

**CHANGE DETECTION OF INFORMAL
SETTLEMENTS USING REMOTE SENSING AND
GEOGRAPHIC INFORMATION SYSTEMS: CASE OF
KAWANGWARE, NAIROBI (1990-2010)**

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B42/82054/2012

**RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE AWARD OF THE POST
GRADUATE DIPLOMA IN HOUSING ADMINISTRATION,
SCHOOL OF THE BUILT ENVIRONMENT,
DEPARTMENT OF REAL ESTATE AND CONSTRUCTION
MANAGEMENT,
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OCTOBER, 2013

DECLARATION

This research project is my original work and it has never been presented for award of a degree in any other university.

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DATE

This research project has been completed under my supervision and submitted in accordance with the university regulations.

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DATE

ACKNOWLEDGEMENT

I would like to express gratitude to the Permanent Secretary Ministry of Housing for availing resources for me to undertake this course, my workmates and fellow students at the University for their honourable Support. I would like to thank Mr Museleku for his assistance and guidance with this project paper. I thank my partner, Fred, for his love, kindness and support he has shown during the time I was working on this project. Furthermore I would also like to thank my parents for their endless love and support.

DEDICATION

I dedicate this work to all people living in informal settlements.

ABSTRACT

Informal settlements behave dynamically over space and time and the number of people living in such housing areas is growing worldwide. The reasons for this dynamical behaviour are manifold. Nevertheless, informal settlements represent a status quo of housing and living conditions which is from a humanitarian point of view in the most cases below acceptable levels. Sub-standard sanitary situations and high crime rates are only a few of attributes which go aside with the phenomenon informal settlement. Due to their informal character, reliable and accurate data about informal settlements and their inhabitants is rarely available. On the other side there is a strong need to transform informal into formal settlements and to gain more control about the actual spatial development of informal settlements. Consequently, reliable procedures for detecting and monitoring the spatial behaviour of informal settlements are required in order to react at an early stage to changing housing situations. Thus, obtaining spatial information about informal settlement areas which is up to date is vital for any actions of enhancement in terms of urban or regional planning.

The complexity of urban systems makes it difficult to adequately address their changes using a model based on a single approach. In this project, the researcher developed a GIS-based integrated approach to modelling and prediction of urban growth in terms of land use change. The model was built upon a binomial logistic framework, coupled with a rule-based suitability module and focus group involvement, and is designed to predict land transition probabilities and simulate urban growth under different scenarios. The model was calibrated in the Kawangware region of Nairobi County through a GIS-facilitated participatory process involving both statistical assessment and human evaluation. The model achieved high overall success rates, although its predictive power varied spatially and temporally with different types of land use. The model was used to predict future urban growth in the region through the years 2020 and 2030.

The study findings indicate that there has been a steady growth in the built environment of the study area. The model also depicts that this growth will continue. As a result of this growth it is concluded that it is critical to establish a GIS land and infrastructure database. From the study findings, it is recommended that there should be public sensitization on planning regulations as well as development of land information systems.

The study is organised in to five chapters. Chapter one contains background information about the study problem, research objectives and questions. Chapter two discusses available literature, making comparison and drawing conclusions. Chapter three study methodology, data analysis, interpretation and presentations of findings in chapter four, and chapter five summary findings, conclusion and recommendations.

TABLE OF CONTENTS

DECLARATION	i
ACKNOWLEDGEMENT	ii
DEDICATION	iii
ABSTRACT.....	iv
TABLE OF CONTENTS.....	v
LIST OF FIGURES	viii
LIST OF TABLES.....	ix
LIST OF ACRONYMS	x
CHAPTER ONE	- 1 -
1.1 INTRODUCTION	- 1 -
1.2 STATEMENT OF THE PROBLEM	- 3 -
1.3 STUDY OBJECTIVES.....	- 4 -
1.4 RESEARCH QUESTIONS.....	- 4 -
1.5 SIGNIFICANCE OF THE STUDY.....	- 4 -
1.6 RESEARCH METHODOLOGY.....	- 6 -
1.7 SCOPE AND JUSTIFICATION OF THE STUDY	- 6 -
1.8 ORGANIZATION OF THE STUDY	- 8 -
1.9 DEFINITION OF KEY TERMS	- 9 -
CHAPTER TWO	- 10 -

LITERATURE REVIEW	- 10 -
2.1 INFORMAL SETTLEMENTS.....	- 10 -
2.2 HOW AND WHERE INFORMAL SETTLEMENTS EMERGE	- 12 -
2.3 SLUM POLICIES IN DEVELOPING COUNTRIES	- 14 -
2.4 INFORMAL SETTLEMENTS DATA.....	- 16 -
2.5 REMOTE SENSING AND GIS	- 17 -
2.6 MONITORING AND DETECTING INFORMAL SETTLEMENTS USING REMOTE SENSING AND GIS.....	- 19 -
2.7 CONCEPTUAL FRAMEWORK/THEORETICAL MODEL	- 23 -
CHAPTER THREE	- 24 -
RESEARCH METHODOLOGY	- 24 -
3.1 OVERVIEW OF METHODOLOGY	- 24 -
3.2 DATA COLLECTION AND PREPARATION	- 25 -
3.2.1 Scanning and Orthorectification of Aerial Photographs	- 26 -
3.3 GEO-REFERENCING OF AERIAL PHOTOGRAPHS.....	- 29 -
3.4 SATELLITE IMAGERY PROCESSING.....	- 30 -
3.5 DIGITIZATION OF FEATURES (BUILDINGS, ROADS ETC)	- 32 -
3.6 SUPERVISED CLASSIFICATION	- 32 -
3.7 SUB PIXEL CLASSIFICATION	- 36 -
3.8 RASTER TO VECTOR CONVERSION	- 37 -
3.9 FEATURE CLIPPING.....	- 39 -

3.10	MODEL DESIGN, CREATION AND TESTING	- 40 -
3.11	RUNNING A MODEL FROM WITHIN ModelBuilder.....	- 42 -
3.12	MODELLING PYTHON PROGRAMMING SCRIPTS.....	- 43 -
	CHAPTER FOUR.....	- 45 -
	DATA ANALYSIS AND PRESENTATION	- 45 -
	CHAPTER FIVE	- 53 -
	CONCLUSIONS AND RECOMMENDATIONS	- 53 -
5.1	SUMMARY OF FINDINGS	- 53 -
5.2	CONCLUSIONS.....	- 53 -
5.3	RECOMMENDATIONS	- 54 -
5.4	AREAS OF FURTHER RESEARCH	- 55 -
	REFERENCES	- 56 -
	APPENDICES	- 60 -

LIST OF FIGURES

Figure 1: Location of Study Area within Nairobi City County.	- 8 -
Figure 2: An iteratively holistic method based on remote sensing imagery and GIS data	- 23 -
Figure 3: Overview of the Methodology.....	- 24 -
Figure 4: Part of Aerial Photograph Showing the GCP's	- 27 -
Figure 5: Signature Collection on a Satellite Image	- 34 -
Figure 6: Adding Signatures to Signature Editor.....	- 35 -
Figure 7: Classified Image for Kawangware using Supervised Classification Method.....	- 35 -
Figure 8: Vectorized layer of Buildings.....	- 38 -
Figure 9: Clipping of Features in the Study Area	- 39 -
Figure 10: Figure Showing Clipped Study Area.....	- 39 -
Figure 11: Figure Showing Example of creating a GIS Model	- 40 -
Figure 12: GIS Model Creation Process	- 41 -
Figure 13: Changes in the Built Development in the years 1990 to 2000	- 45 -
Figure 14: Changes in Built Development in Kawangware from the year 1990 to 2010	- 46 -
Figure 15: Changes in Built Development in the years 1990 to 2020	- 47 -
Figure 16: Changes in Built Development in the years 1990 to 2030 – Buildings.....	- 48 -

LIST OF TABLES

Table 1: Population data of study area.....	- 26 -
Table 2: Table showing features that were captured during SubSubpixel classification.....	- 37 -
Table 3: Comparison statistics in computation of areas of occupied by buildings	- 49 -
Table 4: Summary of study findings.....	- 53 -

LIST OF ACRONYMS

DPI	Dots Per Inch
GCP	Ground Control Points
GIS	Geographic Information Systems
GPS	Ground Positioning System
LIS	Land Information Systems
RCMRD	Regional Centre for Mapping and Resources Development
RMS	Root Mean Square
RMSE	Root Mean Square Error

CHAPTER ONE

1.1 INTRODUCTION

In the last 50 years the shape of cities has changed dramatically. People have started to migrate from rural areas, attracted by the opportunities created by a more dynamic economy and by the apparent easier life within the cities. In Africa, but also in other continents, urban growth has reached situations close to anarchy, enhanced by civil wars and internal disturbances. The result of this very rapid and unplanned urban growth is that 30% to 60% of residents of most large cities in developing countries live in informal settlements, (UNHCS, 2013).

Nairobi was founded in 1901 along the Mombasa Kampala railway (Kenya Uganda Railway). It grew in an organized way, like almost all the colonial cities, until the Second World War, reaching a population of 118,000 in 1946. The present spatial distribution of the population reflects the patterns laid by the British rather than the traditional African ones, (Obudho, 1999). Characterised by large avenues and well planned areas, it was considered one of the most modern cities of Africa. Like many other cities of the continent, its population has grown quickly, reaching more than two million in less than 50 years due to in-migration and natural increase.

In recent times, large areas of the city, where access to land was easier, have literally been “occupied” by low-income migrants. The in-migrants had no choice other than to organise themselves in an informal way to cope with the lack of infrastructures. Everything had a tendency to become informal - accommodation, employment, transport and even industrial activities. In these areas of the town and also in Nairobi, the informal population growth has

resulted in environmental degradation, overcrowding, poor housing, limited access to water and poor sanitation.

Slums or informal settlements are without any doubt a reality and their rapid growth is one of the major challenges that authorities in charge of providing essential services have or will have to face in the near future. This reality has appeared while the world economy has shown a global decline, leaving most of the least developed countries with fewer and fewer resources available to cope with the exponential growth of the population, unable to address their needs for basic infrastructures, like potable water, waste evacuation, energy, education and health care facilities.

If the trend in urban growth has been quite difficult to manage and regulate, more can now be done to monitor the extent of this problem. Basically, one will have to answer these questions: where are these settlements and how many exist; at what pace have they grown; and, finally, how many people will need basic services.

Paradoxically, some of these answers can now be found using new methodologies, derived from sophisticated technologies, developed to study the earth from the sky, from aerial photographs to satellite imagery, in combination with local competences and more accessible software and hardware, presently available and used throughout the world.

Aerial or remote sensing imagery now has the capacity to provide planners and decision-makers with information previously restricted to specialized units, at competitive costs, opening new ways to monitor the dynamics of fast growing settlements.

1.2 STATEMENT OF THE PROBLEM

One of the biggest obstacles for development in the developing countries is rapid population growth. This, together with continuing poverty and a lack of basic needs for an acceptable life (e.g. food, clean water, shelter, basic health care, security of tenure) imposes a great challenge for sustainable development. Most of the population growth in the world during the next 15 years will be urban growth, and the vast majority of it will take place in developing countries. The population growth rate for years 2000-2020 is estimated at 1.3 percent in developing regions (2.4 percent in Sub-Saharan Africa) compared to only 0.1 per cent in developed regions (UN-Habitat, 2003A). There remains a huge potential for urban growth for the countries in Africa, since in the year 2000 only 37.1 percent of their total populations were urban – this is estimated to grow up to 47.8 percent by the year 2020.

In Kenya, the level of urbanization in 2000 was 33.4 percent and it is estimated to go up to 50.8 percent by 2020, indicating an annual growth rate of 3.76 percent in the next 15 years (HABITAT, 2003A). Of all urban population in Kenya, 70.7 percent lived in informal settlements, a total of 7.6 million people (HABITAT, 2003B: Table 1), which is alarmingly high when compared to the average of developing regions, 43.0 percent (HABITAT, 2003A:). Thus, a major focus in sustainable development and issues related to it in Kenya should be directed towards the urban environment and problems caused by rapid urban growth.

Given the facts raised above in the urban areas of the developing world, there is an urgent need for fast decision making and planning in order for the government officials and urban planners to maintain at least some control of the city growth. This is not possible without up-

to-date information about various aspects in the urban areas, e.g. cadastral and socio-economic data.

Detecting change in urban areas is not only of academic interest, because it serves as the major data source for strategic planning and analysis in urban areas (Donnay et al., 2001).

1.3 STUDY OBJECTIVES

- I. To exploit GIS databases and high resolution remotely sensed imagery to study changes in the built environment of Kawangware between 1990 to 2010
- II. To create a model that can predict the rate and direction of change for 2020 and 2030.

1.4 RESEARCH QUESTIONS

- I. What is the rate of change in the built-up environment of Kawangware from 1990 to 2010?
- II. How will the built-up environment of Kawangware be like in 2020 and 2030?

1.5 SIGNIFICANCE OF THE STUDY

Historically, Kawangware has experienced steady growth over the past five decades. Although urban growth is perceived as necessary for a sustainable economy, uncontrolled or sprawling urban growth causes various problems. Not only does urban sprawl rapidly consume precious rural land resources at the urban fringe, but it also results in landscape alteration, environmental pollution, traffic congestion, infrastructure pressure, rising taxes, and neighbourhood conflicts. All these have become public concerns. How large will the Kawangware slum become over the next 30 years? Where will the new urban areas be

located? What are the consequences of future urban growth? What are the policy implications of new growth? What should be done now to avoid or mitigate negative impacts in the future? Unfortunately, there are as yet no answers to these questions. No urban growth prediction has been made at the regional level in the entire county of Nairobi. Without information generated from reliable predictions, discussions or debates on these issues will remain at a superficial level.

In the past decades, aerial photographs have played an important role in mapping. However, satellite data are becoming increasingly available with spatial resolution of 1 m or better (Yu et al., 2006). They are considered to be an essential data source as they provide timely and valuable information for analysing the landscape. In general, the benefit of using remotely sensed data can be viewed from three perspectives:

- ❖ They provide spatially consistent datasets that cover large areas with both high detail and high temporal frequency (Herold et al., 2001)
- ❖ They save cost and time through quick detection as well as providing site specific information on natural and manmade features; and
- ❖ They combine both high accuracy and affordability since the same database can be used by a cross-section of agencies reducing data redundancy and effort duplication

Image analysis can be done in two ways:

- ❖ Pixel/spectral based supervised and unsupervised classification where classification is done based on spectral reflectance of a pixel;
- ❖ Object based- which utilises rule based, knowledge based techniques.

The purpose of this study was to evaluate the growth of Kawangware slum in the last 30 years with the aim of creating a model that can predict the rate and direction of growth of the settlement. This will give vital information to planners and service providers. The findings are useful to the newly created counties as they plan their towns.

1.6 RESEARCH METHODOLOGY

The main source of data for this research was topographical map, black and white aerial photographs and QuickBird satellite images. Erdas IMAGINE software was used to interpret the images as well as creation of the growth model. Maps depicting area occupied by the built environment of Kawangware were derived from the images as well projection of future development trend.

1.7 SCOPE AND JUSTIFICATION OF THE STUDY

Predicting urban land use change is important if city planners are to provide, even at minimum standard, necessary infrastructure and services to their residents. Forecasting where and how urban change will manifest itself, however, is a challenge for any city and its planners. Thus, it is envisaged that if the growth process of urban and informal settlements is better understood it can be modelled and applied in real situations for the prediction of growth under likely future scenarios. Spatially explicit modelling can be used to conduct experiments that test our understanding of key processes and for describing them in quantitative terms. As a simplification of reality, a model can allow the user to structure data collected from real world in a manner that is easily interpreted and understood by the scientific world as well as the general public.

