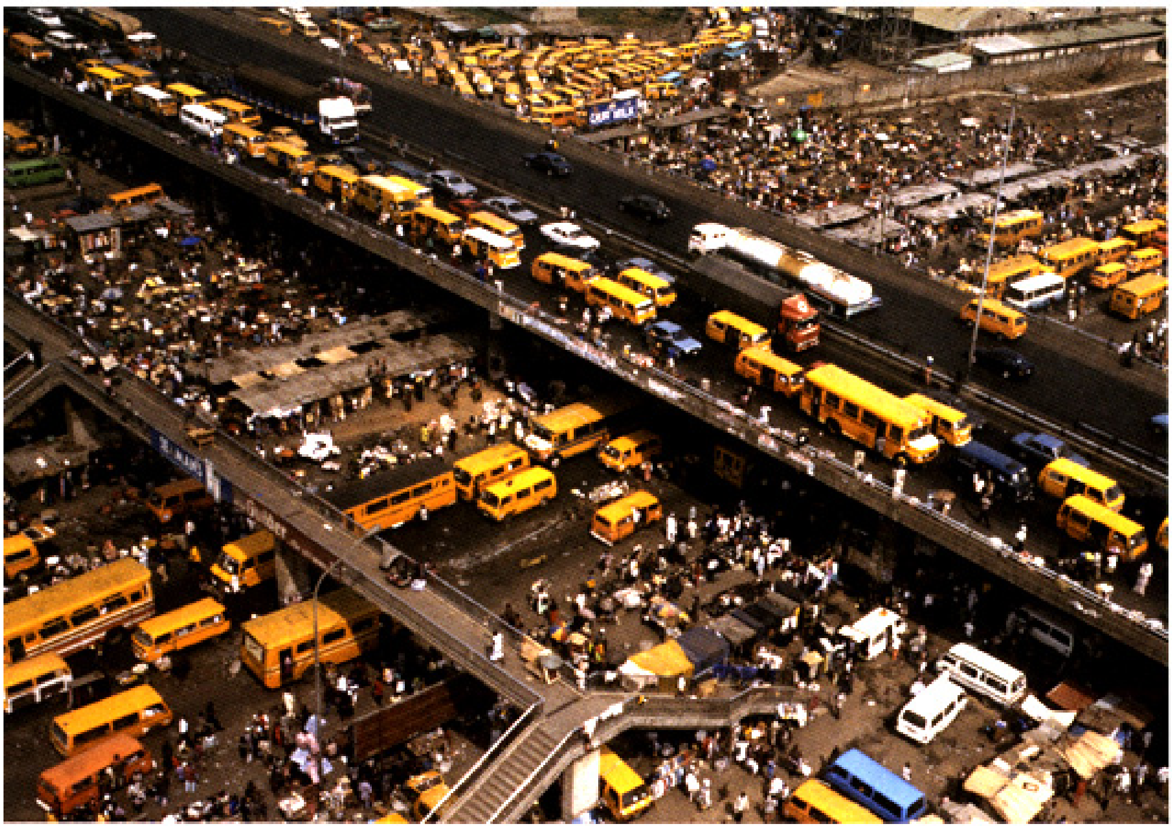
LUMA-GIS Thesis nr 12

MONITORING URBAN GROWTH IN GREATER LAGOS:
A case study using GIS to monitor the urban growth of Lagos 1990 - 2008 and produce future growth prospects for the city



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Source frontpage image: Lawson et al., 2001.

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ABSTRACT

The aim of this thesis is to show how the city of Lagos has grown in size and population between the years 1990-2008. Comparisons over the city for the years 1990, 1999 and 2008 have been made so that the main characteristics of the city's growth can be shown and analyzed. Based on this expansion future prospects for the city has been provided through producing three different scenarios on how Lagos might look in the year 2020. The study has been conducted through remote sensing where satellite images over the city have been acquired; these images have been edited and combined with population data so that demographical comparisons can be done. The results indicate that the city has experienced an extreme growth, both in area and in population. The growth has however been more characterized by an expansion in area than population increase. Over the total study time the population in the city more than doubled from around five million inhabitants in 1990 to over ten million in 2008, during the same time period the city expanded almost three times in size. The lack of high resolution satellite data and the fact that the population figures used is based on estimates however create some unreliability in the results. That the city has experienced growth over the study time was not surprising since it is the type of region that has grown the fastest in the world during the last decades, an urban area in a developing country.

Key words: Remote sensing, Change detection, Lagos, Urban growth, Future predictions

SAMMANFATTNING

Syftet med denna uppsats är att visa hur staden Lagos har vuxit i storlek och ökat i befolkning mellan åren 1990-2008. Jämförelser över staden för åren 1990, 1999 och 2008 har gjorts så att huvudragen i stadens tillväxt har kunnat visas och analyseras. Baserat på hur staden har vuxit och förändrats under dessa år så har även tre stycken framtidsmodeller för hur Lagos kan tänkas se ut år 2020 producerats. Studien har genomförts genom en fjärranalys där satellitbilder över Lagos har använts och redigerats på olika sätt för att visa stadens tillväxt. Befolkningsstatistik har även använts så att demografiska jämförelser har kunnat genomföras över tid. Resultaten visar att staden har vuxit kraftigt över studietiden. Ökningen har framförallt kännetecknats av att staden expanderat i yta. Över studietiden fördubblades befolkningen i Lagos från runt fem miljoner invånare 1990 till över tio miljoner invånare 2008 samtidigt som den expanderade runt tre gånger i yta. Bristen på satellitbilder i hög upplösning och att befolkningssiffrorna är baserade på uppskattningar gör dock att det finns en viss felmarginal i resultaten. Att staden vuxit över studietiden är inte särskilt förvånande eftersom området utgör den typ av region som vuxit mest under senare årtionden; en urban region i ett utvecklingsland.

Nyckelord: Fjärranalys, Förändringsstudie, Lagos, Urban tillväxt, Framtidsmodeller

ABBREVIATIONS

CIA	Central Intelligence Agency
CIAT	Centro Internacional de Agricultura Tropical
CIESIN	Center for International Earth Science Information Network
CRISP	Centre for Remote Imaging, Sensing & Processing
DCW	Digital Chart of the World
DESA	United Nations Department of Economic and Social Affairs/ Population division
EOSAT	Earth Observation Satellite Company
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper +
FAO	United Nations Food and Agriculture Program
GIS	Geographical Information Systems
GLS	Global Land Survey
GPW	Gridded Population of the World
GRUMP	Global Rural – Urban Mapping Project
GSFC	Goddard Space Flight Center
LUMA-GIS	Lund University Master´s Program in Geographical Information Systems
MSS	Multispectral Scanner System
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SCB	Statistiska Central Byrån
SEDAC	Socioeconomic Data and Applications Center
SLC	Scan Line Corrector
SPOT	Système Pour l'Observation de la Terre
TM	Thematic Mapper
UN	United Nations
USGS	United States Geological Survey
USK	Stockholms Stads Utrednings- och Statistikkontor AB
WGS	World Geodetic System

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1 INTRODUCTION

In geographical terms the 20th century should be seen as the century of urbanization, even if the movement had started earlier in some places it now became a global phenomenon. Urban populations of the world grow almost twice as fast as the general population and approximately half of the population on our planet in 2010 lives in urban areas compared to less than 5 percent in the 1800s. Several factors have led to this development but the main reason is the shift in our society from an agricultural to a service- and market based (Knox et al, 2003).

A shift in the urbanization trend during the latter parts of the 20th century could be seen; from being a movement primarily taking place in the developed world it changed to becoming a phenomenon in the developing world. In fact the rate of urban growth in many developing countries is the fastest urban growth ever seen on our planet (World Urbanization Prospects: The 2007 Revision, 2008). In the 1950s 20 of the world's 30 most populated cities were located in the developed world (Knox et al, 2003); in 2010 18 of these cities were instead situated in the developing world (Demographia World Urban Areas & Population Projections, 2010). Prognosis show that the urban population is expected to continue to grow all over the world and is predicted to almost double from 2010 till the year 2050 when 6, 4 billion people are estimated to live in urban areas, an increase that almost entirely will take place in the developing world (World Urbanization Prospects: The 2007 Revision, 2008).

The study is conducted over Lagos, Nigeria by monitoring the growth of the city from 1990 – 2008. It has been performed through using GIS where images over the city and its population has been compared and analyzed for the years 1990, 1999 and 2008. The reason why the study has been performed over this region is that it is a city that has experienced an extreme population increase during the last 50 years (World Urbanization Prospects: The 2007 Revision, 2008). Lagos had the 4th highest urban growth rate in the world between the years 1975 to 2000 with an annual population increase of around 6, 1 %. (World Urbanization Prospects: The 2001 Revision, 2001). Since then the growth rate of the city has slowed down in percentage terms, but the actual increase in inhabitants has continued to rise (World Urbanization Prospects: The 2007 Revision, 2008).

Other studies monitoring urban growth in the developing world have been investigated thoroughly (Al-Awadhi et al, 2003, Azaz, 2001, de Jong et al, 1997 & Naseem et al, 2000), this to find similarities to this study and to gain insight in useful parameters. All the cases monitored experienced a fast urban growth over the study time. None of these cases where however performed over longer time periods which made it impossible to see changes in characteristics over the urban growth through the years and none of them produced and showed likely future outcome for their cities, which has been performed in this study.

Worth mentioning is that the terms “developing world” and “developed world” frequently are used in the thesis. These terms have been criticized because they imply an inferiority of the developing world to the developed world. Trends change in which terms are used to describe these parts of the world but since none of the existing terms are as widely accepted and the course literature uses these terms they have been used. The expressions “urbanization”, “urban growth” and “urban sprawl” are also used in the study; the distinction between these terms should be understood. Urbanization has to do with an increase in people moving from rural to urban areas, urban growth has to do with an increasing urban population in general and urban sprawl is when a network of smaller urban communities starts appearing outside of a larger city (Pacione, 2005).

1.1 Aim

The aim of this study is to show how the city of Lagos has grown between the years 1990 to 2008. This has been deduced through a change detection study where images over the urban area of the city combined with population data have been compared for the years 1990, 1999 and 2008. The main shifts of the city in area and in population have then been analyzed so that conclusions can be drawn. Based on these statistics three different future growth scenarios over the city for the year 2020 have been produced.

<u>Research questions:</u>
How has the population and area of greater Lagos changed between the years 1990-2008?
What are the main reasons for this development?
How can possible future developments for the city look?

1.2 Study area

Figure 1 illustrates the study area which is located in the south western part of Nigeria and covers an extent from approximately 3.0 E to 3.5 E and 6.2 N to 6.6 N. The area is square shaped and spans 50km in all directions from the center of Lagos, covering a total area of around 10 000km^2 (100x100km).

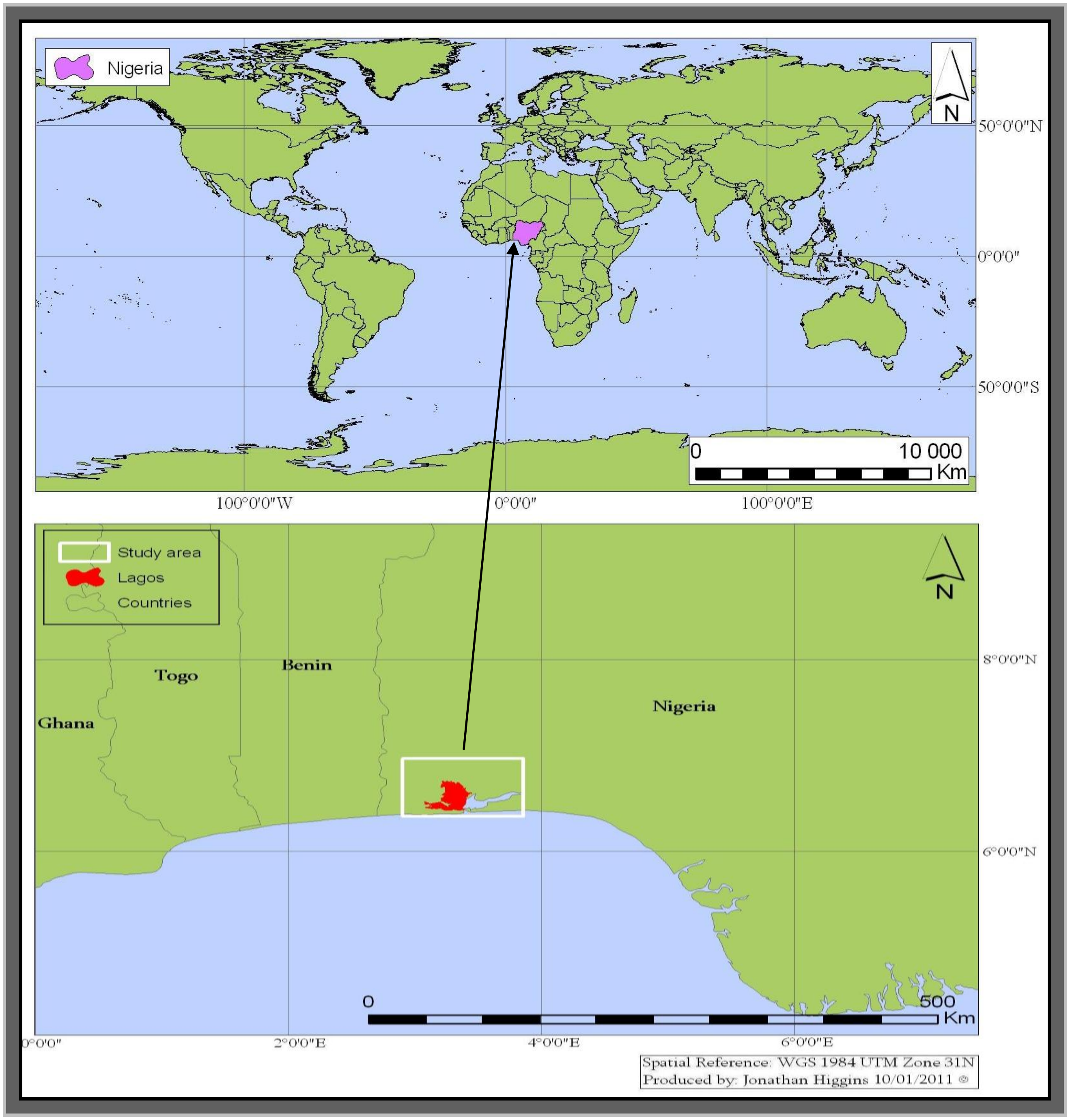

Figure 1: Nigeria & Study area

Source: Digital Chart of the World, 2010.

1.3 Outline

This thesis is constructed in a traditional manner. After a brief introduction to the subject the aim of the project will be described. The main theories involved in the subject will then be explained. This will be followed by the methods used to reach the results before finally showing the results. The results will be provided in a comparative way where data between the various years will be shown. These results will then be analyzed together with the theories involved in the subject so that some main conclusions can be drawn.

This study has been carried out mainly using GIS software. The GIS methods used to perform the study have been selected through the alternatives that were deduced to provide the most accurate results. These methods were selected from methods used in similar case studies (Al-Awadhi et al, 2003, Azaz, 2001, de Jong et al, 1997 & Naseem et al, 2000) and by studying change detection methods (Lillesand et al, 2008 & Janssen et al, 2001). The results have been provided through using remote sensing that has produced classified images over Lagos that have been compared through using an algorithm called the post classification comparison change detection. This algorithm has been used because it is performed after classification and is preferable when only monitoring the change for one land class because the changes easily can be visualized (Jensen, 1996). The accuracy of the produced images has been assessed through different measurements that measure their quality. The thesis has been written through inductive reasoning, where results have been produced before fitting them into a more general context. This has been done in an empirical manner using population figures and maps that are explained through a naturalistic philosophical approach where geographical theories describe the results (Flowerdew et al, 2005). Using quantitative methods has been more useful than qualitative methods since the study has focused on the macro perspective for Lagos. The statistics and images compared with each other are for the total population and area changed and is not focused on developments for specific areas or neighborhoods of the city.

All the maps used in this study have been produced through ArcGIS software through using the programs ArcMap and ArcCatalog in the ArcGIS desktop version 9.3 (ESRI, 2010). This program has also been used for statistical analysis. The Microsoft programs Microsoft Office Excel 2007 (Microsoft office, 2007), Microsoft Office Word 2007 (Microsoft office, 2007) and Microsoft Paint (Microsoft, 2007) have also been used. Excel has been used for calculations and to produce tables; the thesis has been written using Word. Paint has been used for image enhancement operations.

2 LITERATURE

2.1 Sources used

Sources for this thesis have mainly been selected from university course literature for remote sensing and human geography courses, from references used by other similar studies and by looking at information provided by GIS data producers. The books used for the thesis are broad, dealing with wider areas such as remote sensing in general whereas the internet sources used are more specific, the books used have therefore been sighted for more information and have been extensively used while many of the internet references only have provided some facts or figures.

Sources that have been influential when constructing this thesis are the books Principles of remote sensing by Janssen and Huurneman (2001), Remote sensing and image interpretation by Lillesand, Kiefer and Chipman (2008), Human geography, places and regions in global context by Knox and Marston (2003), Urban geography: a global perspective by Pacione (2005), Methods in human geography, a guide for students doing a research project, by Flowerdew and Martin (2005) and the article World Urbanization Prospects: The 2007 Revision (2008).

2.2 Earlier studies

Several urban growth studies have been conducted throughout the world. The studies that have been investigating urban growth through similar methods to this study and in countries with similar demographic trends and structures have been closely monitored. The reports looked at have monitored urban growth in Al-Seeb Wilayat, Oman (Al-Awadhi et al, 2003), Ouagadougou, Burkina Faso (de Jong et al, 1997), along the Islamabad highway, Pakistan (Naseem et al, 2000) and in Alexandria, Egypt (Azaz, 2001).

