ANALYSING AND MODELLING URBAN LAND COVER CHANGE FOR RUN-OFF MODELLING IN KAMPALA, UGANDA

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March, 2013

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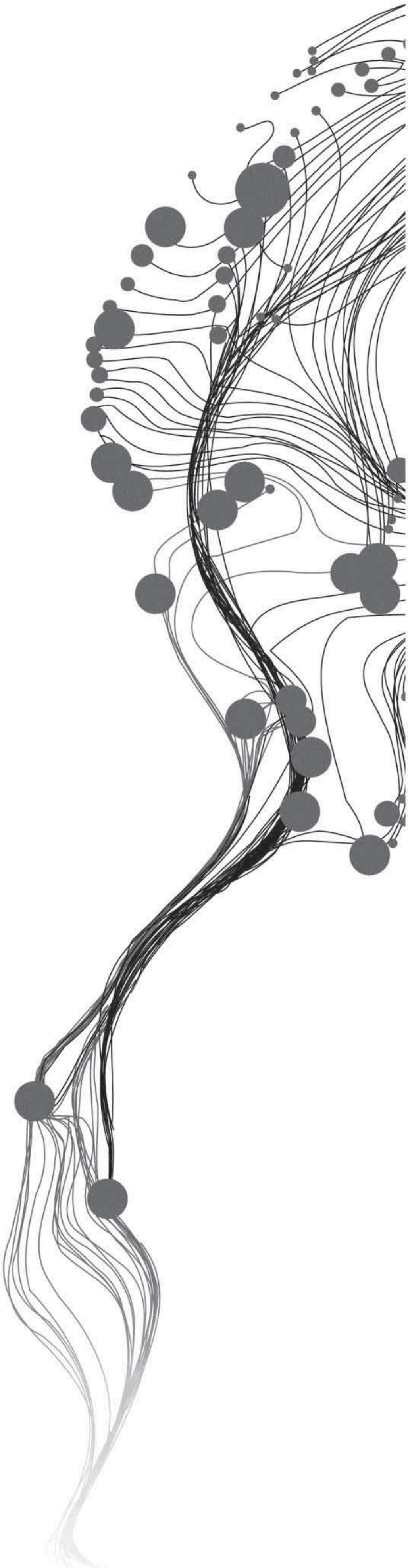

ANALYSING AND MODELLING URBAN LAND COVER CHANGE FOR RUN-OFF MODELLING IN KAMPALA, UGANDA

GEZEHAGN DEBEBE FURA
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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning and Management

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ABSTRACT

Land cover change (LCC) is amongst the most widely increasing and significant sources of todays' change in the earth's land surface. It results in the degradation of natural vegetation and significant increases in impervious surfaces. This particularly create several problems and become an issue in the rapidly urbanizing cities of developing countries, such as Kampala, coupled with the high population growth rate leading to modification or complete replacement of the land surface contributing to increased run-off rates thereby. This study, analyse and model the LCC over space and time in the Upper Lubigi catchment area (ULCA) of Kampala city by using the potential of remote sensing, geo-information systems (GIS), and logistic regression modelling (LRM) techniques forming a partial contribution to Integrated Flood Management (IFM) (run-off simulation and prediction) in the city. The study basically focused on analysing the composition and proportion of land covers, the rate and determinants of the LCC, and possible future growth location and various growth scenarios for the built-up land cover in the study area in the course of preparing land cover data for run-off modelling.

The outcome of the analyses mainly revealed that the built-up, bare soil, and various roads land cover classes have significantly increased at the expense of decrease in the vegetation land covers in the period 2004-2010. The built-up land cover has increased in area from about 5.59km² in 2004 to 7.79km² in 2010 while the vegetation land cover decreased from about 11.29km² to 8.89km² and the bare soil is considerably remain high in both years containing about 9.27km² (more than one third of the study area). The built-up land cover increases at annual growth rate of 6.85% and the vegetation decrease at the decreasing rate of 3.5% in the period. The significant physical driving forces of the LCC are evaluated based on expertise rating score and statistically quantified using LRM. The proportion of urban land in a surrounding area, distance to CBD, distance to minor roads, distance to industrial sites, and distance to major roads attract the growth while the variables slope, distance to market centres, distance to streams, and proportion of undeveloped land in a surrounding area are influentially prohibiting the growth. The prediction of the built-up based on trend growth interpolation in the LRM has also revealed that the built-up land cover area will increase from 7.79km² in the year 2010 to 11.56km², 15.26km² and 18.96km² by the year 2020, 2030 and 2040 respectively. The cumulative impacts of the existing built-up, minor roads, major roads and industrial sites have played significant role in the manifestation of the development in all prediction periods. Furthermore, all the three scenarios: the trend growth, the high growth, and the low growth scenarios constructed based on the daily demand for built-up area for the year 2020 in this study have shown much of the available open spaces and wetlands in the study area are placed under boundless pressure, with the increase in the built-up contributing to the increase in the imperviousness of the land surface. In the trend growth scenario the built-up land has increased to about 3.78km² while in the high growth it has increased to about 5.03km², and the low growth is obtained decreased to about 2.91km². Further, the predicted change in the land cover and the results of the scenarios alongside the estimation of the proportion of the other remaining land cover types are compiled and mapped as required in run-off modelling. The obtained results and approaches stretched in this study can help to improve understanding of the phenomena of the LCC at micro-scale to contribute to the process of decision making for urban planners and managers to be able to forecast and ultimately mitigate and/or reduce risks of flooding associated with the increase in impervious land surfaces at the defined geographic province.

Key words: analyse and model land cover change; logistic regression modelling; GIS and remote sensing; Integrated Flood Management; run-off modelling; Kampala

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CA	Cellular Automata
CBD	Central Business District
CCCI	Cities and Climate Change Initiative
CI	Confidence Interval
CLUE-S	Conversion of Land Use and its Effects
DEM	Digital Elevation Model
DF-C	Driving Forces-Land Cover Change
GIS	Geographic Information System
KCC	Kampala City Councils
KCCA	Kampala Capital City Authority
KIFM	Kampala's Integrated Flood Management
KPDP	Kampala Physical Development Plan
IFM	Integrated Flood risk Management
ITC	ITC International Training Centre, (currently, Faculty of Geo-Information Science and Earth Observation, University of Twente
LCC	Land Cover Change
LISEM	Limburg Soil Erosion Model
LR	Logistic Regression
LRM	Logistic Regression Model
LRMs	Logistic Regression Models
NSDFs	National Slum Development Federations
PCP	Percentage of Correct Predictions
PDCs	Parishes Development Committees
SPSS	Statistical Package for Social Science
UBOS	Uganda Bureau of Statistics
ULCA	Upper Lubigi Catchment Area
VHR	Very High Resolution imagery
VIF	Variance Inflation Factor

1. INTRODUCTION

Urban land cover change is mainly characterized by the increase in impervious land surface covers that result in the increase in surface water run-off (Praskievicz & Chang, 2009). To be able to forecast and ultimately mitigate and/or reduce risks of flooding associated with the increase in impervious land surfaces methodological approach to analysis and model urban land cover change for run-off modelling is required.

This research aims to analyse and model land cover change (LCC) over space and time in Kampala city; in the Upper Lubigi catchment area (ULCA), using the potential of remote sensing, geo-information systems (GIS) and various modelling techniques forming a partial contribution to Integrated Flood Management (IFM) in the city. The analysis explores trends and future location of LCC in the study area through the use of various growth scenarios. The result of the analyses are considered to be valuable in process of run-off modelling in the catchment and to deepen the understanding of the land cover changes in the study area and elsewhere in the city for purposes of similar application as well.

This chapter introduces and explains the background justification, identification of the research problem leading to the research objectives and the corresponding research questions. It also presents the conceptual framework and research design matrix pertained to the research topic in which the study attempts to achieve the identified research objectives. The chapter winds up by providing detailed descriptions of the research design and methodological approaches followed by brief explanation of the structure of the thesis.

1.1. Background and Justification

LCC is amongst the most widely increasing and significant sources of todays' change in the earth's land surface (Houet, Verburg, & Loveland, 2010; Lambin et al., 2001). In urban areas, much LCC is the result of degradation of urban natural vegetation and intensification of impervious surfaces (built-up, bare soil and other impermeable artificial and natural surfaces), which leads to modification or complete replacement of the cover of the land surface due to the rapid urbanization coupled with high population growth rate. Currently, in the cities of developing countries, where more than 90 per cent of the world's urban population growth is taking place and expected to continue, the impact of urbanization and climate change are converging in dangerous ways causing extreme environmental and socio-economic deteriorations (Blanco et al., 2009; UN-Habitat, 2011). Urbanization degrades and fragments natural habitats (e.g. loss of biodiversity, agricultural land and open space), which in turn cause change in climate condition (e.g. rise in temperature) and environmental pollutions (e.g. ground water pollution) (Berling-Wolff & Wu, 2004), while climate change increase vulnerability of the people and their properties (e.g. flooding or rise in sea level, heat-related illness or mortality) (UN-Habitat, 2011).

Urban LCC may cause the degradation of the natural environments including: soil erosion, reduced rain fall, reduced capacity of soil to hold water and increased frequency and severity of flooding (Houghton, 1994) amongst others. Subsequently, such changes determine the vulnerability of places and people to climatic or socio-economic problems (Verburg, Koomen, Hilferink, Pérez-Soba, & Lesschen, 2012). For instance, the potential for surface run-off is strongly affected by the condition of LCC (Van Rompaey, Govers, & Puttemans, 2002). Different land covers have different nature to absorb or retain rain water, for example impervious surfaces do not allow or allow little percentage of rain water to retain than grassed surfaces.

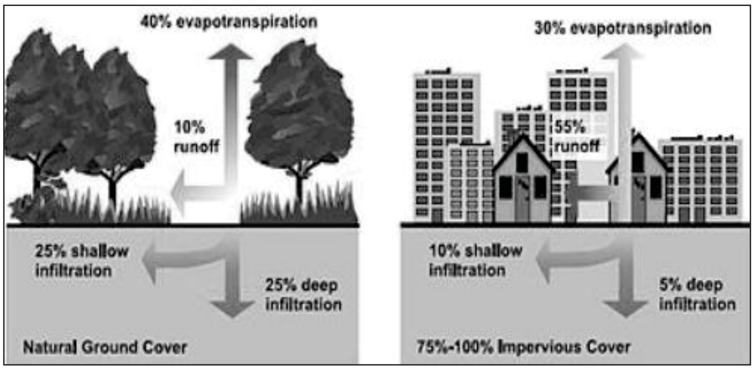
LCC is a consequence of complex interaction of different actors, driving forces, and the land itself (Verburg, 2006; Verburg et al., 2002). It is mostly seen as the result of the complex interaction (due to the interaction of decision making at different levels) between changes in social and economic opportunities linked with the biophysical environment (Koomen, Rietveld, & Nijs, 2008; Verburg & Lesschen, 2006). The various interacting components that take place over a wide range of space and time and driven by one or more factors (e.g. availability of road network, land suitability) that influence the actions of the actors involved in the system (Alberti & Waddell, 2000; Verburg et al., 2002). A combination of increasing urbanization and increasing per capita land consumption in cities leads to unprecedented rate of land cover conversion (Berling-Wolff & Wu, 2004; Verburg & Lesschen, 2006).

Planners seek to influence land developments through a set of interventions that either constrain or favour certain developments (Koomen et al., 2008), so that land configurations are achieving balanced environmental and stakeholder needs (Verburg et al., 2012; Verburg et al., 2002). Environmental managers and land use planners need information about the dynamics of LCC (Verburg et al., 2002), policy makers need to understand the trade-offs between different policy options and the mechanisms that cause LCC; planners therefore need to provide appropriate information to policy makers (Verburg & Lesschen, 2006). Thus, in the study of urban development process quantifying and analysing urban LCC over space and time is essential for appropriate policy intervention, particularly for development programs.

LCC is a main issue in studies of sustainable development and integrated assessment of environmental problems (van der Veen & Otter, 2001). Apart from the economic point of view that is concerned with land value in terms of spatial process (location choices) as discussed by van der Veen and Otter (2001), urban development (buildings, roads etc.) entails substantial public and private investments with long economic life spans. So any urban development that greatly increases imperviousness will also have significant and long lasting environmental impacts, such as increased run-off. This view is supported by Arnold and James (1996); Alberti and Waddell (2000). For instance, the amount of run-off and water retention is highly depends on the condition of land covers and so that it is important to integrate development programs with impacts of LCC on the developments in the current and the future time. The physical condition of land surface covers, the pattern and intensity of the surface of the land cover types determine the balance of the water basin (Praskievicz & Chang, 2009). Figure 1-1 below show relationship between impervious surfaces and run-off.

Figure 1-1: Impact of built-up surfaces on urban water flow

Source: IWA Water Wiki, http://www.iwawaterwiki.org/xwiki/bin/view/Articles/StormwaterRunoff; International Resource & Hub for the Global Water Community.

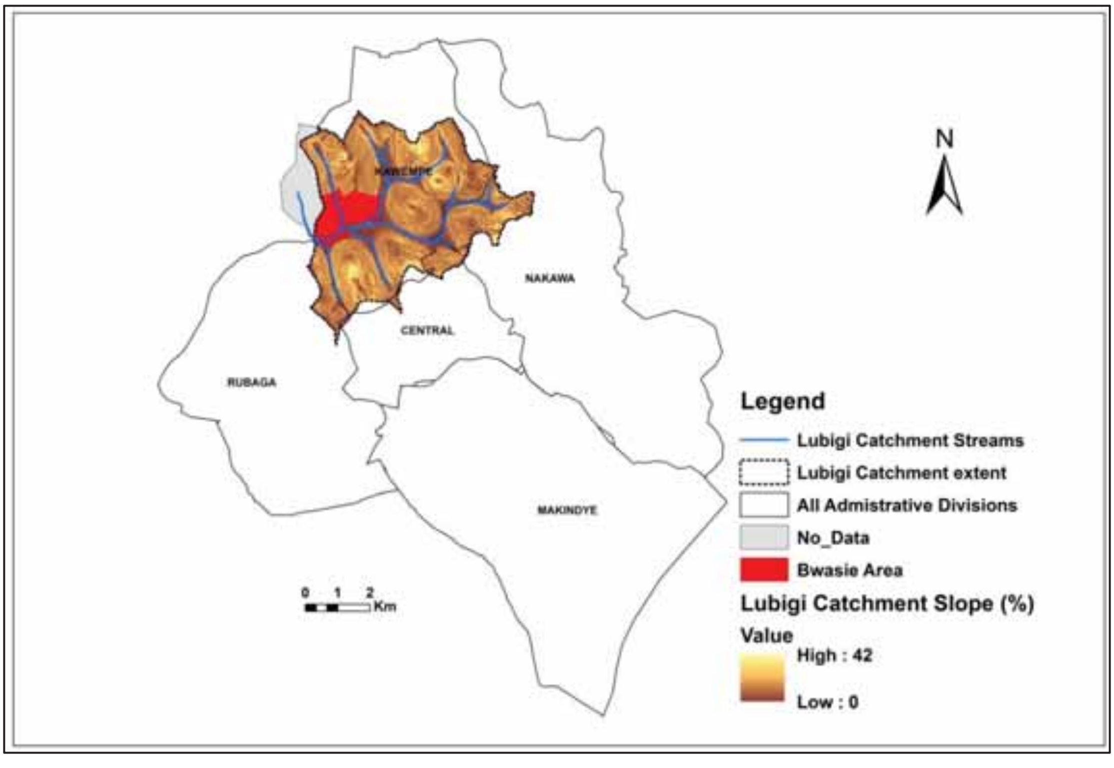


The better understanding of LCC process and the driving factors helps to identify policy measures that can be used to efficiently modify or mitigate issues related to land development and also helps to project possible future LCC trajectories and conditions of land cover patterns under different scenarios (Koomen & Stillwell, 2007; Verburg & Lesschen, 2006). This can be achieved through the use of different modelling approaches, such as Logistic Regression Model (LRM), Cellular Automata (CA) models, Conversion of Land Use and its Effects (CLUE-S) dynamic models.

Spatial models that predict LCC are required to help evaluation of the long run impacts of development patterns on the structure of landscapes and the values derived from them (Wear & Bolstad, 1998). A numbers of LCC modelling approaches and their domain of application areas have been widely discussed among many researchers (see for example, Koomen et al., 2008; van der Veen & Otter, 2001; Verburg, Kok, Pontius, & Veldkamp, 2006; Verburg, Schot, Dijst, & Veldkamp, 2004). For instance, Lambin (1997), have discussed that LCC models can be used to either statistically estimate the transition probabilities of LCC from a sample of transitions occurring during some time interval or be introduced by switching between stationary transitions matrices at certain intervals or can be used to model dynamic transition probabilities by the contribution of exogenous or endogenous variables to the transitions. Moreover, Koomen and Stillwell (2007) have also made very extensive discussion of the most common LCC or land use change models and their theoretical backgrounds (see section 2.9 for the details).

Kampala is one of the African cities, that is growing rapidly where social, economic and environmental challenges are several posing pressure on the quality of life of the inhabitants (UN-Habitat, 2009), with annual growth rates of 5.6% (Vermeiren, Van Rompaey, Loopmans, Serwajja, & Mukwaya, 2012). As reported in UN-Habitat (2009), Kampala's annual population growth rate is 3.7%, faster than that of any other urban area in Uganda in 2009, and the city is also highly vulnerable to effects of flooding and heavy storms that cause destruction of houses, social services and livelihoods of urban dwellers, while the city's vulnerability to various climatic and socio-economic problems is expected to rise and continue. One of the flooding hotspots, Bwaise in the division of Kawempe, is located on a former wetland land with high risk of flash flooding induced from the ULCA (NEMA, 2009). (See Figure 1-2 below)

Figure 1-2: Map of the upper Lubigi catchment and Kampala City Administrative Areas



Kampala's Integrated Flood Management (KIFM) project, supported by UN-HABITAT's Cities and Climate Change Initiative (CCCI) and Kampala Capital City Authority (KCCA), addresses many stakeholders and aims at two spatial levels; administrative city-wide and neighbourhoods (for introducing an integrated flood management approach in Kampala) with main focus of inception, data collection, flood modelling and analysis and strategic development (Sliuzas, 2012). Run-off and flood modelling analysis in this project require intensive data inputs of which current land cover and the built environment are among the required data; as one of the important contributors of flash floods leading to increased rates of run-off in the Kampala city is the increases in impervious surfaces. Information data about the land cover will also be a base, for example to examine " building and planning regulations to identify opportunities for increasing rain water harvesting and infiltration options which will help to reduce the amount and speed of run-off " (Sliuzas, 2012).

The intensive construction of development in the ULCA in favour of unplanned settlements linked with climate change and drainage related problems has contributed to flash flood vulnerability of the lowland settlements, such as Bwaise (NEMA, 2009). The flooding problem calls for an exploration and analysis of LCC in the catchment, the key driving factors of the LCC, and the future locations of LCC over space and time, which are very essential sources of information for sustainable policy interventions related to issues of flood risk management. This research is intends to analyse and model urban LCC over space and time for the upper Lubigi catchment for run-off modelling using the potential of remote sensing, LRM and GIS techniques forming a partial contribution to IFM in this area.

1.2. Research problem

According to NEMA (2009), the Lubigi catchment area is characterized by intensive developments of housing, industries, institutions and commercial buildings through the conversion of wetland and clearing of the buffer zones and open spaces from being a potential area for urban ecosystem conservation. As impervious surface area increases, the entire water balance of the catchment will be altered. The increase in the intensity of impervious surfaces in the ULCA has led to the increase high storm waters in the lowland settlements of the catchment; in Bwaise (NEMA, 2009). This is the most significant impact of urban land development (Praskievicz & Chang, 2009). It causes an increase in the overall surface run-off and quick flashing of the storm water and therefore causing an increase in the level of vulnerability of urban land to the effect of climate change. The magnitude and the level of surfaces run-off and flash floods are directly or indirectly impacted by the types of the physical condition of land surface covers, the pattern and intensity of the surface of the land cover types (e.g. impervious surfaces; built-up, asphalt road, and pervious surfaces; vegetation, grass land) among others.

Lwasa (2010), and NEMA (2009) have discussed a number of LCC related impacts in this catchment, such as the increase in surface run-off and flood vulnerability. So far there is no research done regarding LCC modelling to predict the future location of the LCC as an influential driver of surface water runoff for the study area. Currently, there is the need for information about predicted location of LCC for run-off modelling for the IFM in the catchment.

Hence, this research aims to develop methods for analysing and modelling urban LCC for the ULCA in Kampala city. It will explore different LCC scenarios based on trend growth, high growth and low growth policy options to determine future location of the LCC. The out-put of the study is believed to be useful as an input for the Integrated Flood risk Management project program. This study could also give insight in to the understanding of the LCC in Kampala and the impact of various adaption measures to reduce or mitigate impacts related to LCC Lwasa (2010), for sustainable land development and management in the catchment. The method can be successfully applied to other catchments in Kampala and elsewhere.

1.3. Research objective

The main objective of this research is to develop methods to analyse and model urban land cover change for Integrated Flood Management in Kampala

1.3.1. Specific objectives and research questions

In order to achieve the main research objective the following specific objectives are identified and corresponding research questions will be answered.

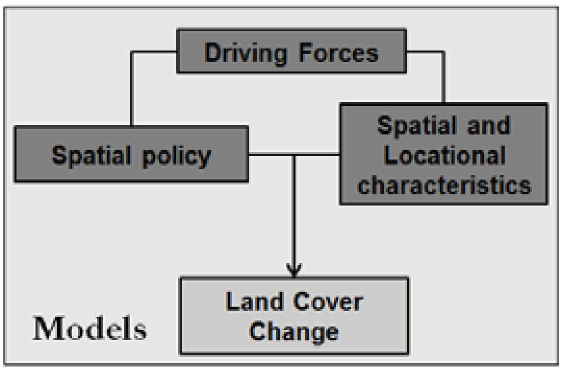
1. To analyse the proportion of LCC over the period 2004 - 2010.
   1.1. What is the composition of the land cover types in the study area?
   1.2. What are the proportions of these LCC over the periods?
   1.3. What are the rate of change and the spatial distributions of impervious land covers?
2. To determine an appropriate method to model LCC for run-off modelling
   2.1. What type of LCC data is required for run-off modelling?
   2.2. How does the spatial resolution requirement for surface water modelling affect the LCC modelling process?
   2.3. What is an appropriate modelling approach for simulating the LCC?
3. To determine and quantify the driving forces of LCC for the period 2004 - 2010.
   3.1. What are the key driving factors of the LCC for the period?
   3.2. How did the driving forces contribute to the LCC?
4. To determine possible future location of LCC for various growth scenarios.
   4.1. What are relevant growth scenarios for the study area?
   4.2. Where are probable future locations of impervious land for the different scenarios?
   4.3. What implications do the outcomes have for urban development policy?
   4.4. What implications do the outcomes have for flood management policy?

1.4. Conceptual framework

LCC research conceptualization is essential to help to focus on particular aspects of a study and to make the underlining assumption clear (Hersperger, Gennaio, Verburg, & Burgi, 2010). As such, based on the interrelations among the three main components (determinants) of LCC: driving forces, actors, and the land itself, Hersperger et al. (2010) have developed four conceptual frameworks that underlie different approaches of LCC analysis, referring to different past experiences of relevant research literatures. Driving forces are the forces that interact with actors to shape the land change; create complex system and affect a whole range of spatial and temporal state of the components, and actors (e.g. farmers, individuals or groups who own the land and affect it directly; primary actors) make decisions; act accordingly and influence other actors (e.g. policy makers who indirectly influence the primary actor by either prohibiting or promoting the land to change; secondary actors) and the environment with in their actions, while LCC refers to change in the state of the land; land developments as a result of the interactions. Figure 1-3 below show the conceptual model (DF-C) and link between driving forces of LCC. Limited to the objective of this study, here it is acknowledged that the other three LCC models, of which more focuses, are on the causal relationship between actors and driving forces to change are not discussed and the detail description of the models can be found in Hersperger et al. (2010).

The DF-C model is a generalised model that seeks to correlate driving forces with observed LCC without considering the role of land users and other actors in determining LCC i.e. the driving forces directly affects the location and nature of LCC. Causal relationships between drivers and LCC are not primary concern to explore; rather, the connections within wide, spatially explicit data sets of key explanatory variables are the primary interest (Hersperger et al., 2010), and it also help to explore past trends or potential future changes and allow to answer questions, such as which driving forces associate with change; which of the driving forces contribute to change and how much. DF-C is useful for exploratory analysis that is fully based on statistical methods that are related to the definition of theoretical relations among driving forces and LCC (that are calibrated based on empirical data) and while the relation between driving forces and LCC can be hypothesized, the DF-C is also applicable at several spatial scales (Hersperger et al., 2010), making it quite flexible in use.

Figure 1-3: Conceptual frame work



The conceptual model for Linking LCC with driving forces, the arrows indicate only the main directions of influence (Source: Hersperger et al., 2010; Fig: 1).

1.5. Research design matrix

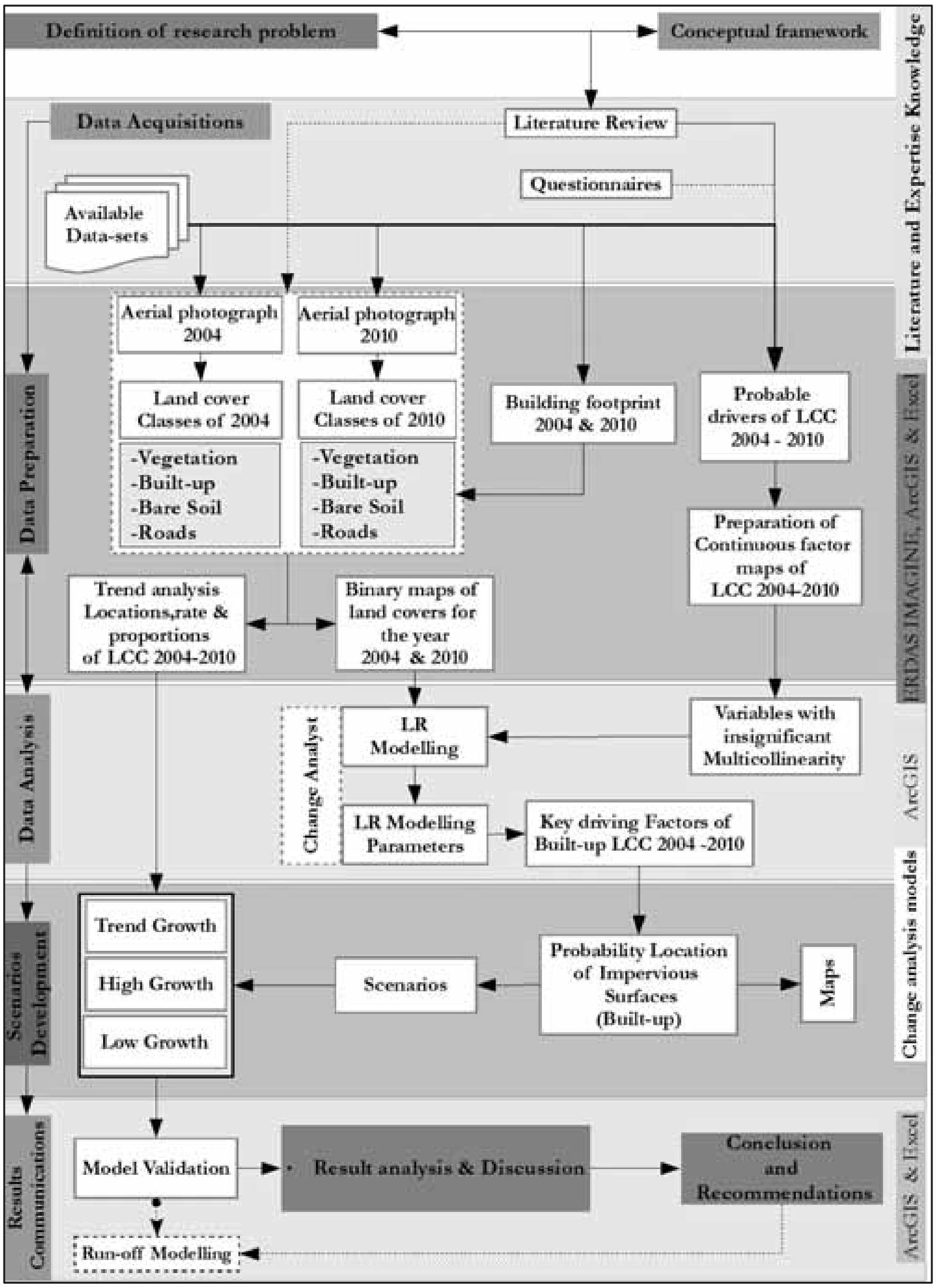
Table 1-1: Research design matrix

Main research Objective	**The main objective of this research is to develop methods to analyse and model urban land cover change for Integrated Flood Management in Kampala.**			
Sub-objectives	Respective research Questions	Techniques of Analysis	Data Required & Soft-wares	Data sources
1. To analyse the proportion of LCC over the periods 1993-2004 and 2004-2010.	• What is the composition of the land cover types in the study area? • What are the proportions of these LCC over these periods? • What are the rate of change and the spatial distributions of impervious land covers?	Literature review, GIS and Excel analysis	Literatures, Expert knowledge, Land cover data, Road, rivers, slope (DEM), map showing environmentally sensitive areas (e.g. Wetlands, flood prone area), ArcGIS and Excel	Books, Journals/Articles available, ITC archive and Kampala City Council
2. To determine an appropriate method to model LCC for run-off modelling	• What type of LCC data is required for run-off modelling? • How does the spatial resolution requirement for surface water modelling affect the LCC modelling process? • What is an appropriate modelling approach for simulating the LCC?	Literature review, Expert knowledge, and GIS analysis,	Literatures, Expert knowledge, ArcGIS, and Change Analyst.	Books, Journals/Articles available
3. To determine and quantify the driving forces of LCC for the period 1993-2004 and 2004-2010.	• What are the key driving factors of the LCC for the two time periods? • How did the driving forces contribute to the LCC? • What relations exist between the driving forces of these periods?	Literature review, Questionnaires, GIS and SPPS data analysis, and Logistic Regression Modelling	Literatures, Expert knowledge, Land cover data, Road, rivers, slope (DEM), map showing hazard prone areas (flood), Factor maps, Land cover maps, ArcGIS, SPPS, and Change Analyst	Books, Journals/Articles available, ITC archive and KCCA/own derived
4. To determine possible future location of LCC for various growth scenarios	• What are relevant growth scenarios for the study area? • Where are probable future locations of impervious land for the different scenarios? • What implications do the outcomes have for urban development policy? • What implications do the outcomes have for flood management policy	Literature review, GIS analysis, and Allocation Modelling	Population data (Built-up area growth rate), ArcGIS, , and CommunityViz (Scenarion-360) Results of LRM (Probability Maps)	Articles/Journals, Results of LRM, Kampala Physical Development Plan (KPDP)

1.6. Research design and methodology

The main phases of the study are summarized in the Figure 1-4 below. The research process generally contains six main steps. It starts with definition of research problem supported by literature review from relevant topic. This served as a basis to develop conceptual framework in which the depth and extent of the research is defined. Data acquisition, data preparations, data analysis and modelling, scenario development and result communication are the other steps of the research process in which the study try to address the research problem and communicate the results. During these steps available data preparation, processing and analysis using different modelling techniques and approaches are employed to achieve the main objective of the research.

Figure 1-4: Research design and methods



1.7. Structure of the thesis

This thesis is organised into six successive chapters. **Chapter-1: Introduction,** this chapter introduces and explains the background justification and research problem area leading to the identification of the research objectives and the corresponding research questions. It also presents the conceptual framework and research design matrix pertinent to the research topic in which the study tries to achieve the identified research objectives. **Chapter-2: Literature review,** discuss the theoretical background information about LCC, the driving forces, and LCC modelling and the approaches in in details. **Chapter-3: Study Area,** this provides background information about the study area. The chapter review LCC practises in Lubigi catchment and illustrates the general profile of the existing main land cover types. **Chapter-4: Data processing and Methodology,** describe the bases and processes within which this study is considered and executed. It describes the data source, tools, and approaches employed to determine key driving forces of LCC and scenarios development in the case study. Generally, it frameworks the overall research methodological approach and data analysis underpin the study to achieve the research objective. **Chapter-5: Results and Discussion,** present results analysis of the LCC along with the detailed discussion and evaluations of the results. **Chapter-6: Conclusion and Recommendations,** this chapter provide the main concluding remarks of the study and recommendations on further research directions.