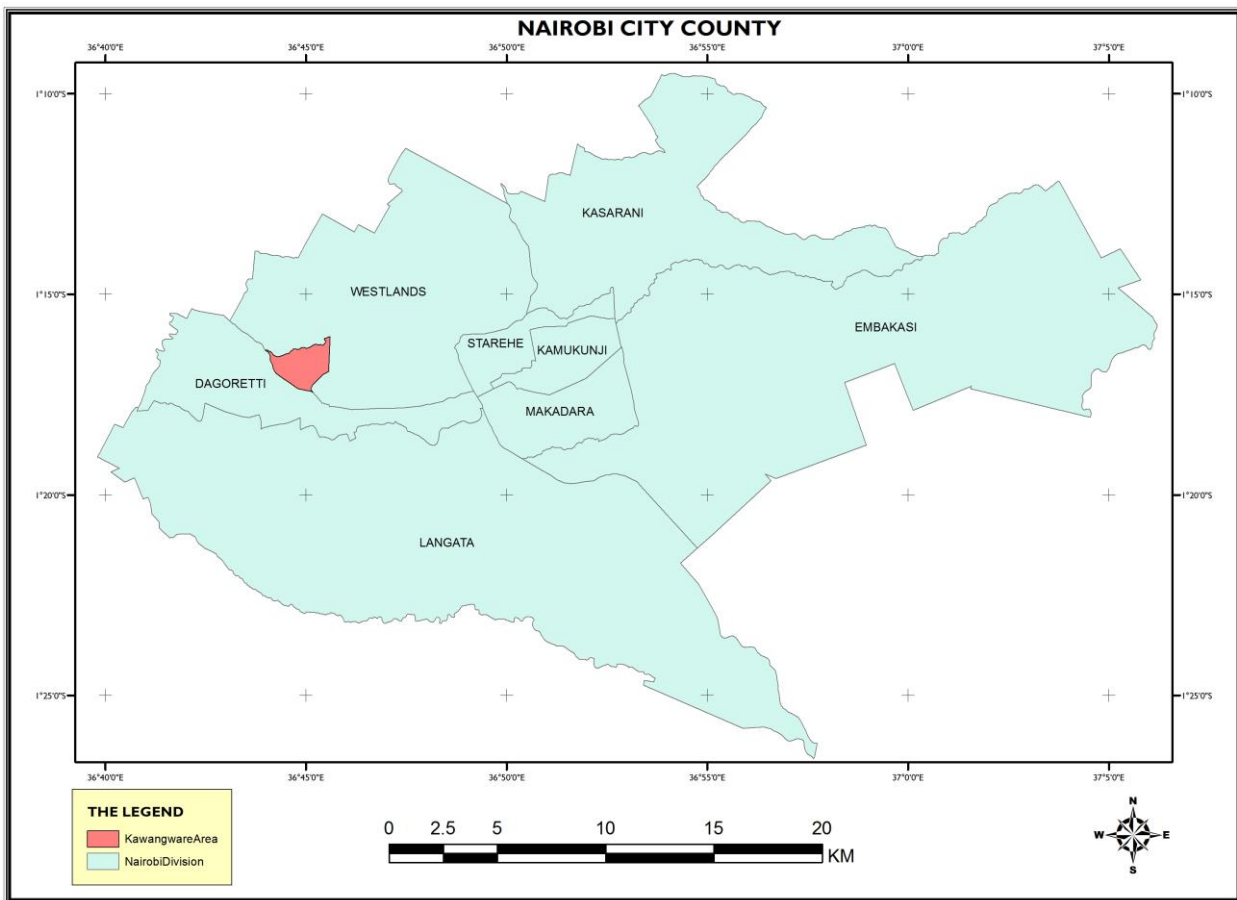
The result of the study helped identify the spatial growth pattern of Kawangware informal settlement in order to make adequate future planning for proper provision of social and infrastructural facilities to the area.

Study Area

Kawangware is a slum in Kenya located about 15 kilometers west of the city centre of Nairobi. It is between Lavington Estate and Dagoretti. It is Kenya's second largest slum after Kibera, and the fourth largest in Africa with a population of over 300,000 people (Kenya 2009 census data) located in an area of 16sq.km. It is one of the fastest growing and poorest slums in the city.

Its coordinates are 1°16'60" N and 36°43'60" E in DMS (Degrees Minutes Seconds), UTM position is BU45 and its Joint Operation Graphics reference is SA37-05. It is located at an elevation of 1,805 meters above sea level. Figure 1 below shows a map of Nairobi City County and shows location of the study area.

Figure 1: Location of Study Area within Nairobi City County.



SOURCE: mapatlas (2013)

The study is organised in five chapters. Chapter one contains background information about the study problem as well as objectives and research questions. Chapter two discusses available literature, making comparison and drawing conclusions. The methodology used in data collection and analysis is discussed in chapter three. Detailed data analysis, interpretation and presentations of findings are outlined in chapter four. Chapter five contains summary findings, conclusion and recommendations.

1.9 DEFINITION OF KEY TERMS

Remote sensing: Is the process of collecting and interpreting information about the environment and the surface of the earth from a distance, primarily by sensing radiation that is naturally emitted or reflected by the earth's surface or from the atmosphere, or by sensing signals transmitted from a device and reflected back to it. Examples of remote-sensing methods include aerial photography, radar, and satellite imaging, (Esri, 2013).

Geo-information systems: A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analysing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps you answer questions and solve problems by looking at your data in a way that is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework, (Esri, 2013).

GIS Modelling: Also Spatial modelling can be defined as the process of describing basic properties and processes for a set of spatial features. The aim is to study spatial objects or phenomena in the real world

CHAPTER TWO

LITERATURE REVIEW

2.1 INFORMAL SETTLEMENTS

Informal settlements are usually a phenomenon which mostly occurs in developing and newly industrializing countries. Although different definitions of *informal settlement* do exist, *slum*, *squatter settlement* or *shanty town* are commonly used synonyms for this special type of settlement. Nevertheless, the United Nations (UNSTAT, 2005) define *informal settlements* as:

- “1. Areas where groups of housing units have been constructed on land that the occupants have no legal claim to, or occupy illegally;*
- 2. Unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing).”*

Both definitions are obviously emphasizing the illegal character of informal settlements. In contrast, the definition of Mason, O.S. & Fraser, C., (1998) takes the environmental, socioeconomic and living conditions more into account. They describe *informal settlements* as:

“... dense settlements comprising communities housed in self-constructed shelters under conditions of informal or traditional land tenure They are a common feature of developing countries and are typically the product of an urgent need for shelter by the urban poor. As such they are characterized by a dense proliferation of

small, makeshift shelters built from diverse materials (such as plastic, tin sheeting and wooden planks), by degradation of the local ecosystem (for example, erosion and poor water quality and sanitation) and by severe social problems.”

Independent of these different definitions, according to UN-Habitat, (2006a) the number of people living in slums or shanty towns worldwide will grow from approx. 1.0 Billion in 2005 to 1.2 Billion in 2010 and 1.5 Billion in 2020. Thus, from the perspective of an urban or regional planner, as well as from the perspective of local or regional authorities, informal settlements might become a more and more challenging problem in the years to come. Programs, such as the *Global Campaign for Secure Tenure* (UN-Habitat, 2006) are emphasizing this challenging character.

Busgeeth et al. (2008) notes that a common phenomenon that distinguish informal settlements from formal settlements are:- do not adhere to local building codes, have either low levels of infrastructure or no infrastructure altogether, are either poorly serviced or not serviced at all, have no security of tenure and are characterised by a rather non-functional pattern.

In 1999, the World Bank and UN-Habitat introduced a “Cities Without Slums” initiative with the defined goal of achieving a significant improvement in the lives of at least 100 million slum dwellers by the year 2020. This target, commonly known as Target 11 under Millennium Development Goal 7 ensures environmental sustainability and gives a new meaning to the term ‘slum’, which was then defined as any area that met the following six criteria; Lack basic services, Inadequate building structures, Overcrowding, Unhealthy and hazardous conditions, Insecure tenure, Poverty and Exclusion (Huchmeyer et al., 2006)

Factors that have led to the mushrooming of informal settlements in developing countries, most particularly in Africa, are massive rural-urban migration, poverty and unequal distribution of wealth, poor land delivery systems, political instability, inability of the government to define a clear and long-term land and housing policy and, lastly, high demand from very low-income groups that makes the management and upgrading of these settlements more difficult (Mosha, 1996). Reasons for the increase in migration are mainly attributed to cities offering better possibilities for employment, education and access to social infrastructure.

It is recognised that the existence of informal settlements is a serious concern as they accommodate a large proportion of the urban population who live in sub-standard living conditions. In addition, it is also realised that an increase in migrants to urban areas inevitably leads to a shortage of basic engineering services such as water, sewerage and solid waste removal, and places essential services such as health and education under pressure.

2.2 HOW AND WHERE INFORMAL SETTLEMENTS EMERGE

Various reasons are often put forward to explain the emergence and growth of slums in developing countries. For instance, research shows that slums excel in marginal or less valuable urban land such as riverbanks, steep slopes, dumping grounds, abandoned or unexploited plots, along transportation networks, near industrial areas and market places, and in low lying areas or wetlands (Blight & Mbande, 1998).

Other work suggests that slums seem to be mutually attracted, at least in part, by spiritual or religious activities (Davis, 2004). Such correlation is also well documented for new urban migrants who prefer to settle in neighbourhoods that share similar socio-cultural backgrounds (Malpezzi & Sa-Adu, 1996). It could therefore be argued that the knowledge of dominant

ethnic, cultural and religious groups in existing neighbourhoods or slums could provide useful clues for exploring future expansion and location of slums. Such knowledge is valuable for the spatial prediction of slum growth, especially in cities where ethnic, cultural and religious differences highly influence the location choice of the urban dwellers.

Moreover, there is now sufficient evidence to argue that informal settlement dwellers tend to have been born in cities and previously lived in informal settlement (probably nearby) or they are planning to move to a future informal settlement and preferably in the peri-urban areas (UN-Habitat, 2003). This suggests that established slums can duplicate themselves and serve as a stepping-stone for the emergence of future settlements on the nearest available land.

Another important factor is the close correlation between the informal economies and informal settlements (Kengne, 2000). This is because knowledge, skills and experience are not often pre-requisites for accessing the informal job market, as it is the case within the formal or public sector (Happe & Sperberg, 2003). Migrants to the urban areas have long fuelled the informal economic sector (often represented by popular market places), which employs more than 70% of the labour force, and contributes an average of 40% of the gross domestic product of developing cities (Kengne, 2000). Another important factor that helps to explain the proliferation of slums is the rigidity of urban planning regulations associated with other factors such as poor governance, corruption and nepotism, which all lead to a severe shortage of land and urban housing, squatting, and infringements of building regulations (Fekade, 2000; Global Urban Observatory, 2003).

The end result of all these factors is rapid, unstructured and unplanned expansion, conflicting land tenure and property rights, poor quality dwellings, decay of the physical environment, unhealthy living environment, severe social problems, and low socio-economic status for

informal settlements occupants that all constitute the common characteristic of informal settlements. Various measures have constantly been undertaken to improve the conditions of slums in developing countries, but their effectiveness are often questionable.

2.3 *SLUM POLICIES IN DEVELOPING COUNTRIES*

Slums are often conceived and portrayed as institutional failures in housing policy, housing finance, public utilities, local governance and secure tenure. Thus, measures to address their existence and appearance have evolved around such thinking. During the postcolonial period, particularly in the 1950s and 1960s, the issue of slum in Developing Countries emerged as an important area for urban research and policies (Pugh, 1997). As a result, various slum strategies were implemented to (at least) mitigate the socio-economic, physical and health wellbeing of slums and their residents.

In the 1970s, most governments in developing countries opted for a direct and centralized (State) intervention, executed through World Bank's instigated programs such as the site and service scheme. This particular scheme advocated the clearance of centrally located slums and their relocation to newly serviced plots often outside the existing urbanized areas. This policy was driven by affordability and cost-recovery strategies (van der Linden, 1986).

In the 1980s, the upgrading strategies emphasized the improvement of communal infrastructure and services within the established slums (Banes et al., 2000). In particular, the upgrading projects targeted the improvement of basic services (e.g., sewage, water, sanitary, garbage collection, electricity) and infrastructure (e.g., road, market, healthcare and education centres) that were lacking or decaying in slum areas (Pugh, 2000). Upgrading projects were to be implemented with lesser intervention of government than in site and service schemes. Local upgrading strategy was appealing because it avoided (unnecessary) demolition, was

cheaper per unit than site and service approach, and preserved social and economic networks. The upgrading program aimed to achieve three main goals: affordability, cost recovery and replicability.

One of the major ways in which urban planning strategies have been approached to improve the slum conditions has been the development of practical mechanisms to consolidate and secure land tenure. The security of tenure campaign is closely associated with the enabling approach (World Bank, 1993). The enabling approach advocated seven major points: development of housing financing systems, targeting of subsidies, encouraging property rights (including security of tenure), improving infrastructure, auditing and removing barriers, restructuring building industries and reforming institutions (Pugh, 2001). The enabling approach is understood as advocating that legal, administrative, economic, political, urban stakeholders and financial institutions should facilitate and secure the shelter and tenure to the most vulnerable portion of urban dwellers. In the 1990s, the enabling approach was implemented through security of tenure strategies largely supported by international agencies, namely UN-Habitat and the World Bank, as a contingent measure to limit the eviction and demolition threat in slums (Jenkins, 2001). The assumption was that although slum settlers do not necessarily have the legal title over the land, they could undertake improvement on their properties without fear of eviction. The enabling approach, via its emphasis on security of tenure, also postulated that the availability of and the accessibility to urban land provide a sense of 'belonging' and brings stability to an urban area (Kombe & Kreibich, 2000).

The new century has called for new strategies and plan for slum. In 1999, the World Bank and the UN-Habitat initiated the Cities Without Slums action plan, which constitutes a part of

the United Nations Millennium Declarations, Goals and Targets. Specifically, the action plan aims at improving the living condition of at least 100 million slum dwellers by the year 2020 (UN-Habitat, 2003). The main innovation in this policy is to move from the physical eradication or upgrading of slums adopted by past policies, to start to address one of the fundamental reasons why slums exist in the first place: poverty. The action plan recognizes that slums are largely a physical manifestation of urban poverty, and to deal with them effectively, future actions and policies should also associate urban and slum stakeholders in the poverty reduction or eradication campaign.

2.4 *INFORMAL SETTLEMENTS DATA*

One of the fundamental difficulties that authorities face when planning a response to the formation and growth of informal settlements is the paucity of spatial and temporal data to assist in recognising and quantifying the understanding of settlement morphology, services/infrastructure, growth, population distribution and emerging settlement patterns. Reasons for the inability to obtain data include:

- ❖ Informal settlements are generally characterised by dysfunctional settlement structure. The distribution of plots follows no planned structure or conventional planning principles and streets and technical infrastructure are not catered for. Plot boundaries are unknown or non-existent, and plot sizes varies greatly;
- ❖ These settlements are highly condensed and difficult to access for surveys. In certain situations, it is also considered to be too dangerous for official enumerators to do house-to house data collection;

- ❖ Informal settlements are dynamic. Population fluctuations and the erection of and removal of structures over short time periods, mean that traditional survey methods cannot effectively capture temporal reality. Traditional surveys may take several months to process, rendering the results out-dated at the time of release;
- ❖ Unclear municipal boundaries and overlapping administrative responsibilities; and
- ❖ Deficits in man power, lack of finance and technical equipment as additional challenges

As a result of these difficulties informal settlements are often not spatially documented. There are no maps indicating the position, pattern, size, complexity and influence of the settlements. Maps are regarded as unbiased and neutral sources of information about the world. Such is the power of the map that if authoritative, official maps and atlases fail to map places, the impression is given that those places do not exist (Stickler, 1990)

2.5 REMOTE SENSING AND GIS

According to White (1977), Remote Sensing includes all methods of obtaining pictures or other forms of electromagnetic records of Earth's surface from a distance, and the treatment and processing of the picture data... Remote Sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. This radiation may have originated directly from separate components of the target area, it may be solar energy reflected from them; or it may be reflections of energy transmitted to the target area from the sensor itself.

American Society of Photogrammetry, defines Remote Sensing as imagery acquired with a sensor other than (or in addition to) a conventional camera through which a scene is recorded,

such as electronic scanning, using radiations outside the normal visual range of the film and camera- microwave, radar, thermal, infra-red, ultraviolet, as well as multispectral, special techniques are applied to process and interpret remote sensing imagery for the purpose of producing conventional maps, thematic maps, resource surveys, etc. in the fields of agriculture, archaeology, forestry, geography, geology and others.

According to the United Nations (95th Plenary meeting, 3rd December, 1986), Remote Sensing means sensing of earth's surface from space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and the protection of the environment.

According to Campbell (2007), Remote Sensing is the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface.

