *et al.* 2004). Models allow the simulation of real world systems and allow the user to get a better insight into how decisions are made. They also allow the setting up of scenarios that compare future states, which are used to investigate the likelihood of a desired situation through experimentation (Leao, Bishop and Evans 2004). Spatially explicit models of land use change focus on rate of change between two or more classes, the location of change to one or more classes or the rate and location of change between two or more classes. These models are usually calibrated using a minimum of two time periods and (or) hypothesis of the driving factors of change.

There are a lot of models dedicated to land use change and each has advantages and disadvantages depending on the research objective and users have to utilise models best suited to their needs. A search for appropriate models for estimating spatial variations in land cover in the United States of America led to a comprehensive review of land use change models (Agarwal *et al.* 2002). The report jointly sponsored by United States Department of Agriculture and Forrest Service, published in 2002, examined Markov models, logistic function models, regression models, econometric models, dynamic systems models, spatial simulation models, linear planning models, nonlinear mathematical planning models, mechanistic GIS models, and cellular automata models. At the end of the exercise they isolated 19 models for their spatial, temporal and decision making characteristics (Agarwal *et al.* 2002). The models they isolated include: CLUE Model (Conversion of Land use and Its Effects) (Verburg *et al.* 2006), Land Use Change Analysis System (LUCAS) (Berry *et al.* 1996) and Cellular Automata (Clarke, Hoppen and Gaydos 1998). A common thread among these models is that they all study space, time and activities/sectors with the aim of determining scale and complexity of land use (Agarwal *et al.* 2002). Since then, many more models have been developed, among these are: Land Use Change Modeller (Eastman 2009), Dinamica EGO (Environment for Geoprocessing Objects) (Soares-Filho, Cerqueira and Pennachin 2002) and open source models like LuccME-TerraMe developed in 2011 by Earth System Science Centre of the National Institute for Space research of Brazil.

Urban Growth Models like land use change models are used by researchers to explain dynamics and drivers of land use/cover change and to inform policies that affect such change. Urban Growth Models are necessary tools that assist planning and development of sustainable urban areas (Herold, Menz and Clarke 2001).

Attempts to model urban land use growth have been made since the 1950s and 1960s when theoretical and descriptive explanations were developed to explain Urban Growth Models. During this period, attempts were made to build Large Scale Urban Models (LSUMs) described by Lee (1994) as models that seek to describe in a functional form an entire urban area, in spatial, land use, demographic and economic terms. These were largely mathematical models, which thrived in a period that coincided with the introduction of computers in planning (Leao, Bishop and Evans 2004). The LSUMs were used as spatial interaction models, which worked with inputs from macro-economic theories. The models at this time adopted a top-down approach. This was in line with the thinking at the time that land development was modelled in equilibrium, macroscopic and deterministic ways. These models were put under scrutiny in the 1970s for their failure to properly explain urban structure. Seven shortcomings of the LSUMs were identified (Lobsterman 1994, Lee and Warner 2006). These are:

1) Hyper comprehensiveness - because they were trying to replicate too much.
2) Grossness - the models provided coarse information that was not useful to policy makers.
3) Hungriness – this refers to the models requirement for too much data.
4) Wrongheadedness - referring to the lack of theoretical structure.
5) Complicatedness - referring to the complexity of the models, this generated large internal errors and had to be carefully tuned to produce reasonable outputs, thus undermining scientific validity.
6) Mechanicalness - refers to the complex computer models that could create large errors due to rounding errors and the need to derive solutions through several iterations.
7) Expensiveness - refers to high cost of running the models.

In spite of these shortfalls, these models were still in use by the 1990s largely due to developments in computer systems and data availability aided by advancements in geographical information systems (Batty 1994). However, during the 1980s developments of new paradigms based on phenomena like complexity, self-organization, chaos and fractals and rapid advancements in computer technology (Batty and Densham 1996) led to development of bottom up approaches. Changes at micro level can result in dramatic changes at macro level (Leao, Bishop and Evans 2004). A key theme of these developments was that these models were developed on the assumption that nothing that happens in space is predetermined. Only rules are pre-determined in advance and open to objective understanding (Couclelis 1997). Examples of these techniques are fractals pioneered by Batty et al (1989) and cellular automata proposed for geographical modelling (Tobler 1979). Things previously difficult for science to explain, and labelled as chaotic and complex, reveal fractal nature when analysed with these new methods. A fractal is an object whose irregularity as a non-smooth form is repeated and propagated across many scales. Examples of fractals in the natural world include mountains, clouds, coastlines and trees. Systems such as cities also fall under this category (Batty, Longley and

Fotheringham 1989). Cellular Automata (CA) on the other hand are discrete dynamic systems whose behaviour is completely specified in terms of local relations. They have four elements, namely: cells, states, neighbourhood cells and transition rules. Cells refer to objects in dimensional space that are adjacent to one another. Each cell can assume one state at any one time from set of states that define the attributes of the system. The state of any cells depends on the state of other cells in the system (Leao, Bishop and Evans 2004). The state of any cell depends on the state of cells that are adjacent or in the neighbourhood of the cell (Fig. 2.2) and, last but not the least; there are transition rules that drive changes in each of the cells in the system. These transition rules are a function of what is happening in the neighbourhood of each cell (Koomen and Stillwell 2007).

Fig. 2.2 Grids depicting the cells in Cellular Automata. The state of a cell is dependent on adjacent cells and transition rules. Source: Google Images (2011)

This study uses CA within the Idrisi software environment for modelling land use prediction, because the outputs of OBIA will provide a more compatible input and can be compared to the outputs of Urban Growth Models (UGMs).

2.15 Case study of Abuja, Nigeria

Recent urbanisation trends in Nigeria provide a case that can potentially be useful for the study of urbanisation in the developing countries of the world. This is due to several factors. Firstly, Abuja, the capital of Nigeria was planned from inception and represents a planned capital city in a developing economy. Secondly, Abuja's development over the last two decades coincides with the era of substantial growth in the amount, quality and diversity of earth observation data and the creation of well-documented archives of these images. Thirdly, there is the presence of cadastral data (and other data e.g. census) which can provide an independent record of urban development to support the analysis. An examination of the origins of modern urban development in Nigeria will be necessary to help understand the context in which Abuja was conceived and developed.

2.15 .1 Urbanisation in Nigeria

Urban development in Nigeria can be divided into two broad groups; these are the pre-colonial and post-colonial developments. The pre-colonial urban developments in Nigeria coincided with areas, which had centralised administration and powerful political leaderships. The two most important areas of these were the Hausa-Fulani areas of northern Nigeria and Yoruba areas of the southwest (Onokerhoraye and Omuta 1995). There were smaller areas like the Nupe and Jukun areas in the north central parts of the country.

According to Metz (1991), urban development in Nigeria is a function primarily of trade and politics. In northern Nigeria, the great urban centres of Kano, Katsina, Zaria, Sokoto, and other cities served as centres of the Saharan and trans-Saharan trade (8^{th} -16^{th} century), and as central citadels and political capitals for the expanding states of the northern savanna of West Africa. They attracted large numbers of traders and migrants from their own hinterlands and generally also included "stranger quarters" for migrants of other regions and nations. In the south, the rise of the Yoruba expansionist empire of Oyo, city-states of Ibadan, Benin Kingdom and others was stimulated by trade to the coast, and by competition among these growing urban centres for the control of their hinterlands and of the trade from the interior to the Atlantic coast. The activities of European traders from 15^{th} century onwards also attracted people to such coastal cities as Lagos, Badagry, Brass, Bonny, Calabar and Port Harcourt. Overlying the original features of the earlier cities were those generated by colonial and postcolonial rule, which created new urban centres while also drastically altering the older ones. All these cities and peri-urban areas generally tended to have high population densities.

Rapid urban growth occurred in the period of colonial rule which lasted from 1900 to 1960. The British colonial administration needed urban centres to actualize its political and economic objectives. This required the provision of a socio-economic framework for some of the pre-colonial urban centres to grow rapidly. While in the areas where pre-colonial urban centres did not exist, efforts were made to stimulate the emergence of towns. Some of the new towns were the headquarters of the administrative divisions that made up Nigeria during the colonial era. With this deliberate policy, the number of urban centres rose from 29 in 1921 to 180 in 1963 (Onokerhoraye and Omuta 1995). The urban centres in Nigeria during the colonial era where divided into first, second and third classes based on the number of facilities they possessed. The classification of towns is shown in Table 2.3. Only Lagos (the colonial capital) was in the first class category. It had its own local authority that consisted of a town council headed by a Mayor. Lagos raised its own revenue through taxes, prepared an annual budget and made its own laws. Second class townships had station magistrates, assisted by an advisory board, had a township fund, levied rates and prepared annual estimates that were ratified from the central government. In third class townships, the local authority rested with the District

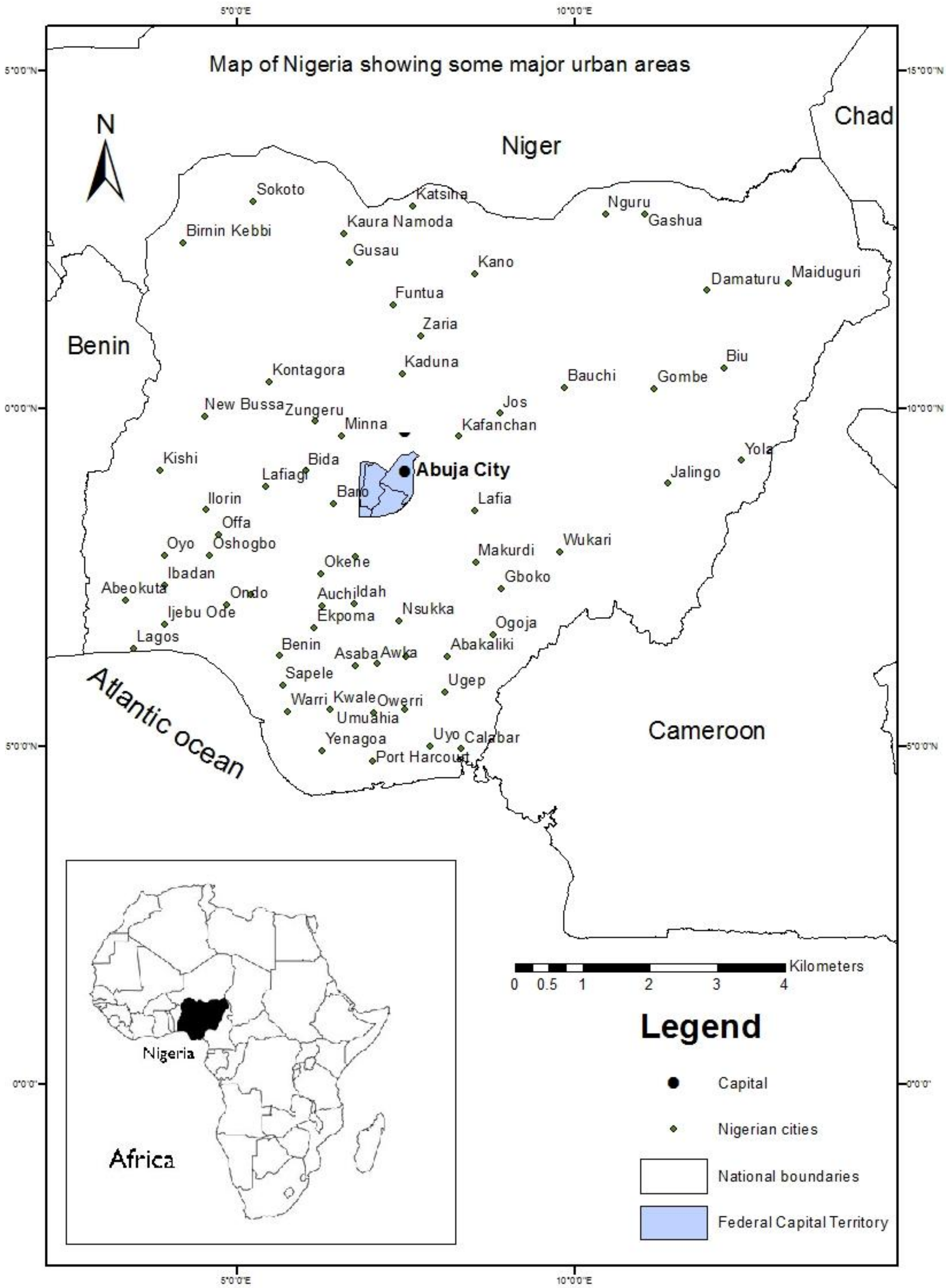
Officer without an advisory board or township fund (Oyesiku 2010). Lagos remained the pre-eminent city in terms of population and physical development until 1991 when the capital was relocated to Abuja.

Aside from Lagos, the most recent rapid rate of urbanization is found in Port Harcourt in the Niger Delta region (which was at the heart of the oil boom), as well as throughout the Igbo and other areas of the southeast. These regions historically had few urban centres, but numerous large cities, including Onitsha, Owerri, Enugu, Aba, and Calabar, grew very rapidly as commercial and administrative centres. The Yoruba southwest with pre-colonial cities like Ibadan, Oyo, Ogbomosho, Offa, Sagamu, Ilorin and Abeokuta was by 1990, still the most highly urbanized part of the country, while the middle belt was the least urbanised (Metz 1991). Some major urban centres in Nigeria are shown in Table 2.3 and also graphically in Fig. 2.3.

The deliberate policy of creating urban centres to speed up development was continued after political independence as successive governments created more administrative divisions. The political divisions (or states) rose from three in 1960, to four in 1963, 12 in 1967, 19 in 1976, 21 in 1991 and 36 in 1996. With each state creation exercise, the cities designated as state capitals received massive infrastructural developments to befit their new status as government headquarters.

Table 2.3 Cities classification in Nigeria during the colonial era 1900-1960

Source: Oyesiku (2010)



Source: Adapted from shapefile courtesy of Diva GIS: http://www.diva-gis.org/ (2012)

Fig. 2.3 Map of Nigeria showing some major urban areas

2.15 .2 Lagos and the need for a new capital city

Lagos became the capital city of Nigeria in 1914 when the British colonial administration merged two separate entities formerly called northern and southern protectorates into a single political entity known as Nigeria. As a coastal capital city, Lagos hosted the main seaport, largest airport and major rail terminus. Multinational and national businesses located their headquarters in Lagos to ensure proximity to the seat of government. As a result, Lagos became a commercial hub for the import-export trade, large construction companies, trading corporations, and financial institutions in Nigeria. Lagos continued to be the political capital of Nigeria after political independence in 1960 until 1991, when the seat of government was officially moved to Abuja. By 1976, Lagos also served in a dual capacity as the capital of Lagos state, which is one of the 36 states that make up modern day Nigeria.

Lagos was and is still the fastest growing city in Nigeria in terms of population. By 1975, it had an estimated population of 3.3 million and estimated at 13.4million in 2000 and 23.2million by 2015 (United Nations 1999). The growth rate of Lagos between 1975 and 2000 at 5.6% was the highest among the 10 most populous urban agglomerations. The growth rate of 3.7% for 2000 – 2015, also remain the highest compared to other urban agglomerations in the world (Adepoju, Millington and Tansey 2006). Lagos was (still is) also plagued with socioeconomic problems, such as overpopulation, traffic congestion, inadequate housing, development of informal settlements, high cost of living. The city's infrastructural facilities were being stretched to breaking point (Oyesiku 2010). The dual role of Lagos as federal and state capital as well as major seaport, airport and the main industrial and commercial centre was threatening to grind the economic and social life of the metropolis to a halt (Oyesiku 1996). Consequently, on 9th August 1975 the federal government of Nigeria under the Murtala Mohammed administration set up a panel, under Justice Akinola Aguda, to decide on the relocation of the federal capital. The panel's terms of reference were (FCDA 1979, Jatau 2007).

(1) To examine the dual role of Lagos as a state and federal capital and advice on the desirability or otherwise of the city retaining that role;

(2) If the committee found that Lagos was unsuitable for the dual role, it should recommend which of the two governments should be moved;

(3) If the committee found that the federal government should move out of Lagos, it should recommend suitable alternative locations, having regard to the need for easy accessibility to and from every part of the country.

The committee's report was submitted on 20th December 1975 and contained the following recommendations:

(1) That Lagos was incapable of performing a dual role as federal and state capital, due to the problem of inadequate space for development commensurate with its status

(2) That the city was identified with predominantly one ethnic group and by implication, did not provide equal access to Nigeria's great diversity of cultural groups

(3) That a new capital was desirable that would be secure, ethnically neutral, centrally accessible, comfortable, and healthy

(4) That a new capital was needed as a symbol of Nigeria's aspirations for unity and greatness.

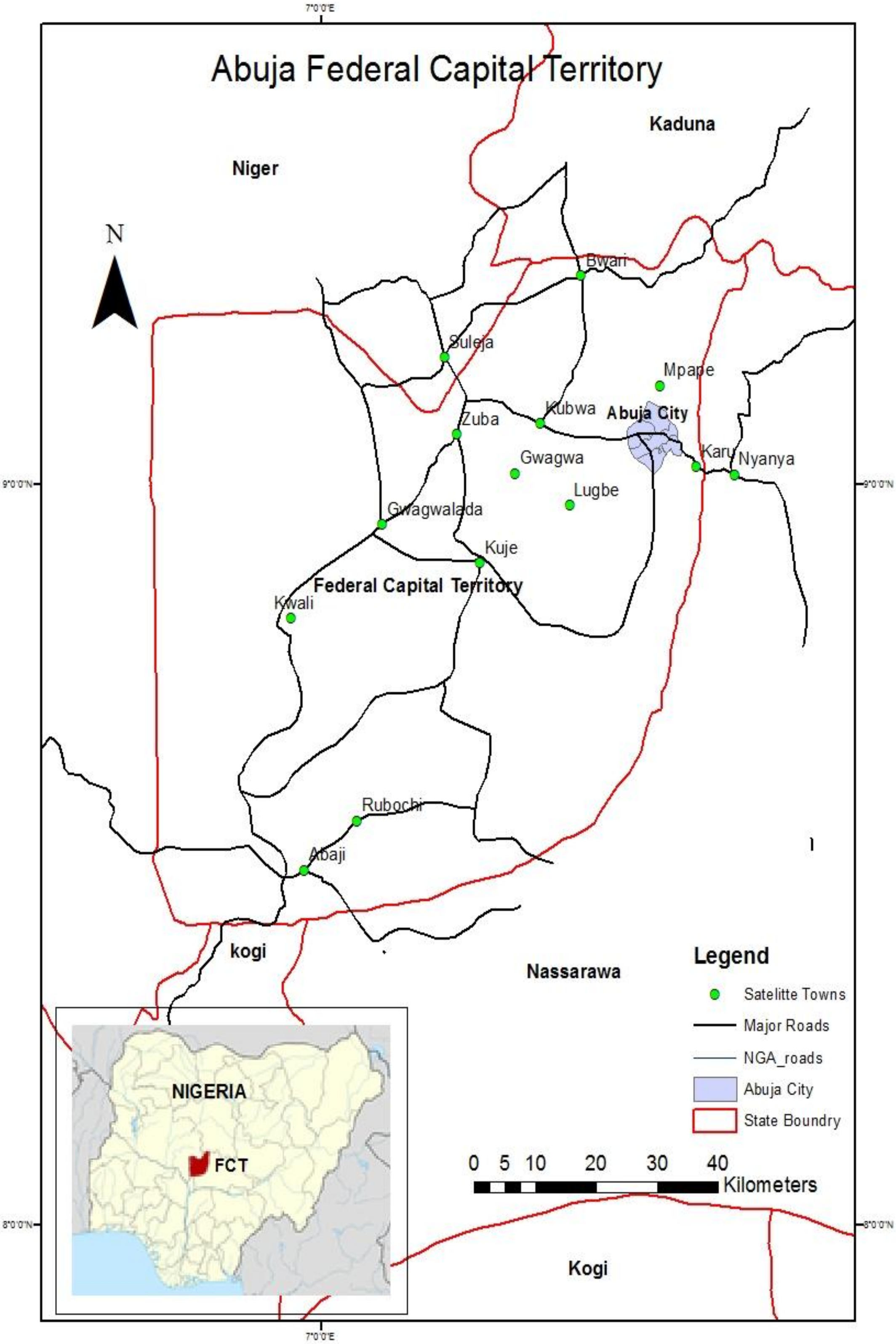
Based on these, the committee visited several sites around the country. The criteria used for the selection of the capital are shown in Table 2.4

Table 2.4 Criteria for the selecting site of the new Federal Capital Territory (FCT)

Source: FCDA (1979)

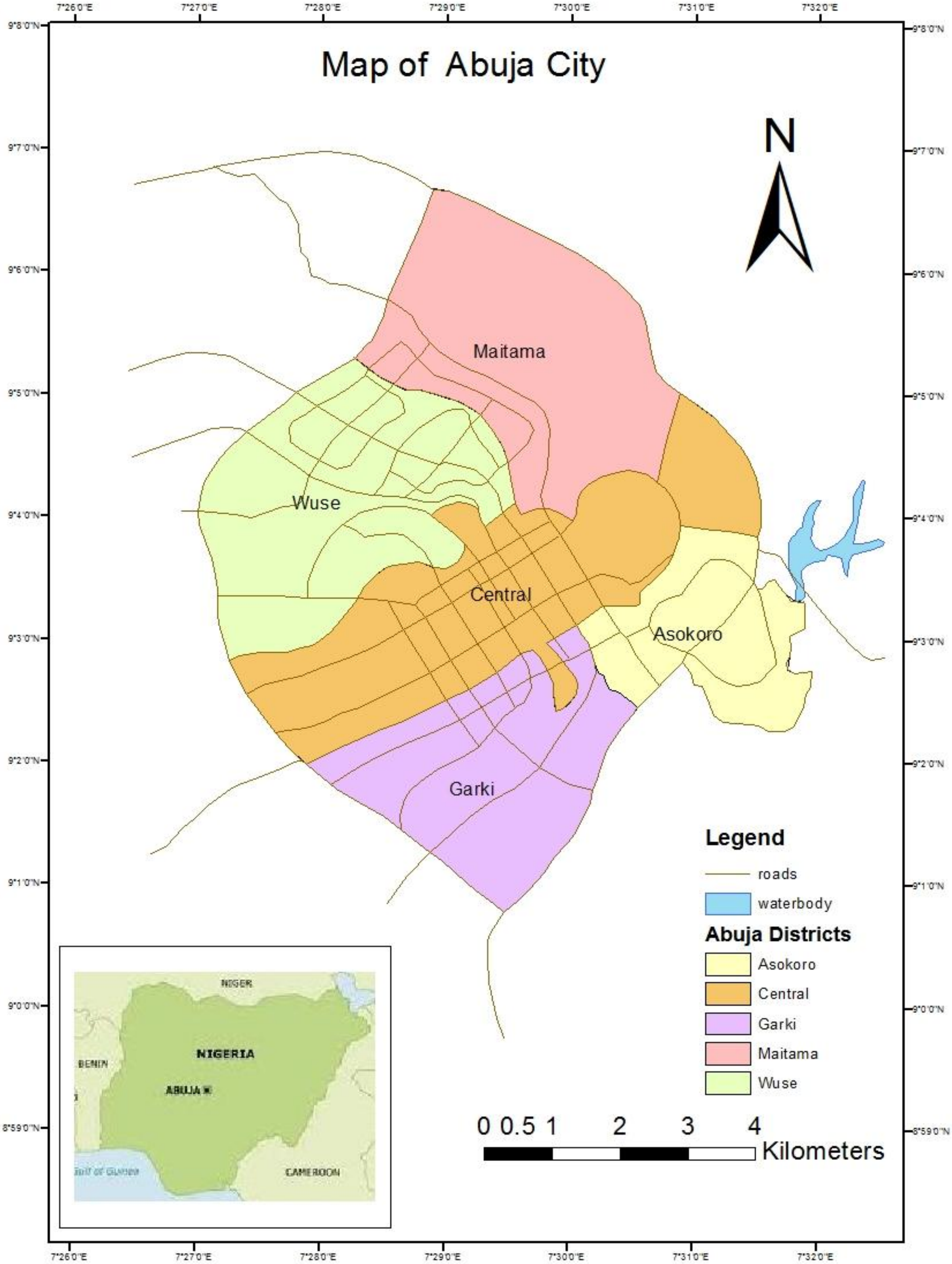
2.15 .3 Abuja Federal Capital Territory and Abuja City

Based on these criteria shown in Table 2.4, the Justice Aguda panel selected a location in the central part of the country, which was subsequently named Abuja Federal Capital Territory (FCT). The FCT covers an area of 8000 square kilometres. See map in Fig. 2.4. In February 1976, decree No 6 was promulgated to give legal backing to the decision. Within the FCT is Abuja City, an area of 250 square kilometres that was carved out of the northeastern quadrant of the FCT. The city, designed by International Planning Associates of USA is approximately between Latitude 9° 0' and 9° 70' North and longitude 6° 45' and 7° 32' East. Fig. 2.5 is a map of Abuja city showing the various districts. The FCT is bounded by Niger, Nasarawa and Kogi States from which it was excised and Kaduna State. Niger State contributed the largest portion to the FCT, accounting for 6,738 sq. km (84.2%), Nasarawa 903.8 sq. km (11.3%) and Kogi with 358.2 sq. km (4.5%) (Jatau 2007). The FCT regional development plan was prepared by Doxiadis Associates Nig. Ltd. in 1983 with the sole aim of guiding the overall physical and socio-economic development of the region. The FCT is divided into six Area Councils namely Abuja Municipal, Bwari, Kuje, Gwagwalada, Kwali and Abaji. Satellite towns such as Karu, Nyanya, Kubwa and Lugbe (see Fig 2.4) also relieve the city of population pressure.



Source: Adapted from shapefile courtesy of Diva GIS: http://www.diva-gis.org/ (2012)

Fig. 2.4 Abuja Federal Capital Territory showing Abuja City and satellite towns



Source: Adapted from a map by FCDA (2006)

Fig. 2.5 Map of Abuja City showing the districts

By virtue of the central location of the FCT within the national context, it is placed in the Middle belt of Nigeria. This belt is a zone of transition between the northern ecological zone with its characteristic grassland vegetation (guinea savannah) and southern ecological zone dominated by rain forest vegetation. The FCT therefore shares some of the attributes of the two zones.

Abuja experiences three weather conditions annually. This includes a warm, humid rainy season and a hot dry season. In between, there is a short period of harmattan accompanied by the North East Trade Winds, featuring dust haze, cold conditions and dryness. The rainy season lasts from April to October, when daytime temperatures are between 28-30° C and night time lows of around 22-23° C. In the dry season, daytime temperatures can reach 40° C and night time temperatures can drop to 12° C, resulting in chilly evenings. Even the coldest nights can be followed by daytime temperatures well above 30° C. The high altitudes and rolling terrain of the FCT act as moderating effects on the weather. Annual total rainfall is between 1100 mm to 1600 mm (FCDA 1979).

Abuja city has grown with influx of government and private sector establishments. As expected in a country with very high rural urban migration, Abuja has grown from a population of 107,067 (National Population Commission 1991) in 1991 to 403,000 people in 1999 (United Nations 1999) and 590,400 in 2006 (National Population Commission 2006) to a recent estimate of 1,078,700 in 2011 (UNFPA 2011a).

2.15.4 Urban form and cityscape in Abuja

The design of the new capital city was carried out after a review of planned capital cities and thorough consideration of the positive and negative aspects that characterised those designs. The cities reviewed include country capitals like Canberra (Australia), Washington D C (USA), Brasilia in Brazil and regional capitals like Chandigarh (India) (FCDA 1979). The 'grand philosophy' was to design the city as a public space that will serve the entire Nigeria (Ikoku 2004), by replicating the forms and structures of existing Nigerian urban centres where possible. This section gives a brief overview of urban design of Abuja based on information from the Abuja Masterplan (FCDA 1979).

Just as the selection of the location of the federal capital of Nigeria was based on suitability criteria, the actual design of the cityscape and architecture was based on rational analysis of alternative locations within the selected area in the middle of the country. A review of previous experiences of new city planning gave the planners an insight into varying degrees of success and failures encountered in the solutions to basic developmental problems. It also revealed to them that difficulties, which were later encountered because of formal design, became only apparent after actual occupation of the city. These experiences were grouped into three and provided the basic goals for the design of the urban form both from a site related point of view and functional characteristics independent of the site (FCDA 1979). The issues related to urban form and design are

1) Image-ability - which refers to an observer's perception of the city's purpose, organisation and symbolism
2) Efficiency - the ease of which with which government decisions are carried out, and
3) Flexibility - the ease with which growth and change can be accommodated.

The functional characteristics, which are independent of the natural site (but related to the city's design), are related to the cultural relevance of the new city. The incorporation of Nigerian urban traditions in the city's design ensure that existing patterns of organisation within Nigerian cities and towns were considered. This concept of cultural relevance was examined and used to test the urban form developed from the three stated goals and to suggest the major sub-organisational elements incorporated in the master plan.

A strong and positive image of the government should be apparent in capital cities. This can be achieved in the relationships among the city's purpose, form and symbolism, through architectural character of the cityscape and relationship of urban design within the context of the natural environment. From the review of past capital city designs like Brasilia, Washington and Chandigarh by the city planners, efficiency and flexibility were compromised in order to achieve a strong order of symbolic meaning to government functions. In order to ensure that the design of the new city had a functional design, which did not compromise on efficiency, three factors were given proper consideration. These are:

1) City's location within the geography of its natural environment
2) Relationships among public functions
3) Identifiable units within the city's internal organisation

Among the capital cities reviewed by the designers of Abuja (FCDA 1979), the location in relation to the spatial characteristics of the selected site was the major factor affecting the overall image of the governmental functions. The location of the seat of government was selected to achieve unique visual relationship with key natural features of the site. Examples include the Paranoa Lake in Brasilia, the Capitol Hill in Washington D.C. and the distant hills in Chandigarh. In Abuja, the three arms of government: the Executive, Legislative and Judicial are located in the foreground of Aso Hills in an area known as the Three Arms Zone. See Fig 2.6.

Fig. 2.6 Abuja city in foreground of Aso Hill. The Thee Arms Zone near Aso Hill is home to the three arms of government. Source FCDA (1979)

While these natural factors help to define the city's identity, they also define the urban landscape of the city. Where the landforms, geology and topography cannot be built upon, they are incorporated into the cityscape. The shape of Brasilia (Fig. 2.7) which has been variously defined as a butterfly or airplane (Staubli 1966) is defined by the nearby Lake and topography of the rolling plains around the city. Likewise, the hills of Canberra in Australia affect its form and organisation.

Fig. 2.7 Image of Brasilia from above. Source Google Images (2011)

In Abuja, the determinants of urban form and cityscape are based on the surrounding topography of the local area (FCDA 1979). The geology and the rocky outcrops thrusting out suddenly up and out of the plains, might be thought of as an enormous inselberg (which provides beautiful landmarks to a visitor), but because of its steep rocky character it cannot be built upon. The influence of the surrounding landscape is evident in Abuja's characteristic crescent shape.

In Abuja, efficiency of design was considered in two contexts. Form of city design that will achieve the fastest travel times and the use of the site's natural geography to provide services efficiently. Overall form of the city (or cityscape) and organisation of major functions in relationship to transportation networks affects the efficiency of city operations. Single centre/radial concentric forms impose inefficiencies on travel. Linear forms are easier to serve with high-quality public transport systems. Multi-centred forms may minimize local travel but they require substantial metropolitan scale travel. In Abuja a linear form with nodes was selected to minimise travel times and to ensure that in future the incremental growth is accommodated.

The landform and topography was used as the basis for design of the services. The network of water, sewage and drainage infrastructure was designed to take advantage of the gravity of the natural environment and to respect the natural drainage patterns of the landscape.

The magnitude of development involved with construction of a capital city requires phased development, which requires that there is an orderly urban growth over an extended period of time. Master plans cannot be considered as final recipes for cities but as an overall framework for growth, which can deal with predictable and unpredictable change. A practical urban master plan must therefore leave room for change by avoiding construction decisions that do not allow for future modification when needed. This should reflect in the flexibility of the design to accommodate growth increments. Urban forms can accommodate growth in five ways: 1) Linear extension, 2) Accretion, 3) Replication of modules, 4) Infill or densification and 5) Rebuilding or gentrification. Extension of development in the form of self-sufficient modules is the typical method of growth employed in recent city developments. Apart from providing a systemic means of expansion, the module by module expansion approach reduces the impact of noise, dust and disruption that can accompany long term construction programmes envisaged in a new capital city. This approach was utilised for the Abuja master plan.

The incorporation of Nigerian urban design traditions into Abuja's design involved the study of 42 Nigerian cities in order to in determine if there is a traditional form, resulting from the interactions of social and physical characteristics of the cities that may lend a uniquely Nigerian character to the capital city. The characteristics were examined to identify the various conditions evident in Nigerian cities in relation to key urban planning and design issues like overall form, role of central public places and organisation of residential areas. The cities included in this survey were drawn from the 19 (at that time) state capitals and traditional Nigerian cities. They are cities based in the open savannah grasslands of the Northern parts of Nigeria, with long external trading links during the trans Saharan trade like Bauchi, Bida, Illorin, Kano, Katsina, Maiduguri, Sokoto, Yola and Zaria. Cities based in the forest regions with an ancient history of strong monarchies such as Abeokuta, Akure, Benin City, Calabar, Ikeja, Ile-Ife, Onitsha, Oyo, Ogbomosho, Ibadan and Ilesha and finally cities built during the colonial era such as Enugu, Jos, Kaduna, Makurdi, Minna, Owerri and Port Harcourt.

Syntheses of three major findings were incorporated into the final plan. These are

1) A contiguous urban form with a single centre and residential and commercial sub-sectors.

2) Local residential communities averaging 3,500 - 5,000 people, with more emphasis on (200ppl/hectare) medium density residential neighbourhoods, because in none of the 27 cities is a single family household the dominant pattern. Multi-family households comprising of extended family was the norm in the cities studied. This approach will also provide affordable plots of land and optimum distances to the neighbourhood centre within each sub sector.

3) A central public place with large scale public allocation for public gatherings.

Synopsis

This chapter has reviewed the literature along the three major themes of this research, namely LULCC in developing countries, methods of satellite data classification and Urban Growth Models. It also reviews the literature of urban developments in Nigeria.

Various definitions of urban areas were mentioned followed by a synopsis that defined urban areas as places with a minimum population of 20,000 and a high proportion of non-agricultural specialists. The difference between land use and land cover was established before reviewing the urban land use and land cover change in developing countries. The causes or drivers of urban land use change were highlighted and the key driver in developing countries was identified as population growth. Planning of new cities as a strategy to control urbanisation was reviewed followed by the use of remote sensing for urban studies.