2. LAND COVER CHANGE MODELLING AND THE DRIVERS IN KAMPALA

2.1. Introduction

This chapter presents the general review of literature that compiles information on the topic of land cover, LCC, models and modelling issues. It discusses the theoretical background information on definition and bases for the classification of land covers in the context of this study, impacts of urbanization and the LCC in Kampala, driving forces of LCC, LCC modelling approaches, theoretical concepts of scenarios, and links between land cover and run-off modelling in details. The chapter concludes by providing short review on methodological approaches from previous studies; review of few selected studies from the scientific research in the domain to link the studies of LCC with run-off modelling.

2.2. Land cover change (LCC)

The land used by human leads to changes in land cover that can negatively impact biodiversity (Verburg & Lesschen, 2006). Land that is intensively developed as built-up structure decreases the amount of available natural habitat and cause habitat fragmentation. Land cover refers to the physical conditions of earth surfaces, such as vegetation; trees, grass or built-up structures: buildings, paved land, road or other features that cover the land surfaces, such as bare soil, water, etc., while LCC refers to the change in the state or the condition of the land surfaces. Land covers can be classified in various ways based on various conditions, such as the nature of the surfaces, and purposes of the underlining study (see e.g. Anderson, Hardy, Rocah, & Witmer, 1976). To this end, in this study land cover class are considered as impervious surfaces (e.g. building footprint, bare soil, and road) and vegetation land; pervious surfaces (e.g. grassland, agricultural land and open-green space), as required in run-off modelling (see also section 2.12and 4.3).

According to Arnold and James (1996), impervious surfaces can defined as any material that prevents the infiltration of water into the ground soil. Mostly, it includes: roads, rooftops, bedrocks and compacted soil. They do not allow rainwater to infiltrate into the ground soil; it generates more run-off than the natural undeveloped surfaces (Arnold & James, 1996). Unlike the impervious surfaces, pervious surfaces are surfaces that allow rainwater to infiltrate into the ground soil; it helps to reduce the impacts of impervious surfaces (e.g. dense forest covers slows down water flow; flow resistance) and it includes grasslands, agricultural and open-green spaces (Figure 1-1). The intensification of impervious surfaces therefore, causes the increase in volume and velocity of surface run-off and gives rise to physical and ecological impacts. Urbanization has been characterized by the increase in impervious land cover addressing complex environmental and health issues (Arnold & James, 1996). This is particularly a concern for rapidly growing cities of the world, such as Kampala without or with less control on the urban development.

2.3. Urbanization and land cover change in kampala

The current evolution of Kampala city from small town of 8 km2 square in 1906 to 195km2 is occurring in a haphazard manner (Oonyu & Esaete, 2012). The city history can be traced back to the time when it was established as the capital of Buganda Kingdom and while the city has served as a political and administrative capital until 1894; when the British declared Uganda a Protectorate and transferred the capital to Entebbe. It was returned as capital city in 1962 at Uganda's independence (Omolo-Okalebo, Haas, Werner, & Sengendo, 2010).

Initially, the modern structural plan for Kampala was developed in 1912, covering Nakasero and Old Kampala hills, an area of 56.7 square kilometres with a population of about 2850 people (Omolo-Okalebo et al., 2010). This was followed by other planning schemes of 1919, 1930, 1951, 1968, 1972 and the latest in 1994 successively (Omolo-Okalebo et al., 2010; Oonyu & Esaete, 2012). After Kampala become the capital city of Uganda, the city has experienced to grow sprawl from a city of 7 hills on to 25 different hills separated by wide valleys and has been served as centre of rapid economic growth centre after 1970s (Oonyu & Esaete, 2012). According to the authors, this result in the increased demand for employment, land for housing, social services and infrastructure that have stimulated the urban development and industrialization attracting about 55% of population from rural areas.

The unprecedented population growth in Kampala city has become a challenge for natural environment of the metropolitan area (NEMA, 2009; Nyakaana, Sengendo, & Lwasa, 2007). According to NEMA (2009), the natural environment, such as the wetlands, buffer zones of forests and open spaces has continued to face degradation for industrial and housing developments, agricultural use, as well as pollution from industrial and domestic waste. The intensive building construction, the paved land, and infrastructure development have therefore put countless impact on the forests, open spaces, and the wetland vegetation in the city area (Lwasa, 2010; NEMA, 2009; Nyakaana et al., 2007).

2.4. Land cover change and its environmental impact in Kampala

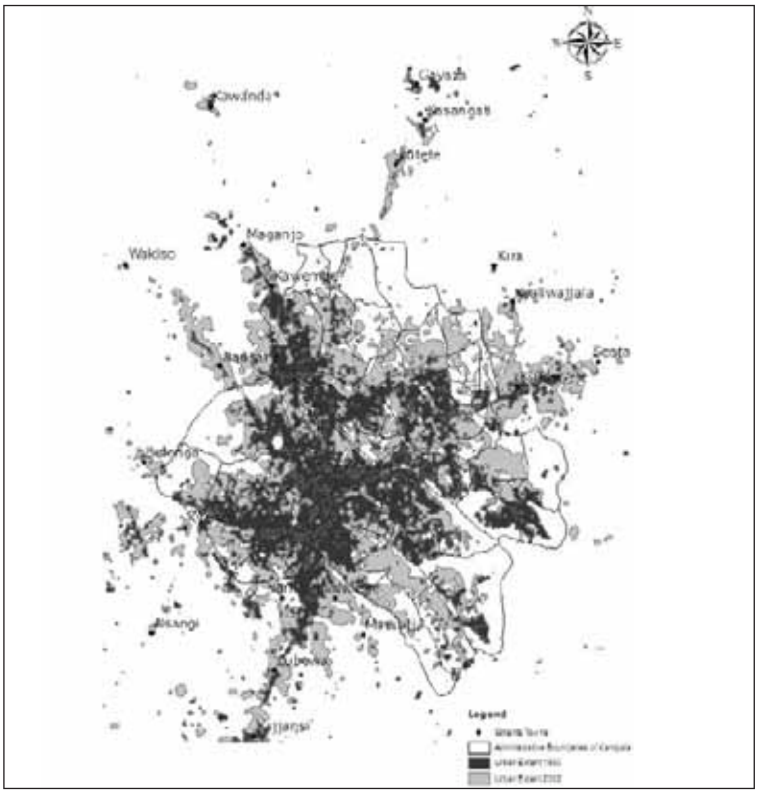
Kampala has been experiencing rapid physical expansion of land use pattern and land cover changes as the result of the increase in urban population, industrialization, and associated demand for housing (Nyakaana et al., 2007). According to the authors, the main land cover types in urban area of the city include built-up, open spaces, wetlands and agriculture, which was predominantly occupied by agricultural activities in 1980s. However, as the analysis of the authors indicates, in the 1990s the situation was dramatically changed in a way that built-up areas were increased by more than double while the agricultural land tends to decline by quarter. Similarly the wetlands have severely reduced with complete change in some parts of the city while facing continuous and serious degradation due to its being the only available and cheap land for development (Nyakaana et al., 2007). Figure 2-1 below shows urban expansion of Kampala between the year 1980 and 2002.

The land cover changes in Kampala as the result of wetlands, open spaces and forest lands encroachment and destruction for housing and infrastructure development causes reducing in the ecological services of the natural environment (NEMA, 2009; Nyakaana et al., 2007). The vastly increased built-up area and paved surfaces in the city leads to reduced water infiltration contributing to the increase in the level of storm water, which causes flooding in the low-laying area of the city such as Bwasie (NEMA, 2009). The heavy run-off leading to continuous flooding has been exacerbated by the increased urbanisation through the encroachment and deforestation of wetlands in several places in the city (NEMA, 2009; Nyakaana et al., 2007). The shrinkage of wetland system, for instance the Lubigi wetland in the upper part of the catchment due to the increase in the densely populated settlements, has caused the increase in the water retention time during rainy season resulting in to flooding (NEMA, 2009; Nyakaana et al., 2007).

There has been wide coverage of wetlands, dense forest buffer zone and quality drinking water streams and natural springs in many parts of the city in the 1960s (NEMA, 2009). However, this is completely changed and deteriorated as the result of waste disposal from the construction sites and industries constructed nearby water ways through the clearing of buffer zones that serve as natural filtration of wastes before it reaches the water basin (NEMA, 2009; Nyakaana et al., 2007). According to Nyakaana et al. (2007), this situation is worsen since 1993 and appears to be dramatic change after the year 1999.

As the wetland systems that offer environmental services to the in habitants exposed to complete degradation, there has been vulnerability of the settlers in the wetlands to the increased floods that has threatened their livelihood, which has also caused disturbance to the wild life in the areas (Nyakaana et al., 2007). The increased in the removal of vegetation covers and development of hilltops have also loads silt and organic matters in the low-laying channels, such as Nakivubo and Bwaise, which adversely changed the environmental quality and caused the increase in the water pollution and surface run-off (Nyakaana et al., 2007). These abrupt changes in land cover in Kampala city can be attributed to several factors.

Figure 2-1: Growth of Kampala and its Environs 1980 and 2002



Urban built-up 1980 (drak black), and 2002(in gray) (Source: Nyakaana et al., 2007, p. 16)

2.5. Drivers of urban land cover changes

Driving forces are factors that cause change in the phenomenon of spatial features and are influential in the evolution processes of the land surfaces (Burgi, Hersperger, & Schneeberger, 2004). Spatial change, such as LCC is a consequence of natural, socioeconomic, political, and technological factors that drive and influence the development of spatial structure of a place (Burgi et al., 2004; Dietzel, Herold, Hemphill, & Clarke, 2005). Researchers in various fields of studies have categorized the different driving forces of LCC into various types based on the purpose and case being studied. Understanding the fundamental types of the driving factors is one of a basic requirement to identify the most important drivers of change to develop realistic models of LCC (Veldkamp & Lambin, 2001).

According to Barredo, Kasanko, McCormick, and Lavalle (2003), and Burgi et al. (2004), the driving factors can be identified as: (1) environmental factors; (2) local scale neighbourhood factors; (3) spatial factors (accessibility); (4) level of economic development; and (5) urban and regional planning policies, which can be further categorized as site characteristics, neighbourhood characteristics, and proximity characteristics (Dubovyk, Sliuzas, & Flacke, 2011; Huang, Zhang, & Wu, 2009). These are discussed in the following sections in details.

2.5.1. Site characteristics

Environmental factors: these drivers are natural factors which includes site factors, such as topography, soil characteristics, climate, and natural hazards, such as flooding risk, volcanic events, and landslides (Burgi et al., 2004). They are all related to the biophysical characteristics of land, such as terrain and water bodies. The environmental characteristics may be represented as constraints for urban land development (e.g. quality of slopes, prone areas to natural hazards and natural barriers) or opportunities to a development (e.g. physical suitability of soil, slope, aesthetic or view of the landscape to attract land users). These are termed as "site selection" factors that concerns the issue of spatial site characteristics in the allocation of certain land uses to put in the contexts of Cheng and Masser (2004).

Urban and regional planning policies: urban and regional planning policies are policies that are related to zoning, which regulates urban space (locations) to be occupied by a land cover type over space and time (Barredo et al., 2003). These factors can be generally considered as constraints. According to the author, zoning is a core driving factor in urban development process, for example introducing protection of forest land cover may affect the location of urban residential lands.

Socio-economic development: these driving forces are basically associated with issues of economy and social behaviour (Burgi et al., 2004). It comprises factors that are related to level of economic development, individual preferences, and socio-economic and political system that are basically related to human decision making processes (Barredo et al., 2003; Burgi et al., 2004).

2.5.2. Neighbourhood characteristics

Local scale neighbourhood factors: these factors refer to the correlation and causality of certain land cover or land use types up on the neighbouring land cover in the immediate surroundings. These are related to the effects of one or more land cover types up on the others as a function of distance decay (Barredo et al., 2003). For instances forest land cover near or adjacent to existing built-up areas has high probability to change to built-up area than those that are located at far.

2.5.3. Proximity characteristics

Spatial factors (Accessibility): these are factors related to the locational characteristics of the land uses, such as flows or transport networks, distance to the centre, accessibility, and others utilities lines (Barredo et al., 2003). They are factors related to technology (e.g. railroads and highways) that has highly shaped the landscape and affect patterns of land use (Burgi et al., 2004). For instance, a new links in the road network introduced somewhere in or around a city might cause enormous urban dynamics as an attractor for urban development.

In general, the socioeconomic, natural, and technological driving factors can be constraining and non-constraining factors. The constraining factors indicate limitations posed on the urban development due to policy impact and/or the physical characteristics of the land cover, such as, conserved land, government lands, and water bodies. They do not have any development potential. While, in contrast, the non-constraining factors are factor that promote LCC. For instance, proximity factors, such as distance to road, distance to city core, and other factors, such as contiguous neighbourhood, and availability of usable land among others. However, the nature of the influences of these factors depends on various spatial and temporal dimensions (the scale of analysis and time steps), and the case under study (the geographical region) (De Koning, Veldkamp, & Fresco, 1998; Hu & Lo, 2007; Verburg, De Koning, Kok, Veldkamp, & Bouma, 1999); and (Cheng & Masser, 2004).

2.6. Drivers of land cover change in Kampala

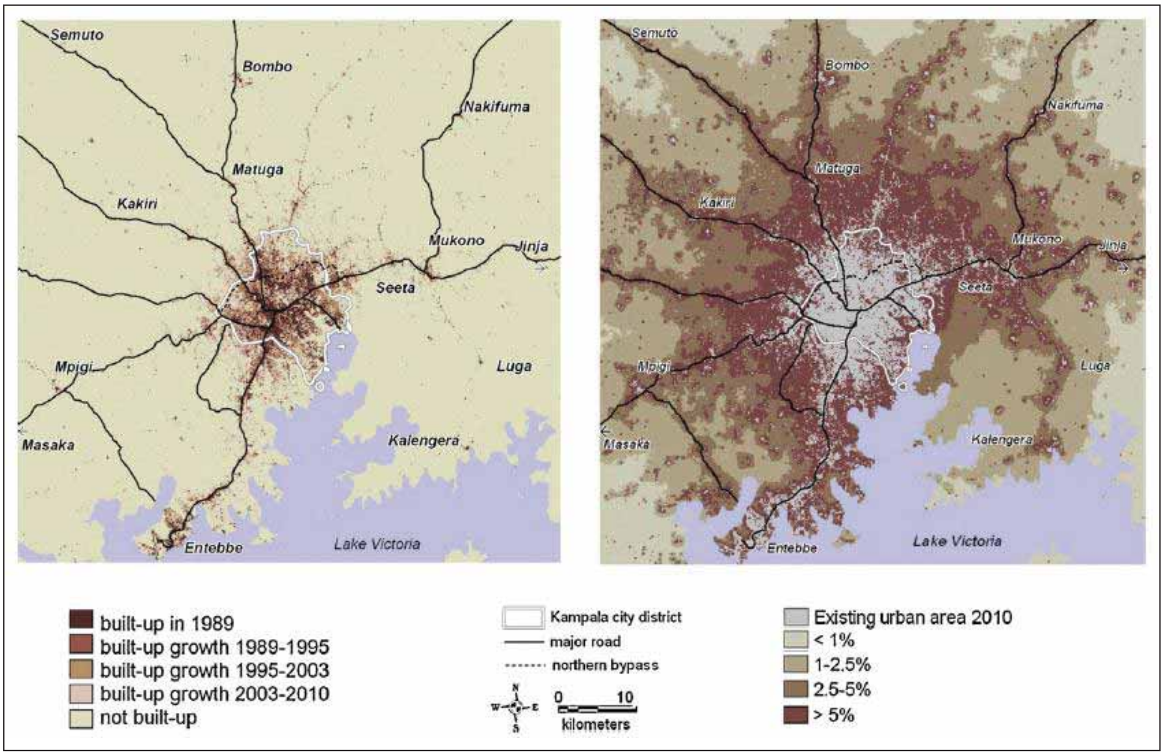
LCC in Kampala city can be attributed to several biophysical, socio-economics, and management system. In the first instance population dynamics are the most significant driving factor of LCC (urban expansion) in the city (Lwasa & Nyakaana, 2004; NEMA, 2009; Nyakaana et al., 2007). The rural urban migration and the natural fertility rate have stimulated urban spatial development and industrialization, leading to rapid environmental changes (NEMA, 2009). Policies for the economic transformation of Uganda that declares Kampala as centre for economic development through industrialization is the second main driving forces of the urban expansion (Lwasa & Nyakaana, 2004; Nyakaana et al., 2007). Associated with economic transformation, several driving forces such as market forces, commodification of land and informalization of the land acquisition has been the conversion factors of environmentally sensitive land in the urban area (Lwasa & Nyakaana, 2004). Apart from these, LCC in the city are also initiated by the development of various new infrastructures across the city. For instances, the construction of the northern bypass highway and traverses to the eastern length of Lubigi wetlands have made boundless contributions to the degradation of the surrounding natural environments (Kityo & Pomeroy, 2006).

2.7. Spatial characteristics of land cover change in Kampala

The LCC in Kampala is mainly characterized by the consumption of wetlands and agricultural lands for industrial development and unplanned settlements (NEMA, 2009; Nyakaana et al., 2007). According to Nyakaana et al. (2007), industrial built-up has changed at the increasing rate of 8.9%, and built-up land at 15.7% while forestland has change decreasingly at the rate of 11.4% in the year between 1980 and 2002 (Figure 2-1 above). Furthermore, a study done by Vermeiren et al. (2012), for the years between 1989 and 2010 indicate that the growth of the Kampala city has increased exponentially from 71 km² to 386 km² densely along the main roads and the already built-up urban centres. This expansion of the city has been taken place through the encroachment of wetlands, such as Kinawataka wetland, between Nakawa, Ntinda and Kireka and part of Nalukolongo for industrial activities, and while unplanned developments, such as Nsooba, Bulyera, Kiyanja, Kansanga, Kyetinda, Mayanja and Nakivubohas have severely caused degradation of the land cover in these parts of the city (Nyakaana et al., 2007). The recent study conducted by Vermeiren et al. (2012), has indicated the probability of the city to grow increasingly in the surrounding area based on various policy assumptions (Figure 2-2). This can be an indication of a caution of the continuation of the city growth through the encroachment of the wetlands and over the available pre-urban lands, given that situations are not mantained.

According to Vermeiren et al. (2012) prediction models, based on three various policy scenarios (business as usual, restrictive, and visioning scenarios) and assumption that the current population growth rate (5.6%) remain constant, the total built-up area of the city is expected to increase from 386 km2 in 2010 up to 653 km2 in 2020 and to 1000 km² in 2030. The authors also revealed that, in the year between 1989 and 2010 much of the city growth were take place in the low-laying areas hosting about 61% of the built-up area while the hilltops form green low-density, upper class neighbourhoods and hosts 18% of built-up area. The remaining 21% of the present built-up area is occurred in the low lying wetlands.

Figure 2-2: Urban expansion and assessed probabilities for new built-up area.



(a) Observed urban expansion between 1989 and 2010 in the Kampala metropolitan area. (b) Assessed probabilities for new built-up in the metropolitan. (Source: Vermeiren et al., 2012, p. 203 figure 4)

2.8. Spatial policies and land cover change in Kampala

Since 1903, when the legal framework for the planned growth of Kampala was laid down, a number of rules and regulations governing the physical development of the city's area were also outlined (UN-Habitat, 2007). However, according to UN-Habitat (2007) report, all development plans prior to the 1972 were characterized by impartiality of urban settlements; mainly the plans were considered targeting the Europeans and Asians in planning the provision of spacious and expensive residential areas along with well laid out administrative, commercial and industrial areas. This results in high density per-urban slum settlements, which adversely put pressure on the surrounding environments. Following the 1972 development plan, the 1994 structural plan was developed. However, challenges of rapid urbanisation and the individual land tenure rights assigned across the city have left the Kampala City Councils (KCC), the currently named Kampala Capital City Authority (KCCA), powerless in enforcing planning as well.

The land issues in Kampala city are most complex thereby contributing to the increase in uncontrolled/unplanned development vastly. The multiple land tenure system (Mailo, Leasehold, Freehold and Customary tenure system) has complicated the issues of land tenure system, in such a way that an "individual or different individuals can hold different layered interests on the same piece of land either as plot owners, tenants, lawful or bonafide occupants" (UN-Habitat, 2007). These create a big challenge for KCCA to implement the development control and plans. Although the KCCA has the mandate to control development in the City, the lack of the ownership or jurisdiction over all the land put great pressure on the development of the city. This can be witnessed from the way in which the city development pattern has been evolved.

2.9. Models and modelling land cover change

Models are simplified and logical representation of realities. They are instruments used to mimic and provide the better understanding of process or phenomenon, such as urban expansion. Although they are simplified representation, models are powerful tools to simulate and predict the implication of certain actions in the future (Couclelis, 2005). Models can be used to predict and forecast future based on logical assumptions. They are tools to facilitate thinking (Couclelis, 2005). However, the form of the representation depends on the underlying theories and methods (Hersperger et al., 2010; Koomen & Stillwell, 2007). Bhatta (2010); Koomen et al. (2008); Koomen and Stillwell (2007) have made extensive discussion of the most common LCC or land use change models and their theoretical backgrounds.

2.9.1. Classifications of models

Many researchers have proposed various models and modelling conceptual frame works as a base for models classification, see for example (Hersperger et al., 2010; Koomen & Stillwell, 2007). Although the fundamental goal and concept of models are to understand the causes and consequences of change in the earth's surfaces, yet there is no unifying theory of the land evolution models are attained (Hersperger et al., 2010). However, since theory, interpretations, and models are essential and indispensable components in the study of land related issues (Hersperger et al., 2010), conceptualization and explanation of the system under study is also equally important to focus on particular aspects.

Hersperger et al. (2010), have made brief summary of three main traditions of theorizing land use change /LCC models referring to Briassoulis (2000). These includes: urban and regional economics and regional science, sociological and political economy, and nature-society theories (Hersperger et al., 2010). The sociological and political economy model emphasize on the importance of human agency, social relationships, social networks, and socio-cultural change. The urban and regional economics, which are mostly know as von Thunen's agricultural land rent and Alonso's urban land rent theories are used either independently or in combination with other theories while the nature-society theories refer to a holistic view of the human causes of environmental change and deal with the totality of interactions between natural environment, economy, society, technology, and culture. On the other hands, based on the function/ purpose of the models, Hersperger et al. (2010) have also classified models in to two general categorizes: Descriptive and Prescriptive models.

Descriptive models are predictive models that are used to explore the effects of possible future (Hersperger et al., 2010). They are explanatory models used to simulate a process or a system (the causes and consequences) to predict the future. Predictive models are used for extrapolation of trends, evaluation of scenarios, and the prediction of future states (Christian & Andrew, 2006). On the other hand, the prescriptive models are exploratory models that are used to test how best match a set of goals and objectives to a certain standard or assumption (Hersperger et al., 2010). Prescriptive models are normative models used to test the extent of agreements between theory and reality while descriptive models are mathematical process of describing land use change or LCC and the factors that are responsible for the change and they are used to support the better understanding of the process of the land use change or LCC. The normative (exploratory) models are used to support planning and policy development; they are used to explore theory and generate hypotheses (Christian & Andrew, 2006; Itami, 1994).

Furthermore, models can be classified as static or dynamic models, transformation or allocation models, deterministic or probabilistic models, sector-specific or integrated models, and zones or grids models based on a certain theories and principles to allocate land use (Koomen & Stillwell, 2007). However, these classifications of models do not imply that they are homogenously grouped and no matter how the models are classified, understanding the purpose and the characteristics of a good model is essential.

2.9.2. Characteristics of good models

As the number and the types of models and modelling approaches are many, understanding the characteristics of good models on which the relevance of the models will be evaluated are important. According to Cecchini; (1999) cited by Blecic, Cecchini, and Trunfio (2008), a good model characteristics should satisfy the following conditions: 1) Model should not be a black-box; it is essential for a model to be understood how it works and why; 2) Model should be enabling the assessment of as many alternatives as possible, as well as the understanding of them and the differences between them; 3) Model should be compatible with other models, even if differing in formulation and techniques used; 4) Model should not require an excessive number of variables, amount of data or computational power; 5) Model should be flexible for different situations and contexts, and should allow processing and handling with what is at hand; 6) Model should be fast to build, at least with respect to the schedules of the project the model is built for (Blecic et al., 2008). However, in the fields of land use/land cover studies, the selections of relevant and appropriate models are essentially depend on basic principles and theories of allocating land (Koomen & Stillwell, 2007) and the subject under study (Hersperger et al., 2010).

2.9.3. Modelling land cover change

Spatial models that predict LCC are required to help evaluation of the long run impacts of development patterns on the structure of landscapes and the values derived from them (Wear & Bolstad, 1998). As such, a numbers of LCC modelling approaches and their domain of application areas have been widely discussed in many literatures (see for example, Koomen et al., 2008; van der Veen & Otter, 2001; Verburg, Kok, et al., 2006; Verburg, Schot, et al., 2004). For instance, Lambin (1997), has described that models can be used either to statistically estimate the transition probabilities of land covers from a sample of transitions occurring during some time interval or by switching between stationary transitions matrices at certain time intervals (e.g. Logistic Regression Model (LRM), as in Hu and Lo (2007); Huang et al. (2009) and Verburg et al. (2002)) or they can be used to model dynamic transition probabilities of the land covers by introducing exogenous or endogenous variables to the transitions in to a model (e.g. Cellular Automata models (CA), as in Alberti and Waddell (2000)). However, the selection among the different modelling approaches and tools also depend on the purpose and the spatial extent of the study, and the data characteristics (Verburg et al., 1999). The next sections will discuss some of the LCC models and their characteristics.

2.9.4. Logistic regression modelling

Logistic regression model (LRM) is mathematical estimation of the relationships between urban expansion and the drivers from historical data through the use of statistical techniques to generate probability location maps of urban growth and can be used to identify the influence of the driving forces as well as to provide a degree of confidence regarding their contribution in the process of predicting the future urban expansion pattern (Cheng & Masser, 2003; Hu & Lo, 2007; Lambin, 1997). It has been extensively and yet widely used in the processes that involve pattern analysis. For instance, Cheng and Masser (2003); Hu and Lo (2007), Huang et al. (2009); and Verburg, van Eck, de Nijs, Dijst, and Schot (2004) among others, have appreciated the potential of LRM to determine the probable locations of LCC and the drivers associated to the changes. As such, LRMs are helpful to understand the complex process of LCC to obtain valuable information on possible future locations and patterns of land covers. Moreover, LRM is advantageous over other modelling approaches in that it consume less time during the process of data calibration compared to other modelling approaches, such as CA modelling (Hu & Lo, 2007).

However, a LRM has its own limitations. One of the limitation is that the probability map can only indicate where urban development will take place, but not when it to take place (lack of temporal dynamics) and do not incorporate effects of some factors, such as personal preferences (Dubovyk et al., 2011; Hu & Lo, 2007). Second, in LRM the empirical estimation to select the predicting variables are based on data driven; rather than knowledge based. Despite of this limitations, LRM is spatially explicit and appropriate for multi-scale analysis and intrinsically it allow much deeper understanding of the driving forces of LCC and the spatial pattern (Hu & Lo, 2007), as a result.

In the process that involves complex system, such as LCC or urban expansion process, LR models are advantageous in explaining dependent variables (urban expansion or densification; land to change), explanatory variables (factors that cause the land to change) and normality assumption than other statistical analysis techniques, such as linear regression and log-linear regression (Cheng & Masser, 2003). Table 2-1 below indicates comparisons of the different regression analysis.

Table 2-1: Comparison of multi-regression, log-linear and logistic regression

Type of regression	Dependent variable	Independent variable	Computation method	Normality assumption	Relationship
Multivariate regression	Continuous	Only continuous	OLS[a]	Yes	Linear
Log-linear regression	Categorical	Only categorical	GLS[b]	No	Non-linear
Logistic regression	Binary categorical	Mixture	GLS[b]	No	Non-linear

[a] OLS: ordinary least square.
[b] GLS: generalized least square.

Source: (Cheng & Masser, 2003, p. 202 table 1)

In urban expansion process the driving factors are mostly the combinations of continuous and categorical variables (Cheng & Masser, 2003). However, the nature of urban LCC (the dependent variables) can be understand as dichotomous (the presence of change or no change) and can be described using binary values (1 or 0) indicating the presence of change (1) or absence of change (0) (Cheng & Masser, 2003; Hu & Lo, 2007). Furthermore, to correlate urban expansion (LCC) with the driving forces and to generate a probability map of LCC, the logistic regressions can be generally described by the mathimatical equations (Cheng & Masser, 2003):

$$\mathrm{y} = \mathrm{a} + \mathrm{b}_1\mathrm{x}_1 + \mathrm{b}_2\mathrm{x}_2 + \cdots + \mathrm{b}_\mathrm{m}\mathrm{x}_\mathrm{m} \quad (1)$$

$$y = \log_e\left(\frac{P}{1-P}\right) = \mathrm{logit}\ (\mathrm{p}) = \log(0dds) \quad (2)$$

$$\mathrm{p} = \frac{e^y}{1+e^y} \quad (3)$$

Where x_1, x_2, x_3. . . x_m are explanatory variables, y is the dependent variable which can be expressed as a linear combination function of the explanatory variables representing a linear relationship (Eq. (1)). The parameter a is a constant; b_1, b_2 . . . b_m are the regression coefficients to be estimated. If the dependent variable, y is represented as a binary (0 or 1), the value close to 1 means the high likely occurrence of new cell (e.g. transition from non-urban to urban cell), and the value close to 0 means the less likely a change to occur.

The function y can be also represented as logit (P), i.e. the log (to base e) of the odds or likelihood ratio that the dependent variable y is 1 (Eq. (2)). The P implies the probability of occurrence of a change. The probability value P can be defined as a non-linear regression of the explanatory variables (Eq. (3)). This implies that the probability value P will strictly increase with the increase in the value of y (following the logistic curve). Regression coefficients b_1, b_2 . . . b_m indicate effect of each explanatory variables on the value of P. A positive sign of a coefficient imply that the explanatory variable will contribute to increase in the probability of change to occur where as a negative sign imply the opposite effect.

2.9.5. Cellular Automata Modelling

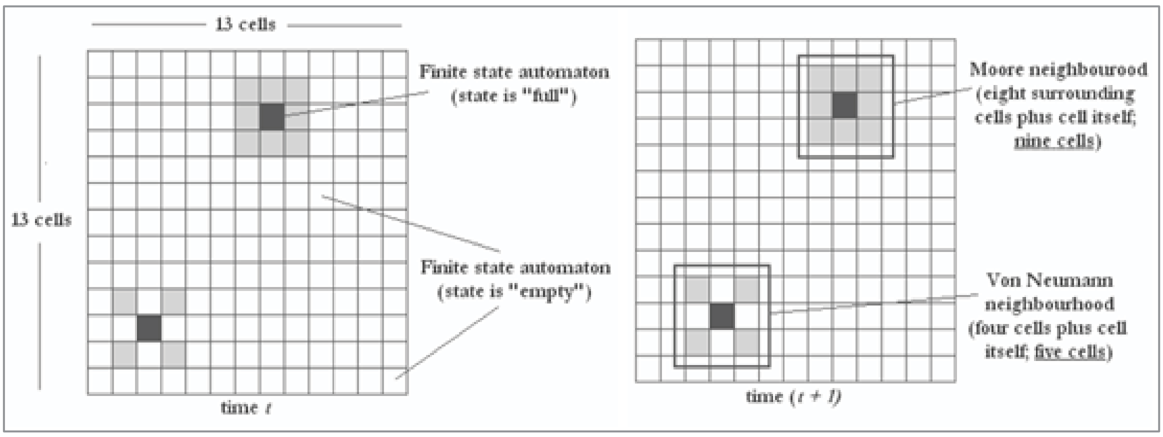
Cellular Automata (CA) models are cells based dynamic models that change the state of cells according to a specific transition rules as a function of their original state and local neighbourhoods (Alberti & Waddell, 2000; Itami, 1994; Torrens, 2000). CA is potential platform to explore complexity (Torrens, 2000). CA is a grid based iterative array aroused by placing copies of similar sequential machines at each of the grid cells in one dimension (1D) (a single row of identical cells), two dimension (2D) (cells that are composed of a matrix of identical cells regularly arranged in rows and columns.) or three dimensional (3D) grid spaces in a uniform fashion (Itami, 1994).