International Training Centre (ITC), Holland defined Geographic Information System (GIS) as a computerised system that facilitates the phases of data entry, data analysis and data presentation especially in cases when we are dealing with geo referenced data. Burrough (1986) defined GIS as a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose. Arnoff (1989) defined GIS as a computer based system that provides four sets of capabilities to handle geo referenced data, viz. data input, data management (data storage and retrieval), manipulation analysis and data output.

From the above definitions, it can be concluded that a GIS user expects support from the system to enter geo referenced data to analyse it in various ways and to produce output (maps

and other) from the data. GIS draws on concepts and ideas from many different disciplines, such as cartography, cognitive science, computer science, engineering, environmental sciences, geodesy, landscape architecture, law, photogrammetry, public policy, remote sensing, statistics and surveying.

Remote sensing and GIS are integral to each other. The development of Remote Sensing is of no use without the development of GIS and vice versa. Remote Sensing has the capability of providing large amount of data of the whole earth and also very frequently. GIS has the capabilities of analysing a large amount of data within no time. These voluminous data would have become useless without the development of GIS. Manual handling of one time remote sensing data would take years together, by the time a number of multi date data would have piled for analysis. Likewise capability of GIS would have no use without the development of Remote Sensing technology, which provides voluminous data.

2.6 MONITORING AND DETECTING INFORMAL SETTLEMENTS USING REMOTE SENSING AND GIS

From a methodological point of view, the challenge lies in having appropriate methods to detect and monitor the spatial behaviour of informal settlements reliably (Lemma, T. et al., 2005). Regarding available data sources, remotely sensed imagery from satellites therefore offers a well suited data source. To benefit from the advantages of this data source and to obtain the information as needed, adequate methods for analysing remote sensing data are necessary. In an ideal case, these methods can be applied without the need of expert knowledge and human interaction. In practise easiness of use and the degree of automation for information extraction from imagery depends on the data used and the phenomena to be extracted from the image. In this context, informal settlements show a relatively high inner-

structural heterogeneity which leads to particularly hard describable patterns in the image. This hampers the generation of an automated detection process which is easy to use.

High-resolution satellite imagery has become more readily available over the past few years. This category of satellite commonly includes IKONOS (1999), EROS (2000), QuickBird (2001), SPOT-5 (2002), ALOS (2006) and GeoEye-1 (2008). Urban geographers have recognized the potential of this information for various applications, including updating of maps, extraction of urban features such as road networks and other engineering and social infrastructure, generation of urban models, land-use mapping, and a wide range of other possible applications (Voipe and Rossi). Despite its potential application Herald et al. (2006), noted that remote sensing remained an underutilized data source in urban studies. The use of high-resolution remote-sensed satellite data in developing countries is sparser, although examples are available as discussed below;

Hofmann (2001) showed how informal settlements can be detected from other land-use-forms by describing typical characteristics – of colour, texture, shape and context using remote-sensed data from IKONOS in Cape Town. He showed that results are very dependent on the data used. In cases where the settlements were not appropriately classified, visual inspection was carried out or a final correction was performed by hand with eCognition. He concluded that while high resolution IKONOS data is well suited to detect informal settlements areas, using pure IKONOS image data was not sufficiently feasible to detect a single shack.

Hurskainen (2004) used black & white and true-colour aerial photography from 1985, 1993 and 2004 for studies of growth and change of informal settlements in Voi, Kenya. The images were processed in EnsoMosaic and Erdas software. Scale, shape and compactness parameters were adjusted and thematic layers were incorporated to improve the classification

accuracy. Results showed that iron sheet roofs were segmented and classified with 95% accuracy. Limitations encountered were related to misclassification, e.g grey tones for roofs were not spectrally distinct enough to separate them from the background. In such cases, visual inspection of the classification was done in Arcview and necessary corrections were made.

Stosolla et al. (2007) used SPOT-5 images with 2.5m spatial resolution to detect informal settlements (refugee camps) in Darfur Sudan. They developed a semi-automatic procedure adopting an unsupervised approach that allows detecting, with high precision, the boundaries and the extent of the settlements, both formal and informal, and, to some extent; were able to separate those two classes based on differing building densities. This was achieved by using variance measures and K-means algorithm. Once the position of the settlement had been detected, the next step in the procedure was to try and identify different building densities to discriminate the city core from the refugee camps. The inability to differentiate single buildings due to scale and resolution, and similar textural properties between certain vegetation classes and settlements leading to incorrect classification were cited as limitations.

Nobrega et al. (2007) explored the use of IKONOS images to detect and classify roads in informal settlements in Sao Paulo, Brazil. Rules were created to cater for unique land cover and land use. The methodology employed three software technologies, namely Erdas Imagine, eCognition and ArcGis. Misclassification problems involved confusion between large buildings and parking lots with streets. The problem was minimised by creating filtering rules based on geometric properties. The accuracy assessment for the resulting classification was 65%.

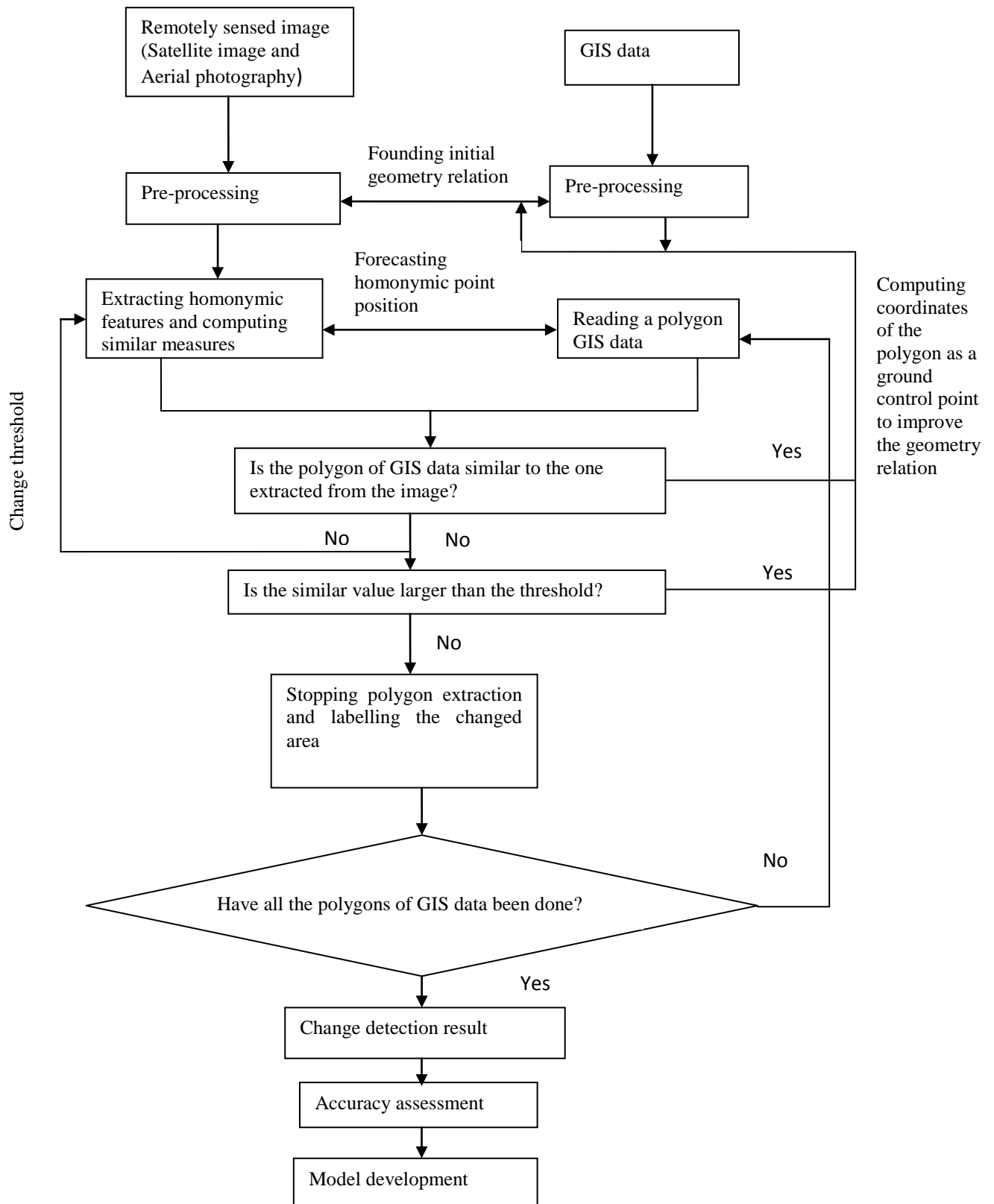
Busgeeth (2008) studied the potential of QuickBird images for monitoring informal settlements in Soweto area of South Africa. He manually extracted a list of human

settlements attributes that can be observed from QuickBird images. The study noted that applying existing typology from knowledge factory and statistics to classify human settlements in Soweto was not possible. Reasons for this were because the typology of Statistics South Africa is limited whilst the typology of Knowledge Factory contains a socio-economic data dimension that cannot be assessed by merely interpreting the images. The study proposed an urban settlement typology to facilitate the effective classification of informal settlements in South Africa. The proposed settlement typology integrated three elements of settlements that are of particular importance, namely; the physical features, the intrinsic features, and the contextual features. It provides a tool for the visual, systematic and representative analysis of South African settlements from remote sensing images.

This study used a combination of Hurskainen's and Nobrega's approaches. Black and white aerial photographs for the year 1980 were used to create the baseline map for the study. Aerial photography gives better resolution as opposed to Landsat images- satellite imagery available for that period. QuickBird images for 2000 and 2010 were used. GIS software Erdas Imagine was used in image analysis as well as model development.

2.7 CONCEPTUAL FRAMEWORK/THEORETICAL MODEL

Figure 2: An iteratively holistic method based on remote sensing imagery and GIS data



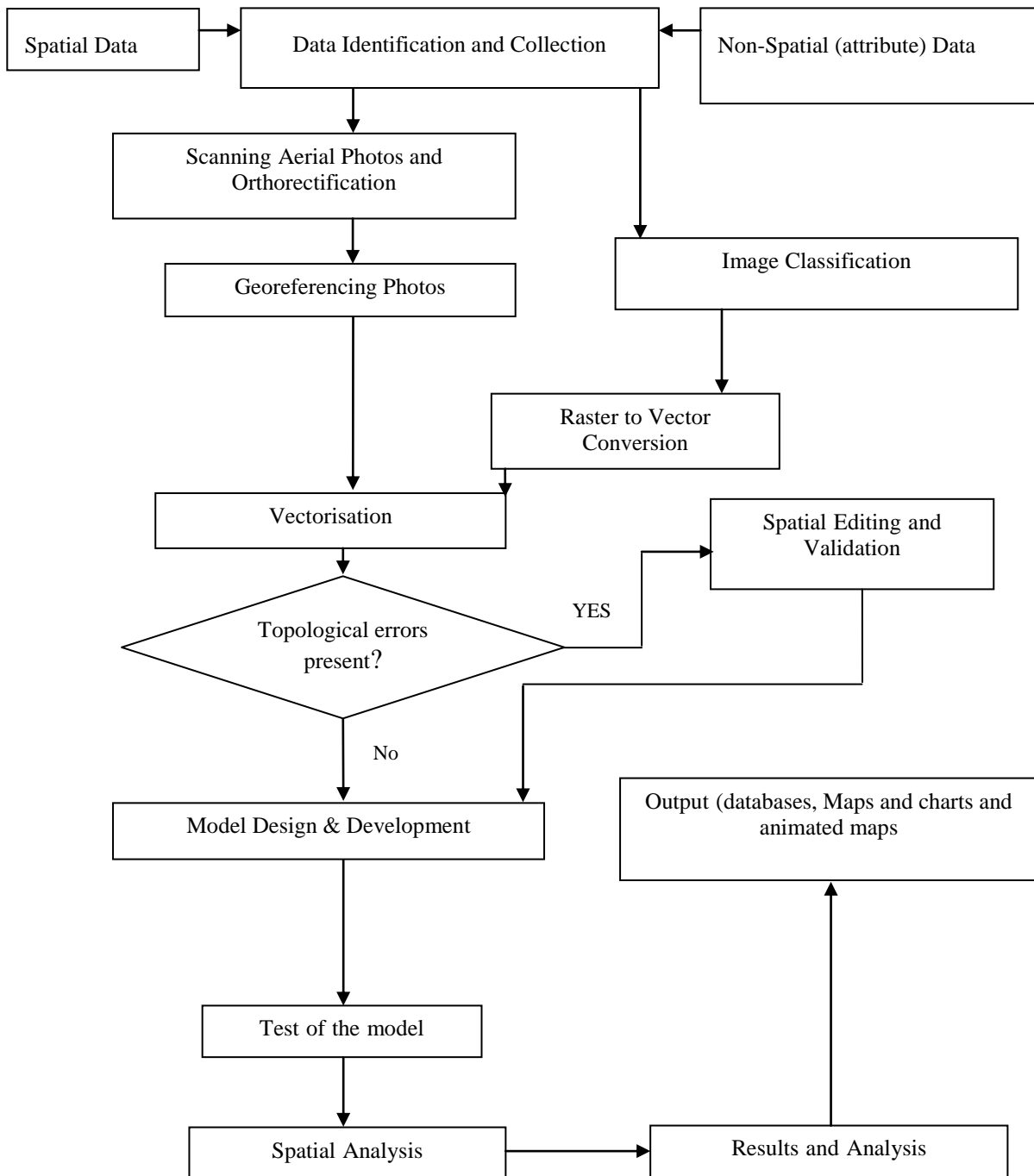
SOURCE: Zhang et al. (2006)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 OVERVIEW OF METHODOLOGY

Figure 3: Overview of the Methodology



SOURCE: Author (2013)

3.2 DATA COLLECTION AND PREPARATION

The data collected was mainly secondary data. Since the project was aimed at creation of a model to predict changes at Kawangware area, satellite imagery was needed was collected. Data on buildings was also obtained from the satellite image.

From the users' requirements and in view of the general scope of the conceptual model, the following data was identified as being necessary.

Aerial Photographs (Scale 1:12,500)

This is the spatial data and it contains the ground information and the spatial location of developments in 1990.



QuickBird Images (Spatial resolution 60 cm)

This spatial data gives information on the location and distribution of roads, buildings and other structures at different scales within Kawangware area.



List of Population Data

Table 1 below indicates the total population in Kawangware area from 1990 to 2010. This data was included in the model to predict the population in the year 2020 and 2030.

Table 1: Population data of study area

S/No	Year	Population
1	1990	80,650
2	2000	86,329
3	2010	91,379

Source: The Survey of Kenya and Regional Centre for Mapping and Resources Development (RCMRD).

3.2.1 Scanning and Orthorectification of Aerial Photographs

The scanning of the aerial photograph was done at 600 DPI resolution. Orthorectification of 1990 aerial photograph was done using GPS points as reference Ground Control Points (GCPs). This was done in the following steps using ERDAS Imagine software: Creating Orthorectified Images, Importing Reference Points, Examining a Camera Calibration Information, Measuring Fiducial Marks as shown below, and Setting Projection and Saving the Model

Once the points are measured, the GCP Tool was used to solve the polynomial transformation and generate an estimate of the associated error. This is called Root Mean Square Error (RMSE). Control Point Error is the same as RMSE. RMSE is calculated by using the transformation matrix. Measured points are transformed into the new coordinate system, and then retransformed into the original system. The difference between the original and the retransformed is the root error in measurement.

Ideally, the Total RMSE should be less than 1.0 pixel. If the RMSE is too high, the GCP was redigitized by first selecting it. Redigitizing of those GCPs with the highest value in the RMS Error column was done.