The results for all the case studies monitored showed that a rapid urban growth had occurred in all of the investigated places, this through both an expansion of the main urban area and through urban sprawl. The main reason for the urban growth was in all of these cases due to a high natural population increase throughout the countries because of high birth rates. Urbanization was also taking place in the cities, these rates tend to increase when regional and national economy is prospering (Masek, 1996). This could clearly be seen in Oman when oil was found there. The reason for this is because of the employment opportunities that this offers to the cities (Al-Awadhi et al, 2003). Similarities could also be seen in the way the urban growth was occurring, it was so fast that it was taking place without any planning from the government which created huge areas of informal housing (Azaz, 2001, Naseem et al, 2000).

These different case studies have all monitored change detection for several different land classes, this to show the effects that urban expansion have on other land classes. This study has however only focused on the change for the land class urban.

3 THEORY

The results are explained through human geographical urban growth theories. These theories explain the main factors involved in urban growth and specifically the ones relating to the developing world.

3.1 Urban growth

As the name implies urban growth has to do with the growth of an urban population. The causes for this are either because of a natural population increase, a movement of people from the rural to the urban or migration. A theory called the demographic transition model describes the main phases of population change through industrialization and urbanization over history (Pacione, 2005); it shows how urban growth is closely linked to economic development (Knox et al, 2003). Figure 2 shows this model.

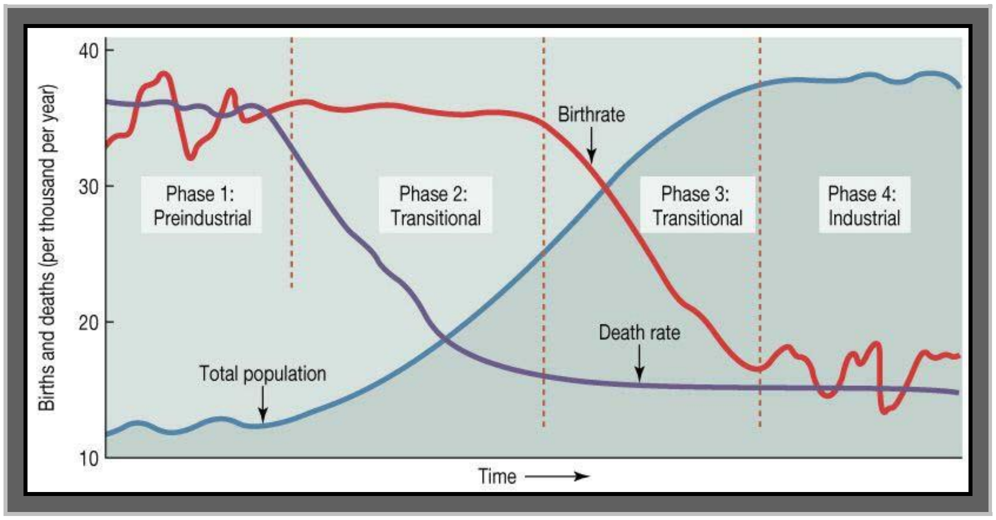

Figure 2: The demographic transition model
Source: Fusch, n.d.

Figure 2 describes the main phases of population change through industrialization and urbanization. Phase 1 is the pre-developed society characterized by both high birth and death rates; it is the high mortality rates that keep the population from increasing. This phase is found in rural areas before industrialization, and can be found in the poorest rural areas in the world today, for example Sub-Saharan Africa (Pacione, 2005).

Phase 2 is called the transitional phase and is when a society starts its industrialization and where development starts to take place. Birth rates are still high due to family and religious values but improvements in public health and in medicine lead to a drop in mortality rates. It is during this phase that urbanization starts and where the population growth in a society is the highest, examples of regions in this phase is developing countries such as Nigeria (Pacione, 2005).

The next phase, phase 3 is when a society is industrialized and has moved from a rural to an urban society. This change makes larger families less beneficial and more of an expense to a families budget leading to decreasing birthrates and a slower population growth. This is a phase that Europe and North America has passed through (Pacione, 2005).

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The 4th and final phase is when the population increase stagnates, this because of the education- and career opportunities that make it disadvantageous with large families. The difference between this phase and the first phase is that the population growth is low here due to low birth rates and not due to high mortality rates. This is a phase that many European, North American and some Asian countries have reached (Pacione, 2005).

3.2 Natural population growth

The two factors involved in a natural population change are fertility rates (birth rates) and mortality rates (death rates). If the birth rates are higher than death rates the population will increase (Knox et al, 2003). The most common way to show the composition of a population is to use an age-sex pyramid. It shows the distribution of a population in cohorts which are groups of people who share the same demographic characteristics, in this case people in the same age group and of the same sex. The pyramid shows the composition of a population which makes it possible to draw many conclusions of future population outcomes. The shape of the pyramid shows this, a triangular shaped period pointing upwards indicates a young fast growing population while a more evenly distributed pyramid indicates a slower growth. The higher the proportion of population who are old the slower the population growth will be, too high values and the population will start decreasing. Figure 3 shows how typical age-sex pyramids look for countries experiencing a rapid, slow and no population increase (Knox et al, 2003).

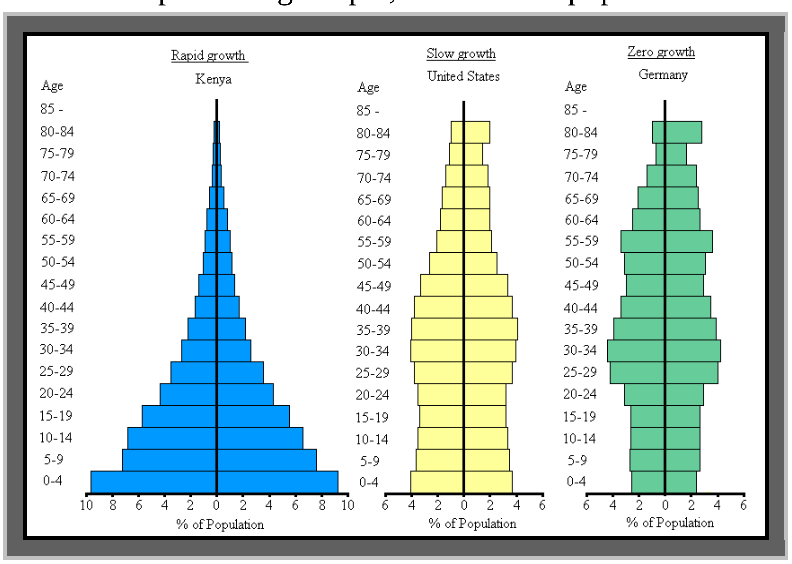

Figure 3: Age-sex pyramids

Source: Weller et al, n.d.

The pyramid over Kenya seen in Figure 3 is typical for a country in the developing world experiencing a fast increase in population which can be seen by the shape of the pyramid. The increase in population is characterized by high birth rates which can be seen by the high proportion of the population that are young. The Age-sex pyramids over United States and Germany has a more even population distribution through the various age groups. This distribution indicates an older population compared to Kenya. Pyramids with this shape are countries with lower birthrates experiencing a slow or negative population increase (Knox et al, 2003).

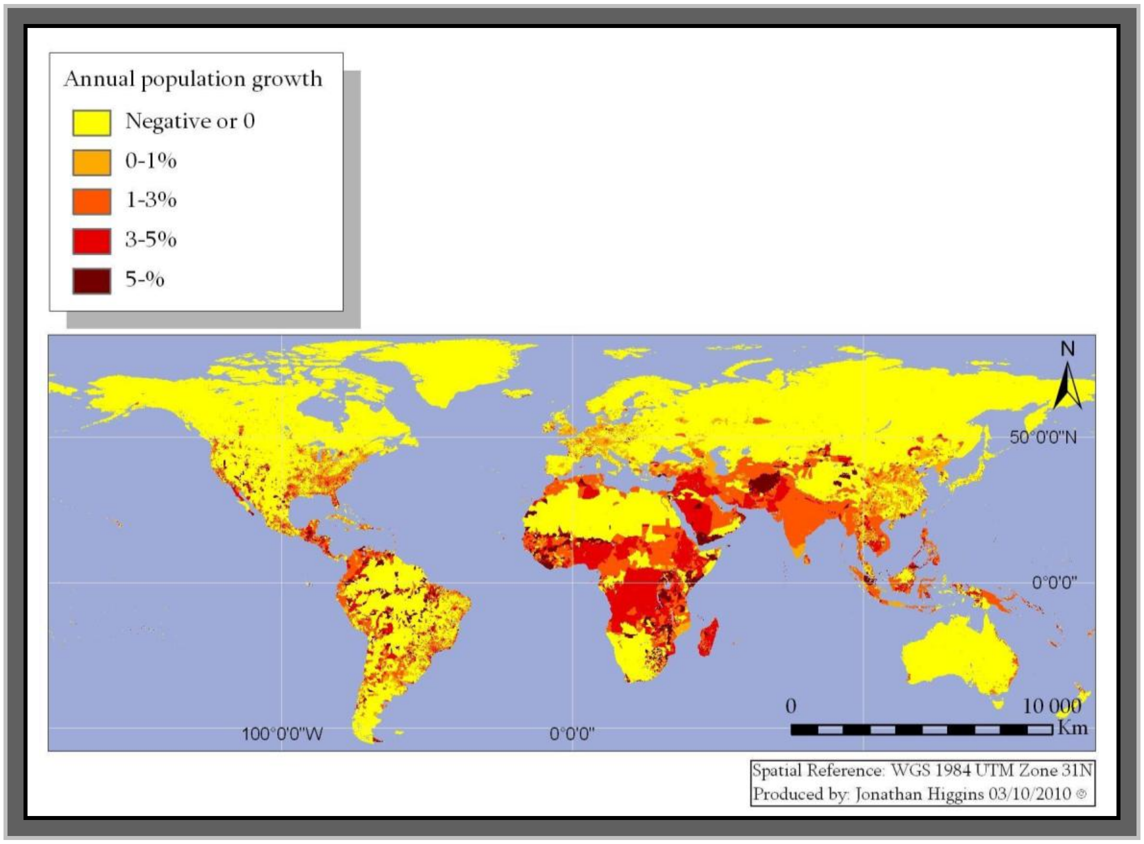

Figure 4: World annual population growth

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010.

Figure 4 shows the annual population change in the world between the years 1990-2010. This map has been constructed according to Equations 6-8 (*p.26-27)*. The population increase has been highest in central Africa and in southern Asia. The population growth in these areas has occurred throughout the whole countries compared to Europe and the American continent where the increase has taken place mainly in the urban areas. This indicates that the countries in Africa and Asia have a high natural population increase whereas the growth in Europe and America is in urban areas due to urbanization.

3.3 Urbanization

Urbanization is the process when people move from rural to urban regions. The main reason for this is the shift from an agricultural to an industrial society (Knox et al, 2003). The most important impetus for urbanization is economic, such as employment opportunities, higher wages and better future prospects that are offered in the cities (Gilbert et al, 1982). This can clearly be seen in the way that most of the world largest cities are in the world's largest economies. Countries where economies are growing are also the countries where the levels of urbanization are increasing the most (Pacione, 2005). Urbanization in the western world started during the industrialization era but it did not reach the developing world until the industrialization reached them, around the 1960s, a time when a lot of colonies especially in Africa gained their independence (Knox, 2003). Figure 5 illustrates the urban development over the world the years 1950-2050.

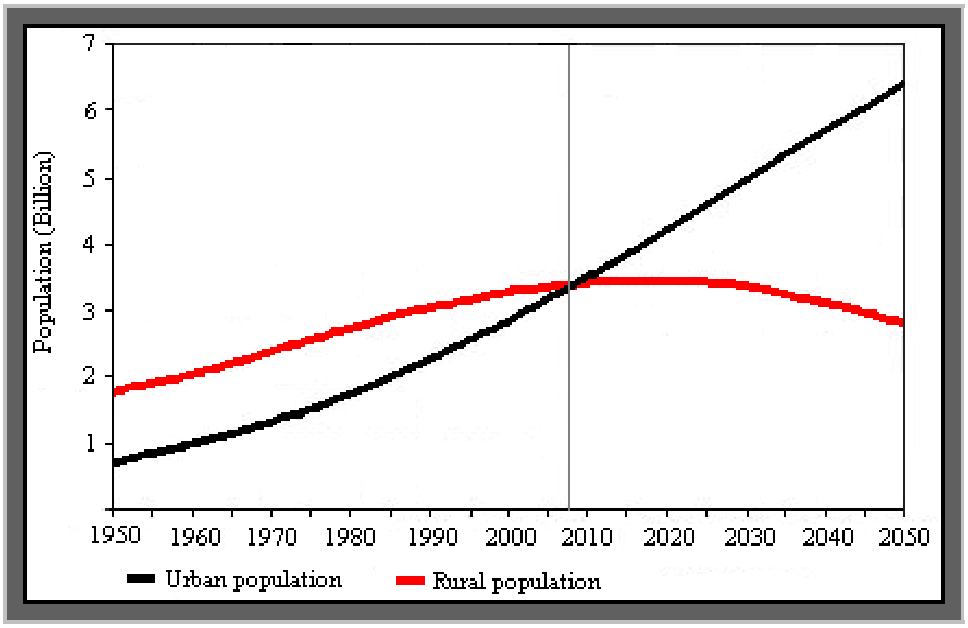

Figure 5: World urbanization rate

Source: World Urbanization Prospects: The 2007 Revision, 2008

Figure 5 shows the relationship between the rural and the urban population of the world. The rural population is starting to decrease and instead it is the urban population that is growing faster than ever before. In 2008 the urban population in the world outgrew the rural population. Future prognosis indicates that this development will continue to take place where world urbanization rates will continue to increase. There are however still huge differences in the rate of urbanization between the developed and the developing world (World Urbanization Prospects: The 2007 Revision, 2008), which can be seen in Figure 6.

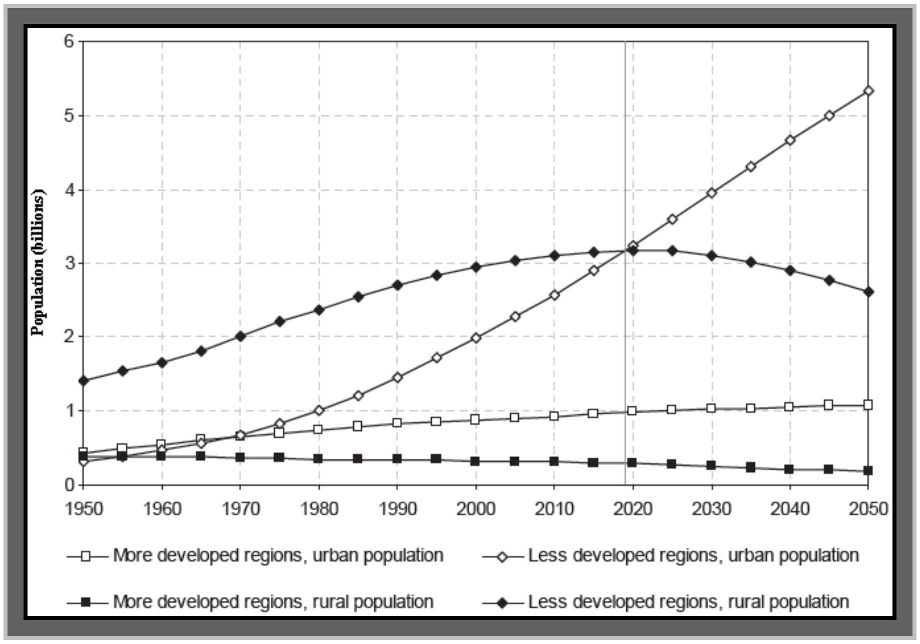

Figure 6: Developed and developing countries rate of urbanization
Source: World Urbanization Prospects: The 2007 Revision, 2008

Figure 6 shows that the rate of urbanization is fast increasing in the developing world. In 1950 the urban population outgrew the rural population in the developed world and is expected to do the same in the developing world around the year 2019. One can clearly see that the population increase in the world is taking place in urban areas, especially in the developing world. There is hardly any population increase in the developed world and even though urbanization is taking place it is occurring at the expense of the rural population. The rural population in the developing world is still increasing but only just and is expected to start decreasing in the coming 50 years. (World Urbanization Prospects: The 2007 Revision, 2008).

3.4 Urban growth in the developing world

There are differences in the characteristics of urban growth in the developing and the developed world. In the developing world the main reason for urban growth is a high natural population increase while it in the developed world almost only has to do with urbanization. Urbanization in the developing world is also driven more by "push" factors than "pull" factors; meaning that more people are moving away from rural areas because of the lack of employment and the competition for space there rather than jobs or opportunities in urban areas. This is called rural flight (Knox et al, 2003). This together with the shift from an agricultural society and that developing countries traditionally have been more centralized has led to an over urbanization in some cities. This centralization dates back to colonialism where all administrative and important functions where located in one city (Pacione, 2005).

Urban growth in the developing world is occurring even in countries with low levels of economic development and is also occurring faster and with larger volumes of people than it ever did in the developed world (Pacione, 2005). This development has caused a huge housing problem that has created large areas of poverty with high population density levels. This has created environmental and health hazards for many cities and people in the developing world (Knox et al, 2003).

Different theories exist that describe urbanization in the developing world. The main ones are the following:

Modernization theory

This theory means that urbanization in the developing world is taking place because these countries are now starting their industrialization with innovations and economic development that will start and spread from urban centers (Pacione, 2005).

Dependency theory

This theory means that there exists an unequal relationship between the developed world and the developing world; where the developed world constantly will exploit the developing world. This dates back to colonization where many European countries founded cities for trade and commerce in the developing world. These cities are still exploited in the world trade market, where raw materials are exported cheaply and expensive manufactured products imported. This leads to that cities there never evolve and still are at the bottom of the production chain. This development has led to that cities in the developing world become important hubs to the outside world where a lot of the heavy production is located creating job opportunities leading to urbanization (Pacione, 2005).