Fundamentally CA is characterized by five defining elements (Itami, 1994; Torrens, 2000): 1) Girds cells, a discrete lattice of sites; 2) Temporal space, discrete time steps; 3) Cells state, a finite set of possible values; 4) Transition rules, deterministic rules; 5) Surrounding neighbourhoods, a local neighbourhood of sites.

The concept of the two dimensional CA originally developed in 1950s by John Von Neumann and his colleague (Itami, 1994). This is further introduced as a game theory called "Conway's Game of Life" by Martin Gardner in 1970s (Torrens, 2000). In this game of life (played on 2D grids of cells) the cells exist either dead (0) or alive (1) states, indicating presence or absence of change in state (new generation) in Moore neighbourhood cells. For example, the change from non- urban to urban based on the transition rules in the next time period can be described as change from dead (0) to alive (1) states, given that the state zero and one representing non-urban and urban cells respectively. In the next time period the state of each cell is dependent on the original state of the cell itself and its nearest neighbours within a radius of eight cells in the current time period which can be affected by the transition rules as well. Figure 2-3 below shows the two most common way of describing neighbourhood: the von Neumann neighbourhood (4-cells) and the Moore neighbourhood (8-cells) in 2D cellular automata.

The transition rules of the game are defined as: (1) survivals, every live cell (one) within two or three live neighbours survives into the next time steps; (2) deaths, every live cell within four or more live neighbours, or less than two, dies (zero); (3) births, every dead cell within exactly three live neighbours becomes live in the next time steps. More detailed explanation of this concepts can be found in Itami (1994); Torrens (2000). From these simple transition rules coupled with the original state of the cells and its neighbours effect greater variety and complexity of behaviour evolves over time.

Figure 2-3: Two-dimensional cellular automata



Source: (Torrens, 2000, p. 22 Figure 3)

To start the game, some of the live cells (1) are originally seeded randomly (matrix of live cells) in the lattice sites. Up on the beginning of the game, the transition rules are applied to each cell in the lattice spaces. Through time steps and over space, the results are displayed graphically on the screen in regular or chaotic patterns, and the process continuous iteratively until the action is stop. On the process of evolution, the cells may collapse into extinction, or they may produce the self-replicating structures. These result in complex behaviour emerged from iterative simulations that can be used generally to represent the complexity of the natural systems, but some modifications are required (Itami, 1994; Torrens, 2000).

CA models have been widely used in different fields of disciplines for various purposes. CA has been primarily applied in the exploration of the natural and physical sciences at a wide range (Itami, 1994). For instance, among many researchers, Alberti and Waddell (2000), have applied a CA prototype to predict human induced environmental pressures; land conversion, in a dynamic and spatially explicit framework that links human decisions to changes; Itami (1994); Wu (2002), have also explained the potential of CA models to simulate the complexity of LCC process in a sequence of steps through a set of states. CA models are relatively easy generally to represent natural systems, such as urban system (Itami, 1994; Torrens, 2000), and advantages in modelling spatial dynamics in particular (Itami, 1994). However, CA models are very dependent on the initial state of the cells and the transition functions that define their behaviour, and therefore may not have the capacity to accurately predict the change (Itami, 1994). Calibration of CA models are also not simple; depicted to its stochastic nature each time a CA model is run the result will be different (Itami, 1994; Ward, Murray, & Phinn, 2003).

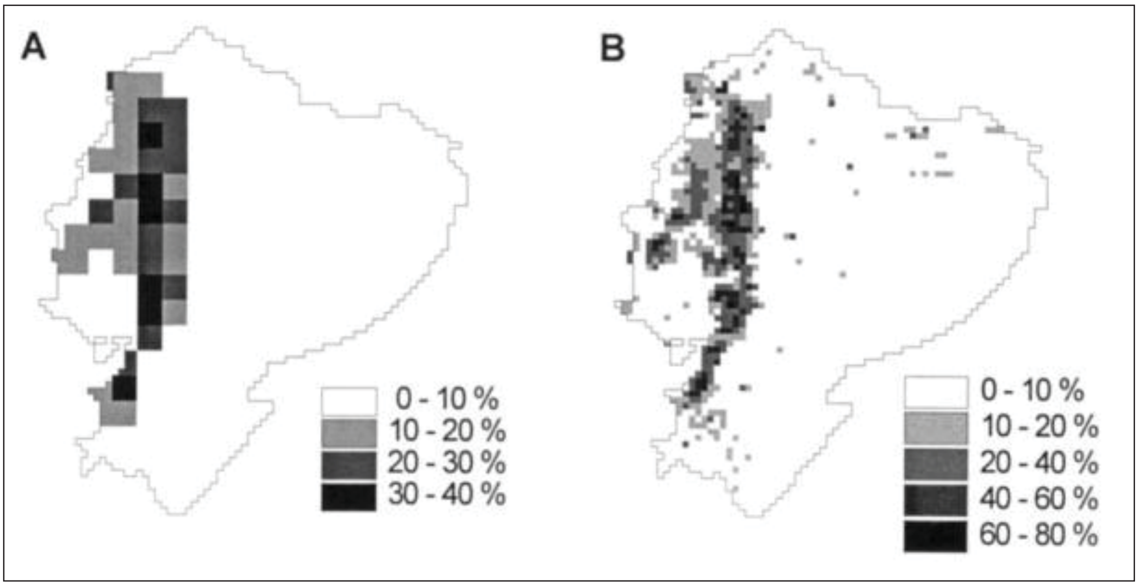
2.10. Modelling and issues of spatial resolutions

Among some scientific requirements of modelling process, one is the spatial resolution (scale) dependency of explanatory variables (Gibson, Ostrom, & Ahn, 2000; Hu & Lo, 2007; Veldkamp & Fresco, 1997; Veldkamp & Lambin, 2001; Verburg, Schot, et al., 2004). Gibson et al. (2000), have defined the term scale as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon whereas resolution is defined as the precision used in the measurement while they refers level as a region along a measurement dimension or locations along a scale. Scale, resolution and level are all can be interpreted in terms of space, time or phenomenon. For instance, the terms: micro, meso, and macro levels can be used as to refer to small, medium, and large sized spatial scale of a phenomena. Likewise, levels can be related to time as to refer to short, medium, and long term time durations. Furthermore, scale, extent and resolution are all interdependent (Gibson et al., 2000); may not be distinguished explicitly.

Problems of scaling can be associated with issues of scale and/or level; extent and resolution (Gibson et al., 2000). As described in Gibson et al. (2000), the extent (degree of a dimension used in quantifying a phenomenon) defines the limit of the measured phenomenon while resolution used to observe quantity depends on the extent. Therefore, issues related to scale are very important in all scientific inquiry explicitly or implicitly in order to identify impacts of scale, extent, and resolution on pattern of a particular subject under study. This is predominantly true in urban studies, ecology and landscape modelling.

Models result and the interpretation are therefore determined by scale of analysis at which phenomena are explained. For instance, in statistical analysis, such as multiple regression analysis, there are turning points (the optimal scale) where the scale of spatial resolutions are no longer significant for the models to perform good (Hu & Lo, 2007). This idea is also supported and explained by De Koning et al. (1998), based on their practical cased study in Ecuador. During their investigation of land use change with various independent variables at six aggregation levels, the authors found that at the high spatial scale (coarser resolutions) model fits decrease quite strongly for all land use types. Furthermore , De Koning et al. (1998) have cautioned and suggested that it is very essential to consider different level of aggregations for different geographic regions in the process of describing and explaining effects of scale in explaining effects of different driving forces on land use change. Figure 2-4 below shows effect of variation in spatial resolution on models result.

Figure 2-4: Effect of variation in spatial resolution on models result.



Simulation results at various scale A) at coarse resolution; B) at fine resolution (Source: Verburg et al., 1999, p. 55).

2.11. Scenarios development

Although, different definitions for the concept scenario were noted, Couclelis (2005), has made a brief summary of the definition referring to different scholars. Scenario is "hypothetical sequences of events constructed for the purpose of focusing attention on casual process and decision points;… projection of both wishes and fears regarding the future;….tools to reach one's understanding of the world;…and description of a future situation and courses of events…"(Couclelis, 2005, p. 1363), to remark some from the lists of given definitions to the concept. Scenarios are essential and powerful means of interpreting and understanding planning and policy analysis (Barredo et al., 2003; Couclelis, 2005; Guhathakurta, 2002 ; Itami, 1994). According to Guhathakurta (2002), scenario is "important in securing and endorsing the premises needed to make decisions under conditions of uncertainty and complexity….they shape the course of a discourse by reshaping the initial positions of the actors concerned….and need not be factual at all" (Guhathakurta, 2002 p. 896). Enforcing to this, Couclelis (2005), has made a notion that state "future can be understood as a coherent and plausible story" and scenarios are the most important toolbox in this regards (Couclelis, 2005). Based on various assumptions, different scenarios can be constructed. However a common way of constructing scenarios is the consideration of population growth trends: Trend growth scenario, High growth scenario, and Low growth scenario assumptions to predict the future possible situation, such as location of built-up land covers based on demand calculation.

Trend growth scenario: trend extrapolation also called "business as usual scenario" is a technique of projecting past trends based on historical data (historical time series); the assumption that past growth rate remain unchanged to the future. It assumes no change in the structure of the underling factors and conditions in general. It considers the probable of future growth with no significant externalities or intervention. This approaches of predicting future change is expected to be useful for the analysis of short term change as it does not necessitate explanation of causality. However, the different conditions and assumptions can be influenced by many variables to remain unchanged (e.g. demand for built-up area, which is highly dependent on level economic development and demographic characteristics).

High growth scenario: high growth scenario also known as "worst case scenario" is the assumption that based on the expectation of accelerated demographic growth will happen driven by external factors such as increased uncontrolled birth rate and rural in-migration.

Low growth scenario: this is the assumption based on the expectation of there will very significant radical intervention to be undertaken to ensure the future sustainable growth. It is also called "best case scenario" were by sustainable urban growth is expected. This scenario considers, the reduced population growth rate; birth rate and rural in-migration, administrative reforms, effective development regularisation and appropriate services in all sectors to achieve a balanced urban system. The fundamental preconditions for this assumption is that major structural reforms.

2.12. Link between land covers and run-off models

Among many variables that are required for run-off modelling, land cover data is the most prerequisite (De Roo & Jetten, 1999). For example, land cover data, such as building rooftops, vegetation, asphalt road, murrum (compacted soil) and bare soil are essential for runoff modelling in Limburg Soil Erosion Model (LISEM). All input maps in LISEM are prepared in raster format. This raster GIS is produced by PCRaster environmental software (a software which is an integration of C++ code, GIS operations, mathematical operations and hydrological functions used to easily produce and displayed the input and output maps for LISEM as raster maps format) and these data are useful to drive information about the nature of interception (water on tops of roof or leaf), infiltration (water on ground) and surface roughness; surfaces resistance and water storage in the process of determining overland flow or surface water run-off (http://www.itc.nl/lisem/).

Now days, there are several run off modelling tools available devised by researchers (Jetten, De Roo, & Favis-Mortlock, 1999; Nearing et al., 2005). The models are designed to take different advantages of spatial variations to simulate runoff and erosion yield within spatial unit (Nearing et al., 2005). The models have been developed to simulate run-off dynamics of larger and more complex catchments to put it in the words of (Jetten, Govers, & Hessel, 2003). However, for the IFM project program in the study area, LISEM is the proposed run-off modelling tool.

2.12.1. Limburg Soil Erosion Model and its data requirements

LISEM is can be used to simulate the effects of the current land cover or land use on the surface run-off (De Roo & Jetten, 1999). It is a process based model used to model run-off for the better understanding location of run-off hotspots to predict and to evaluate the effects of different overland flow and water conservation measures as well (Hessel, Jetten, Liu, & Qiu, 2010). The model incorporated basic processes that are used to determine overland flow and channel flow among others (http://www.itc.nl/lisem/).

LISEM is used to simulate surface run-off (overflow) by calculating the discharge flux of land cover types based on the average water height in the grid cells of the raster land cover maps using a kinematic wave of the water leading to the outlet (http://www.itc.nl/lisem/). As discussed in on the web site, LISEM can simulate several types of surface, such as paved surface, coated and compacted surface, vegetation surface, for each raster cell of the land cover types. Different infiltration rates are applied to the water height on each surface type and the surface weighted average is then taken as the representative water height. Thus, the infiltration process is applied separately to all surface types in the grid cell, which results in different water heights on each surface type. The infiltration characteristics vary according to the surface and the infiltration is calculated for each type. LISEM needs various types of maps depending on the input options which can be derived from four basic maps that include: DEM, land use, soils, and roads (http://www.itc.nl/lisem/). Therefore, the land cover maps are among the fundamental data required in LISEM to simulate surface run-off. Further and detail information about LISEM model can be obtained from the website (http://www.itc.nl/lisem/). Moreover, LISEM require definite spatial resolution.

According to Nearing et al. (2005), in spatial modelling the scale of analysis affects models result and thus models should be based on an analysis of the process at various spatial and temporal scales. Spatial resolution (cell size) is one of the most arbitrary choices made by the researchers (Jetten et al., 2003). LISEM is designed for small scale areas (50 m2 to 5 km2) and all input and output data are processed in the form of raster maps with grid cell resolution that usually various between 2 and 20 meters (Nearing et al., 2005). In simulation models the spatial resolutions are among one of the determinants of the models result. This also holds true in the case of LISEM model. However, the selection of spatial resolutions of a model depends on the application, area studied and data availability (Verburg et al., 1999; Walsh, Crawford, Welsh, & Crews-Meyer, 2001).

2.13. Previous studies to linking LCC with run-off modelling

Through the use of opportunities provided by both remote sensing and GIS numerous amount of research studies have been done to map urban impervious and open space for the determination of run-off modelling at various conceptual and spatial level and extent over different geographic space. To mention few, Thanapura et al. (2007); Solin, Feranec, and Novacek (2011); Van Dessel, Van Rompaey, Poelmans, and Szilassi (2008); Van Rompaey et al. (2002) are amongst others.

For instance, Thanapura et al. (2007), presented a methodological approach to derive land cover data from remote sensing imagery in GIS spatial modelling environment. The authors introduced the use of Normalized Difference Vegetation Index (NDVI) to map urban land cover data from high spatial resolution satellite imagery. They make the use of Quick-Bird imagery band reflectance characteristics; the red (630 to 690 nm) and NIR (760 to 900 nm) bands, and the NDIV image classification scheme (algorism) to assess categories of open space and impervious urban areas. According to the authors the methodological approach was very effective and efficient to extract urban land cover data that are useful to determine run-off modelling. This method could have used to derive the land cover data for this case study. However, the method is not relevant for this case study for two reasons: One is the method makes use of high spatial resolution of Quick-Bird imagery with specific bands characteristics, which is not available for the study area. The second reason is the levels of the land cover classes required for run-off modelling for this case study is in a much more detail as discussed in the previous sections (see also section 4.3).

On the other hand, Van Dessel et al. (2008) have used high resolution land cover maps to measure soil connectivity and erosion rate for the Lake Balaton catchment in Hungary for over 25 years (1981-2005). In their case study, the authors have delineated the land covers maps in a more detailed way which includes: built-up area, arable land, vineyard, grassland and forest. The level of the land cover classification was logical as the study was done in agricultural landscape, where a number matrix of land conversion are possible among the aforementioned land cover classes, but this is not relevant in urban environment like Kampala, where in most cases the land conversion is from any non-built-up to built-up. After their detail study on the trends of the land cover conversion in the catchment (rate of change in the land covers in the past) the authors have develop a land cover scenarios using LRM.

The LCC scenarios developed by Van Dessel et al. (2008), was to assess the conversion probabilities of the land covers as the function of physical and socio-economic driving forces and to estimate future levels of sediment input into the Lake in the future. During the scenarios development, the authors use trend extrapolation to construct future land cover maps for over the periods of 25 years (2010-2030) at an interval of 10-years periods. The study of Van Dessel et al. (2008), is pretty similar to the approaches preferred in this case study. However, the level of consideration of the land conversions and the scenarios development are exceptional.

3. THE STUDY AREA

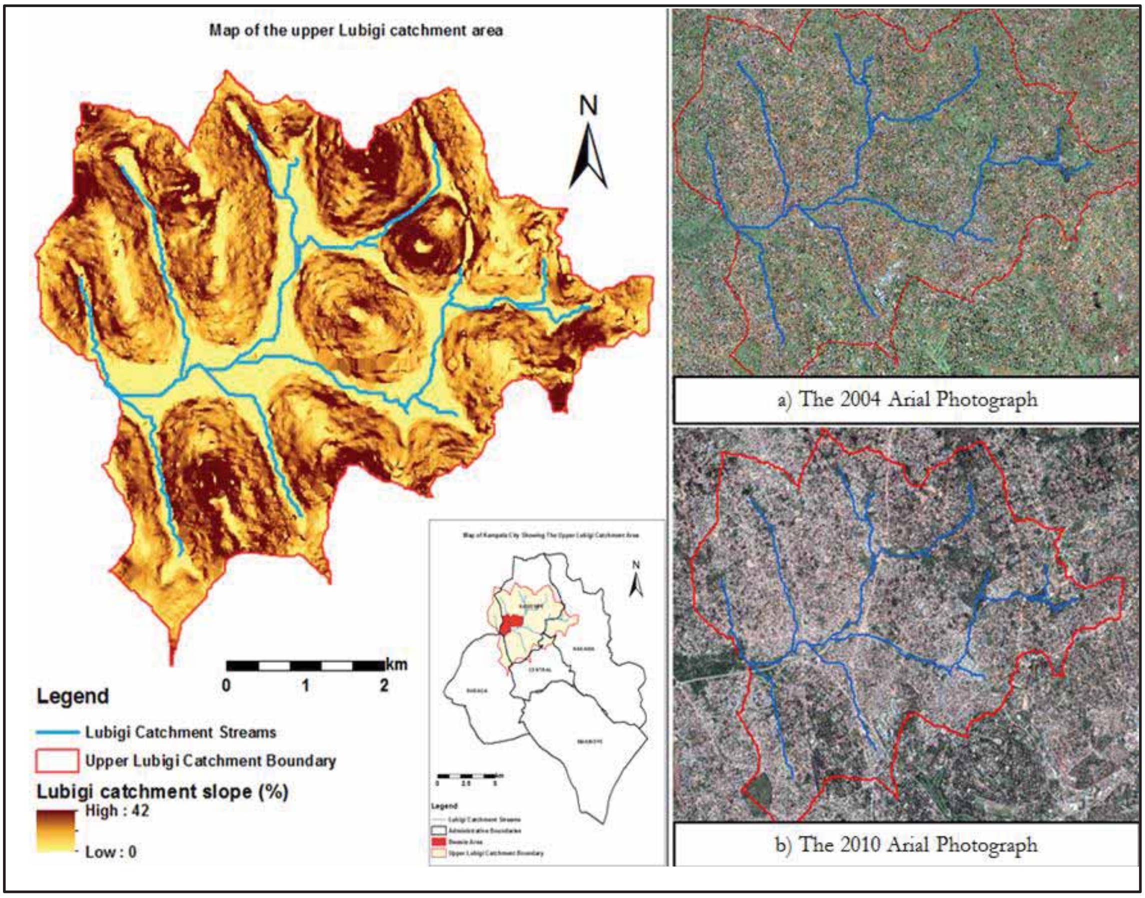
3.1. Introduction

This chapter provides background information on the study area. It explains the physical characteristics and the condition of land covers in the study area. It also provides an overview of the challenges of the settlements and the surrounding environment in the study area. The chapter concludes with brief explanation on the socio-economic activities and the main types of land use in the catchment.

3.2. Physical characterstics and the land covers in Lubigi catchment

The natural environment in Kampala has generally faced continuous degradation with the increase in population growth rate, which has put enormous pressure on natural resources neighbouring districts. The increase in highly paved built up areas have caused to reduced water infiltration and generation of high storm water (NEMA, 2009). As reported in NEMA (2009), the wetlands in Kampala has been degraded for industrial and housing developments, agricultural use as well as pollution from industrial, construction dumps and domestic waste. This is particularly a case of wetlands located in the Lubigi catchment area.

Figure 3-1: The study area, (Aerial photographs of the study area in the right side)



The Lubigi catchment is located about 7.5km on the west of Kampala city (Namakambo (2000), as cited by Kityo & Pomeroy, 2006). According to Kityo and Pomeroy (2006), Lubigi contains the largest wetlands and extend through Lubaga and Kawempe. However large portion of Lubigi catchment is found in Kawempe division, while the remains of parts are located in Nakawa and Lubaga and covers about 33 square kilometres (see section 1.1, Figure 1-2). The wetlands could be accessed at several locations on Masaka, Hoima, Mityana and Sentema roads and surrounded by highly populated sub urban villages that includes: Busega, Natete, Bulenga, Nakuwadde, Lubanyi, Masanafu, Kawala, Nganda and Namungoona with high impacts on the condition of the wetland near to them (Kityo & Pomeroy, 2006). At the time writing the authors, Lubigi wetland has no conservation status in any part of it and while the new northern bypass highway and construction traverses the eastern length of Lubigi wetlands have resulted in the infilling of those sections of the swamp crossed by the highway. The topography of Lubigi catchment is characterized by hills and valleys with a slope lying from zero per cent along Lubigi primary channel to 42 per cent to the hill tops. It contain permanent water logged wetlands and several streams drains into and forms part of the Lake Kyoga system (Kampala District State of Environment Report, 1997). Figure 3-1 above shows the study area and its topographic characteristics.

3.3. Land cover change and its impacts in Lubigi catchment

The vegetation covers of Lubigi catchment is dominated by papyrus as reported in the Kampala District State of Environment Report (Kampala District State of Environment Report, 1997). In the 1980s, much of the land cover was wetlands, which was gradually cleared from 1986 onward as the population increased (Nyakaana et al., 2007). As reported in Kampala District State of Environment, this "…..Wetlands act as large sponges which absorb water from the run-off and release it steadily through evaporation into the atmosphere and through gravity drainage into rivers and streams. The hydraulic resistance of the vegetation diminishes the force and amount of flooding downstream and where the vegetation has been disturbed or removed flooding is bound to occur as in some suburbs like Bwaise…." (Kampala District State of Environment Report, 1997, p. 22). As many of the land covers in other parts of the city, the vegetation land covers and wetlands in this catchment has been degraded for industrial development and to host the informal settlements.

The degradation of these land covers in the upper Lubigi catchment have caused the increase in the magnitude and the level of surfaces run-off and flash floods that directly or indirectly impacted the livelihood of the low-laying settlements, such as Bwasie areas (Nyakaana et al., 2007). The increase in storm water run-off causes destruction of properties and pollution of drinking water (Kampala District State of Environment Report, 1997).

3.4. Major socio-economic characterstics of the Lubigi catchment

Lubigi catchment area, which includes parts of Kawempe, Nakawa and Lubaga administrative divisions is characterized by high industrial and housing development witnessing the issues of inadequate infrastructure and basics services in the city. Kampala city, the centre of industrial and commercial economic activities of Uganda in addition to being the capital city of the country, is generally characterized by poor infrastructure and services provisions, including road network, water supply and sewer systems, unreliable supply of energy and poor rail access that virtually remained unimproved (IHC, 2009; UN-Habitat, 2009).

The industries in Kampala are simulators of development in the city serving also as the location of job opportunities for majority of labour forces including untrained, low skilled and semiskilled employee with low salaries/ wages earning (Nyakaana et al., 2007). According to the authors, however, the industries produce below capacity to provide goods with high production cost for local consumption, which result in low consumption rates of the domestic products given that most of the inhabitant, earn low income to afford the market. This has made Kampala a centre of imported goods that contributed to the low rates of economic development (Nyakaana et al., 2007).

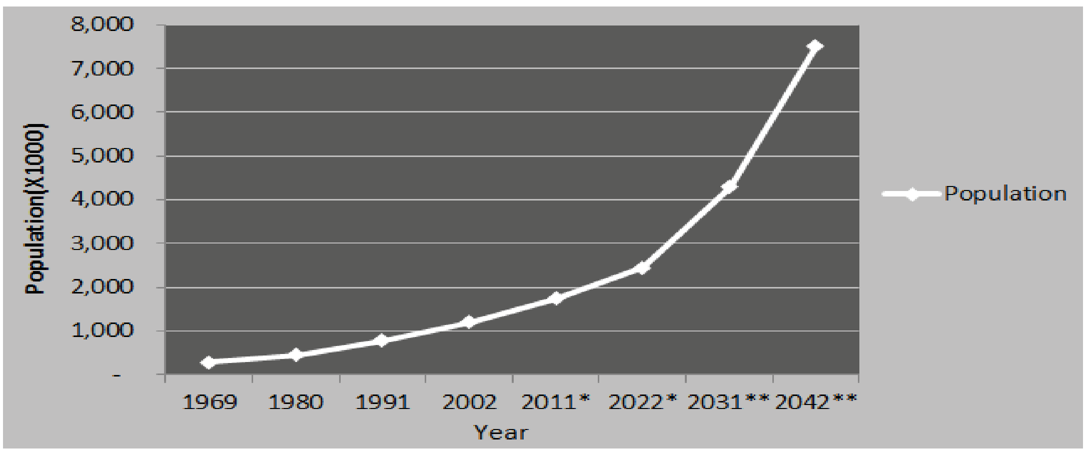
Although, there is a variation in level of economic development and infrastructure distribution in the city (Nyakaana et al., 2007), the characteristics of economic activities in Kawempe, Nakawa and Lubaga administrative division are generally similar. The divisions are mushroomed by a number of businesses such as, industries, retail shops, a blooming farmers market, institutional buildings (universities and hospitals), and residential housing. According to Nyakaana et al. (2007), Nakawa is dominated by industrial establishments while Lubaga dominated by residential facilities and Kawempe has a number of industries, commercial establishments, and residential facilities.

All the three divisions are relatively characterized by high population distributions compared to the rest of the divisions in the city according to the 2002 census data. Lubaga, Kawempe and Nakawa have hosted about 25, 22, and 20 per cent of the total population in the city respectively by the year 2002. Table 3-1 and shows population distribution in the five divisions and Figure 3-2 shows the Kampala city growth trend in the year 1969 to 2042 projected based on the 2002 National Population Census Reports.

Table 3-1: Population distribution by division

Division	1969	1980	1991	2002	2011	2022	2031	2042
Lubaga	74,098	103,846	179,328	302,105	417,000	603,000	1,055,656	1,848,107
Kawempe	60,259	82,885	161,316	268,659	425,000	555,000	971,623	1,700,994
Nakawa	59,711	81,913	133,813	246,298	354,000	542,000	948,864	1,661,151
Makindye	40,155	113,304	186,997	301,090	450,000	609,000	1,066,160	1,866,496
Central	56,168	76,655	112,787	90,392	104,000	139,000	243,343	426,015
Total	290,391	458,603	774,241	1,208,544	1,750,000	2,448,000	4,285,646	7,502,763

Figure 3-2: Population growth trend in Kampala 1969-2002



*Projection accessed from KPDP Draft Final Report (2012), ** own projection based on annual growth rates.

3.5. Characteristics of existing land use and the issues in Lubigi catchment

The main land use in Kampala generally include: residential settlement, industrial plots, commercial, open spaces, agriculture, and wetlands (Nyakaana et al., 2007). These land uses are on land under the Mailo, Freehold, Leasehold and Customary tenure systems in a most complicated manner influencing planning and controlling development in the city (Nyakaana et al., 2007; UN-Habitat, 2007).

Residential housing is among the most intensively increasing land use located on different parts of the city. Following the rapid population growth as discussed in the preceding section, the demand for housing is exceeding any other time in the city since the time the "Uganda Government has facilitated macro-economic stability, economic liberalization, security, infrastructural development, constitutional land tenure reform which have greatly improved the performance of the sector" (Nyakaana et al., 2007). According to the authors, this causes the spreading of unplanned residential housing development at the peripherals of the city forming fast growing slums, particularly around institutional facilities including Kikoni, Katanga, Kivulu, Kagugube slums around Mekerere University while the Central Business District (CBD) has been changed into shopping arcades, hotels, apartments and office buildings.

The industrial land use has significantly influenced the natural environment and the structure of the city; being a centre for employment both for the population in and outside of the city (Nyakaana et al., 2007). According to Nyakaana et al. (2007), the industrial land use has both informal and formal nature accommodating 93 per cent of the county total industrial area in parts of the city, in which Nakawa and Kawempe are the two hot spots and the industrial development has conversely attracted by the liberalization of investment and macro-economic policies.

As a result of the uncontrolled and unplanned industrial and residential development, the agricultural and wetlands, such as Lubigi which contains the largest wetlands in the city are under extreme pressure (NEMA, 2009; Nyakaana et al., 2007). According to Nyakaana et al. (2007) the wetlands, such as Nakawa-Kyambogo, Nalukolongo, and Kinawataka wetland, between Nakawa, Ntinda and Kireka, and part of Nalukolongo are consumed by industrial developments, while Ndeeba, Bwaise areas, Nateete and Katanga in Wandegeya among others are consumed by housing construction and other socio-economic activities.

4. DATA AND METHODOLOGY

4.1. Introduction

This chapter is mainly devoted to provide the overall research methodological approach and data analysis details that underpin the study. After providing briefs on data sources and the data quality issues, it describes the research methodology adopted to attain the objectives of the study and explain the details of data analysis and processing on the main phases of the research progress. The chapter also provide summary on possible sources of errors in the courses of the study process.

4.2. Data source and qualities

The data used during the courses of this study are accessed from two main sources: ITC's data archive and field work survey. Most of the spatial data are obtained from ITC's data archive. While some of them are raw data (not processed) and generated by own data processing, a number of other data are derived from these originally processed and available data. The remained spatial and information data were collected through field survey, later from which other substantial data are derived. Table 4-1 below shows an over view of lists of all data used in the study along with the data sources and the data characteristics. Generally, lists of provisional required data were collected from both primary and secondary data sources.

4.2.1. Primary data collection

To collect primary data, such as qualitative information and expert opinions that cannot be derived from the secondary data, but are most important elements to determine the relevance of the proposed analysis, questionnaire method was chosen and deployed. Questionnaires were prepared before field work and distributed to key informants and experts (Appendix-C). The questionnaires mainly aims: 1) to evaluate the significance of the collected probable driving forces of LCC to the context of study area, 2) to determine the relevance of the proposed scenarios as well as to identify possible future growth location in the study area. The key informants were local people and experts selected from various institutes of KCCA and experts from academic staff (Appendix-G Table 8-7). The key informants from KCCA includes: KCCA physical planner, Kawempe division environmental officer, and the representatives of the parishes' development committee (who possess local knowledge and are responsible for development control in the selected parishes). The academic staffs were selected from Mekerere University and include a specialist (who has done a significant research on various issues related to the urban growth and the land covers of the Kampala city) and students (from department of geography who have participated in the preparation of land use map for 2010).

Apart from questionnaires, combinations of formal and informal discussions on various issues of urban growth of Kampala; issues related to the urban development and flood in the study area in particular, were held with different groups of people collected from various institutes in the city. The informal discussion was conducted with a group of committee from National Slum Development Federations (NSDFs). The formal discussion on a workshop was spanned for a day with various expertise, specialists and local people invited from various institutes. As a main source of information, the discussions were very essential to gain deeper understanding of the issues of urban growth of the Kampala city (opportunities and impacts) over time.

4.2.2. Secondary data collection

Most of the secondary data were compiled during pre-field work phase of this study. The datasets, which include: building footprint of 2004 and 2010, roads network 1993 and 2004, and stream (river) lines, are originally processed and available. The data are obtained from ITC's archive. The aerial photograph of the year 2010 and the mosaic image of the year 2004 from which land cover class of the respective years are processed, and the digital elevation model (DEM); from which slope is generated, are also obtained from ITC's archive. The recent population information data is available only for year 2002 and accessed from the 2002 census statistics; Uganda Bureau of Statistics (UBOS) report available online.
All the data are geo-referenced to the same geographic coordinate system; (GCS) Clarke1880 = Arc_1960_UTM_Zone_36N, D_Arc_1960 (Datum), Clarke_1880_RGS (Spheroid). See also Appendix-A, Table 8-1: List of data and data sources used for the detailed description of the data and data sources.

Table 4-1: Summary of lists of the spatial and non-spatial data used in the study.