While editing GCPs, it is important to remember that the RMS error provides only a guideline as to which points may be contributing to overall inaccuracy. If you can visually

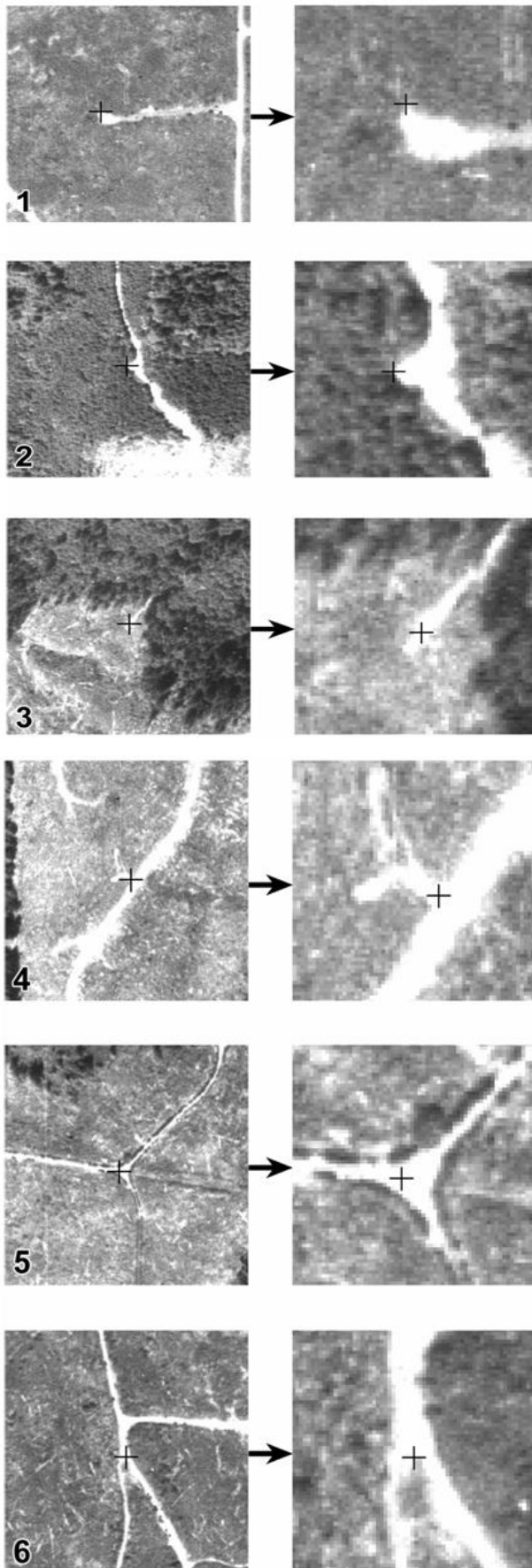
see that a point has an accurate correspondence in both Viewers, then this is more important than the RMS Error. The figure below shows 6 GCP's used for orthorectification process.

Figure 4: Part of Aerial Photograph Showing the GCP's

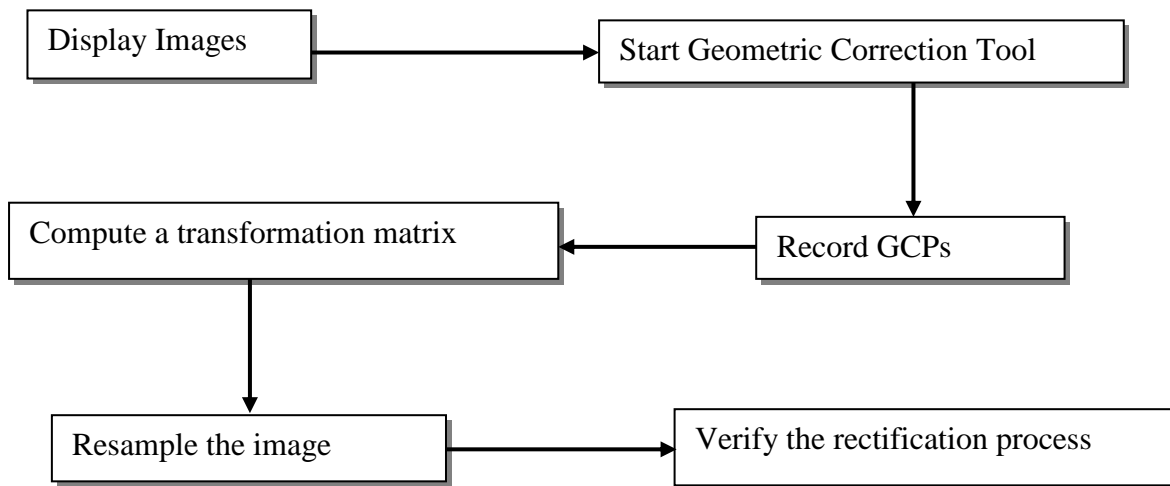


SOURCE: Author (2013)

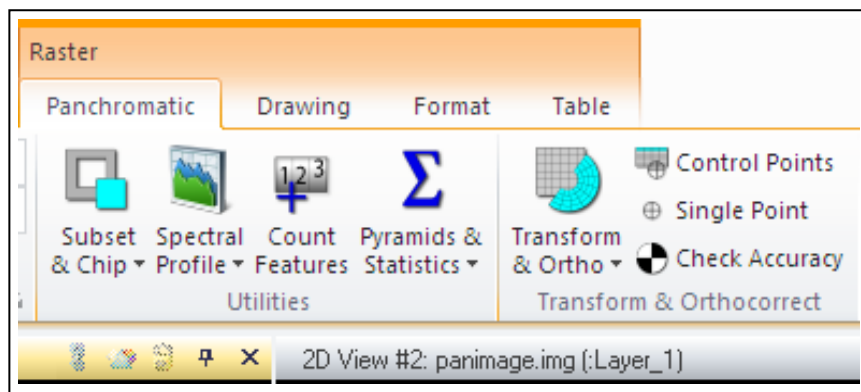
The six GCP's that were identified on the photos were used to perform the Orthorectification of the photo. Orthorectification was important because during photography, some features that were further away from the principal point appear to be displaced therefore these features were brought back to their correct positions during orthorectification.



In rectifying the QuickBird images, the basic steps shown in the chart below were used.

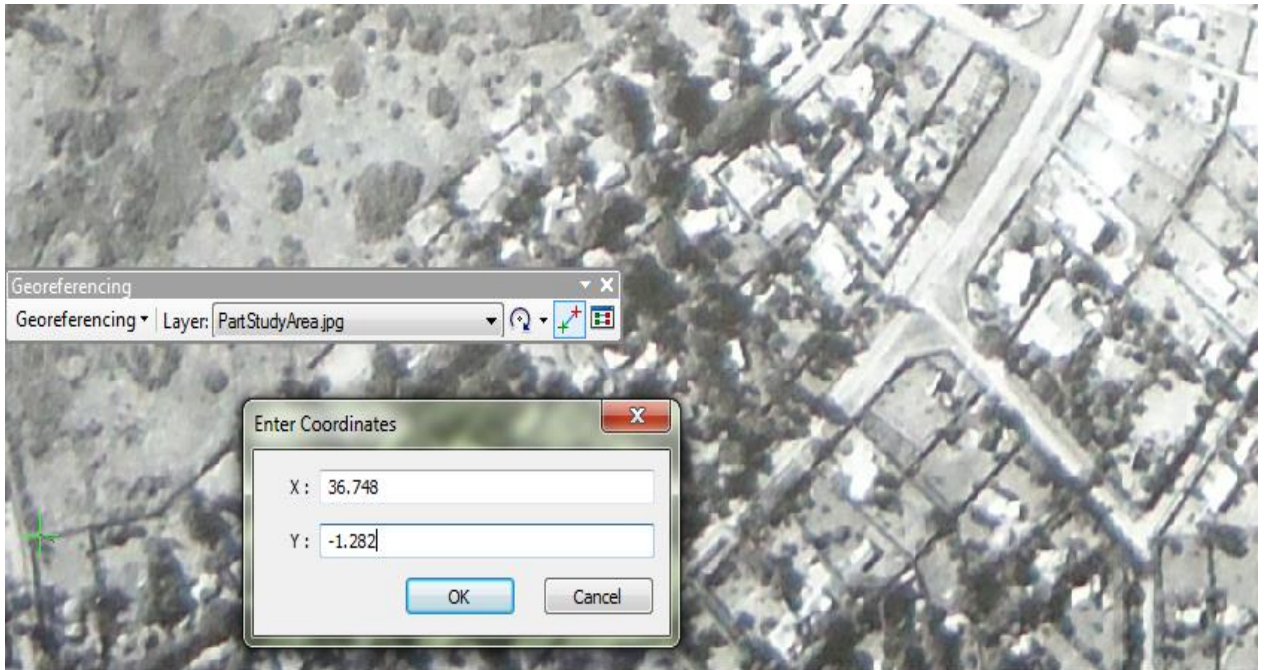


In ERDAS Imagine, the following graphic shows the tools that were used in the above processes.



3.3 GEO-REFERENCING OF AERIAL PHOTOGRAPHS

This is the process of projecting the data onto a plane and making it conform to a map projection system whereas assigning map coordinates to the image data. This process was done using four ground control points that were identified on the photograph. Geographic Coordinate System was adopted since satellite imagery had this coordinate system and therefore making the modeling quite easy within a unified coordinate system.



3.4 *SATELLITE IMAGERY PROCESSING*

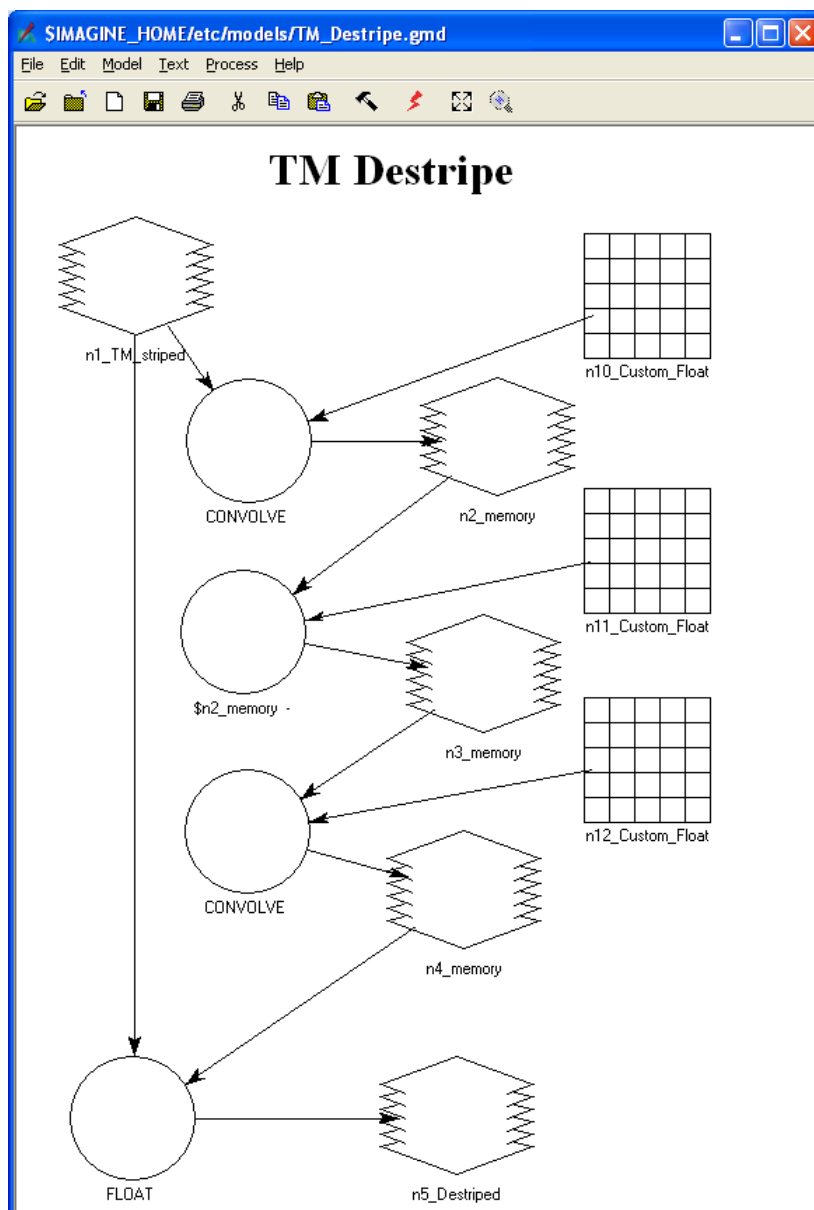
The use of digital satellite image data for a spatial database requires several pre-processing procedures. These procedures include, but are not limited to: radiometric correction, geometric correction, terrain correction, image enhancement, and feature selection. The goal of digital image pre-processing is to increase both the accuracy and the interpretability of the digital data during the image processing phase. Pre-processing of satellite images is necessary prior to image classification and change detection.

The satellite images that were collected underwent various processing prior to classification, digitizing and modeling. This was done to minimize errors and improve the quality of output products.

Colour Balancing: This is the process of ensuring that the satellite images have a uniform distribution of continuous colour values or digital numbers of the pixels. This was done using ERDAS Imagine software. Several band enhancements and corrections are applied to the rectified imagery to normalize the DN (digital number) values, facilitating direct spectral comparisons between imagery bands and a comparable set of values as input to indices and clustering programs.

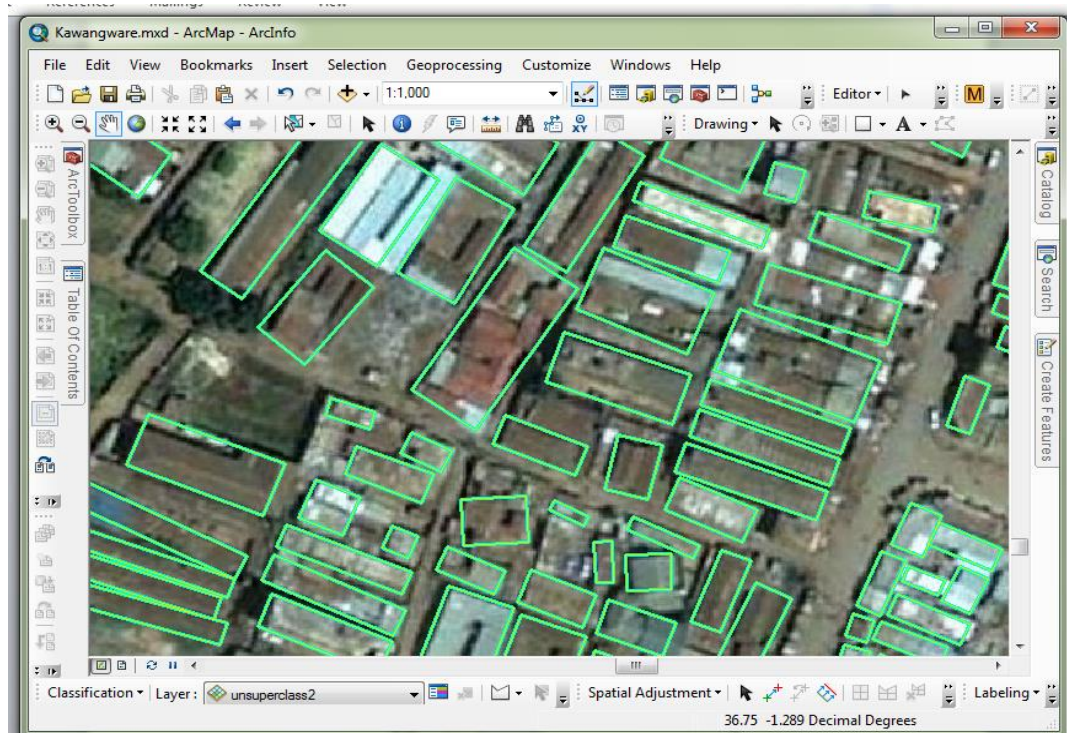
Contrast Enhancement: The aim of image enhancement is to make an image better interpretable for a particular application. Image enhancement improves the clarity of images for human viewing by removing blurring and noise, increasing contrast, and revealing details.

De-stripe: Striping or banding occurs if a detector goes out of adjustment - that is, it provides readings consistently greater than or less than the other detectors for the same band over the same ground cover. De-striping brings some amount of smoothing effect on the images. ERDAS is equipped with various algorithms for de-striping such images. De-striping was done on the satellite images prior to classification.