Methods used for the analysis of remotely sensed data of urban areas were reviewed. It was noted that heterogeneity of urban land cover presents mapping challenges, which often result in the 'mixed pixel problem'. Various approaches to solve this problem were highlighted; these include suggestions for standardized mapping approach for urban surfaces and the use of high resolution images that have become available due to improvements in satellite image resolution technology. Different sensors that can potentially be used to map urban surfaces were mentioned including Nigeriasat-1 SLIM sensor data. This sensor is part of the DMC satellites, but it is used in this research to establish if it can contribute to urban studies. Pixel and object based methods of satellite image classification were also reviewed alongside classification accuracy assessment of maps produced from satellite remotely sensed data.

Urban sprawl phenomenon and its effects were examined, after which Urban Growth Models were reviewed. Finally, the origins of urban development in Nigeria were presented to help understand the context in Abuja was conceived and developed.

Chapter 3: Methodology

Urban studies have been conducted in many different ways. Studies of land cover and land use dynamics relate to the interaction of planning policy, economic drivers and the personal actions of citizens. As such, it is possible to examine urban areas through both quantitative and qualitative methods. In this research a Positivist, quantitative and technological approach was adopted using empirical data. A technological approach was used to develop a method to characterise land use change from the analysis of GIS and remote sensing data. This approach was preferred because the analysis of satellite data can be scientifically replicated given the same tools of analysis. A Positivist, quantitative method was then adopted because there is bound to be a logical explanation to observed phenomena devoid of human feelings, which would have been introduced under Behaviourism and Humanism. This approach is utilised to provide a better understanding of how structural controls, imposed through urban planning, can help to control land cover/land use developments.

An empirical case study was used as a platform for this work in order to ground the research in the real world. The combination of a technological method to compute inputs to a land use change model and a quantitative analysis of the results supported the research in its attempts to expose the underlying structural controls on land use in a new, post-colonial capital city in a developing economy.

3.1 Specific approach to achieve aim and objectives of the study

The broad objective of this research is to use an empirical case study approach to investigate the nature of land use and land cover change in a planned capital city of a developing country. The approach adopted to achieve the aim and objectives is dependent on data availability and the innovative use of existing software tools and analysis concepts. The three major themes of this research are; a) urban land use/land cover change in developing countries, b) methods of satellite data classification and c) urban growth modelling.

The first objective of this research, which is to design an object based classification method to extract urban land cover and land use information from medium resolution satellite data, was chosen due to affordability and availability. This task was achieved by adapting the classification scheme from Land use map of Abuja Federal Capital City (FCDA 1979) shown in Fig 3.1 below.

This map has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

Source: FCDA (1979)

Fig 3.1 Land use plan of Abuja (Phase 1)

Land use classes identified on the map were grouped into classes that could be discerned on the Landsat ETM, Nigeriasat-1 and SPOT 5 datasets used for this research. Anderson *et al*. (1976) "Land use and Land cover Classification System for Use with Remote Sensor Data" , was used as a basis to develop a hybrid classification system comprising level 1 for land cover classes and level 2 for land use classes. According to Campbell (2007), this classification system is a good example of a general purpose LULCC classification system intended to provide a comprehensive classification of LULCC. Land use classes, which could not be easily identified on the satellite images, were grouped together for classification purposes. For instance, the commercial and residential land uses were grouped together because it was difficult to differentiate between the two on satellite images.

The second objective is to validate a method to extract LULC information from multiple sources of remotely sensed data. This involved the use of pixel and Object Based Image Analysis (OBIA) to classify the datasets into level 1 land cover maps, before using the error matrix (Congalton and Green 1999, Congalton 2001, Foody 2002, Lunetta and John 2004) to test classification accuracies and compare the results to determine which classification method achieved higher classification accuracy. The method with a higher classification accuracy was then employed to achieve the third objective of the research, which is to classify and produce a level 2 land use map of Abuja from the satellite datasets.

The outputs of the classification was used for urban change detection and also served as inputs towards achieving the fourth objective, which is to validate an Urban Growth Model. Successful validation meant that the classified land use maps were used as inputs to achieve the fifth objective of this the research, which is to utilise the UGM to represent land use patterns and trends and through this process, identify and prioritise the driving forces of urban change. Finally, identification of the driving forces behind the land use processes formed the basis of discussions on how the planning regulations can control land use processes and dynamics in newly planned capital cities.

3.2 GIS and remote sensing

This section focuses on the sources of satellite datasets and ancillary data as well the methods used to process that satellite datasets to extract land use and land cover information that were later used for change detection. The accuracy assessment methods used to determine the reliability of the extracted land cover information is also covered in this section. Finally, the techniques for the modelling of land use change with the outputs of the classification are presented.

3.2.1 Data

This study utilised different types of data like remotely sensed satellite images, maps, land use cadastre, population/census data, and field surveys. A description of each dataset utilised for this research is given below.

3.2.1.1 Remotely sensed data and land use cadastre

Three cloud free remote sensing images were acquired during the dry season to reduce the seasonal effects on vegetal cover and solar illumination. The scenes were captured by Landsat 7 ETM+, Nigeriasat-1 SLIM and SPOT 5 HRG as shown in Table 3.1. An urban land use plan of Abuja produced in 2006 and parcel boundaries shapefiles supplied by Abuja Geographic Information Systems (AGIS 2006) were used to complement the images. Characteristics of the sensors used are presented in Tables 3.1 and 3.2. The datasets were all acquired for this research courtesy of corporate and academic research institutions that have made them available for research purposes.

Table 3.1: Characteristics of datasets used in this study

	Platform (sensor)	**Acquisition Date**	**Image bands used**	**Image resolution**	**Local time of overpass**	**Scene Identification**	**Acquisition source**
(a)*	Landsat 7 ETM+	27 Dec 2001	6 bands	28.5m	09:39:04am	LE1890542001361EDC01	Global land cover facility
(b)	Nigeriasat-1 SLIM	4 Dec 2003	3 bands	32m	09:24:49am	Abuja and Environs	NASRDA
(c)	SPOT 5 HRG	24 Nov, 2006	4 bands	10m	10:06:54am	KJ 74-332	OASIS SPOT project
(d)	Land use cadastre of Abuja	2006	n/a	n/a	n/a	n/a	Abuja Geographic Information Systems(AGIS)

*see Figs.3.2 a, b, c, and d respectively for visual display of the datasets

Landsat 7 ETM, 2001 (NASA 2004): Data was downloaded from the website of Global Land Cover Facility, University of Maryland. This data was made freely available for research purposes. The satelitte 8-band image was acquired on 27 December 2001 at 9:39:04 am local time. The image has a 28.5 x 28.5 meter (approximated to 30m x 30m) resolution for bands 1 to 7, except band 6 with 60 meter resolution and band 8 with 15 meter resolution. The image has been pre-processed and geometrically corrected. Summary details are shown in Table 3.1 with further details in Table 3.2.

SPOT 5 HRG 2006: Data was a acquired from the OASIS (Optimising Access to SPOT Infrastructure for Science) project which encouraged the use of SPOT data for research in European research institutions (SPOT 2005). The satelitte image was acquired on 24 November 2006 at 10:06:54am local time. The data has four spectral bands. Details of the bands are shown in Tables 3.1 and 3.2. It has been geometrically corrected and processed to Level 1B (SPOT 2011). This level of processing ensures that the data is orthorectified, terrrain corrected and resampled across track to remove the off nadir imaging effects.

Nigeriasat-1SLIM 2003: This data was made available by the Nigeria Space Research Development Agency (NASRDA). This data is provided free for this research to encourage research in GIS and remote sensing in Nigeria and also to help in the evaluation of the data for socio-economic activities (Boroffice 2007). The data was acquired on 4 December 2003 at 9:24:49 am local time. Data was captured in three spectral bands. Details of the bands and other sensor information are shown in Tables 3.1 and 3.2.

Land use cadastre: Land use cadastre prepared by Abuja Geographic Information Systems (AGIS) and was acquired courtesy of AGIS. The land use cadastre was prepared in 2006.

Table 3.2 Characteristics of the three sensors used to acquire the datasets used in this research

Characteristic	**Landsat7ETM+**	**Nigeriasat-1 SLIM**	**SPOT-5 HRG**
Spatial resolution	30m	32m	10m
Number of bands	7	3	4
Temporal resolution	16 days	Daily in combination with satellites of the DMC	2-3days
Swath width	185km	640km	80km
Quantisation	8bit	8bit	8bit
Band-(Blue)	1 (0.45 - 0.52 µm)		
Band-(Green)	2 (0.52-0.60 µm)	1(0.52-0.62 µm)	1(0.52-0.59 µm)
Band-(Red)	3 (0.63-0.69 µm)	2(0.63-0.69 µm)	2(0.61-0.68 µm)
Band(Near Infra Red)	4 (0.76-0.90 µm)	3(0.76-0.90 µm)	3(0.78-0.89 µm)
Band(Mid Infra Red)	5 (1.55 - 1.75 µm)		4 (1.58 - 1.75 µm)
Band(Thermal Infra Red)	6 (10.4 - 12.5 µm)		
Band (Mid Infra Red)	7 (2.08 - 2.35 µm)		
Panchromatic band	8 (0.50-0.90)15 m resolution	None	5 (0.48 - 0.71 µm)2.5& 5 m resolution
Orbital altitude	705km	686km	822km
Orbital type	Sun synchronous	Sun synchronous	Sun synchronous
Inclination angle	98.2^0	98^0	98.7^0

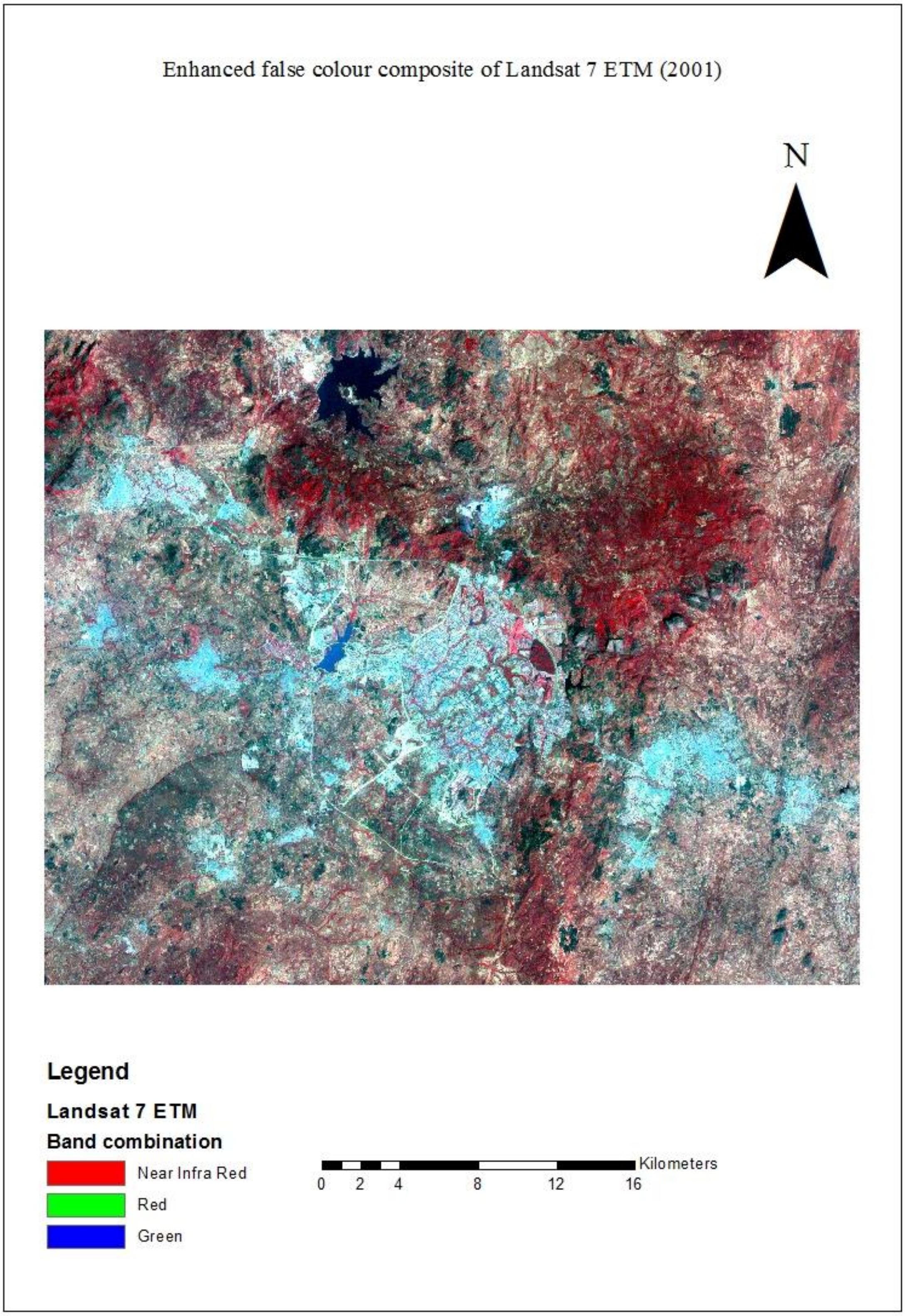


Fig. 3.2 (a) 2001 Landsat 7 ETM acquired on 27 December 2001 at 9:39:04am RGB (432)

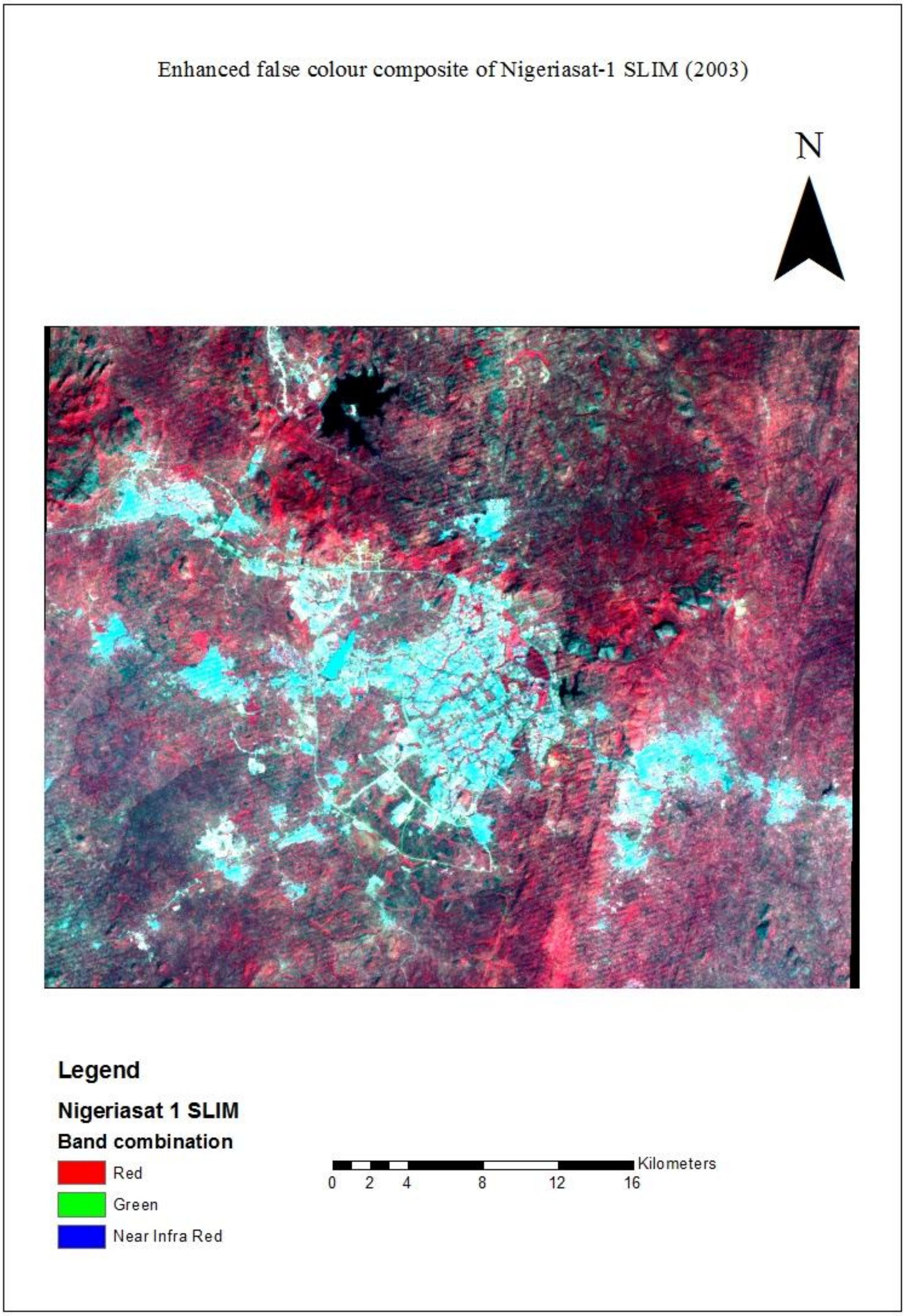


Fig. 3.2 (b) 2003 Nigeriasat 1 SLIM acquired on 4 December 2003 at 9:24:49 RGB (123)

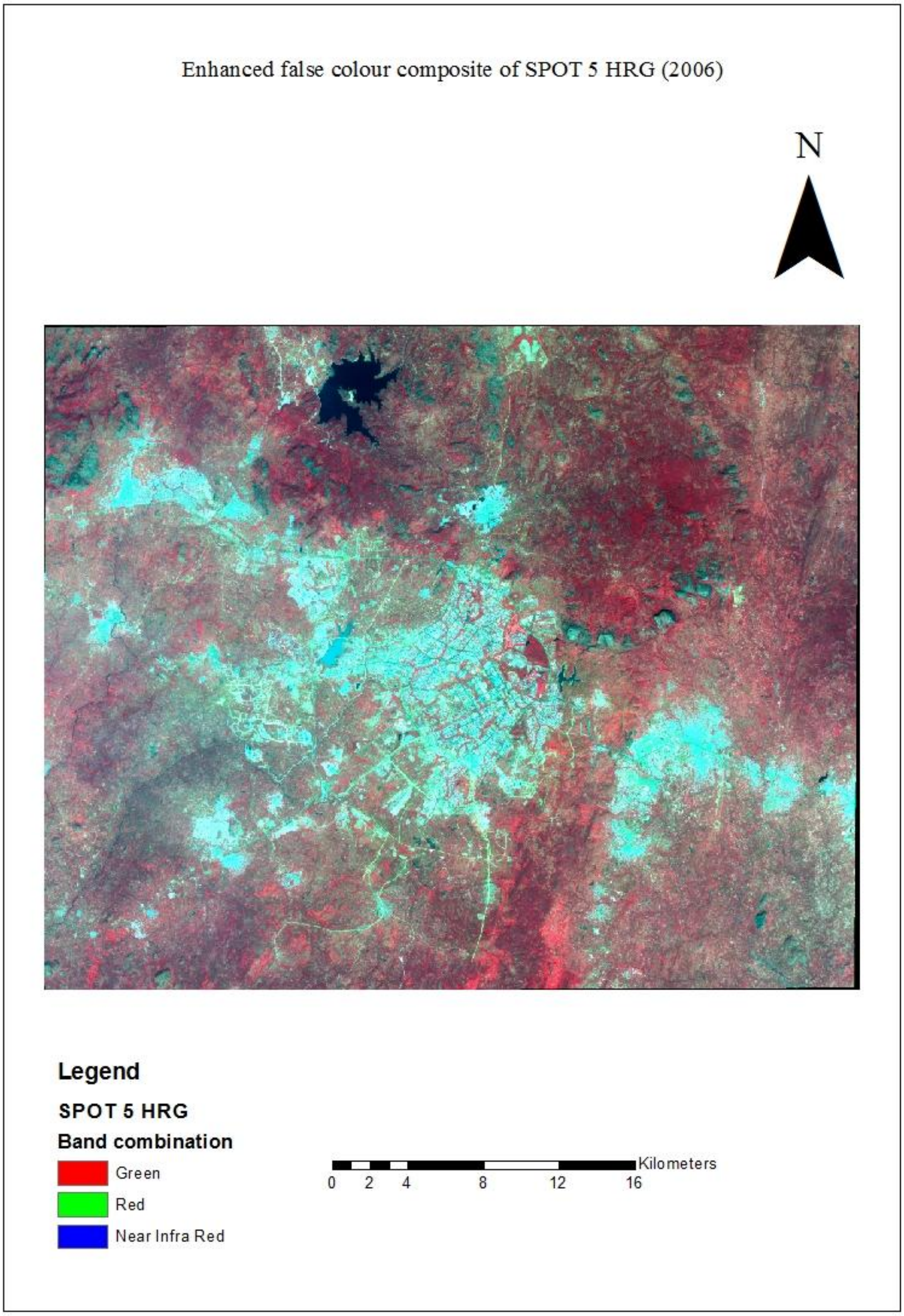


Fig. 3.2 (c) 2006 SPOT 5 HRG acquired on 24 November 2006 at 10:06:54am RGB (123)

Fig.3.2 (d) 2006 Land use cadastre of Abuja. Inset is a zoomed in portion showing lines of the cadastral boundaries.

3.3.2 Image processing

Image processing of satellite data to obtain urban land use information presents challenges because of the numerous features that make up the urban fabric. The introduction of fine resolution imagery of sub 10 meter (and even as fine as 1meter) did not bring the much desired solution (Mather 1999). This was because most urban features are larger than 1 meter, which leads to these urban features being erroneously, classified (Aplin 2003). Researchers have tried to solve this misclassification problem by introducing different approaches. Ridd (1995) suggested a conceptual model for remote sensing analysis of urban landscapes, i.e., the vegetation - impervious surface - soil (V-I-S) model. It presumes that land cover in urban environments is a linear combination of three components, namely, vegetation, impervious surface, and soil. Ridd believed that this model could be applied to spatial-temporal analyses of urban morphology, biophysical, and human systems. However, as long as this innovative concept was applied to medium resolution imagery the mixed pixel problem persisted (Melesse *et al.* 2007). This problem of misclassification becomes a major issue of image classification of cities in developing countries, as there is very little distinction between the various cover types that make up the urban landscape (Adepoju, Millington and Tansey 2006). Different land use types like play grounds, un-paved roads, open spaces and green areas have the same cover materials and creates classification problems because these features have similar spectral reflectance. Object based classification presents an alternative approach for analysis of satellite images (Lang 2008) because it classifies an image by partitioning it into objects similar to the way humans understand the landscape.

This research adopts a twin approach of pixel based and OBIA as a way of identifying the method best suited for isolating and identifying urban features during image analysis. Pixel based method was implemented with Erdas Imagine 9.1 (Leica Geosystems 2005) and the OBIA was achieved with Definiens 5.0 (Definiens 2005).

The flowchart of data processing in this research is presented in Fig. 3.3. According to the flowchart the first step before analysis of the images is to pre-process the images. This step will involve sub setting the images to extract an area of overlap between the three images. Then the images will be co-registered (explained in Section 3.3.2.1) to ensure that change detection can be effectively carried out after the analysis. After co-registration, the edges of the images will be trimmed to ensure that there is accurate overlap. Image analysis will then follow with pixel based and OBIA approaches to extract land cover maps using the level 1 land cover classes. See Section 3.4.1 and Table 3.5.

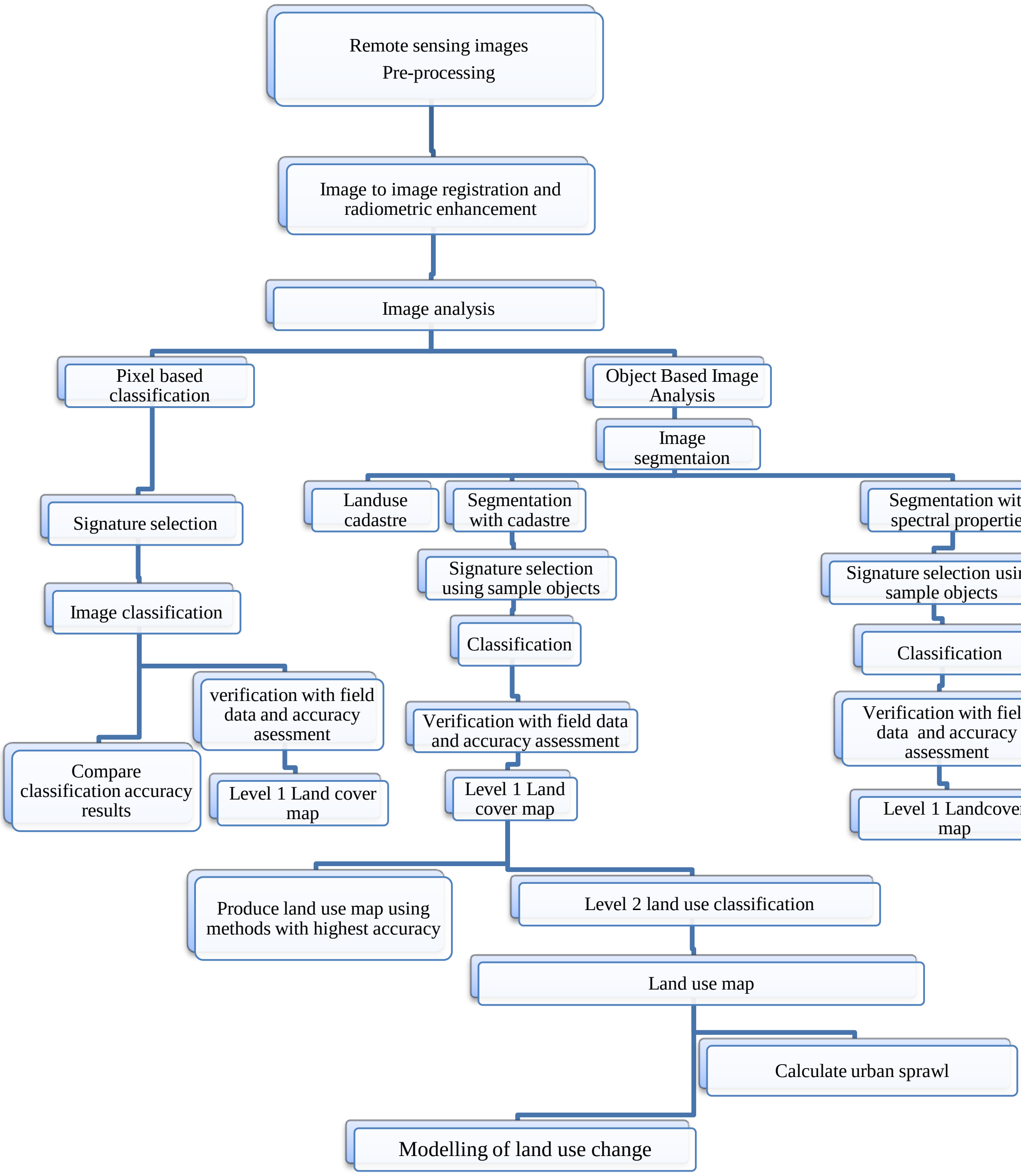


Fig. 3.3 Data processing Flowchart

The pixel based approach as explained in Section 3.4.2.2 involves signature selection, image classification and classification accuracy assessment. In respect of the OBIA, the first step involves the image segmentation into object primitives, which will later be classified. Details of the segmentation parameters are explained in Section 3.4.2.1. Using the same segmentation parameters, the images will be segmented along two lines. Firstly, the images will be segmented with the use of land use cadastre boundaries shapefile, which will serve as hard boundaries during the segmentation. Secondly, they will be segmented with the spectral properties of the images. After segmentation, the images will be classified and assessed for classification accuracy.

Accuracy assessment results from the three maps will then be compared to determine which of the three methods records the highest classification accuracy results. The method with the highest classification accuracy will then be used to classify the images into land use maps using level 2 land use classes (shown in Tables 3.4 and 3.6). The land use maps will then be used to calculate urban sprawl and model land use change.

3.3.2.1 Image co-registration and enhancements

The datasets were geo-registered to the Universal Transverse Mercator (UTM) map projection (WGS 84 UTM 32 North). The Landsat 7 ETM+ image, which was orthorectified from source, was used as basis of a co-registration (see Table 3.3). This was done with Erdas Imagine Autosync tool (Leica Geosystems 2009). The standard measure of location error is the Root Mean Square (RMS) error, which is numerically almost identical to the standard deviation of the difference between actual position of Ground Control Points (GCP) and calculated positions on the uncorrected image after registration. These differences are known as residuals (Campbell and Wynne 2011). Put differently, RMS error is expressed as a distance in the source coordinate system. If data file coordinate are the source coordinate, then RMS error is a distance in pixel widths. For example, an RMS error of 2 means that the reference pixel is two pixels away from the retransformed pixel (Leica Geosystems 2005). RMS error of *0.27* was achieved for Nigeriasat-1 SLIM and *0.32* for SPOT 5 HRG. After registering the images, a subset area of image overlap measuring 1138 km^2 (38.14km x 29.84 km) was extracted from the three datasets. Subsequently the images were enhanced for visual image interpretation on the screen using histogram equalisation.

Table 3.3 Image to Image co-registration parameters

Input Image	**SPOT 5 HRG**	**Nigeriasat-1 SLIM**
Reference Image	Landsat7 ETM+	Landsat7 ETM+
Reference layer	Green	Green
Geocorrection Method	Resample	Resample
Resample method	Nearest neighbour	Nearest neighbour
Image resolution	10m	32m
Output correction method	Polynomial	Polynomial
Polynomial order	3	3
RMS error	0.32	0.27
Tie points	23	23
Coordinate System	WGS 84 UTM 32 North	WGS 84 UTM 32 North

3.4 Classification

Classification is the process of assigning pixels to informational classes of interest (Campbell and Wynne 2011). The classification process involves spectral or pattern recognition in order to create a cluster of classes from multispectral images. The objective of image classification in this research is to make sense out of the spectral information present in the multispectral images and create cluster classes that match the informational classes of interest. The area coverage of the different classes of multispectral images were then compared to determine changes that have taken place between the dates under study.

3.4.1 Land use and Land Cover Classification scheme

Land cover classification is the classification of satellite images based on the reflected signals from the earth surface materials. Land use classification considers the socio-economic activity of the location of interest and is interpreted from the land cover in the context of surrounding features. For instance an area with grass as land cover, when identified within the context of surrounding features may be the field of a football stadium or a public park. Depending on the aims of the research, either land use or land cover classification can be used for remote sensing change detection.

The land use classification scheme used in this study (Table 3.4) is adapted from Land use map of Abuja Federal Capital City. Land use classes identified on the map were grouped into classes that could be visually discerned on the datasets used for the research. Anderson *et al.* (1976) was used as a basis to develop and adapt a hybrid classification system after field reconnaissance in 2008 and 2011. The land use classes developed are Level 1 (Table 3.5) for land cover classes and Level 2 (Table 3.6) for land use classes. This classification system (Anderson *et al.* 1976) is a good example of a general purpose LULCC classification system intended to provide a comprehensive classification of LULCC (Campbell and Wynne 2011). Land use classes, which could not be easily separated in terms of their land cover characteristics on the satellite images, were grouped together for classification purposes. For instance, the commercial and residential land uses were grouped together because it was difficult to differentiate between the two on satellite images. The industrial land uses identified on the land use map were also classed as residential/commercial because industrial activities were not present in the study area during the study period.

Table 3.4: Classification scheme

Original classes in Abuja land use map. *	**Reclassified classes**	
	Level 1- Land cover	**Level 2- Land use**
Residential land use	Built up	Residential/ Commercial
Commercial land use	Built up	Residential/ Commercial
Public buildings or institutions	Built up	Residential/ Commercial
Industrial uses	Built up	Residential/ Commercial
Recreational uses	Built up	Parks and open spaces
Other urban uses without buildings	Water body Bare surface Vegetation	Water body Recreational/open spaces
Non urban land	Vegetation Bare surface	Vacant land

*Key

Residential uses –
(1) Low density (2) Medium density (3) High density

Commercial uses –
(1) Shops (2) Banks (3) Hotels (4) Offices (5) Warehouses

Public buildings or institutions -
(1) Hospital, clinics, post offices, railway stations, Dock and harbour buildings, Police stations, Airport (2) Cinema theatre, Stadia, Community hall, Religious buildings
(3) Educational buildings e.g. schools, colleges, university, day centre, etc. (4) Military formations

Industrial uses –
(1) Heavy industry e.g. surface mineral works, electricity power station, gas works and water works (2) Light industries e.g. small scale industry (woodwork, shoe factory, government industry, motor repair workshop) (3) Manufacturing and packaging, metal fabrication

Other urban uses with few or no buildings –
(1) Land covered by water including reservoir (2) Sewage disposal works (3) Refuse dump or landfill site (4) Rail line (5) Airfields (6) Roads (7) Public car parks (8) Cemetery (9) Forest game reserve and private recreation area (10) Flood plain, parks and private recreational areas

After the determination of the land cover and land use classes to be mapped, a menu of the classes to be mapped and colours for each land use and land cover used in the mapping process was developed. Table 3.5 shows the land cover classes and colour schemes. While Table 3.6 displays the land, use classes and colours.

Table 3.5 Level 1 Land cover classes

Classes	Colour	
Built up	Pink	
Vegetation	Green	
Water body	Dark Blue	
Bare surface	Yellow	

Table 3.6 Level 2 Land Use Classes

Classes	Colour	
Residential/ Commercial	Orange	
Recreational/ Open spaces	Light Green	
Transport	Red	
Vacant land	Green	
Water body	Blue	

3.4.2 Classifiers

Classifiers refer to computer programs or algorithms that implement a specific procedure for classification (Campbell and Wynne 2011, Lillesand, Kiefer and Chipman 2004). The choice of classifier depends on the specific task at hand because at present it is not possible to state that there is a specific classifier best suited for all situations (Lillesand, Kiefer and Chipman 2008). The two classifiers used in this study are the Multi Resolution segmentation patented by Definiens AG, and Maximum Likelihood Classifier.