	Data types	Data format	year	Own derive	Data sources
Spatial	Building footprints	Vector	2004 & 2010	Proportions of built-up	ITC
	Road	Vector	1993 & 2004	proximity factor maps	ITC
	Rivers/streams	Vector	10yrs flood level	Proximity factor map	ITC
	Aerial photograph	Image	2010	Land cover map 2010	ITC
	Mosaic image	Image	2004	Land cover map 2004	ITC
	Land use map	vector	2010	Industrial site locations	ITC &KCCA
	DEM	Raster	2010	Slope map	ITC
	CBD	vector	2012	Proximity factor map	Google earth 2012
	Market centres	Vector	2012	Proximity factor map	Field survey & Google earth
Non spatia	Population data	Table/pdf	2002/2012	Population projection	UBOS/KPDP
	Lists of probable driving factors	Questionnaire	2012	Probable driving forces	Field survey & Literature/Expertise

4.2.3. Data accessibility and quality issues

Although currently there is a great progress, the accessibility of spatial data in cities of developing countries, such as African is not simple (Barredo, Demicheli, Lavalle, Kasanko, & McCormick, 2004). Kampala is not exceptional. Unfortunately, there is no secondary spatial data available about spatial policy, such as maps of protected area and risk zones, and land cover map for the study area. However, there is land use map of 2002 available, which is not verified through fieldwork (as described in the metadata) and therefore cannot be used for the purpose of this study. Land use map of 2010 is currently under planning. Thus, land cover maps for the years 2004 and 2010 are not available and need to be prepared consistent with the building footprints of the two years.

Besides to the inaccessibility of spatial data, the data inconsistences among some of the available data are apparent, as the sources of these data are from various institutions prepared across different periods of time for various purposes. In addition, the difficulty of producing absolute and accurate data from remote sensing data can contribute to the inconsistence in data quality. The variability of the data source could also introduce some errors into the data. Therefore, the compilation of primary and other secondary data requires the establishment of inevitable errors to avoid or reduce the risk of expected errors for further processing and analysis.

Being aware of these issues, to maintain the data quality and inconstancy, the period of study of the LCC of past trends for this research was limited to the year between 2004 and 2010. Most of the required data for this study are available for the period. The data consistency was possibly able to be maintained for this period. This was particularly beneficial to process land cover maps of 2004 and 2010 (see section 4.2.3) at relatively the same resolution (cell size of 0.5 meters). This enable to get comparable information about the land covers at the same scale of analysis. It is also valuable to maintain data consistence between land cover classes and the available building footprints, which were derived from the topographic maps of the respective years at the same resolution. The limitation of the study to this period was also equally important to update the roads data set (see section 4.2.2.). However, it should be noted that the issues of data inconsistence is not new and simple and cannot be absolutely avoided rather it remains in the form of "salt and pepper" as discussed in many literatures. Nevertheless, to maintain the data quality of and consistency, necessary and sufficient steps and decisions were considered referring to relevant literatures and with the help of expertise knowledge as discussed in the respective sections as part of data preparation and processing.

4.3. Land cover maps preparation and methodology

In this study, the land cover maps preparation generally comprises two major steps: the general classification and the detailed classification. The general classification is the classification of land cover maps from remote sensing data. This is referred to as the Level-1 in this study. The detailed classification is obtained by overlying the vector layers of building footprints and roads with the classification at level-1 and this is denoted as Level-2. Figure 4-1 below summarizes the methodological approach to the preparation of land cover maps from the remote sensing data and the vector layers.

4.3.1. Preparation of land cover maps from remote sensing data

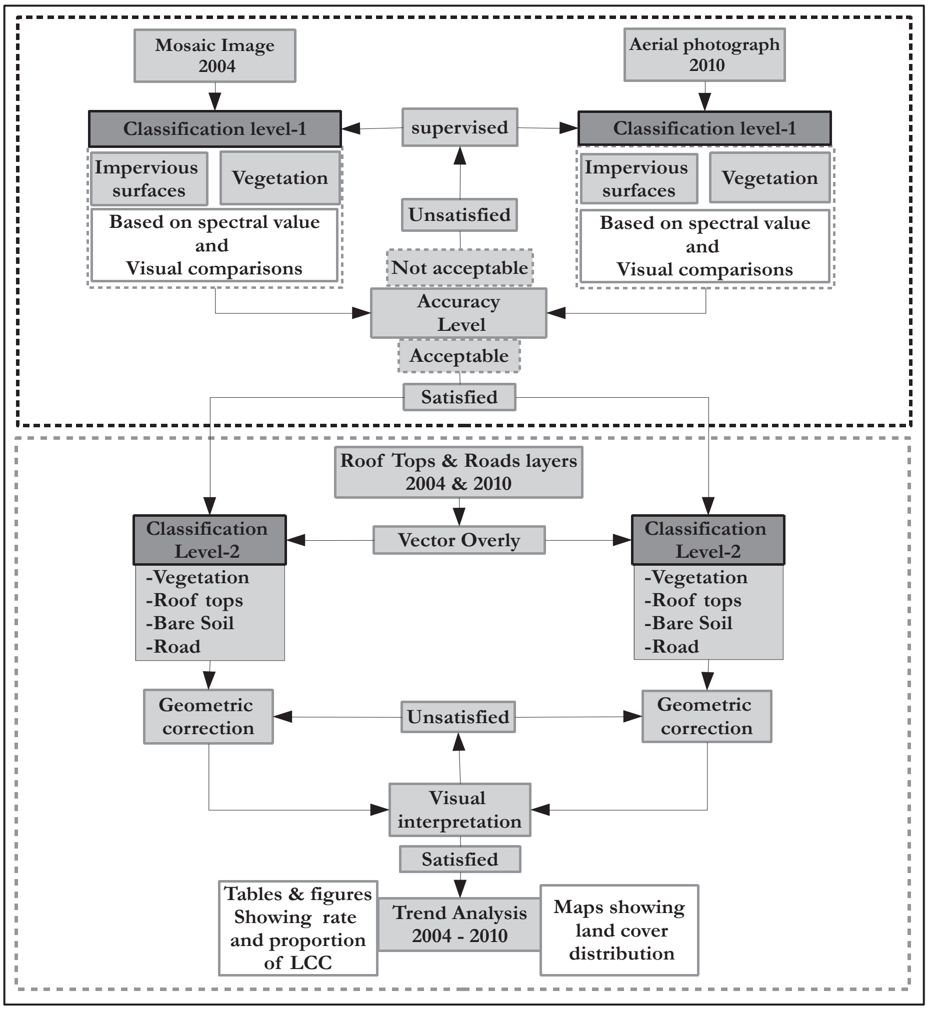
The preparation of the land cover maps of the year 2004 and 2010 are processed at two levels. First, the two major classes: vegetation and impervious land covers were derived from the Very High Resolution (VHR) imagery of the respective years using supervised classification. This is useful to identify the impervious from vegetation to step to next level. In the second level, the two major classes were combined with the vector layers to obtain the detailed classification using vector overlay techniques in ArcGIS environment for each year (Figure 4-1: below).

Land cover map of the year 2004 was derived from mosaic image of 0.6 meter ground resolution (resampled to 0.5m) while the land cover map of the year 2010 was derived from aerial photograph of resolution 0.5 meter using maximum likelihood classification in ERDAS-imagine 2011 software package. The land cover classes for the two years are categorized in to two main groups: (1) impervious, which includes bare soil, paved land, roads, and all built-up structures; (2) vegetation which includes, forests, wetlands and grass lands. This is useful later to overlay it with the available vector layers of the building footprints (section 4.3.2 and 4.3.4). The classification accuracy of the land cover maps was assessed. The classification accuracy for the land cover map 2010 was about 93% while that of 2004 was 83%. The accuracy assessment was performed based on 125 randomly collected ground control points from Google earth 2010 with the help the VHR images. The VHR images were used to validate the reference points.

The obtained kappa index values are 0.65 and 0.85 for the year 2004 and 2010 indicating the random agreement among the assessed maps and the reference points are above 65% and 85% respectively.

Due to problem related to seasonal variation (end or beginning of rainy season; not defined), when the image was taken, the quality of the mosaic image is less. The roof tops and the grass have reddish soil colour similar to bare soil. This makes the classification of the land cover 2004 relatively challenging. The greater similarity in the reflectance of bare soil and corroded roof tops of corrugated iron sheet and the confusion from grass grow on the roof tops of the building as well as the heterogeneity of the coloured roof tiles makes the classification process difficult. As a result, the classification accuracy of the image 2004 was low compared to the 2010. These result in less average kappa index of the classes for this year. Nevertheless, the vegetation and the impervious surfaces were sufficiently classified to meet the objective of this study. Besides to this, to improve the quality of the classifications, majority filter were applied using window size of 4x4 neighbourhood cells for the two maps during post classification. This was useful to merge pixels that are located dispersal with the large class area. The effect of shadow is not taken into consideration during the classification of the land cover maps for both years. Furthermore, as a separate process, to reduce the problem of mix in the built-up with bare soil a number of computations were performed. These are discussed in details in the next section.

Figure 4-1: Process workflow for the preparation of land cover maps



4.3.2. Updating building footprints

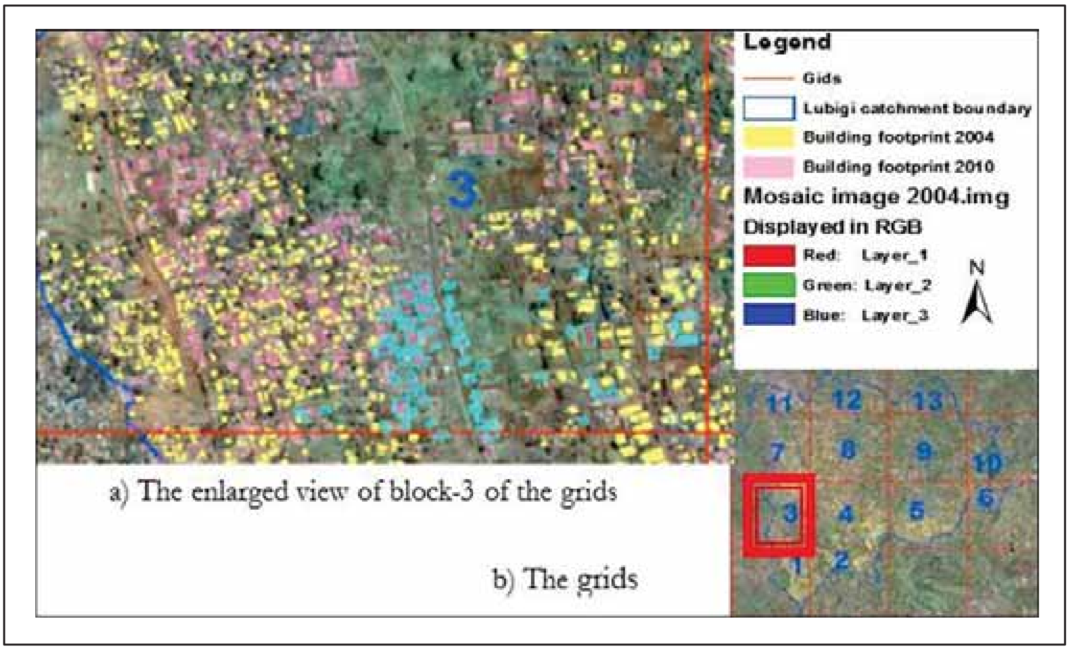
Although building footprints of the year 2004 and 2010 are available, further processing of the data required establishing the inconsistence among them. Using visual comparison of the building footprint 2004 with the VHR mosaic image, it is found that some of the rooftops in the 2004 are not well extracted (missing) while it is relatively well extracted in the year 2010. Some of the buildings that exist in the 2004 are also missed in the year 2010. This might be due to two reasons and need to be maintained.

One of the reasons could be attributed to the error that can occur during the process of extracting the building footprints itself while the other might be due to the removal (demolishing) of the buildings in the 2004 in the period as a result of new development, such as the newly constructed northern by pass road and other cases, such as updating (reconstructing) the structures through the modification of its location. Therefore, maintaining this gap is very essential. This is processed at three successive stages in ArcGIS environment. These are discussed in details in the following few paragraphs.

In the first stage, the building footprints that are missing in the year 2004, but exist on the 2010 were updated. The missed building footprints were refined and extracted manually with the help of a combination of the building footprint 2010 with the aerial photograph of the year 2010, and the building footprint 2004 with that of the mosaic image of the year 2004. The updating process was carried out using of series of steps as follows.

First, the layers of the four aforementioned data are positioned one on the top of the other as follows. The building footprint 2010 is placed on the top of the mosaic image 2004. The layer of the building footprint 2010 (brown) is set to sufficient display transparency so that it is easy to see clearly the building lay-out on the mosaic image 2004. Next, the layer of the building footprint 2004 (yellow) was set to other different display colour to the 2010, so that it will easy the process of differentiating the missed building footprint in 2004 from the mosaic image; placed on the top of the building footprint 2010.

Figure 4-2: Partial view (block-3) of the process of extracting the missed building in 2004



Finally, the missed building footprints in 2004 that are available on the 2010 layer are selected (brown; cyan edged) and exported as a layer. The selections of the missed building footprints are guided with the help of blocks of grids (13-blocks of 2000m x 2000m uniform grid that cover the study area). A block of the girds represents a layer of missed building footprint. This approach was useful to avoid and/or reduce the overpassing of missed building footprints during the selection. Figure 4-2 above shows the partial view of the process of extracting the missed building footprints in 2004 (block-3 of the grid at the right lower corner). To avoid confusion, whenever necessary during the selection of the missed building, the selection processes was further supported by visual comparison of the aerial photograph 2010 with building footprint of 2010. However, some of buildings that are available on mosaic image 2004 are also missed from the building footprints of both years. The updating process for this case was treated in the third stage (see Figure 4-3, and Appendix-C). Some attempt was also made to maintain the geometric inconsistence among the building footprints of the two years. This was computed in the second stage.

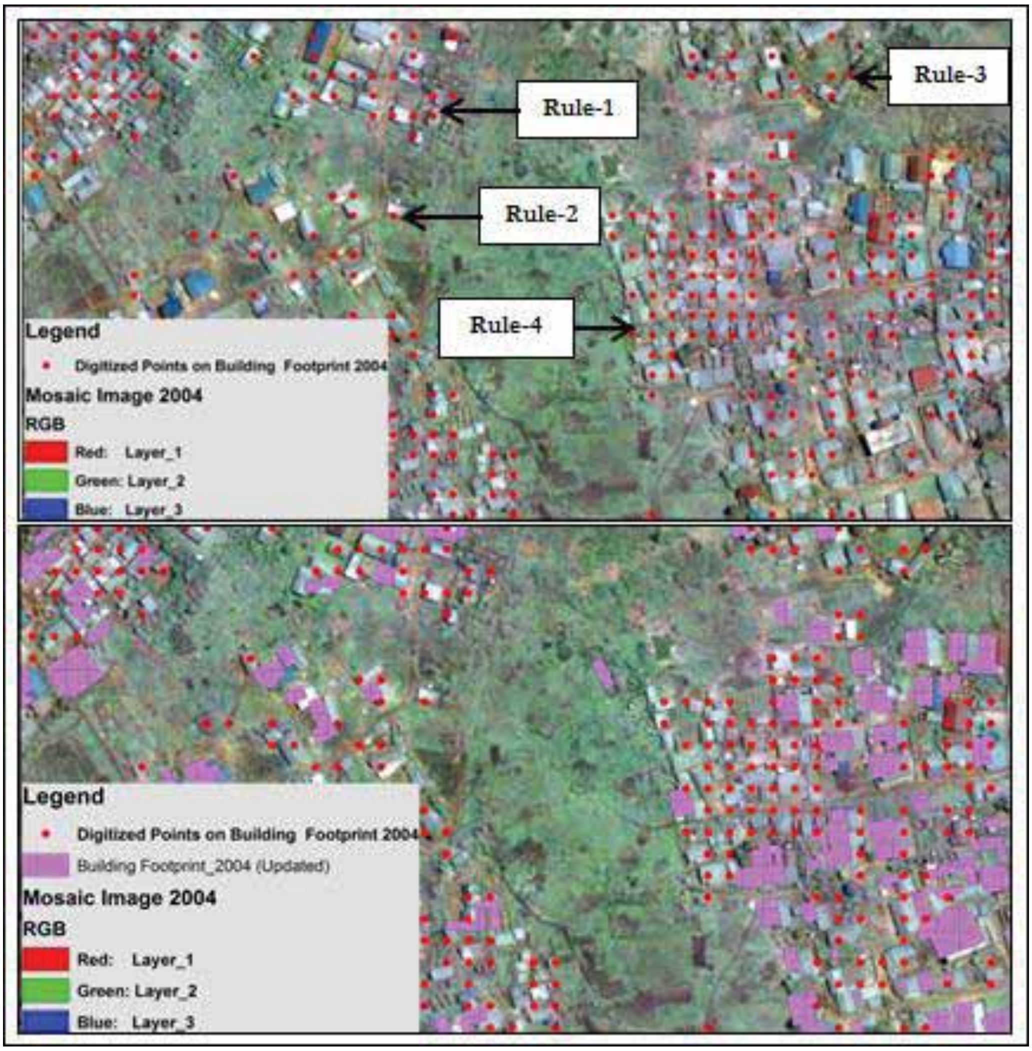
In the second stage, geometric inconsistency and the quality of the building footprints were triggered to be maintained for both years. This is useful to reduce the over or under estimation of built-up areas (building footprints) in the process of analysing the land cover changes. Geometric inconsistence in the building footprints of the two years might arouse from shadows in between the buildings that are extracted as building footprint and the difference in characteristics of the images due to the difference in their sources. To reduce or eliminate this effect some techniques of the data (building footprints) manipulation were applied in ArcGIS environment.

The geometric calibration of the building footprints were processed through the use of overlay tools with the help of both visual interpretation and technical approaches. In the first place, the building footprints for each of the two years were aggregated (dissolved) using the attributes "ID" for building footprint 2004 and building structure "Type" for the 2010. This allows merging the smaller area into one large group. Subsequently, the building footprint 2004 is subtracted (erased) from that of the 2010. The result hence belongs to the change in the built-up area. The 2004 building footprint was then combined with the obtained change in the built-up area to give the updated building footprint 2010. The partial view of the process of maintaining the geometric inconsistence in the building footprints are show in (Appendix-C).

In final the stage of the process of updating the building footprints, the 2004 building footprints that were not well extracted from the image are digitized manually. This is important as many of the building footprints for this year remain un-extracted; particularly in the area of low-laying wetlands and area of old roof topped locations. In the process, both the existing building footprints of the two years and the 2004 classified land cover map containing the two main classes (level-1) were used. The computation process was done through a series of steps in ArcGIS environment. The process of digitizing and the finally updated building footprints for the two years illustrated in Figure 4-3 below (see also Appendix-C).

Initially, the 2004 land covers map that was classified as vegetation and impervious is converted into polygon. The impervious land cover class contains bare soil and built-up are selected. Other land covers classes, such as the different road types were originally erased from this class. Therefore, the impervious land cover assumed contains only the bare soil and built-up (building footprints). The 2004 existing building footprints are erased from the class bare soil and built-up. The remained layer then contains only the bare soil. The detail process of separating the classes is discussed in next section (section 4.3.4).

Figure 4-3: Partial view of the digitized points on the mosaic image 2004



The polygon layer of the class bare soil is converted into a raster layer of cell size 10mx10m.The 10m cell size is selected for computation purpose and assuming that it can represent the smallest building size. The raster layer is converted in to points so that each of the raster cells is represented by its centroid. The points are then located on the top of the building footprint 2004 and the mosaic image 2004 at a time. By using the option "select feature by location" in ArcGIS, all the points that are located on the top of the existing building footprints are selected and excluded from the remaining points to be digitized. This simplifies the process of digitizing the remained points; those points that are located outside the existing building footprints but located on the mosaic image. Accordingly, all the points that are on the mosaic image and meet the following guiding rules were digitized. The defining rules are represented as follows:

Rule-1: If a point is located on the top of the building on the mosaic image then the point is built-up.
Rule-2: If 50% a point is located on the top of the building, then the point is the built-up.
Rule-3: If a point is not located on the top of the building on the mosaic image, but appears to be built-up compared to the surrounding, then the point represents the built-up.
Rule-4: If a pairs of point is located either horizontally or vertically following the gird but not on the top of the building and fulfilling the above rules, then the pair of point that define the building represents the built-up (Figure 4-3above, see also Appendix-C).

In addition, the considerations of other different cases were also made based on the situation of the surrounding cells. The digitized points are then converted to raster of the same cell size as the original. This was finally converted to equivalent polygon to combine it with the available building footprints.

After erasing the layer of the building footprint 2004 and the road layers from the converted polygon; the polygon obtained from the digitized points, the remained layer is combined with the built-up 2004, which gives the finally updated building footprint of this year. In same manner the digitized polygon is updated to the 2010 building footprints due to all the building exist on the 2004 assumed to be also on the 2010. However, some consideration is also made here. The buildings that are located along the northern by pass and do not exist on the building 2010 are omitted (see Appendix-C).

4.3.3. Updating roads networks

The road networks available for the year 1993 and 2004 are used to derive roads data in this study. Road centrelines of the year 1993 are used for centreline references. There is no centreline available for the road layer 2004. Therefore, the 1993 roads centrelines were updated to the road 2004. In addition, some of the road networks for the year 2004 were also updated through manual digitizing from the aerial photograph 2010. The newly constructed northern by-pass roads were also included into the process. Finally all the roads layer were updated to the year 2010 with the help of the aerial photograph 2010. This updated roads layer was used through the entire periods of this study.

The roads type were not clearly defined and categorised in the available road data. The road layer was classified into major roads and minor roads with the help of the aerial photograph. Similarly, these roads network were also further classified as tarmac, gravel and earth roads for the purpose of this study (needed at these class levels for run-off modelling). Finally, the roads were converted into respective polygon layers using the roads centreline as a reference. The dimensions of the roads were measured from the aerial photograph for the respective road types. The widths of the roads were considered to be uniform for the tarmac, gravel and earth road types. However, some variations in the width for the northern by-pass road were considered per segments of the road. Finally, the roads were combined into one layer.

4.3.4. Compilation of the land cover maps

The primarily classified land cover maps (level-1) and the two vector layers (the road and building footprints) were compiled in to a detailed land covers data that includes: vegetation (VG), bare soil (BS), roads (RD) and building footprints (BF). This level (level-2) of the land covers class is required for run-off modelling in the study area. Accordingly, the primarily classified land cover maps (level-1 classification) were combined with the updated building footprints and the road layers for both years separately using vector overlay tools. The classification of the land covers at this detailed level is useful to determine the proportion of the land covers in the study area. The assumption is that the sum of all the land cover types per unit of a cell of defined size summed up to give 100%. This proportion of each of the land covers class: RD, BU, VG, and BS per unit of a cell of defined resolution (e.g. 10m x 10m) can be formulated by the equation (Eq.5) so that the proportion of each of the land cover types per a cell of certain size for the period of 2004 and 2010 can be estimated. These land cover data are useful to drive input data as required in LISEM model using PCRaster environmental software (see section 2.12).

$$RD + BF + VG + BS = 100 \quad (5)$$

4.4. Analysing and quantifiying the LCC in the ULCA 2004 – 2010

The process of analysing and quantifying the land covers and the LCC in the study area are executed in ArcGIS environment. The combination of various land covers data obtained from different sources are used to generate the land cover maps as required in LISEM model, as discussed in the previous sections. In order to predict the future location of the land cover, understanding the composition and trends of the land covers and LCC in the past are essential. The following subsections are therefore devoted to provide the detail discussions on the methodological approaches implemented to quantify and analyse the trends of land covers change and its distribution across the study area.

4.4.1. The composition of the land cover types

The identification of the composition of the land cover types are determined based on the land cover data requirement in LISEM model (see section 2.12). The currently needed data for this specific study is the detailed land cover maps obtained at the level-2. Therefore, land cover classes in the ULCA are identified as vegetation (VG), bare soil (BS), roads (RD), and building footprints (BF) obtained through the combination of the various the land cover data (section 4.2.3). The land cover maps derived from remote sensing data are overlaid with the vector layers of building footprints (section 4.2.1) and road networks (section 4.2.2) for both of the year 2004 and 2010 in ArcGIS environment. The overlying of the land cover maps (containing two classes; vegetation and impervious surfaces) with building footprints and the road layers for the year 2004 and 2010 were employed as follows.

First, the building footprints of the corresponding years were subtracted from the land cover maps that comprise the two main classes derived at level-1. The remained layer hence contains vegetation, bare soil, and roads. Second, the roads of various classes (tarmac, gravel and earth roads) were overlaid with (erased) form the remained layer aforementioned so that the resulting layer contains only bare soil and vegetation classes. Finally, all the layers; building footprints, roads, and the layer that contain vegetation and bare soil are combined (union) in to one layer for each of the two years to get a layer that contains all the land cover classes. This allows computing the proportion of the land covers classes in the study area.

4.4.2. The proportions of the LCC types in the period 2004 – 2010

The quantification of the proportions of the LCC was analysed in the percentage of change in the total land area of each land cover classes in the study area for the period 2004-2010. The proportions of the LCC for the period were calculated through the use of ArcGIS and statistical analysis (Microsoft-excel) (Table 5-1; section 5.2.2). The map of the LCC was produced by overlaying (subtracting) the layers of the two maps (Figure 5-3, section 5.2.2). The LCC map here shows the general change in the land cover from non-built-up (vegetation) to built-up (building footprints, roads and bare soil). The road networks used for the year 2004 remains unchanged through the entire periods of the study. However, the newly constructed northern by-pass road in the time period was considered as an addition for the 2010 land cover map as discussed in previous sections. In the process, there are also some gravel roads in the 2004 that are changed into tarmac road in the year 2010. The proportions of change in the land cover were calculated using the equation (Eq. 6):

$$\left(\frac{A_2 - A_1}{A_1}\ X\ 100\right) \tag{6}$$

Where, A_1 and A_2 are the area of the land cover at the year 2004 and 2010 respectively.

4.4.3. The rate of change of impervious surfaces

The quantification of the rate of change (%) of the land cover types for the year between 2004 and 2010 were calculated by applying the formula (Eq. 7) per year.

$$\left(\frac{Y_2 - Y_1}{Y_1}\ X\ 100\right)/N \qquad (7)$$

Where, Y_1 and Y_2 are the area of the impervious land cover type at the year 2004 and 2010 respectively, and N is the total number of year in the period.

4.4.4. The spatial distributions of the impervious surfaces

The proportion of the spatial distribution of the land cover classes for the year 2004 and 2010 were calculated by using a uniform rectangular grid of area 10m x 10m. The rectangular grid was created in ArcGIS using "create feature" tool (fishnet). The grid was overlaid (intersected) with the land cover maps of respective years. Then, the proportion of each land cover types per unit of the grid cells were calculated as discussed in the previous section (section 4.3.4). The proportional distributions of each class are therefore illustrated (Figure 5-6). The maps were visualized using quantile of five classes. In addition, the classification of the proportion of the land covers (as impervious and vegetation) were computed based on the rules of land cover classification proposed by Thanapura et al. (2007), for the determination of run-off coefficient (Table 4-2). This was convenient to understand the general location of the impervious surfaces in the study area. The maps showing the spatial distributions of the proportion of the land covers were visualized in ArcGIS using the attribute that shows proportion of each class. These maps were visualized in quantile of three class (section 5.2.3; Figure 5-5 a, and b).

Table 4-2: Rules of classification of land covers based on surface characteristics

Land-cover Labels	Rules
Impervious Area	If land area has < 25% covered with areas characterized by vegetative open spaces, then **Impervious Area** If land area ≥ 75% characterized by impervious surfaces (e.g., Asphalt, concrete, buildings), then **Impervious Area** If land area ≥75% covered by bare land (e.g., Bare rock, gravel, silt, clay, dirt, and sand or any other earthen materials), then **Impervious Area.**
Vegetation	If land area < 25% covered with areas characterized by impervious surfaces, then **vegetation** If land area ≥75% covered with vegetation naturally existing or planted [e.g., grass, plants, tree (leaf-on/leaf-off), forest, shrub, and scrub], then **vegetation** Else **Impervious Area**

Source: Adapted from (Thanapura et al., 2007)

4.5. Methodological selection to model the LCC in the study area

The methodological selection of a study of LCC depends on various conditions (Verburg et al., 1999). The data requirement, the purposes of the study, the geographic location of the study area, and the spatial scale of analysis are the primary determinants of the selection of appropriate method in the study of issues related to land cover changes (see for example Cheng & Masser, 2004; Koomen & Stillwell, 2007; Veldkamp & Fresco, 1997; Veldkamp & Lambin, 2001). As such, based on the data requirement for run-off modelling and the available data for the study area a combinations of a number of LCC modelling approaches are selected as discussed in the previous sections of this chapter. All the methodological approaches deployed in the preceding sections are based on the attempts to generate the data required in LISEM model in the process of determining surface water modelling. The main data required for surface water modelling in LISEM model are disused in section 2.12 in details.

The next sections also focus on the process of identifying and determining the key driving forces of the LCC in the study area. After explaining the procedure of input data preparation for LRM and issues of scale selection, it describes the process of quantifying the key driving factors and model evaluations so as to achieve the second objectives of this study. The over view of the justification of the methodological selection of LRM discussed in the previous section (section 2.9.4) is also drawn. The section also discussed the methodological approach to develop scenarios of locations of the built-up land cover in the near future based on the trend growth. Figure 4-4 below shows an overview of work flow and methodological approaches to determine the driving forces of LCC and scenarios developments.

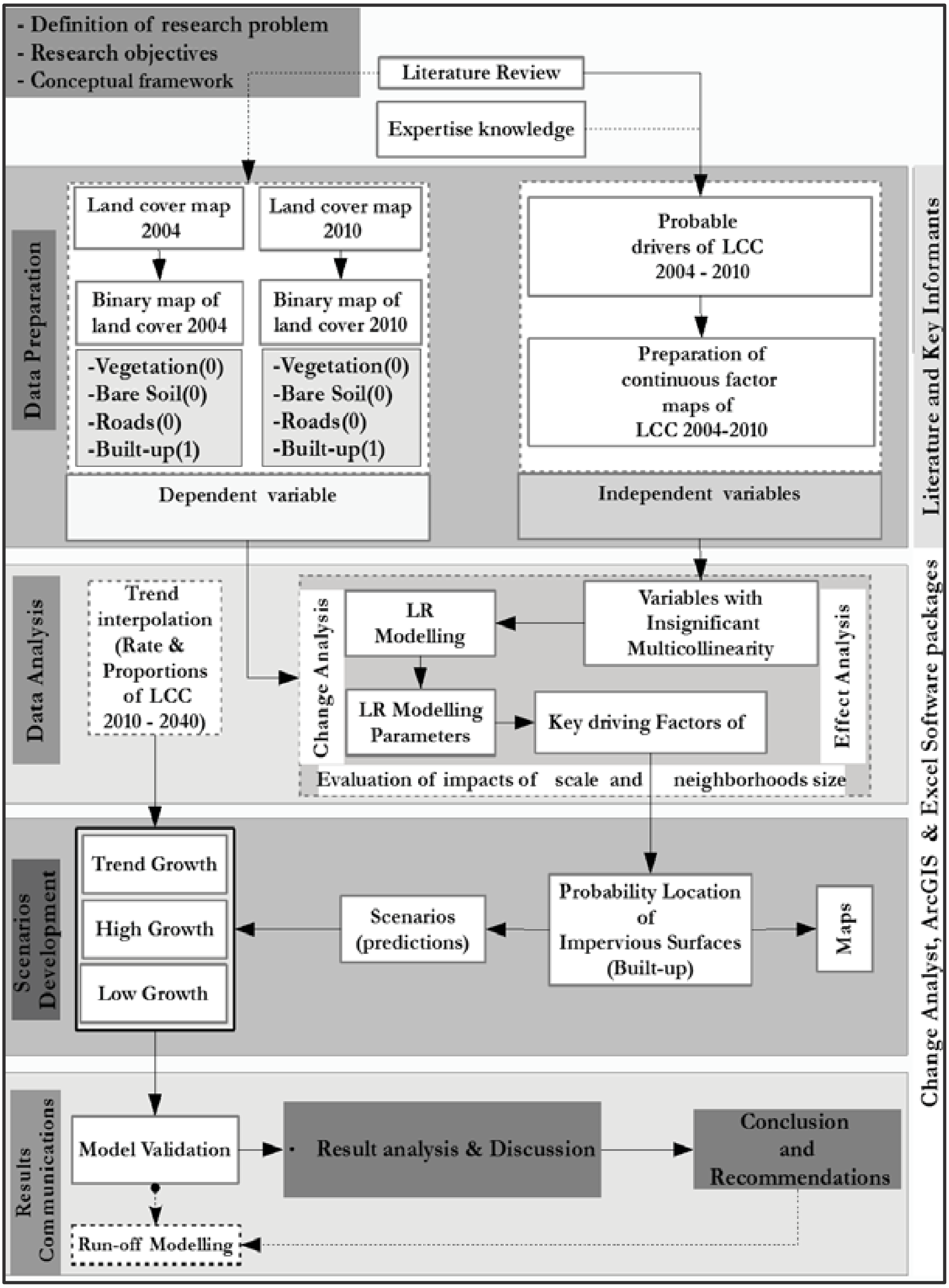
4.6. Determining and quantifying the driving forces of LCC

In the process of determining and quantifying the driving forces of LCC in the study area, a combination of two approaches were applied: (1) consultation of literatures and expertise opinions, and (2), LRM techniques. Qualitative information about the driving forces of the LCC was generally obtained from literature review and expertise opinions (Appendix-D; Table 8-2) and translated into quantitative data with the help of questionnaires survey based on rating scale (Appendix-F; Table 8-4). The questionnaire was used to evaluate the relevance of the driving forces to the study area. Finally, the lists of the driving factors were subjected to LRM to statistically quantify and determine the significance level of the factors as proposed by Cheng and Masser (2003); Hu and Lo (2007) among others. This is valuable to achieve reliable anticipated scenarios development based on trend growth, which later could be used for the prediction of run-off model in LISEM, a separate research project on going currently.