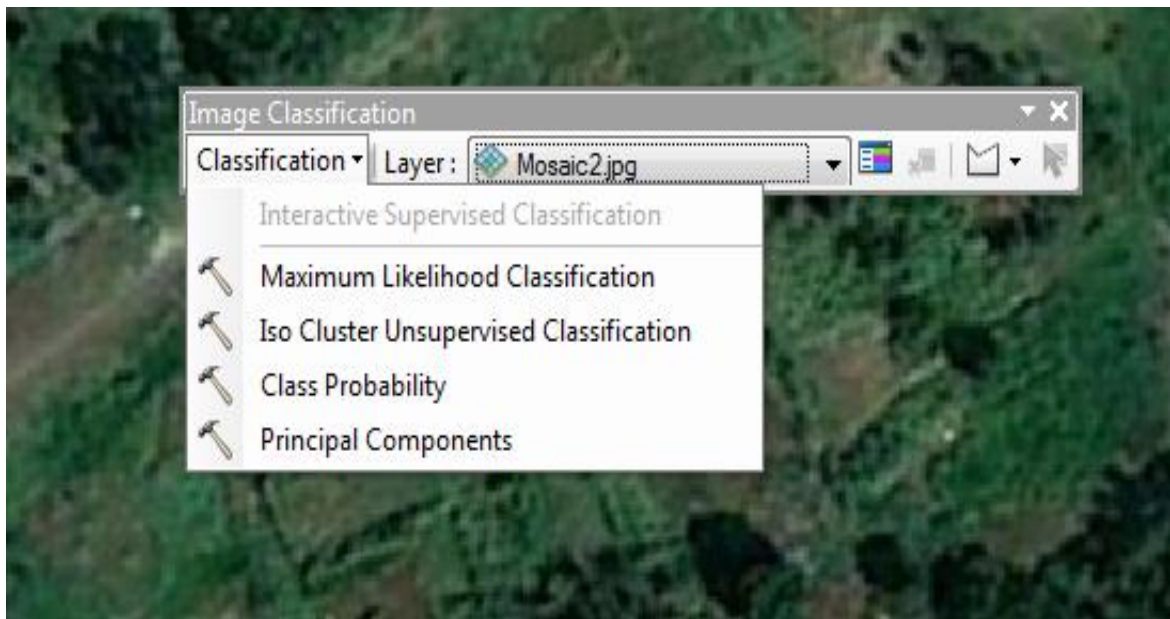
Line Noise Removal: Line dropout occurs when a detector either completely fails to function or becomes temporarily saturated during a scan (like the effect of a camera flash on a human retina). The result is a line or partial line of data with higher data file values, creating a horizontal streak until the detector(s) recovers, if it recovers. Line dropout is usually corrected by replacing the bad line with a line of estimated data file values. The estimated line is based on the lines above and below it. This was done using ERDAS Imagine prior to image classification.

3.5 ***DIGITIZATION OF FEATURES (BUILDINGS, ROADS ETC)***

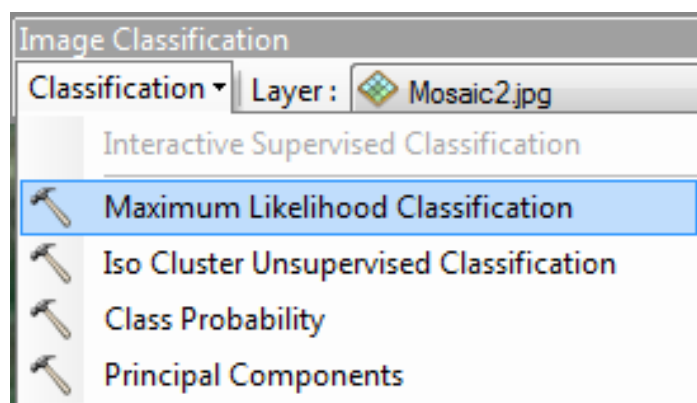


3.6 ***SUPERVISED CLASSIFICATION***

In supervised classification, spectral signatures were developed from specified locations in the image. These specified locations were given the generic name 'training sites' and were defined by the user. Generally a vector layer was digitized over the raster scene. The vector layer consists of various polygons overlaying different land use types.



Supervised classification was much more accurate for mapping classes, but depended heavily on the cognition and skills of the image specialist. The strategy was simple: the specialist recognized conventional classes (real and familiar) or meaningful (but somewhat artificial) classes in a scene from prior knowledge, such as personal experience with what's present in the scene, or more generally, the region it's located in, by experience with thematic maps, or by on-site visits. This familiarity allows the individual(s) making the classification to choose and set up discrete classes (thus supervising the selection) and then, assign them category names. As a rule, the classifying person also locates specific training sites on the image - either a print or a monitor display - to identify the classes.



The resulting Training sites were areas representing each known land cover category that appeared fairly homogeneous on the image (as determined by similarity in tone or color within shapes delineating the category). In the computer display these sites were located and circumscribed with polygonal boundaries drawn using the computer mouse. For each class thus outlined, mean values and variances of the Digital Numbers (DNs) for each band used to classify them are calculated from all the pixels enclosed in each site. More than one polygon is usually drawn for any class. The classification program then acts to cluster the data representing each class. When the DN's for a class are plotted as a function of the band sequence (increasing with wavelength), the result is a spectral signature or spectral response curve for that class.

The multiple spectral signatures so obtained are for all of the materials within the site that interact with the incoming radiation. Classification now proceeds by statistical processing in which every pixel is compared with the various signatures and assigned to the class whose signature (usually as a data set within the computer rather than a plot) comes closest. A few pixels in a scene do not match and remain unclassified, because these may belong to a class not recognized or defined.

Figure 5: Signature Collection on a Satellite Image

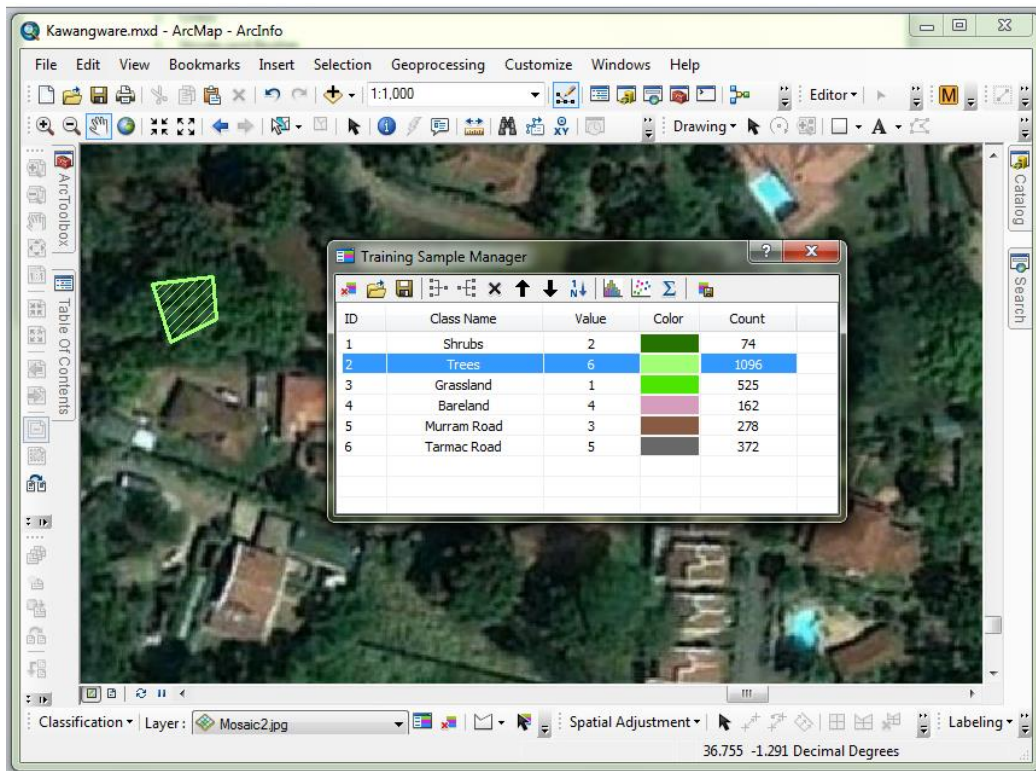
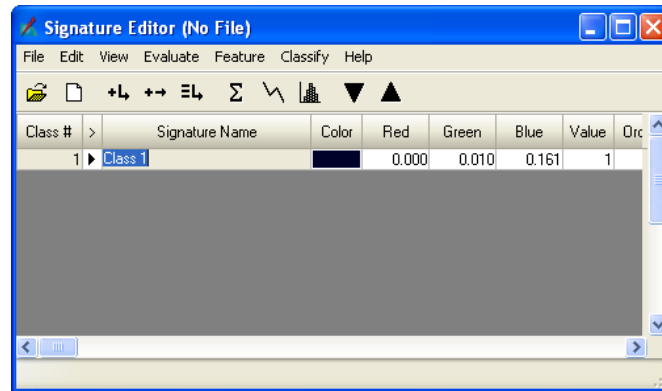
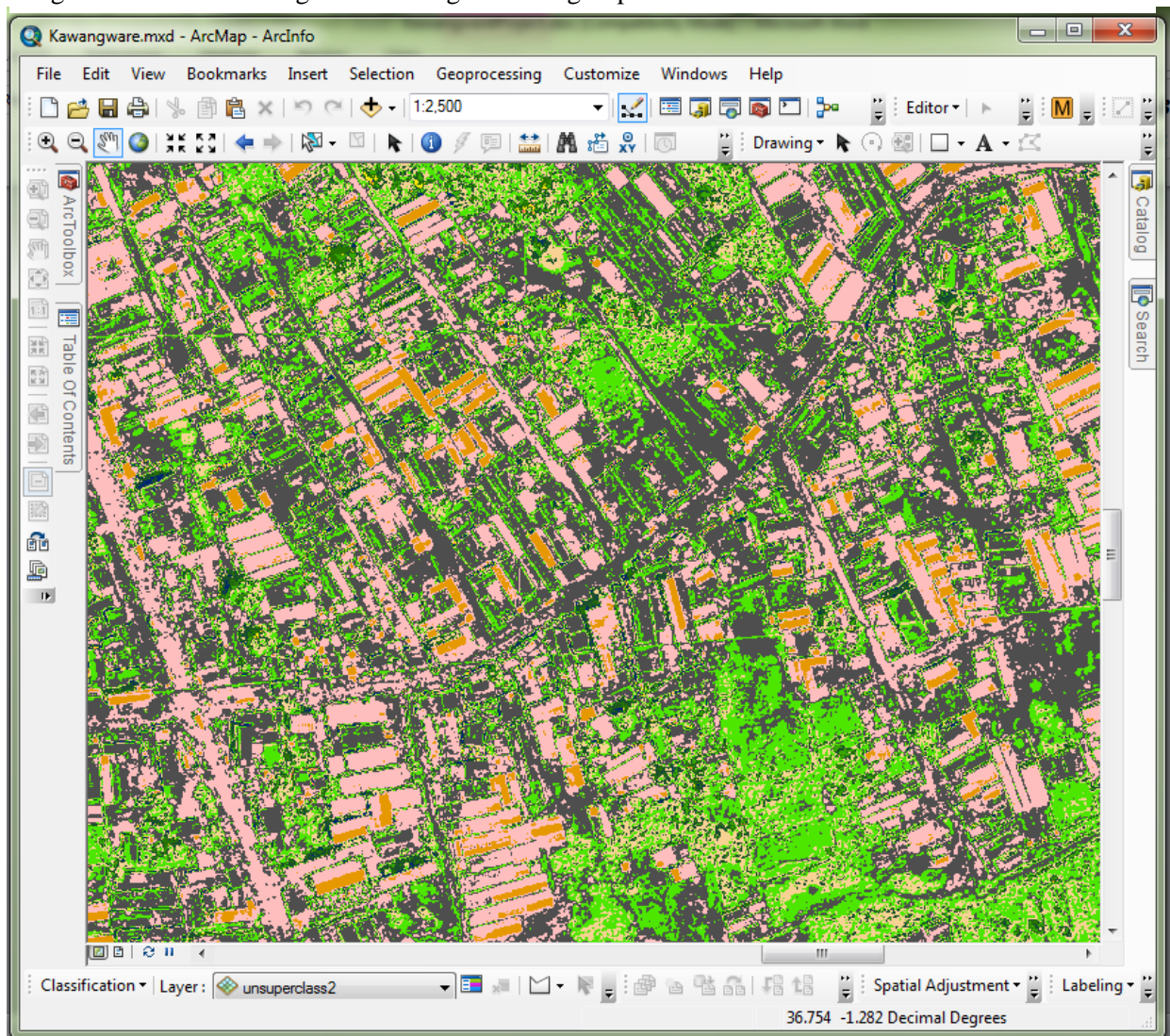


Figure 6: Adding Signatures to Signature Editor



Source: Author (2013)

Figure 7: Classified Image for Kawangware using Supervised Classification Method

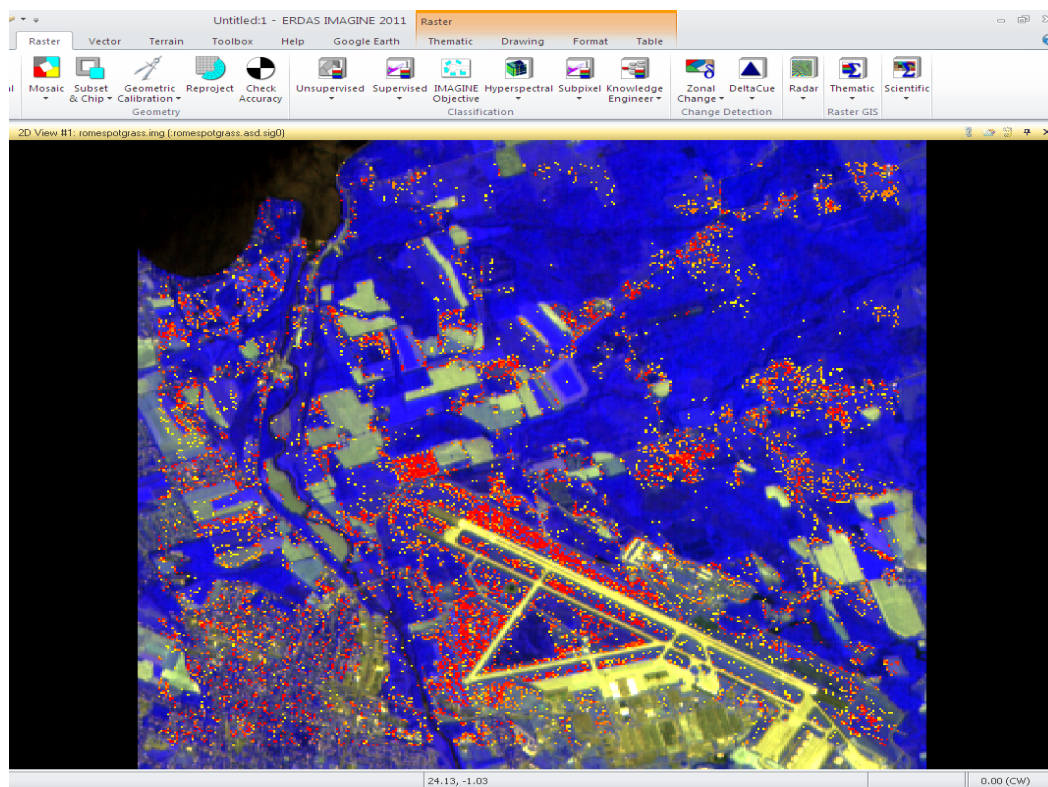


Source: Author (2013)

3.7 SUB PIXEL CLASSIFICATION

The main problem and limitation of traditional hard (pixel based) image classification procedures is in the classification of mixed pixels. Mixed pixel classification is a process which tries to extract the proportions of the pure components of each mixed pixel. To resolve the mixed pixel problem, there are different approaches. There are two different mixture models for mixed pixel classification: the nonlinear mixing and the linear mixture model. IMAGINE Subpixel Classifier is an advanced image exploitation tool designed to detect materials that are smaller than an image pixel, using multispectral imagery. It was also useful for detecting materials that cover larger areas but are mixed with other materials that complicate accurate classification. It addresses the “mixed pixel problem” by successfully identifying a specific material when materials other than the one you are looking for are combined in a pixel. It allows you to develop spectral signatures that are scene-to-scene transferable. For example roads pixels resembled buildings pixels in some parts of the image. To refine the results to remove the mixed pixel problem, sub pixel classification process was employed. Below figure shows the result of this method of classification.

Figure 8: Classified Image for Kawangware using Sub Pixel Classification



Source: Author (2013)

Results Compared to Traditional Classifier Results

For a given training set, IMAGINE Subpixel Classifier will often classified different pixels than a traditional classifier such as a maximum likelihood classifier.

When developing a signature, IMAGINE Subpixel Classifier excluded sub-pixel components of the training pixels that are not common.