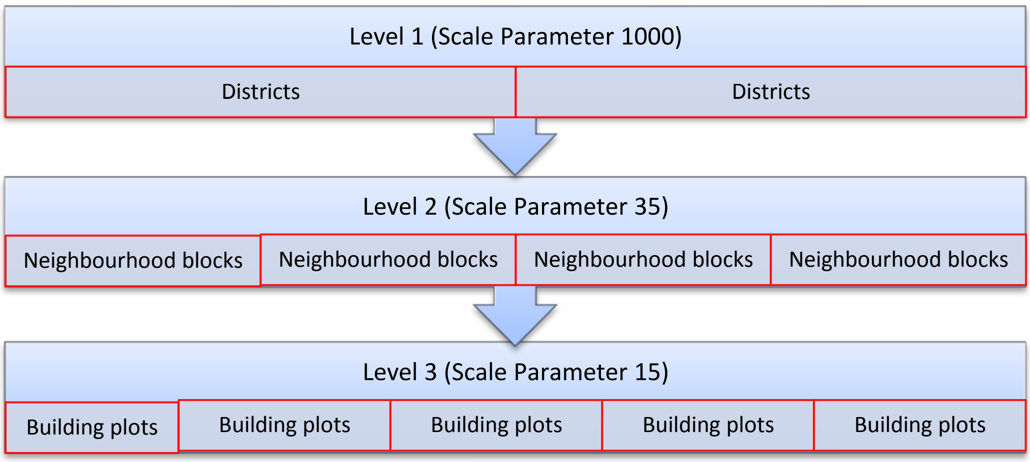
3.4.2.1Object Based Image Analysis (OBIA)

Object based classification presents the most effective way to analyse satellite images (Lang 2008) because it classifies an image by partitioning it into objects similar to the way humans understand the landscape. A comparison of object oriented image classification and pixel based approach (Mittleberg 2002) shows that the object based approach presents a better method for LULCC. To implement OBIA the relevant tool is required. A robust evaluation involving all commercially available image object processing software up to the start of this research (Neubert and Meinel 2003, Neubert and Herold 2008) indicates that eCognition now known as Definiens (Lang and Tiede 2007) software was a market leader in the field. The Definiens method for image object analysis is a patented procedure known as Multi Resolution segmentation.

The first step in image object extraction is the segmentation of the entire image. The image objects from the initial segmentation provide object primitives, which serve as building blocks for classification. This method is a bottom up approach, which groups objects with certain criteria of homogeneity and heterogeneity (Definiens 2005, Lang and Tiede 2007). The analyst determines which real world objects the resultant images represent. Image object extraction, in Definiens software relies on user defined processes, which ultimately make the procedure more adaptive to different datasets as different approach, is required for each dataset (Darwish, Leukert and Reinhardt 2003).

The Definiens approach uses a segmentation technique called Multi-resolution Segmentation (MS) (Definiens 2006). This is a region based algorithm, which begins with the consideration of each pixel as a separate object. In subsequent iterations pairs, of image objects are merged into larger objects or segments. The criteria for merging the objects is based on local homogeneity criteria between adjacent image objects based on a user defined threshold or Scale Parameter (SP). Merging stops once this threshold is exceeded by the smallest increase. The right SP is therefore central to a successful image object extraction. A high SP will allow more merging and consequently bigger objects, and vice versa. The homogeneity criterion (explained further in Table 3.8) is a combination of colour (spectral values) and shape properties (shape splits up in smoothness and compactness). Another unique feature of the MS technique is that it is hierarchical, by applying different SPs and colour/shape combinations; the user is able to create a hierarchical network of image objects (Darwish, Leukert and Reinhardt 2003).

As shown in fig 3.4 a different SP can be used to segment the images at different levels of the hierarchy. A large SP may be used to segment the image at level 1or 2 (e.g. into urban districts or neighbourhoods blocks), and a smaller SP to further segment the image into smaller units (e.g. building plots) at level 3.



Adapted from Definiens (2006)

Fig.3.4 Hierarchical Segmentation in Definiens 5.0. It is possible to classify broad Land cover classes in level 1 and specific land uses in level 2 and below.

Another dimension to the Definiens method is that it allows for the introduction of ancillary data in the form of parcel boundaries or land use cadastre data from the urban plan as a shapefile in the form of a thematic layer. This thematic layer can be integrated with multispectral satellite images and used for analysis. The parcel boundaries from the land use plan then act as hard boundaries that can be used to segment the images. In a built up area these parcel boundaries can be used to segment the images into various plots and shapes based on the shapes from the land use cadastre.

3.4.2.2 Maximum Likelihood Classification

Maximum Likelihood Classification (MLC) is parametric decision rule implemented quantitatively to consider several classes and spectral bands simultaneously and forms a very powerful technique that is computationally intensive (Lillesand, Kiefer and Chipman 2008). This classifier is sensitive to variations in the quality of the training data used for analysis even more so than other supervised classification techniques. Computation of the estimated probability that each pixel belongs to particular class is based on the assumption that both training data and the informational classes display multivariate normal frequency distributions. Data from remotely sensed data do not strictly adhere to this rule although the variations are so small that the procedure is preserved (Campbell and Wynne 2011). Of all the supervised classification techniques this was adopted as the classification technique most suited for urban land cover classification because it has successfully been used to classify urban areas like Lagos where it was able to handle and show the spatial distribution of land uses and land cover types in metropolitan Lagos (Adepoju, Millington and Tansey 2006). However, this resulted in “Salt and Pepper” pattern classification (Lu and Weng 2004) which was smoothened using a majority filter (Lillesand, Kiefer and Chipman 2008). The classification accuracy of 96.6% for level 1 Land cover classification and 87% for land use classification was achieved. This underlines the strength of MLC to handle remotely sensed data from metropolitan Lagos, where land use classes have little or no spectral distinction because of organic development due to lack of planning and zoning laws at the initial stage of growth. The MLC effectively handled this problem better than other types of classifiers tested (Adepoju, Millington and Tansey 2006).

3.4.3 Validation of Classification methods

To test the classification methods and assess how they perform with the data sets three experiments were designed to classify the images using Level 1 classes (land cover) from the classification scheme (see Table 3.4). Subsequently accuracy assessment was performed on all the classified images with the error matrix.

a) The first of the experiments was classification of the data sets with Maximum Likelihood Classification, a pixel based method.
b) The second was the classification with OBIA using only the spectral properties of the images.
c) The third experiment involved the classification with OBIA using a combination of the cadastre data and spectral properties.

Before the experiments could proceed the training sites were selected

Selection of sampling sites

To enable direct comparison, between the three experiments, similar training sites were prepared and imported as X and Y coordinates into both classifiers. Using stratified random sampling, training sites were selected in such a way that they were spread throughout the study area. The trade-off faced in the development of the training data is that of having sufficient sample size to ensure the accurate determination of the statistical parameters used by the classifier and to represent the total spectral variability in a scene (Congalton and Green 1999, Congalton 2001) without going past the point of diminishing returns (Lillesand, Kiefer and Chipman 2004). Due to the nature of stratified random sampling design, some land cover types may be under-represented in the selection of samples. To ensure that all land cover classes were represented sampling was allocated with respect to variability within each land cover category (Congalton and Green 1999, Lillesand, Kiefer and Chipman 2004).

Using ArcMap (within the ArcGIS 9.1 environment) grid areas measuring $1km^2$ were generated over the images of the datasets. In four separate iterations, the grid areas covering each land cover area were selected and populated with 150 random points using the Hawth's tools extension for ArcGIS 9.1. Then based on the variability of the land cover type samples were selected. For example out of the 150 points generated for the built up areas the first 50 points were selected. See Fig. 3.5 for details. As shown in Table 3.7, the rest of the training locations were selected as follows, first 50 out of 150 for vegetation. First 30 out 150 for water bodies and first 20 out of 150 for bare (soil) surface. A total of 150 training locations were selected for all the land cover classes.

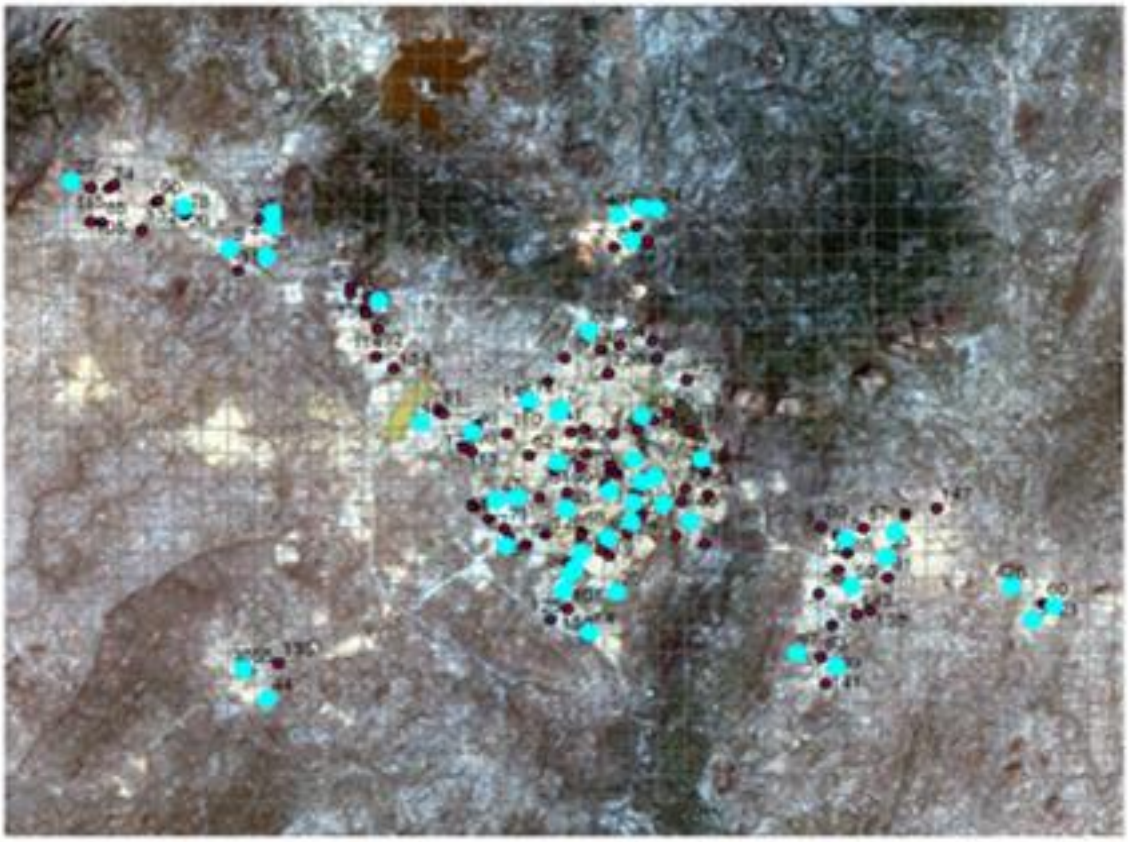


Fig.3.5 Location of 50 Training sites (cyan dots) selected from 150 stratified random locations (brown dots) for the built up area

Table 3.7 Number of stratified random points generated and used as training sites for image classification

Land cover type	Total random points (Locations) generated	Number of points (Locations) used
Built up	150	50
Vegetation	150	50
Water body	150	30
Bare Surface	150	20
Total random locations		150

For the per pixel classification, clusters of pixels that fall directly or near the imported X and Y coordinates were delineated and saved as signature files. Emphasis was made to zoom in to ensure that areas delineated contained homogenous pixels representing a single land cover category. Subsequently the signature files were used for supervised Maximum Likelihood Classification. The results of the classification are presented in Chapter 4.

In respect of the OBIA, before the classifications could proceed the first task was to segment the image into object primitives. Image segmentation parameters were chosen from the procedure by Definiens in the user guides when a thematic layer is used (Definiens 2004). Three image object levels were created. The actual classification was on image object level 2. Image object level 3 consists of image objects that are identical to the polygons of the thematic layer and image object level 1 formed sub-object to level 2. The thematic layer was used to create each of the object levels. Areas outside the coverage of the urban plan were segmented based only on local homogeneity criteria without the spatial constraint of parcel boundaries shapefile.

In other to determine if there is a significant difference between the segmentation performed with the thematic layer and the segmentation performed without it, one set of segmentation was performed without the thematic layer using only the spectral properties of the images. The segmentation parameters remained the same in both iterations. The image segmentation parameters are shown in Table 3.8. Portions of the segmented images before the images were classified are shown in Fig. 3.6 below. Fig 3.7 shows a section of the false colour composites of the three images segmented with parcel boundaries before classification into various land use classes.

Table 3.8 Image Segmentation Parameters

Image/ Segmentation Level	Scale Parameter*	Colour	Shape		Segmentation mode	Classification Method
			Smoothness	compactness		
Level 1	1000	0.8	0.3	0.7	Thematic layer /Spectral properties	
Level 2	35	0.7	0.3	0.7	Thematic layer /Spectral properties	Nearest neighbour
Level 3	15	0.8	0.3	0.7	Thematic layer /Spectral properties	

* The Scale Parameter (SP) is an abstract term, which determines the maximum allowed homogeneity (or heterogeneity) for the resulting image objects. Homogeneity criterion is a combination of *colour* (spectral values) and *shape* properties (*shape* splits up in *smoothness* and *compactness*).The higher the SP the larger the segmentation and vice-versa.

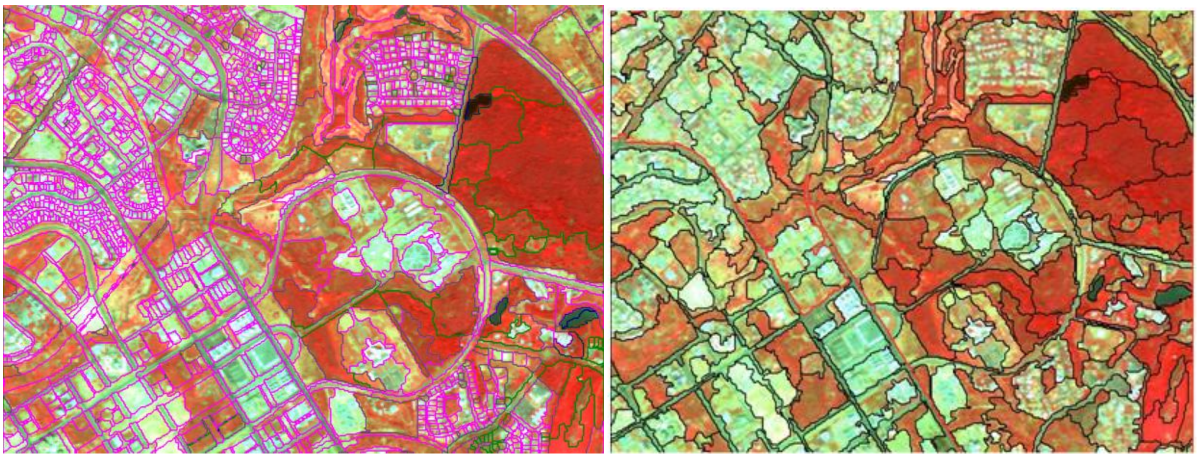


Fig. 3.6 Screen shots of Abuja image segmented with land use cadastre (left) and spectral properties (right)

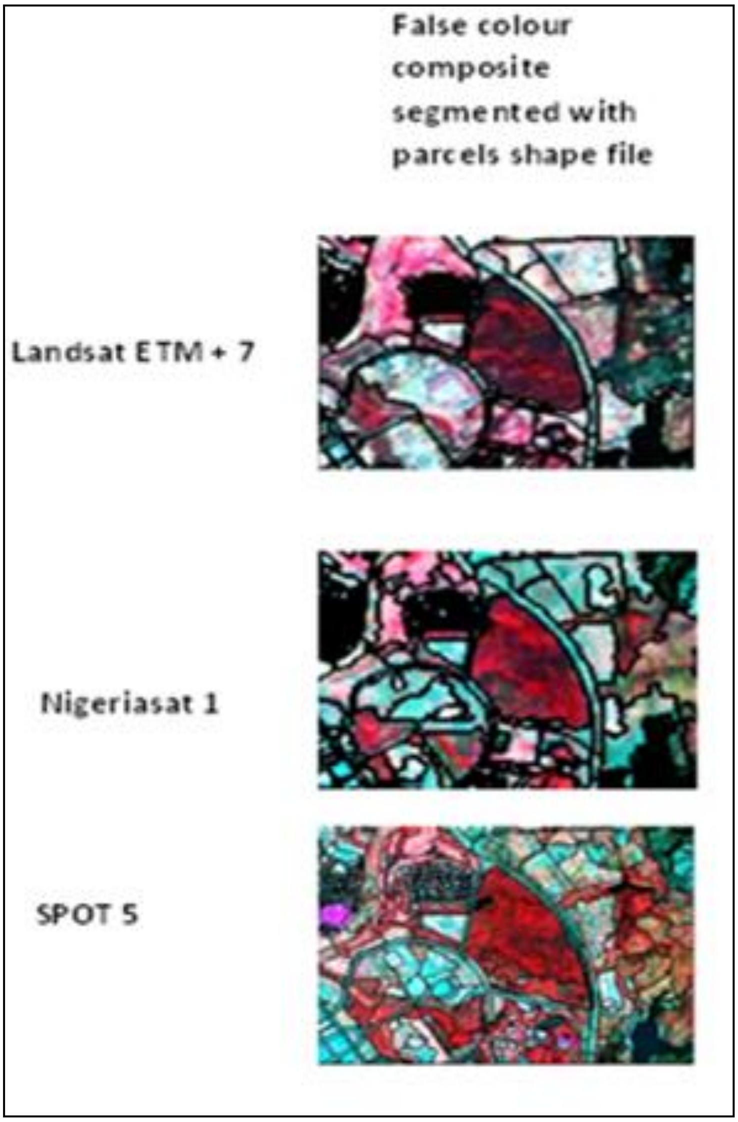
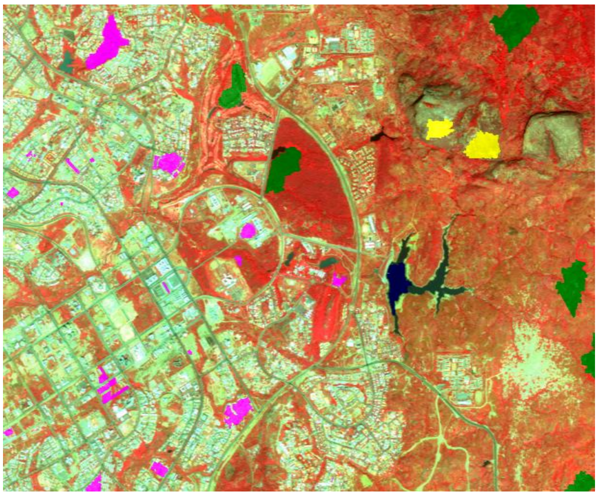
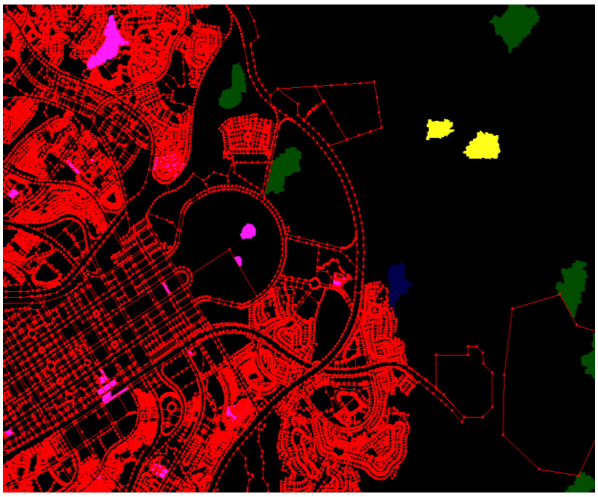


Fig. 3.7 Portion of three images segmented images before the classification into various land cover classes

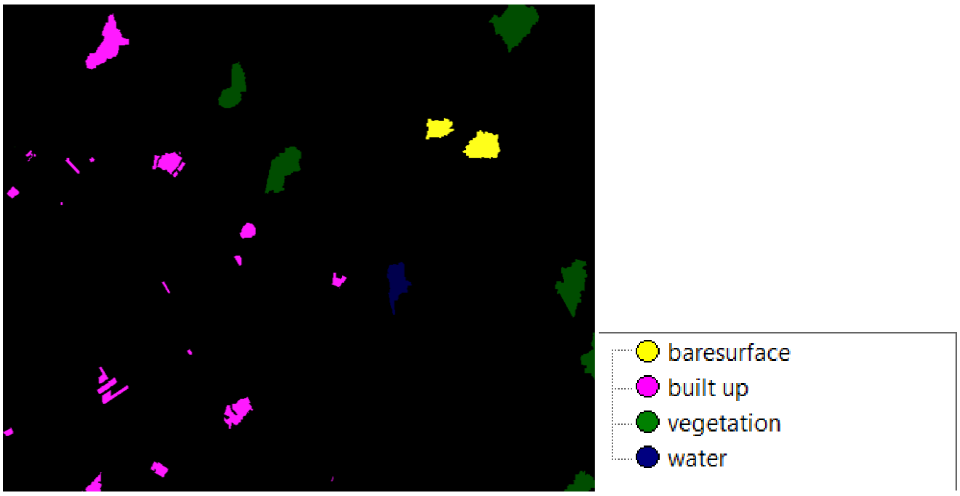
Use of prepared training sites for OBIA classification: In respect of the OBIA classification, the X and Y coordinates were imported and used to create Training Areas (TA) masks (Fig. 3.8) that were later used to classify the images. The image object primitive that corresponds with the imported coordinates are selected as training samples as shown in Figs. 3.8 (a) and (b)



(a) Sample objects selected on satellite image



(b) Sample objects selected on fusion of satellite image and cadastral data



(c) Training Area mask used for classification

Fig. 3.8 Training Area mask used to classify the Images in OBIA. Sample objects are selected based on x and y coordinates of the imported training sites. The Training Area mask ensures that the same sample locations are used as training sites for the classification of all the images.

3.4.4 Classification accuracy and sampling size

The error matrix was used to calculate the accuracy of the classification (Foody 2002). As explained earlier in Section 2.11, the error matrix can be used to calculate several measures of map accuracy like Overall Accuracy (OA), Producer's Accuracy (PA), User's Accuracy (UA), Kappa Index of Agreement (KIA) and Conditional Kappa (CK).

Selection of Sites for accuracy assessment

The sampling sites for the accuracy assessment were selected from random sampling using different sets of coordinates from the training sample locations. Stratified random sampling similar, but slightly different, from the procedure used earlier for the selection of training parcels was used. The difference this time was that the selection of the accuracy assessment locations was different for each of the land cover classifications. This was deemed necessary because the area extent of the land cover development varied in each of the classification outputs. The sampling sites had to spread across entire classified area for each image to ensure that all land cover developments were considered in the accuracy assessment. Fig 3.9 shows accuracy assessment location over the Landsat 7 ETM classification and Fig. 3.10 shows the accuracy assessment locations generated over the SPOT 5 HRG classification. For OBIA, the X and Y coordinates were imported into the classifier and used to create a training area mask used for the accuracy assessment.

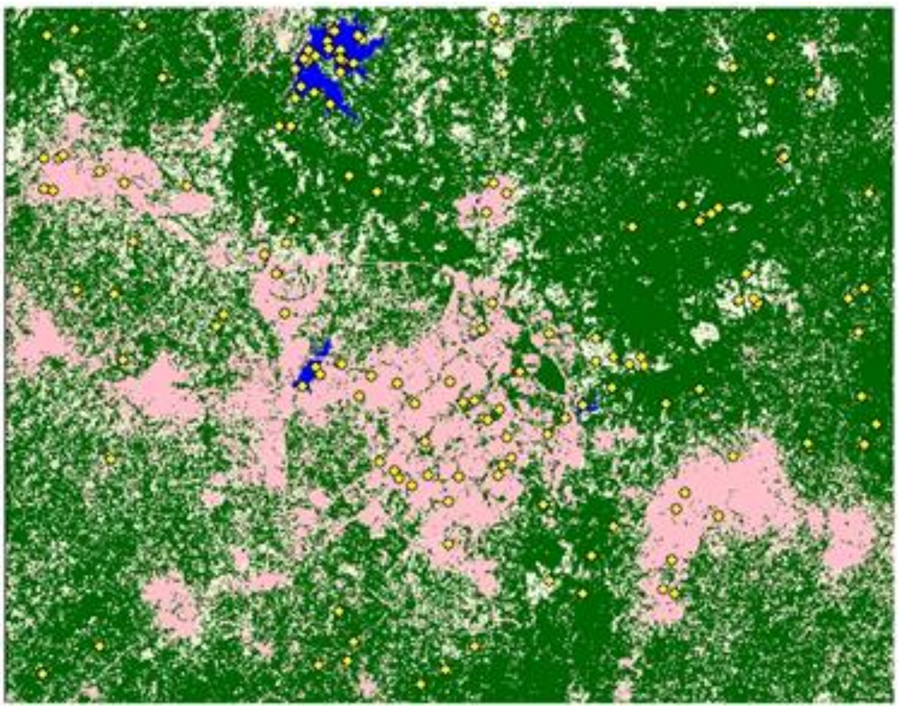


Fig. 3.9 Accuracy assessment locations (yellow dots) generated over the MLC for Landsat ETM 2001

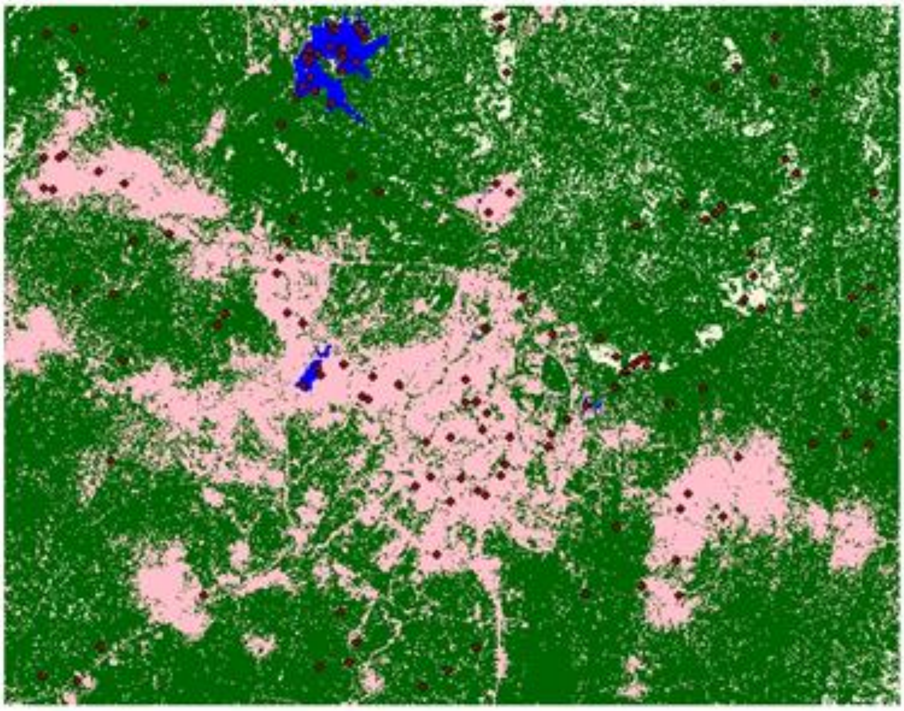


Fig. 3.10 Accuracy assessment locations (red dots) generated over the MLC for SPOT 2006

3.5 Calculating Shannon's Entropy in Abuja

The land cover maps derived from the OBIA were used to calculate Shannon's Entropy. Shannon's Entropy can be calculated by measuring growth around major arteries or around the built up areas of the city. The second option was chosen because Abuja has an identifiable city centre that can be used as focal point to generate buffer rings that will serve as zones for the calculation of landscape dispersal around the city. An entropy value varies from 0-1. If the distribution is maximally concentrated in one region, the lowest entropy value of zero (0) is obtained. While an evenly dispersed distribution across space gives a maximum value of 1.

First, the classified land use maps for 2001, 2003 and 2006 were imported into the ArcMap software environment and converted to shapefiles. Then 22 buffer rings (1km apart) were drawn around the core of Abuja as shown in Fig. 3.11

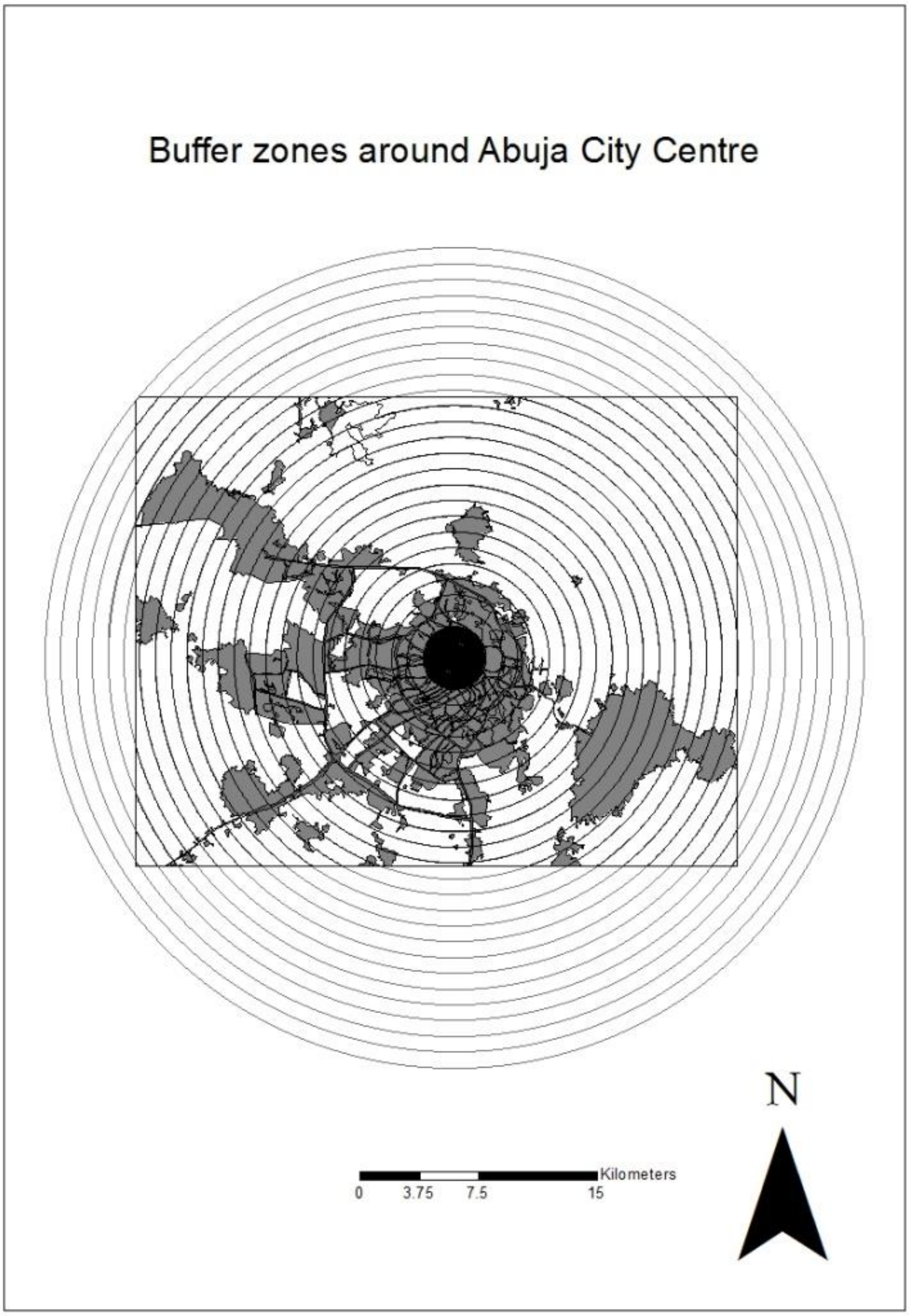


Fig. 3.11 Buffer zones over the land use map of Abuja. **The zones were used for the calculation of Shannon's Entropy**

The distance between each buffer ring on the map, is used as a zone for the calculation of Shannon's Entropy. Within each zone the area of built up land and non-built up land were calculated separately. Then the area of the built up land was divided by the area of non-built up land to generate the figures required for the calculation of the Shannon's Entropy. Relative entropy can be expressed as in this formula (Ye and Li 2001):

$$En = \sum_i^n Pilog(1/Pi)/\log(n) \qquad \text{Equation 1}$$

Where $i = xi/\sum_i^n xi$, *pi* is the proportion of the variable in the ith zone, *pi* refers to the impervious areas in ith zones, *xi* is the density of land development, which equals the amount of built-up land divided by the total amount of land in the ith zone in the total of n zones. The number of zones means the number of buffer zones around the city centre. Since entropy can be used to measure the distribution of a geographical phenomenon, the difference in entropy between two time periods can be used to indicate the degree of dispersal (Ye and Li 2001):

$$\Delta E_n = E_n(t+1) - E_n(t) \qquad \text{Equation 2}$$

Where ΔE_n is the difference of the relative entropy values between two time periods,

E_n (t+1) is the relative entropy value at time period t+1,

E_n (t) is the relative entropy at time period t

3.6 Modelling land use change

Modelling of land use change in GIS involves the use of geostimulation techniques to predict land use change. Land use prediction involves examining the land use change between two points in time and then extrapolating this change into the future (Eastman 2009).

Two modelling methods were used to produce the predictions: Markov Chain and Cellular Automata analysis. These analyses tools were used because they support the raster outputs from Definiens 5.0. The Markov Chain analysis was implemented using the Markov module in the Idrisi Taiga software. A Markov process is one in which the state of a system at time 2 can be predicted by the state of the system at time 1. Change in land use patterns between the two known dates was used to develop a transition probability matrix (see table 3.9) and a transition areas file. These in turn were used to make the prediction. A transition probability is the likelihood that a land use would remain the same or change in future (Eastman 2009).

In Idrisi Taiga, Cellular Automata analysis is accomplished by the CA Markov module. This module provides a cellular automata procedure very specific to the context of predictive land use change modelling (Eastman 2009). The CA Markov module takes as input the land use map (y) from which changes should be projected, the transitions areas file produced by Markov from the analysis of that image (y), and an earlier one (x), and a collection of suitability images[1] (see footnote), that expresses the suitability of a pixel for each of the land use types under consideration. It then begins an iterative process of reallocating the land cover until it meets the area totals predicted by the Markov module. According to Eastman (2009) the logic used is a follows,-

1) The total number of iterations is based on the number of time steps set by the user. If the projection is for 10 years, the user might chose to complete the module in 10 steps.
2) Within each iteration, every land use/cover class will typically loose or gain some land to one or more classes.

The Markov module calculates the likelihood of the raster cells in each land use class to transition to other land uses as shown in Table 3.9. These alongside the urban growth likelihood maps are used as transition rules in the cellular automata process.