World-system theory

This theory is an extension of the dependency theory indicating that the world consist of three different types of countries, core-, semi peripheral- and peripheral countries. The wealthy countries in the world (core) will constantly take advantage and utilize the less wealthy countries and all trade is done primarily to the gain of the wealthier countries. Countries can however change their place in the world system and can start to exploit other countries instead of being exploited. Urban areas in peripheral countries will be important production hubs according to this theory and therefore urban growth will be huge (Pacione, 2005).

4. METHOD & DATA

This chapter will contain descriptions of the research methods used for the results together with information over the data used and how it has been managed.

4.1 Data

Three different sources of spatial data have been used for this study:

- Satellite images
- Population data
- International borders

Basic operations performed to the data which have not been described include:

- Referencing the data to WGS 1984
- Clipping and merging the data to cover the study area

4.1.1 Satellite images

All the satellite images used in the study have been acquired from Landsat satellite imagery, through their United States Geological Survey Global Visualization Viewer (Earth Resources Observation and Science Center, 2011-11-01). Satellite images are classified into different categories depending on their resolution, a spatial resolution lower than 4 meters is classified as a high resolution satellite, a spatial resolution between 4 – 30 meters is classified as a medium resolution satellite and a resolution greater than 30 meters is classified as a low resolution satellite (Satellite Imaging Corporation, 2010). The images used have a resolution of 30 meters and are therefore classified as medium resolution. Ten different images over the study area were downloaded in total, all in TIF format. Metadata over this data can be seen in Table 1.

Table 1: Metadata over satellite data

	1[1,2]	**2**[1,2]	**3**[1,2,3]	**4**[1,2]
Producer	NOAA , EOSAT & USGS	NOAA , EOSAT & USGS	USGS	NOAA , EOSAT & USGS
Publication date	2010	2010	2010	2010
Collection Name	Landsat 4-5	Landsat 4-5	GLS	Landsat 4-5
Sensor name	MSS	TM	TM	TM
Epoch	1984	1984	1990	1990
Bands	4 68x83m	6 30x30m & 1 120x120m	6 30x30m & 1 120x120m	6 30x30m & 1 120x120m
Image name	LM51910561984353AAA03	LT51910551984353XXX07	p191r056_4x19901227	LT41910551990361XXX03
Acquisition date	18/12/1984	18/12/1984	27/12/1990	27/12/1990
Extent	Latitude 5.8 Longitude 3.1	Latitude 7.2 Longitude 3.4	Latitude 5.8 Longitude 3.1	Latitude 7.2 Longitude 3.4
Cloud cover	20%	20%	20%	30%
Publisher	NASA	NASA	USGS	NASA
Publisher Location	Houston, Texas	Houston, Texas	Sioux Falls, South Dakota	Houston, Texas

	5 [1,2,3]	**6** [1,2,3]	**7** [1,2,4]	**8** [1,2,4]
Producer	USGS	USGS	USGS	USGS
Publication date	2010	2010	2010	2010
Collection Name	GLS	GLS	Landsat 7	Landsat 7
Sensor name	TM	TM	ETM+	ETM+
Epoch	2000	2000	2002	2002
Bands	6 30x30m & 1 120x120m	6 30x30m & 1 120x120m	7 30x30m & 1 15x15m	7 30x30m & 1 15x15m
Image name	p191r056_7x20000206	p191r055_7x20000206	LE71910562002362EDC00	LE71910552002362EDC00
Acquisition date	06/02/2000	06/02/2000	28/12/2002	28/12/2002
Extent	Latitude 5.8 Longitude 3.1	Latitude 7.2 Longitude 3.4	Latitude 5.8 Longitude 3.1	Latitude 7.2 Longitude 3.4
Cloud cover	0%	0%	0%	0%
Publisher	USGS	USGS	NASA	NASA
Publisher Location	Sioux Falls, South Dakota	Sioux Falls, South Dakota	Houston, Texas	Houston, Texas
	9 [1,2,4]	**10** [1,2,4]		
Producer	USGS	USGS		
Publication date	2010	2010		
Collection Name	Landsat 7	Landsat 7		
Sensor name	ETM+ SLC off	ETM+ SLC off		
Epoch	2008	2008		
Bands	7 30x30m & 1 15x15m	7 30x30m & 1 15x15m		
Image name	LE71910562008363ASN00	LE71910552008363ASN00		
Acquisition date	28/12/2008	28/12/2008		
Extent	Latitude 5.8 Longitude 3.1	Latitude 7.2 Longitude 3.4		
Cloud cover	0%	0%		
Publisher	NASA	NASA		
Publisher Location	Houston, Texas	Houston, Texas		

Source: [1]Rocchio, 2011-11-01 & [2]Landsat missions, 2010-30-12 & [3]Global Land Cover Facility, 2011 & [4]Earth Resources Observation and Science Center, 2011-11-01.

Detailed information regarding the sensors used to acquire these images can be found in Appendix I *(p.60)*.

4.1.2 Population data

The population and population density data used in this thesis has a cell size of 4166 x 4166 meters and has been derived from the Gridded Population of the World. From here data has been downloaded both over the world and over Nigeria (Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010). Table 2 shows the metadata over the population data used.

Table 2: Metadata of population data

Name	Gridded Population of the World, Version 3 (GPWv3)
Originator	CIESIN (Columbia University), CIAT
Publication date	2005
Epoch	1990, 1995 & 2000
File name	nga_gpwv3_pcount_wrk_25 (Nigeria population 1990, 1995 & 2000)
	gl_gpwv3_pcount_90_wrk_25 (World population 1990)
Publisher	SEDAC (Columbia University)
Publisher Location	Palisades, New York
Name	Gridded Population of the World, Future estimates, 2015 (GPW2015)
Originator	CIESIN (Columbia University), FAO, CIAT
Publication date	2005
Epoch	2005, 2010 & 2015
File name	nga_gpwfe_pcount_wrk_25 (Nigeria population 2005, 2010 & 2015)
	gl_gpwfe_pcount_10_wrk_25 (World population 2010)
Publisher	SEDAC (Columbia University)
Publisher Location	Palisades, New York

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010.

4.1.3 International borders

A map over Nigeria and over the world has also been used for the study. They have been downloaded from the digital chart of the world (Digital Chart of the World, 2010). Table 3 provides information over this data.

Table 3: Metadata of international borders

Name	Digital Chart of the World
Originator	National Imagery and Mapping Agency
Publication date	1992
Epoch	1992
File name	ponet.e00 (Political/Ocean boundaries)
Publisher	National Imagery and Mapping Agency
Publisher Location	Fairfax, Virginia

Source: Digital Chart of the World, 2010.

4.2 Image classification

Satellite images are converted to classified images through grouping the pixels of an image to specific clusters to categorize themes (Lillesand et al, 2008). This can be done through a supervised or an unsupervised classification (Janssen et al, 2001). This study has been conducted through an unsupervised classification. The land classes over the study area have been grouped into three different classes, urban areas, water bodies and other land.

The flowchart seen in figure 7 below outlines how the classified images over Lagos have been constructed.

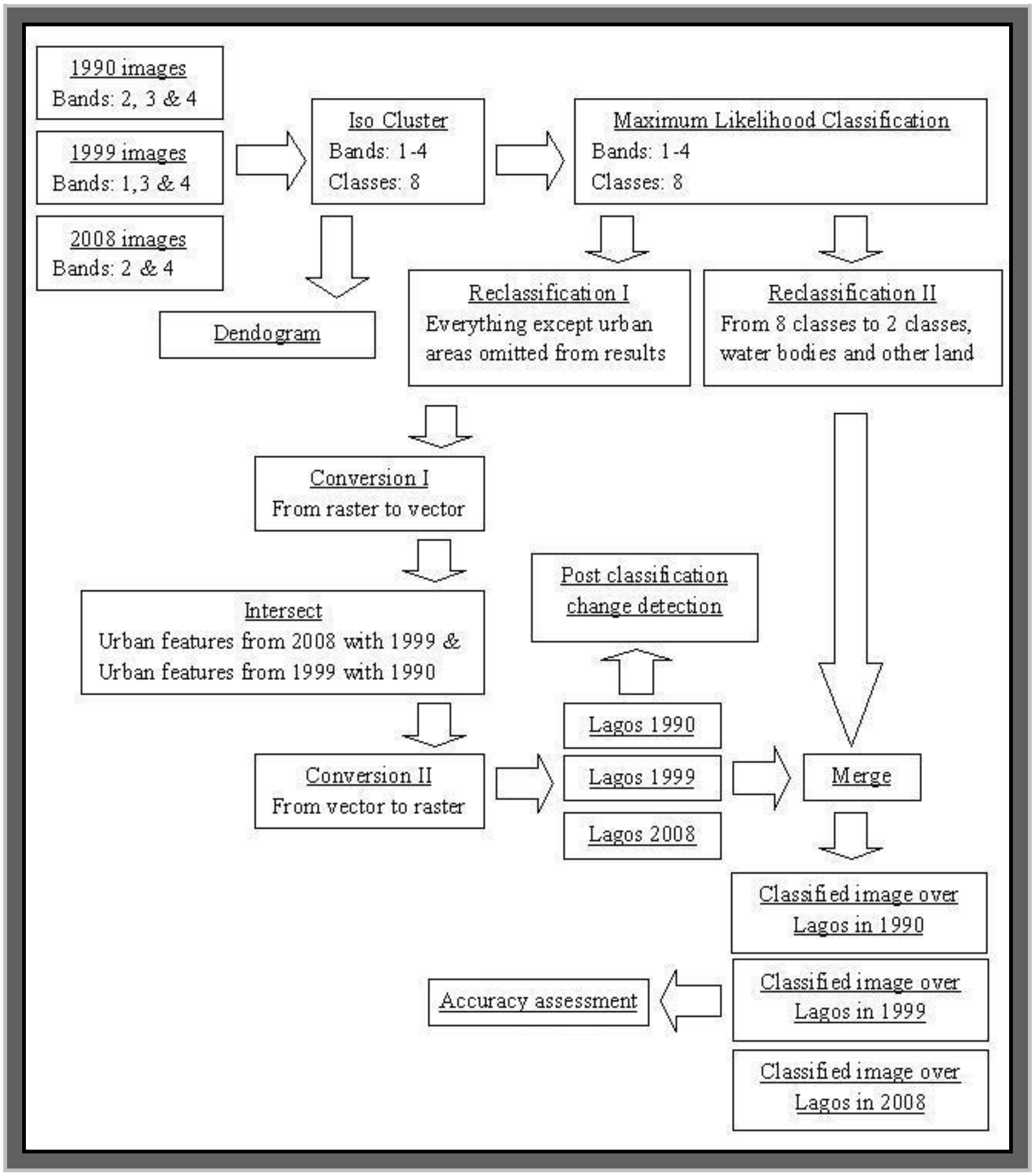

Figure 7: Steps performed when producing classified images

The classified images constructed in Figure 7 were produced using an unsupervised maximum likelihood classification. This method was used since no reference data existed and it is the classification method that takes the most factors into account (Janssen et al, 2001). Normally change detection studies are carried out using the same bands for all the years, however in this case different input bands have been used for the various years. This was done because various bands yielded the highest accuracy for different years and for some years some bands could not be used because the data was not normally distributed, which led to that the maximum likelihood classification failed (Lillesand et al, 2008). The bands used for each of the years were selected after several different attempts had been tried and then using the most optimal bands after performing an accuracy assessment where the overall accuracy of the classifications was measured. The classifications were originally classified to eight classes were visual interpretation was used to later reclassify the classes to the three classes used in the study (urban, water bodies, other land). The reason why three classes were not used in the classification directly was that it led to worse classification accuracy. The amount of classes used during the maximum likelihood classification seemed optimal after several attempts. The intersect function was used between the urban features for the different years. The reason for this was so that urban features in the earlier years only would remain if they also were present in the later ones. This was done to reduce error because it is not probable that urban features are present in earlier years and not in later if a city is expanding. The produced images over Lagos were overlaid and compared with each other through the post classification change detection algorithm so that the growth of the city could be measured. Finally an accuracy evaluation was performed on the classified images to measure their quality; the result of these can be seen in Tables 4-6 *(p.33-34)*. Further information over the input bands selected for this operation can be found in Appendix II *(p.61-63)*.

4.2.1 Unsupervised Classification

The difference between a supervised and an unsupervised classification is that in a supervised classification samples over the ground truth can be compared with the results of the classification. In an unsupervised classification this is conducted without any samples or knowledge about the exact ground truth. Unsupervised classifications work through using algorithms that group and classify pixels together with similar values according to the amount of spectral classes chosen (Lillesand et al, 2008). The user specifies the number of classes, the distance between different cluster centers, the radius of a cluster and the minimum number of pixels a group can contain (Janssen et al, 2001). By editing and changing different inputs such as the number of classes deviating results are obtained and this should be done until results are plausible. Finally the results should be compared with some form of reference data to determine what these different spectral classes represent (Lillesand et al, 2008).

4.2.2 Iso cluster

To be able to perform a classification one needs a signature file, in an unsupervised classification this is normally done through the Iso Cluster function. This function works through using a clustering algorithm that group the multivariate data for the different input bands together based on their characteristics and saves this information in a signature file. These clusters are calculated based on their cell values, which is the mean of the attribute values gathered from the different input bands and the total variation within and between different bands, also known as variance and covariance values. Figure 8 explains how this function works.

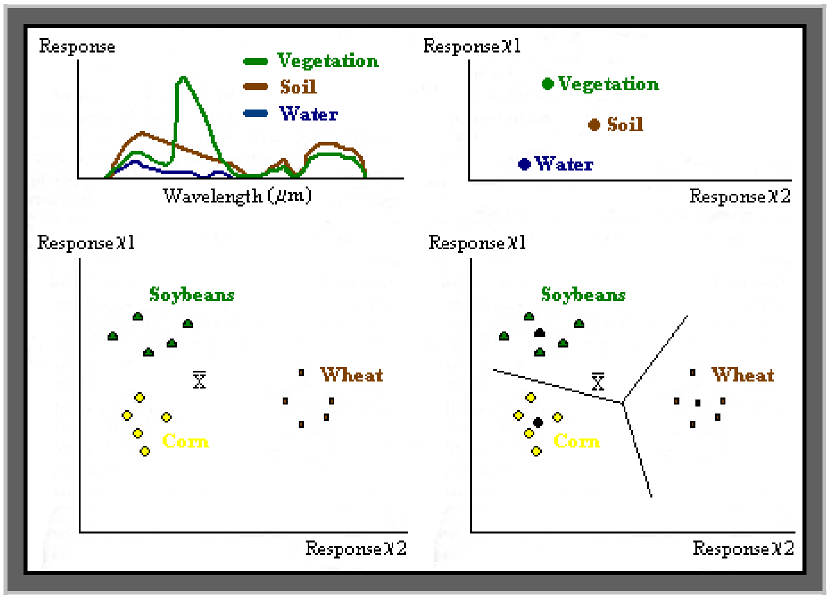

Figure 8: How Iso cluster works
Source : Short, n.d.

Figure 8 shows this through a graph where one can plot the different values for one band on the x-axis and values for the other band on the y-axis. A 45 degree line runs straight through the graph and divides the graph into the number of classes specified by the user. The centre point for each line segment for this 45 degree line corresponds with the mean value for the different classes. Each sample cell is plotted on the graph and the distance to each mean centre. The mean values are continuously updated and changed for each new sample cell added to the graph. The ranges between different values within each band should not be too high to get good results and the value ranges between different bands should be similar. If these ranges are not similar several clusters could have a mean of zero meaning that the classification will fail (ArcGIS Resource Center, 2010).

Inputs for this algorithm have to be specified, this includes which bands to use, the number of classes, the minimum class size, the sample interval and the number of iterations. The most important inputs are which bands to use for this function and the number of classes the data should be categorized into. Various settings have huge effects on the results and one should try using different settings before selecting which inputs to use (ArcGIS Resource Center, 2010).

4.2.3 Dendogram

A dendogram shows the distance between the different classes in a signature file and provides information over the likeliness of error when classifying cells. It works through a hierarchical clustering system where the distances between different classes in a study area are measured and the two classes closest to each other are merged. This is done through producing a text file that displays a tree diagram showing the relationship and the hierarchy between different classes and a table giving information over the distances between different pairs of classes, the further the distance the less likely a class merge will be (ArcGIS Resource Center, 2010). Dendograms over the signature files used for this study can be found in Appendix II *(p.61-63)*.

4.2.4 Maximum likelihood Classification

A classification can be performed through using different algorithms. In this study the most common method has been used, the maximum likelihood classifier (Janssen et al, 2001). It classifies and groups different cells together based on the covariance and the variance of the data in the input signature file (ArcGIS Resource Center, 2010). This calculation is done through a formula where the probability that a specific cell belongs to a cluster is based on a covariance matrix and the mean values for the different cells in a cluster. Figure 9 shows how features are grouped together for each band in a maximum likelihood classification.