IMAGINE Sub-pixel Classifier's classification of sub-pixel residuals was based upon differences between band to band relationships as well as upon spectral intensity.

Using the grass-field training set in this exercise with traditional supervised classification techniques produced a spectral signature that contained more diverse spectral variation than the IMAGINE Subpixel Classifier signature.

IMAGINE Subpixel Classifier, classified only those pixels that contained more specific type of grass that is common to the training set pixels.

Table 2: Table showing features that were captured during SubSubpixel classification

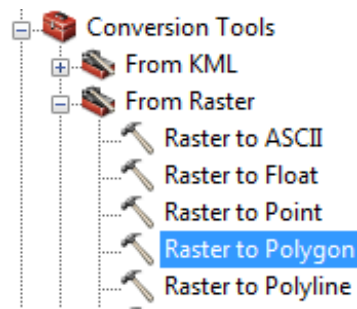
Row	Histogram	Color	Red	Green	Blue	
0	0		0	0	0	Unclassified
1	39274		0	0	1	Water
2	34572		0	0.392157	0	Forest
3	45097		0.498039	1	0	Scattered Trees/ Shrubs
4	79798		0.498039	1	0.831373	Developed Area/ Rock
5	143868		0	1	0	Grasslands
6	147349		0.627451	0.321569	0.176471	Farmlands/ Bare Soils
7	163305		0.647059	0.164706	0.164706	Farmlands
8	106427		0.752941	0.752941	0.752941	Bare Ground
9	34574		0.823529	0.705882	0.54902	Sand/ Bare Ground
10	2744		1	0.647059	0	Water/ Silt Deposits

Source: Author (2013)

3.8 RASTER TO VECTOR CONVERSION

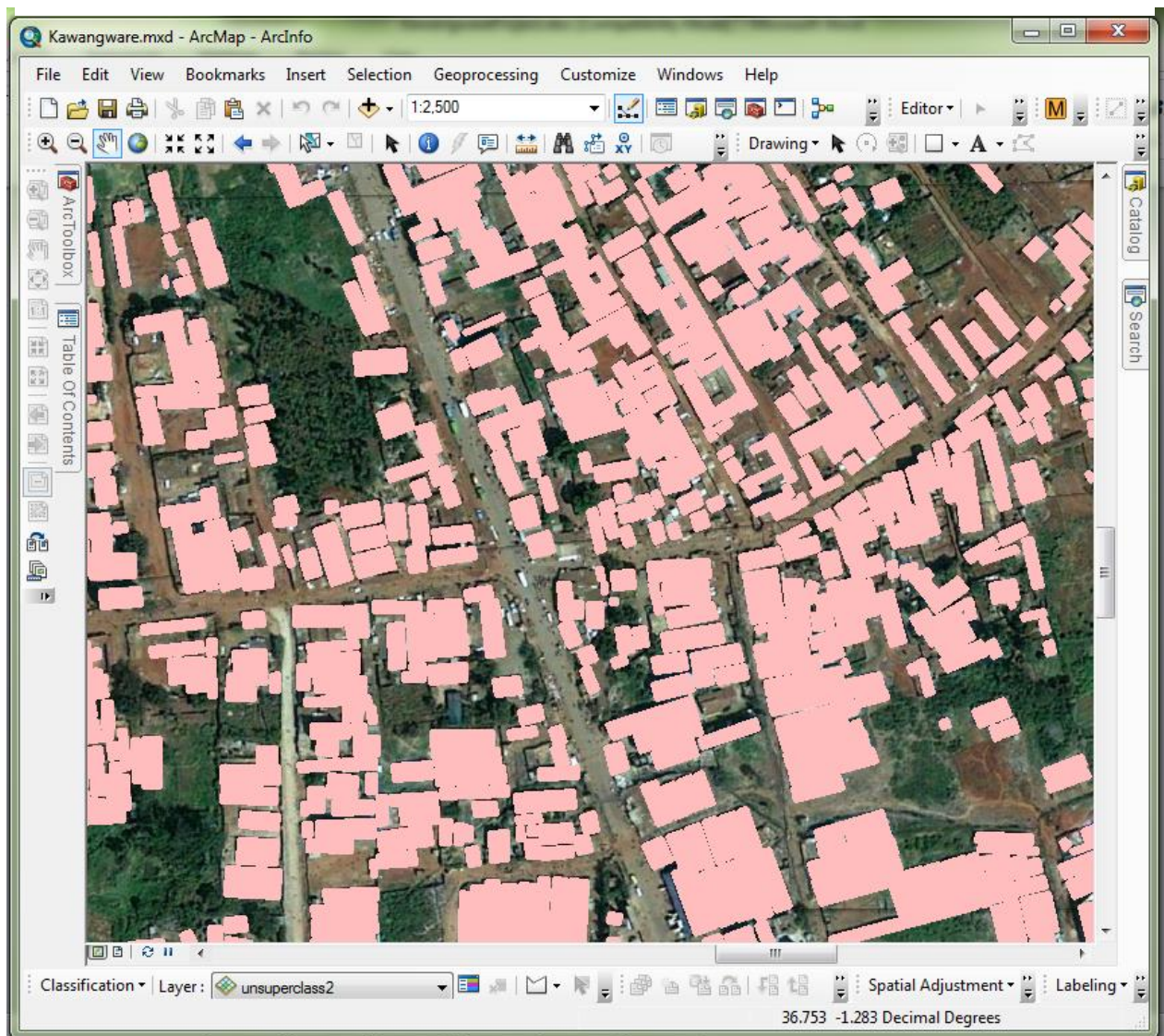
Once the features were classified, the resulting output was in raster format. It was therefore imperative to convert the raster layers to vector layers which were then used in GIS environment for model creation.

This process of raster-to-vector conversion was done in ArcGIS environment using ArcToolbox as shown in the diagram below.



The result of the output vector layers that were obtained are as shown in the figure below.

Figure 8: Vectorized layer of Buildings

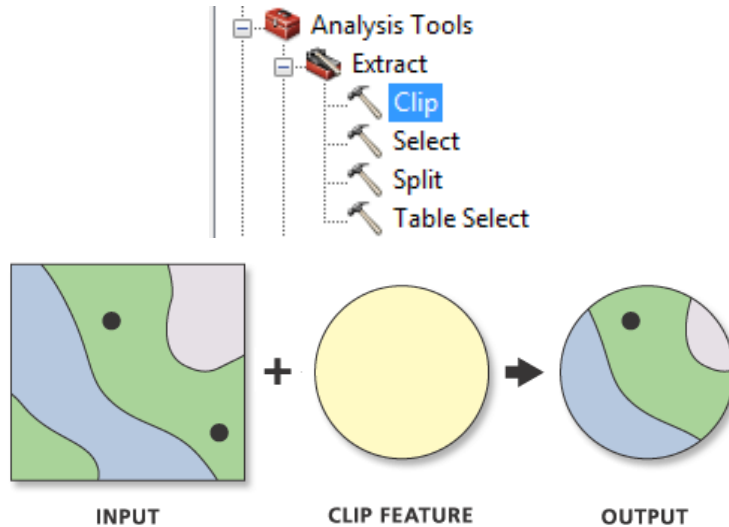


Source: Author (2013)

3.9 FEATURE CLIPPING

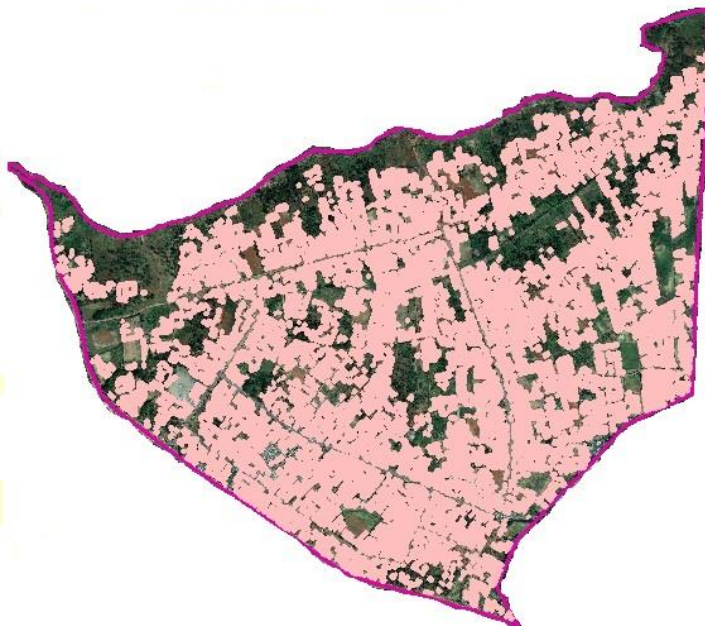
Clipping extracts input features that overlay the clip features. Clipping tool cut out a piece of one feature class using one or more of the features in another feature class as a "cookie cutter". This was particularly useful for creating a new feature class – also referred to as study area or area of interest (AOI) – that contains a geographic subset of the features in another, larger feature class.

Figure 9: Clipping of Features in the Study Area



In the above figure, input represents the entire rectangular area covered by the satellite images. Clip feature is Kawangware area as outlined by its boundary (extent as depicted by its shapefile). Feature clipping was done after raster-to-vector conversion so as to reduce the area of coverage and minimize the time taken for model building.

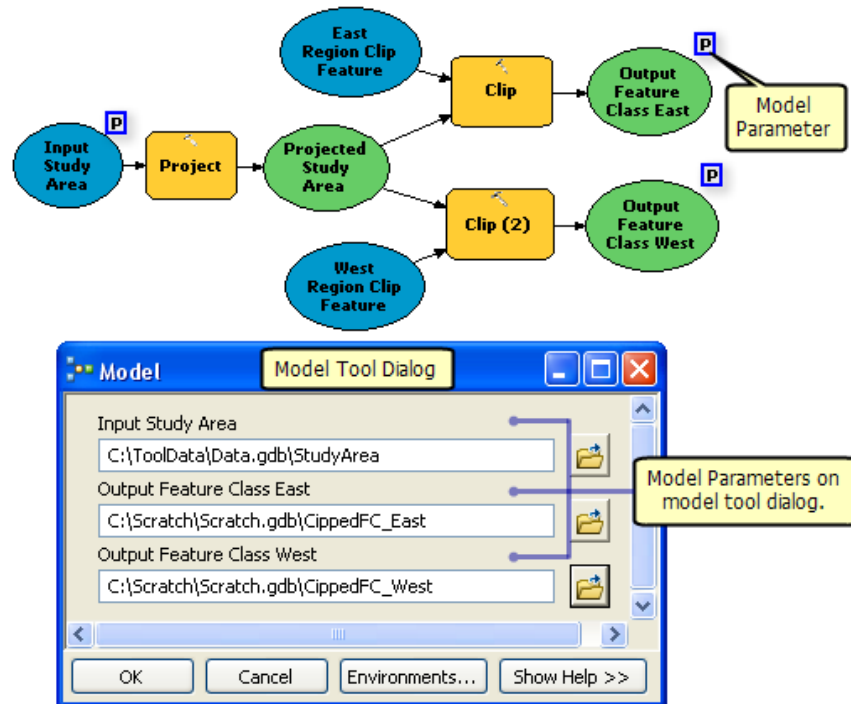
Figure 10: Figure Showing Clipped



3.10 MODEL DESIGN, CREATION AND TESTING

Any model variable can be made into a model parameter. When a variable is made into a model parameter, its value can be specified in the model tool dialog box.

Figure 11: Figure Showing Example of creating a GIS Model



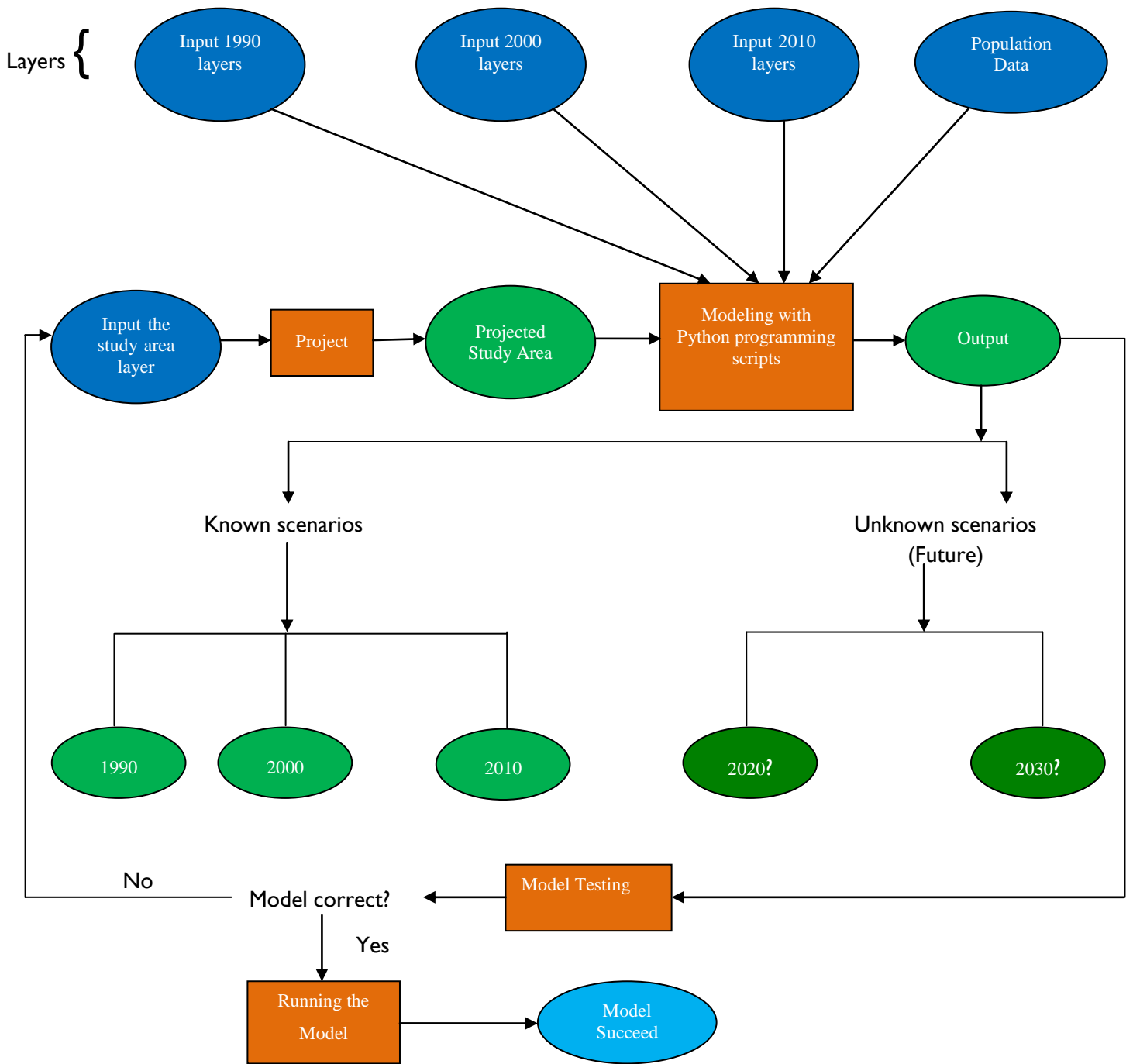
Before the model was created, all parameters were put together and further analyzed. The parameters for 1990, 2000 and 2010 years include the following:

- ❖ Buildings Layer;
- ❖ Vegetated area layer;
- ❖ Roads network layer ;
- ❖ Population Data;
- ❖ Bareland Layer;

When a model variable was exposed as a parameter, the variable names become the parameter label on the model tool dialog box. If building generic or general use tools with ModelBuilder (tools that will be used by different users with different data), make sure model variable names are clear and easy to understand so the tool dialog parameter labels are also

clear and easy to understand. The flowchart below shows how the model was created, tested and finally run.