4.6.1. Compilation of the list of factors for LCC modelling

Based on literature review, lists of probable driving factors of LCC were collected (Appendix-D: Table 8-2). The factors were grouped in to three categories: site specific characteristics, proximity characteristics, and neighbourhood characteristics (section 2.5). Evaluating the relevance of the collected driving factors to context of the study area prior to the modelling process is essential as suggested in many literatures (see for example Lambin et al., 2001; Turner & Robbins, 2008; Veldkamp & Fresco, 1997). Therefore, the lists of driving forces were subjected to key informants (section 4.2.1 and Appendix –E, Table 8-3) and the responses of the respondent were rated based on Likert scale (Appendix –F, Table 8-4).

Figure 4-4: Over view of methodological approaches to LRM and Scenarios



Although, the consideration of socio-economic factors are very essential and have significant impacts on the process of LCC (Burgi et al., 2004; Bürgi & Turner, 2002; Lambin et al., 2001), due to the lack of data in these regards, factors considered in this study were limited to only lists of the physical driving forces.

Despite of this, the limited number of variables in a model is also valuable to understand phenomena that involves complex process and to identify the factor that are more attributed to the process (Bürgi & Turner, 2002; Huang et al., 2009). To this end, a list of 14 probable physical driving factors were subjected to endogenous knowledge (local people and expert opinion) via questionnaire method to evaluate their relevance to the study area based on the opinion of local expertise (Appendix-E, Table 8-3, Appendix -D, Table 8-2). During the field work, 20 questionnaires were prepared to be distributed to different expertise selected from various institutes of KCCA and academic staff from Mekerere University (see Appendix-G). However, only 12 questionnaires were able to be completed and collected successfully from the respondents (section 4.2.1 and Appendix-F, Table 8-4).

Although, the numbers of the collected questionnaires are arguably low, the information collected from these respondents was sufficient to evaluate the relevance of the factors to the context of the study area. This was helpful to give the impression that whether the factors are important factors or not to proceed to the process of identifying and determining the key driving factors of the LCC in LRM and later to compare the model result with expertise opinion in the discussion part to further evaluate their agreement and the views of the expertise about the factors.

4.6.2. Preparation of input data for LR modelling

The input data required for LR modelling are identified as dependent variables and independent variables (Table 5-3). The dependent variables are the land cover maps prepared for the year 2004 and 2010 (themes to be explained by the determining factors). They are represented as binary maps (1, indicating presence of change; 0, absence of change). The built-up land cover is given the binary code (1) and all the other land cover classes (vegetation, bare, and the roads) are given (0) code and named "vegetation", assuming that all road classes remain unchanged. However, later after the process of prediction, the road classes are subtracted from the category "vegetation" as it is already developed land in reality. The independent variables are factor maps of the driving forces (determining factors) and all of them are represented as continuous maps with value normalized to the same range (value ranging from 0 – 1 as required in Change Analysis Software package for computation purpose. All maps of the dependent and the independent variables are originally converted to raster maps of 2.5m x 2.5m cell size and masked to the same spatial extent (the study area) to avoid data inconsistencies.

Selection of cell size: after performing a number of models run on various cell size (varying from 2.5m x 2.5m to 20m x20m), which earned less or no significance to a number of variables as the cell size get coarse, the 2.5m x 2.5m cell size was selected. Although, the cell size with10m resolution is required spatial resolution for run-off modelling for the study area in LISEM, the model performance at the 2.5m x 2.5m spatial scale is found significant for all the variables in the model. However, the 2.5m cell resolution is also suitable for the run-off modelling in LISEM (Nearing et al., 2005). Originally, the cell size 2.5m is selected based on the consideration of the cell size of most of the data used in this study. In most cases, the majority of the data used in this case study are derived from VHR imagery (0.5m) aerial photograph (e.g. DEM, building footprints and land cover maps). Therefore, the selection of the 2.5m cell size is valuable to reduce problems related to issues of scaling as suggested by Hu and Lo (2007). All the data were prepared in ArcGIS environment. Moreover, the detail preparations of the factor maps for the independent variables are executed under the three categories: the site specific, proximity, and neighbourhood characteristics.

Site specific characteristics: slope is the only representative of site specific characteristic considered in this study. It is most important factor in determining the nature of urban expansion (Cheng & Masser, 2003). This factor map is generated from the DEM of 0.5m resolution and represented as a percentage.

Proximity characteristics: these are represented by distance to major roads, distance to minor roads distance to industrial sites, distance to streams, distance to market centre, and distance to CBD. Proximity factors are primary causes of urban expansion (Cheng & Masser, 2003). The recent study of Vermeiren et al. (2012), indicate that at the Kampala metropolitan level proximity to CBD, existing built-up and major roads are significant factors influencing the city growth between the year 2003 and 2010. As agreed by expertise (see Appendix-F) most of these factors are considered to be significantly impact the patterns of urban development in the study area.

To this end, two categorise of road layers: the major and minor roads are identified from the updated road data. The newly constructed northern by-pass road between the year 2005 and 2009 was digitized manually with the help of the aerial photograph 2010. Moreover, all the road layers assumed to remain unchanged for the entire periods of the study. The market centres that are located within and/or adjacent to the study area (assumed to have influences) are identified and digitized with the help of expertise and Google earth during the field work. The locations of each industrial site, located within and/or around the study area (Appendix- H, Figure 8-5), were generated from land use map 2010 and represented by a corresponding central point (median of each block of industrial sites). For both CBD and industrial site the nearest distance to the existing built-up are calculated. The factor map for all other proximity factors are calculated from the respective layers based on Euclidean distances measured to the selected factor (Huang et al., 2009).

Neighbourhood characteristics: these include two factor maps representing proportion of built-up and proportion of non-built-up in the base year 2004. They are prepared to incorporate the effects spatial interaction between developed and undeveloped area around a central cell of circular neighbourhood of radius 7 cells containing a cell size 10m x 10m. The most commonly used neighbourhood window size in the studies of simulation models range from 3 x 3, 5 x 5, or 7 x 7 (Hu & Lo, 2007). In most of similar studies, the 7 cell radius window size is preferred to define neighbourhood size; for instance Cheng and Masser (2003) with cell size of 10mx10m, Hu and Lo (2007) with cell size 20mx20m.

4.6.3. Executing LR modelling

To recall, LRM has been used to model the connection between the driving forces (independent variables) and the LCC (dependent variables) based on historic data. As it is mentioned in the previous section (section 2.9.4), it also used to identify the influence of independent variables by statistically computing a degree of confidence about their contribution (Hu & Lo, 2007). Mathematically, logistic regression model can be given by the equation (Eq.3) discussed in section 2.9.4. This technique is a multivariate estimation method in examining the relative strength and significance of the explanatory variables and can be also explained as (Hu & Lo, 2007):

$$\mathrm{p(y)} = \frac{1}{1 + e^{-(a + b_1 x_1 + b_2 x_2 + \cdots + b_m x_m)}} \tag{7}$$

$\mathbf{P(y)}$ is the probability of a dependent variable $\mathbf{y}$ to occur, as the function of the base natural logarithms $\mathbf{e}$, a constant $\boldsymbol{a}$, a coefficient attached to explanatory variable the $\mathbf{b_m}$, and an explanatory variable $\mathbf{x_m}$.

4.6.4. Multicollinearity analysis

Multicollinearity occurs when one or more of the independent variables are linear related to each other's (Field, 2009). Thus, analysing the effect of spatial correlation among the independent variables is very essential (Cheng & Masser, 2003; Huang et al., 2009). The existence of high degree of multicollinearity between spatial factors consequently causes disproportionately high values of standard deviation of regression coefficients in the model (Cheng & Masser, 2003; Field, 2009). This can lead to wrong interpretation and conclusion of the models result. Therefore, it is essential to eliminate the variables with high degree of multicollinearity in the LRM (Field, 2009; Van Dessel et al., 2008). This can be done by applying Variance Inflation Factor (VIF) test (Field, 2009), expressed by the formula:

$$\mathrm{VIF} = \frac{1}{1 - \mathrm{R}^2} \qquad (8)$$

where, R^2 is a square of standard error of the explanatory variables, the explanatory variables with VIF greater than 10 indicate the existence of multicollinearity among the variables (Field, 2009). Therefore, only variables with VIF less than 10 will be incorporated in to the model. Hence, multicollinearity analyses were performed for the sets of the independent variables to evaluate the degree of spatial correlation among them.

4.6.5. Sampling scheme

Once spatial correlation between the independent variables were established, it is also equally important to deal with spatial autocorrelation across or with in the dependent variables (Cheng & Masser, 2003; Irwin & Geoghegan, 2001). As its name indicates, the spatial dependency among variables arouses from the spatial contiguity "adjacent-neighbour" (Bell & Bockstael, 2000). This is sated as "everything is related to everything else, but near things are more related than distant things" Tobler's first law of geography. This can affect the results of analysis and lead to conclusion of accepting wrong hypothesis; as regression coefficient and significance level are highly sensitive to the effects of neighbouring cells "sphere of influence" (Bell & Bockstael, 2000; Irwin & Geoghegan, 2001). The sources and levels of the problems of spatial dependency can vary with the estimation of sampling sizes (Bell & Bockstael, 2000). For instance, the higher the sample results in the higher variation in the values of the variables hence help to reduce the spatial auto correlation among the variables. Therefore, the selection of sampling size and sampling approaches in representing the population size involved in the interaction is very essential.

In LRM, the two commonly used approaches are either systematic sampling or random sampling. These are sampling schemes designed to reduce spatial autocorrelation in LRM (Cheng & Masser, 2003). Systematic sampling is efficient to represent spatial dependence reduction but may lose data on adjacent neighbours if population is heterogeneous while the stratified sampling is efficient to represent a population but not to reduce spatial dependence (Cheng & Masser, 2003; Huang et al., 2009). To this end, in this case study, to determine the optimal window size at which the model can perform good systematic unbalanced sampling method was preferred and performed. This has allowed to repeatedly perform and evaluate the searching for a matrix of widow size (varying from fine; 2x2 to coarse; 20x20) that good fit to estimate the maximum likelihood model as suggested by Bell and Bockstael (2000).

4.6.6. Logistic regression parameters

The empirical parameters in LRM that can be used to describe the influences of independent variables to explain the dependent variable includes: coefficient $(\mathbf{b}_m)$, odds ratios, chi-square statistics and T-Wald statistics ($\mathbf{z}$-value) among others.

Parameters of the models $(\mathbf{b}_m)$:

These are the coefficients of explanatory variables estimated from LRM by applying maximum likelihood algorithm to determine the best fit of the explanatory variables in explaining the occurrence of the outcome variable (Cheng & Masser, 2003; Huang et al., 2009). According to Cheng and Masser (2003); and Huang et al. (2009), the (+) positive and (-) negative signs of the coefficients indicates the nature of correlation of the explanatory variables to the dependent variable.

Odds ratios:

These are parameter used to estimate the nature of relation of the explanatory variables to the dependent variable from their coefficients in explaining the occurrence of the dependent variable. They are described by the ratio of an event occurring in a model of a group of explanatory variables compared to another model group and it is expressed as $\frac{\boldsymbol{P}(\boldsymbol{y})}{\mathbf{1}-\boldsymbol{P}(\boldsymbol{y})}$. They are odds of the model's successful performance. The value of the odds range from zero (0) to positive infinity. It increases with the increase in the value of the coefficients or decreases otherwise. The odds value greater than one (increase in odds ratio value), implies the increase in the chance of occurrence of the dependent variable.

Chi-square statistics:

Chi-square is the parameter that can be used to evaluate goodness of fit of LRM. It is used to indicate accuracy or reliability of the model (Cheng & Masser, 2003; Huang et al., 2009). It used to test whether the variables are associated with the outcome of the model or not. Statistically it can be described by the formula:

$$\mathrm{x}^2 = \sum \frac{(\text{observed count} - \text{predicted count})^2}{\text{predicted count}} \qquad (9)$$

Where x^2 stands for chi-square, observed and predicted count are observed and predicted values of the same cell in the model respectively.

The larger the value of the chi-square implies the explanatory variables have significant influence on the model outcome. The assumption of the null hypothesis, (H_0) that all the explanatory variables are insignificant (has zero value of coefficients) to explain the dependent variable, hence, can be statistically verified by comparing the corresponding p-value estimated with the selected significance level ($\propto$). In this case study the selected significance level is, $\propto = 0.05$ and confidence interval (CI), is 95%; as the model was built on the base of these assumptions. If the estimated p-value is less than the selected $\propto$, then H_0 is rejected implying that there exist at least one explanatory variable that has an influence on the outcome of the model (Field, 2009).

T-Wald statistics (z-value):

These are parameter obtained by dividing the value of a regression coefficient of the variables to their respective standard error. Wald statistics are used to test the significance of explanatory variables to explain the dependent variable (Cheng & Masser, 2003; Hu & Lo, 2007); they are used to evaluate whether the coefficient of an independent variable is significantly different from zero. If the values are significant, the variables contribute to the model outcome.

$$Z = \frac{b}{SE_b} \tag{10}$$

Where Z is Wald statistics, b is a coefficient of the variables, SE is a standard error the respective variables

4.6.7. Model evaluation

As model evaluations is an essential aspect of modelling process, the evaluation of the model was executed based on the Percentage of Correct Predictions (PCP) among a number of possible measures available to assess models reliability and performances. In most literatures of similar studies, the commonly used approaches are: 1) Percentage of Correct Predictions (PCP), for example used in Huang et al. (2009), 2); (Berling-Wolff & Wu, 2004); Cheng and Masser (2003), Relative Operating Characteristics (ROC) used in Verburg, van Eck, et al. (2004); Dubovyk et al. (2011), and 3), Cohen's Kappa, used in Verburg et al. (2002); Millington, George L. W. Perry, and Rau´ l Romero-Calcerrada (2007); van Vliet, White, and Dragicevic (2009), measures amongst others. The next paragraphs discuss few of the characteristics of these measures explained in the various literatures.

Percentage of correct predictions (PCP):

The PCP measures is the central and the most widely used measure of accuracy assessment (Foody, 2002). It is a measure of the percentage of total number of correctly predicted against the ground (real) reference data computed based on contingency table. Although, there is no single universally accepted measures exist to assess accuracy of a prediction or classification, the confusion matrix approaches, such as PCP are preferred among most researchers as it is based on the assessment of perfect co-registration of data set Foody (2002). PCP measure gives a quick indication of the model performance and it is available incorporated with the Change Analyst Software package used to execute the regression modelling for this case study.

Relative Operating Characteristics (ROC):

ROC also known as "receiver operating characteristics" is performance graphing technique used to evaluate and compare algorithms (Fawcett, 2006). It is a graph curve plot on a two-dimensional plane in which correctly classified and wrongly classified values are plotted along the Y-axis and X-axis respectively, and the area under the ROC curve indicates how well the classification are performed to represent the expected value (Fawcett, 2006); probabilities assigned to the locations to be correctly represented as built-up in this case. It equates the value of the actual map with the simulated probability map through a succession of 2x2 contingency tables (confusion matrix) and calculate ratios of true-positives and false-positives values that are plotted in the form of graph curve (Fawcett, 2006).

As discussed in a deep detail by Fawcett (2006), these values are compared to a certain threshold (which conceptually vary from $+\infty\ to - \infty$ and need careful analyses to make decision) taken from the ROC space and ranked to accept or reject the assessment. The values of the ROC are therefore, interpreted as the percentage of all possible pairs of cases in the model assigned with a higher probability to a correct case than to an incorrect case. The $+\infty$ produces the point (0, 0) while as the threshold reduced and finally get $-\infty$ produces (1, 1) and these values are rated between 0 to 1 and plotted along the respective axis, as it is aforementioned, so that the value under the cure (area value) will also range from 0 to1 indicating the high (1) to poor (0) classification accuracy (Fawcett, 2006). However, as it was mentioned by the author, no area under the curve has a value less than 0.5 in principle. Moreover, although it able to provide a richer measure of classification performance, ROC methods of performance evaluation has also its limitations in that it is "sensitive to class distributions and error costs, and this formulation of area under the curve as well" (Fawcett, 2006).

Cohen's Kappa (K):

The Kappa statistic is a pixel by pixel statistic measures to assess the goodness of fit between two nominal datasets (van Vliet et al., 2009). It used to assess the goodness of fit between the model outcome and the real land cover map at the end of the simulation period based on K values. The K values range from positive (+1) to negative (-1) indicating the better agreement (+1) and a worse agreement (-1) based on the expected output (van Vliet et al., 2009). However, as it is discussed in van Vliet et al. (2009), K measure is highly dependent on the number of cells that change; a simulation with small changing pixels will result in high K value when the absolute value of K is used. The K statics is also sensitive to locational precisions of pixels in the model; small deviation in location of a pixel will result in incorrect classification of the pixel. Despite of this, K measure can be used for accuracy assessment to evaluate agreement between the modelled map and the real reference map based on a direct pixel by pixel map comparison.

4.7. Prediction of future locations of LCC

4.7.1. Probability maps

The prediction of the probable location of the LCC change was simulated based on the extrapolation of the past trend of change in the land covers for three decades in the future. The extrapolation of the trend was made by setting the simulation option provided with in the Change Analyst model to high probability mode to accommodate the change. The predictions were made by fitting all the significant parameters of the LRM for the years 2020, 2030 and 2040 to explain how the patterns of the growth take place at an interval of 10-years as well. Based on these predicted probability maps and demand calculated from trend growth for various scenarios assumption the possible location of the built-up land was identify on the predicted probability, which is later to be used for prediction of run-off modelling as separate study.

4.8. Scenarios development

In this study, three different scenarios are considered to allocate a certain amount of demand for built-up land onto the predicted probability map. The constructed scenarios are: Trend growth scenario, High growth scenario, and Low growth scenario assumptions. These scenarios are established based on the "Alternative Development Scenarios" proposed by KCCA "Updated Kampala Structure Plan and Upgrading Draft Final Report" (KPDP) September 2012 as well as based on the experts opinion. As discussed in the report, the anticipated scenarios for the Kampala metropolitan area are made to assess the future needs and constraints of the metropolitan based on the consideration of various assumptions, such as in-migration rates and policies regulations at the very detailed level. However, the scenarios considered here in this study are fabricated based on the assumption that the demand for the built-up area is straight linked to the population growth, and hence the building footprints are considered as in the KPDP report.

Certainly, no consideration of demographic and policies issues are apprehended in this case study for the scenarios development. The assumption made here is that the demand for the built-up area can be linearly associated to the population growth. The built-up area referred to this study is also the built footprint. Besides to this, the purposes of the scenarios are here to assign an overall built-up area on the predicted location (section 4.7) systematically. The predicted location of the built-up based on the LRM only gives the probability location map of the built-up in the future based on the trend growth. In addition, all parcels (a unit grid cell) of the land assumed to be fully developed in so doing. Therefore, the anticipated scenarios are aimed at allocating the various projected demand for the built-up area based on the values of the predicted probable location map. The capacity of each parcel of land (grid cells) then can be defined to accommodate only a restricted amount of the calculated demand per unit of a defined parcel size. Hence, the past trend of change in the built-up area is considered to compute the demand for land to construct the anticipated scenarios. The outcomes of the scenarios are thus expected to be used for the prediction of surface run-off in separate research study.

4.8.1. Future demand calculation for built-up land

Based on the annual growth rate of the built-up area in the period 2004 – 2010, the estimated demand for built-up land for the trend growth scenario is calculated using the formula (Eq.11):

$$Y_{t+1} = y_t \ + d(n * 365) \qquad (11)$$

Where, Y_{t+1} is the built-up area at a certain year in the future, d is the daily demand for built-up area, n is the number of year between two time steps, and y_t is the base year (2010).

The projection of demand for the built-up for the remaining two scenarios are thus computed based on the calculation of this initial demand for the trend growth scenario. The next few paragraphs describe the assumptions considered to construct the three scenarios in this study (see also section 2.11).

Trend growth scenario: trend extrapolation also called "business as usual scenario" is calculated based on historical data. The assumption is that past growth rate remains unchanged in the future. It assumes no change in the structure of the underling factors and conditions in general. It considers the probable of future growth with no significant externalities or intervention. It is anticipated to be the feasible scenario for future Kampala, discussed in the KPDP report. The feasibility of the scenario for this case study is also the expectation of the respondents (Appendix –F' Table 8-6). Therefore, the trend growth is extrapolated based on the calculation of the daily demand for land from observed growth in the period 2004-2010. The daily demand for land is calculated by using the equation (Eq.12):

$$d = \left(\frac{Y_t - Y_0}{n * 365}\right) \qquad (12)$$

Where, d is the daily demand for built-up area, Y_t is the built-up area at the year 2010, Y_0 the built-up are at the year 2004, and n is the number of year between the two time steps.

Therefore, by substituting the value of d in to equation (eq.11) the demand for the trend growth scenario at certain year was calculated. This is used as a base for the estimation of demand for the built-up for the other two scenarios at the same point of time period.

High growth scenario: high growth scenario also known as "worst case scenario" is a type of scenario usually constructed based on the assumption that accelerated demographic growth will happen driven by external factors, such as increased uncontrolled birth rate and rural in-migration as well as economic development. Mentioned in many literatures, the population of the Kampala is expected to double itself by the year 2020 (see section 3.4, Table 3-1). According to the report in the KPDP this scenario has relevance for the future Kampala metropolitan. It is also highly agreed by the expertise that the scenario is feasible for this study area too (Appendix–F,
Table 8-6). Accordingly, the demand for the built-up area (building footprint) for this scenario is calculated based on the computed demand for the trend growth and referring to the "Alternative Development Scenarios" proposed by KCCA.

To adopt the assumption made by KCCA to this study, the proportion of the projected building footprint for the long-term period for the three scenarios was considered. The proportion of the projected demand for the building footprint was calculated and compared. Accordingly, it was found that the proportions (%) of the building footprints of the trend scenario to the high and low growth scenarios are about 33% and -23% respectively from the report. Therefore, the proportion 33% is assumed to be apt for the high growth scenario and the -23% for the low growth as well in this case study. However, to estimate the future increase in the built-up for the proposed scenarios, it is mentioned in the report that the scale of population and economic activity affect the scale of the calculated footprint and the gross landmass area to be developed significantly in a diverged way.

Low growth scenario: also called "best case scenario" is mostly based on the assumption that the population growth rate will be reduced. According to the KCCA report, this assumption made based on the birth rate and rural in-migration, administrative reforms, effective development regularisation and appropriate services in all sectors need to be maintained to achieve a balanced urban system. This scenario is less feasible for this case study according to the response collected from the expertise (Appendix –F:
Table 8-6). However, the scenario is projected to see its comparative effect. Hence, in this study the low growth scenario is assumed to be less by 23% compared to the trend growth at the same point in time.

4.8.2. Allocation of the demand

The allocations of the calculated demand for the three scenarios are performed using the ArcGIS extension package known as "CommunityViz planning software". The "Scenario 360" is a powerful analysis and interactive tools of the package used to comprehend planning, site selection and evaluation, and to build-out various analyses among others (CommunityViz Scenario 360 help). To this end, here in this case study, the scenario 360 is used to allocate the calculated demand on the predicted map obtained from the LRM using the flexible and robust option provided by the software; "the allocation wizard" build-out analysis.

To allocate the calculated demand the following procedures are performed. First, a 10mx10m fishnet (grid layer) was created and overlaid with the probability map. Then all the grid areas equal to 80m^2 and above are selected as suitable layer to house the calculated demand. This assumption is made based on the average minimum amount of standard plot size proposed to be occupied by different housing units (own calculation) in the future based on the KPDP report. However, the existing built-up area and other areas that are designate as open space (predefined open areas) were eliminated from this layer (see Appendix-I). The exclusion of the grid cells with area below 80m^2 from the layer was also served as creation of buffer zone between the existing built-up and the land to be allocated. Nevertheless, no other policy restriction or physical suitability of the land is taken into account in the process of allocation.

Second, from the predicted probability map, the probability values of the map are extracted and stored as an attribute to be used to assign suitability value to the suitability layer. Thus, the grid cells with the higher the probability values will have the higher priority to be allocated to accommodate the demand. The extraction of the probability values from the raster map was done through the conversion of the raster layer into vector format. Third, the scoring capacity of each gird cell to accommodate the calculated demand is computed. This was done by adding an attribute table to the suitability layer. In this attribute table, the capacity of each cells are limited to be only 50% of its total (the area of the respective cell). This assumption is also selected based on the maximum amount of built footprint area proposed to be developed according to KPDP report. Finally, in the allocation wizard, allocation of the calculated demand is performed for each of the scenarios using strict allocation order.

4.8.3. Compiling the land cover data for the prediction of run-off by the year 2020 for the scenarios

To assemble the land covers map for the different scenarios, in the courses of preparing the land cover data required for the prediction of surface run-off, the consideration of the increase in the proportion of the bare soil as the result of the increase in building footprint is essential. The underlining assumption is that the increase the amount of settlements in urban area can cause the parallel increase in the quantity of bare soil or paved land. Of course; it should be noted that the causes of bare surfaces can be attributed to many natural phenomenon and human actives, such as outdoor walking paths, construction and domestic waste soil damp, over cropping or grazing, quarrying of sand and clay for construction and pottery works, improperly managed playing ground and various activities on open areas, landslides, volcanic eruptions, eroded soils, fire risk, and others. However, for this case analysis (regarding the scenarios development) the estimation of the bare soil is made by considering only the bare soil that could be generated near to or around the building footprints as a result of activities, such as outdoor walking paths. This could help to estimate the quantity of bare soil in the cells that were allocated only to the 50% of its total area.

As such, to estimate the amount of bare soil that could evolve in the period 2010-2020, the volume of the bare soil in the period 2004-2010 that are around the building footprints of the two years are considered. First, a 10m x10m grid layer was overlaid (intersect) with the layer of bare soil land cover in the study area for both years separately. The 10m x10m grid is selected as the allocation model is desired to be at this spatial resolution. Second, all grid cells that intersect the building footprints were selected. This represents the bare soil around the building footprints for each year. Third, the amount of change in the selected bare soil was computed. Then, the change in the amount of bare soil located around the building footprint is compared to the amount of change in the building footprints in the period 2004-2010. This help to associate the bare soil to be estimated to the increase in the building footprints for each scenario. Finally, the proportional increase in the total amount bare soil is calculated for each of the scenarios (the various increases in building footprints) using the equation (Eq. 13). Therefore, the total increases in the area of bare soil are used to compute the proportion of bare soil in each of the allocated cells for the various respective scenarios. All the computation processes are executed in ArcGIS environment.

$$(A_c * A_{Eb})/A_{Tf} \qquad (13)$$

where, A_c is the area of building footprints allocated to each cell, A_{Eb} is the total area of the estimated bare soil, and A_{Tf} is the total building footprints predicted for the respective scenarios.

4.9. Assumptions and possible source of errors

There may be errors occurred associated with some assumptions and data quality themselves in the courses of data processing. The assumptions that the building footprints are fully extracted and representative of the actual existing roof tops for the period, the consideration of the limited physical drivers as the only causative factors in the LRM, the being the study area is an "island" in which the concern of the influences of neighbouring factors might not be sufficient, and the exemption of data conversion problems to different format to be far may introduce hidden errors. Besides to this, effort made to compensate the lack of data (e.g. manual digitizing of some road and built-up area), the data inconsistences issues as discussed in the previous sections (section 4.2 & 4.3), and cumulative errors that might arise from computation power of the employed soft wares should not be underestimated. The lack of the current data to validate the predicted probability locations of built-up and the lack of reliable method to calculate the projection of demand for land in the cases of scenarios developed and the simplicity of estimating the proportion of bare soil for the scenarios also should be considered.

5. RESULTS AND DISCUSSIONS

5.1. Introduction

This chapter presents overview of methods employed to analyse the land cover and LCC, and the results of the analysis along with the detailed discussions and evaluations of the results. It presents the main research findings on analysing and quantifying the LCC, determining and quantifying the driving forces, prediction of the future growth location of the built-up, and the implications of the growth for urban development and flood management policies in detail leading to the concluding chapter of this study.

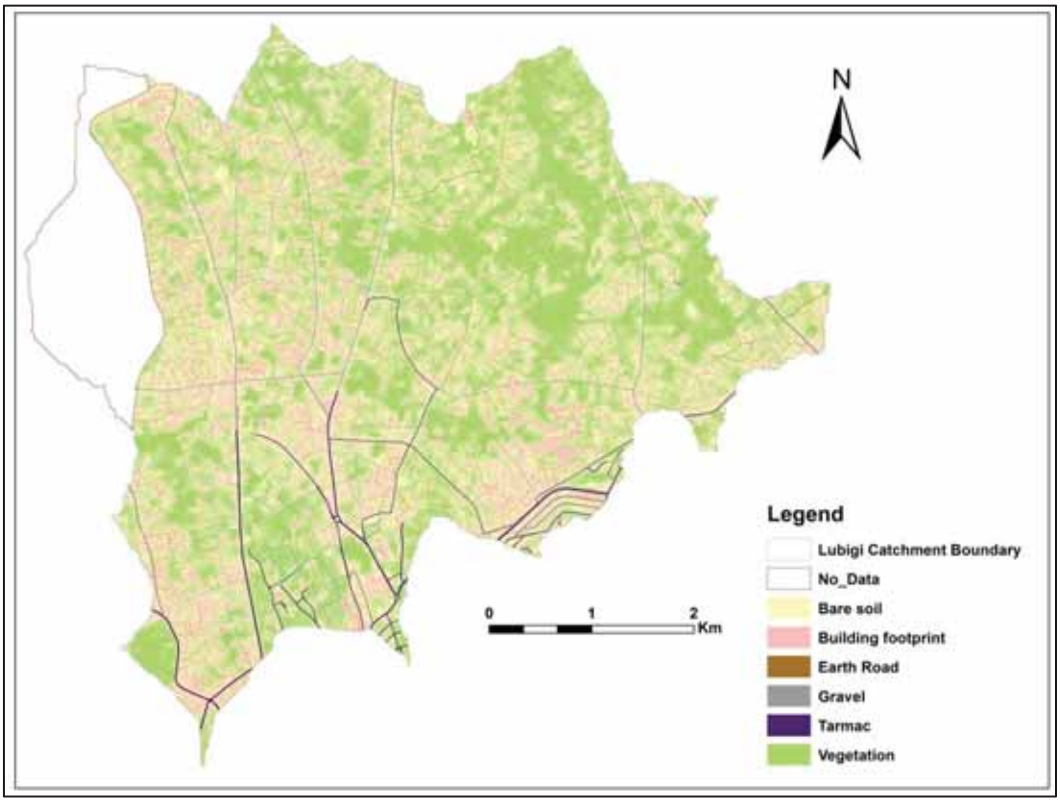
5.2. Quantification of the land cover and LCC in the ULCA in the period 2004 - 2010

5.2.1. The composition of the land cover types

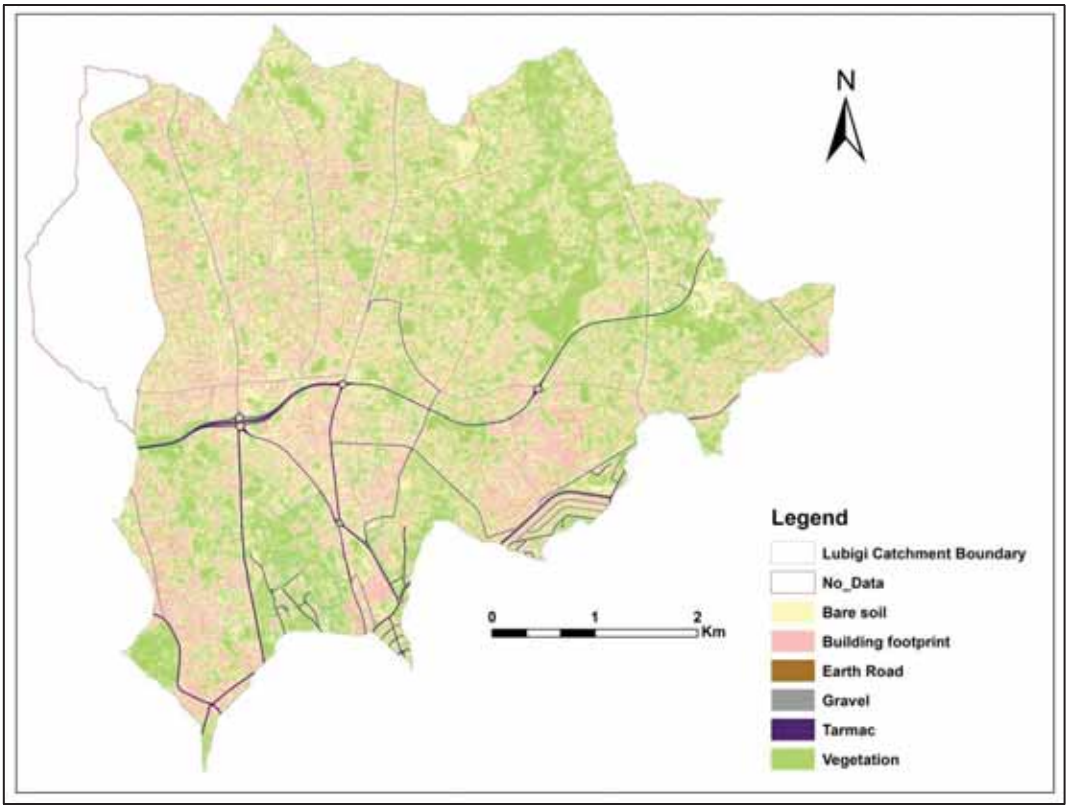
The composition of the land covers in the catchment was identified into six classes: built-up, vegetation, bare soil, earth road, tarmac road, and gravel road (Figure 5-1). The classification accuracy of the land covers maps for both years were reasonably good and sufficient to conclude the result is acceptable. However, it should be noted that there are problems that might arise from the issues of data quality and processing. Although, the land cover maps derived from remote sensing are potential sources of information, it is also judged to be insufficient quality for some operational applications (Foody, 2002; Lu & Weng, 2006). Many researchers underline different possible sources of errors. According to Foody (2002), disagreements among the data and the ground reference are expected to be typical sources of errors; the spatial autocorrelation among the different classes of land cover pixels are also considered to be a problem, particularly during the use of high resolution images to drive land covers data (Friedl et al., 2000). The issues of scale of the image (spatial resolution) from which the data is derived determines the accuracy of the classification (Small, 2004). The temporal and atmospheric issues are also the concerns for the causes (Spruce et al., 2011).