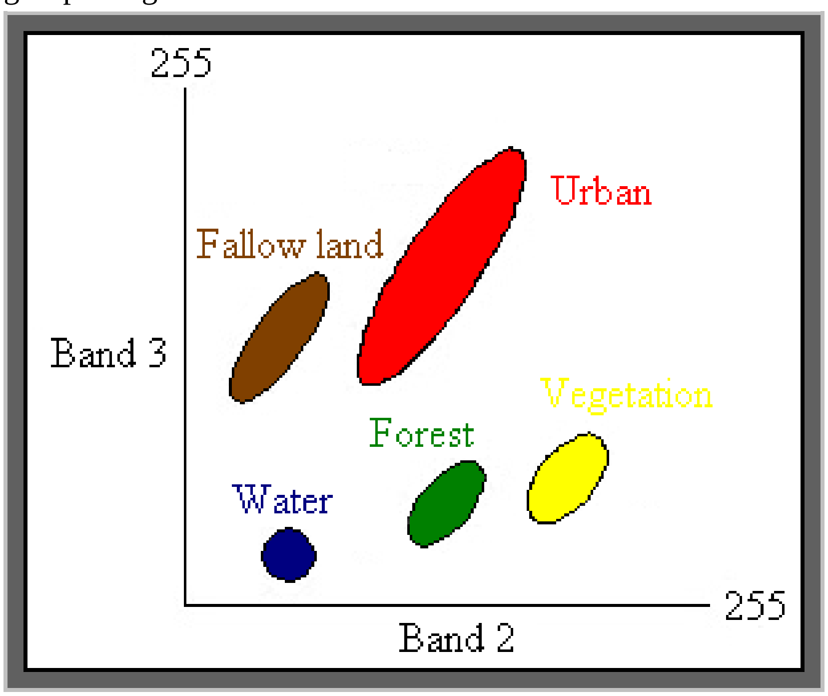

Figure 9: Grouping of features in maximum likelihood classification
Source: Short, n.d.

Figure 9 illustrates how a cell is grouped together with other cells in a cluster where the probability of it belonging to the cluster is the highest. It takes the cluster´s center, size, shape and orientation into account when doing this (Janssen et al, 2001). This makes this function very useful since cell values within a class rarely are uniform and it may be difficult to classify cells that are within the overlap between two different classes (ArcGIS Resource Center, 2010). The input data has to be normally distributed for the maximum likelihood classifier to work (Lillesand et al, 2008). When performing this classification several different inputs have to be chosen. Primarily these are which bands to use for the operation and which signature file to use. One can also specify optional inputs such as the reject fraction and the weighting of a class probability. This is the number of cells that will be unassigned due to a low probability of correct classification and the likeliness of different classes in the classification (ArcGIS Resource Center, 2010).

4.2.5 Accuracy evaluation

An accuracy assessment can be performed on a classification to measure the quality of it. This is normally done through a confusion matrix or a contingency matrix. It is performed through taking sample points from different cells with known features and then comparing these cells to classified images to see the amount of samples that are correctly classified (Lillesand et al, 2008). The number of samples, the spread over the study area and in what land class these samples are located will affect the evaluation. It is important to be thorough and use many samples that are evenly distributed over the study area and through the different land classes when performing this assessment for it to be accurate (Looijen, 2004). The different measurements used for this assessment can be seen in Appendix III (*p.64-65*) and the results of this evaluation can be found in the Error matrix (*p.33-34*)

4.3 Image rectification

Two images were acquired and merged for each of the years of the study to cover the study area. The images acquired in 1990 and in 2008 contained some distortions. The Lagos image in 1990 contained a 30% cloud cover distortion which can be seen in Figure 10; it is mostly the north western part of the study area that is affected. Most of the cloud cover in the image does however not affect the urban area and it is only a smaller area (around 5%) of the urban features in 1990 that have been distorted.

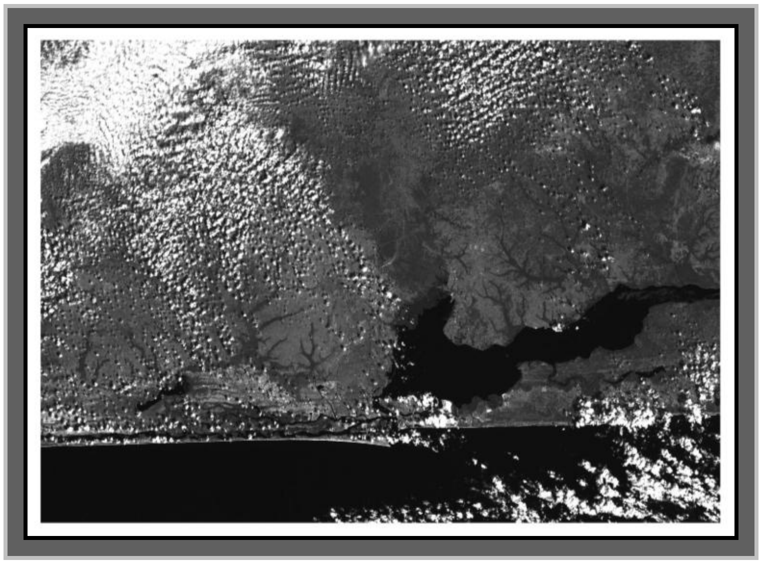

Figure 10: Cloud cover distortion
Landsat 5, band 2, 1990.
Source: Earth Resources Observation and Science Center, 2011-11-01.

The sensor that acquired the images over 2008 had a failure. In May 2003 the Scan Line Corrector (SLC) for the Enhanced Thematic Mapper + (ETM+) unfortunately stopped working. This gave all images acquired from this sensor after that date a zigzag pattern along the sides of the images ruining them and leading to minor data loss (Lillesand et al, 2008). The amount of data loss due to this on the images used for this study was however small and only around 1-2% of the urban features in 2008 were affected by this error. An example of how an image appears after the SLC failure can be seen in Figure 11 showing an image over Lagos in 2008.

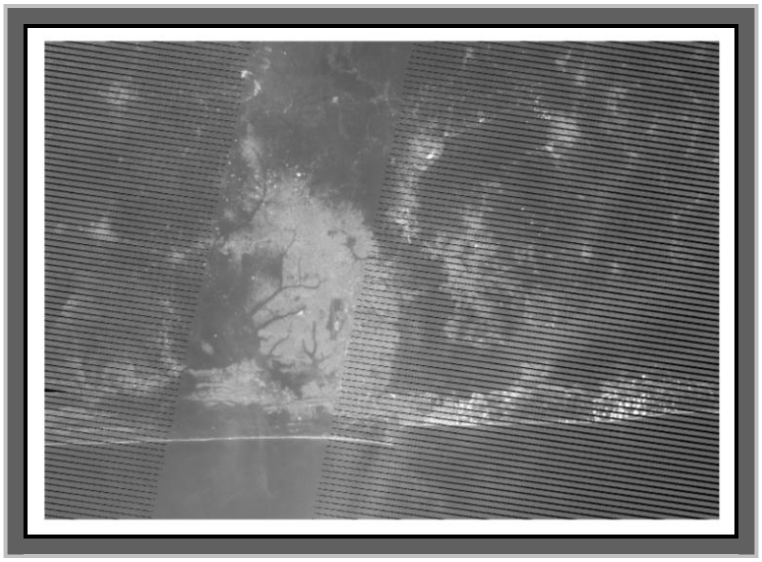

Figure 11: SLC failure
Landsat 7, band 5, 2008, 2010-24-10.
Source: Earth Resources Observation and Science Center, 2011-11-01.

To reduce the effects of the distortions seen in Figure 10 & Figure 11 data from 1984 and 2002 has been used in the areas of error. Figure 12 explains how the areas of error have been removed and replaced with earlier data.

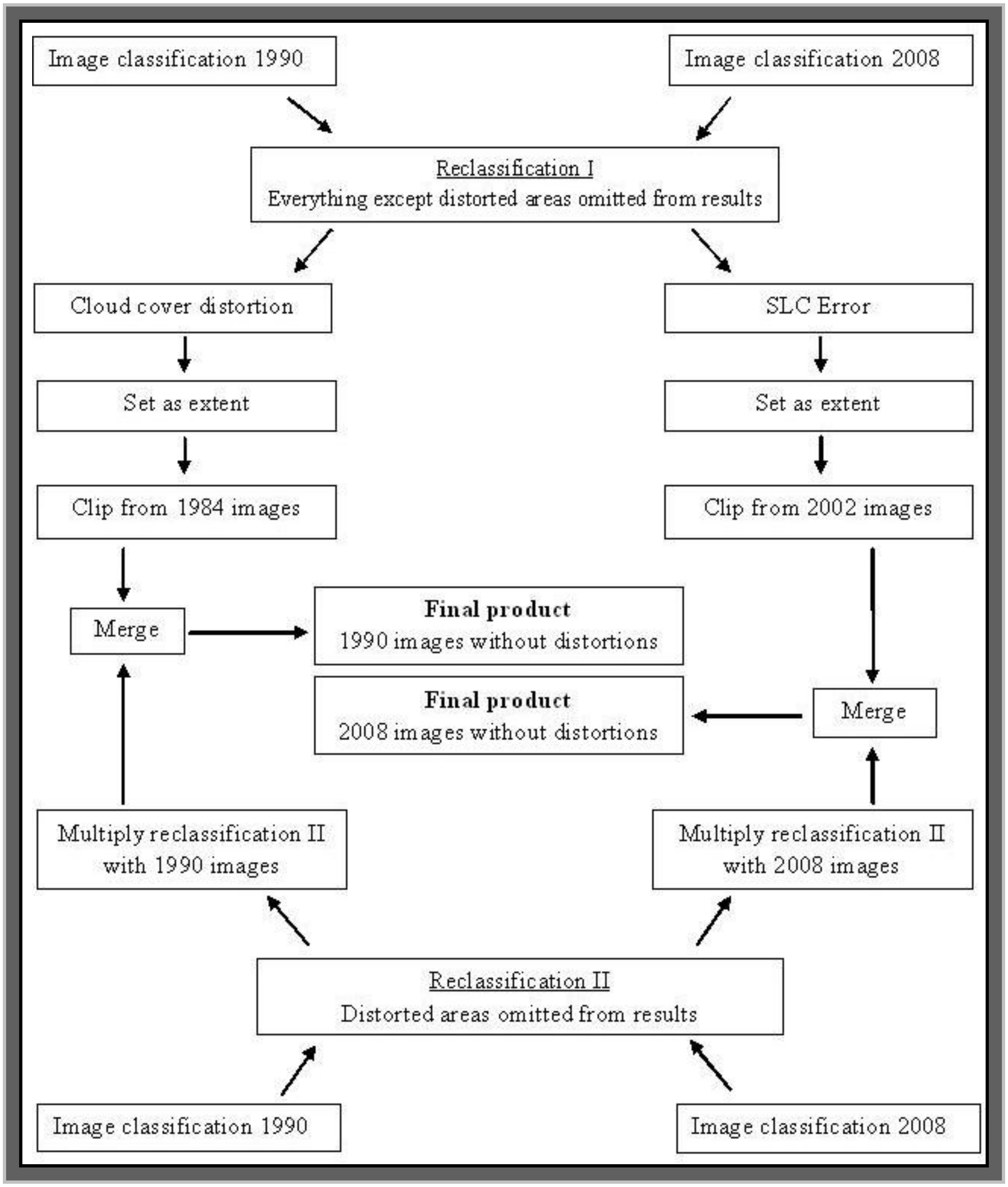

Figure 12: Image rectification operations

Figure 12 shows the steps that have been performed to remove and replace the distorted areas of the different bands in 1990 and in 2008. Replacing these areas was important because otherwise the resulting images would contain areas of an error or of no data. The operations performed omit the distorted areas from the bands and replaces them with earlier data instead. This through cutting out unwanted features and replacing them with wanted features, data from 1984 was used to replace the cloud cover in 1990 and data from 2002 was used to fill the area the SLC error caused in the 2008 image. The reason why data from these specific years was used was that it was the data available closest to the years 1990 and 2008 that did not contain any errors. Through performing these operations the distortions has been removed with as up to date data as possible. This does however mean that some areas of the produced images contain areas that are not from the years specified but instead from six years earlier, however these areas are very small and should not have a huge effect on the results.

4.4 Post classification change detection

The post classification comparison change detection algorithm is performed through classifying data acquired at different times to similar classes and overlaying these images with each other. The classifications are extracted from each other so that the area of change can be seen. It is one of the simplest and most common methods used when performing quantitative change detection. Normally several different land classes are included when performing this algorithm but in this study it was done only using the land class urban for the years of the study (Jensen, 1996).

4.5 Updating population figures

The population figures over Nigeria used in the study have all derived from the population figure in the country in 1990 established by the Federal Bureau of Census Nigeria together with local governments. Population data was available in five year intervals up to the year 2015 based on estimates from the 1990 figures (Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010).

The population figures or especially the population growth in Lagos was lower according to the Gridded Population of the World and the Global Rural – Urban Mapping Project data compared to the figures accounted by the World Urbanization Prospects: The 2007 Revision (2008), which had been updated 18 years later. The data was therefore updated by using population figures over Lagos as expected by the World Urbanization Prospects: The 2007 Revision (2008) instead. The population figures are measured for the first month of every year and since this study is done for the last month of every year the following year's population figures have been used instead (World Urbanization Prospects: The 2007 Revision, 2008). To only display population figures inside the urban areas of the city the population data was intersected with the urban area of Lagos for the different years. Equations 1-4 show the calculations that have been made on the population values to update them to the years of the study and to the figures used by the 2007 Revision (2008). This has been executed on the spatial data by using the raster calculator.

$$In(y) - In(y^2) / yp = gr$$ **Equation 1**

where:
In(y) = The natural logarithm of the population in Lagos for a specific year according to the 2007 Revision. This calculation was performed using the population values for the years 1995, 2010 & 2025.
$In(y^2)$ = The natural logarithm of the population in Lagos for a second specific year according to the 2007 Revision. This calculation was performed using the population values for the years 1990, 2005 & 2020.
yp = Years passed. Since data with five year intervals was used the calculations were performed using the number five.
gr = Annual growth rate.

Since population figures only were provided in five year intervals and not for the years needed a logarithm called the natural logarithm was used so that population values for the years of the study could be found. To be able to do this the yearly growth rate is needed. Equation 1 shows how this value is calculated through subtracting the natural logarithm of a population value for a year with the natural logarithm of a population value some years later and dividing it with the number of years passed. This provides a number in decimal format which represents the annual increase in population.

$$Pop(y) * (gr * y) = Pop(y^2). \qquad \textbf{Equation 2}$$

where:
Pop(y) = Population in Lagos for a specific year according to the 2007 Revision figures. This calculation was performed using the population values for the years 1990, 2005 & 2020.
gr = Annual growth rate.
y = The number of years to the year that data is needed. Since population values were needed for 1991,2009 and 2021 this calculation was performed using the values one and four.
$Pop(y^2)$ = Population in Lagos for the years of the study according to 2007 Revision figures. This value was computed for the years 1991, 2009 and 2021.

Equation 2 describes how the population figures were updated to the years needed for the study using the growth rate computed in Equation 1. It is worth reminding that population values from the following year to this study was used because population figures were provided for the first month of every year and this study has been conducted on images acquired at the last month of every year.

$$GPWPop(y) / Pop(y^2) = Q. \qquad \textbf{Equation 3}$$

where:
GPWPop(y) = Population in Lagos for a specific year according to the Gridded Population of the World and the Global Rural – Urban Mapping Project data. This calculation was performed using the population values for the years 1990, 2000, 2005 & 2015.
$Pop(y^2)$ = Population in Lagos for the years of the study according to 2007 Revision data. This value was provided for the years 1991, 2000, 2009 and 2021.
Q = Quotient. This provides a figure of the difference in population values between the Gridded Population of the World and the Global Rural – Urban Mapping Project data and the updated population data for the years of the study according to 2007 Revision data.

Equation 3 shows how the difference between the population values from the different sources and for the right years was found by providing a quotient. One should note that population data for the year 1999 could be accessed without performing Equation 1 and Equation 2 since 2007 Revision data over the population in Lagos for the year 2000 already was provided.

$$GPWPop(y) * Q = Pop(y^2)$$ **Equation 4**

where:
GPWPop(y) = Population in Lagos for a specific year according to the Gridded Population of the World and the Global Rural – Urban Mapping Project data. This calculation was performed using the population values for the years 1990, 2000, 2005 and 2015.
Q = Quotient. This figure is derived in accordance to Equation 3.
$Pop(y^2)$ = Population in Lagos for the years of the study according to 2007 Revision data. This value was provided for the years 1991, 2000, 2009 and 2021.

Equation 4 describe how the population data finally was updated to the right figures and to the study years through multiplying the Gridded Population of the World and the Global Rural – Urban Mapping Project data figures with the quotient found in Equation 3.

From these updated population figures the density over the various areas of Lagos for the different years was calculated, Equation 5 shows how this was executed.

$$Pop(y) / A(y) = D$$ **Equation 5**

where:
Pop(y) = The Lagos population for a specific year.
A(y) = The city area for the same year.
D = Density.

Equation 5 shows how population density is calculated by dividing the city population with its area.

A map showing the annual growth rate in the world between the years 1990-2010 has also been included in the thesis. Equations 6-9 describe how this map has been produced.

$$Pop(2010) - Pop(1990) = PI$$ **Equation 6**

where:
Pop(2010) = World population in the year 2010
Pop(1990) = World population in the year 1990
PI = Population increase. This provides a figure of the difference in population values between the years 2010 and 1990.

Equation 6 shows how the change in world population has been calculated. It has been calculated by first finding the world increase in population.

$$PI / yp = gr \qquad \textbf{Equation 7}$$

where:
PI = Population increase, derived in accordance to Equation 6.
yp = Years passed. The number of years between the population figures used, which is 20.
gr = Annual growth rate.

Equation 7 shows how the annual growth in world population has been derived by dividing the population change over the study years with the number of years passed.

$$gr / Pop(1990) = \%gr \qquad \textbf{Equation 8}$$

where:
gr = Annual growth rate, derived in accordance to Equation 7.
Pop(1990) = World population in the year 1990.
% gr = Proportional annual growth rate between the years 1990-2010.

Equation 8 finally shows that by dividing the annual growth rate computed over the time period with the population figures for 1990 the proportional annual growth rate over the world between the years 1990-2010 can be found. The results of this can be seen in Figure 4 *(p.9)*.

4.6 The future prospects

Three scenarios on how Lagos will look in the year 2020 have been produced, one representing a limited growth, one a relatively expansive growth and one a very expansive growth. The three different scenarios have been produced in the following way.