Figure 12: GIS Model Creation Process



SOURCE: Author (2013)

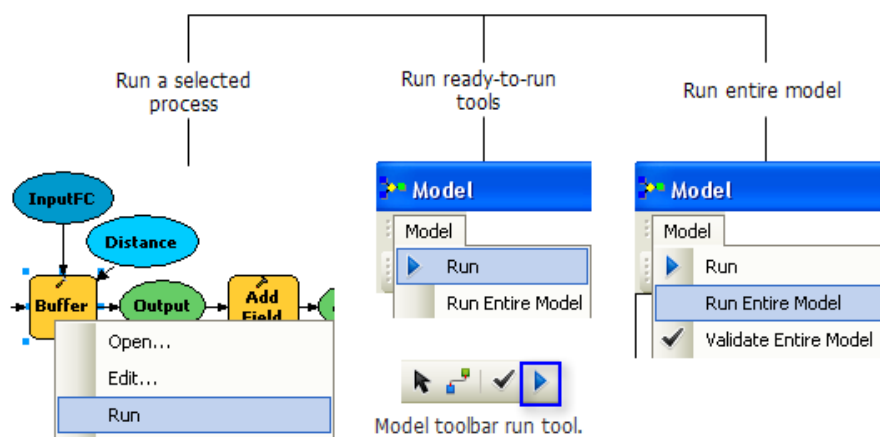
3.11 RUNNING A MODEL FROM WITHIN ModelBuilder

Running a model from within ModelBuilder means to open the model for editing and run it from the ModelBuilder interface. There are three ways to run a model from within ModelBuilder:

Run Single tool—Select one tool, right-click, and then click Run. Earlier processes in the chain also run if needed. Later processes in the chain do not run; however, if they are in the has-been-run process state, their state changes back to ready-to-run.

Run Ready-to-run tools—Click Run from the Model menu or the run tool on ModelBuilder toolbar.

Run entire model—Click Run Entire Model from the Model menu. This runs all tools that are in a ready-to-run state.



When a model is run, all model variables are validated, and those tools in a ready-to run state are executed. If any output variables should be added to display, the outputs are added to the ArcMap table of contents. Tools that are not in a ready-to-run state or are dependent on a tool that is not ready-to-run do not execute. There are some key differences when running a model from within ModelBuilder and running a model from its tool dialog box. When a model is run within ModelBuilder, the following apply:

- ❖ Intermediate data is preserved between model runs. This data is also preserved if the model is saved, closed, and reopened for editing. When a model is run from the tool dialog box, Intermediate data is deleted.
- ❖ All the outputs with a check mark next to Add to Display are added to the display.
- ❖ Progress will be shown in the geoprocessing progress dialog box, as the process is executing in the foreground. Models run within ModelBuilder never execute as a background process. Models executed from the tool dialog box can be run in the background.
- ❖ A result is not written to the Results window.

3.12 MODELLING PYTHON PROGRAMMING SCRIPTS

The following are some of Python scripts were used in creation of the model.

Building Layer Script

```
import arcpy
arcpy.env.workspace = "C:\Student\PYTH\Database\Kawangware.gdb"

arcpy.MakeFeatureLayer_management("Buldings1990", "Buildings2000", "Buildings2010 > 0 AND
                                Estab > 2010")

featCount = arcpy.GetCount_management("Buildings2020", "Buildings2030")
print "Number of features in the Feature Layer is: " + str(featCount) and

display ("Buildings2020.shp", "Buildings2030.shp")

arcpy.CopyFeatures_management("DisplayLayer")

if os.path.exists(finalshp_filename):
    os.remove(finalshp_filename)
```

Vegetated Area Layer Script

```
import arcpy
arcpy.env.workspace = "C:\Student\PYTH\Database\Kawangware.gdb"

arcpy.MakeFeatureLayer_management("Vegetation1990", "Vegetation2000", "Vegetation2010 > 0 AND
                                Estab > 2010")

featCount = arcpy.GetCount_management("Vegetation2020", "Vegetation2030")
print "Number of features in the Feature Layer is: " + str(featCount) and

display ("Vegetation2020.shp", "Vegetation2030.shp")

arcpy.CopyFeatures_management("DisplayLayer")
```

```
if os.path.exists(finalshp_filename):
    os.remove(finalshp_filename)
```

Roads Layer Script

```
import arcpy
arcpy.env.workspace = "C:\Student\PYTH\Database\Kawangware.gdb"

arcpy.MakeFeatureLayer_management("Roads1990", "Roads2000", "Roads2010 > 0 AND Estab >
2010")

featCount = arcpy.GetCount_management("Roads2020", "Roads2030")
print "Number of features in the Feature Layer is: " + str(featCount) and

display ("Roads2020.shp", "Roads2030.shp")

arcpy.CopyFeatures_management("DisplayLayer")

if os.path.exists(finalshp_filename):
    os.remove(finalshp_filename)
```

Bareland Layer Script

```
import arcpy
arcpy.env.workspace = "C:\Student\PYTH\Database\Kawangware.gdb"

arcpy.MakeFeatureLayer_management("Bareland1990", "Bareland2000", "Bareland2010 > 0 AND
Estab > 2010")

featCount = arcpy.GetCount_management("Bareland2020", "Bareland2030")
print "Number of features in the Feature Layer is: " + str(featCount) and

display ("Bareland2020.shp", "Bareland2030.shp")

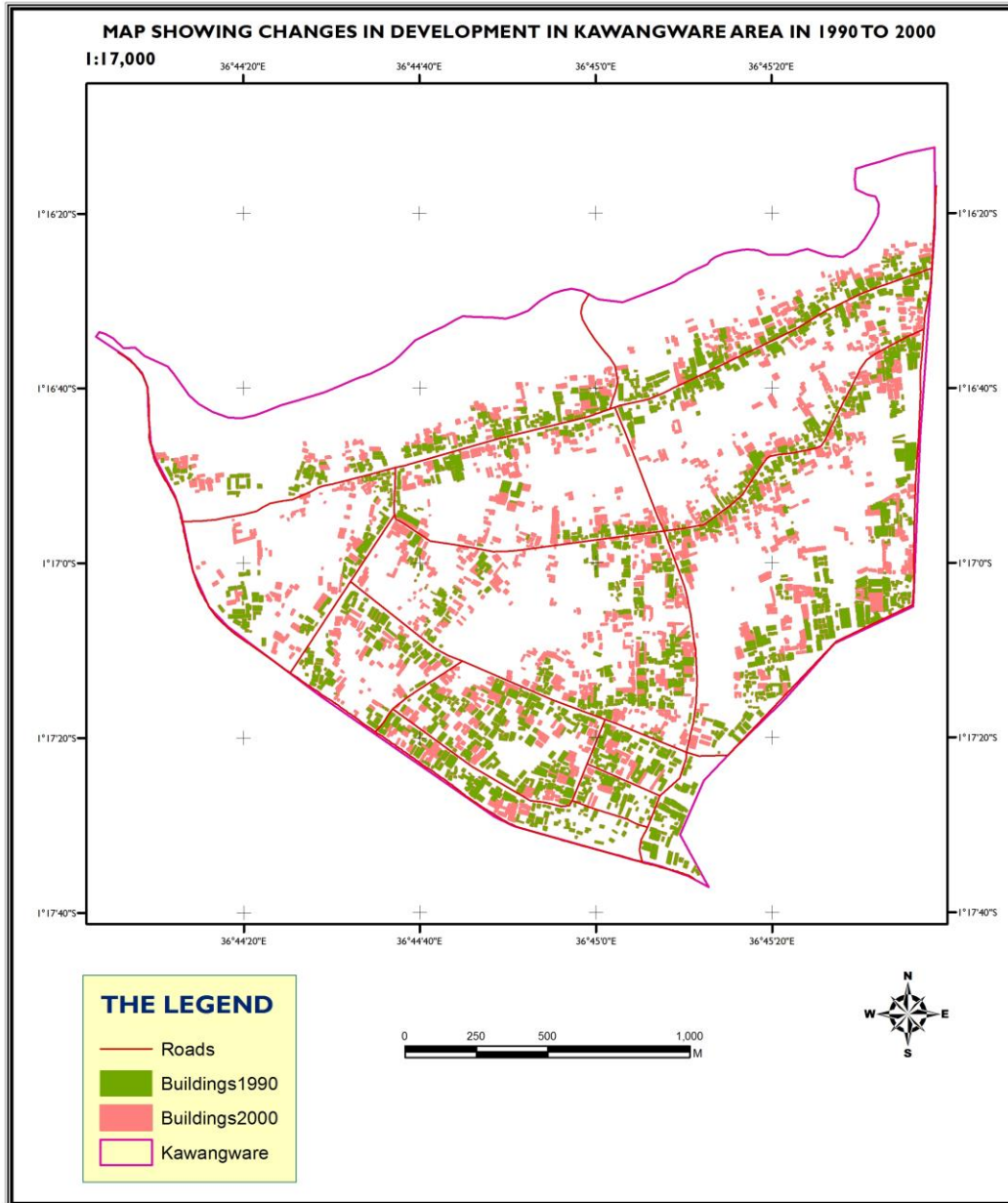
arcpy.CopyFeatures_management("DisplayLayer")

if os.path.exists(finalshp_filename):
    os.remove(finalshp_filename)
```

CHAPTER FOUR

DATA ANALYSIS AND PRESENTATION

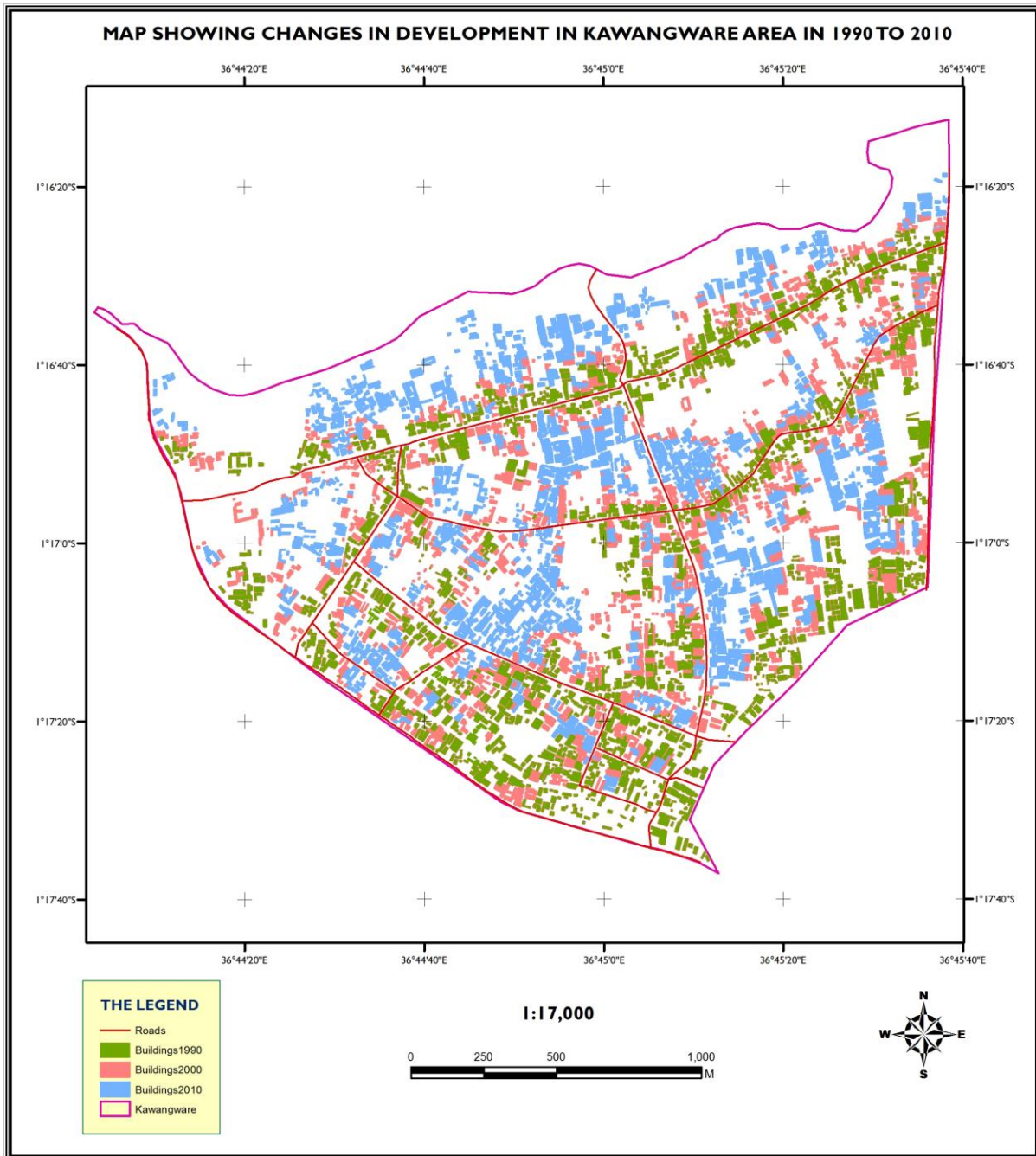
Figure 13: Changes in the Built Development in the years 1990 to 2000



Source: Author (2013)

Area covered by buildings in 1990 (green colour) was 890,000sq.m. In 2000 (pink colour) this area had increased to 945,345 sq.m. The buildings are concentrated along the roads an indication that infrastructure played a critical role in shaping the built environment in the study area during this period.

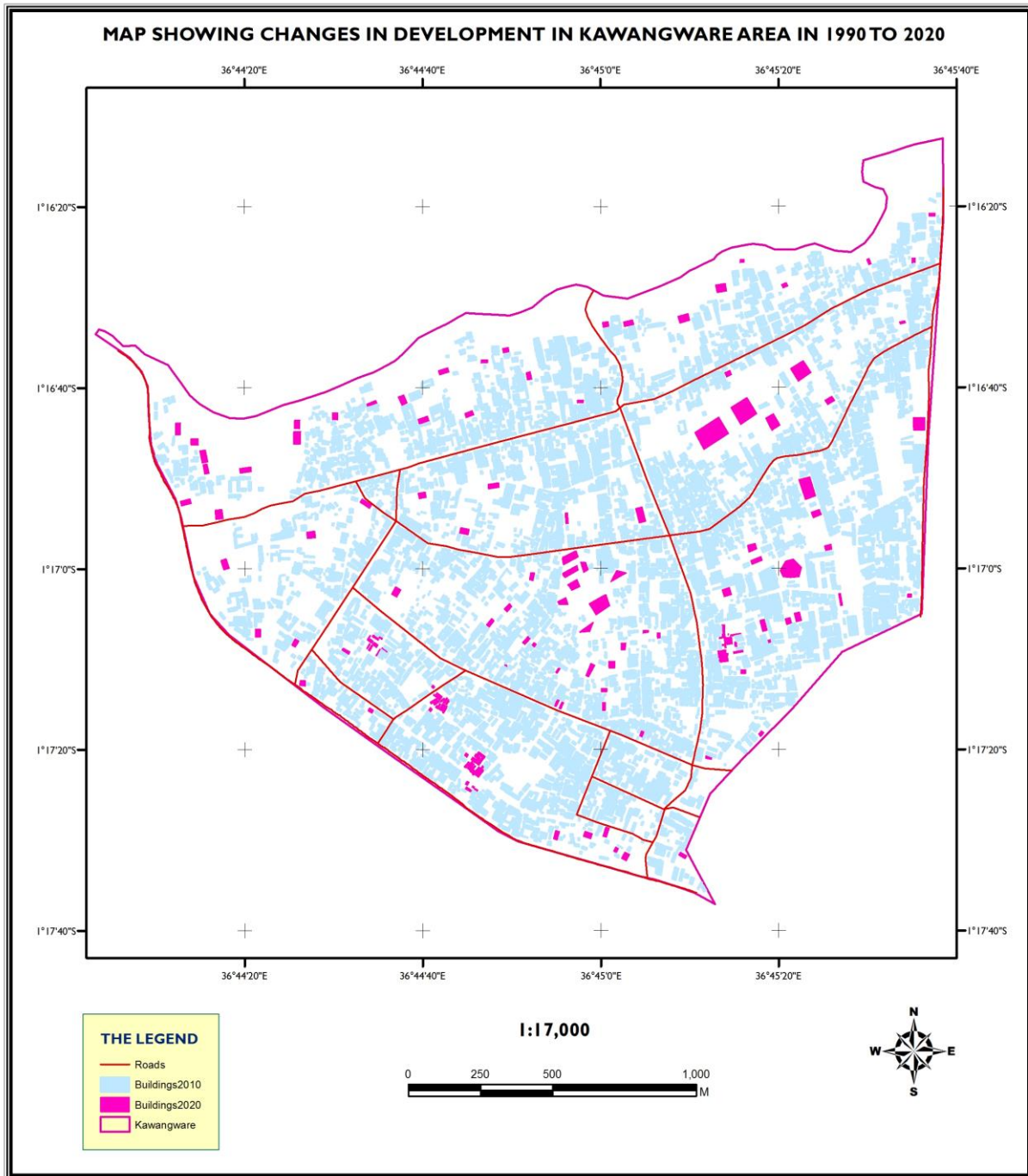
Figure 14: Changes in Built Development in Kawangware from the year 1990 to 2010



Source: Author (2013)

In 1990 buildings covered 890,000sq.m, this is represented in green colour in figure 16 above. In 2000 (pink colour) this area had increased to 945,345 sq.m. In 2010, this area was at 1,458,906 sq.m.