As discussed in the previous section (section 4.3.2) there was some mix of the land covers which can introduce a basis of exaggerating or underestimating the land covers. This problem is expected particularly among the built-up and bare soil land covers due to their complete similarity in some parts of the study area. To maintain this problem, some digitization processes are implemented (see section 4.3.2). It was not easy to overcome the problem owing to the existence of densely populated buildings besides to their high variability in pattern, size and shape in most parts of the study area using the proposed techniques in the aforementioned section. However, the applied technique was potentially sufficient to reduce the effects and has helped to attain more reliable results (Appendix-C). Much of the built-up are classified as bare are able to be extracted and reclassified as built-up. In addition, some of the building footprints that remained un-extracted in the 2004 and exist on the building footprints of the 2010 are also updated with the help of the high resolution images and calibrated for the two years to improve the data consistency. Therefore, the obtained result is sufficient to achieve the objective of this study.

Figure 5-1: Lubigi catchment area land cover class 2004 and 2010



a) Land cover class 2004 derived from mosaic image 2004



b) Land cover class 2010 derived from aerial photograph 2010

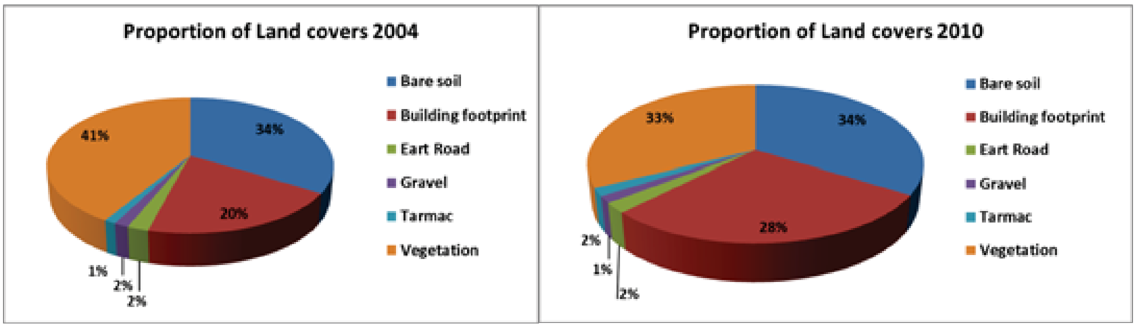
5.2.2. The proportions of the land cover changes in the period 2004-2010

The calculation of the proportion of the LCC for the year between 2004 and 2010 was performed using vector overlay and statistical analysis techniques. The proportions of the LCC for the period were found considerably significant. High proportions of the built-up, tarmac and vegetation LCC between the two years were observed while the other classes were relatively show slight change or remains unchanged (Figure 5-2). The built-up land cover shows an increase in area from about 5.59km² in 2004 to 7.79km² in 2010 while the vegetation land cover shows a decrease from about 11.29km² to 8.89km² conversely of the 27.34km² total area of land in the study area. The gravel road show slight decrease while the tarmac road was doubled in area. The increase in the tarmac road is owing to the addition of newly constructed northern by-pass road. The rest of the land covers relatively remains unchanged.

Table 5-1: Rate of the LCC in the ULCA between the year 2004 and 2010

Land covers types	2004 Area (m²)	2010 Area (m²)	Proportion of LCC in the period	Rate of LCC (per year)
Bare soil	9271850	9280956	0.01%	0.02%
Building footprint	5519610	7789440	41.1%	6.85%
Earth road	570478	570098	0.0%	-0.01%
Gravel	390235	379097	-2.9%	-0.48%
Tarmac	315455	438004	38.8%	6.47%
Vegetation	11286327	8891168	-21.2%	-3.54%
Total	**27348761**	**27348761**	-	-

Figure 5-2: The percentage of the land covers in the ULCA between the year 2004 and 2010



5.2.3. The rate of the land cover changes in the period 2004-2010

The rate of the LCC for the built-up, tarmac road and vegetation land covers were relatively significant in the period. The built-up land cover changes at an increasing annual growth rate of 6.85% contributing to the increase in the built-up by about 41.1% in the 2010 while the tarmac road increased at a rate of 6.47%. The vegetation land cover changes at a decreasing rate of 3.5% during the period. It shows a decreased by about 20.3% in the same year (Table 5-1). The result shows that the nature of the observed LCC is both densification and expansion type. Surrounding the existing built-up in the upper parts of the catchment along the low laying land, more developments were observed in parts of Kawempe I, Kyebando, Kikaya, Bukoto-I, Kanyanya, Kasubi, Kamwokya II, Mulugo III, Kamwokya II, Bukoto II, Bwaise I, Bwaise II, Mekerere III, Mekerere I, Mulugo II, Nakulabye, Mulugo I, Bwaise III and Wandegeya parishes in the form of intensification and expansion while scattered types of both newly emerging settlements are observed expanding on the Bulyera wetlands of Kikaya and Bukoto II, Kawempe I and Kanyanya parishes (Figure 5-3 & 5-4). The pulling or pushing effects of the various factors has role for the LCC.

The impacts of neighbourhood, proximity to road and availability of land appear to be the observable factors for the growth to happen in these parishes. Although, there are no sufficient roads in most parts of these parishes; where the increased in the development are observed, and the land is swampy (not suitable) the developments are much more in these locations than in other parishes both in the form of expansion and densifications in the period along the existing road lines and on the low-laying land. Figure 5-3 and Figure 5-4 below shows the distribution of the LCC in the study area.

Figure 5-3: Location of LCC in the Lubigi catchment area in the period 2004 – 2010

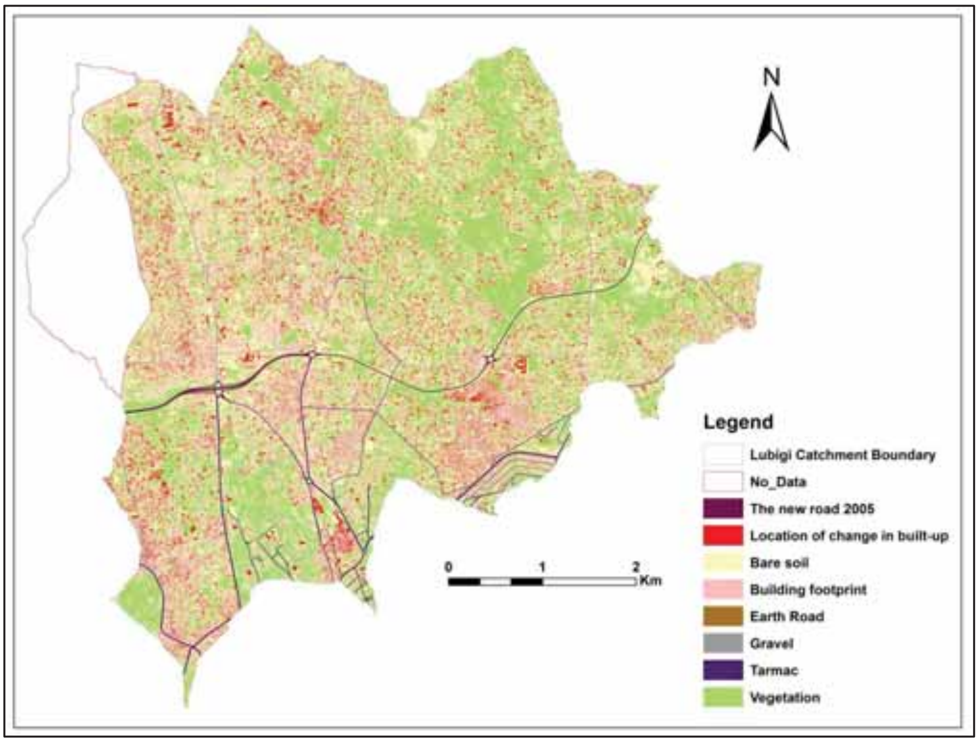


Figure 5-4: Distribution of the built-up LCC across the Lubigi parishes in 2004 - 2010

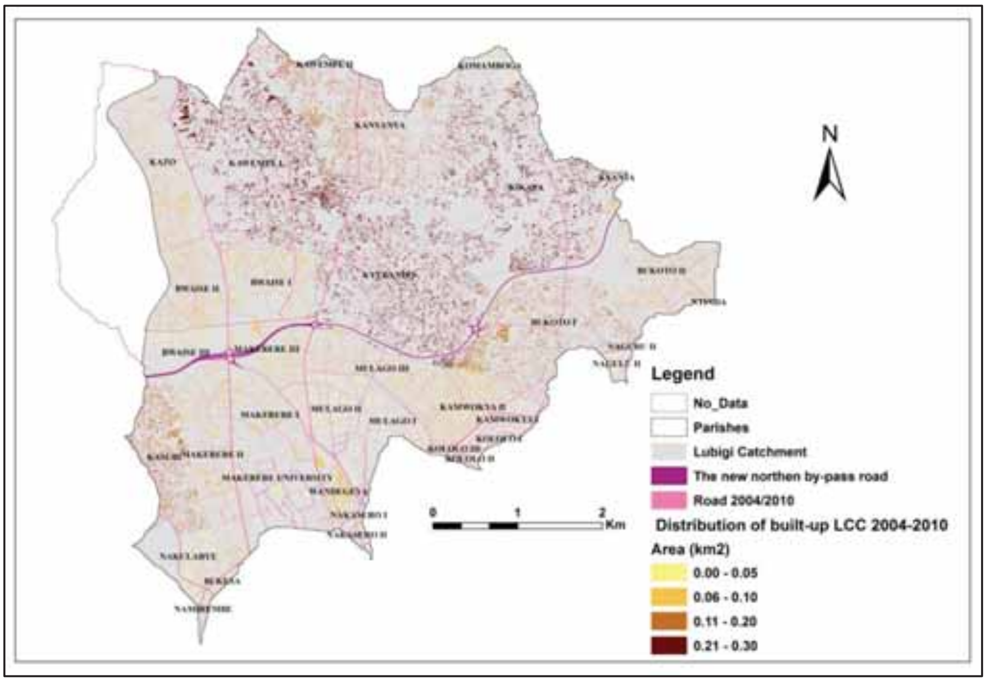
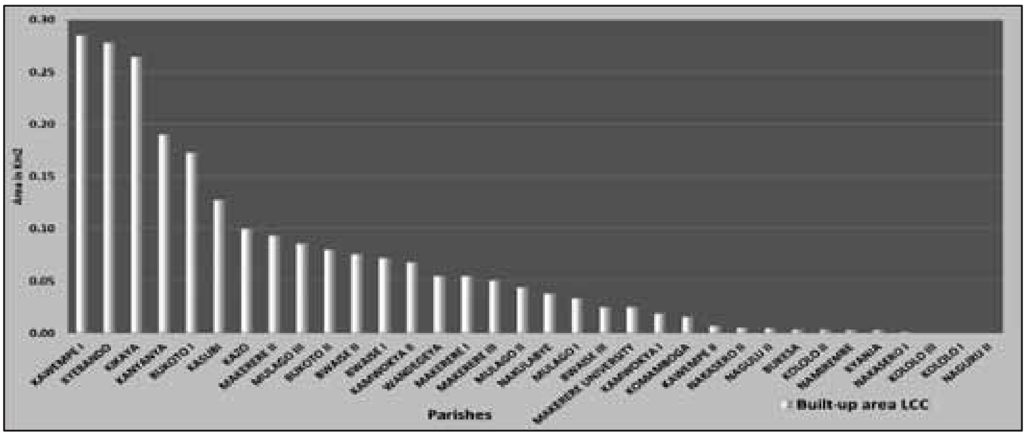


Figure 5-5: Comparison of the distribution of the built-up LCC across the parishes in 2004 – 2010



As it can be observed from the maps (Figure 5-3 and 5-4) and the graph (Figure 5-5) Kawempe I, Kyebando, Kikaya, Kanyanya, Bukoto I, Kasubi, Kazo, Mekerere II, and Mulago III are the most developed parishes accommodating the change in the area of the built-up by 0.29, 0.28, 0.26, 0.19, 0.17, 0.13, 0.1 and 0.9 in kilometre squares respectively between the year 2004 and 2010 contributing about 1.51 km² (66.52%) of the total 2.27 km² observed change in built-up in the period.

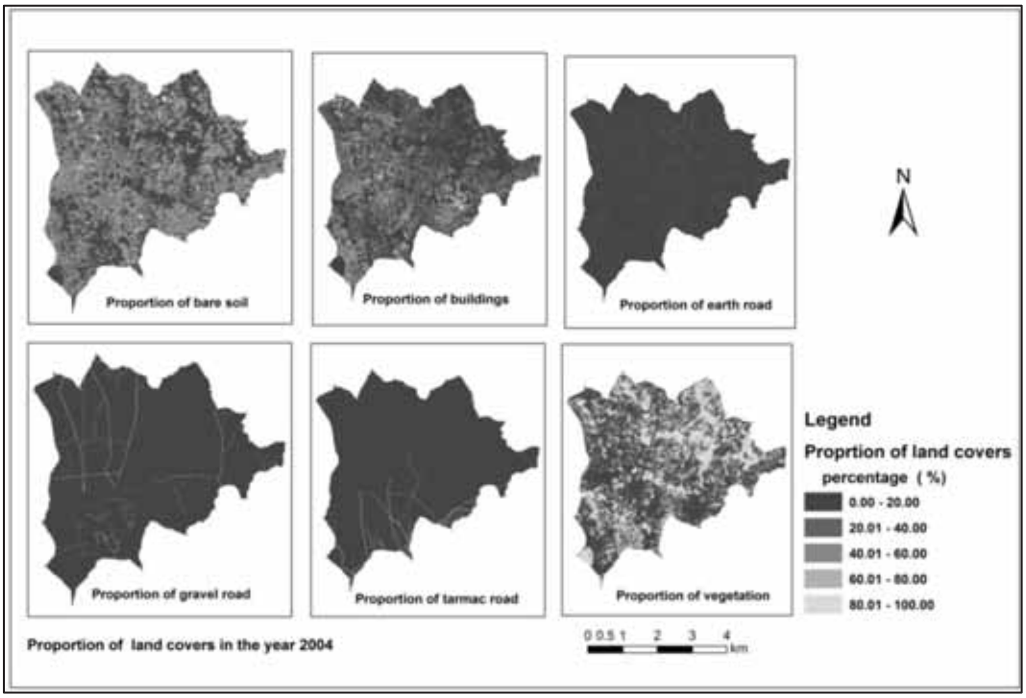
5.2.4. The spatial distributions of impervious surfaces

The spatial distribution of the impervious surfaces were calculated and mapped based on the theoretical assumptions discussed in section 4.3.4. The proportion of each impervious surface: the built-up, bare soil and the roads were computed per 10m x10m grid cells for the year 2004 and 2010. The distributions of each class are mapped in ArcGIS environment. Similarly the distribution of the vegetation land cover was also calculated. The maps are visualized in percentage of five quantile divisions (Figure 5-6 a, and b). This is the information data required to be used to model surface water run-off in LISEM. The result of the analysis shows that the spatial distributions of the impervious surfaces are significant in the year 2010 than that of the 2004 (Figure 5-6 a, and b). Bare soil contributes much of the impervious surfaces in both years. The increase in amount of this naked surface is due to the presence of quarried land for clay searching, open fields for playground, market centres and parking lots that are not well managed, damped soil waste, agricultural land, and eroded mud soil from the quarry and other bare surfaces.

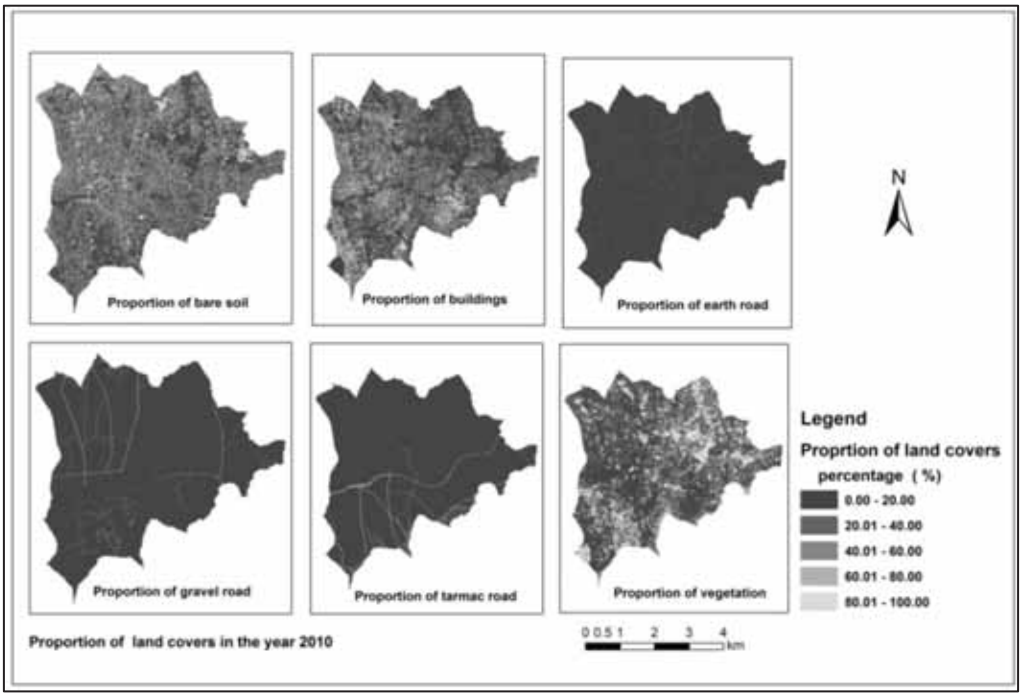
Further, based on the methodological approach proposed by Thanapura et al. (2007), the analysis of the distribution of the land cover classes was employed. The impervious surfaces were classified in to three categories based on the percentage of each of the land cover classes per unit of the grid cell (see section 4.4.4 Table 4-2). This can essentially provide valuable information in mapping the general location of the intensity of the impervious land covers over space in the study area (Figure 5-7). Moreover, this methods of classifying the land covers can be useful to calculate run-off coefficient that could be used as an input parameter in the most commonly used "rational method" for storm water run-off calculation as well storm drainage design and analysis (Thanapura et al., 2007). From the result of the analysis much of the impervious surfaces are located in the upper parts of the catchment, such as Kawempe I, Kyebando, Kikaya, Kanyanya, Bukoto I, and Kazo parishes (Figure 5-8). For instance, in Kawempe-I there is about 2.5km² impervious land out of the 2.90km² total land area in the parish in the year 2010, which is about more than 90% of the total of the area parish. Similarly, Kyebando, Kikaya, Kanyanya, Bukoto I, and Kazo parishes contain about 2.85, 2.34, 1.83, 1.65, and 1.06 km² are covered by impervious surfaces, which account about 84%, 66%, 81%, 84% and 89% of the parishes' respective total area respectively.

In the previous analysis, it was indicated that these parishes are the most developed parishes in the study area in the same year. Kololo-I is the parish with the least percentage of impervious land cover observed (60.3%) in the study area, compared to the total land of the parish. As a whole the result indicates that the increase in imperviousness of the land is highly related to the urban development, which has an implication on the increase in surface run-off.

Figure 5-6: The proportional distribution of each impervious land cover classes in the ULCA

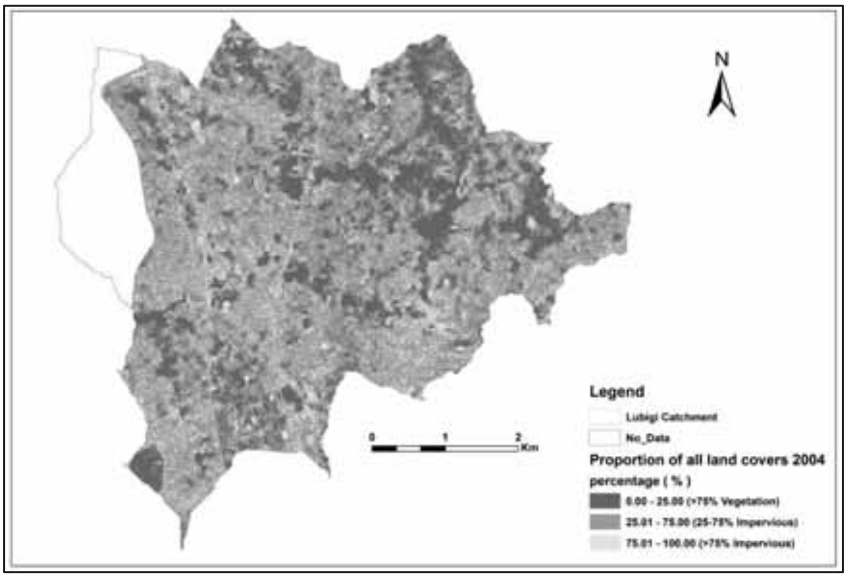


a) Proportional distribution of the impervious land covers classes in 2004

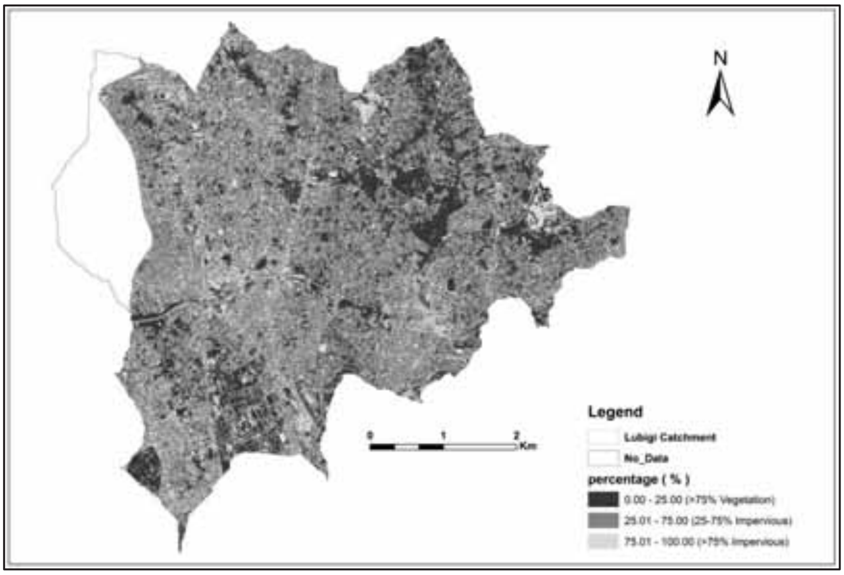


b) Proportional distribution of the impervious land covers classes in 2010

Figure 5-7: The proportional distribution of the impervious land cover class in the ULCA

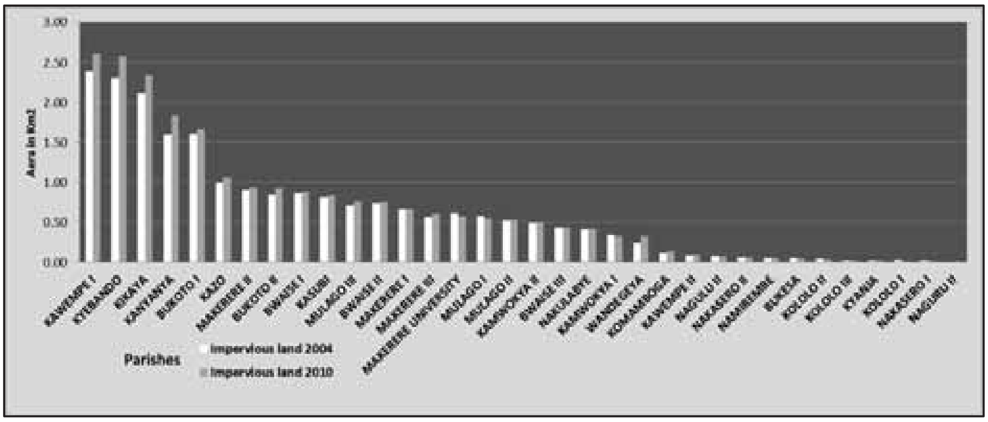


a), Proportion of impervious land covers 2004



b), Proportion of impervious land covers 2010

Figure 5-8: The comparative distribution of impervious land covers across parishes in 2004 & 2010



5.3. Evaluation of the methodological approach and data preparation for run-off modelling

In this study, different methodological approaches were adapted and proposed to generate the land cover data for run-off modelling as required in LISEM modelling platform based on the available data. As discussed in the previous sections (section 2.12, 4.4.3, 5.2.4, and 5.2.1), the land cover information required in LISEM model are at the detailed level of the classification. In LISEM the proportion of each land covers per unit of a cell size varying from 2m to 20m are required in a separate layer as explained in Nearing et al. (2005). The model is very sensitive to the selection of cell size (resolution) and perform better at the lower cell size (Jetten et al., 2003). The model result improved with more spatial information in a given landscape. Therefore, given the requirements of the model, all the methodological approaches implemented and the scales of analysis selected are constructed based on the considerations of the model characteristics.

Although, uncertainties are always inherent in the process of modelling, the methodological approaches proposed and implemented so far sufficiently allowed to prepare the land cover data required in LISEM model. The selected scale of analysis: the cell size 2.5m for LRM (section 5.2.1) and the cell size 10m for the calculation of the proportion of the land covers are found to be suitable complied with the land cover maps, the building footprints, and other data, such as DEM used in this study. In addition, the 2.5m cell size is virtually the minimum cell size required in LISEM model. Subsequently, the land cover data are prepared at the 0.5m resolution. The 2.5m cell size therefore could offer relatively the less aggregated information in the process of determining the driving forces and the predicted location of the LCC. The 10m gird cell was used to calculate the proportion of each land cover types per unit of the cell on separate layer (Figure 5-6). Therefore, it does not have any implication on the composition of the land cover. However, it should be noted that the appropriateness of the cell size are evaluated only in the context of this study. Acknowledged the variability of the data sources and its scarcity for the study area, the obtained result could be used in the quantification of surface run-off in the study area adequately.

5.4. Evaluating and determining the probable driving forces of the LCC

5.4.1. Probable driving factors of LCC in the study area based on expert opinion

According to the response obtained from the key informants except the variable “spatial policy”, all the selected variables have scored a rating score equal or greater than half out of the reference rating score 5; the maximum significance level considered for this study (Table 5-2). Most of the variables scored above 2.5 out of 5 (very significant) but the variables: Master plan, spatial policies, and distance to rivers/streams have relatively scored less. This could be an indication that these factors have the negative influence on the development in the study area, which is not foreseen by the expertise. Luckily, all the variables scored above 2.5 were incorporated in to the LRM, but due to the lack of data to define locational suitability, zoning, distance to bus stops, and master plan these factors are not included in the LRM. It worth good had they were incorporated in to the model. Accordingly, all the remained 9 factors were incorporated in to the LRM. Table 5-2 below shows the rating score and the variables included into the LRM.