- Scenario I is computed through using the trend of growth through comparing the discrepancy in growth between 1990-1999 and 1999-2008 and using this to compute future growth.
- Scenario II is computed through using the average growth rate during the last 9 years of the study time 1999-2008.
- Scenario III is computed through using the average growth rate during the whole study time 1990-2008.

It is only the growth of the city that forecasts have been made for and not for different population outcomes. These future scenarios have been constructed through digitizing and adding new polygons to the image over Lagos in 2008 and are based on the expected size of Lagos through calculating changes between the different earlier images over the city. Growth was deemed to take place in areas where previous expansion had occurred and not in areas where there were obstacles such as water bodies. This growth should not be seen as a realistic future growth for the city but rather as an attempt to provide images of possible future expansion to the city. Small edits have continuously been done and merged to the urban features of 2008 until the total area of the feature corresponded to the area that my calculations said that the different scenarios over the city should have in 2020. When results were plausible the features were merged and the different scenarios created. Several calculations have been performed to establish the size of the different scenarios and equations 9-13 below show how scenario I was calculated.

$$A(y) - A(y^{II}) = AC$$ **Equation 9**

where:
A(y) = The urban area of Lagos for a specific year.
$A(y^{II})$ = The urban area of Lagos for an earlier year.
AC = Areal urban change between years ^{I} and ^{II}.

Equation 9 shows how the difference in area over Lagos over a given time period can be calculated.

$$AC / yp = gr$$ **Equation 10**

where:
AC = Areal urban change between years.
yp = Years passed.
gr = Annual areal growth in Lagos between given years.

Equation 10 describes how the annual areal growth of the city can be computed by dividing the areal change over the time period with the number of years passed.

$$gr^{I} / gr^{II} = T$$ **Equation 11**

where:
gr^{I} = Annual areal growth over Lagos 1990-1999.
gr^{II} = Annual areal growth over Lagos 1999-2008..
T = Trend of growth by comparing growth 1990-1999 with 1999-2008.

Equation 11 describes how the trend of growth over the study time was calculated by dividing the annual growth rate over the first nine years of the study time with the last nine years.

$$T * gr^{II} = gr^{III}$$ **Equation 12**

where:
T = Trend of growth by comparing growth 1990-1999 with 1999-2008.
gr^{II} = Annual areal growth over Lagos 1999-2008.
gr^{III} = Annual areal growth over Lagos 2008 -.

Equation 12 displays that by multiplying the trend of growth with the annual growth during the last nine years of the study the future annual growth could be found.

$$gr^{III} * yp^{II} + A(2008) = A(2020)$$ **Equation 13**

where:
gr^{III} = Annual areal growth over Lagos 2008 -.
yp^{II} = Years to reach 2020, in this case 12.
A(2008) = The urban area of Lagos in 2008.
A(2020) = The size of Lagos in 2020.

Equation 13 finally shows how the area of Lagos for scenario I representing a limited growth was found. This was computed by multiplying the future annual growth with the number of years to reach the year 2020 and adding this corresponding area to the urban feature of Lagos in 2008.

Scenario II representing an average expansive growth was calculated based on the growth of Lagos for the last nine years of the study while as scenario III that is the most expansive scenario is based on the average urban growth over the whole study time. These scenarios have been computed through using Equations 9, 10 and 13 but using different input values.

These three future scenarios can be seen in Figure 19 *(p.41)*.

These scenarios were combined with population and density data over the region for the year 2020. This data was updated through calculations to the population data in the same way as Equations 1-5 (*p.24-26*) but using the input values that provided population figures for the year 2021.

5 RESULTS

In this section the results of the study will be shown. This will be done in a comparative way where classified images over Lagos combined with population statistics for the study years will be presented. The main reasons for the city development will then be described before future prospects for the city will be shown.

5.1 Classifications

Figure 13 shows the classified images over Lagos for the years 1990, 1999 and 2008 produced according to Figure 6 *(p.16)*.

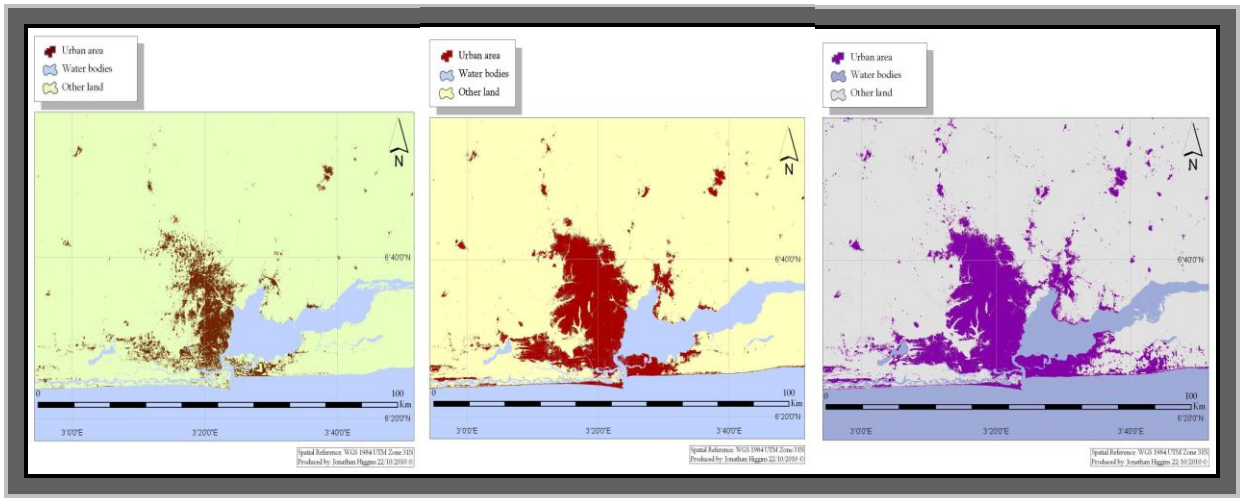

Figure 13: Classifications Lagos 1990, 1999 & 2008
Source: Earth Resources Observation and Science Center, 2011-11-01.

The classified images in Figure 13 have been constructed through an unsupervised classification using Landsat satellite images. It has been performed through using bands good at detecting urban features, where three different land classes were chosen to represent the area (urban area, water bodies & other land). One can clearly see on Figure 13 that the urban area of Lagos has increased through the 18 year period.

Figure 14 shows the urban development over Lagos using the post classification change detection algorithm. The classified urban images for the years of the study have been laid on top of each other so that the areal change for the city can be visualized.

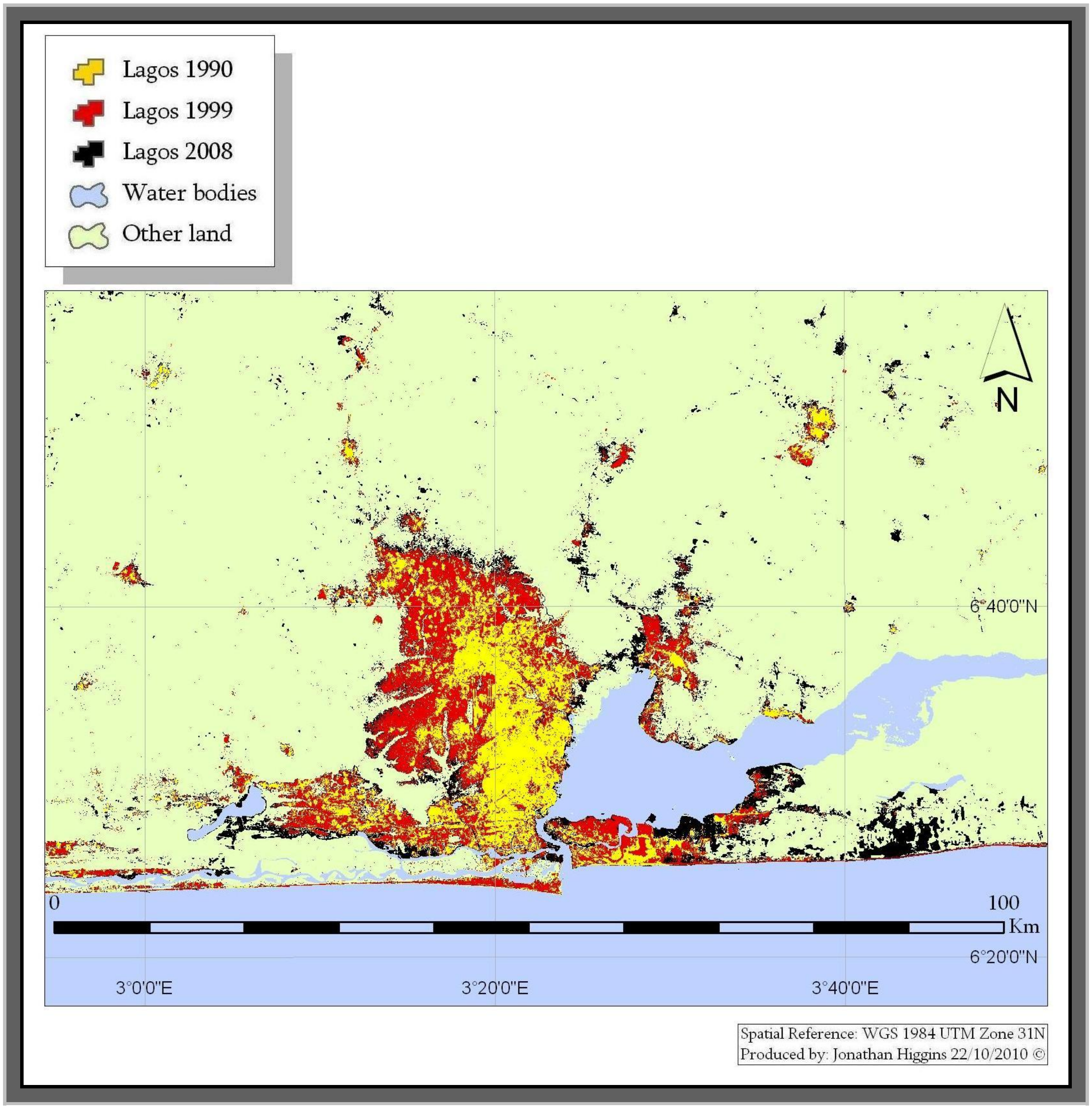

Figure 14: Comparison of classifications
Source: Earth Resources Observation and Science Center, 2011-11-01.

Figure 14 shows that over the 18 year period greater Lagos experienced a fast growth that led to an expansion of almost three times the initial city size.

In 1990 the urban area of greater Lagos accounted for approximately 328 km^2. The city was relatively compact and little urban sprawl had occurred.
In 1999 the same area over the city corresponded to almost 710km^2. This means that the urban area over the region had more than doubled over the nine years, expanding approximately 42km^2

annually over the time period. The growth had taken place in almost all directions but primarily in the northern and western parts of the city, urban sprawl had now also started to occur in the region.

In 2008 the total urban area over the region was around 974km^2. This means that the urban area had continued its rapid increase even though the growth had slowed down a bit compared to between the first nine years of the study. The expansion over these last nine years was approximately 29km^2 annually. The increase had now predominately taken place in the southeastern outskirts of the city and urban sprawl was now a common phenomenon all over the study area.

5.2 Error matrix

An accuracy assessment was performed on the classifications through creating 100 sample points in each of the land classes used in the study area (urban, water bodies and other land). These samples where widely spread over the study area and were placed where the belonging land class clearly could be seen through visual interpretation on the satellite bands; these sample points represent the reference data (ground truth). These samples where then compared to the produced classified images using the extract value to points function to see if the land classes had been classified in the same way in the classified data as in the reference data. Samples were only placed in locations were the belonging land class clearly could be seen, therefore the sample locations were not completely random and were chosen in locations with a clear defined land class, this suggest that overall accuracy probably is a bit lower than provided. The calculations performed can be seen in Equations 14-20 found in Appendix III (*p.64-65*).

Assessments of the classified images have been made through using an error matrix and the results of these can be seen in Tables 4-6 below.

Table 4: Accuracy assessment 1990

	Ground truth				
Classification	Class	Urban	Water bodies	Other land	Total
	Urban	83	2	2	87
	Water bodies	1	98	0	99
	Other land	16	0	98	114
	Total	100	100	100	300
Overall accuracy	93,33%				
Total Kappa	90,00%				
Class	Urban	Water bodies	Other land		
User accuracy	95,40%	98,99%	85,96%		
Producer accuracy	83,00%	98,00%	98,00%		
Mean accuracy	88,77%	98,49%	91,59%		
Areal difference	-13,00%	-1,00%	14,00%		
Individual Kappa	76,06%	97,01%	96,77%		

Table 5: Accuracy assessment 1999

	Ground truth				
Classification	**Class**	Urban	Water bodies	Other land	Total
	Urban	87	2	1	90
	Water bodies	1	97	0	98
	Other land	12	1	99	112
	Total	100	100	100	300
Overall accuracy	94,33%				
Total Kappa	91,50%				
Class	Urban	Water bodies	Other land		
User accuracy	96,67%	98,98%	88,39%		
Producer accuracy	87,00%	97,00%	99,00%		
Mean accuracy	91,58%	97,98%	93,40%		
Areal difference	-10,00%	-2,00%	12,00%		
Individual Kappa	81,43%	95,54%	98,40%		

Table 6: Accuracy assessment 2008

	Ground truth				
Classification	**Class**	Urban	Water bodies	Other land	Total
	Urban	82	1	3	86
	Water bodies	2	99	1	102
	Other land	16	0	96	112
	Total	100	100	100	300
Overall accuracy	92,33%				
Total Kappa	88,50%				
Class	Urban	Water bodies	Other land		
User accuracy	95,35%	97,06%	85,71%		
Producer accuracy	82,00%	99,00%	96,00%		
Mean accuracy	88,17%	98,02%	90,57%		
Areal difference	-14,00%	2,00%	12,00%		
Individual Kappa	74,77%	98,48%	93,62%		

Tables 4–6 above show that the land class that most often is wrongly classified is the land class urban, and it is especially mixed up with the land class other land. This is not surprising because both these land classes consist of several different features with very ranging pixel values (Farooq, n.d.). Water bodies is the land class with the best classification ratio and this is neither surprising since water pixels tend to deviate from pixels containing other features. Tables 4-6 also show us that there only are smaller differences between the classifications between the different years, their accuracies are very similar and it is the same type of land classes which are confused. The assessments suggest that the classified images are relatively accurate and provide a quite realistic image over reality.

5.3 Population and density

The classified images over Lagos have been combined with population data so that population densities and population development trends for different areas of the city can be seen. This population is displayed in inhabitants/ km^2 and has been calculated through dividing the population with its corresponding area. Figure 15-17 displays the population and population density in Lagos for the years 1990, 1999 and 2008 computed according to Equations 1-5 *(p.24-26)*.

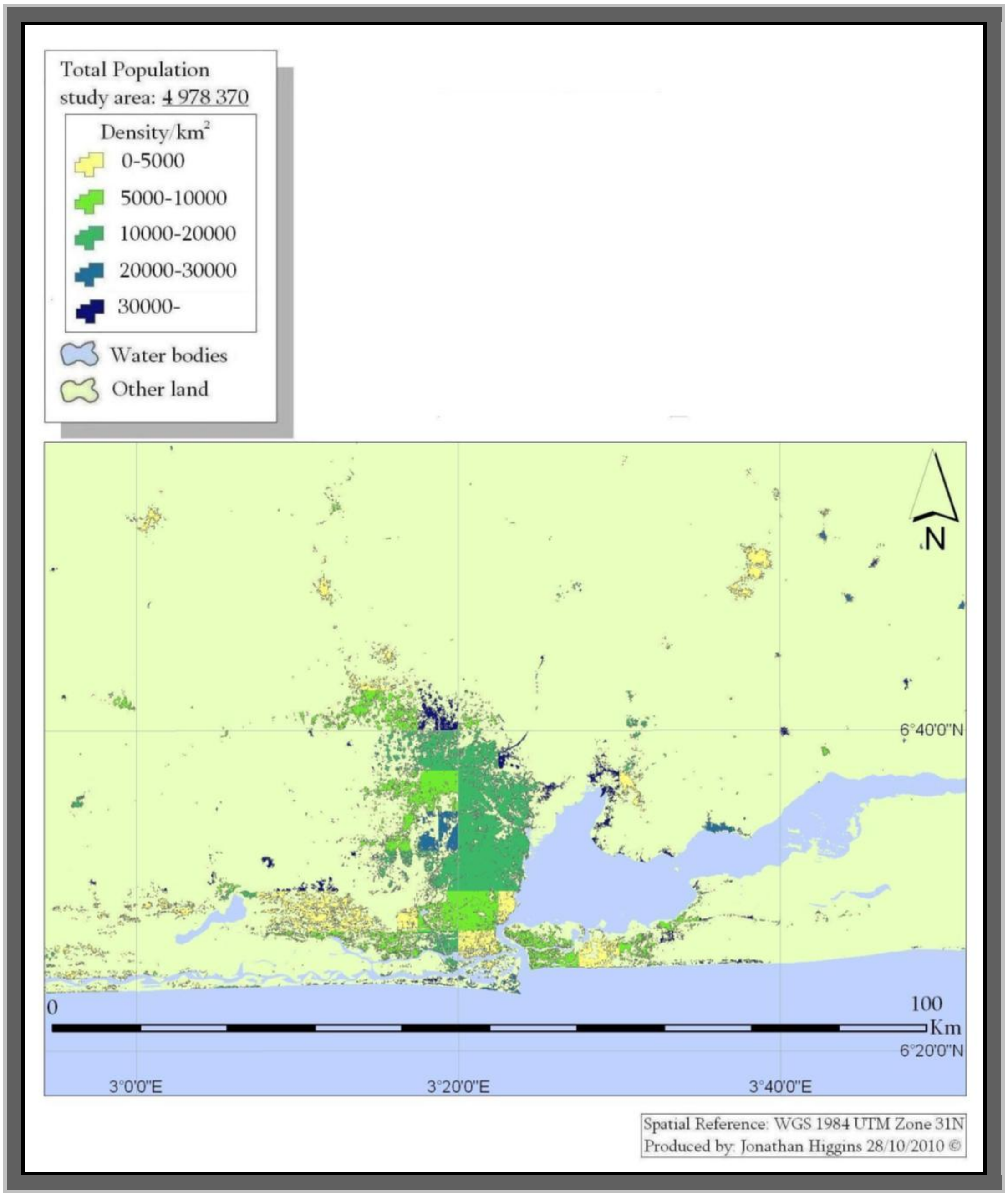

Figure 15: Population and density Lagos 1990

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 15 shows that in 1990 almost the entire population of around five million people lived in the central parts of Lagos. The average density over the urban area was 15 182 individuals/ km^2. The city was compact and the areas with the highest density levels were found in the northern, western and eastern parts of the city.