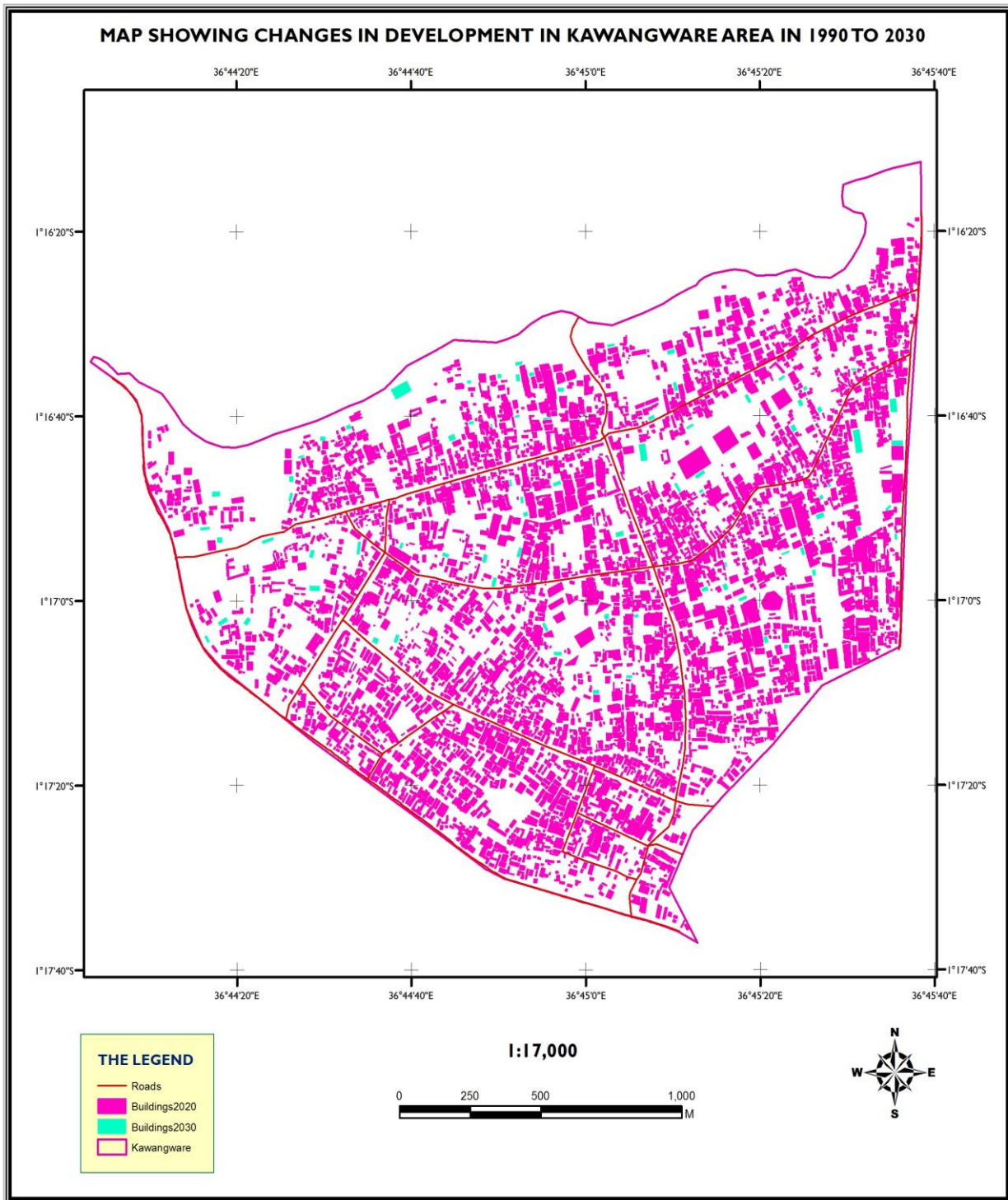
Figure 15: Changes in Built Development in the years 1990 to 2020



Source: Author (2013)

In 2010, the area covered by buildings was at 1,458,906 sq.m, depicted by blue colour in figure 17 above. This area – with all factors held at constant- will increase to 1,695,623sq.m in 2020.

Figure 16: Changes in Built Development in the years 1990 to 2030 – Buildings



Source: Author (2013)

The model predicted that in 2030 the area that will be covered by the built environment in Kawangware will be 1,712,814sq.m.

Error Propagation Analysis

The errors that were encountered during the study include: coordinate transformation errors, scanning and tracing errors, digitizing errors, topological errors, Georeferencing errors, overlay errors and errors in feature identification on the QuickBird image.

Error sources and estimated quantities

Scanning at 300dpi = $\pm 0.000125\ m$

Georeferencing errors = $\pm 0.07673\ m$

Horizontal Accuracy = $\pm 0.9582\ m$

Digitizing errors:

(a) Aerial Photo: (i) Visible line width = $\pm 0.0002\ m$

(ii) Zoom scale factor = $\pm 0.5\ m$

(b) QuickBird Image: (i) Visible line width = $\pm 0.0002\ m$

(ii) Feature identification = $\pm 0.61\ m$

(iii) Zoom scale factor = $\pm 0.5\ m$

$$\begin{aligned} \text{Sum error} &= \sqrt{0.000125^2 + 0.07673^2 + 0.9582^2 + 0.0002^2 + 0.5^2 + 0.0002^2 + 0.61^2 + 0.5^2} \\ &= \pm 1.3402\ m \end{aligned}$$

Statistical Test of Means for Areas

The test was carried out by comparing the buildings areas obtained from the ground survey and that obtained from the GIS database developed so as to assess the accuracy of the results. The projected results were taken into consideration too.

Table 3: Comparison statistics in computation of areas of occupied by buildings

GIS Database Results			Ground Survey Results		
Year	Σ Peri meter (m)	Σ Area (M^2)	Year	Σ Perimeter (m)	Σ Area (M^2)
1990	130,159	890,000	1990	131,652	892,654
2000	189,945	945,345	2000	190,453	945,891
2010	302,856	1,458,906	2010	301,234	1,459,231
2020	378,312	1,695,623	2020	-	-
2030	401,923	1,712,814	2030	-	-

Source: Author (2013)

Data on areas for a sample of buildings obtained by ground survey method and digitizing method was exported to MS excel. The means, variance and standard deviations were computed. Test of means was carried out to establish whether there is a significant difference between the means achieved by the two methods. If so, we could conclude that there is some kind of a systematic error in carrying out the task. The procedure below was followed.

Step I: Mean, Variance and standard deviation for GIS results

Mean \bar{X} for perimeter = 213,298.089 m

Mean \bar{X}_1 for area = 1,230,291.029 m²

Variance for area = 0.4218

Standard deviation for area = 0.6495

Step II: Mean, Variance and standard deviation for ground survey results

Mean \bar{X}_2 for perimeter = 214,123.207 m

Mean \bar{X}_2 for area = 1,231,120.025 m²

Variance for area = 1,231,120.025 m²

Standard deviation for area = 1,231,120.025 m²

Step III: Computation of t

Let μ_1 and μ_2 be the population means estimated by \bar{X}_1 and \bar{X}_2 respectively. Then the test is:

$$H_0: \mu_1 = \mu_2 \text{ OR } H_A: \mu_1 \neq \mu_2 \dots\dots\dots (4.2)$$

If μ_1 and μ_2 are the two sample standard errors and n and n are the sample sizes respectively, then the statistic is given by:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s_1^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)}} \dots\dots\dots (4.3)$$

The statistic given above will have a t-distribution with r degrees of freedom, where

$$r = n_1 + n_2 - 2$$

$$S^2 = \frac{S_1^2(n_1 - 1) + S_2^2(n_2 - 1)}{r} \dots\dots\dots (4.4)$$

The procedure then is to select the level of significance, α ; t is computed from equation 4.3 and is compared with the relevant percentile obtained in statistical table in Appendix C. If the computed value of t is greater than the percentile from the table, the null hypothesis is rejected, and if otherwise it is accepted.

$$\begin{array}{llll} \bar{X}_1 = 0.0219 & \bar{X}_2 = 0.0205 & n_1 = 20 & n_2 = 20 \\ S_1 = \pm 0.0062125 & S_2 = \pm 0.00751049 & S^2 = 6.862745 \times 10^{-3} & r = 38 \end{array}$$

Step IV: Comparison of t computed and the value obtained from statistical table

Substituting relevant values in equation 4.3 above,

$$t = 2.040$$

The test is to be performed at 5 % significant level, noting that α has to be small for the test to be useful. The percentile in the t-distribution is 2.101, while the computed test statistic, t, is 2.040. Thus the null hypothesis is accepted at this level and a conclusion is made that the difference between \bar{X}_1 and \bar{X}_2 is insignificant and therefore the coordinate transformation was correct.

Definition of Parcel Boundaries

The type of parcel boundary used in Kawangware estate is informal boundary. This type of boundary is not marked by beacons on the ground and not the features like roads, rivers as it is in the case of general boundary. It becomes difficult for parcel owners to know the exact position of the boundaries of their parcels. This often leads to construction of unplanned buildings on the road reserves.

Land Management Database

GIS database which is the main objective of this project was finally created. It is from the database that the above results were output. The database brings together most of the

parameters needed for the management and inspection of the status of land parcels, construction etc. Its efficiency is demonstrated in the fact that there is integration of spatial and non-spatial data. The database will therefore support the following:

- ❖ Interactive and batch data entry and update,
- ❖ Querying, reporting and spatial display of the results,
- ❖ Thematic representation of information,
- ❖ Maintenance and decision support,
- ❖ Land management needs and analysis, and
- ❖ Future Development trends

Overlay Operations

Most land parcels in Kawangware estate have illegal extensions. There is therefore a need to come up with a criterion that decision making on which land is maintained. Such could be achieved through overlay. This is done by using QuickBird images covering the area taken in different times for instance after every five years. These images can then be overlaid on parcels layer. This aids in monitoring the status of land parcels as well as the buildings. In Kawangware area, most parcels have unplanned and poor building structures.

Challenges Faced During the Research

Financial constraint was a major challenge, especially during acquisition of the images and GIS software.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

The study findings are as summarised in table 3 below.

Table 4: Summary of study findings

Year	Area in Sq.M.	Change in area coverage in sq.M. compared to the initial year (1990)
1990	890,000	-
2000	945,345	+55,345
2010	1,458,906	+568,906
2020	1,695,623	+805,623
2030	1,712,814	+822,814

According to the model, by 2030 the built environment of the study area will be two times what it was in 1990.

Source: Author (2013)

5.2 CONCLUSIONS

The main objective of this project was to come up with a complete package methodology that exploits GIS databases and high resolution remotely sensed imagery to create a model for changes in Kawangware. Based on the results achieved and analysis done it is concluded that the objectives of the project were adequately achieved. The following conclusions were deduced from the study:

Integration of GIS and Remote Sensing

From the study, it was shown that the GIS and remote sensing application provides users with the ability to view satellite images and cadastral boundaries in a chosen road reserves and to display parcels or houses on the road or houses recently developed as a layer on top. The users can access and assess the information on any parcel such as owner and size and the

development status on each parcel. It is also possible to monitor unplanned buildings. This can incorporate frequent monitoring ensuring that encroachments do not occur.

The Role of GIS Database in Land Management

The cadastral database will act as a tool for policy makers in matters related to land management. The graphics produced can be adjusted from time to time without enormous costs that are associated with revision of manual databases. Since land developments are continuous processes, the GIS database developed demonstrates and provides quick update facilities. For instance, if a parcel of land has unplanned structure, a record on the database is updated as well as its graphics.

Overlay Operations in Mapping Encroachments

Overlay provides addition information on the physical developments on each parcel. This can be done from time to time to assess the parcel status.

5.3 RECOMMENDATIONS

1. Development of Land Information System

From the project, it has been demonstrated that spatial data can be linked with non-spatial data (attribute data) to form a GIS database. Other information like transportation, utilities, infrastructure and population data can be input in the database to develop a comprehensive LIS. LIS facilitates data sharing and enhances decision making in matters related to land management like rural and urban planning.

2. Public Sensitization on Boundary Information

Most land owners are not conversant with the boundary information of their parcels. Since fixed boundaries are not described by physical features like general boundaries, it is therefore important that the public is sensitized about boundary information by land experts so that they can know the position of their parcels in relation to the abuttals and the adjoining roads. This will prevent or rather minimize the incidents of encroachments.

3. Compensation

All public land including forests, game reserves and roads belong to the government. In the case of those buildings that have been constructed on road reserves, the owners must

compensate the government for using land which is not theirs. The amount of money that the government should be compensated must be accordance with the size of the area encroached. The information on encroached area can be readily obtained from the database developed. This will prevent further encroachments from occurring.

4. Approval of Development Plans

Most encroachments occur because of using unapproved development plans. Developers site the lengthy procedures and modalities of approval as the main reason they use unapproved plans. There should be clear policies in Lands Department and the City Council that will govern the procedures taken before the development plans are approved and used.

5.4 AREAS OF FURTHER RESEARCH

The following are areas for further research that would be very useful in strengthening the model

Local land and housing market could be considered/incorporated in future models. This will give the model economic aspect.

In early stages of settlement development the majority of house owners are derived from rural-urban migrant population. However, as the settlements ages the demand for housing arises from descendants of existing house owners. This aspect is necessary for consideration so as to accurately capture the growth phenomenon.

Since the model did not factor in high-rise buildings, another model factoring this can be developed to give a more

The university can initiate development of a Land Information System which is a critical component of planning.

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APPENDICES

Appendix A



A section of Kawangware showing unplanned development



A section of Kawangware market

Appendix B



A 2010 QuickBird Image of Kawangware

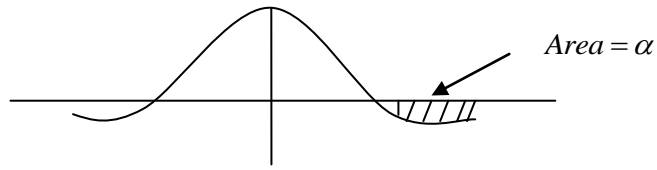
Appendix D
Transformed Coordinates

Point No.	CASSINI COORDINATES		UTM COORDINATES	
	X (m)	Y (m)	E (m)	N (m)
1.	-14000	-142700	263539.159	9857458.412
2.	-14000	-143300	263539.573	9856858.190
3.	-13500	-143300	264039.757	9856858.534
4.	-13500	-142700	264039.345	9857458.757
5.	-13500	-142400	264039.137	9857670.084
6.	-13500	-143300	264039.757	9856858.534
7.	-13000	-143300	264539.943	9856858.883
8.	-13000	-142400	264539.324	9857759.212
9.	-13545	-142040	263993.874	9858118.970
10.	-13500	-143160	264039.662	9856998.586
11.	-12860	-143160	264679.889	9856999.027
12.	-12860	-142040	264679.127	9858119.442

Appendix E

Statistical Table for Student t Density Function

Area is given by: $t_{\alpha,m}$ such that $P(t_m > t_{\alpha,m}) = \alpha = \int_{t_{\alpha,m}}^{\infty} f(t) dt = 1 - \int_{-\infty}^{t_{\alpha,m}} f(t) dt$



m	$\alpha=0.25$	0.20	0.15	0.10	0.050	0.025	0.010	0.005	0.0005
1	1.001	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	0.727	0.920	1.156	1.476	2.015	2.571	3.465	4.032	6.859
6	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	0.706	0.899	1.108	1.397	1.860	2.306	2.896	3.353	5.041
9	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	0.690	0.866	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	0.869	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.762
24	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	0.677	0.844	1.042	1.289	1.658	1.980	2.358	2.617	3.380