To make the predictions, land use maps of 2001, 2003 and 2006 (Produced from OBIA) were imported into the Idrisi GIS environment as raster files. For this research, urban growth suitability (urban growth likelihood) was determined using Abuja land use maps. Five urban growth likelihood images were created to tally with five land use classes in this research. The images are shown in figs. 3.13 – 3.17 at the end of this chapter). Recreational/open spaces and water bodies were considered not to change during the period from 2001 to 2006. Vacant area is a special class. Since the process of urban development is a process of consuming vacant area, all non-urban land surrounding the urban areas were treated as vacant land. Urban growth likelihood image collection was created using the five urban growth likelihood maps.

Table 3.9 Transition areas matrix produced from the Markov module*

	Expected to transition to				
Raster cells in	Residential /commercial	Recreational/open spaces	Transportation	Vacant Land	Water body
Residential /commercial	184777	11610	10209	38700	647
Recreational/open spaces	7532	12116	473	793	257
Transportation	5141	713	13508	966	31
Vacant Land	174029	11631	3636	623360	1043
Water body	18	64	7	2150	6913

*The diagonal elements of the matrix indicate no change in land use between the two time periods.

The initial Cellular Automata analysis used Idrisi's default settings and the 2001 and 2003 land use maps to predict the land use in 2006. Fig. 3.12 shows the land use map for 2006 and the 2006 land

[1] Suitability image collection is a term used in Idrisi Taiga® to describe the images which show the likelihood of a land use transitioning to another. Suitability in this context is different from the suitability mapping used in GIS location analysis. To ensure that the terms are not confused the images in this study are called *urban growth likelihood* images.

use projection. Once this had been deemed to be a success through model validation (see the next paragraph) a real prediction for the year 2020 was produced based on the change that occurred between 2003 and 2006.

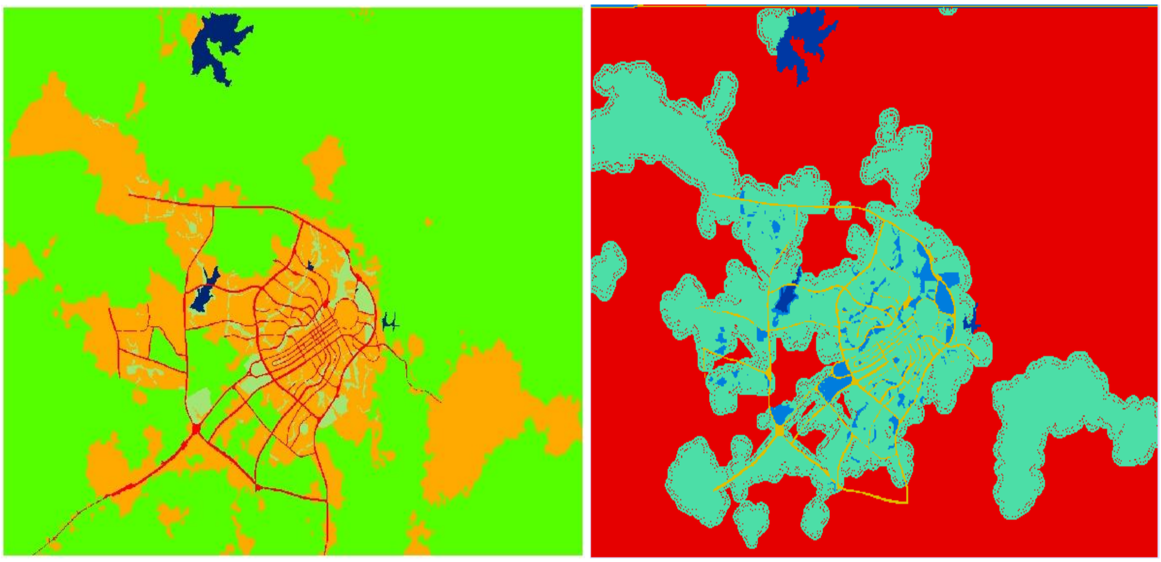


Fig. 3.12 2006 land use map (left) and 2006 projected from the land use changes in 2001 and 2003 (right)

Model Validation:

An important stage in the development of any predictive change model is model validation. The ability of the model to accurately predict is tested by using it to predict a period of time when the land use condition is known. Then it is used as a test for validation (Eastman 2009). Model validation is done with the Validate module in Idrisi Taiga. The Validate module provides a comparative analysis on the basis of the Kappa Index of Agreement (KIA), which is a statement of proportional accuracy, adjusted for chance agreement. Validate process provides several measures of agreement each with a special form of Kappa (Pontius 2000). Some of these measures are Kstandard – the standard KIA and Klocation-Kappa for location (of correctly predicted cells). The Kstandard was 0.65 and Klocation – 0.78. These values indicate above average level of agreement between the classification and the predicted land use. Once the methodology had been successfully validated, the 2006 land use map was used in the same way to provide a prediction for the year 2020. Details of the decision to use the model will be explained in the discussion chapter.

The 5 urban growth likelihood maps used for the projection of land use for 2020 are presented in Fig. 3.13- Fig. 3.17

The legend 1 indicates data for the specific land use category while, 0 represents no data.

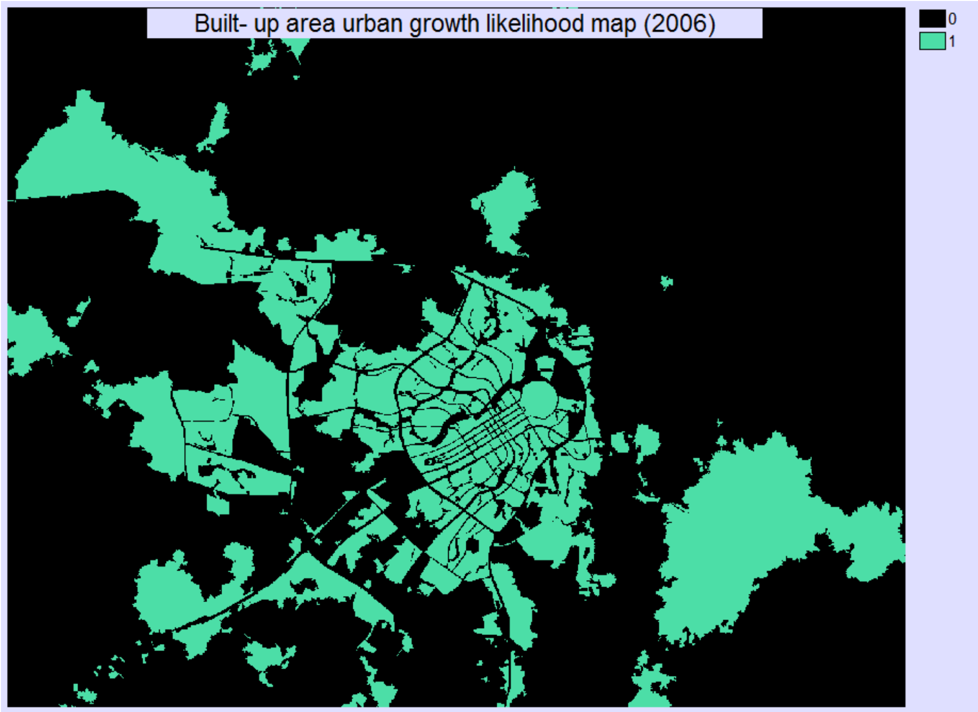


Fig. 3.13 Urban growth likelihood map for residential /commercial (Built up area) 2006

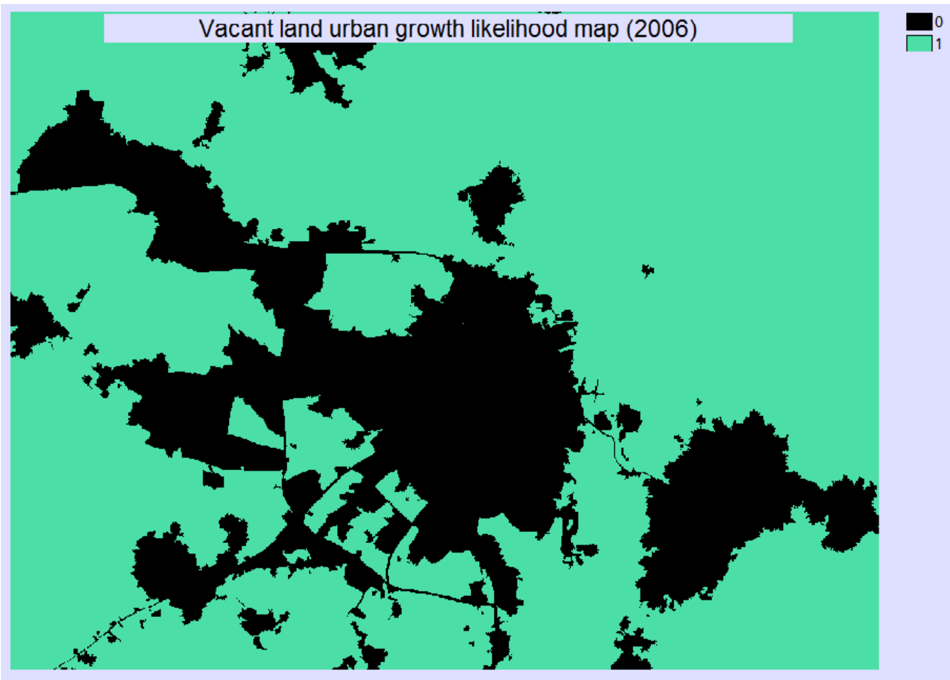


Fig. 3.14 Urban growth likelihood map for vacant land 2006

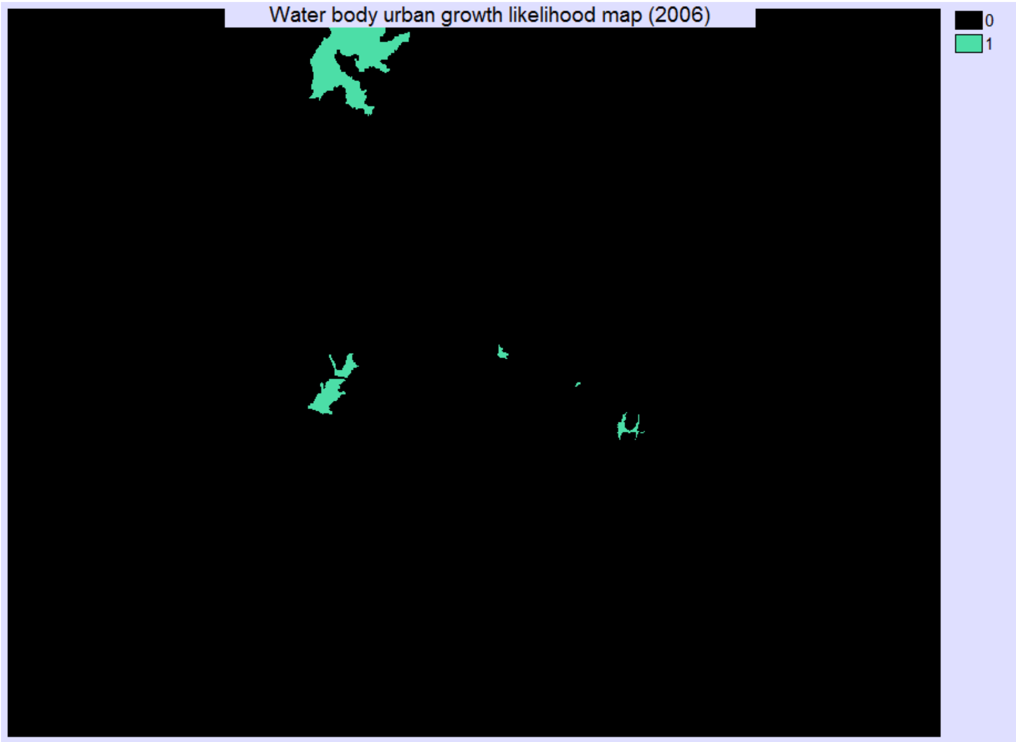


Fig. 3.15 Urban growth likelihood map for water bodies 2006

Fig.3.16 Urban growth likelihood map for transport 2006

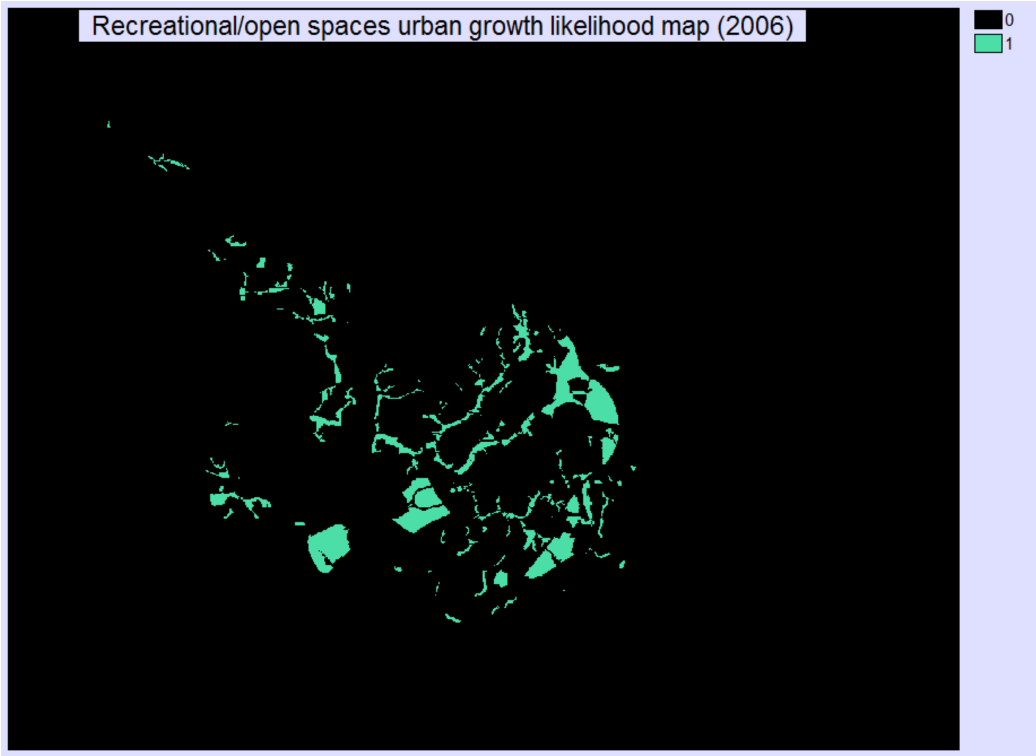


Fig.3.17 Urban growth likelihood map for Recreational / Open spaces 2006

Synopsis

This chapter has presented the specific methods used for the pixel and object based image analysis of multi date/ multi-sensor satellite data. Afterwards, the methods used to measure urban sprawl and model urban growth were also presented.

Chapter 4: Results and Analysis

This chapter is divided into two sections. The first- Section 4.1 presents the results from the different classification procedures used in this study. Firstly, the single date classifications are presented followed by their error matrices.

Section 4.2 present analyses of the classification of the datasets in tabular form and maps. Cross tabulation of the land use maps derived from the datasets also presented in maps and tables. The cross-tabulation results help to show areas where change has occurred.

The purpose of the analysis was to identify and quantify

1. Areas of change between the images that have occurred due to reasons such as image registration errors and misclassification.

2. Areas of change that have occurred over the study period. Identification of these areas will enable detailed examination and help to establish drivers of land use land cover change.

Section 4.1

4.1.1 Classification with Maximum Likelihood Classification

The land cover maps produced with Maximum Likelihood Classification of the datasets followed by the error matrices used to assess the accuracy of the classified maps are presented here.

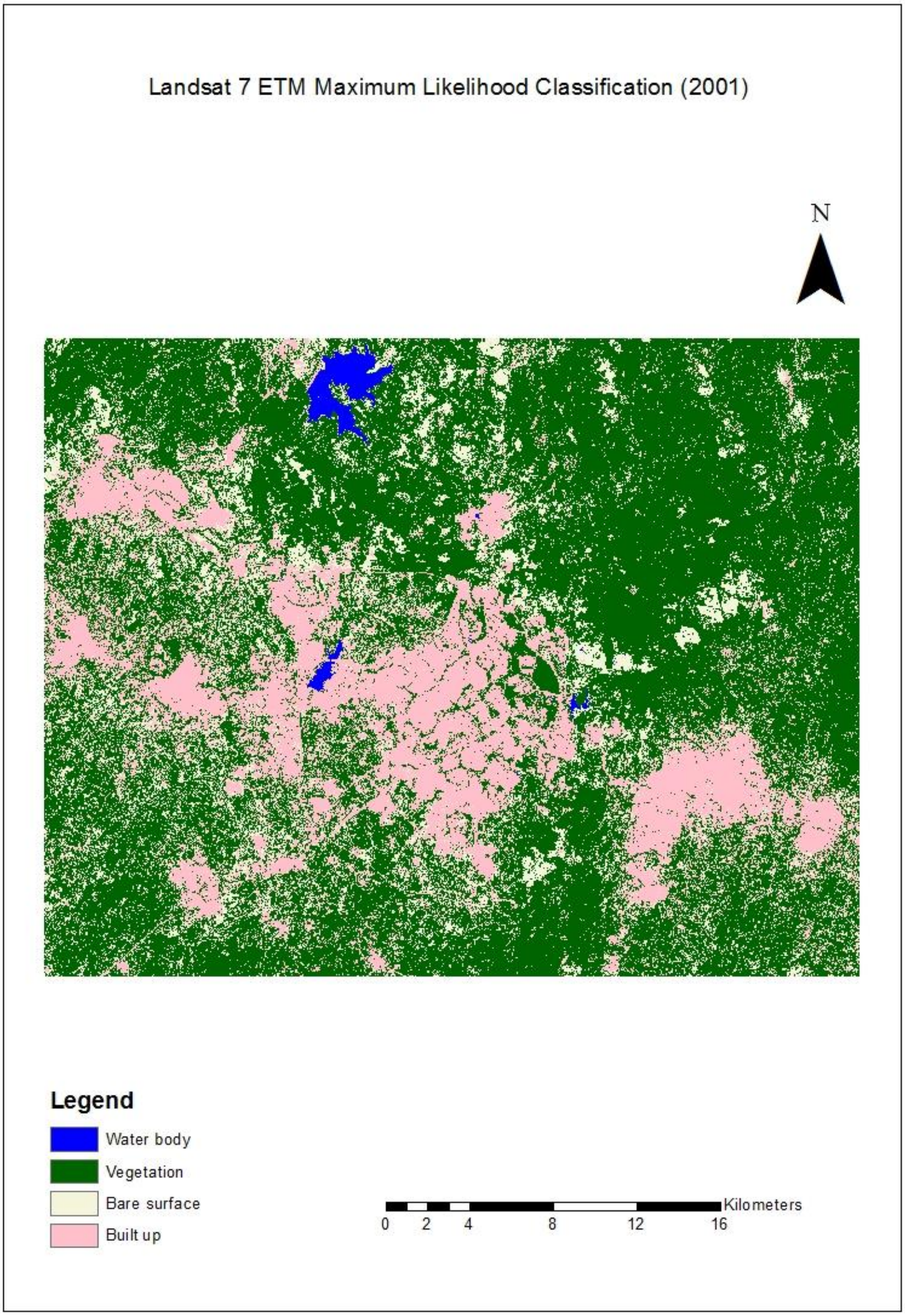


Fig. 4.1 2001 Land cover map produced by Maximum Likelihood Classification

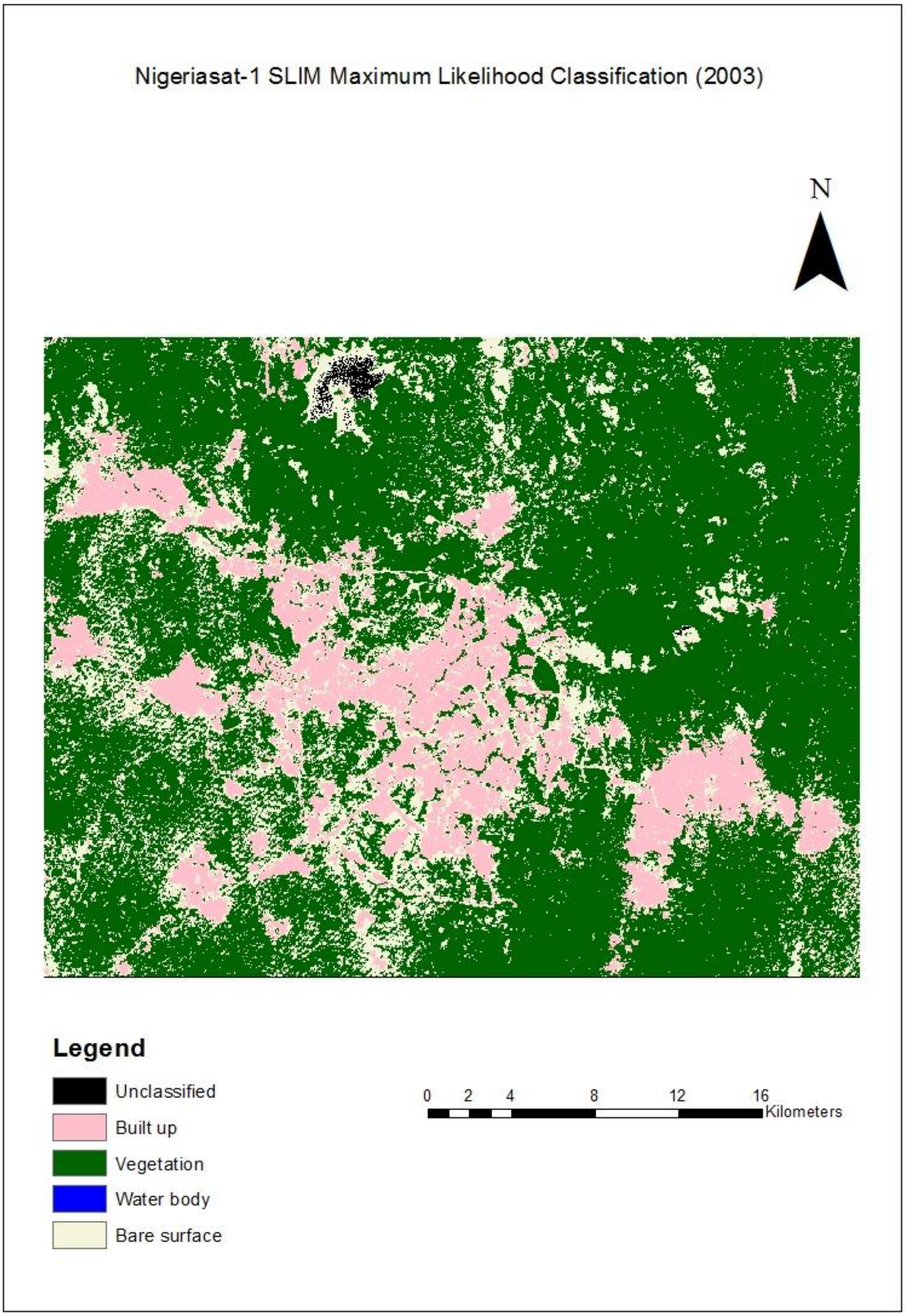


Fig. 4.2: 2003 Land cover map produced by Maximum Likelihood Classification

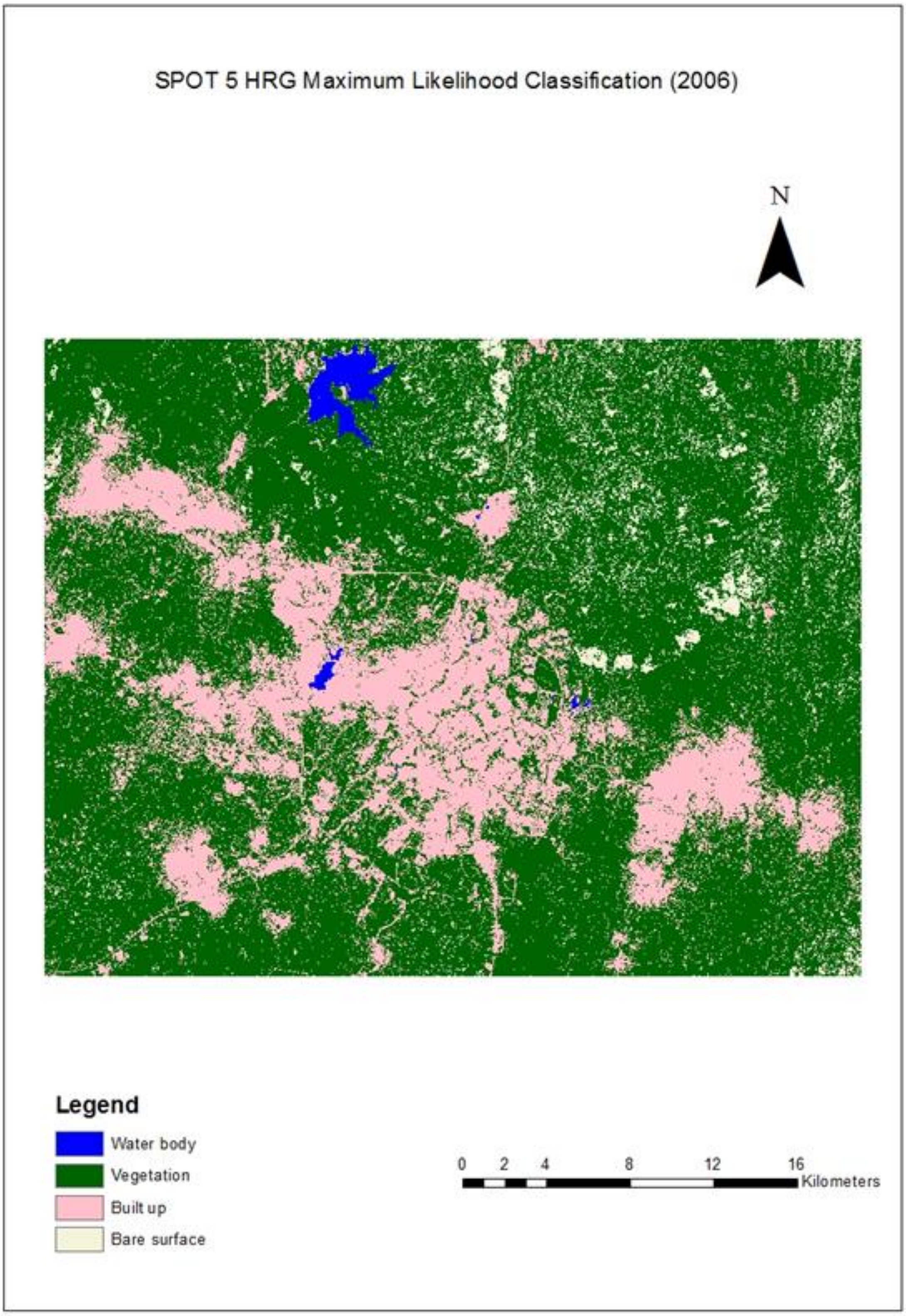


Fig. 4.3 2006 Land cover map produced by Maximum Likelihood Classification

Table 4.1: Error matrix for Landsat 7 ETM Maximum Likelihood Classification

Classified data ↓	**Reference data**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	48	1	0	2	51	94.12%
Vegetation	2	43	1	6	52	82.69%
Water body	0	0	29	0	29	100%
Bare surface	0	6	0	12	18	66.67%
Reference totals	50	50	30	20		
Producer's accuracy	96.00%	86.00%	96.67%	60.00%		
Overall accuracy	88.00%					
KIA	0.83					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.91
Vegetation	0.74
Water body	1.0
Bare surface	0.61

Table 4.2: Error matrix for Nigeriasat-1 SLIM Maximum Likelihood Classification

Classified data ↓	**Reference data**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Unclassified	_	_	15	_	15	-
Built up	42	0	3	2	47	89.36%
Vegetation	2	44	1	9	56	78.57%
Water body	0	0	0	0	0	-
Bare surface	6	6	11	9	32	28.13%
Reference totals	50	50	30	20		
Producer's accuracy	84%	88%	-	45%		
Overall accuracy	63.33%					
KIA	50.63%					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.84
Vegetation	0.67
Water body	0.00
Bare surface	0.17

Table 4.3: Error matrix for SPOT 5 HRG Maximum Likelihood Classification

Classified data ↓	Reference data						
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy	
Built up	46	3	0	1	50	92.00%	
Vegetation	4	46	1	6	57	80.70%	
Water body	0	0	29	0	29	100.00%	**Conditional Kappa for each Category.**
Bare surface	0	1	0	13	14	92.86%	Class Name Kappa
Reference totals	50	50	30	20			Built up 0.88
Producer's accuracy	92.00%	92.00%	96.67%	65.00%			Vegetation 0.71
Overall accuracy	89.33%						Water body 1.0
KIA	0.85						Bare surface 0.91

4.1.2 Object based Image Analysis (OBIA) with spectral properties of the images

The land cover maps produced with Object Based Image Analysis using only the spectral properties of the datasets to extract image objects are presented here. This is followed by the error matrices used to assess the accuracy of the classified maps.