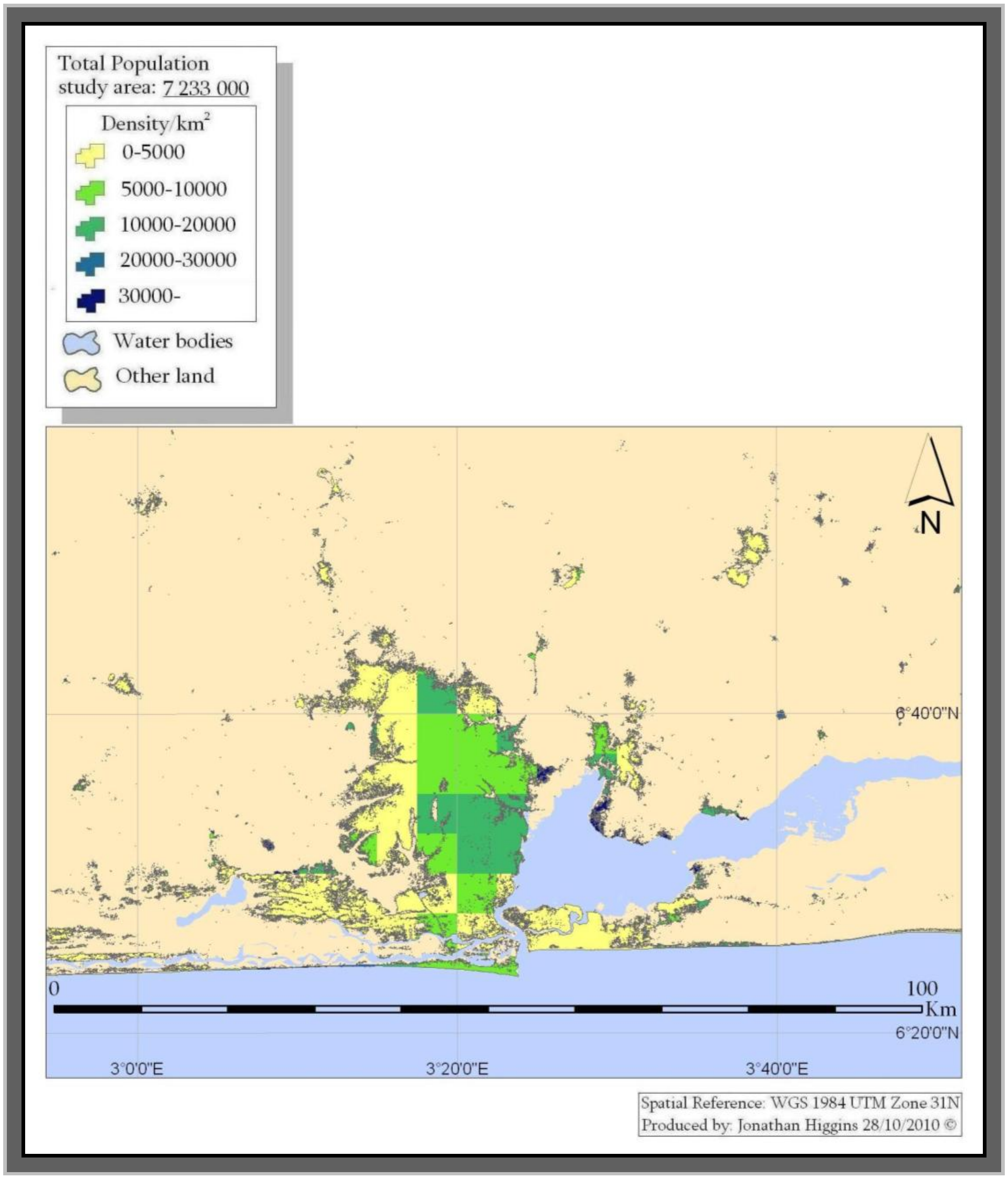

Figure 16: Population and density Lagos 1999

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 16 show that the city both grew in population and expanded in area between the years 1990-1999. The population rose with around 2, 25 million inhabitants over the time period, giving an annual population increase of around 250 000 inhabitants. Even if both the population and urban area increased over the time period the crowdedness in general started decreasing. In 1999 the average density over the city was 10 188 people/ km^2, a decrease of almost 5 000 people/ km^2 since 1990. The density in the central parts of the city has continued to increase but the areas where the city had expanded since 1990, predominately the western parts of the city were characterized by more sparsely populated areas giving that the total urban area now was less dense then in 1990.

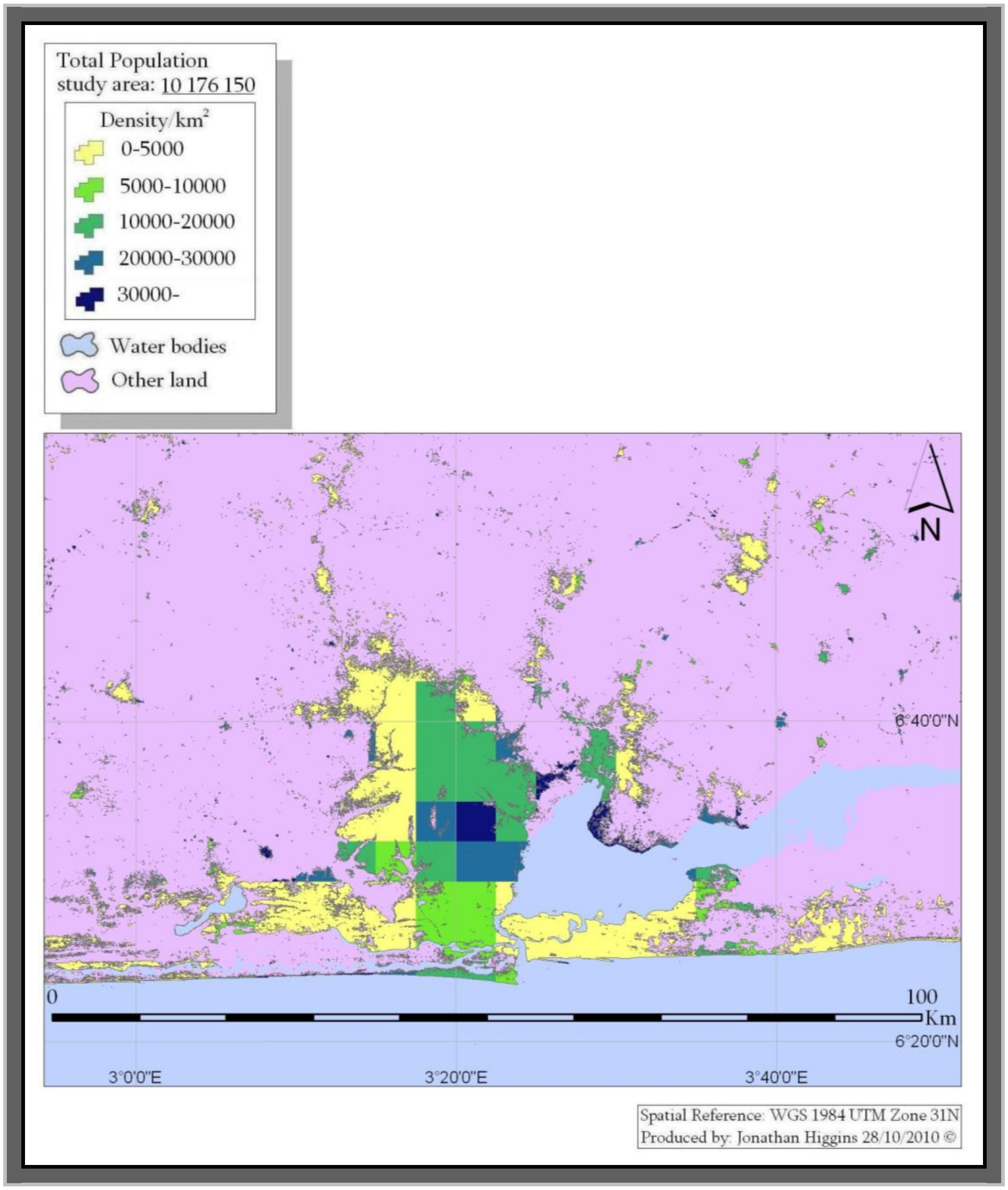

Figure 17: Population and density Lagos 2008

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 17 show that Lagos in 2008 had continued to grow both in population and in area. The expansion of the city had started to slow down but the population increase was faster than before. Between the years 1999 and 2008 the population over the area increased with almost three million inhabitants, giving an annual growth of almost 330 000 people. The average density over Lagos had slowly started to increase again and was now 10 455 inhabitants/ km^2, however still lower than in 1990. The density in the central parts of the city had continued to rise where areas now had density levels higher than 30 000 people/ km^2. The outskirts of the city continued to be more sparsely populated bringing down the average density.

5.4 Population growth vs areal growth

A rapid expansion both in urban area and in population has taken place in Lagos over the study time. Table 7 shows and compares the population growth with the areal growth of the city.

Table 7: Population and areal growth

	Population (millions)	Population increase (%)	Urban area (Km2)	Areal increase (%)
1990	4,98		328	
1999	7,23	45,18%	710	116,46%
2008	10,18	40,80%	974	37,18%
Total increase	**5,20**	**104%**	**646**	**196,95%**

Source: World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Table 7 illustrates that the population over the 18 year time period has more than doubled and increased with more than 5 million people. Over the same time period the city has almost expanded three times in size expanding from 328 km^2 in 1990 to 974km^2 in 2008. It was especially between the years 1990 to 1999 that the city expanded widely. Table 7 confirms that the growth has been more expansive in area than it has been in actual population.

5.5 Reasons for urban growth in Lagos

The large population increase in Lagos started during the latter part of the 1900s, the main reason for this development was the huge natural increase in population affecting the whole country (Preston, 1988). Most of Lagos annual growth in population over the study time at around 3, 99 % is accounted by the whole countries annual rise in population over the same time at around 2, 58 %. Natural population increase therefore accounts to around 65 % of the city's growth over the 18-year period (The World Factbook, 2010). An age sex pyramid over Nigeria according to the latest national census in 1991 can be seen in Figure 18.

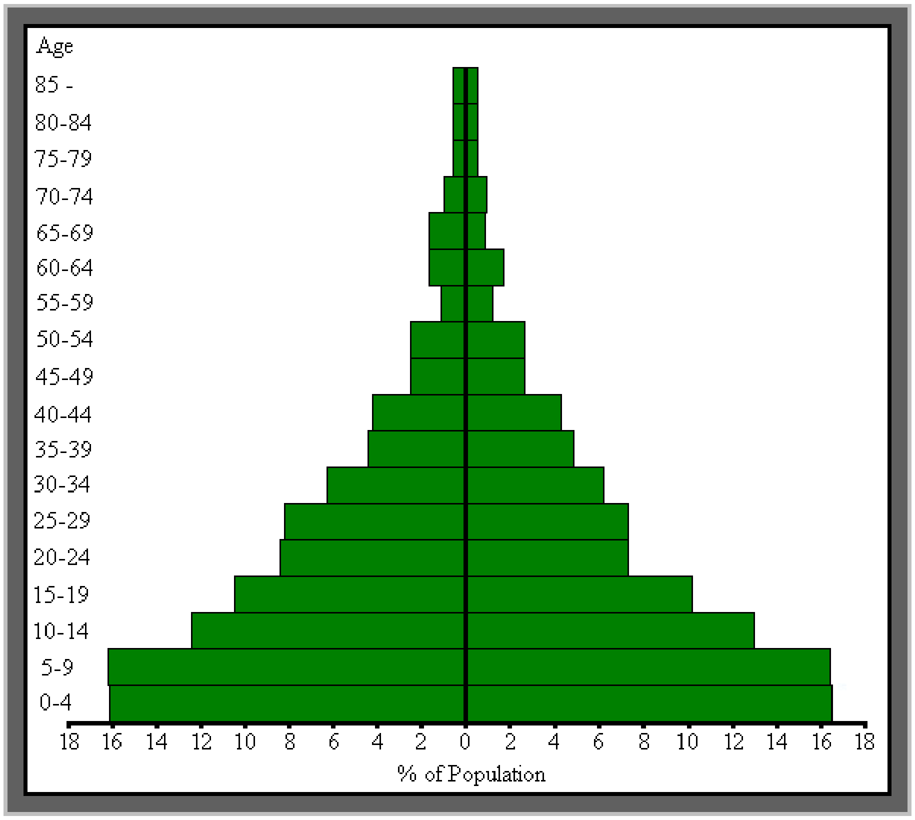

Figure 18: Age-sex pyramid Nigeria 1991

Source: Online Nigeria, 2005-21-05.

The pyramid over Nigeria seen in Figure 18 has the shape of a population that is increasing. This can be seen by the high proportion of the population that are young suggesting high fertility rates. Measures indicate that the fertility rate in Nigeria has started to decrease since 1991 but levels are still high. In 2010 the fertility rate was 4, 82 children/ woman and 40% of the population were younger than 14 years old (The World Factbook, 2010). This suggests that the population in the country will continue to increase in the future.

Natural population growth does not account for the entire growth of Lagos. Over the study time urbanization to the city accounted for around 35% of the city's growth (The World Factbook, 2010). The main reasons why individuals choose to migrate to Lagos can be hard to define without doing larger surveys. The economic importance a city has and the job opportunities this leads to is however the most influential reason to migrate to a place. The economic importance that Lagos has in Nigeria cannot be questioned. This can be seen in the way that most of the production in Nigeria is based in the city. Even though only around seven percent of the population in Nigeria lives in Lagos it produces 70 % of the total industrial capacity of the country, 40 % of its international export and wholesaling and 25 % of its retailing (Knox et al, 2003).

5.6 Future growth

The future growth has been computed for Lagos for the year 2020 by using data from the earlier years. The total population in the city used for all these scenarios is the same and it is the updated population in the area according to Equations 1-5 *(p.24-26)*. The population over the city in 2020 is estimated to be around 14, 5 million inhabitants. Three different scenarios have been computed according to Equations 9-13 *(p.28-29)* and are the following.

- Scenario I is computed through using the trend of growth over the study time and applying this trend to the future development of the city.
- Scenario II is calculated through using the average growth rate during the last 9 years of the study time to produce future growth.
- Scenario III is computed through using the average growth rate during the whole study time when producing future growth.

These scenarios are just models and the areas of possible expansion have been created based on growth during the earlier years of the study and should not be looked upon as representative of future development. Figure 19 show the three different future scenarios for Lagos.

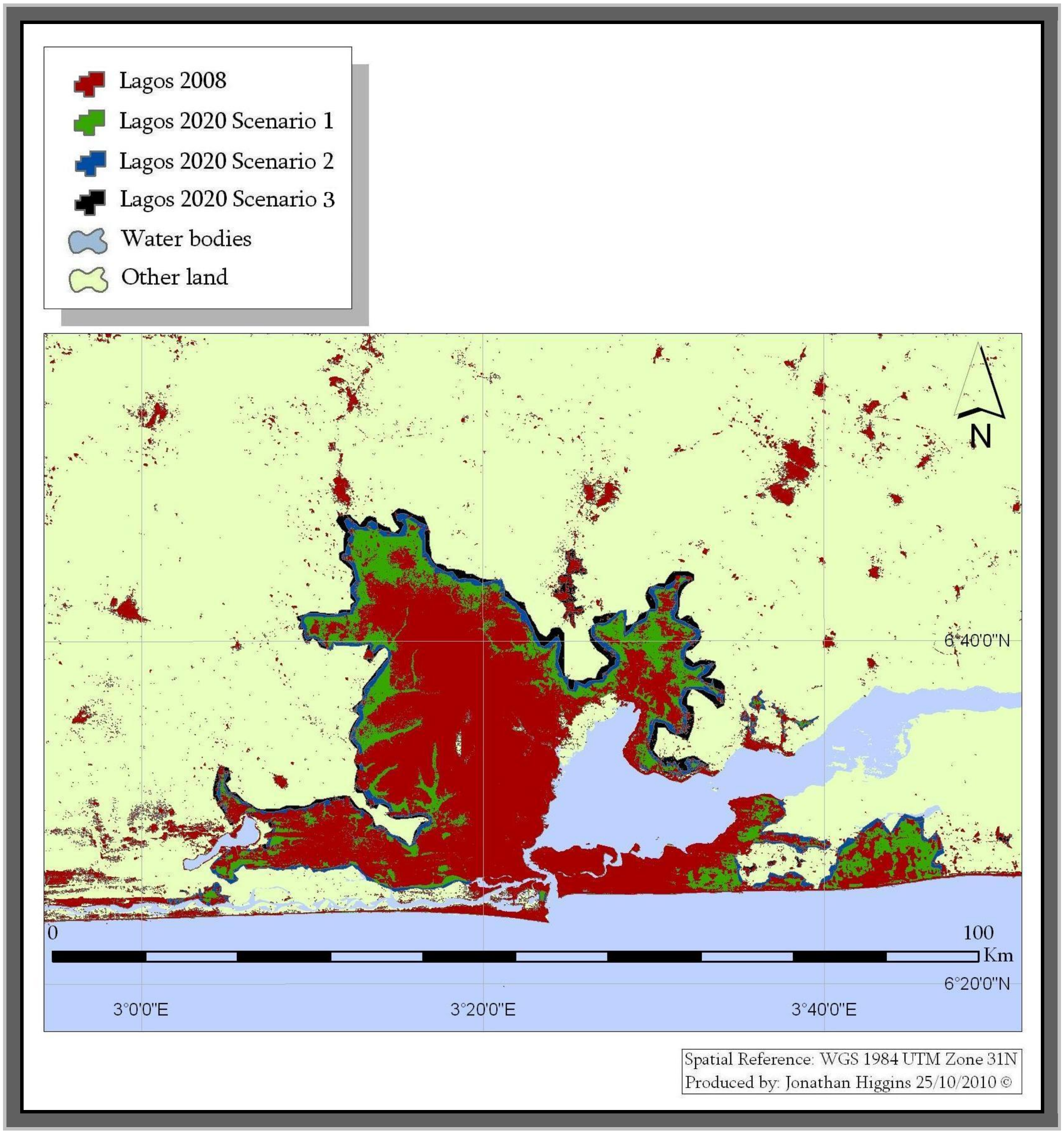

Figure 19: Future growth comparison

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 19 shows how the expansive-, moderate- and limited growth scenarios over Lagos for the year 2020 look.