Table 5-2: List of variables scores according to the respondents

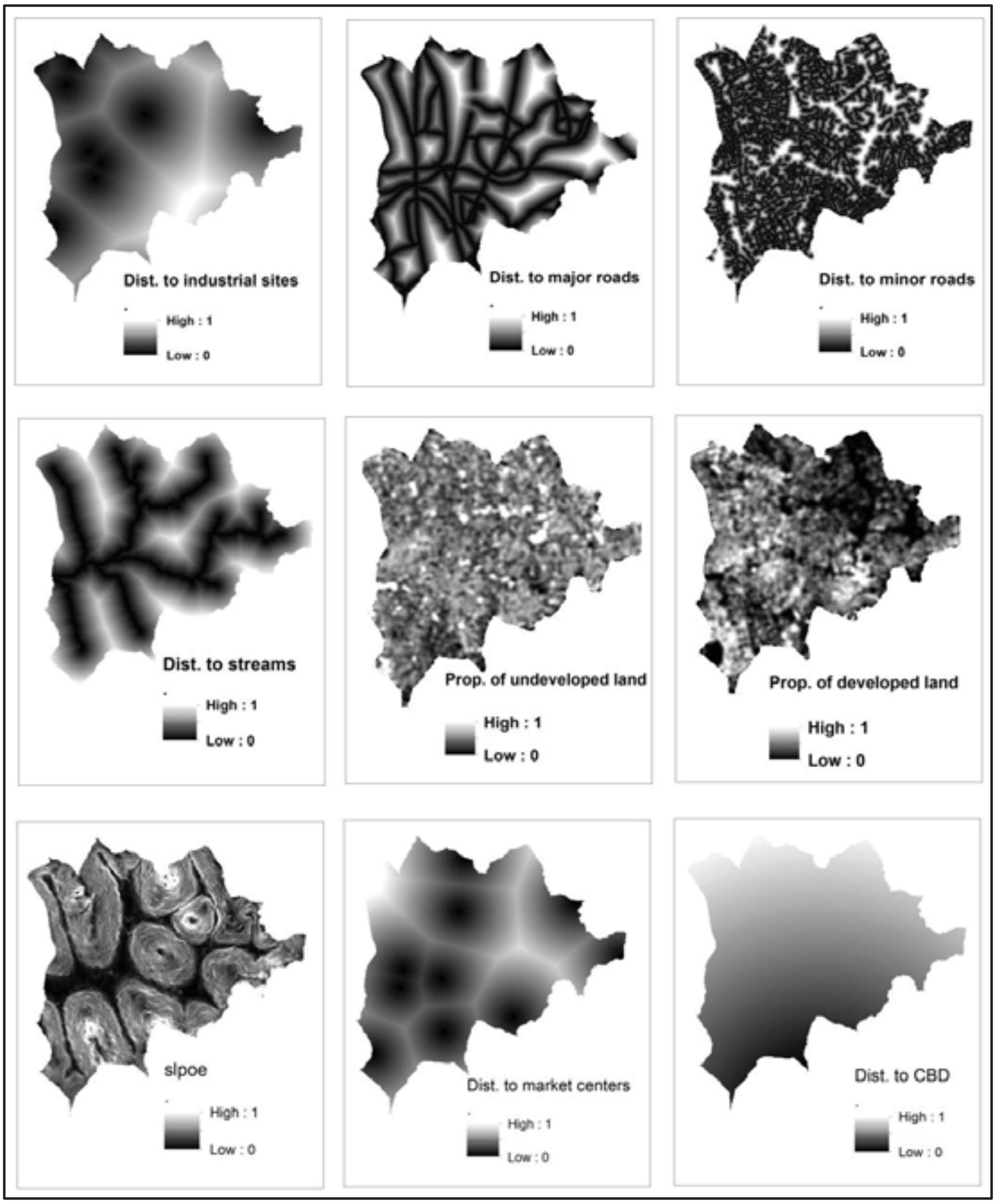
Driving factors		Respondent rating scores: 5	4	3	2	1	Rating Score	Total Respondent	Remark
Site characters	Slope	2	5	1	1	3	3.2	12	✓
	Zoning status of the land	2	2	2	3	3	2.8	12	Not in LRM
	Master plan	1	1	4	3	3	2.5	12	Not in LRM
	Suitability of the land	6	2	3	1	-	4.1	12	Not in LRM
Neighbour hoods	Proportion of undeveloped land	4	3	-	3	2	3.3	12	✓
	Proportion of urban land	5	5	1	-	1	4.1	12	✓
	Spatial policies	-	1	-	3	8	1.5	12	Not in LRM
Proximity characteristics	Distance to major roads	10	2	-	-	-	4.8	12	✓
	Distance to minor roads	3	3	3	3	-	3.5	12	✓
	Distance to industrial sites	2	3	1	3	3	2.8	12	✓
	Distance to minor city centres	3	5		2	2	3.4	12	✓
	Distance to rivers/ streams	2	1	3	1	5	2.5	12	✓
	Distance to market centres	5	5		1	1	4.0	12	✓
	Distance to bus stops	2	2	2	-	6	2.5	12	Not in LRM

In addition to the aforementioned physical factors, there are also other socio-economic factors that were recommended by the respondents to be considered as the drivers of the LCC in the study area. Factors, such as land values, economic development of the individuals, population density, migration rate, presence of social communities and individual preferences are considered to be important drivers of the LCC. These factors are also suggested to be the main drivers of LCC in various geographic regions in many literature (see forexample, Cheng & Masser, 2003; Hu & Lo, 2007; Schneeberger, Bürgi, Hersperger, & Ewald, 2007), explicitly to the study area (Lwasa & Nyakaana, 2004; Nyakaana et al., 2007) among others. However, due to lack of data the factors are not considered in the model. Based on the expertise opinion and data availability the factor maps of the probable driving forces were prepared. Table 5-3 and Figure 5-8 below, shows the descriptions of the variables in the LRM and the factor maps of the independent variables respectively.

Table 5-3: List of variables included in LRM

Types of variable	Variable	Description	Nature of Variable
Dependent	Y	1- Built-up (building footprints) 0 – Vegetation (others)	Dichotomous
Independent	X		
Site specific characteristics	X_1	Slope	continuous
Neighbourhood characteristics	X_2	Proportion of undeveloped land in a surrounding area	continuous
	X_3	Proportion of urban land in a surrounding area	continuous
Proximity characteristics	X_4	Distance to major roads	continuous
	X_5	Distance to minor roads	continuous
	X_6	Distance to rivers/ streams	continuous
	X_7	Distance to industrial sites	continuous
	X_8	Distance to market centres	continuous
	X_9	Distance to CBD	continuous

Figure 5-9: Raster layers of independent variables.



5.5. Determining and quantifying the driving forces of the LCC in LR M

5.5.1. Multicollinearity analysis

Multicollinearity diagnosis was performed for the lists of the independent variables. In many literatures of similar study, for instance (Cheng & Masser, 2003; Dubovyk et al., 2011; Hu & Lo, 2007; Huang et al., 2009; Van Dessel et al., 2008), it is suggested that the analysis of causative dependence among specific factors are very important. Therefore, the VIF was calculated for each of the variables. As the result of the analysis shows (Table 5-4) there was no significant multicollinearity observed among the sets of the variables in the model. All the variables score VIF less 10; the threshold level suggested to deal with the multicollinearity (Field, 2009). Since the lists of the variables are relatively few, the absences significant collinearity is not surprise. Therefore, the entire variables were incorporated into the model.

Table 5-4: Result of multicollinearity analysis

Description	Variable Label	VIF
Slope	X_1	1.257
Proportion of undeveloped land in a surrounding area	X_2	1.295
Proportion of urban land in a surrounding area	X_3	1.269
Distance to major roads	X_4	1.277
Distance to minor roads	X_5	1.291
Distance to rivers/ streams	X_6	1.258
Distance to industrial sites	X_7	1.200
Distance to market centres	X_8	1.196
Distance to main CBD	X_9	1.128

5.5.2. Sampling scheme and scale sensitivity

Sampling is a very important process that needs caution to analyse the influences of factors and effects of neighbourhoods in determining and predicting spatial changes (Bell & Bockstael, 2000; Hu & Lo, 2007; Irwin & Geoghegan, 2001) while the consideration of the scale sensitivity of the variables are also important (Bell & Bockstael, 2000; De Koning et al., 1998; Hu & Lo, 2007; Verburg et al., 1999). To deal with the neighbourhood effect and the scale sensitivity of the model, a number of sampling schemes and scale of analysis were considered by varying the sampling window size from 3x3, 5x5, 7x7 and 9x9 for each of the 2.5mx2.5m, 5mx5m, 10mx10m,15mx15m and 20mx20m grid cells of the model run. The model revealed that the variables are highly sensitive to both the change in the window size to select the sampling size (neighbourhood effects) and the grid cell size (spatial resolution). In this study, the significance of the variables in the model decreases with an increase in sampling windows size from 3x3 to 9x9 for each of the 2.5m x2.5m to 20mx20m grids space in general. For instance, by holding the 2.5mx2.5m gird space size constant, and varying the sampling window size from 3x3 to 7x7, it was found that the values of the odds ratio of the variables X_1, and X_8 ; both significant at p-value = 0.0000, shows slight decreased, but it results in insignificant t-test value of these explanatory variables: 0.8018 and 0.0545 respectively at the defined confidence interval indicating the less predictability of the outcome variable as the effect of these predicting variables (Cheng & Masser, 2003).

To obtain the optimal resolution at which a model performs best different approaches are proposed by different scholars. For instance, Hu and Lo (2007), have proposed the use of fractal dimension analysis calculated form the residual of the predictions. However, according to the authors obtaining true fractal dimension to evaluate the models at all scale are not possible. In this study, the optimal scale at which the model is powerful to predict the change was evaluated on the base of the statistical values, such as PCP cells obtained from the model. To reduce the effects of neighbourhoods, the selection of the sampling size was performed by varying the sampling widow size.

To select sampling size Hu and Lo (2007); Bell and Bockstael (2000) have proposed different approaches. For instance, Bell and Bockstael (2000); Cheng and Masser (2003) have suggested that systematic and unbalanced sampling method is appropriate to deal with effect neighbourhood influence at micro level while Hu and Lo (2007) have mentioned three step approch: applying data aggregation and pixel thinning functions, including spatial coordinates of data points into the list of independent variables, and sampling. In this study, the systematic and unbalanced sampling approach was used to determine the population size in the interaction. After several simulation of the model for all others sampling window and grid cell size combinations, the predictability performance of the variables in the model was obtained best at the 3x3 sampling window size and the 2.5mx2.5m grid space with PCP value of 91.81% (Table 5-6 below).

5.5.3. Logistic regression modelling

LRM was applied to analyse and determine influence of the driving factors of the LCC and to predict future location of the built-up land cover in the study area. LRM is effective method to analyse and understand land cover changes and the influencing factors (Hu & Lo, 2007; Huang et al., 2009; Veldkamp & Lambin, 2001). It is a powerful technique to explore the relationships between the explanatory variables and the dependent variable in spatially explicit manner to determine the observed change as a consequence (Hu & Lo, 2007; Huang et al., 2009). However, the causative effect of these variables depends on various conditions and the case under study. The scale of analysis and the spatial level, (De Koning et al., 1998; Hu & Lo, 2007; Verburg et al., 1999), the temporal dimension; time steps (Cheng & Masser, 2004), context of the geographical region; culture of the specific area under study (Cheng & Masser, 2004; Huang et al., 2009), are some of the factors that influence the significance level of driving forces in determining the observed change. Nevertheless, LRM is valuable to explain the relationship between the driving forces and the LCC that may allow a better understanding of the process in space and time (Hu & Lo, 2007; Huang et al., 2009; Verburg et al., 1999); for urban planners and policy makers (Hersperger et al., 2010). In this study, binary logistic regression model was applied and the model has revealed the significant of driving forces of the LCC form the lists of the variables in the model suggested by literature and expertise (Table 5-2 above). The model result is summarized as follows and the parameters of the model are presented in the Table 5-5 below.

Model summary: Sample size = 4368080, P-value = 0.0000, PCP: 91.81%, Log Likelihood = -125004.8405
Overall Model Fit: Chi Square = 17893.2984, df = 27, Threshold value= 0.102467

Table 5-5: Parameters of factors of LCC

Variable	Coefficient	Standard Error	z-value	t-test(p)	Odds-ratio
X_1	-0.191486	0.092351	-2.073455	0.0381*	0.82573
X_2	-0.757909	0.062346	-12.156570	0.0000*	0.46865
X_3	3.168508	0.047049	67.345343	0.0000*	23.7720
X_4	0.366353	0.026924	13.606951	0.0000*	1.44246
X_5	0.508823	0.044717	11.378683	0.0000*	1.66333
X_6	-0.597565	0.037281	-16.028856	0.0000*	0.55015
X_7	0.400489	0.027835	14.388009	0.0000*	1.49256
X_8	-0.306679	0.036884	-8.314808	0.0000*	0.73589
X_9	0.739585	0.039323	18.807919	0.0000*	2.09507
a	-3.0088	-	-	-	-
a is the constant , *Variables are significant at α =0.05					

The result of the LRM indicated that all the factors in the model are significant determinants of the LCC at the significance level α = 0.05 and p-value 0.0000, but the variable X_1, has gained p-value = 0.0381. The variables: proportion of urban land in a surrounding area (X_3), distance to CBD (X_9), distance to minor roads (X_5), distance to industrial sites (X_7), and distance to major roads (X_4), are positively related to the change while slope (X_1), distance to market centres (X_8), distance to rivers/streams (X_6), and proportion of undeveloped land in a surrounding area (X_2) are negatively related to the change. The relative significance of each of the driving forces and the nature of their influences can be analyzed from the odds ratio value and the value of coefficients of the variables obtained from the model respectively.

5.5.4. Key driving factors of LCC and their nature of influences

From the result of the model it can be deduced that the variables from X_1 to X_9 are all significant factors of the LCC for the period 2004 - 2010. The variables: proportion of urban land in a surrounding are (X_3), distance to CBD (X_9), distance to minor roads (X_5), distance to industrial sites (X_7), and distance to major roads (X_4) contributes to development positively (promote growth) with odd ratio of 23.77200, 2.095067, 1.66333, 1.49256, and 1.44246 respectively; all with odd ratio >1, which indicates that at the presence of these variables the probability of the land covers to change is high while slope (X_1), distance to market centres (X_8), distance to rivers/streams (X_6), and proportion of undeveloped land in a surrounding area (X_2) contribute negatively to the growth (prohibit the growth) all with odd ratio <1(Table 5-5 above). In most cases, the model results have agreement with the suggestion given by the respondents.

Although comparing the statistical parameters of the model with the scoring of expertise is hollow, the information given by the expertise about the nature and existence of the link between the influencing factors and the outcome variable are found to be good indicators. Verburg, Schot, et al. (2004) have noted that, expert knowledge can be used as a method to quantify the relations between driving forces and LCC. According to the expertise opinion, the distance to major roads (score 4.8), proportion of urban land in the surrounding area (4.1), distance to minor roads (3.5), and distance to minor city centres (3.4) are the main promoters of the growth in the study area. However, distance to market centre with high expertise rating score (4.1) was found to be negatively related to the growth according to the model result. On the other hands the relatively low score of the expertise rating value for the variables: slope (3.2), distance to rivers/streams (2.5), and proportion of undeveloped land in a surrounding area (3.3) could be an indicator of the negative influences of the factors on the growth (Table 5-2 above).

From the result of the model, the variable distance to CBD (X_9) is found to be very significant factors next to the variable proportion of urban land in a surrounding area (X_3). This variable was not in the expertise model. It was included into the model based on the study of Vermeiren et al. (2012). According to Vermeiren et al. (2012) for the Kampala metropolitan area the distance to CBD was found to be one of the major drivers of the city growth in addition to distance to the major roads and distance to the existing building negatively influencing the growth. However, in this study the model revealed that the distance to CBD is found the growth positively in contradiction.

An interesting observation revealed by the model is that the proportion of undeveloped land in a surrounding area (X_2) has significantly negative relation to the development, which could be an indication that the available land is not suitable for development. From the previous analysis (section 5.2.2; 5.2.3 & 5.2.4), it is observed that much of the undeveloped land are found in the low laying area of the study and most part of this land belongs to the wetlands (Figure 5-5). The negative association of the undeveloped land to the growth could be therefore for the reason that the land is not suitable for development as it is swampy. However, there is much development remain taking place in this location as the only available land for development is the wetlands (Lwasa & Nyakaana, 2004; NEMA, 2009).

The remaining variables in the model revealed similar outcomes with other comparable studies. The variables proportion of urban land in a surrounding area (X_3), distance to minor roads (X_5), distance to major roads (X_4), and distance to industrial sites (X_7) attract growth while distance to rivers/streams (X_6), and slope (X_1) prohibit development in most cases (Cheng & Masser, 2003; Dubovyk et al., 2011; Hu & Lo, 2007; Verburg et al., 1999). However the effects of these variables depend on various conditions and the cases under study as discussed in the early sections (section 2.10 and 5.2.3).

5.5.5. Model evaluation and interpretations

The evaluation and interpretation of the results and the fit of the LRM are based on the estimated value of the model parameters associated with the corresponding variables that can best explain the connection among the variables in the model as suggested by (Cheng & Masser, 2003; Field, 2009; Hu & Lo, 2007) among others. Discussed in the previous section (section 4.6.5), the estimated coefficient value and the associated odds ratio for the corresponding variable, the chi-square and the corresponding p-value estimated and compared with significance level can be used to interpret the model results while the percentage of correct predictions; PCP used to evaluate the model fit and performance.

To proceed to the interpretation of the model result, the performance of LRM was first evaluated based on the observation of the reality and the PCP value of the model. The predicated residual map obtained from the model for the year between 2004 and 2010 was visually compared with the actual land covers map 2010. It has been found that there was high agreement among the maps, but there were some pixels which are not present on the predicted map while they are on the actual map 2010. Nevertheless, form the model parameter, the PCP cells was found to be 91.81% for the same prediction period endorsing the agreement between the maps are high. Compared to results of similar approaches used by previous studies (Cheng & Masser, 2003; Huang, Xie, & Tay, 2010; Huang et al., 2009), the obtained PCP value was found to be magnificent. For instance, for three different models, Cheng and Masser (2003) had a model with maximum PCP equal to 83%, and also Huang et al. (2009), had similarly a model with maximum PCP equal to75.62% among three distinct models. Hence, the interpretation of the model outcome was preceded. Table 5-6 shows summary the model assessment.

Table 5-6: Accuracy evaluation of the model

	Predicted			
Observed	**0**	**1**	**Total**	Correct Prediction : 4010368 Wrong Prediction : 357712 Percentage of Correct Prediction (PCP) = 91.81%
0	3105104	3216	**3108320**	
1	354496	905264	**1259760**	
Total	**3459600**	**908480**	**4368080**	

Entirely, all the driving forces considered in the model are found to be associated with the LCC in the study area. The driving force: proportion of urban land in a surrounding area (X_3), distance to CBD (X_9), distance to minor roads (X_5), distance to industrial sites (X_7), and distance to major roads (X_4) contributes to the development positively. All are significant at $\propto = 0.05$, p-value 0.0000 with odd ratio of: 23.77200, 2.095067, 1.66333, 1.49256, and 1.44246 respectively. The odds ratio of the driving force (X_3), proportion of urban land in the surrounding area, indicates that the existence of built-up area tends to attract much growth in the area. To state it statistically, the log odds of being built-up area for a location around the existing built-up will increase by about 23.8% for a unit increase in the coefficient of the variable holding the value of all the other independent variables constant. In another word, for any non-built-up land around the existing built-up the probability of the land to be changed in to built-up will be by about 23.8 times higher than that of the land at far or less built-up. This implies that the probability of a location existing nearby built-up area is 95.97%. Similarly, the effects of the rest of the driving forces attracting growth (promote the LCC) can be interpreted. The proximity factors: distance to CBD (X_9), distance to minor roads (X_5), distance to industrial sites (X_7), and distance to major roads(X_4) are all contributes to the increase in the built-up in the period. The respective contribution of the factors to the log odds of being the built-up at a location is about 109%, 66%, 49%, and 44% respectively indicating that the influences of the factors to attract growth are significant (Table 5-5).

On the other hand, the variables slope (X_1), distance to market centres (X_8), distance to rivers/streams (X_6), and proportion of undeveloped land in a surrounding area (X_2) are negatively associated to the LCC. They prohibit growth to take place in the study area. All are significant at $\propto = 0.05$ and odd ratio: 0.82573, 0.735887, 0.55015, and 0.46865 respectively. This logit transformation of the outcome variable, which has linear relationship with the predictor variable, indicates that for a unit increase in the distance to rivers/streams (X_6), holding the other variables value constant, the odds of being a built-up area for a location will decrease by about 55.02%. The odds value 0.55015 or 1/1.81769 indicates that a location one unit away from river/stream would have a probability of 1.81769 times higher than a location at one unit near to the river/stream to be built-up. Similarly, the variable distance to market centres indicate that for every unit distance increase in proximity to market centres the odds of a plot being built-up would fall by 73.59%.

The urban growth (built-up) tends to develop near to the low lying land in the year 2004 -2010. As it can be observed from the odds of the variable, the odds of being built-up for a location will decrease by about 82.57% for every 1% increase in slope. This result of the model also complies with the opinion of the expertise. According to the expertise, much of the slums are settled in the low lying area of the Kampala city in general. The land value is cheap and the construction of building is relatively simple in this area. On the other hand, the presence of high proportion of undeveloped land in the surrounding area of built-up land has also shown the pushing effect on the built-up area in a location by about 46.87%; i.e. the odds of a location being built-up surrounding the available land will be 0.53135 time less than otherwise. Given that the policy to protect the available land is loose this might not be the case, particularly in urban area. Here, the incident could be hypothesized as, most of the available land in the study area are swampy and not suitable for built-up besides to its being prone to flooding. During the field observation made in the study area it is also witnessed that most of the currently available lands surrounding the existing built-up in the study area are entirely wetlands that are unsuitable for development t are covered by "papyrus" plant.

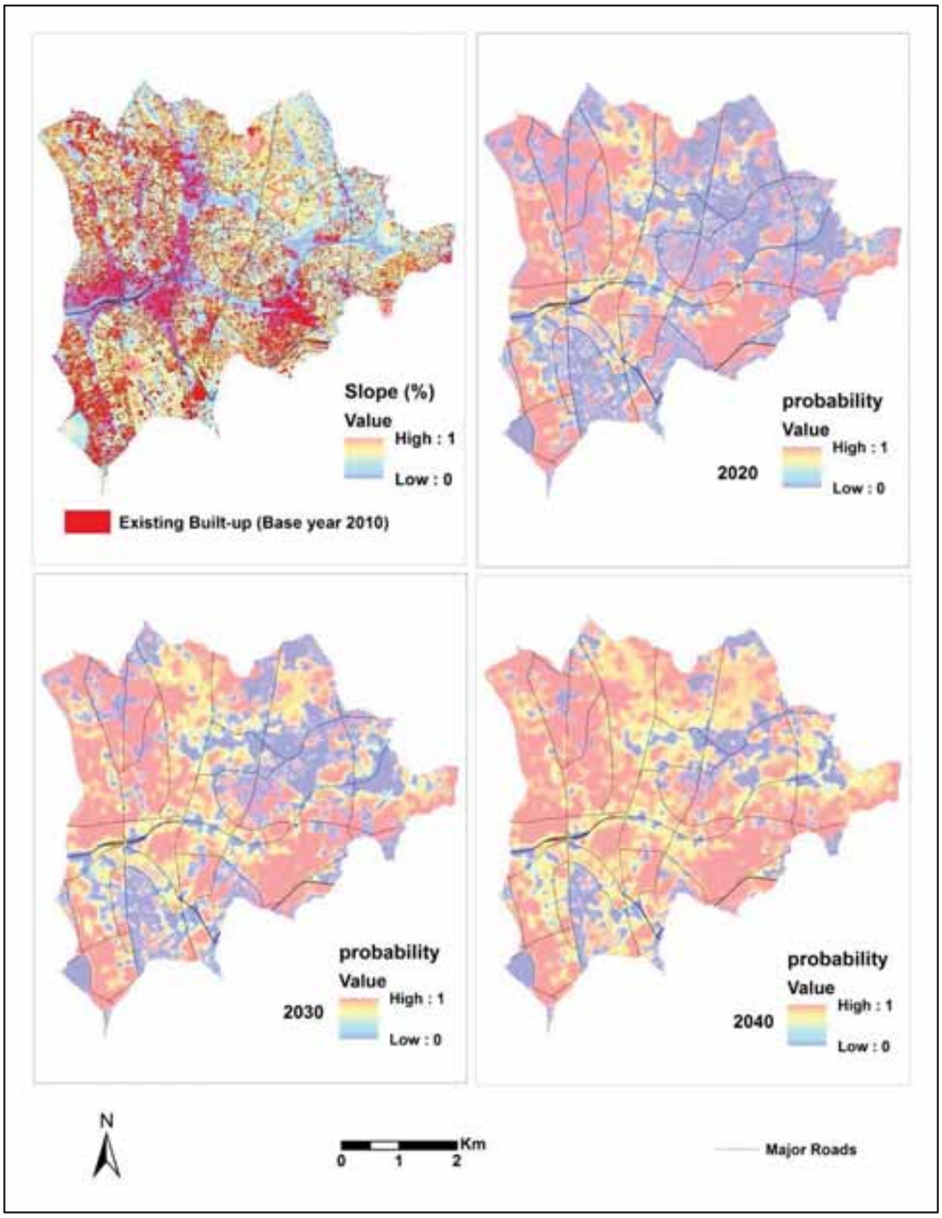
Generally, the LRM model parameters was enabled to identify the causative and influential factors that determine the location of built-up land covers in the study area in the period. Although the time period of the study in the past fall short and span few, the model result could be a base for the indication that the identified factors are potential determinants of the LCC in the period and help to predict where the probable growth area tends to be in the future rigorously; particularly for the short term development plan. Among the physical driving factors in the model, proportion of urban land in a surrounding area (X_3), distance to CBD (X_9), distance to minor roads (X_5), distance to industrial sites (X_7), and distance to major roads (X_4) are the most significant factors of the land cover changes with positive connection to the change in declining order while the variables slope (X_1), distance to market centres (X_8), distance to rivers/streams (X_6), and proportion of undeveloped land in a surrounding area (X_2) are significant negatively linked to the change in diminishing order as well.

5.6. Probability location maps of built-up area

5.6.1. Probable location maps

The predicted probability location maps of the built-up for the next three decades were interpolated in the Change Analyst based on the trend growth. The result the model shows that the built-up area will increase relatively at a constant rate from the 7.79km^2 in 2010 to 11.56km^2, 15.26km^2 and 18.96km^2 by the year 2020, 2030 and 2040 respectively. The result also indicates that the pattern of the growth in the catchment generally follows the 2010 layout having more of densification types of development for the first two periods while it appears an expansion types of development on the available land by the 2030 and entirely expansion sort of new development by the year 2040 as an extension of existing built-up at an average annual growth rate of 6.85% (Figure 5-8).

Figure 5-10: The topography and predicted probability maps of built-up 2010-2040



The predicted map also shows development is pushed by the available open space (wetlands) and slope. However, much of the new development appears to be on the low-lying lands following the base of the hills along the edge of the wetlands in the upper part of the catchment. The cumulative impacts of the existing built-up, minor roads, major roads and industrial sites have played significant role in the manifestation of the development in all prediction periods. Furthermore, as it can be comprehended from the maps (Figure 5-8 and Figure 5-11) the presence of minor roads appears to be most influential than other factors in this case. This is particularly true for the short term prediction (2020). The proximity to industrial sites also seems to be influential for the predicted location remotely. These ensure the implication that the needs for accessibility and employment or job are encouraging a settlement to happen at certain location.

Figure 5-11: Probable location maps and the patterns of trend growth 2010-2040

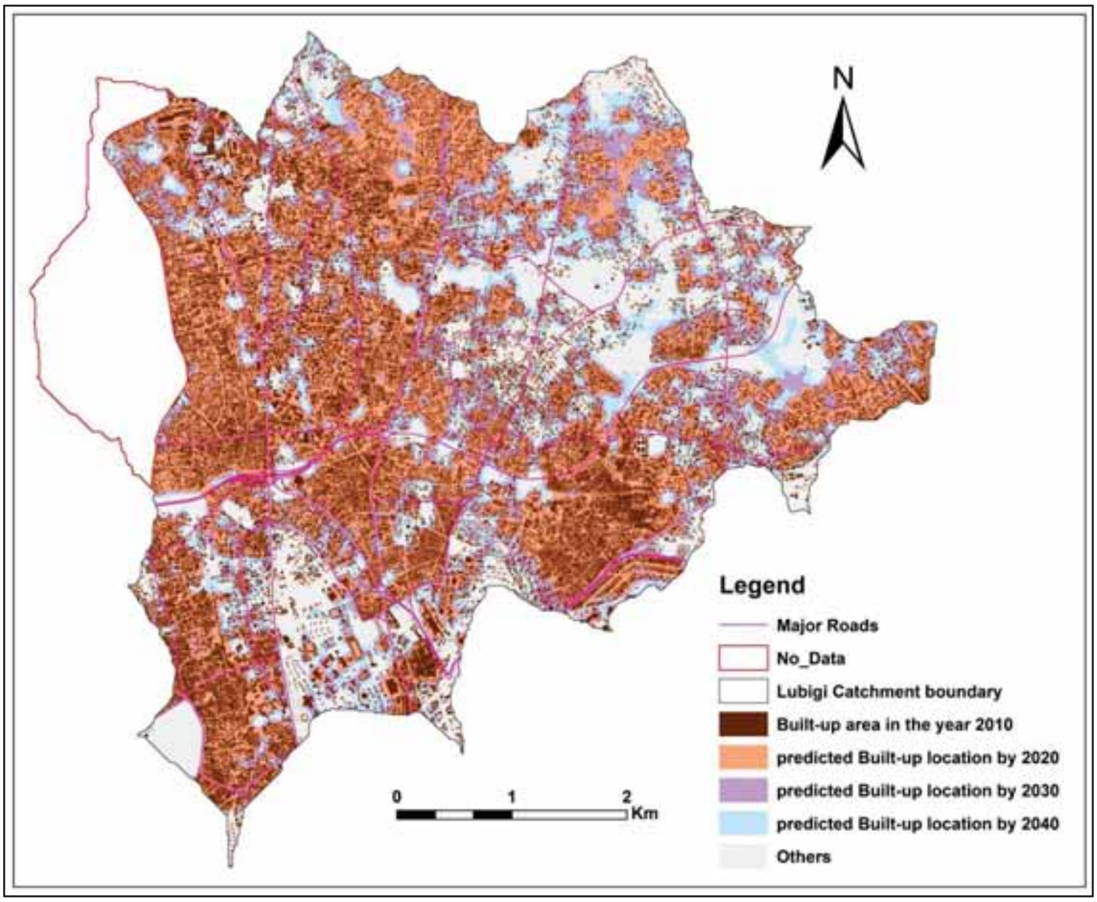
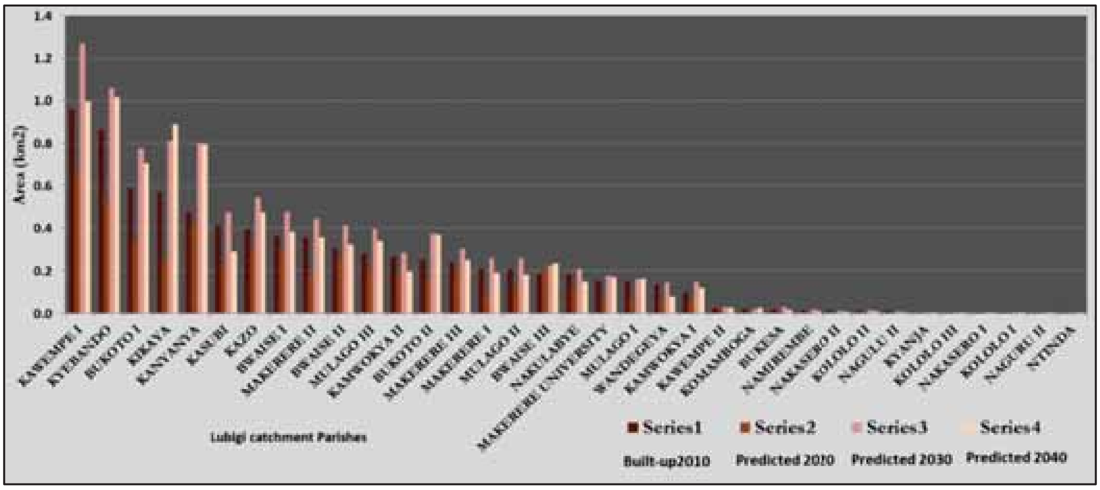


Figure 5-12: Comparative location of existing and the predicted built-up by 2020-2040 across parishes



The graph (Figure 5-12) shows comparative location of the predicted growth across the parishes. Similar to the past trend (growth trend in the period 2004-2010), much of the growth are still hosted by the parishes: Kawempe I, Kyebando, Kikaya, Kanyanya, Bukoto I, Kasubi, Kazo, Bwasie I Mekerere II Bwasie II, Mulago III and Bukoto II in all prediction periods. In most cases, the predicted location of the growth across the parishes has high agreement with the view of the expertise. According to the expertise rating score much growth are expected in the near future in the parishes: Kanyanya (4.0), Kikaya (3.8), Kyebando (3.8), Kazo (3.4), Bwaise III (3.3), Mekerere II (3.2), Bwaise II (3.1), Mekerere I (3.1), Mulago III (3.0), Kawempe I (2.9), and Bukoto I (2.6). The predicted location of the growth in the parishes Kawempe I, Kyebando, Kikaya, and Kanyanya is most significant. This could be for the fact that most of the available land for development exist in these parishes.

5.6.2. Model validation

Model validation is a crucial component of a spatially explicit simulation model to know the model prediction accuracy (Pontius Jr & Schneider, 2001). The model validation could have been made by comparing the map that show actual change and no changed against predicted change and no change based on contingency table. However, given the prediction was made based on the extrapolation of past trends and the absence of comparable recent data, which is not in the model, in this study the validation of the model is remained unexplained.