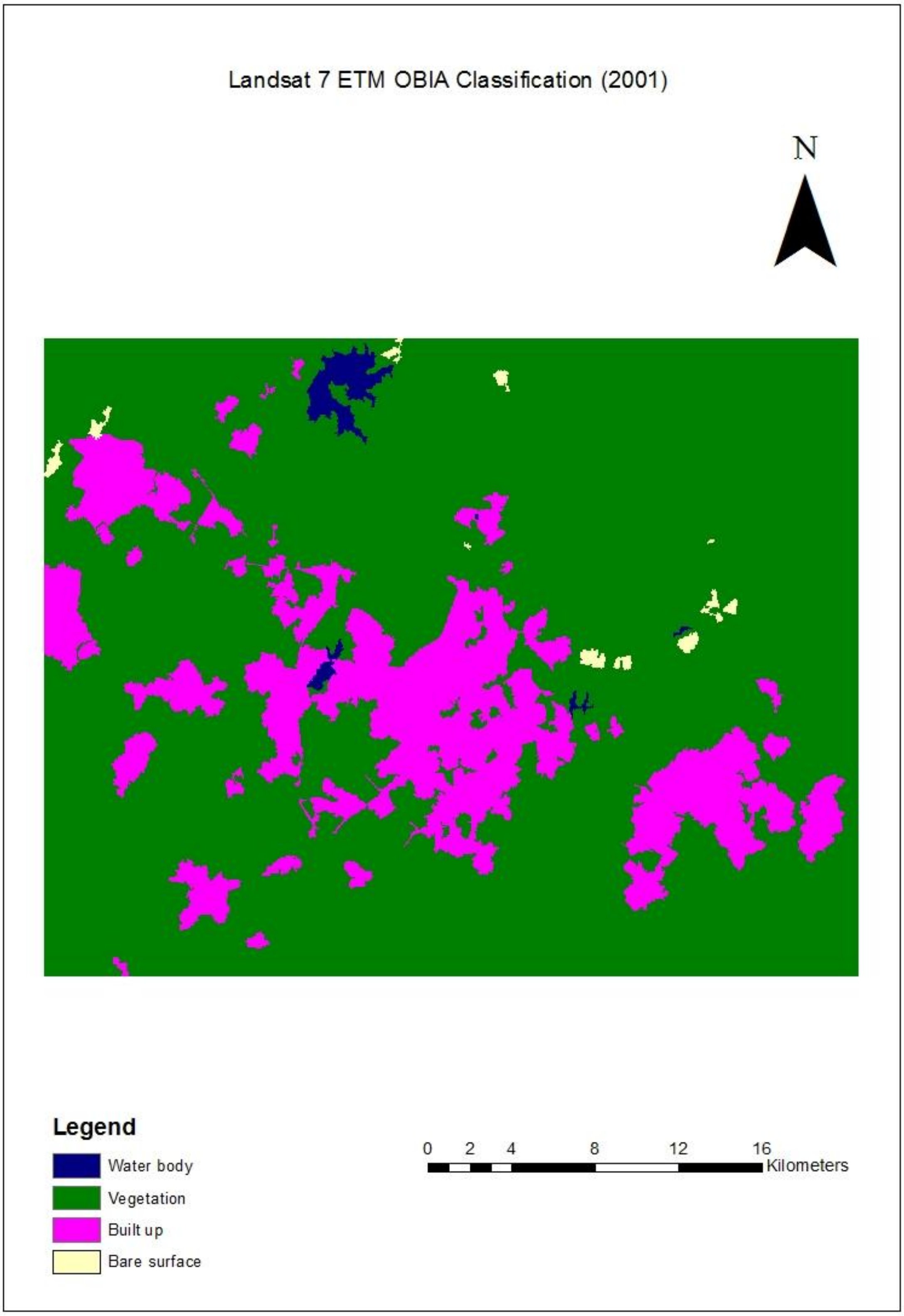


Fig. 4.4: 2001 Object Based Image Analysis (OBIA) with spectral properties

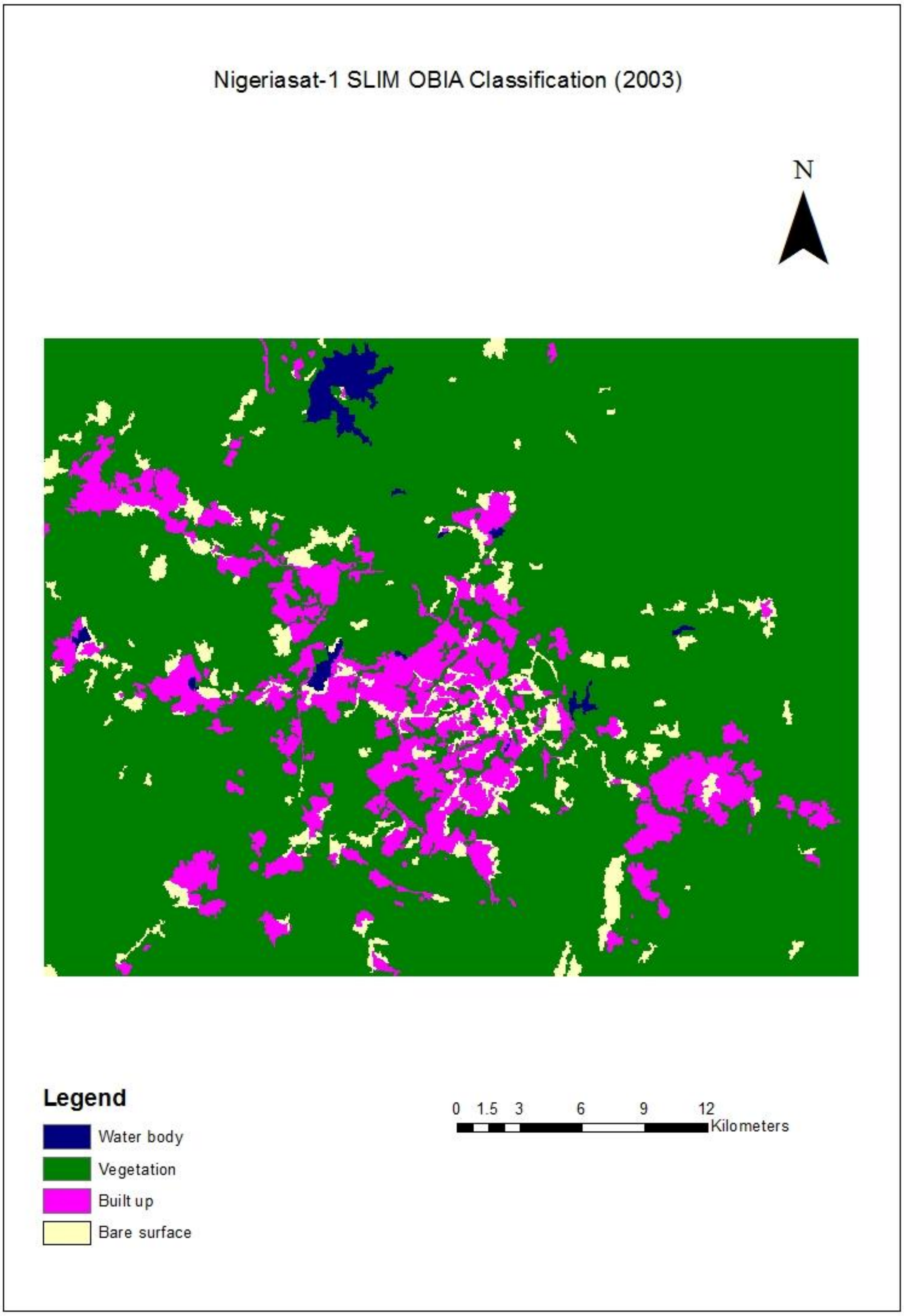


Fig. 4.5: 2003 Object Based Image Analysis (OBIA) with spectral properties

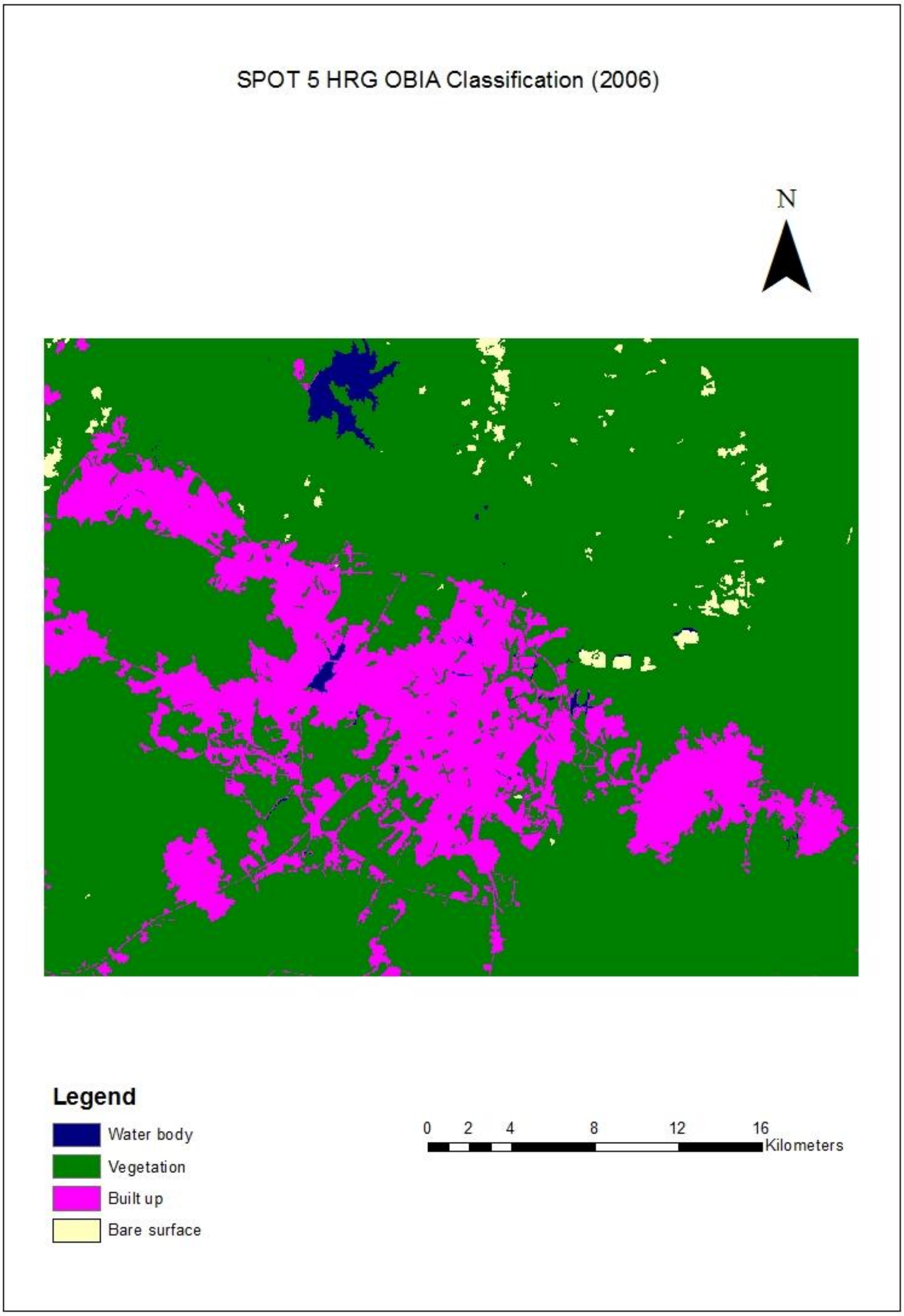


Fig. 4.6 2006 Object Based Image Analysis (OBIA) with spectral properties

Table 4.4: Error matrix for Landsat 7 ETM OBIA with spectral property

Classified data ↓	**Reference data**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	2550	284	12	0	2846	89.60%
Vegetation	749	9333	157	1520	11759	79.40%
Water body	0	0	6444	0	6444	1%
Bare surface	0	0	0	779	779	1%
Reference totals	3299	9617	6613	2299		
Producer's accuracy	77.30%	97.05%	97.44%	33.88%		
Overall accuracy	87.54%					
KIA	0.80					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.73
Vegetation	0.93
Water body	0.96
Bare surface	0.31

Table 4.5: Error matrix for Nigeriasat-1 SLIM OBIA with spectral properties

Classified data ↓	**Reference data**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	1646	54	37	0	1737	94.76%
Vegetation	623	7462	55	943	9083	82.15%
Water body	4	0	5174	0	5178	99.92%
Bare surface	344	162	5	871	1382	63.02%
Reference totals	2617	7678	5271	1814		
Producer's accuracy	62.90%	97.19%	98.16%	48.02%		
Overall accuracy	87.19%					
KIA	0.80					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.81
Vegetation	0.92
Water body	0.96
Bare surface	0.46

Table 4.6: Error matrix for SPOT 5 HRG OBIA with spectral properties

Classified data ↓	Reference data					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	20204	0	0	0	20204	100%
Vegetation	6556	78588	0	3093	88237	89.06%
Water body	11	0	53749	0	53760	99.98%
Bare surface	0	0	0	15478	15478	100%
Reference totals	26771	78588	53749	18571		
Producer's accuracy	75.47%	100%	100%	83.35%		
Overall accuracy	94.56%					
KIA	0.91					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.72
Vegetation	1.00
Water body	1.00
Bare surface	0.81

4.1.3 OBIA with Cadastre data

The land cover maps produced with a combination of Object Based Image Analysis and land use cadastre to extract image objects are presented here. This is followed by the error matrices used to assess the accuracy of the classified maps.

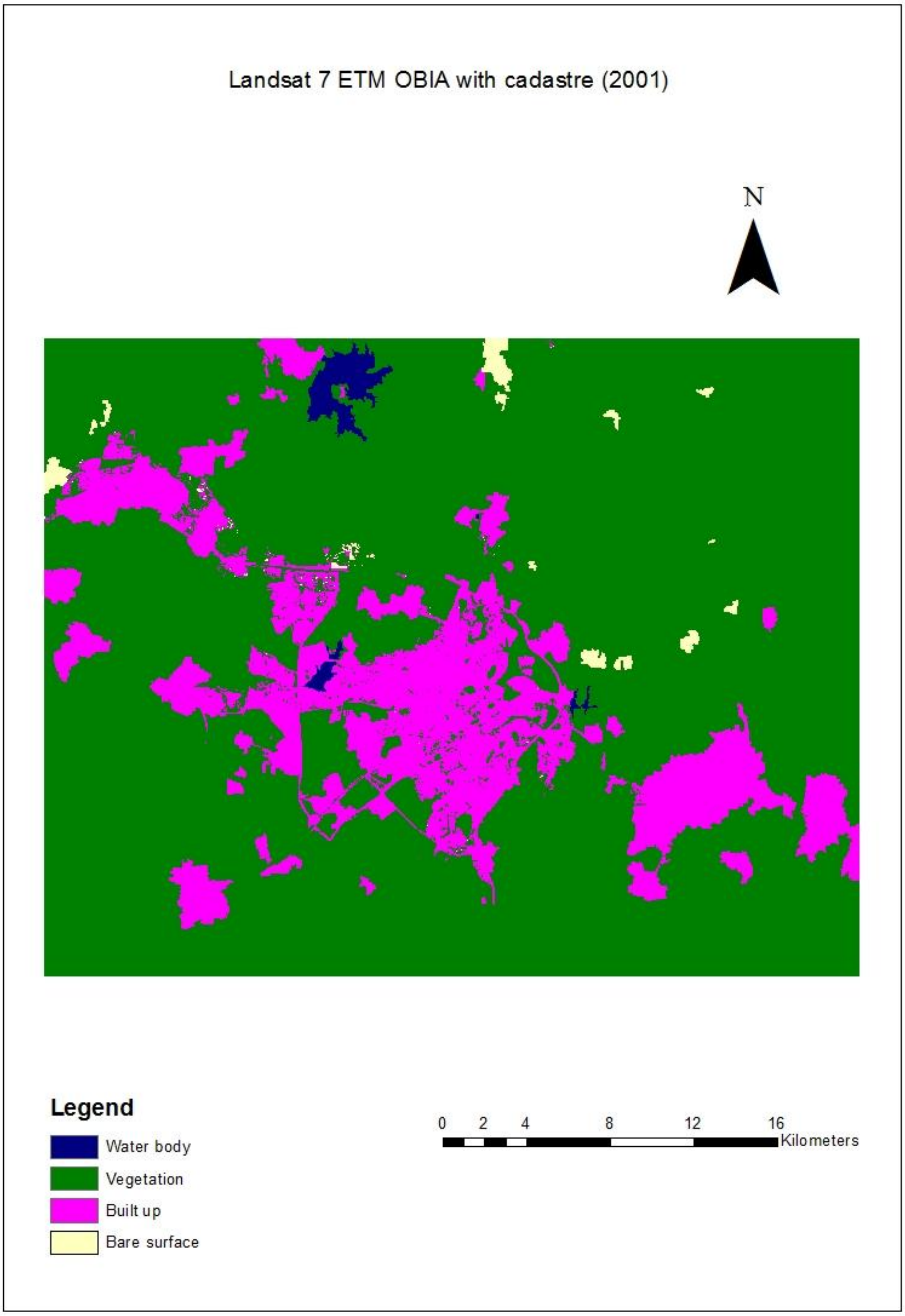


Fig. 4.7 Landsat 7 ETM 2001 OBIA with Cadastre data

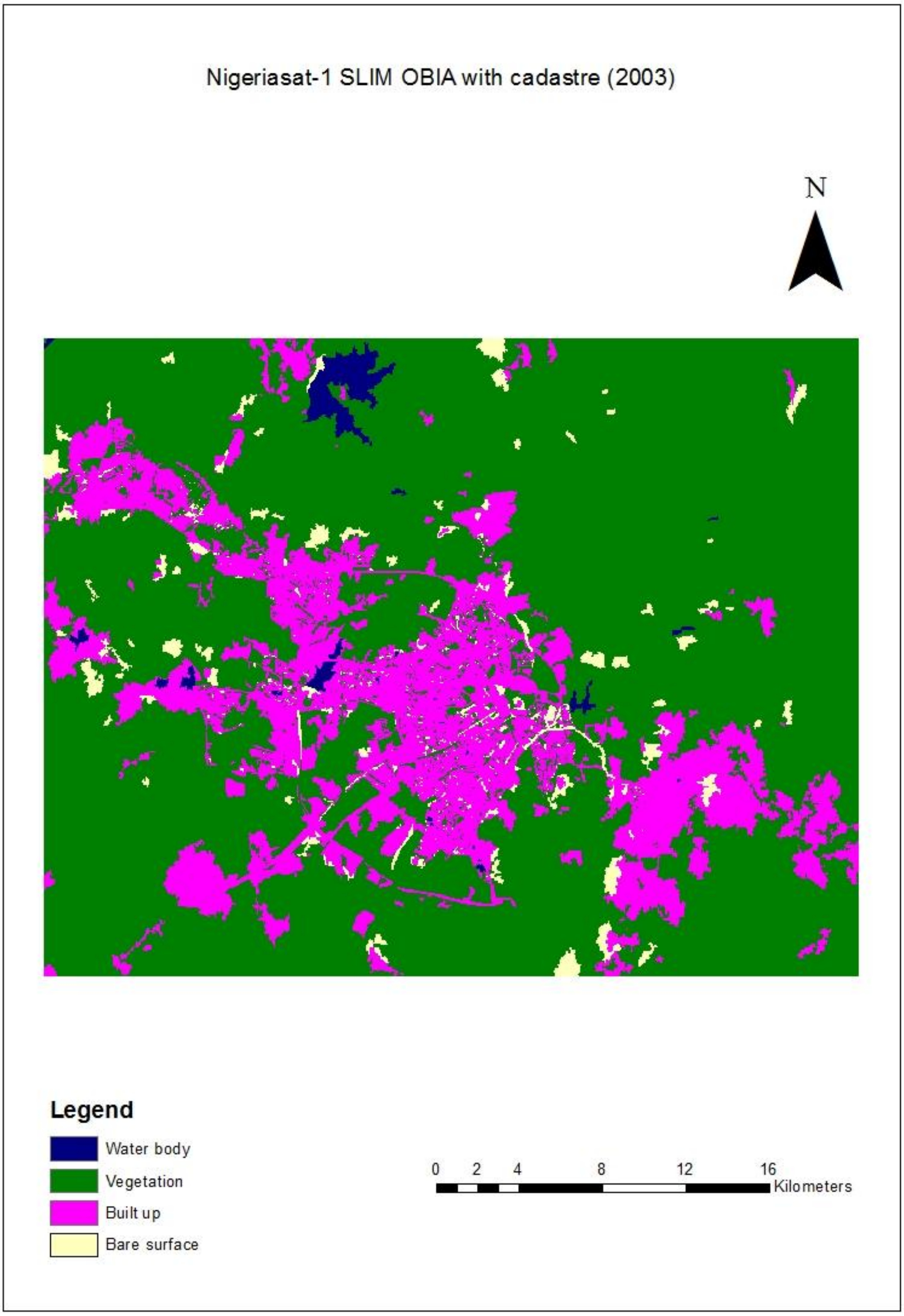


Fig. 4.8 Nigerisat-1 SLIM 2003 OBIA with Cadastre data

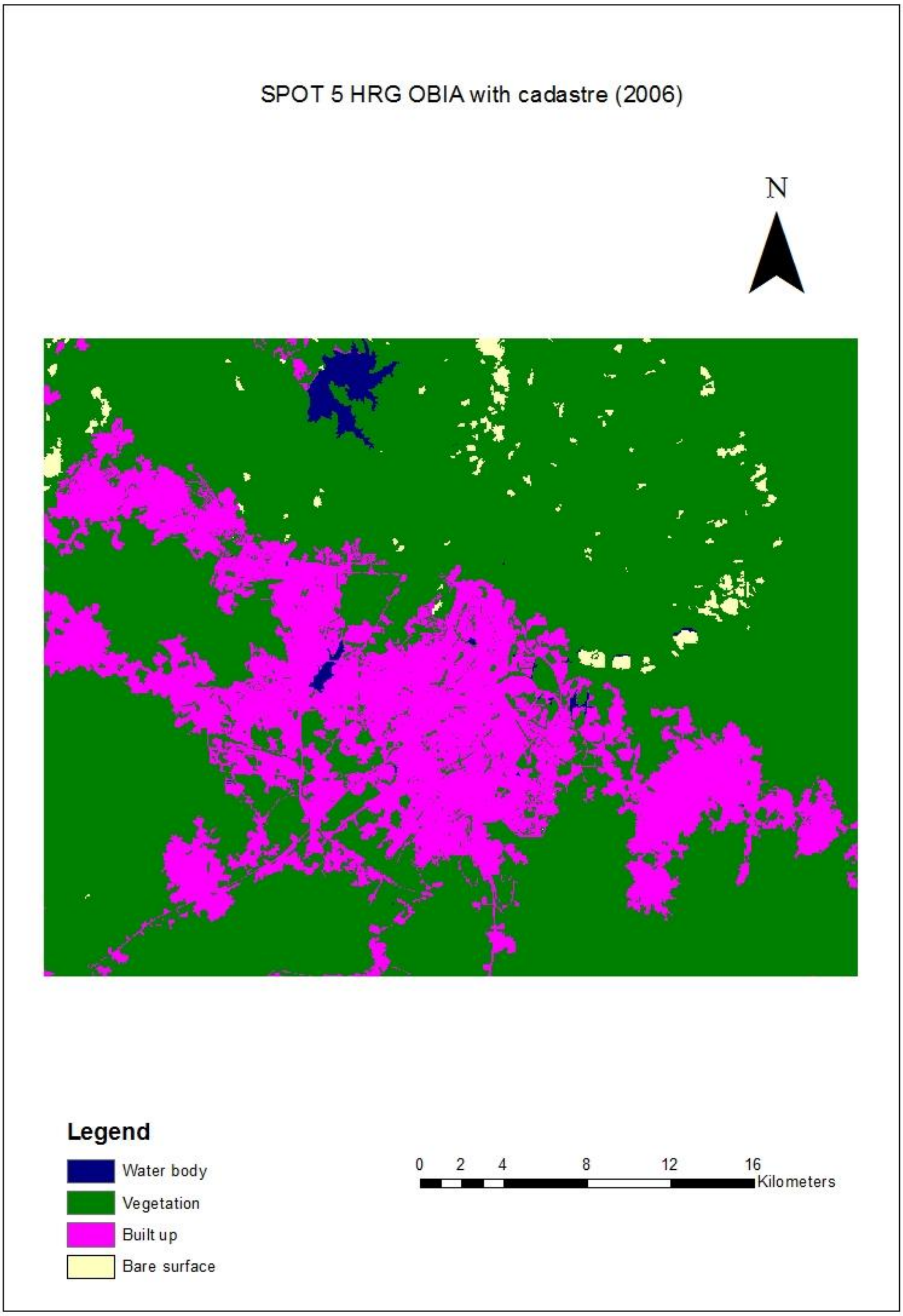


Fig. 4.9 SPOT 5 HRG 2006 OBIA with Cadastre data

Table 4.7: Error matrix for Landsat 7 ETM OBIA with cadastre data

Classified data ↓	**Reference data**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	2783	0	0	0	2783	100%
Vegetation	516	9637	162	1051	11366	84.79%
Water body	0	0	6451	0	6451	100%
Bare surface	0	0	0	1248	1248	100%
Reference totals	3299	9637	6613	2299		
Producer's accuracy	84.36%	100.00%	97.55%	54.28%		
Overall accuracy	92.09%					
KIA	0.87					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.82
Vegetation	1.0
Water body	0.96
Bare surface	0.51

Table 4.8 Error matrix for Nigeriasat-1 SLIM OBIA with cadastre data

Classified data ↓	**Reference data**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	2189	195	0	0	2384	94.70%%
Vegetation	196	7388	119	905	8608	97.18%%
Water body	9	0	5149	0	5158	99.99%
Bare surface	223	95	3	909	1230	73.84%
Reference totals	2617	7678	5271	1814		
Producer's accuracy	83.65%	96.22%	97.69%	50.11%		
Overall accuracy	89.96%					
KIA	0.84					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.81
Vegetation	0.92
Water body	0.96
Bare surface	0.46

Table 4.9: Error matrix for SPOT 5 HRG OBIA with cadastre data

Classified data ↓	**Reference data _**					
	Built up	Vegetation	Water body	Bare surface	Row totals	User's accuracy
Built up	22937	54	0	0	22991	99.77%
Vegetation	3834	78534	0	1722	84090	93.39%
Water body	0	0	53749	0	53749	100%
Bare surface	0	0	0	16849	16849	100%
Reference totals	26771	78588	53749	18571		
Producer's accuracy	85.68%	99.93%	100%	90.73%		
Overall accuracy	96.84%					
KIA	0.95					

Conditional Kappa for each Category.	
Class Name	Kappa
Built up	0.83
Vegetation	0.99
Water body	1.00
Bare surface	0.89

4.1.4 Land use maps

The Land use maps produced from the combinations of OBIA and land use cadastre are presented in this subsection.

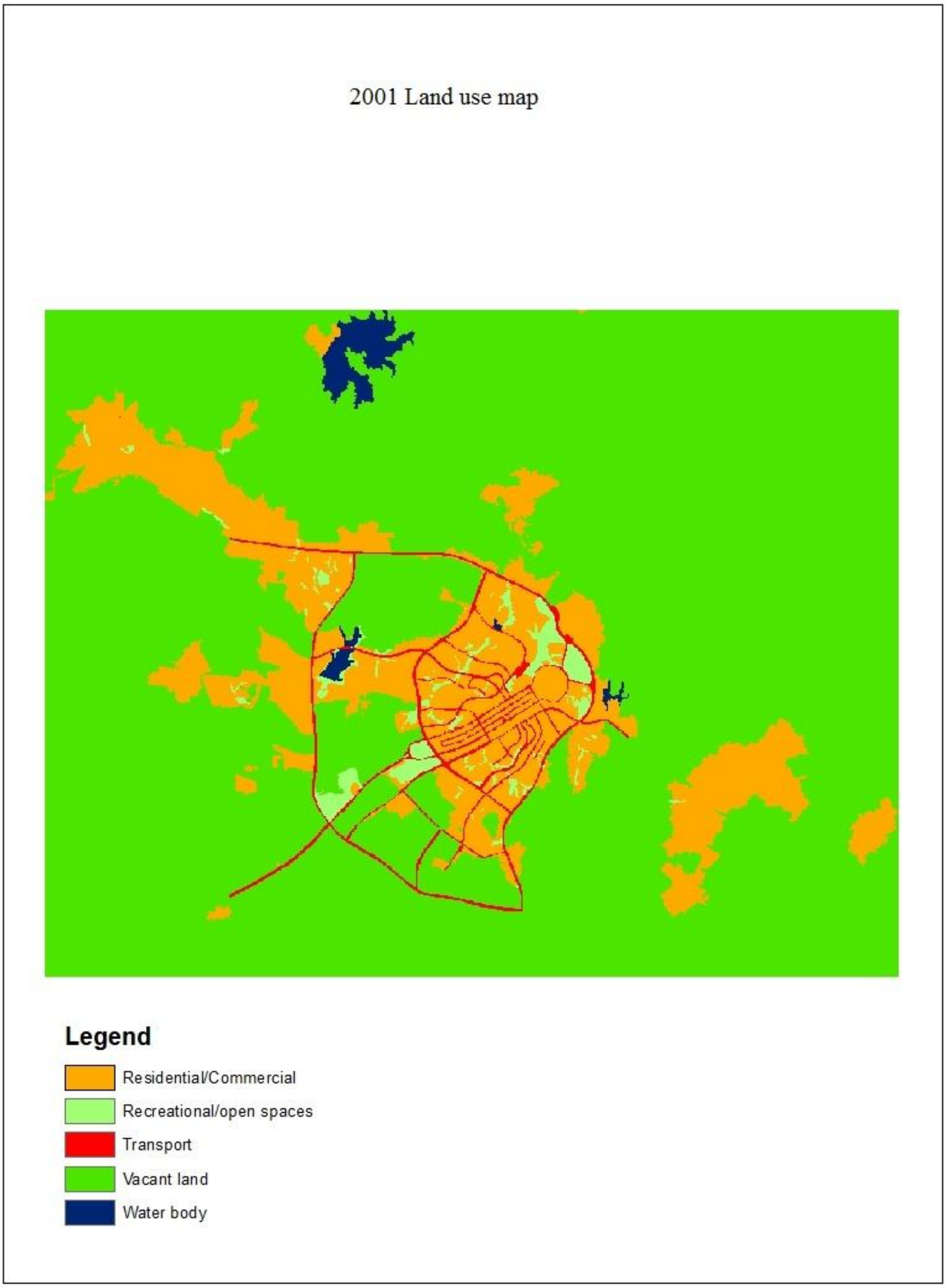


Fig.4.10 2001 Land use map of Abuja

Fig.4.11 2003 Land use map of Abuja

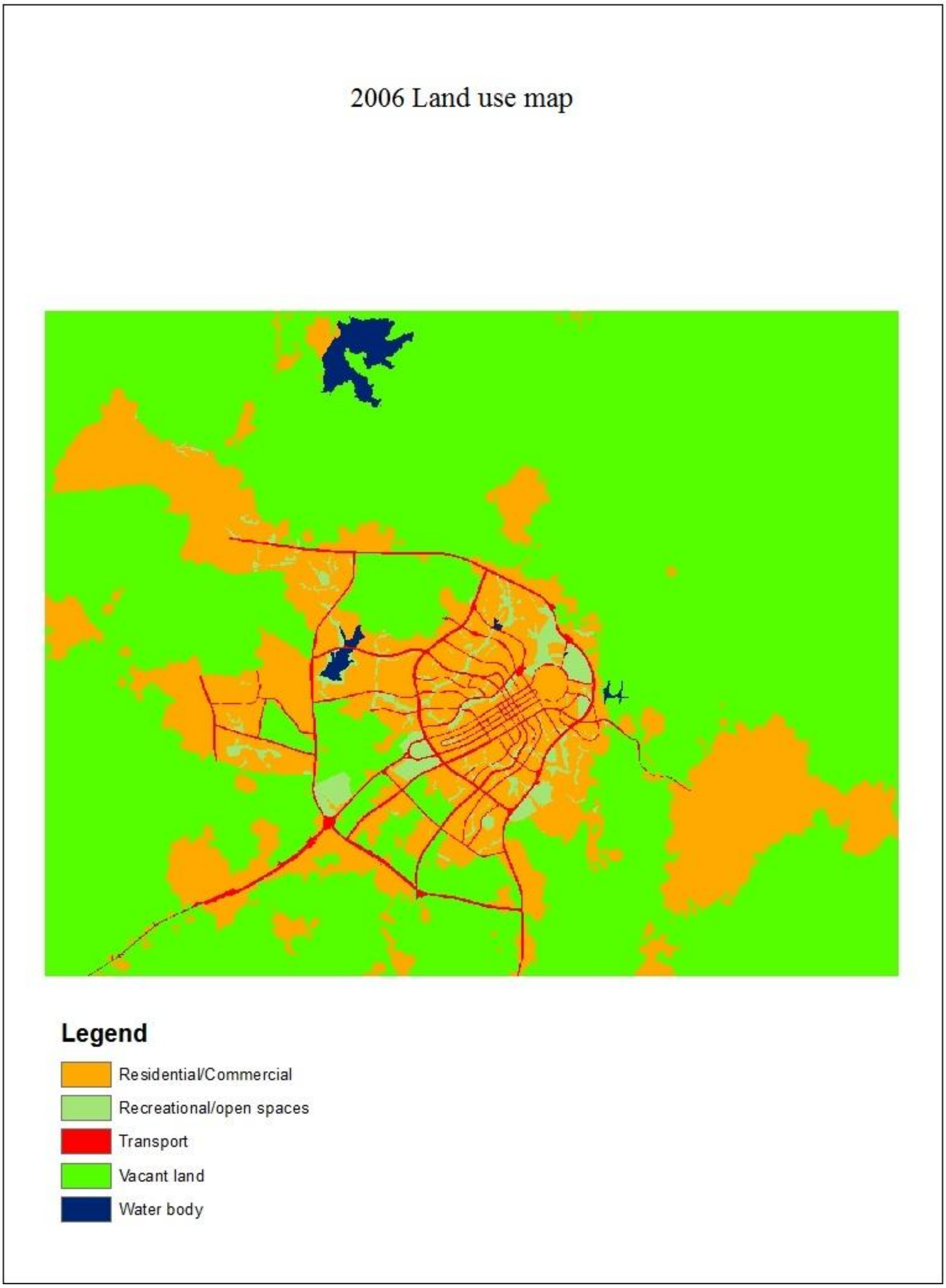


Fig.4.12: 2006 Land use map of Abuja

4.1.5 Results of the modelling of the land use change

The results of the land use prediction implemented with CA Markov module in Idrisi Taiga are presented here.

Detailed explanations on the trajectory of change predicted by the modelling tools are presented in discussions chapter.

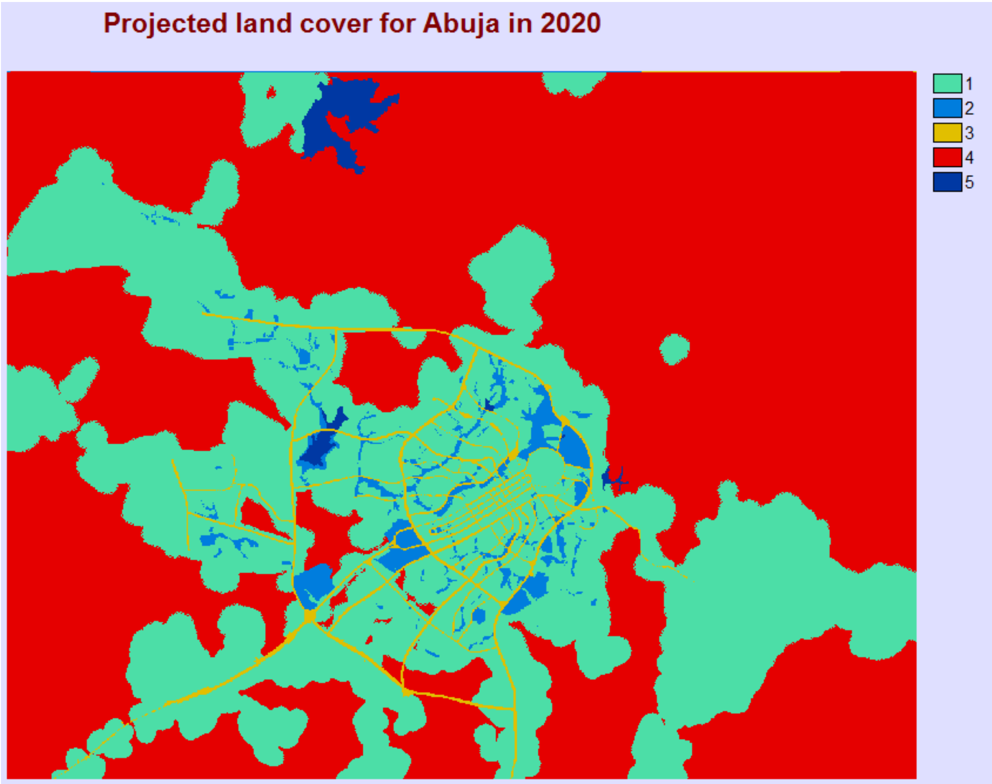


Fig. 4.13 Projected land cover for Abuja in 2020 using CAmarlov

Legend: 1- Residential/commercial, 2- Rec. /open spaces, 3-Transport, 4-Vacant land, 5- Water body.

4.2 Analysis of the results

The section presents the analyses of the error matrices and the classified maps. The error matrices were also analysed to help determine which aspects of the classification helped to improve or reduce the classification accuracies recorded in the land cover maps. In order to identify the exact locations of change in the years under study, a cross tabulation of the classified maps was carried out. This procedure helped to identify locations where change had taken place during the years under study and also identify areas where minor changes may have occurred due image registration errors

4.2.1 Assessing the classification accuracy assessment.

Accuracy assessment is a key component of any project employing spatial data, which helps to ensure that the resulting information has enough quality to be used for decision making processes (Congalton 2001). Anderson *et al.* (1976) recommended that minimum level of classification accuracy, in the identification of land use and land cover categories from remotely sensed data, should be at least 85%. This suggestion is particularly relevant in the identification of broad land cover classes, such as those in Anderson's Level 1 land cover mapping (Foody 2008), which has been used for the identification of land cover classes from sensors like Landsat 7 ETM (28.5m), Nigeriasat-1 SLIM (30m) and SPOT 5 HRG (10m) in this study. To ascertain the usefulness of the maps derived from this study the results from the error matrix were analysed for classification accuracy.

The individual classification accuracy for the 3 datasets showed that Overall Accuracy (OA) for the land cover maps produced from Maximum Likelihood Classification were 88% for Landsat 7 ETM, 63% for Nigeriasat-1 SLIM and 89% for SPOT 5 HRG. These figures showed that in terms of Overall OA the Nigeriasat-1 data had the lowest percentage. The Kappa Index of Agreement (KIA) also showed that the land cover map from Nigeriasat-1 recorded a moderate agreement (0.50) with the reference data. While the maps produced from Landsat 7 and SPOT -5 recorded a strong agreement at 0.83 and 0.85 respectively. The reasons for these low accuracy results in the land cover map produced from the Nigeriasat-1 data was evident when the Conditional kappa for each of the classified categories were examined. As shown in Table 4.10, two of the land cover categories, water body (0.00) and bare surface had (0.17), had very low agreement with the reference data. These two categories contributed to the low OA of the Nigeriasat-1 classification.

Table 4.10: Results from Maximum Likelihood Classification of the datasets

Sensor/ Data	Overall Accuracy%	Kappa Index of Agreement	Conditional kappa per category			
			Built up	Vegetation	Water body	Bare surface
Landsat7 ETM	88%	0.83	0.91	0.74	1.00	0.61
Nigeriasat-1 SLIM	63%	0.50	0.84	0.67	0.00	0.17
SPOT 5 HRG	89%	0.85	0.88	0.71	1.00	0.91

The result of the Maximum Likelihood Classification shows that the classification of the Nigeriasat-1 data did not have a high classification accuracy that would permit its usage for land use or land cover analysis. According to Foody (2002), accuracy assessment helps to determine if maps produced from land use/ land cover classification have sufficient or "insufficient quality for operational applications". This informed the use of OBIA for the analysis of the datasets because based on the literature review (see Section 2.12) there is the likelihood that OBIA based methods would produce land use maps with higher classification accuracies; which can be used for LULC analysis.