Figure 20 show how Lagos looks in 2020 according to Scenario I.

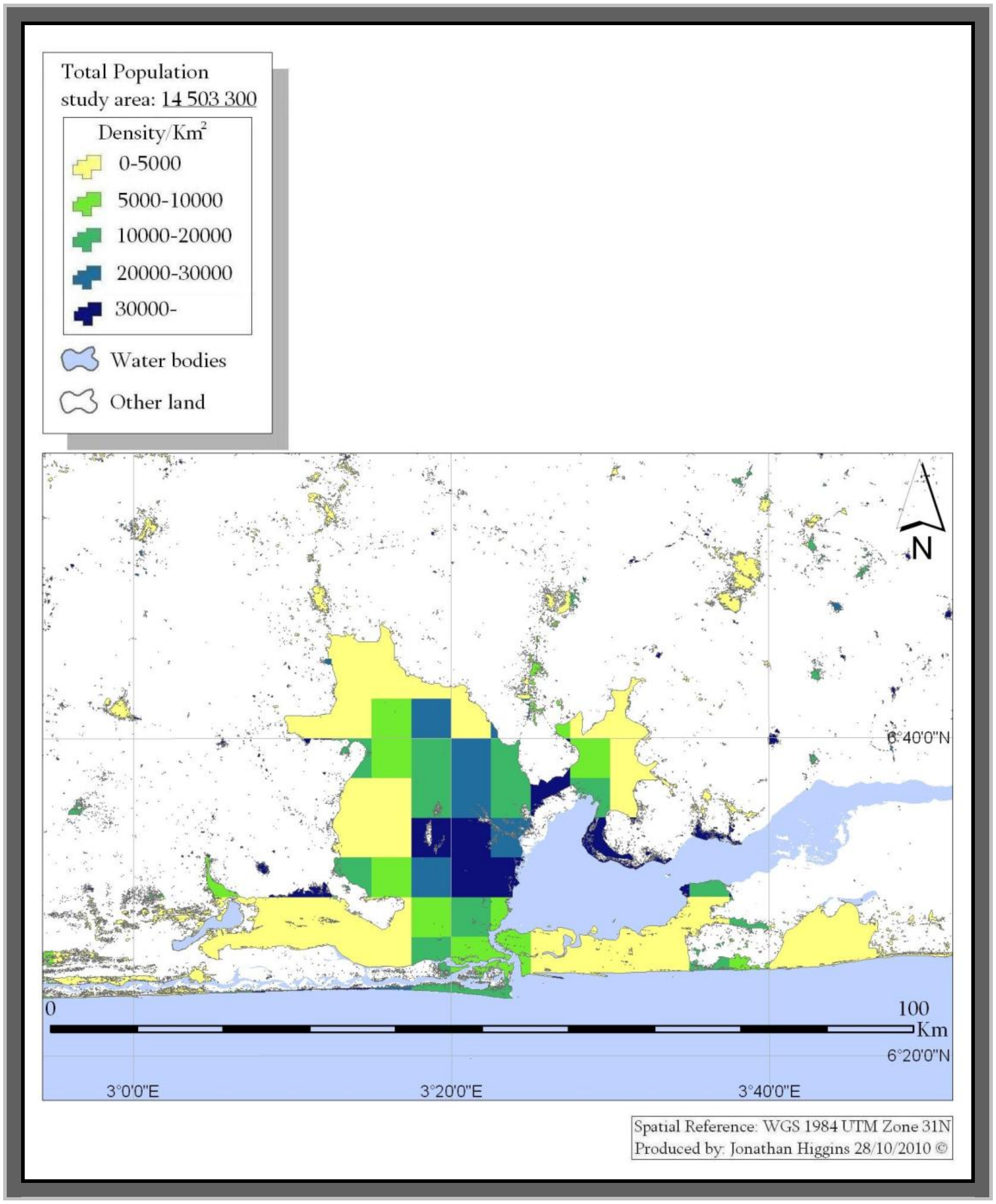

Figure 20: Future growth Scenario I (limited growth)

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 20 indicates that the future development is not going to be expansive and the population increase is going to be more about higher levels of density. The size of the city would according to scenario I be 1 218 km^2 with an average population density of 11 907 people/ km^2.

Figure 21 illustrates future Lagos according to Scenario II.

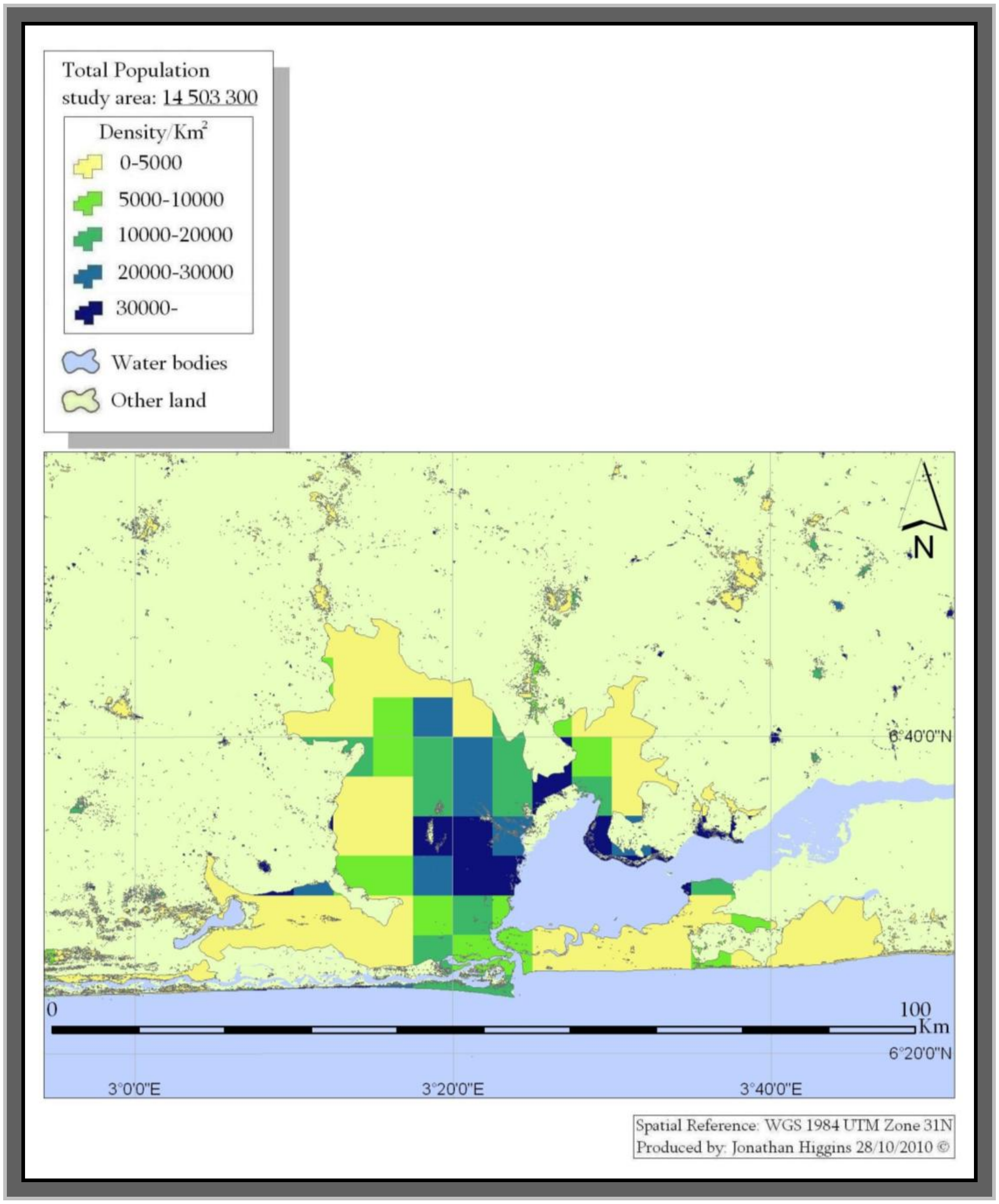

Figure 21: Future growth Scenario II (moderate growth)

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 21 suggest that the city will have an even expansion in both area and in population. According to this scenario the urban area of the city would correspond to 1 327 km^2 and the average density over the urban area would be 10 933 inhabitants/ km^2.

Figure 22 illustrate how Lagos will look in 2020 according to Scenario III.

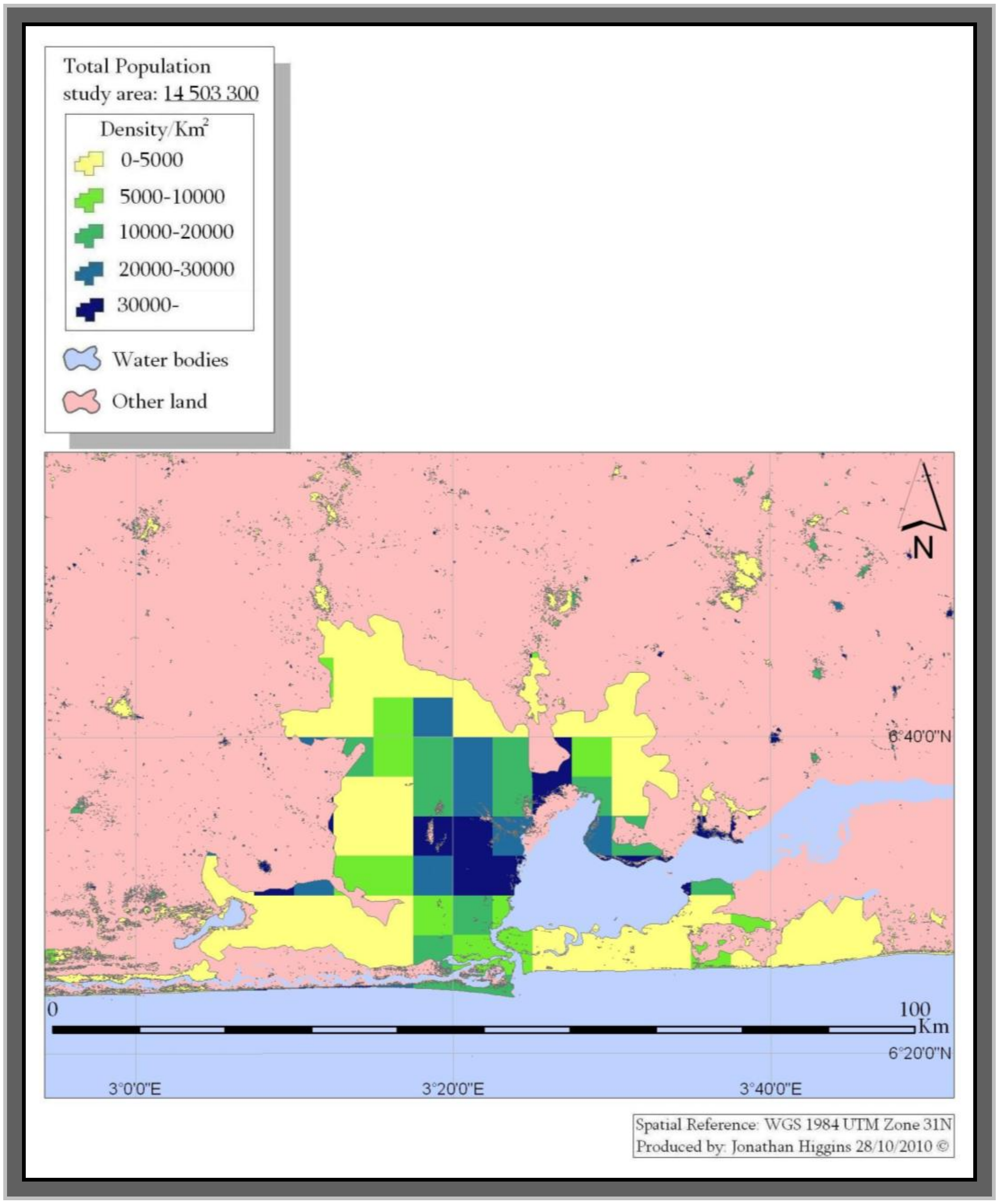

Figure 22: Future growth Scenario III (expansive growth)

Source: Gridded Population of the World and the Global Rural – Urban Mapping Project, 2010, World Urbanization Prospects: The 2007 Revision, 2008 & Earth Resources Observation and Science Center, 2011-11-01.

Figure 22 provides the most expansive scenario, according to this the city will continue to expand widely and growth will be characterized by low levels of density. The urban area of the city would be 1 405 km^2 and the average density would be 10 322 people/ km^2, density levels very similar to what they were in 2008.

5.6 Key findings

The population and area of Lagos has increased between the years 1990-2008. The city grew by over 5 million inhabitants from 4, 98 million in 1990 to 10, 18 million in 2008, over that time period the city expanded almost three times its initial size from 328 km2 to 973 km2. The main reason for this development has been a high natural population growth accounting for almost 2/3 of the city's increase. Urbanization has also affected Lagos, the main causes for this seems to be the importance the city has in Nigeria economically. The increase has been expansive indicating that the fight for space in central areas or improvements in infrastructure has driven people further away from its center. Different scenarios over Lagos for 2020 have been produced to show possible future outcomes for the city.

6 DISCUSSION

6.1 Limitations

The literature used for this study has been selected by attempting to use some of the most adequate and reliable information available in the subject. Since more information in this subject exists than used the validity of the study is dependent on the quality of the information used.

This thesis is mainly written for people either interested in geography or GIS and especially individuals interested in urban geography or in change detection monitoring. Most parts of the thesis would be understood even by individuals not having any earlier knowledge within any of the fields involved in the subject. The part of the thesis that requires some knowledge of GIS is the methodology part. Some of the basic GIS steps performed to the data have not been thoroughly described because they are expected to be comprehended by the reader. The more advanced GIS steps and the theories involved in the process have however been thoroughly described. If there is an interest to learn GIS and to get a better understanding the book *An introduction to Geographic Information Systems* (Heywood et al, 2006) is recommended.

The reliability of the results can be questioned to some extent. This because:

- The study has been conducted through using medium resolution satellite data
- The maps produced contain older data in certain areas due to errors
- The population data used is in low resolution.
- The population figures are based on estimates.

One should therefore acknowledge an error margin when looking at the results. However the results are so clear that general trends definitely can be seen. The validity of the thesis can however not be questioned. Population statistics and map images clearly show if urban growth has occurred or not.

Only population data and satellite images over the area have been used and not land cover data or any ancillary data. The reason for this is the lack of available data that is up to date, in high resolution, accessible and accurate. The satellite images have been classified to as few land classes over the region as possible to avoid confusion and because it would not be relevant to use more land cover features than necessary for the results.

The effects that foreign migration can have on urban growth in the receiving country should not be neglected. The lack of existing statistics concerning this in Lagos has however made it impossible to draw any conclusions on how this has influenced the growth of Lagos.

6.2 Discussion over method

The study has been conducted in a quantitative manner using population figures and maps to provide and explain results. Since the main focus of the study has been to show and provide statistics of the actual change for the whole city and population and not to describe why this has taken place in certain parts of the city or focus on individuals the methodology used was straight forward. Critique can be directed towards the natural philosophical approach used in the thesis because human geography and urbanization is a complex subject involving human and natural processes and therefore causality can be questioned and an anti-naturalism approach could instead have been used (Flowerdew et al, 2005).

The reason for the time period selected for the study was the accessibility of satellite data over the region that both had an equal time interval (9 years) and that were acquired during a similar season/time of the year. The difficulty in finding accessible satellite data that achieved these requirements unfortunately led to that images with minor distortions were used (Cloud distortion and SLC error). These distortions were removed using data from six years earlier (Figure 12, *p.22)*. This means that certain areas of the images over Lagos in 1990 and in 2008 not are completely accurate for the specified years, these areas are however small and should not have huge effects on the results.

Concerns regarding the population data used for this thesis can also be addressed. Population statistics based on estimates is a very uncertain science specifically in countries or cities where population measures are done based on irregular censuses instead of using civil registration systems. Most likely the population figures over Lagos are underestimated because of the fast growth and the amount of population who live in informal housing areas (Knox et al, 2003). It is difficult to assess the accuracy of various population statistics when different sources provide different figures and it is also hard to know what area that is included in the population data. Is it over the inner urban area or over a larger metropolitan area? The population data used is in low resolution (a cell covers 17, 35 km^2) creating a margin of error where huge variations in density can exist within these cells. The results should take this into account.

The study was conducted using the GIS and classification methods that were deemed to provide the most accurate results (Figure 7, *p.16*). These classifications could have been performed through using other bands and through altering and using other settings. The settings and bands used where believed optimal after testing and comparison with controls, these settings can be seen in Appendix II *(p.61-63)*. Normally change detection studies are carried out using the same bands for the comparing years this was not done because different bands had better accuracies for different years and certain bands could not be used for some years because the values in them were not normally distributed.

The study could have been performed through using other change detection methods. Jensen describes nine different existing algorithms to choose from when one wants to monitor change detection (Jensen, 1996). The opinion was that the post classification comparison change detection algorithm would be most appropriate to use since only the change for one land class was measured, this method allowed one to easily see the change that had taken place. This algorithm was also selected because edits were done to the classified images after classification. Most of the other change detection algorithms are performed before classification and using these would therefore lead to incorrect results.

Other methods could have been used when producing future growth prospects for the city. Using buffers could be an option, but this would lead to an equal expansion all over the city and the assumption was that the growth should occur in places where expansion had taken place in earlier years. This function would also lead to that growth takes place in regions where an increase could not occur such as in water bodies. This method was therefore rejected and instead the expansion was shown through digitizing it manually. The areas of growth might therefore not be completely probable but it is a way of illustrating possible future developments.

Further measures could have been undertaken to understand the main reasons for urbanization to Lagos through surveys, interviews or other qualitative in depth methods. This has however not been undertaken due to the lack of time and the difficulty in doing so.

6.2 General discussion

An accuracy evaluation has been performed on the resulting images over Lagos indicating an overall accuracy at around 93% which can be seen in Tables 4-6 *(p.33-34).* Since the accuracy assessments however only could be performed in areas where it was obvious through visual interpretation of the belonging land class the total accuracy of the images is most likely lower. Pixels with varying features are more likely to be inaccurately classified and could not be used for the assessment due to the difficulty in finding out what ground feature they represented.

A real shift can be seen in the world's urban development, from being a feature predominately occurring in the developed world it has changed to becoming a process mainly in the developing world. Most of the world's largest cities are today located in the developing world and these cities grow faster than ever before. In 2010 Lagos was the 18th most populated metropolitan region in the world and the second biggest city in Africa after Cairo, Egypt. The city is however expected to continue its growth and Lagos is in 2025 expected to be the 12th biggest city in the world with a population of around 15, 8 million (World Urbanization Prospects: The 2007 Revision, 2008). The population in Lagos has increased almost ten times as fast as the population in New York or Los Angeles did during the beginning of the 21st century (Lagos State Government, 2009). Almost the whole estimated population increase in the world till the year 2050 (3 billion) is expected to be accounted by growth in urban areas in the developing world. (World Urbanization Prospects: The 2007 Revision, 2008).

That urban growth had occurred over Lagos over the study time was not surprising since it is a city in the type of region where fast urban growth is taking place (World Urbanization Prospects: The 2007 Revision, 2008). The growth rate was however faster than expected. This growth rate can be compared to the growth rate of the largest city in Sweden, Stockholm. During the time period 1950 - 2010 the population in Stockholm increased from around one million inhabitants to around two million (Stockhoms Stads Utrednings- och statistikkontor AB, 2008). During the same time period Lagos increased from around 300 000 inhabitants to 10, 2 million (World Urbanization Prospects: The 2007 Revision, 2008), meaning that the population growth in Lagos occurred a staggering 34 times as fast as the growth in Stockholm.

The characteristic of this growth was also a bit surprising, that the rate of expansion was faster than the actual increase in population, my expectations were the opposite. Modern cities due however tend to expand geographically (so called urban sprawl). The reasons for this can be improvements in infrastructure and better living conditions and lower house costs in suburban areas or because of the fight for space in urban centers (Pacione, 2005). The exact same development was seen in the other case studies mentioned earlier (de Jong et al, 1997, Al-Awadhi et al, 2003, Naseem et al, 2000 & Azaz, 2001) where urban sprawl became a dominant feature over time. The paper over Ouagadougou (de Jong et al, 1997) showed the same development as Lagos in the way the urban expansion was taking place over time. The city expanded more during the 1990s than it did during the 2000s. This indicates that the characteristics of the urban growth had changed from expansion to higher levels of density, a development that could be seen even clearer in Ouagadougou (de Jong et al, 1997). Similarities between this thesis and the other cases studies can be seen in the time when the urbanization wave started. In Oman (Al-Awadhi et al, 2003) in Egypt (Azaz, 2001) and in Pakistan (Naseem et al, 2000) it started during a time when the national economy was prospering.

The results of this study and the main causes for this development coincide with the results of the similar case studies. This suggests that the development taken place and the causes for this can be generalized. The main reason for the urban growth in all the cases is the high natural population increase. That Nigeria has experienced a high natural population increase can clearly be seen by the fast increase in population over the country. The population in Nigeria in 2010 was five times higher than the population in 1950 (World Urbanization Prospects: The 2007 Revision, 2008). This has made Nigeria the most populated country in Africa and the 8^{th} most populated country in the world. In 2010 Nigeria had the 60^{th} highest annual population growth rate in the world, which is not surprising being situated in a continent where 17 of the 20^{th} fastest growing populations are located (The World Factbook, 2010). There is a clear correlation between poor countries and a rapid increase in population. This can sound contradictive where countries where people have low income levels and a shorter life expectancy are the countries where the population is increasing the most. The main reason for this is that larger families tend to be more beneficial for survival when career and education possibilities are limited (Knox et al, 2003).

Urbanization has also been a factor in Nigeria and especially affecting Lagos. The main reason for this is most likely economic reasons, urbanization in general is closely linked to economic growth and development and the economic importance Lagos has to Nigeria should not be questioned. Further measures and research however have to be undertaken to fully understand the main motives behind why people choose to move to Lagos.

Different theories that describe the reasons for urban growth in the developing world have been explained. This study shows that the main mechanisms involved in urban growth in the developing world deviate from the main factors involved in this process in the developed world. In my opinion modernization theory does not completely explain the recent urban growth in the developing world, even if economic development has had a huge part of the recent development. The developed world has had a great impact on how the developing world has been reshaped and urbanized through our position in the world trade market and through our cultural influence. The dependency theory and the world-system theory indicate this but these theories do not describe the whole picture. Therefore this is an area where more research could be carried out to gain a more accurate and understanding picture of the process. In general many geographic theories are based on how things developed and evolved in the "western world" and the same development is projected to take place in the rest of the world. This can be problematic when development and reasons for this are not put into context.

GIS and remote sensing can be a powerful tool when monitoring change detection, specifically in places where there is a lack of existing maps and data. It does not only show us the change that has taken place, it also shows the development trend which makes it possible to make future predictions for an area, in this case urban growth models. These models can assist us in the planning challenges that a city might face in the future and can help in preparing for these challenges (Pamuk, 2006). Planning for future populations by meeting the needs of new housing, improvements in infrastructure and investments at an early stage can be wise to avoid the negative environmental, social and economic effects that a fast and uncontrolled urbanization can have. Attempts to maintain a sustainable growth has been difficult in many fast growing cities (Preston, 1988). Lagos is no exception in this regard (Knox et al, 2003). Trying to cope with this development and to successfully plan for the future will be crucial for cities that already face problems due to over population. This is a problem that most likely will worsen in the future, when even more people will fight for space and employment in a situation where poverty, unemployment and underemployment already is widespread. It will also put pressure on already insufficient housing and service markets (Knox, 2003).

7 CONCLUSIONS

In this thesis a change detection study over Lagos using remote sensing and GIS has been performed the years 1990-2008 to show how the city has changed over time. This has been done through producing classified images over the city for the years 1990, 1999 and 2008 and comparing the areal change of the city between these years. These images have been combined with population figures and have been analyzed together with the main theories involved in urban geography.

The findings indicate that the area of Lagos has experienced a rapid growth over the study time. The urban area over the city almost tripled in size from 1990 to 2008, this both through an expansion of the city and through urban sprawl. The population had over the same time period more than doubled from around five million inhabitants in 1990 to more than ten million inhabitants in 2008.

The main reason for urban growth in the region was a high natural population increase that has affected the whole country. This can be seen by the fast population increase Nigeria has experienced together with the high fertility rates and the high proportion of the population that is young. This can also be seen in a broader context where the greatest reason for urban growth in the developing world is the very fast natural increase in population. Rural flight and the economic importance that Lagos has in Nigeria have been the main reasons for urbanization to the city.

The growth in the city has been more characterized by an expansion in area than it has in population increase. The study shows that over the first nine years the average density in the investigated zone dropped while it expanded geographically. The opposite development was more characteristic for the last nine years when the city more grew in population than in area, even though the average density levels still were lower than in 1990. The growth in general has however been characterized by higher population density levels in the inner parts of the city and more sparsely populated areas in the outskirts and the surrounding areas.

Different scenarios for the future of Lagos have also been computed based on the earlier growth rates, this to show possible future outcomes for the city in the year 2020. Three scenarios have been produced, all with the same total population figure but with differences in size representing an expansive, moderate and limited future growth for Lagos.

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APPENDIX I: LANDSAT 5 & 7 SENSORS

Information over the sensors used for this study can be seen in Table 8-10.

Table 8: Multispectral Scanner System

	Spectral sensitivity(µm)	Nominal Spectral Location	Ground Resolution (m)
Band 4	0.50-0.60	Green	68 x 83
Band 5	0.60-0.70	Red	68 x 83
Band 6	0.70-0.80	Near-Infrared	68 x 83
Band 7	0.80-1.10	Near-Infrared	68 x 83

Source: Rocchio, 2011-11-01 & Short, n.d.

Table 9: Thematic Mapper

	Spectral sensitivity(µm)	Nominal Spectral Location	Ground Resolution (m)
Band 1	0.45-052	Blue	30 x 30
Band 2	0.52-0.60	Green	30 x 30
Band 3	0.63-0.69	Red	30 x 30
Band 4	0.76-0.90	Near-Infrared	30 x 30
Band 5	1.55-1.75	Mid-Infrared	30 x 30
Band 6	10.40-12.50	Thermal-Infrared	120 x 120
Band 7	2.08-2.35	Mid-Infrared	30 x 30

Source: Landmap spatial discovery, n.d. & Short, n.d.

Table 10: Enhanced Thematic Mapper +

	Spectral sensitivity(µm)	Nominal Spectral Location	Ground Resolution (m)
Band 1	0.45-0.52	Blue	30 x 30
Band 2	0.53-0.61	Green	30 x 30
Band 3	0.63-0.69	Red	30 x 30
Band 4	0.78-0.90	Near Infrared	30 x 30
Band 5	1.55-1.75	Short-wave Infrared	30 x 30
Band 6	10.40-12.50	Thermal Infrared	60 x 60
Band 7	2.09-2.35	Short-wave Infrared	30 x 30
Band 8	0.52-0.90	Panchromatic	15 x 15

Source: Rangeland Assessment and Monitoring Methods Guide, n.d. & Earth Resources Observation and Science Center, 2011-11-01.

APPENDIX II: DENDOGRAM

The classifications were performed using bands good at detecting urban features. The three classified images were first classified to eight classes before being reclassified to three (urban, water bodies and other land). The reason for this operation was that accuracies where much higher if a reclassification was performed. Table 11 shows the dendogram over the classified image over Lagos in 1990 using bands 2, 3, & 4.

Distances between Pairs of Combined Classes
(in the sequence of merging)

Remaining Class	Merged Class	Between-Class Distance
3	4	3,080978
6	7	3,438263
3	5	3,482984
1	2	4,434816
6	8	6,853926
1	3	7,942283
1	6	11,622435

Dendrogram of c:\gis\lagos\gls&tm~1\test\m146c8.gsg

```
C   DISTANCE
L
A
S  0      1,3     2,6     3,9     5,2     6,5     7,7     9,0    10,3    11,6
S  |-------|-------|-------|-------|-------|-------|-------|-------|-------|

 4 ------------------|
                   |-|
 3 ------------------| |---------------------------|
                     |                     |
 5 --------------------|                     |----------------------|
                                           |                 |
 2 --------------------------|                   |                 |
                       |---------------------|                 |
 1 --------------------------|                                 |-
                                                           |
 7 --------------------|                                     |
                     |--------------------|                  |
 6 --------------------|                  |-----------------------------|
                                      |
 8 -----------------------------------------|

  |-------|-------|-------|-------|-------|-------|-------|-------|-------|
  0      1,3     2,6     3,9     5,2     6,5     7,7     9,0    10,3    11,6
```

Table 11: Dendogram I

Table 12 provides information over the classified image over Lagos in 1999 using bands 1, 3 & 4.

Distances between Pairs of Combined Classes
(in the sequence of merging)

Remaining Class	Merged Class	Between-Class Distance
3	5	2,633376
3	4	2,745462
6	7	3,178545
3	6	4,499570
1	2	4,525798
3	8	8,001291
1	3	11,836707

Dendrogram of c:\gis\lagos\gls200~1\test\m134c8.gsg

```
C  DISTANCE
L
A
S  0     1,3    2,6    3,9    5,3    6,6    7,9    9,2   10,5   11,8
S  |-------|-------|-------|-------|-------|-------|-------|-------|-------|

 5 ---------------|
                |
 3 ---------------|----------|
                |        |
 4 ---------------|        |--------------------|
                    |                |
 7 ------------------|     |                |
              |-------|                |-----------------------|
 6 ------------------|                    |                  |
                               |                  |
 8 ---------------------------------------------|                  |-
                                                  |
 2 --------------------------|                                |
                    |--------------------------------------------|
 1 --------------------------|

  |-------|-------|-------|-------|-------|-------|-------|-------|-------|
  0     1,3    2,6    3,9    5,3    6,6    7,9    9,2   10,5   11,8
```

Table 12: Dendogram II

Table 13 shows the dendogram over the classified image over Lagos in 2008 using bands 2 & 4.

Distances between Pairs of Combined Classes
(in the sequence of merging)

Remaining Class	Merged Class	Between-Class Distance
3	4	2,625335
6	7	2,667050
5	6	4,561089
5	8	6,134879
3	5	10,261668
1	2	15,011652
1	3	1101474850,620499

Dendrogram of c:\gis\lagos\etm200~1\test\m24c8.gsg

```
C   DISTANCE
L
A
S  0   1,2e+008 2,4e+008 3,7e+008 4,9e+008 6,1e+008 7,3e+008 8,6e+008 9,8e+008 1,1e+009
S  |-------|-------|-------|-------|-------|-------|-------|-------|-------|

  4
  |
  3
  |
  7 --------------------------------------------------------------------|
  |                                                    |
  6                                                    |
  |                                                    |
  5                                                    |-
  |                                                    |
  8                                                    |
                                                       |
  2                                                    |
  |--------------------------------------------------------------------|
  1

  |-------|-------|-------|-------|-------|-------|-------|-------|-------|
  0   1,2e+008 2,4e+008 3,7e+008 4,9e+008 6,1e+008 7,3e+008 8,6e+008 9,8e+008 1,1e+009
```

Table 13: Dendogram III

APPENDIX III: ACCURACY ASSESSMENT CALCULATIONS

Overall accuracy

$Z_{i\Sigma} / X_{i\Sigma} = \%$ **Equation 14**

where:

$Z_{i\Sigma}$ = *The sum of correctly classified samples.*

$X_{i\Sigma}$ = *The sum of samples.*

Equation 14 shows how overall accuracy measures the proportion of correctly classified samples. This is computed through comparing the number of correctly classified samples in the classified images with the total number of sample points.

User/ object accuracy

$X / Y = \%$ **Equation 15**

where:

X = *The number of samples in the reference data/class.*

Y = *The number of samples in the classified data/class.*

Equation 15 provides how user/ object accuracy is measured. It measures the probability that a random sample point in the reference data is classified in the same way in a classification.

Producer/ classification accuracy

$Y / X = \%$ **Equation 16**

where:

Y = *The number of samples in the classified data/class.*

X = *The number of samples in the reference data/class.*

Equation 16 shows the calculation to measure producer classification accuracy. This accuracy is the probability that a random sample point in a classification is classified in the same way in the reference data.

Mean accuracy

$2 * Z / Y+X = \%$ **Equation 17**

where:

Z = *The number of correctly classified samples/class.*

Y = *The number of samples in the classified data/class.*

X = *The number of samples in the reference data/class.*

Equation 17 provides the calculation to compute mean accuracy. It is a combination of user and producer accuracy and will provide a value that will fall in between these two values.

Areal difference

$$X - Y / Y = \%$$ **Equation 18**

where:

X = The number of samples in the reference data/class.

Y = The number of samples in the classified data/class.

Equation 18 shows how the areal difference is calculated. It measures the area of the different classes to monitor if they are under- or overrepresented in a classification compared to the ground truth.

Overall kappa

$$X_{i\Sigma} * Z_{i\Sigma} - P_{\Sigma} / X_{i\Sigma}^{2} - P_{\Sigma} =$$ **Equation 19**

where:

$X_{i\Sigma}$ *= The sum of samples.*

$Z_{i\Sigma}$ *= The sum of correctly classified samples.*

P_{Σ}*= The sum of the products between the number of samples in the classified data/class and the number of samples in the reference data/class.*

Equation 19 describes how overall kappa is computed. Kappa provides information over the quality of a classification. It provides values between -1 and 1, where -1 means that the classification does not correspond to the ground truth at all and 1 means that is correlates exactly.

Individual kappa

$$X_{i\Sigma} * Z - P / X_{i\Sigma} * Y - P =$$ **Equation 20**

where:

$X_{i\Sigma}$ *= The sum of samples.*

Z = The number of correctly classified samples/class.

P = The product between the number of samples in the classified data/class and the number of samples in the reference data/class.

Y = The number of samples in the classified data/class.

Equation 20 provides the formula how to calculate individual kappa. Individual kappa measures the quality of a classification for each of the different land classes. It provides a figure in the same way as the overall kappa (GIS-centre, 2004).

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