Extracts from the error matrix results of the OBIA (in Table 4.11) shows that OA achieved with OBIA was higher than those achieved from the Maximum Likelihood Classification in respect of the Nigeriasat-1 and SPOT 5 classifications. As earlier shown in Table 4.10 in Maximum Likelihood Classification the OA for Nigeriast-1 was 63%, SPOT 5 was 89%. With OBIA, the datasets returned the values of 87% and 94% respectively. The figure was however, 88% for the land cover map produced from Landsat 7. The kappa index of agreement from the OBIA analysis also showed strong agreement between the datasets and reference datasets.

Table 4.11: Results of OBIA (with spectral) classification of the datasets

Sensor/ Data	Overall Accuracy%	Kappa Index of Agreement	Conditional kappa per category			
			Built up	Vegetation	Water body	Bare surface
Landsat7 ETM	88%	0.80	0.73	0.93	0.96	0.31
Nigeriasat-1 SLIM	87%	0.80	0.58	0.94	0.97	0.17
SPOT 5 HRG	94%	0.91	0.72	1.00	1.00	0.81

From Table 4.11, the Conditional kappa for each category also showed strong agreement for water body and vegetation in the three land cover maps. In the built up category the Conditional Kappa showed moderate agreement for the three maps. However, the bare surface category showed low agreement for the maps from Landsat 7 and Nigeriasat-1 while showing strong agreement for the SPOT 5 map. The moderate to low agreement between the land cover maps and the reference data indicates that land cover maps produced from Landsat 7, Nigerisat-1 and SPOT 5 classifications do not meet the criteria for inclusion in a mapping project because it had insufficient quality. To improve the results an extra layer of ancillary data was integrated into the OBIA process to improve the classification. It has been noted that sometimes spectral information is not enough for image analysis (Definiens 2006).

The results of the error matrix of the OBIA with the cadastre presented in Table 4.12 show that OA for three land cover maps are Landsat 7 92%, Nigeriasat-1 89% and SPOT 96%. In addition, the KIA shows strong agreement with the reference data as follows Landsat 7 0.82, Nigeriasat-1 0.81 and SPOT 5 0.83. The conditional kappa per category also shows that the three land cover maps have moderate to high agreement. Maps from Nigeriasat-1 and Landsat 7 have 0.46 and 0.51 respectively while the SPOT-5 has 0.89 for the bare surface category.

Table 4.12 Results of OBIA with cadastre

Sensor/ Data	Overall Accuracy%	Kappa Index of Agreement	Conditional kappa per category			
			Built up	Vegetation	Water body	Bare surface
Landsat7 ETM	92%	0.87	0.82	1.00	0.96	0.51
Nigeriasat-1 SLIM	89%	0.84	0.81	0.92	0.96	0.46
SPOT 5 HRG	96%	0.95	0.83	0.99	1.00	0.89

A comparison of the Overall Accuracy and Kappa Index of Agreement results from the error matrices is presented in graphical form in Fig. 4.14. The comparison of the conditional kappa for the three land cover maps is also presented in Fig. 4.15. From the comparison in Fig. 4.14, it can be seen that the is above 85% and kappa index of agreement is above 80% for all the land cover categories in the land cover maps produced with the aid of the land use cadastre. This improvement in classification accuracy is also reflected in conditional kappa values shown in Fig. 4.15. These conditional kappa values indicate moderate to strong agreement in values ranging from 0.46 for bare surface to 1 for vegetation and water body. A marked departure from the values recorded in the pixel based classification especially for the water body category which had a conditional kappa value of 0 (refer to Table 4.10) in the land cover map produced from Nigeriasat-1 SLIM data.

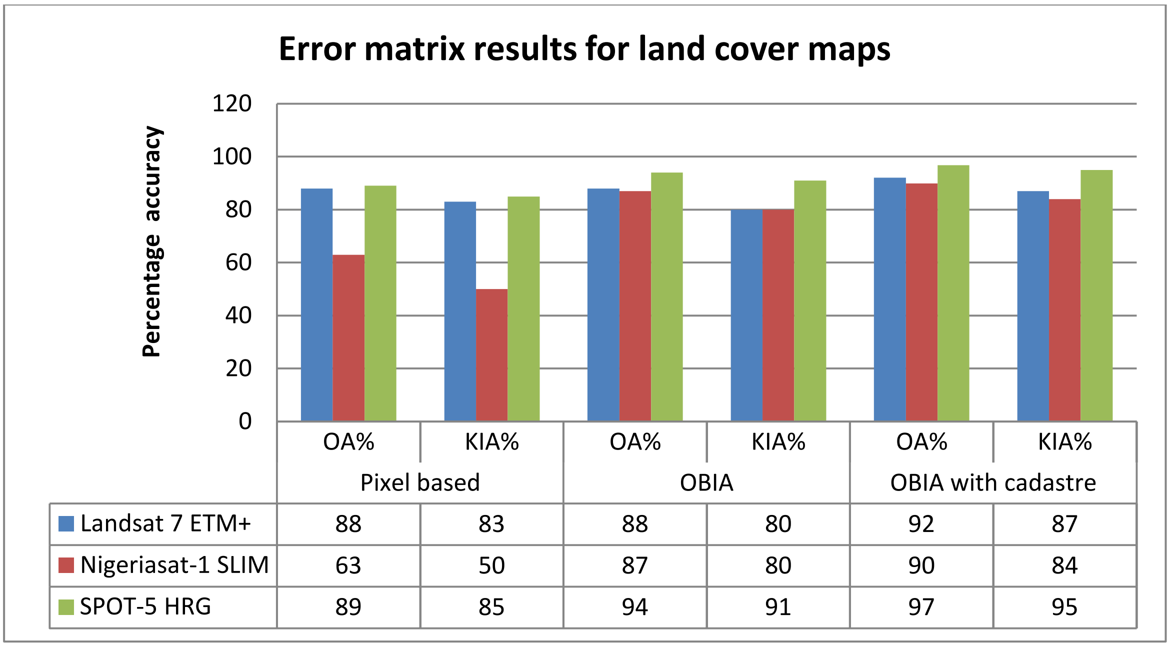
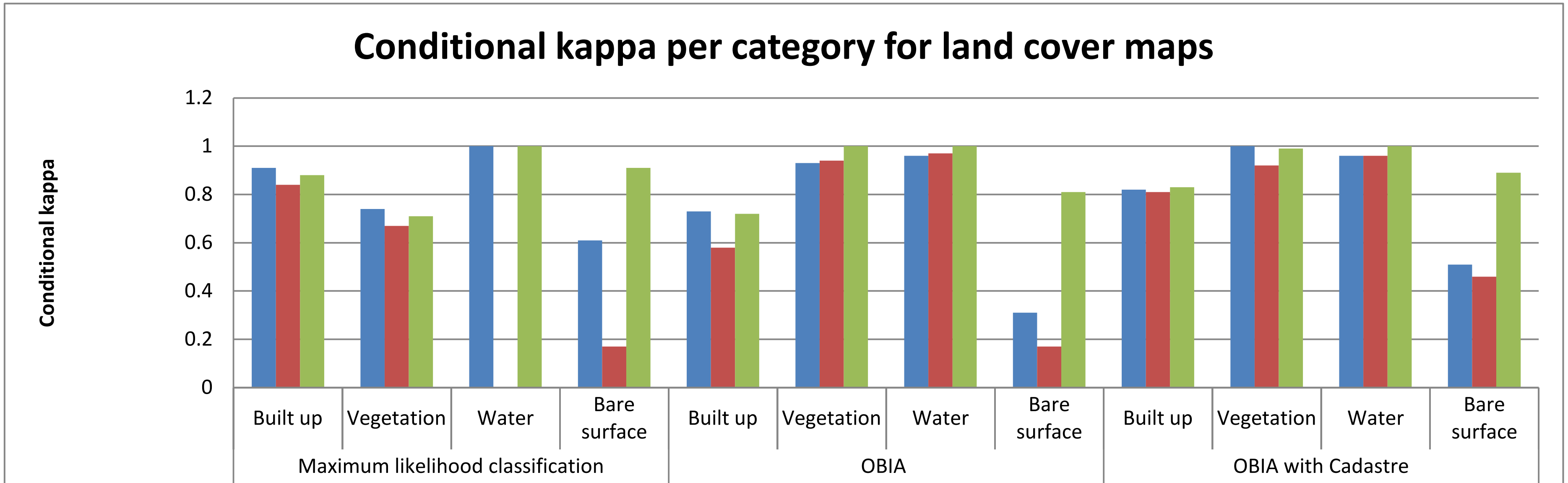


Fig. 4.14 A comparison of the error matrix results from the land cover maps for 2001 (Landsat 7 ETM), 2003 (Nigeriasat-1 SLIM) and 2006 (SPOT 5 HRG). The statistics are provided as percentages for the OA and KIA



	Maximum likelihood classification				OBIA				OBIA with Cadastre			
	Built up	Vegetation	Water	Bare surface	Built up	Vegetation	Water	Bare surface	Built up	Vegetation	Water	Bare surface
Landsat 7 ETM	0.91	0.74	1	0.61	0.73	0.93	0.96	0.31	0.82	1	0.96	0.51
Nigeriasat-1 SLIM	0.84	0.67	0	0.17	0.58	0.94	0.97	0.17	0.81	0.92	0.96	0.46
SPOT5 HRG	0.88	0.71	1	0.91	0.72	1	1	0.81	0.83	0.99	1	0.89

Fig. 4.15 Conditional Kappa for the three land cover maps from Landsat 7 ETM, Nigeriasat-1 SLIM and SPOT 5 HRG showing the improvements in classification for the land cover categories. The improvement is particularly noticeable for water body in Nigeriasat-1 SLIM with 0 kappa in Maximum Likelihood Classification compared to 0.96 in OBIA with cadastre

4.2.2 Analysis of the classified maps

Post classification change detection techniques were applied after the co-registered images were separately classified from 2001, 2003 and 2006. The change between 2001 and 2006 detected from satellite imagery helped to analyse and understand the growth and development of Abuja from the perspective of land use and land cover development.

This sub-section presents a cross classification of the maps derived from the OBIA and land use cadastre. The cross classification was used to tease out areas of land use change. In Fig 4.16 cross-classification of 2001 and 2003 land use maps is presented. The details in the cross classified maps are explained in the Tables 4.13 and 4.14. The land coverage area for the land use classes was calculated from the classified images derived from the object based image analysis.

The cross classification for the 2001 and 2003 Land use maps is presented in Fig. 4.16.The details are explained in Tables 4.13 with a summary in Table 4.14.

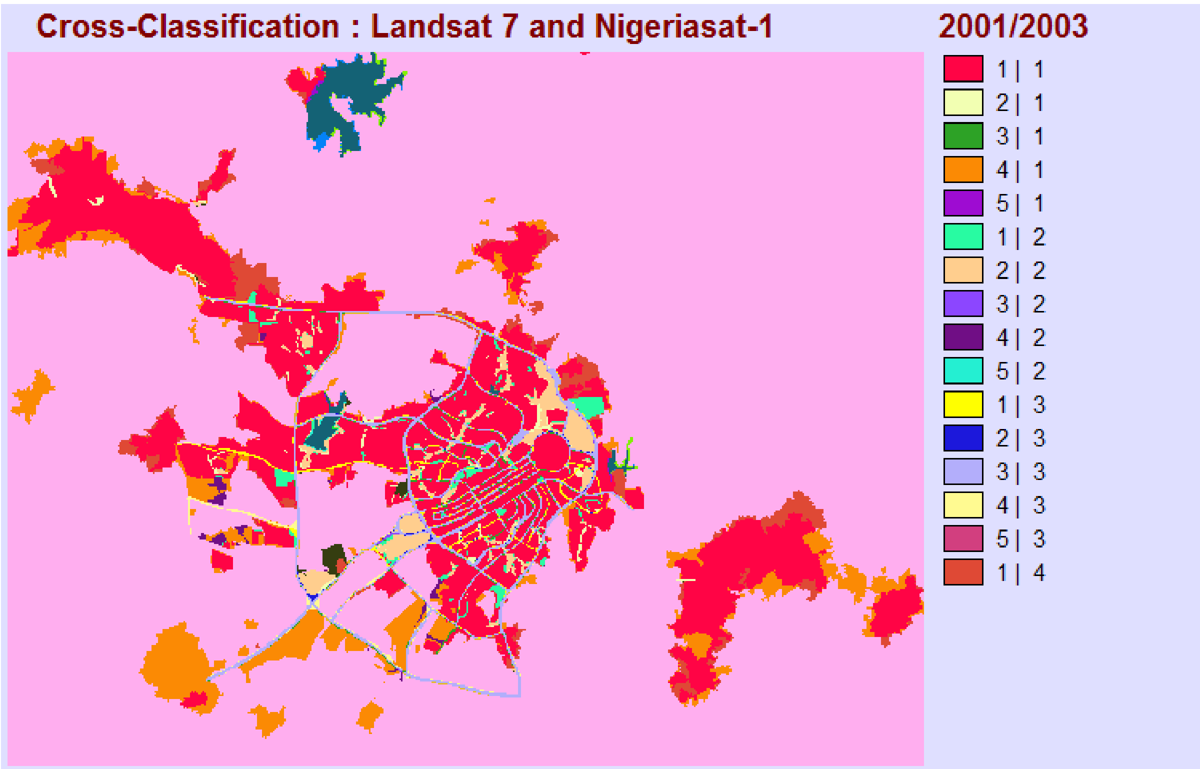


Fig. 4.16 Cross-tabulation of 2001 and 2003 classification.

The image presented here displays the first 16 lines of the legend in the native format of the Idrisi software used for this research. The full legend and the changes are explained in Table 4.13

Table 4.13 Cross tabulation of classification for 2001 and 2003

Area-km²	*2001*	*2003*	*Change(C) /no Change(NC)*	*Observation*
137.60	1-Res./com.	1-Res./com.	NC	Same area
2.63	2-Rec. /open spaces.	1-Res./com.	C	Infilling
2.28	3-Transport	1-Res./com.	NC	Spectral confusion
40.60	4-Vacant land	1-Res./com.	C	Sprawl
0.24	5-Water body	1-Res./com.	C	Urban infilling
4.51	1-Res./com.	2-Rec. /open spaces.	C	Development control
10.75	2-Rec. /open spaces.	2-Rec. /open spaces.	NC	Same area
0.38	3-Transport	2-Rec. /open spaces.	C	Open spaces beside roads
1.59	4-Vacant land	2-Rec. /open spaces.	C	development
0.12	5-Water body	2-Rec. /open spaces.	C	Spectral
3.66	1-Res./com.	3-Transport	NC	Spectral confusion
0.36	2-Rec. /open spaces.	3-Transport	NC	Spectral confusion
14.01	3-Transport	3-Transport	NC	Same area
1.54	4-Vacant land	3-Transport	C	Urban spread
0.01	5-Water body	3-Transport	NC	misclassification
15.59	1-Res./com.	4-Vacant land	C	Development control
1.25	2-Rec. /open spaces.	4-Vacant land	C	Spectral confusion
0.67	3-Transport	4-Vacant land	C	Spectral confusion/ unpaved roads
888.52	4-Vacant land	4-Vacant land	NC	Same area
0.70	5-Water body	4-Vacant land	NC	misclassification
0.06	1-Res./com.	5-Water body	NC	Artefacts of data
0.04	2-Rec. /open spaces.	5-Water body	NC	Image registration
0.00	3-Transport	5-Water body	NC	Artefacts of data
0.79	4-Vacant land	5-Water body	NC	Vacant flooded lakeside
9.45	5-Water body	5-Water body	NC	Same area

Table 4.14 Matrix showing areas of land use change in Abuja between 2001 and 2003 in Sq. km (%)*

		2003					
		Residential/ commercial	Recreational/ open spaces	Transportation	Vacant land	Water body	Total (Sq. Km^2)
2001	Residential/ commercial	**137.60 (12.10%)**	4.51 (0.40%)	3.7 (0.32%)	15.59 (1.37%)	0.06 (0.01%)	161.43
	Recreational/ open spaces	2.63 (0.23%)	**10.75 (0.94%)**	0.4 (0.03%)	1.25 (0.11%)	0.04 (0.00%)	15.02
	Transportation	2.28 (0.20%)	0.38 (0.03%)	**14.0 (1.23%)**	0.67 (0.06%)	0.00 (0.00%)	17.33
	Vacant land	40.60 (3.57%)	1.59 (0.14%)	1.5 (0.14%)	**888.52 (78.12%)**	0.79 (0.07%)	933.05
	Water body	0.24 (0.02%)	0.12 (0.01%)	0.0 (0.00%)	0.70 (0.06%)	**9.45 (0.83%)**	10.52
	Total (Km^2)	183.34	17.35	19.6	906.73	10.34	1137.34

- The diagonal entries(in red) indicate areas of no change

The cross classification for the 2003 and 2006 Land use maps is presented in Fig. 4.17.The details are explained in Tables 4.15 followed by a summary in Table 4.16

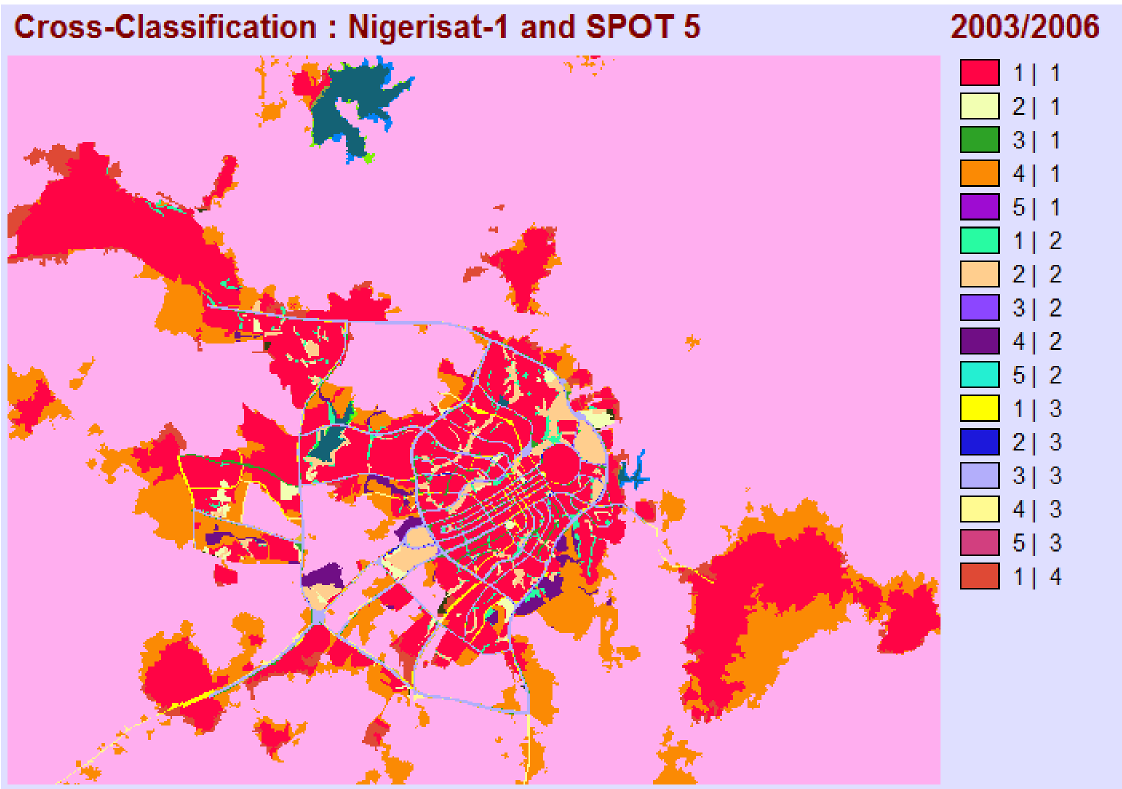


Fig. 4.17 Cross-tabulation of 2003 and 2006 classification

The image presented here displays the first 16 lines of the legend in the native format of the Idrisi software used for this research. The full legend and changes in land use are explained in Table 4.15

Table 4.15 Cross-tabulation of classification for 2003 and 2006

Area KM^2	2003	2006	Change(C) /No change(NC)	Observation
162.05	1-Res./com.	1-Res./com.	NC	Same area
4.72	2-Rec. /open spaces.	1-Res./com.	C	infilling
3.22	3-Transport	1-Res./com.	C	Spectral confusion
81.85	4-Vacant land	1-Res./com.	C	Infilling, sprawl, development
0.01	5-Water body	1-Res./com.	NC	Artefacts of data
4.04	1-Res./com.	2-Rec. /open spaces.	C	land use conversion
11.68	2-Rec. /open spaces.	2-Rec. /open spaces.	NC	Same area
0.45	3-Transport	2-Rec. /open spaces.	C	Open spaces at road sides
5.47	4-Vacant land	2-Rec. /open spaces.	C	Infilling and development
0.04	5-Water body	2-Rec. /open spaces.	NC	Image registration error
3.55	1-Res./com.	3-Transport	NC	Spectral confusion
0.30	2-Rec. /open spaces.	3-Transport	NC	Spectral confusion
15.29	3-Transport	3-Transport	NC	Same area
1.71	4-Vacant land	3-Transport	C	Urban development
0.00	5-Water body	3-Transport	NC	Artefacts of data
13.47	1-Res./com.	4-Vacant land	NC	Spectral confusion at the edges
0.50	2-Rec. /open spaces.	4-Vacant land	NC	Spectral confusion at the edges
0.61	3-Transport	4-Vacant land	NC	Spectral confusion at the edges
817.21	4-Vacant land	4-Vacant land	NC	Same area
1.45	5-Water body	4-Vacant land	NC	Vacant land liable to flood at lake edge
0.23	1-Res./com.	5-Water body	NC	Image registration error
0.16	2-Rec. /open spaces.	5-Water body	NC	Image registration error
0.02	3-Transport	5-Water body	NC	Artefacts of data
0.49	4-Vacant land	5-Water body	NC	Lake edge liable to flooding
8.84	5-Water body	5-Water body	NC	Same area

Table 4.16 Matrix showing areas of land use change in Abuja between 2003 and 2006 in Sq. km (%)*

		2006					
		Residential/ commercial	Recreational / open spaces	Transportation	Vacant land	Water body	Total (Km^2)
2003	Residential/ commercial	**162.05 (14.25%)**	4.04 (0.36%)	3.55 (0.31%)	13.47 (1.18%)	0.23 (0.02%)	183.34
	Recreational/ open spaces	4.72 (0.41%)	**11.68 (1.03%)**	0.30 (0.03%)	0.50 (0.04%)	0.16 (0.01%)	17.35
	Transportation	3.22 (0.28%)	0.45 (0.04%)	**15.29 (1.34%)**	0.61 (0.05%)	0.02 (0.00%)	19.58
	Vacant land	81.85 (7.20%)	5.47 (0.48%)	1.71 (0.15%)	**817.21 (71.85%)**	0.49 (0.04%)	906.73
	Water body	0.01 (0.00%)	0.04 (0.00%)	0.00 (0.00%)	1.45 (0.13%)	**8.84 (0.78%)**	10.34
	Total (Sq. Km^2)	251.85	21.68	20.85	833.23	9.74	1137.34

- Diagonal entries (in red) are areas of no change

The cross classification for the 2001 and 2006 Land use maps is presented in Fig. 4.18.The details are explained in Tables 4.17 followed by a summary in Table 4.18.

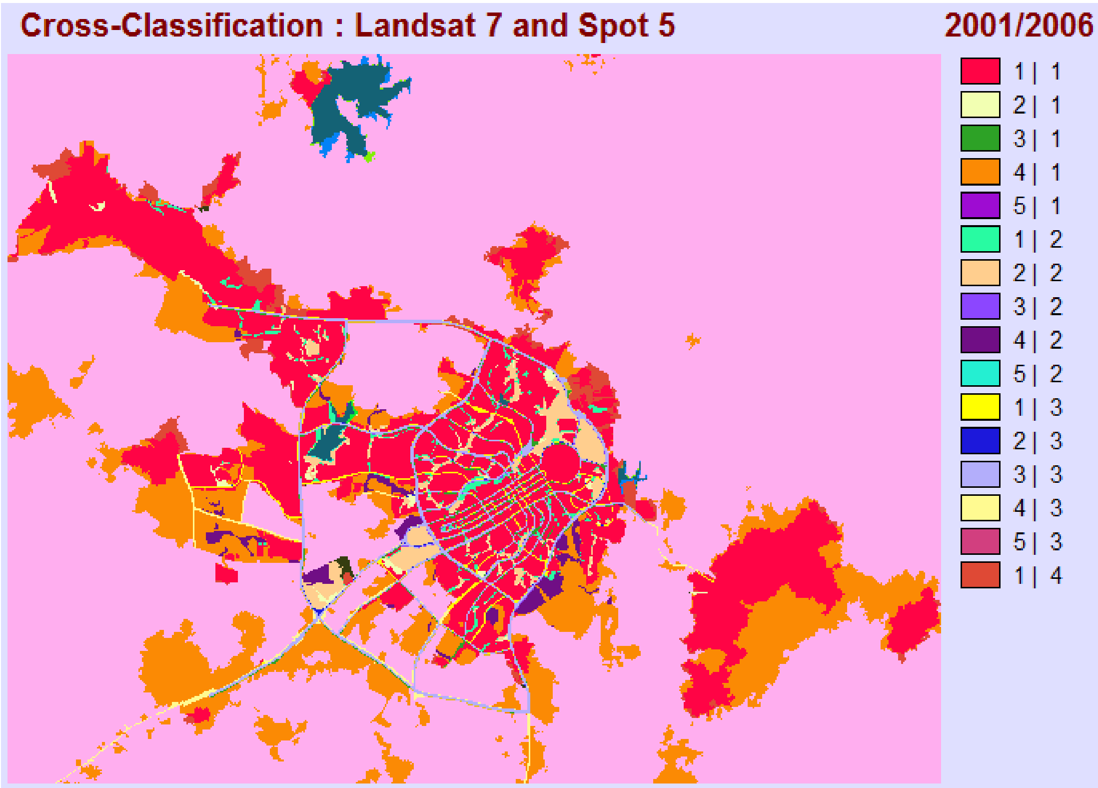


Fig. 4.18 Cross-tabulation of 2001 and 2006 classification.

The image presented here displays the first 16 lines of the legend in the native format of the Idrisi software used for this research. The full legend and the changes in land use are explained in Table 4.17

Table 4.17 Cross- tabulation of classification for 2001 and 2006

Area Km^2	2001	2006	Change(C)/No change(NC)	Observation
141.09	1-Res./com.	1-Res./com.	NC	Same area
2.75	2-Rec. /open spaces.	1-Res./com.	C	infilling
3.08	3-Transport	1-Res./com.	NC	Spectral confusion
104.90	4-Vacant land	1-Res./com.	C	Urban development
0.02	5-Water body	1-Res./com.	NC	Image registration error
4.08	1-Res./com.	2-Rec. /open spaces.	NC	Image registration error
11.25	2-Rec. /open spaces.	2-Rec. /open spaces.	NC	Same area
0.53	3-Transport	2-Rec. /open spaces.	C	Open spaces at roadside
5.74	4-Vacant land	2-Rec. /open spaces.	C	infilling
0.08	5-Water body	2-Rec. /open spaces.	N	Image registration error
4.18	1-Res./com.	3-Transport	C	Development control
0.41	2-Rec. /open spaces.	3-Transport	NC	Image registration error
12.97	3-Transport	3-Transport	NC	Same area
3.28	4-Vacant land	3-Transport	C	Urban development
0.01	5-Water body	3-Transport	NC	Image registration error
12.01	1-Res./com.	4-Vacant land	NC	Spectral confusion
0.47	2-Rec. /open spaces.	4-Vacant land	NC	Image registration error
0.73	3-Transport	4-Vacant land	NC	Image registration error
818.79	4-Vacant land	4-Vacant land	NC	Same area
1.22	5-Water body	4-Vacant land	NC	Lake edge liable to flooding
0.06	1-Res./com.	5-Water body	NC	Image registration errors
0.15	2-Rec. /open spaces.	5-Water body	NC	Lake liable to flooding
0.02	3-Transport	5-Water body	NC	Image registration error
0.33	4-Vacant land	5-Water body	NC	Lake edge liable to flooding
9.18	5-Water body	5-Water body	NC	Same area

Table 4.18 Areas of land use change in Abuja between 2001 and 2006 in Sq. km (%)*

		2006					
		Residential/ commercial	Recreational/ open spaces	Transportation	Vacant land	Water body	Total (Km^2)
2001	Residential/ commercial	**141.09 (12.41%)**	4.08 (0.36%)	4.18 (0.37%)	12.01 (1.06%)	0.06 (0.01%)	161.43
	Recreational/open spaces	2.75 (0.24%)	**11.25 (0.99%)**	0.41 (0.37%)	0.47 (0.04%)	0.15 (0.01%)	15.02
	Transportation	3.08 (0.27%)	0.53 (0.05%)	**12.97 (0.04%)**	0.73 (0.06%)	0.02 (0%)	17.33
	Vacant land	104.9 (9.22%)	5.74 (0.5%)	3.28 (1.14%)	**818.79 (71.99%)**	0.33 (0.03%)	933.05
	Water body	0.02 (0%)	0.08 (0.01%)	0.01 (0%)	1.22 (0.11%)	**9.18 (0.81%)**	10.52
	Total (Km^2)	251.85	21.68	20.85	833.23	9.74	1137.34

- The diagonal entries are areas of no change

Table 4.19 presents the summary of Lands use change between 2001, 2003 and 2006 followed by an explanation of the summary. The full cross tabulation table is shown in Appendix 2.

Table 4.19 Summary of land use change between 2001, 2003 and 2006

Land use	2001(Km^2)	% total 2001	2003(Km^2)	% total 2003	2006(Km^2)	% total 2006(Km^2)
Residential/commercial	161.43	14.19	183.34	16.12	251.85	22.14
Parks/ open spaces	15.02	1.32	17.35	1.53	21.68	1.91
Transport	17.33	1.52	19.58	1.72	20.85	1.83
Vacant land	933.05	82.04	906.73	79.72	833.23	73.26
Water body	10.52	0.92	10.34	0.91	9.74	0.86
Total (Km^2)	1137.34	100.00	1137.34	100	1137.34	100.00

Residential commercial

In 2001, residential/commercial land use was 161.43 km^2 or 14% of the study area, while in 2003 the same land use type accounted for 183.34 km^2 % (16%) going up to 251.85 km^2 % (22%) in 2006. The gradual increase in this land use type reflects the increase in population within the study period. Available census figures shows that in 1999 the population was 403,000 (United Nations 1999) rising to 590,400 in 2006 (National Population Commission). This reflects an increase by 117,000 people requiring accommodation and the necessary service infrastructure to live in Abuja.

Parks and open spaces

Parks and open spaces accounted for 15.02 km^2 (1.32%) in 2001 17.35 km^2 (1.53%) in 2003 and 21.68 km^2 (1.91%) in 2006. The increase in this land use category can be explained by the increase in residential/ commercial land use. As more people moved in to the city, took up residence and started one commercial activity or the other the city expanded physically requiring the development of open spaces for recreational uses.

Transport

The road transportation network in the town gradually grew and expanded as the city limits expanded. In 2001 the road network accounted for 17.33 km^2 (1.52%) of the land area. This increased to 19.58 km^2 (1.72%) in 2003 and 20.85 km^2 (1.83%) in 2006.

Vacant land

This land cover category encompasses all the land surrounding the developed area made up the land use classes mentioned above. The vacant lands may be bare surface or under some form of vegetation. Essentially the vacant land category are potentially open to urban expansion, this means that whenever other land use categories increase the vacant land will reduce. In 2001 the vacant land accounted for 933.05 km^2 (82.04%) of the land area. This reduced to 906.73 km^2 (79.73%) in 2003 and 833.23 km^2 (73.26%) in 2006.

Water body

The water bodies in the study area are in the form lakes and reservoirs. This land cover category was gradually reducing throughout the study period. In 2001 the water bodies accounted for 10.52 km^2 (0.92%) in 2001 and in 2003 it reduced to 10.34 km^2 (0.91%) and further reduced to 9.74 km^2 (0.86%) in 2006. This reduction can be attributed to either human or natural activities around the water bodies. There has been an increase in developments around the lake edges as residential/commercial land use and roads continue to expand. These developments may have been responsible for the reduction of the area covered by the lakes. See pictures in Fig. 4.19 and Fig.4.20. Natural activities like run off from rainwater may have carried silt into water bodies leading to eutrophication (silting and algal bloom) within the receiving water bodies. However, there is not enough evidence to corroborate this as is this study does not have independent information on the size of the water bodies around the corresponding period.

Field pictures 2008

Fig.4.19 Algal Bloom at the edge of Lake Jabi in Abuja

Field pictures 2008

Fig. 4.20 Construction pillars at the edge of Jabi Lake

4.2.3 Trajectory of land use change in Abuja

An overlay analysis of the built up areas (residential/commercial land use class), helped to show the direction of growth in Abuja from 2001-2006. The overlay analysis also helped to visually represent the growth happening around the study area. This overlay is shown in Fig. 4.21. The area extent is also depicted with a bar chart in Fig. 4.22.

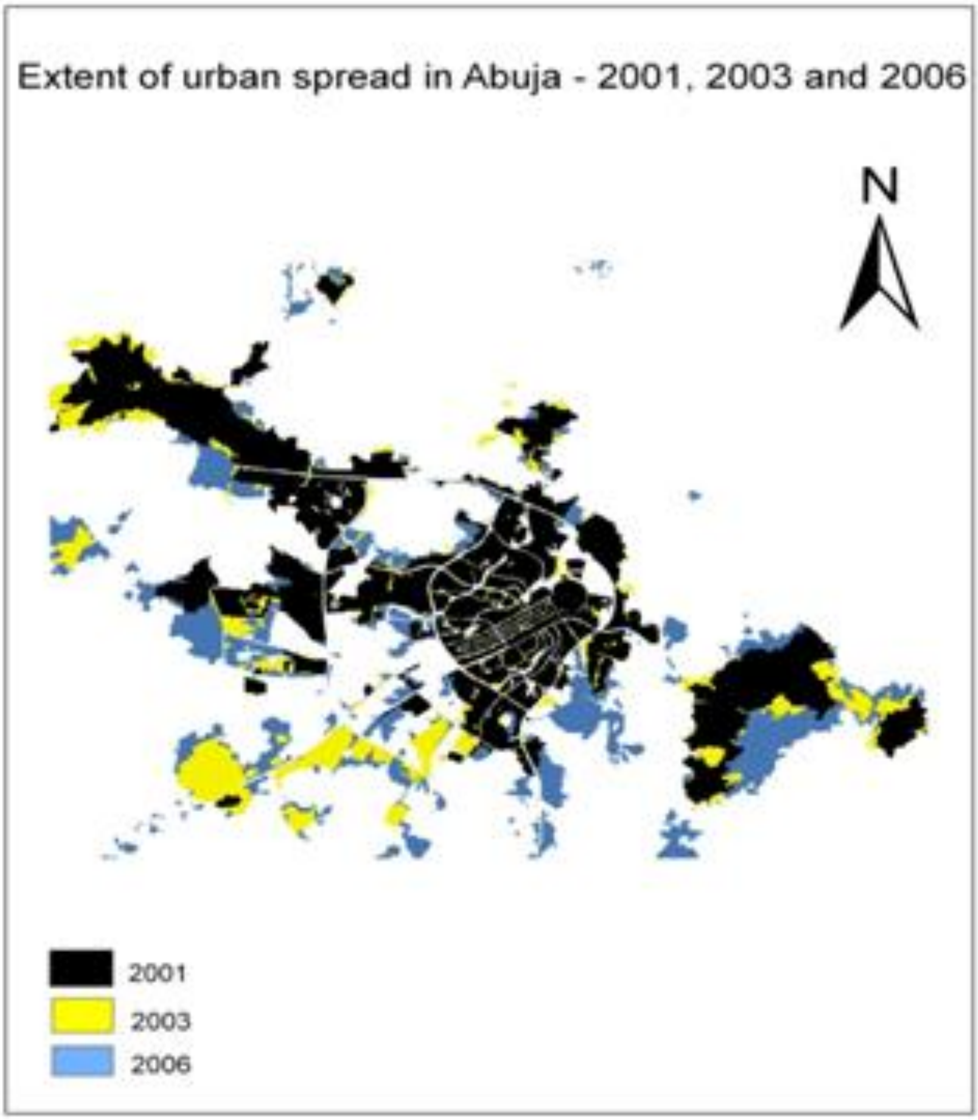
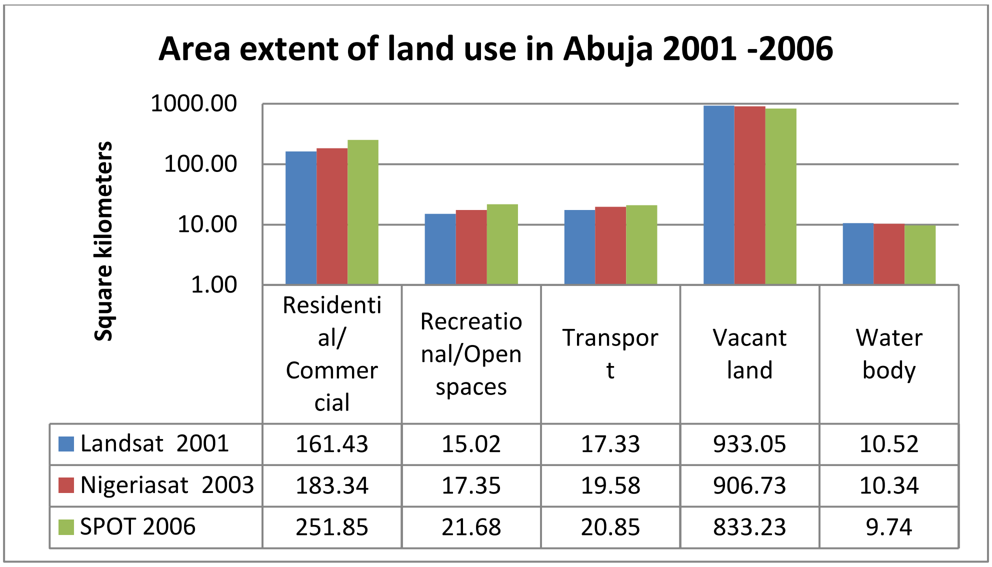


Fig.4.21 Land use maps of Abuja depicting extent of urban spread in 2001, 2003 and 2006



	Residential/ Commercial	Recreational/Open spaces	Transport	Vacant land	Water body
Landsat 2001	161.43	15.02	17.33	933.05	10.52
Nigeriasat 2003	183.34	17.35	19.58	906.73	10.34
SPOT 2006	251.85	21.68	20.85	833.23	9.74

Fig. 4.22 Area extent of land use in Abuja in 2001, 2003 and 2006

A cursory look at the Fig. 4.21 above indicates urban growth at the outskirts of the city. Field visits in 2011 showed that this growth was actually happening in the form of informal settlements at the edges of the city. See pictures in Fig. 4.22 below.

Source: Field pictures (2011)

Fig. 4.23 Some informal settlements in Abuja. Left: Along Abuja-Bwari Road and Right: South of Jabi Lake

Entropy values were calculated to ascertain if these informal settlements could be classified as urban sprawl. The values returned from the analysis indicate the presence of sprawl around Abuja. Relative entropy is calculated on a scale of 0-1. The results show that 0.804 in 2001, 0.898 in 2003 and increased to 0.930 in 2006. The trend of entropy is shown in Fig. 4.23.

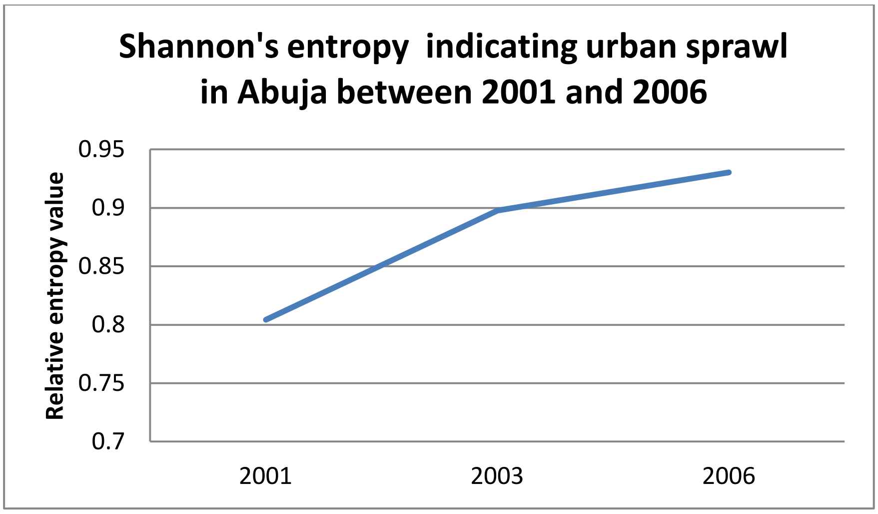


Fig. 4.24 Entropy values calculated from the land use maps of Abuja between 2001 and 2006

A detailed look at the developments at the location of the land use changes that occurred in Abuja during the study period are shown in three year cross tabulation shown in Appendix 2. A summary of the land use change is shown in Table 4.20 below. The table shows the area extent of land uses that have changed over the study period. As shown in Appendix 2, some of the changes noticed from cross classification of the classified images are due to artefacts of the data and image co-registration errors. These areas cover 0.05km^2 or less. The details from the table in Appendix 2 are further separated into two tables (Tables 4.21 and 4.22) to help capture the exact epoch that the land use changes occurred.

Table 4.20 Changes in land use 2001-2006

Land use	2001	% total 2001	2003	% total 2003	2006	% total 2006
Residential/commercial	161.43	14.19	183.34	16.12	251.85	22.14
Parks/ open spaces	15.02	1.32	17.35	1.53	21.68	1.91
Transport	17.33	1.52	19.58	1.72	20.85	1.83
Vacant land	933.05	82.04	906.73	79.72	833.23	73.26
Water body	10.52	0.92	10.34	0.91	9.74	0.86
Total	1137.34	100.00	1137.34	100	1137.34	100.00

The general pattern from the analysis shows that most of the urban growth occurred between 2003 and 2006. As shown in Table 4.22 the residential/commercial land use increased by 6.02% between 2003 and 2006. Between 2001 and 2003, this land use increased by 1.93%. From the analysis of land use between 2001 and 2006 shown in Table 4.22 it was possible to get an indication of annual rate of urban of growth over the study period. The percentage total of residential/commercial land use at 22.14% meant that during the 5 year period under study the annual urban growth was 4.43%.

Table 4.21 Changes in land use of Abuja 2001-2003

	2001	% total 2001	2003	% total 2003	change area	% increase/decrease
Residential/commercial	161.43	14.19	183.34	16.12	21.91	1.93
Parks/ open spaces	15.02	1.32	17.35	1.53	2.33	0.20
Transport	17.33	1.52	19.58	1.72	2.25	0.20
Vacant land	933.05	82.04	906.73	79.72	-26.32	-2.31
Water body	10.52	0.92	10.34	0.91	-0.18	-9.61
	1137.34	100	1137.34	100		

Table 4.22 Changes in land use 2003-2006

	2003	% total 2003	2006	% total 2006	change area	% increase/decrease
Residential/commercial	183.34	16.12	251.85	22.14	68.51	6.02
Parks/ open spaces	17.35	1.53	21.68	1.91	4.33	0.38
Transport	19.58	1.72	20.85	1.83	1.27	0.11
Vacant land	906.73	79.72	833.23	73.26	-73.5	-6.46
Water body	10.34	0.91	9.74	0.86	-0.6	-0.05
	1137.34	100.00	1137.34	100		

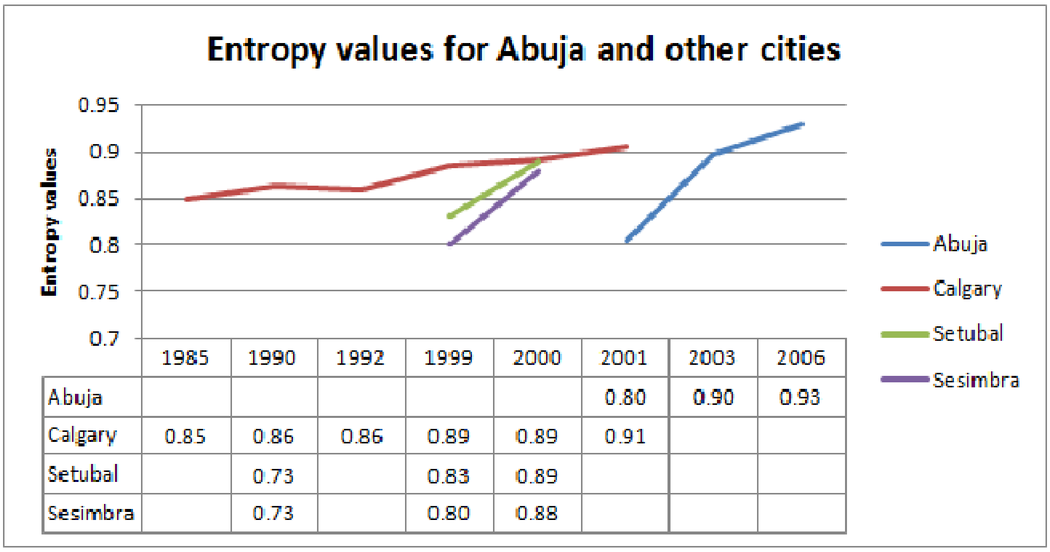
Chapter 5 Discussion

This Chapter discusses the implications of the land /use land cover changes that can be inferred from the land use maps for 2001, 2003 and 2006, and what it means to the development of the Federal Capital Territory. The discussions will focus on sprawl developments and their effects on the land cover of the surrounding area and the overall effects of the growth on developments on the cityscape of Abuja. Drawing inferences from these changes, discussion will focus on comparing changes in Abuja with other capital cities.

5.1 The Implications of Sprawl on Abuja and environs

The development of sprawl in Abuja can be traced to the certain factors, which led to deviations from the Abuja master plan at various times between 2003 and 2006. To reconstruct the reasons for these developments, the views of experts like Urban Professor Akin Mabogunje, UN Habitat reports, and two Non-Governmental Organisations (NGOs) who work in collaboration with UN Habitat, are used. The NGOs are Nigerian based Social and Economic Rights Action Center (SERAC) and Switzerland based Centre on Housing Rights and Evictions (COHRE).

In section 4.2.3 Shannon's Entropy was used to measure sprawl developments in the study area. The values were between 0.804 in 2001 and 0.930 in 2006. These figures indicate that there is urban sprawl happening around Abuja. To put the sprawl developments around Abuja into a global perspective the sprawl measurements for cities in Europe and Canada were used for comparison. Fig. 5.1 shows the trend of urban sprawl in Sesimbra and Setubal in Portugal (Araya and Cabral 2010) and Calgary, Canada (Sun, Forsythe and Waters 2007). These figures were used because the analysis methods were the same with this study. OBIA methods were used to classify urban land cover from coarse and medium resolution images. The Figures indicated that the trend in Abuja is consistent with global patterns. Entropy values above 0.5 indicated that there was landscape fragmentation, which characterises urban sprawl (Araya and Cabral 2010). These sprawl developments are linked to population increase in all the cases considered.



	1985	1990	1992	1999	2000	2001	2003	2006
Abuja						0.80	0.90	0.93
Calgary	0.85	0.86	0.86	0.89	0.89	0.91		
Setubal		0.73		0.83	0.89			
Sesimbra		0.73		0.80	0.88			

Fig. 5.1 Entropy measures of urban sprawl in Portugal, Nigeria and Canada

From field visits and expert opinions the causes of urban sprawl in Abuja can be traced to several factors: Increase in the population of the city, strict town planning regulations, which permit developments in designated areas within the city centre and poor implantation of the master plan around the outskirts of the city. These have forced developers to seek land in areas just outside the planned city. These developments have had adverse effects on the surrounding areas. These adverse effects are discussed below.

5.1.1 Poor implementation of the master plan

The deviations in the master plan of Abuja, which resulted in the informal settlements, have been traced to human error based on manual methods being used for the operations within the land registry in Abuja (Jibril 2006). Some these errors were:

1) Multiple allocations of plots
2) Forgeries of land documents
3) Unauthorized bodies involved in Land Allocation
4) Land use abuses through illegal occupation
5) Encroachments on road corridors, road reservations, sewer lines and water mains reservations
6) Multiple surveys
7) Lack of current topographical base maps
8) Obsolete survey equipment

9) Rampant subdivision and redesign of plots
10) Extensions beyond the FCC Limits without proper authorization

Other studies have argued that the connivance of land speculators and corrupt officials created problems of poor implementation, because the manual methods of using files and paper (hard copy) can work if properly implemented (Akingbade, Navarra and Georgiadou 2010). However, the failures of the existing approach led to the establishment of Abuja Geographic Information Systems (AGIS) in 2003 by the government. AGIS was able to computerise the operations, identified shortcomings in the system and produced maps detailing areas of informal settlements and other land use violations. These details helped to carryout development control within the FCT.

5.1.2 Loss of natural vegetation

The occurrence of sprawl around Abuja has resulted in the loss of natural vegetation around the study area. Some of these lands are used as croplands and farmlands by the communities in the outskirts of Abuja. The natural forests around the city are also being carved into plots of residential land by local land owners and sold off to private and institutional estate developers. This loss of forest will no doubt have adverse effects on the biodiversity of the flora and the fauna of the area. Urban encroachments may symbolise permanent forest loss, unless developments are removed and the forests are regenerated.

5.1.3 Development of informal settlements

During the field visits, the sprawl developments noticed from the classification of the satellites images were identified as informal settlements. The underlying reasons for these can be traced to certain government decision that compelled civil servants to relocate from Lagos to Abuja before the city was ready to accommodate them.

The Abuja master plan recommended a four-phased growth, which would be associated with population growth and infrastructure (FCDA, 1979). The planned relocation from Lagos to Abuja would be done in phases with the incoming population balanced against existing infrastructure and services. What followed was mainly dictated by the political climate in the country and relocation of the capital to Abuja was used as a campaign issue in the 1979 elections because the inadequacies of Lagos were becoming more glaring (Adama-Ajonye 2005). The presidential candidate of the National Party of Nigeria, Shehu Shagari, promised that if elected, he would expedite work on Abuja (Ministry of the Federal Capital Territory 1998). He won the elections and took the decision to shift the movement date forward to 1982/83 from the 1986 target set by the Plan. This resulted in the decision to move civil servants into Abuja as early as 1983 to serve as forerunners to the government. With the absence of adequate accommodation civil servants were housed in the accommodation (known as the "accelerated district") meant for construction workers. This decision to house incoming civil servants in the "accelerated district" was a major aspect in the deviation of the Abuja master plan (Mabogunje 2001).

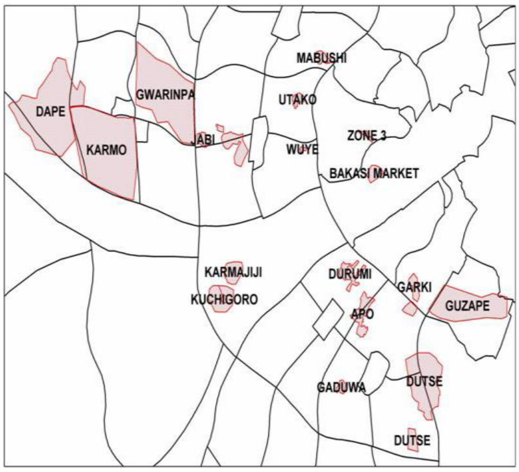
With the district taken over by civil servants, alternative accommodation had to be found (Adama-Ajonye 2005). A decision was made the by government to build a labour camp in Nyanya. According to Mabogunje (2001), the decision to hasten the movement of civil servants from Lagos to Abuja led to "helter skelter" building activities within the city and denied planners the opportunity to test out the various plan concepts and more seriously made it impossible to use the accelerated district to house construction workers. In the initial implementation strategy construction workers were to be housed in the accelerated districts, a move meant to prevent the development of informal towns (Mabogunje 2001).

By 2003, the high costs of living in the city coupled with the shortages of houses, enlarged the number of illegal developments citywide at an alarming rate (COHRE 2008). The hardest hit areas were Karu/Nyanya, Karmo, Kubwa and Gwagwa, occupied by workers and growing service population. These settlements grew rapidly within areas otherwise earmarked for other types of city development. Some of the squatter settlements were close points in the city centre or at sites originally designed to protect Abuja's periphery from development encroachments or unplanned expansions. They were generally overcrowded and lacked basic amenities and infrastructure (AGFE 2007, COHRE 2008). Some of the informal settlements identified by staff of Abuja Geographic Information Systems (AGIS) for development control, which sometimes entailed outright demolition are shown in Table 5.1 below and displayed in Fig.5.2.

Table 5.1 Informal settlements in Abuja as documented by Abuja Geographic Information System in 2004

Name	Type	Area (ha)	District
Bakasi market	Market	20.7	Central area
Zone 3	Mechanics	5.9	Wuse I
Garki	Village / market	19.0	Garki II
Guzape	Village	225.8	Guzape
Garki village	Market	14.7	Gudu
Apo	Village/ market	46.8	Durumi, gudu
Durumi	Informal	32.3	Durumi
Mabushi	Informal / market	15.5	Mabushi
Katampe	Village	13.9	Katampe
Gaduwa	Village	9.4	Gaduwa
Dutse	Informal	189.0	Dutse
Dutse	Village	21.1	Dutse
Wumba	Village	5.3	Wumba
Mada	Informal	165.4	Outside federal capital city (fcc)
Kurbo	Informal / market	54.5	Outside fcc
Kuchigoro	Old village	3.7	Kukwaba
Kuchigoro extension	Informal	59.9	Kukwaba
Karmajiji	Informal	37.9	Kukwaba
Wuye	Informal	2.4	Wuye
Jabi	Informal	14.0	Jabi
Jabi	Informal	4.3	Jabi
Jabi/dakibiyu	Informal	51.6	Jabi, dakibiyu
Utako	Informal	11.9	Utako
Karmo	Informal	524.0	Karmo
Gwarinpa	Informal	408.0	Gwarinpa 1
Dape	Informal	455.0	Dape
	Total	2412	

Source: AGIS (2004)



Source: AGIS (2006)

Fig. 5.2 Some of the informal settlements around Abuja in 2004

5.2 Land use Modelling in Abuja

If informal settlements are not removed or destroyed by regulatory authorities, they soon develop and may gradually attract certain essential services. These could be in the form of retail of household essentials, carpentry or food outlets.

It has been argued that informal settlements will be the dominant form of urban spread across the globe over the next decade by a collaborating team of researchers from Singapore University of Technology and Massachusetts Institute of Technology (SUTD and MIT 2012). The group is using GIS based urban network analysis tools to explore the effects of economic development in informal settlements. The focus is on determining the best locations for services and retail in these settlements to speed the formalization and economic vitality of these areas.

If indeed informal settlements will be the dominant form of urban spread in the future, it is necessary to have some idea of where these settlements might be. This will enable urban planners to prepare for such developments. This preparation could be to abort the process if or when it arises, or to provide amenities like pipe borne water and healthcare facilities to ensure the well being of the residents. Urban growth modelling has been used in the past to indicate growth and spread of urban areas (Sun, Forsythe and Waters 2007, Adu-Poku, Drummond and Li 2011).

Urban growth modelling of Abuja was used to simulate a situation of urban growth into 2020 to give an indication of the direction of urban spread. By 2020, Abuja would have been a capital city for 19 years. This year was chosen for two major reasons. Firstly, because it is a target date for major government initiative in Nigeria. Secondly, also because an attempt will be made to compare the growth of Brasilia and Islamabad at 19 years.

The Nigerian government has launched Vision 2020 programme with the intent of making it one of the top 20 economies in the world by 2020 (Vision 2020 Committee 2009). The Vision 2020 programme has two main objectives to

1) Stimulate Nigeria’s economic growth and launch the country onto a path of sustained and rapid socio-economic development
2) Place Nigeria in the bracket of top 20 largest economies of the world by the year 2020

With these lofty goals by the government, the modelling exercise can be used to inform the government about the land use scenario in Abuja. If current land use trends are not halted, Abuja may not be a dream capital by 2020. From the maps produced (see Chapter 4) and details in Fig. 5.3 and

Table 5.2, the vacant land around Abuja will be affected by urban growth and effort has to be made to stem this tide.

However, it is necessary to mention the limitations of the Cellular Automata (CA) modelling (Koomen and Stillwell 2007), before coming to any real conclusions. In CA based modelling the state of cells (in real terms land use type at a location) depends on the state of cells that are adjacent or in the neighbourhood. As a result of this, land use spread occurs adjacent to existing land use. This means that land use spread projected with CA cannot account for leapfrog development or isolated spontaneous growth that can characterise sprawl. It may be argued that the modelling exercise does not depict reality if it cannot simulate isolated growth. However, it is worthy to mention that CA modelling can give an indication of the kind of growth likely happen when urban areas lack strict controls or buffer areas.

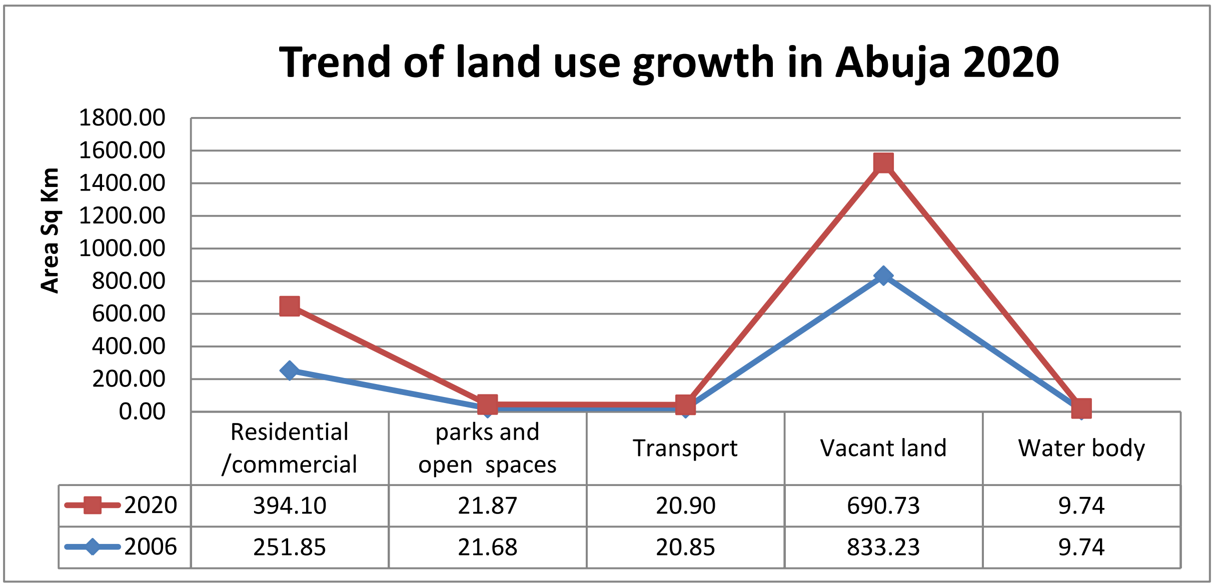


Fig. 5.3 Trend of land use growth from the land use modelling. Using the land use map of 2006 to predict land use in 2020

Figures from the Urban Growth Model are displayed in Fig. 5.3 and Table 5.2. The figures show annual percentage growth of 0.89% in the residential/commercial land use. Incidentally the equivalent amount of land was lost by vacant land surrounding the city. In section 3.6, it was explained that the vacant land category is a special class. All the lands surrounding the built up area was regarded as vacant land with potential to be consumed by urban growth.

In 1979, Islamabad and Brasilia had been capitals for 19 years. There were already signs of informal settlements. Camps of workers were reported at the periphery of Islamabad (Tapner 1977 cited in Malik 2003). These workers may have set up camp because they could not afford the rents in the city

Table 5.2 Land use changes that may occur as predicted by the Urban Growth Model

	2006	2020	Area extent of land lost or gained	% gain/loss	Annual rate
Residential /commercial	251.85	394.10	142.25	12.51	0.89%
park and open spaces	21.68	21.87	0.19	0.02	
Transport	20.85	20.90	0.06	0.00	
Vacant land	833.23	690.73	-142.50	-12.53	-0.89%
Water body	9.74	9.74	0.00	12.51	

(Malik 2003). In Brazil, the existence of informal settlements predated the official occupation of Brasilia in 1960, as migrants workers relocated to the vicinity of Brasilia in search jobs. In 1973 a study titled "Brasília, Plan and Reality; A Study of Planned and Spontaneous Urban Development" documented the existence of informal settlements in the outskirts of the city (Epstein 1973). These informal settlements still exist and have developed a unique identity (Andersen 2010). By 2020, Abuja would have been the capital city for 19 years. Urban growth modelling has been used to predict an annual growth rate of 0.89% for the 14-year period from 2006 to 2020. The current spate of informal settlements might continue if strict controls are not enforced in the outskirts of the city.

5.3 Is OBIA able to support urban studies in developing countries?

At regional level OBIA has been used to produce land cover maps in the United Kingdom (Wallis 2002). These methods have also been used to study urban land use and land cover in the developed countries like Canada (Araya and Cabral 2010, Blaschke 2010, Sun, Forsythe and Waters 2007). The use of OBIA within this research has also helped to show that it is able to contribute to land use and land cover change studies in developing countries. OBIA has been used to study urban land use in Ghana (Stow *et al.* 2007), but its use was limited to single date analysis of high resolution data to determine socio-economic patterns in Accra. This study is the first to use the technique of combining coarse and medium resolution data with land use cadastre in an OBIA for spatial-temporal urban LULCC.

It has been suggested that OBIA is the method that can 'intelligently' exploit information from the abundance of Very High Spatial Resolution data currently available (Lang 2008). This suggestion is also relevant for coarse resolution data. Without the use of OBIA based methods, the use of Nigeriasat-1 data in this research would not be possible. Omojola (2004) suggested that Nigeriasat-1 is useful for 'synoptic mapping' land cover mapping. This is because the data was used in an attempt to map urban and rural land use in Ekiti State, Nigeria. The failure to accurately characterise specific land uses in the urban areas led to that suggestion. As noted in Section 4.2.1 of this thesis also, Nigeriasat-1 data is useful for broad land cover mapping. However, its inability to characterise bare surface land cover was a major concern. With OBIA methods, it was possible to introduce cadastre data and subsequently, the classification of land use categories from Nigeriasat-1 and other data.

The classification accuracy recorded in this research is comparable to others where OBIA has been used for coarse resolution images. As shown in Table 5.3 the OBIA classification of Nigeriasat-1 data compares favourably with Landsat and SPOT at 89% OA. The classification even has higher classification accuracy than the classifications with Landsat TM, which have 70% and 86%.

Table 5.3 Classification accuracy results from studies which utilised OBIA for land cover classification

Satellite image	Overall Accuracy(OA)	Type of classification	Research publication
Landsat TM (30m)	70%	Land cover	(Dorren, Maierb and Seijmonsbergen 2003)
Landsat TM (30m)	86%	Land cover	(Geneletti and Gorte 2003)
Landsat ETM (30m)	91%	Land cover	(Duveiller *et al.* 2008)
SPOT-VEG(1km)	91%	Land cover	(Bontemps *et al.* 2008)
Landsat ETM (28.5m)	92%	Land cover	This research
Nigeriasat-1 (32m)	89%	Land cover	This research

5.4 Can Nigeriasat-1 data contribute to urban LULCC analysis?

The design of Nigeriasat-1 sensor as part of the DMC provides it with a wide swatch width of 640km. This is suited for wide area coverage, which may become necessary during the monitoring of disasters. When the first set of satellite images were acquired in 2003, Nigeria Space Research and Development Agency (NASRDA) organised a series of workshops and invited the GIS community to determine other uses for the data. Most of the papers presented concluded that the data was at best suited for synoptic land cover mapping. They cited its low resolution as its major shortcoming (Ayeni, Uluocha and Saka 2004, Omojola 2004, Oyinloye, Agbo and Aliyu 2004, Rotimi and Ayomaya 2004). This study was able to utilise Nigeriasat-1 data for urban land use studies using innovative OBIA methods to extract land use and land cover information from the data. These methods have also been able to make outputs from Nigeriasat-1 comparable with Landsat 7 ETM and SPOT 5 data

(Chima and Trodd 2010) which are regarded as the 'workhorses' of satellite remote sensing and GIS studies (Blaschke 2010).

5.5 Growth in Abuja and other newly planned capital cities

The new towns and capitals of the 21st Century are planned cities. They are built according to a blueprint designed by an architect or planner. From their inception, they are complete cities; rationally designed with a certain image of the city's future in mind (International New Town Institute 2009). These cities are designed as 'functional cities'. A concept from the works of Le Corbusier whose works notably 'The City of Tomorrow and its Planning' (Corbusier 1971-*This edition is a translation from the original 1929 publication*) was thought to have inspired the Athens Charter of 1933. The Athens Charter is a document about the urban planning which sets out ways of achieving the 'Ideal City'.

These 'ideal cities' are expected to display a perfect equilibrium of infrastructure, housing, services and a social-economic and cultural identity. Nevertheless, what happens after the planners' departure? Inhabitants appropriate the city and the perfect equilibrium is shaken. The complexity of society takes over. New plans are made and the original design is adjusted (International New Town Institute 2009).

These initiatives, after the planners have left, are usually summarized as the 'unplanned', the 'informal' or the 'self-organized' city, definitions of varied phenomena which have, as a common denominator, the absence of professional planners. The unplanned city is made up of inhabitants, entrepreneurs, developers, and immigrants. While the planned city corresponds roughly to a top-down approach, the unplanned city often displays a bottom-up approach (International New Town Institute 2009).

The planning of Abuja was meticulously conceived, as were the other 'created capitals' (Stephenson 1970). The planners visited other planned capital cities to get inspiration and ideas on how to progress with task at hand (FCDA 1979). Among the capitals visited were Brasilia, Canberra, Washington DC and Chandigarh (a regional capital that serves the states of Haryana and Punjab in India). Before Abuja, the world had widely acclaimed Brasilia as a bold and modern new capital (Staubli 1966). Its pioneer status in urban planning prompted the United Nations Educational, Scientific and Cultural Organization (UNESCO) to name Brasília a World Heritage Site in 1987 (Scott and Allen 2010). How has Abuja's growth fared in comparison with other planned cities?

New capital cities can be found in every continent and the growth of Abuja can potentially be compared with them. However due to the economic disparity and sometimes socio/political disparity between the developed and developing countries, a direct comparison of city growth between the two regions of the world might not produce the desired results. For instance, a comparison between Abuja (in a developing economy like Nigeria) and Canberra in Australia (developed economy). Rural-urban migration patterns would vary between the two. The push factors that propel people to cities would not be the same. In order to understand the context of Abuja's growth, it may be necessary to compare it with similar cities in the same socio/political circumstances, i.e. post-colonial developing economies. In addition, emphasis would be to compare urban developments in Abuja with capitals that were built from the top down approach, against cities that were designed from the bottom up. This refers to cities that were conceived and built as capital cities, not cities that existed and were later converted to capitals. The post-colonial developing economies with new capitals are shown in Table 5.4.

Table 5.4 countries with postcolonial capital cities in developing countries

Country	Old Capital City	New Capital City	Year Political Independence	Colonial country	Year of movement to new capital	Conceived and built as new capital
Brazil	Rio de Janeiro	Brasilia	1822	Portugal	1960	yes
Pakistan	Karachi	Islamabad	1947	United Kingdom	1960	yes
Tanzania	Dar-es-Salaam	Dodoma	1961	United Kingdom	1970	No
Cote d'Ivoire	Abidjan	Yamoussoukro	1960	France	1983	No
Nigeria	Lagos	Abuja	1960	United Kingdom	1991	yes
Kazakhstan	Almaty	Aqmola	1991	Russia	1991	No
Myanmar	Rangoon	Naypyidaw	1948	United Kingdom	2005	yes
South Sudan	Juba	Ramiciel	2011	Breakaway from Sudan	2011-2016 (expected)	yes

Dodoma in Tanzania was first established in the early 1900s during the development of the Tanzanian railway line from Dar-es-Salam to Kigoma. As such, it is an existing settlement that was later transformed to the country's capital because of its central location. Yamoussoukro in Cote d' Ivoire was also transformed to the country's capital from a pre-colonial settlement. Aqmola in Kazakhstan is also an existing city that was remodelled as a new capital, due earthquake disturbance in the old capital Almaty. The capitals of Myanmar and the Southern Sudan are recent developments and have not had time to evolve a history that can be compared with Abuja. This leaves only Brasilia and

Islamabad, which were conceived as new capitals when their governments regarded the old capital cities as inadequate. Given the relatively long histories of Brasilia and Islamabad, both established as new capitals in 1960, comparison of Abuja with these established capitals might throw some light into what is happening in Abuja, established in 1991. Abuja is also a sister city with Brasilia. The terms of comparison would typically be around the research questions raised in this study. Two of the research questions that can be examined by this comparison are: does spontaneous and unplanned growth happen around planned cities? If indeed there is unplanned growth, what factors are responsible for this unplanned growth? While the first question hopes to establish the nature of growth within the cities, the second question will help establish the drivers or factors responsible for this growth.

5.5.1 Brasilia

The plan for the new capital close to the centre of the country was originally conceived in 1827 by José Bonifácio, an advisor to Emperor Dom Pedro; he also suggested the name Brasilia. The idea was welcomed by Brazilians and it was written into the constitution in 1891. This article of the constitution was fulfilled in 1956 when the president Juscelino Kubitschek gave directives for the construction of Brasilia. The city was designed and built by Brazilians. Urban planner was Lúcio Costa; Chief Architect was Oscar Niemeyer and Landscape designer Roberto Burle Marx. Brasília was built from 1956 to 1960, when it officially became the capital of Brazil (Staubli 1966). Since its existence, it has become a model of urban planning, credited with implementing the principles of the Athens Charter of 1933, such as strict zoning and separation of residential areas and transportation channels (Scott and Allen 2010).

In terms of the cityscape, the design of the city has been described as an airplane or a butterfly; this shape was determined by the surrounding topography and artificial lake. The low and medium density residential zones of the inner city were arranged into superblocks or groups of apartment buildings along with a prescribed number and type of schools, retail stores, and open spaces. While exclusive residential and diplomatic zones are to be found to the north and south of the city (Staubli 1966), the focal point of the city is the square of three powers which houses the Congressional Palace, Senate building and the Chamber of Deputies. Fig. 5.4 shows the location of Brasilia within Brazil.

This map has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University

Fig. 5.4 The map of Brazil showing the location of Brasilia. Source Google images (2011)

The city is located within Brazilian Federal District (BFD), which constitutes a federal unit, comparable to a state. Included in the BFD are several satellite cities, designed to take the population pressure off Brasilia.

The population of Federal District started to grow even before it was declared the capital in 1960. In the 1960 census, it was almost 140,000. By 1970, this figure had grown to more than 537,000. The population of the BFD was over 2.3million in 2003 (IBGE 2010). Planned for only 500,000 inhabitants, Brasília has seen its population grow much more than expected. According to 2010 census, the population of the federal district was 2,469,489 (IBGE 2010). Several satellite cities have been created over the years to accommodate the extra inhabitants (Carroll and Philips 2008, McElroy 2008).

The innovative design of Brasilia (which prompted UNESCO to name it a World Heritage site), has also drawn criticism. John Norquist, the president of the United States Congress for New Urbanism sees Brasilia as very formal and lifeless, "an example of where you have a very strict plan ..., where most of the streets are grade separated and everything is use separated, and is planned on the utopian model that was predominant in the 1950s," he said, "The capital of Brazil is one of the most lifeless places on earth. The restaurants and the nightclubs and so forth that you find in Rio you don't find that in Brasilia – you find it in the slums around Brasilia" (Andersen 2010).

The population explosion has led spontaneous informal settlements, which are choking infrastructure resulting in the rundown outskirts (Epstein 1973), ushering in scenes of gang violence more commonly associated with the Rio de Janeiro, the former capital, which remained the commercial capital (McElroy 2008).

In a newspaper interview conducted in 2008, Oscar Niemeyer, at 100 years and still professionally active, told the Guardian that his masterpiece was out of control (Carroll and Philips 2008). According to Niemeyer “The way Brasilia has evolved, it has problems. It should have stopped growing some time ago. Traffic is becoming more difficult, the number of inhabitants has surpassed the target, and limits are being exceeded.”

5.5.2 Islamabad

In 1958, a commission was constituted to select a suitable site for the national capital with particular emphasis on location, climate, logistics, and defence requirements. After extensive study, research, and a thorough review of potential sites, the commission recommended the area northeast of Rawalpindi. A Greek firm of architects, Konstantinos Apostolos Doxiadis, designed the master plan of the city, which was based on a grid plan and triangular, with its apex towards the Margalla Hills. The rest of the city was designed by an international roll call of ‘signature’ architects of the time notable among them are Derek Lovejoy and Partners from Britain who were responsible for the capital’s extensive landscaping, Robert Matthew Johnson-Marshall from Britain was responsible for the overall plan of the administrative sector, design of National Museum and National Arts Gallery. Kenzo Tange from Japan designed the Supreme Court and Louis Kahn and Edward Stone from the USA, designed the Parliament Building and the Presidential Lodge (Malik 2003).

The city is divided into eight basic zones: Administrative, diplomatic enclave, residential areas, educational sectors, industrial sectors, commercial areas, and rural and green areas. The city is located within a larger administrative area known as Islamabad Capital Territory, which has five administrative zones. Islamabad had an estimated population of 1.21 million in 2009 and 1.70 million in 2011(Ministry of Population 2012). Fig. 5.5 shows the location of Islamabad in Pakistan.

Fig. 5.5 Map of Pakistan showing the location of Islamabad. Source: Bing maps (2011)

According to Malik (2003), Islamabad has not yet been subjected to a large influx of the urban poor. Only politicians, civil servants, diplomats and the wealthy can afford to live there while those who serve the city commute daily from Rawalpindi, a few miles away. Tapner (1977 cited in Malik 2003) notes that "... Community life is non-existent, and there is no natural blending of the different functions that make a city tick. Everything is compartmentalised and isolated from its neighbouring sectors..."

A senior planner in the Capital Development Authority had this to say about the city: "the master plan was completely ignorant of the socio-economic and political aspects of the country. It is totally incompatible with the topography of the area. The terrain is undulating and rugged, but the master plan proposes straight roads from one end of the city to the other... the master plan does not exploit the natural landscape but forms another landscape of its own" (Malik 2003).

Referring to the 'exclusiveness' of Islamabad at the time, Tapner (1977 cited in Malik 2003) observed that this may eventually lead to its own deterioration as was evident from the camps of workers already being established on the periphery of the city. Islamabad has many years' development ahead of it," he concluded, "but it will be interesting to see if it can retain its look of a very expensive orchard. A cross section of the inhabitants is needed to bring the community to life, but in the meantime it remains a city without a heart". These comments from 1977 suggest that there is orderliness and no unplanned growth in the zones that fall within the planned city.

However, in studies conducted recently as 2010 informal settlements have been noticed in places within the capital territory reserved for conservation purposes (Adeel 2010). Urban encroachments into forest land and natural habitats have also been noticed with studies using GIS and Remote sensing (Butt *et al.* 2012). This much has been acknowledged by the Urban Shelter Programme of the Capital Development Authority (CDA). The body has recognised that there are 11 legal and four illegal informal settlements in the city. Almost all the informal settlements are situated along seasonal rain drains. Most of the residents migrated from Punjab and Khyber Pakhtunkhwa provinces to escape abject poverty and sometimes persecution from enemies. The CDA has made provision for basic facilities within 11 recognised informal settlements because the government's national policy does not allow the authority to facilitate dwellers of informal settlements set up after March 1985 (Kundi 2011). Fig. 5.6 shows some of the informal settlements in Islamabad.

Fig. 5.6 Informal developments in Islamabad. Source: Bing images (2011)

Like Abuja, Islamabad and Brasilia have become home to informal settlements that have resulted from influx of people from the rest of the country. Within these informal settlements are people seeking to provide services and employment opportunities. The city authorities have moved to remove these settlements when they occur within the confines of the planned city and 'accepted' or ignored the existence of these settlements as long as they are outside the confines of the planned city. Eventually these developments have led to the city authorities adopting the *in-situ* measures to upgrade facilities. Thus while these show case capitals have continued to serve as places of abode for the country's ruling elite, the informal settlements have brought the planners to reality of urban planning in developing countries. Urban areas in developing countries will continue to attract people because of the better opportunities for education, jobs, and social advancement. More so, when these urban areas are capital cities they offer more attraction as centre of political of power, and headquarters of major local and international businesses.

To answer the research questions, does spontaneous and unplanned growth happen around planned cities? A study of these three cities shows that spontaneous growth can occur irrespective of strict planning controls. As noted by John Norquist, the president of the United States Congress for New Urbanism, these spontaneous developments bring life to the city. Spontaneous growth is what happens after the planners have left as the city starts to 'assert itself' to develop a unique identify that sets it apart from other cities.

What factors are responsible for this unplanned growth? The factors responsible for these unplanned developments can be traced to city migrants' desire for accommodation. Whether educated or not the city can offer opportunities to earn a living. Be it is in a carwash or banking, once people find jobs they have to settle somewhere nearby. Their financial ability to pay rents will determine their residential location. Often land rents within the city are competitive and the landlords outside the city limits can cash in to provide cheap accommodation. Sometimes too the homeless or unemployed can set up make shift dwellings that serve as accommodation in places where there little or no regulatory control. These areas are likely to be found outside the city limits. A comparison of Brasilia, Islamabad and Abuja is presented in Table 5.5. The table shows that the three capital cities have populations of over 1 million inhabitants. Abuja's population is expected to be Three million at full capacity, while that of Brasilia has already exceeded initial projections. If Abuja has already developed informal settlements at this stage in its history, then it can be inferred that this trend will continue as more people seek employment opportunities within the capital city. Urban planners have to be alert these developments and make adequate arrangements to accommodate the population.

Table 5.5 Comparison of Brasilia, Islamabad and Abuja*

Country		Year capital established	Reasons for relocation	Capital territory or district	Location within country	Governing Body	Area capital territory or district	Population expected in capital territory	Most recent figures	Development of informal settlements	Location of informal settlement	Sister cities
Brazil	Brasilia	1960	National unity, regional development	Brazilian Federal District	Central	Elected governor	5,802Km^2	500,000	2,469,489 (2010) population census	Yes	locations within the capital district and outskirts	Abuja Amsterdam Beijing Berlin Bogota Boston Buenos Aires Doha Khartoum Lima Lisbon Montevideo Rome
Pakistan	Islamabad	1960	National unity, regional development	Islamabad Capital Territory	Central	Capital Development Authority: Aappointed Commissioner	3,626Km^2	n/a	1, 700,000 (2011) Population census	Yes	locations within the capital district and outskirts	Ankara Beijing Jakarta Madrid Seoul Venice
Nigeria	Abuja	1991	National unity, regional development	Federal Capital Territory	Central	Federal capital Development Authority: Appointed Minister	8000Km^2	3,000,000	1,078,700 (2011) UN estimates	Yes	locations within the capital district and outskirts	Brasilia Detroit Kanpur

* Compiled from FCDA (1979), National Population Commission (2006), Official government websites of Pakisan: http://www.pakistan.gov.pk/ (2011)and Brasil: http://www.brasil.gov.br/sobre/brazil (2011)

5.6 Is Abuja the same or different from other capital cities? What are the drivers of change in Abuja?

In terms of planning and development, Abuja shares the same ideals as national symbol of power with other planned capitals. Abuja has been designed to grow in phases that will accommodate the growth. It also has satellite towns that will serve as alternative locations for workers in the city. According to the Abuja master plan, the city should have been completed in 1986 (FCDA 1979) but due to changes in government, the city is still developing. Abuja is constantly growing, as more businesses and people enter the city. It grows from infilling and expansion. This expansion has increased distances to work for many city dwellers. The dominant form of transport is by road. This leads to traffic jams during the rush hour traffic, similar to what has been noticed Brasilia. In Brasilia the original road design was conceived in such way that they will not need traffic lights, but the number of cars have increased beyond all expectations and traffic lights had to be introduced to ensure orderliness (Scott and Allen 2010).

The need for land in Abuja has led to contraventions of the master plan and subsequent demolitions that have drawn the attention of the UN Habitat programme to the plight of the urban poor in Nigeria. According a UN Habitat publication "Since El-Rufai's appointment as Minister (of the FCT) by the President in 2003, the Federal Capital Development Authority (FCDA) has been carrying out mass forced evictions in Abuja in an attempt to re-initiate a master plan that was approved in 1979. These evictions are an attempt by the Government to redress 30 years of deviations from the city's Master Plan, in which land has been misallocated or developed 'improperly'. The Minister of the Federal Capital Territory, Mallam Nasir Ahmad El-Rufai, has ordered mass demolitions of businesses and homes, including over 49 informal settlements" (AGFE 2007, SERAC 2006). These evictions have forced people to seek accommodation in locations outside the city limits, well away from the jurisdiction of the FCDA.

These have led to the sprawling of developments. These new developments are located along the major roads going in and out of Abuja. Some of the locations that fall within the subset of the areas classified in this research are shown in Fig. 5.7. The largest of these destinations is the Karu Local Government Area (LGA) in neighbouring Nasarawa State. Within this LGA are locations like Nyanya, Maraba and Ado

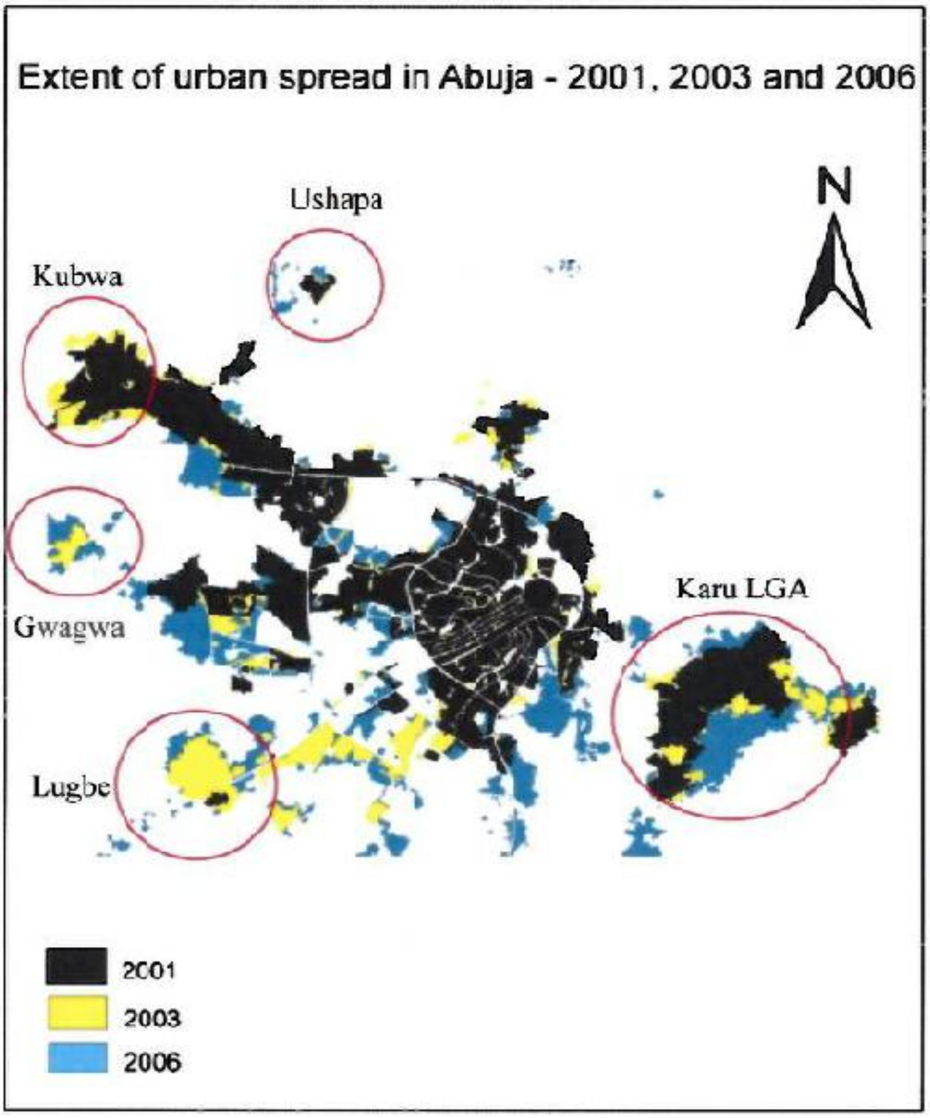


Fig. 5.7 Common destinations of displaced people in Abuja

The drivers of land use and land cover in Abuja FCT are population related. The pressure to allocate land for development, resulted in an inefficient land allocation system. These inefficiencies led to the creation of Abuja Geographic Information Systems (AGIS) (Akingbade, Navarra and Georgiadou 2010, Omole 2009). AGIS has sanitised the system and documented all land uses in the FCT. This documentation exercise has helped to expose violations and resulted in a development control exercise to curb them. Those who were evicted due to illegal land allocation by corrupt officials were not given any compensation or resettled (COHRE 2008).

5.7 Use of multisource imagery for land use and land cover change studies

In section 2.8, it was noted that there are many earth observation satellites. This means there are several earth observation satellites acquiring data of the same places daily or sub-daily. It also means there is a higher possibility of relatively cloud free data of any location on earth. Satellite missions have finite life spans. Therefore, any long-term study of LULCC must necessarily combine data from different sensors in order to cover the epochs of interest. However, the combination of data from different sensors presents challenges.

Different satellite sensors might mean that images are acquired in different resolutions. As shown in Table 3.1 the datasets used in this research had different image resolutions. The images were also acquired in slightly different bands of the electromagnetic spectrum. In terms of information content, the images convey slightly different details to the user. The challenge to the user is to prepare the datasets so that they can have common means of comparison and interpretation. To use the datasets in LULCC studies they have to be comparable.

Post classification LULCC analysis was used in this study as opposed to spectral change detection methods (change vector analysis, image differencing, image rationing, and change vs. no change binary mask). This approach was preferred because of the different sensors used in this research. Post classification LULCC analysis was useful because it allowed for the independent analysis of individual images. This method showed the weakness in each of the classification results after accuracy assessment. The low classification accuracy results recorded in the pixel based classification (Refer to Figs. 4.14 and 4.15) informed the use OBIA and cadastre data. This made the data comparable in terms of classification accuracy assessment (Chima and Trodd 2010). Despite these challenges, the ability to utilise multiple sensor data from different epochs outweighed any difficulties.

Chapter 6 Summary and Conclusions

The overall aim of this research was to investigate the nature of land use/ land cover change (LULCC) in Abuja, Nigeria from 1991 to 2006. In order to achieve this, specific objective were set. These were to 1) Design of an object based classification method to extract urban land cover and land use, 2) Validate a method to extract LULC (useful for developing countries) from multiple sources of remotely sensed data, 3) Apply the method to extract land use land cover data of Abuja for 1991 to 2006, 4) Use the outputs to validate an Urban Growth Model (UGM) for the period 1991 to 2006, 5) Optimise an UGM to represent patterns and trends and through this iterative process identify and prioritise the driving forces of urban change, and 6) Use the outputs of the land use maps to determine if planning has controlled land use development in Abuja.

Abuja, Nigeria was used as a case study to advance knowledge and understanding of land use change at global and local scales. Lepers *et al.* (2005) stated that monitoring of land cover change should be extended to areas where rapid changes are happening but are not hotspots of academic activity to better inform the world and possibly attract the attention of the academic community. Furthermore, the overall picture of causes of land use and land cover change can best be understood using place based research and comparative analyses of case studies of land use dynamics (Lambin *et al.* 2001).

In Chapter 2, the literature review examined urban areas and established the known drivers of land use and land cover change in the developing countries. Remote sensing of urban areas and methods used for remote sensing data analysis were also examined to help establish the state of the art methods. It was established that OBIA yields better results than pixels based methods based on available literature. The use of Urban Growth Models was examined to help establish the modelling tools or methods that are compatible with OBIA. Cellular Automata/Markov within the Idrisi software environment was considered suitable for the outputs of OBIA, because the outputs were in the raster format- the native format of Idrisi software, which hosts the CA/Markov module. Finally, the use of remote sensing for urban studies in Nigeria was reviewed indicating that no known study in Nigeria has utilised OBIA for multi-date, multi-sensor spatial-temporal LULCC.

The methodology chapter traced the evolution of urban areas in Nigeria. This helped to establish the reasons for a new capital city in Nigeria. It then made a case for the study of Abuja, Nigeria as a case study, used to put global occurrences in post-colonial, planned capital cities in perspective. Subsequently the specific GIS and remote sensing methods of data analysis were itemised, starting from pixel based methods to OBIA. After reviewing classification accuracy assessment of the classified data, the chapter concluded by tracing the evolution of urban developments in Nigeria leading up to the establishment of Abuja as national capital.

In Chapter 4, results were first presented, followed by analysis of the results, which helped to establish which aspects of the classification resulted from data artefacts or misclassification. The results showed that Nigeriasat-1 data can be used for urban land use studies using innovative OBIA methods, which allowed for the fusion of cadastre data to aid classification. The methods used also made the outputs of Nigeriasat-1SLIM sensor classification comparable to that from Landsat 7 ETM and SPOT 5 HRG sensors. From the analysis of land use maps produced, sprawling developments were noticed around Abuja and confirmed as such with the use of Shannon's Entropy Index. Land use growth was then modelled using Cellular Automata to get an idea of what the growth trends will be in 2020.

Chapter 5 discussed the causes of the sprawling developments and traced them to high land rents in the city and strict development control measures. These controls were effectively put in place after the establishment of AGIS and the proper documentation of the land use violations within the city. Developments in Abuja were put into global context by comparing them with those in Islamabad in Asia and Brasilia in South America. These comparisons showed that the developments in Abuja are representative of those in a developing country's capital. Planned and unplanned growth was occurring in these post-colonial capitals. The unplanned growth was manifested in the form of informal settlements. Some scholars, as discussed in section 5.2, have argued that these developments are indicative of the types of urban growth expected in the future.

6.1 Main Findings and contributions to knowledge

The novelty of this research rests on three major findings.

1 This work represents the first time OBIA has been used to study urban land use and cover in Nigeria because available literature indicated the absence of OBIA in Nigeria.
2 The use of OBIA and cadastral boundaries enabled the use of Nigeriasat-1 SLIM data for urban studies. This study established that Nigeriasat-1 data can contribute to urban studies. This is in contrast to earlier publications, which suggested that Nigeriasat-1 could not be used for urban land use and land cover studies.
3 The use of Shannon's Entropy index for the study of urban sprawl is novel because other studies have studied urban spread and discussed urban sprawl, but this study represents the first time that Shannon's Entropy index has been used to measure urban spread in Abuja.

6.2 Implications of the study

This study has helped to establish that GIS and remote sensing methods can be used to study formal and informal growth in the developing countries of the world. The specific case study of Abuja, Nigeria's capital shows that in comparison, other capitals in developing countries are also experiencing the same types of growth. There is an indication from this study that regulatory control cannot prevent unplanned growth in urban areas of developing countries due to population pressure on land. If as it has been argued that informal growth will be the dominant form of urban spread in the future, then GIS and remote sensing techniques, especially using OBIA would be an invaluable tool for the study of urban growth. This is because OBIA has the capability to identify objects as they appear to human analysts. This study has also helped to establish that innovative use of OBIA through data fusion (Pohl and Van Genderen 1998) involving a combination of land use cadastre, coarse resolution remotely sensed data (like Nigeriasat-1 and others) can contribute to LULCC studies. This study recommends that urban planners should incorporate land use modelling in their operation, to help them plan for future developments that will ensure sustainable urban development and growth.

6.3 Limitations and suggestions for further study

In the course of this study, certain limitations have been noticed. These arise from the realisation that there are alternate approaches that could have been adopted to give better understanding to the study.

All the images used in this study are from the dry season, because at that time of the year there is higher likelihood of acquiring cloud free data. Data acquisition from the same yearly time frame ensures that seasonal variations do not affect land use land cover change detection. However, it must be noted that in the dry season land cover types in Guinea Savannah areas like Abuja are difficult to differentiate as different surfaces have similar reflectance. For example, un-tarred roads may have similar reflectance values with fields that lose their grass cover in the hot conditions. This study would like to suggest the possibility of exploring the same sensor data from the rainy season with the same methods. This would possibly provide clearer distinctions in the analysis of the land cover types.

Another limitation of this study is the quality of the 28.5m resolution of Landsat 7 ETM data and 32m resolution of the Nigeriasat-1 data. With this resolution it was not possible to study urban infilling. This study recommends that fine resolution data like the second generation Nigeriasat-2 with 5m resolution should be used for urban land use studies. Hopefully with a resolution of 5 meter or less urban land use dynamics can be better analysed and mapped.

Other suggestions for further study include the use of primary survey to provide non-spatial data that can aid the validation of some of the findings in this study. For example, a detailed study of the water bodies in Abuja to determine why they are reducing in size.

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Glossary of Terms

Ancillary data: In digital image processing, data from sources other than remote sensing, used to assist in analysis and classification or to populate metadata

AVHRR: Advanced Very High Resolution Radiometer. A scanner flown on National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites for measuring visible and infrared radiation reflected from vegetation, cloud cover, shorelines, water, snow, and ice. AVHRR data is often used for weather prediction and vegetation mapping.

Cadastre: An official record of the dimensions and value of land parcels, used to record ownership and assist in calculating taxes.

Classification: The process of sorting or arranging entities into groups or categories; on a map, the process of representing members of a group by the same symbol, usually defined in a legend.

Control point: An accurately surveyed coordinate location for a physical feature that can be identified on the ground. Control points are used in least-squares adjustments as the basis for improving the spatial accuracy of all other points to which they are connected. One of various locations on a paper or digital map that has known coordinates and is used to transform another dataset, spatially coincident but in a different coordinate system-into the coordinate system of the control point. Control points are used in digitizing data from paper maps, in georeferencing both raster and vector data, and in performing spatial adjustment operations such as rubber sheeting.

Coordinates: A set of values represented by the letters *x*, *y*, and optionally *z* or *m* (measure), that define a position within a spatial reference. Coordinates are used to represent locations in space relative to other locations.

Cross tabulation: In a GIS, comparing attributes in different coverages or map layers according to location.

Data: Any collection of related facts arranged in a particular format; often, the basic elements of information that are produced, stored, or processed by a computer.

Developing economies: Countries in economic transition from producers of raw materials to industrial processing of those materials.

Digitizing: The process of converting the geographic features on an analog map into digital format using a digitizing tablet, or digitizer, which is connected to a computer. Features on a paper map are traced with a digitizer puck, a device similar to a mouse, and the x,y coordinates of these features are automatically recorded and stored as spatial data. See heads up digitizing

Enhancement: In remote sensing, applying operations to raster data to improve appearance or usability by making specific features more detectable. Such operations can include contrast stretching, edge enhancement, filtering, smoothing, and sharpening.

Fractal: A geometric pattern that repeats itself, at least roughly, at ever smaller scales to produce self-similar, irregular shapes and surfaces that cannot be represented using classical geometry. If a fractal curve of infinite length serves as the boundary of a plane region, the region itself will be finite. Fractals can be used to model complex natural shapes such as clouds and coastlines.

Fuzzy classification: Any method for classifying data that allows attributes to apply to objects by membership values, so that an object may be considered a partial member of a class. Class membership is usually defined on a continuous scale from zero to one, where zero is non-membership and one is full membership. Fuzzy classification may also be applied to geographic objects themselves, so that an object's boundary is treated as a gradated area rather than an exact line. In GIS, fuzzy classification has been used in the analysis of soil, vegetation, and other phenomena that tend to change gradually in their physical composition and for which attributes are often partly qualitative in nature.

Georeferencing: Aligning geographic data to a known coordinate system so it can be viewed, queried, and analysed with other geographic data. Georeferencing may involve shifting, rotating, scaling, skewing, and in some cases warping, rubber sheeting, or orthorectifying the data.

Geostationary: Positioned in an orbit above the earth's equator with an angular velocity the same as that of the earth and an inclination and eccentricity approaching zero. A geostationary satellite will orbit as fast as the earth rotates on its axis, so that it remains effectively stationary above a point on the equator. A geostationary satellite is geosynchronous, but geosynchronous satellites are not necessarily geostationary.

GIS: Acronym for *geographic information system*. An integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed.

Grid: In cartography, any network of parallel and perpendicular lines superimposed on a map and used for reference. These grids are usually referred to by the map projection or coordinate system they represent, such as universal transverse Mercator grid.

Ground control: A system of points with known positions, elevations, or both, used as fixed references in georeferencing map features, aerial photographs, or remotely sensed images.

Ground truth: The accuracy of remotely sensed or mathematically calculated data based on data actually measured in the field.

GUI: Graphical User Interface. A software display of computer program options that allows a user to choose commands by pointing to icons, dialog boxes, and lists of menu items on the screen, typically using a mouse. This contrasts with a command line interface in which control is accomplished via the exchange of strings of text.

Heads up digitizing: Manual digitization by tracing a mouse over features displayed on a computer monitor used as a method of vectorising raster data.

Histogram equalization: In digital image processing this is the redistribution of pixel values in an image so that each range contains approximately the same number of pixels. A histogram showing this distribution of values would be nearly flat.

Iterative procedure: A repetitive or recurring procedure.

Land cover: See Also: Land use: The classification of land according to the vegetation or material that covers most of its surface; for example, pine forest, grassland, ice, water, or sand.

Land use: (See Also: Land cover) : The classification of land according to what activities take place on it or how humans occupy it; for example, agricultural, industrial, residential, urban, rural, or commercial.

Landsat: Multispectral, earth-orbiting satellites developed by NASA (National Aeronautics and Space Administration) that gather imagery for land-use inventory, geological and mineralogical exploration, crop and forestry assessment, and cartography.

Landscape ecology: The study of spatial patterns, processes, and change across biological and cultural structures within areas encompassing multiple ecosystems.

Latitude: The angular distance, usually measured in degrees north or south of the equator. Lines of latitude are also referred to as parallels.

Map: Any graphical representation of geographic or spatial information.

Layer: The visual representation of a geographic dataset in any digital map environment. Conceptually, a layer is a slice or stratum of the geographic reality in a particular area, and is more or less equivalent to a legend item on a paper map. On a road map, for example, roads, national parks, political boundaries, and rivers might be considered different layers.

Legend: The description of the types of features included in a map, usually displayed in the map layout. Legends often use graphics of symbols or examples of features from the map with a written description of what each symbol or graphic represents.

Longitude: The angular distance, usually expressed in degrees, minutes, and seconds, of the location of a point on the earth's surface east or west of an arbitrarily defined meridian (usually the Greenwich prime meridian). All lines of longitude are great circles that intersect the equator and pass through the North and South Poles.

Mixed pixel: In remote sensing, a pixel whose digital number represents the average of several spectral classes within the area that it covers on the ground, each emitted or reflected by a different type of material. Mixed pixels are common along the edges of features.

Nadir: In aerial photography and Satellite Imaging, the point on the ground vertically beneath the perspective centre of the camera lens or sensor.

Nearest neighbour resampling: A technique for resampling raster data in which the value of each cell in an output raster is calculated using the value of the nearest cell in an input raster. Nearest neighbour assignment does not change any of the values of cells from the input layer; for this reason it is often used to resample categorical or integer data (for example, land use, soil, or forest type), or radiometric values, such as those from remotely sensed images.

North arrow: A map symbol that shows the direction of north on the map, thereby showing how the map is oriented.

Neural network: Computer architecture modelled after the human brain and designed to solve problems that human brains solve well, such as recognizing patterns and making predictions from past performance. Neural networks are composed of interconnected computer processors that calculate a number of weighted inputs to generate an output. For example, an output might be the approval or rejection of a credit application. This output would be based on several inputs, including the applicant's income, current debt, and credit history. Some of these inputs would count more than others; cumulatively, they would be compared to a threshold value that separates approvals from rejections. Neural networks "learn" to generate better outputs by adjusting the weights and thresholds applied to their inputs.

Nigeriasat-1: One the satellites that make the Disaster Monitoring Constellation

Overlay: A spatial operation in which two or more maps or layers registered to a common coordinate system are superimposed, either digitally or on a transparent material, for the purpose of showing the relationships between features that occupy the same geographic space.

Panchromatic image: A single band image generally displayed as shades of gray.

Parcel: A piece or unit of land, defined by a series of measured straight or curved lines that connect to form a polygon.

Raster: A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent the same type of geographic feature.

Remote sensing: Collecting and interpreting information about the environment and the surface of the earth from a distance, primarily by sensing radiation that is naturally emitted or reflected by the earth's surface or from the atmosphere, or by sensing signals transmitted from a device and reflected back to it. Examples of remote-sensing methods include aerial photography, radar, and satellite imaging.

Remote-sensing imagery: Imagery acquired from satellites and aircraft, including panchromatic, radar, microwave, and multispectral satellite imagery.

Resampling: (see also nearest neighbour resampling): The process of interpolating new cell values when transforming rasters to a new coordinate space or cell size.

Resolution: The detail with which a map depicts the location and shape of geographic features. The larger the map scale, the higher the possible resolution. As scale decreases, resolution diminishes and feature boundaries must be smoothed, simplified, or not shown at all; for example, small areas may have to be represented as points.

RMS error: Acronym for *root mean square error*. A measure of the difference between locations that are known and locations that have been interpolated or digitized. RMS error is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points, and then taking the square root of that result.

Satellite constellation: The arrangement of a set of satellites in space. E.g. Disaster Monitoring Constellation

Shapefile: A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.

SPOT: Acronym for *Satellite Pour l'Observation de la Terre*. Earth observation satellites developed by Centre National d'Etudes Spatiales (CNES), the space agency of France. The SPOT satellites gather high-resolution imagery used in natural resource management, climatology, oceanography, environmental monitoring, and the monitoring of human activities.

Validation: In modelling, the evaluation of a method to show whether it is assessing the parameter of interest rather than something else.

WGS84: World Geodetic System 1984. The most widely used geocentric datum and geographic coordinate system today, designed by the U.S. Department of Defence to replace WGS72. GPS measurements are based on WGS84.

X, Y coordinates: A pair of values that represents the distance from an origin (0, 0) along two axes, a horizontal axis (x), and a vertical axis (y). On a map, x and y coordinates are used to represent features at the location they are found on the earth's spherical surface.

Suitability Mapping: Mapping the fitness of a given type of land for a defined use.

Shannon's Entropy Index: An index used to measure the degree of sprawl in urban growth.

Urban sprawl: Unplanned and uneven pattern of urban growth which usurps open spaces adjoining urban areas.

Appendix 1 has been removed as it is not known whether this paper was published. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University