5.7. Scenarios development

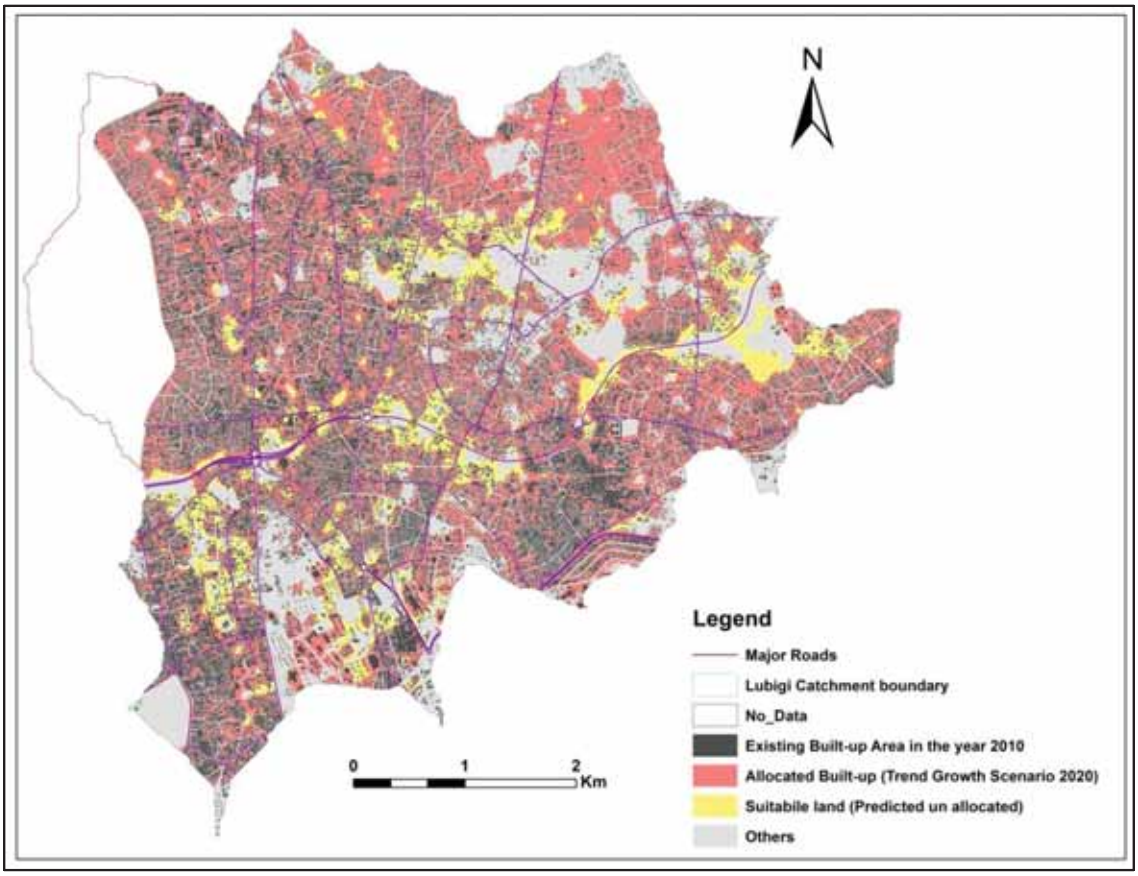
In this study three different scenarios were constructed. The scenario includes: trend growth, high growth, and low growth scenarios. The relevance of the scenarios was evaluated based on expertise opinion and referring to the KPDP report. According to both the expertise and the report, the trend growth and high growth scenarios are realistic for the future Kampala. Explicit to the study area, out of the 12 respondents 11 of them highly agree that the growth will be accelerated depicted to the several factors while 7 expect the trend growth will continue as well and 1 respondent agree the low growth can happen (Appendix-F, Table 8-6). Accordingly, the projection of demand for the three scenarios was performed based on the assumptions discussed in the previous section (section 4.8.1). The scenarios are projected up to the year 2020. The period of the scenarios is selected for it is required to predict the surface run-off for the study area in the near future. Thus, the demand for the scenarios was calculated for the period and the allocations of the calculated demand for each scenario were executed in the CommunityViz as discussed the early section (section 4.8.2).

5.7.1. Trend growth scenario

The demand for the trend growth scenario was calculated based on trend growth in the building footprint for the period 2004 -2010. The demand calculated for the built-up for this scenario for the year 2020 is about 3.78km^2. This demand was allocated on the predicted location of the built-up area obtained from the LRM. The strict ordered allocation of the demand in the CommunityViz was enabled to identify the location of the built-up area by the year 2020. During the process of allocation only 50% of each gird cells were allowed to house the demand (section 4.8.2). Compiled with the predicted probable location of the built-up in the LRM, the allocation of the demand has witnessed that there will be high growth in the parishes, such as Kikaya, Kanyanya, Kawempe I, Kyebando, Bukoto I, Kazo, Bukoto II, Bwasie I, Mulago III, Mekerere II, Bwasie II, and Kasubi among others, if the trend growth remains continuous. Of the total amount of the computed demand for this period about 3.09km2 were allocated in these parishes. This is about 81.89% of the allocated demand in the study area in the period. Strictly speaking, all the aforementioned parishes will host about 0.56, 0.48, 0.46, 0.34, 0.32, 0.23, 0.17, 0.16, 0.14, 0.13, and 0.11 areas in square kilometres respectively in diminishing order (Figure 5-13, Figure 5-16, and Figure 5-17).

The presence of minor roads and existing built-up area seems to be significant to influence the growth. Much of the "vacant land or open space" (wetlands) surrounding the existing built-up and located nearby the minor roads tends to have high probability to lodge the demand. Thus, the trend growth appears to be more of infill and densification type with relatively minor expansion for the period. This impacts of minor roads and existing built-up is more observable and can be witnessed by the high growth scenario. The priority of a plot of land near to minor roads and the existing built-up to host the allocated land is the same in location as the trend scenario for the equivalent demand while the additional demand for the high growth scenario is located in the form of expansion as a continuation of the trend scenario (Figure 5-16).

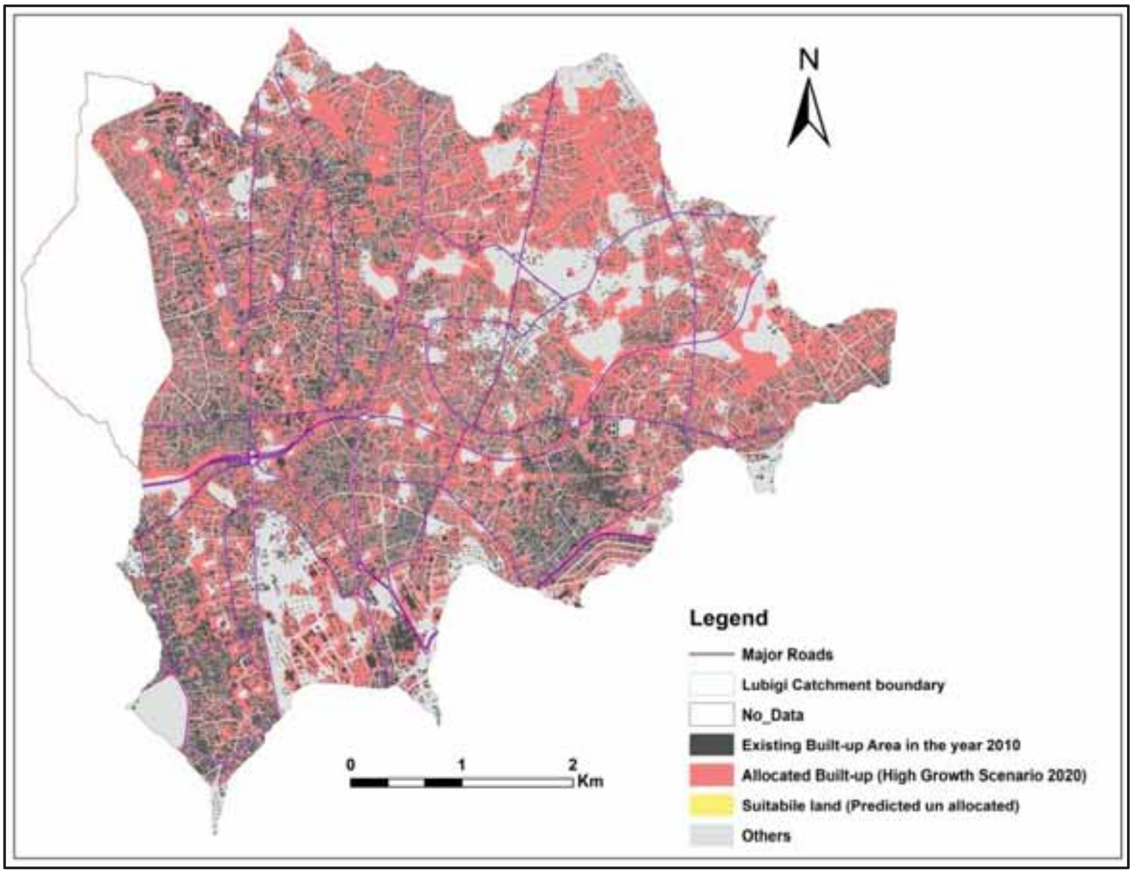
Figure 5-13: The location of built-up for the trend growth scenario 2020



5.7.2. High growth scenario

The demand for the high growth scenario was computed based on the trend growth. The calculated demand for this scenario is about 5.03km^2. Similar to the trend growth, strict ordered allocation of the demand was performed to define the location of the built-up area by the year 2020. Accordingly, there will be high growth to be absorbed in Kikaya, Kanyanya, Kawempe I, Kyebando, Bukoto I, Kazo, Bukoto II, Bwasie I, Mulago III, Mekerere II, Bwasie II, and Kasubi parishes similar to the trend growth scenario. However, this growth scenario shows the additional development (33%) to the trend growth has a form of complete expansion stretching out from the existing built-up. The expansion appears to be much in Kikaya, Kanyanya, Kawempe I, Kyebando, Mekerere II, Mulago III, Bukoto II, and Bukoto I parishes, particularly on the Bulyera wetlands and along the edge of northern by-pass road (Figure 5-14, Figure 5-16, and Figure 5-17). Much of the wetlands and the open space remain under high pressure of the development. These parishes host an area between 0.69km^2 and 0.42km^2 in diminishing order, which is about 68.42% of the projected growth for this scenario. This is particularly true for the low-laying land areas located in the upper part of the catchment. Most of these parishes are the parishes suggested by the experts with high affinity to embrace growth in the future (Appendix-F, Table 8-4).

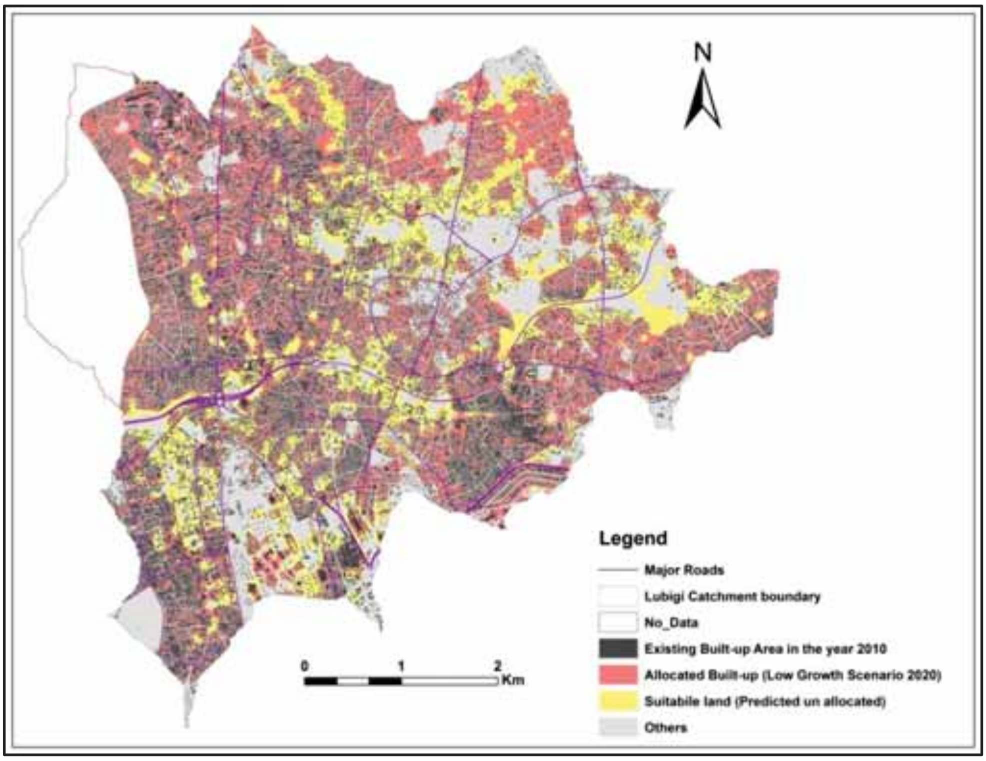
Figure 5-14: The location of built-up for the high growth scenario 2020



5.7.3. Low growth scenario

Similar to the high growth scenario, demand for the trend scenario was computed based on the trend growth. The calculated demand for this scenario is about 2.91km², which is about 23% less than the trend growth (see section 4.8.2). The strict ordered allocation producer was performed to allocate the demand to define the location of the built-up area for the year 2020. In this scenario, much of the allocated built-up tend to development entirely as infilling and intensifying type of growth on the available "vacant land and open space" with few expansion as an extended edge of the existing built-up. Still, the Kikaya, Kawempe I, Kanyanya, Bukoto I, Kyebando, Kazo, Mulago III, Bwasie II, Bukoto II, and Mekerere II, parishes remains attracting much of the growth in diminishing order all hosting the additional development varying in area between 0.41km² to 0.07km², which is about 70.71% of the planned demand (2.91km²) for the scenario (Figure 5-15, Figure 5-16, and Figure 5-17). The wetlands show the impression of being relieved from encroachments for the development. Nevertheless, the amount of the available open space consumed by the development is significantly high. All the scenarios result in contributing high amount of built-up land in the study area.

Figure 5-15: The location of built-up for the low growth scenario 2020



In all scenarios, it was observed that much of the available open spaces and wetlands in the study area are placed under boundless pressure, with the increase in the built-up contributing to the increase in the imperviousness of the land surface. Given the amount of available land is very low and the remained wetlands itself is very important for balancing the associated ecosystems, besides to its being substantial for ecological value (to offer greenness to the city) the increase in the built-up is significantly high. This increase in the built-up is assumed to be only the building footprints. However, the amount of land to be paved and other impervious surfaces to be emerged as the result of the new development are not considered in this case (see the next section). The consideration of these facts could have substantial implication on the surrounding natural environment and eco-system as a whole and the management system thereby. The next two sub-sections have discussed the implication of the various scenarios (the increase in the built-up) developed for the study area for urban development and management policy.

Figure 5-16: Comparison of the allocated built-up per parishes for the various scenarios by 2020

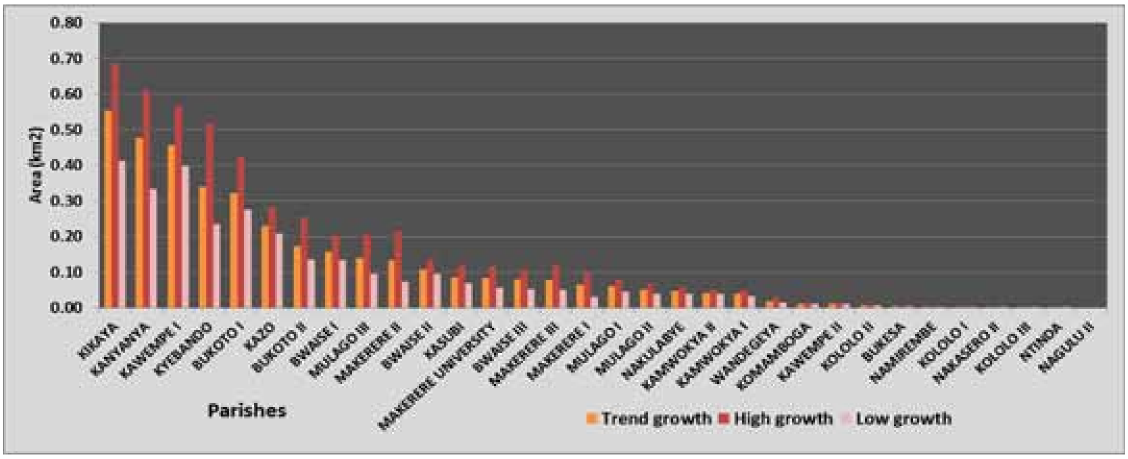
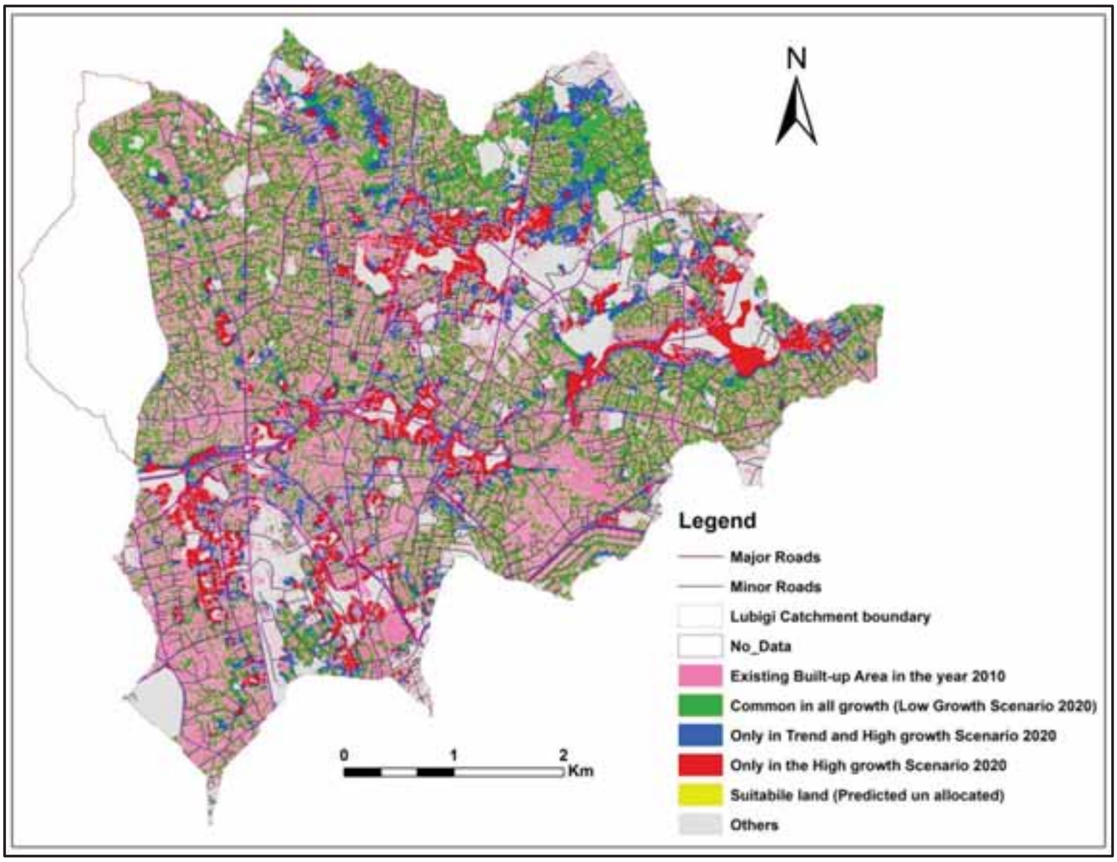


Figure 5-17: Locational patterns of the growth in built-up for the various scenarios 2020



5.7.4. Compilation of the land cover data for the prediction of run-off by the year 2020 for the scenarios

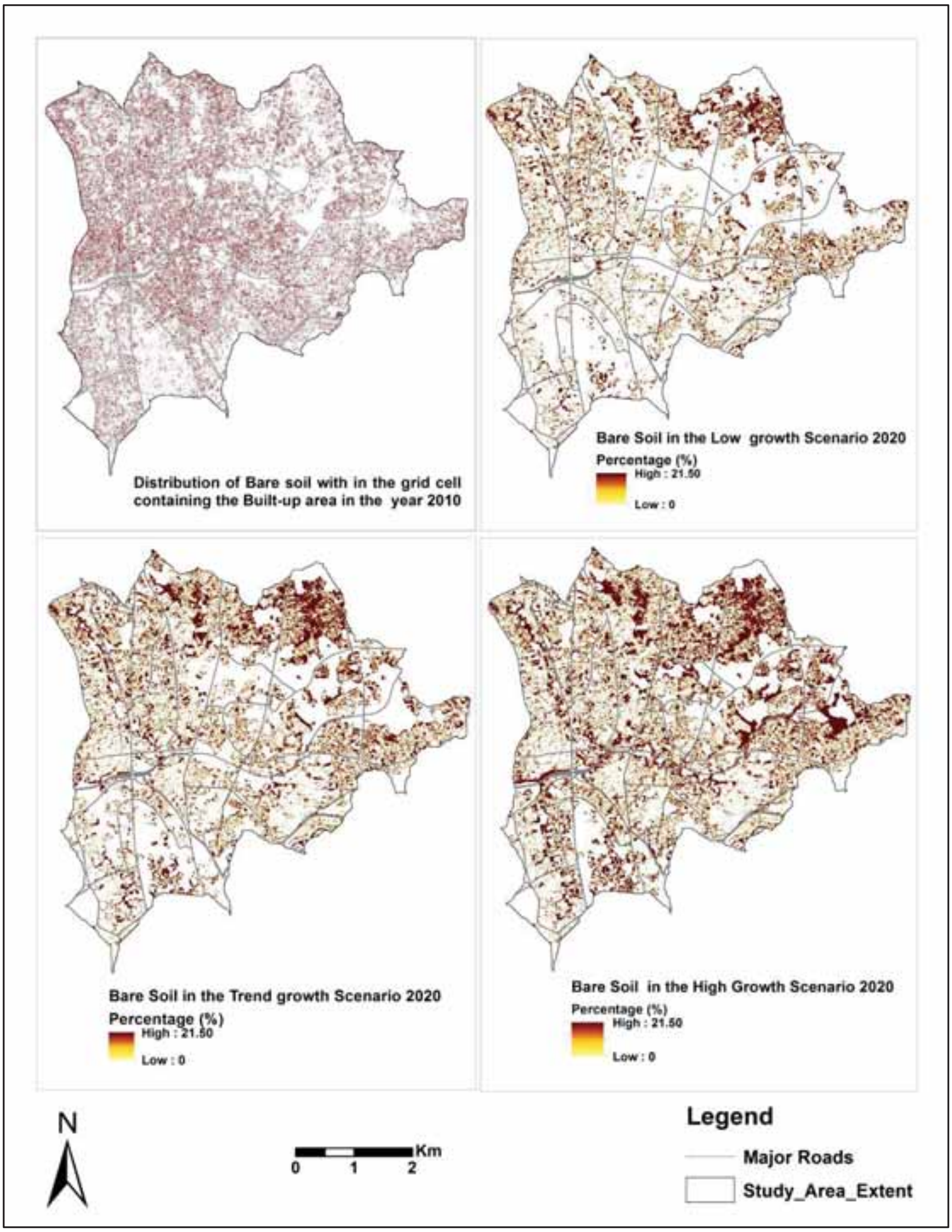
The predicted and allocated land cover maps for the year 2020 were compiled for the various scenarios as required for run-off modelling. In addition to the allocated built-up the quantity and proportion of the vegetation, and the bare soil land cover classes were calculated. Table 5-7 below shows the amount of the land covers in area for the different scenarios in the year 2020.

Table 5-7: Proportion of the land covers for the three scenarios 2020

Land cover type	Base year 2010	Trend growth Year 2020	Low growth Year 2020	High growth Year 2020
	Area (m²)	Area (m²)	Area (m²)	Area (m²)
Bare soil in the allocated cell	*975824	1626373	1252307	2163077
Bare soil	9280956	5614642	5523260	4817919
Building in the allocated cell	*2269829	3783049	2912948	5031455
Building footprint	7789440	7789440	7789440	7789440
Earth Road	570098	570098	570098	570098
Gravel	379097	379097	379097	379097
Tarmac	438004	438004	438004	438004
Vegetation in the allocated cell	*	2055931	3255421	2366266
Vegetation	8891168	5092127	5228186	3793405
Total	27348761	27348761	27348761	27348761
*Areas that are already in the respective cells (land covers) of the base year 2010				

The estimated bare soil with in the total allocated cells was found to be about 1.63Km², 1.25km², and 2.16km² while the remaining proportion, which is accounted for the vegetation land covers, is obtained to be about 2.06Km², 3.26km², and 2.37km² for the trend growth, low growth and high growth scenarios respectively. The earth road, tarmac road, and gravel road assumed to remain unchanged in all scenarios. The proportion of the bare soil in the allocated cells for various scenarios and its spatial distribution were computed and displayed (Figure 5-18). The maximum calculated percentage of the bare soil in the allocated cell is about 21.50% while the minimum is 4.73%. The spatial distribution of the land covers for the various scenarios are compiled in to a layer and displayed as a map (see Appendix-I: Figure 8-7, Figure 8-8, and Figure 8-9).

Figure 5-18: Proportion of the bare soil land cover per unit of the allocated cell for the scenarios



5.7.5. Implications of the growth for urban development policy

The various scenarios are considered in this study to understand development situations in the study area, which can also help to understand situation in the other parts of the Kampala city as well. The scenarios are different only in the amount of demand calculated for the built-up area for the next eight years to identify where will be the demand located assuming that the outside world remain unchanged over the period. Each scenario has shown significantly different demand for land.

However, all the growth scenarios relatively show high growth development in the built-up through infilling of the available open spaces and encroaching the wetlands located at the edge of the existing built-up. Most of the remained wetlands and open spaces will disappear and will suffer from disturbance. Given the trend growth and the loose policy regulation to control the growth agreed to continue, the wetlands are expected to fail to bear all the pressure imposed by the development. Besides to this, the density of the settlements in this area is extremely high. These might result in several social problems and high slum creation with bulk of the population causing more pressure on the surrounding environment.

On the other hand, there is also a situation where a form of fragmented (new settlement) and incremental growth are seen in all scenarios, particularly for the trend and the high growth scenarios. The increase in the growth might have put burden on the existing infrastructure and complicate the issues of accessibility causing high traffic congestion in the city at the large scale resulting in social instability and poor quality of life and living conditions thereby. Accessibility to various services will be problematic given that the current condition is remained continuous and unsolved or unimproved in conjunction with the significant overcrowding of the settlements. As the result, access to public services, opportunities, and employment will require commuting high cost both in terms of time, distance and other resources. This is particularly true for the high growth scenario, which shows more extended types of growth at the edge of the existing built-up prior to the development of basic services and infrastructure.

Although, the purpose of these scenarios development is to identify the location of the anticipated demand on the predicted location of the built-up in the study area on the bases of preparing data for run-off modelling, it could be useful to inform the policy implication of the future development in the study area, which could be also used as the general indication of the development situation in the various parts of the city as well. All the scenarios revealed that there is need for effective control of unplanned and serviced per-urban areas. Delineation of the suffered wetland boundaries around the existing urbanised areas and the available open spaces are crucial. Strict and effective development control by the relevant actors is therefore mandatory in this regard to protect the further intrusion of settlements into these lands. In addition there is a burning issue of accessibility and waste disposal coming up with the overwhelming of new development that needs to critically think how to provide basic infrastructure and other public services. These require high investment, which could be challenge and key for the economic development of the city as well. The increases in the new development (built-up) are also necessitating thinking how to effectively use and plan for draining channels and flood lines for the sustainable development. Strict concern and actively working-out about it is very important for the current Kampala as the whole in this regard (Lwasa, 2010; Lwasa & Nyakaana, 2004; Nyakaana et al., 2007).

5.7.6. Implications of the growth for flood management policy

The overwhelming growth observed in the study area has many implications in the aspects of infrastructure development in general. The development of comprehensive drainage and sewage systems in these areas need a great concern in all scenarios, particularly at the peripheral location of the existing built areas for the trend and high growth scenarios, where the development appears to bloom itself ahead of any infrastructure development. This is very essential to protect settlements; mainly those that are located at the low-laying area from floods and to prevent regular flooding of residential, business, and industrial areas that are located at the lower part of the catchment. Given much of the growth are taking place at the edge of the existing built-up for the trend and high growth scenarios, with more of intensification type for the low growth there should be attention paid to the problem of linking flood line, sensitisation, and the wetlands. These could have many implications on the health risk avoidance, difficulties of providing adequate services and the benefits of conservation and rehabilitation of both the natural environment and the existing infrastructures (Lwasa, 2010). Most importantly, there should be coordination among the different institutes that provide various infrastructure and public services, such as utilities services providers' including: waste disposal and collection service providers with flood risk management programmes with the help of clearly laid down drainage and other utilities master plan to guide the development to arrive at the integrated and sustainable development. The involvements of international and national concerned actors or institutions are very important in this regard (Lwasa, 2010).

6. CONCLUSION AND RECOMMENDATIONS

This chapter presents the general conclusion and recommendations from the results obtained in the process of achieving the general objective that was set up for this case study. It provides summary of key findings in developing methods to analyse and model the land cover change for Integrated Flood Management in the study area that was executed under four specific objectives. The chapter windup by indicating issues left for the future research career.

6.1. Sumary of key findings

It has been explained that the potential of GIS and the availability of remote sensing data have provide the opportunity to understand the phenomena of urban LCC, particularly in geographic region where the scarcity of spatial data are problem. To achieve the general objective of the research, the first focus of this study was analysing trends of the LCC in the study area for the period 2004 – 2010 using the potential of GIS and remote sensing. The computational power of GIS and the availability of the VHR imagery in combination with other available spatial data for the study area have enabled to obtain reliable land cover data to investigate the composition of the land cover for run-off modelling as well as the trends of the LCC in the study area. The composition of the land cover classes in the study area was identified into six classes: built-up, vegetation, bare soil, earth road, tarmac road, and gravel road, as these classes are required for run-off modelling. This detailed land cover classes were required for the process of run-off modelling in LISEM. The proportion of the land cover for the year 2004 and 2010 was found significantly different. The built-up land cover has increased in area from about 5.59km^2 in 2004 to 7.79km^2 in 2010 while the vegetation land cover has decreased from about 11.29km^2 to 8.89km^2 of the 27.34km^2 total area of land in the study area. The gravel road has slightly decreased as the tarmac road was doubled in area.

The built-up land cover changes at an increasing annual growth rate of 6.85% contributing to the increase in the built-up by about 41.1% in the 2010 and the vegetation land cover changes at a decreasing rate of 3.5% resulting in about 20.3% decrease in vegetation land during the period while the tarmac road increased at the rate of 6.47%. The nature of the LCC was observed to be densification type on the available open space and expansion type surrounding the existing built-up on the low laying wetlands. The bare soil relatively remains the same in the period. However, it contributes the highest percentage to imperviousness of the land surface in the study area. It covers about 9.28km^2 of the land; more than one third of the study area. The presence of quarried land for clay searching, open playground fields, market centres and parking lots that are not well managed, damped soil waste, agricultural land, and eroded mud soil from the quarry and other bare surfaces are the attributes to the increase in the amount of naked land. The increase in built-up together with the bare soil contains about 62.5% of the land covers in the study area, which has significantly positive implication to the increase in surface run-off and the flooding of the low laying areas. Analysing trends of the LCC in the study area has helped as a base to simulate the LCC.

The second focus of this study was aimed at determining an appropriate method to simulate LCC. LRM have been preferred and built to simulate the LCC and to predict the future location of the built-up land in the study area as well as to explore the driving forces that are attributed to the change. Despite of its certain limitations, the positive characteristics of the model that enabled to meet the objective of this study has declared to prefer the LRM. The flexibility, simplicity and the power of LRM to incorporate a number of factors that can contribute to the change and to empirically determine the link between the driving factors and the outcome variable and their nature of contribution to the change as well besides to the relatively less time need to execute the model has enabled to determine the probable location of the LCC in the future. The LRM executed with the help of the ArcGIS extension package; the Change Analyst Software, has played a great role to directly analyse the influences of change in the scale of the spatial resolution on the outcomes of the model by allowing a number of quick model run for each of the change in the scale. It was found that the spatial scales of analysis play a significant role on the results of the model. Different driving factors have shown different significance level to contribute to the change in the outcome variable at the various selected scale of analyses. However, the model performs found preeminent at the fine spatial resolution for this case study, where all the independent variables in the model obtained to be significantly influential.

The physical driving factors that contribute to the change in the land covers were analysed as part of the third specific objective of this study process. The list of the driving factors was compiled based on literature review and experts' opinion. Among the physical driving factors in the model, proportion of urban land in the surrounding area, distance to CBD, distance to minor roads, distance to industrial sites, and distance to major roads are the most significant factors of the land cover changes in the study area with positive contribution to the change in declining order while the variables slope, distance to market centres, distance to rivers/streams, and proportion of undeveloped land in a surrounding area are significant negatively linked to the change in diminishing order; prohibiting the growth in the built-up.

The fourth objective focused on predicting the probable location of the LCC and developing anticipated scenarios for the various increase in the building footprint for the year 2020. The predicted probable location of the built-up was interpolated based on the trend growth by fitting all the significant factors in the LRM for the years 2020, 2030, and 2040 to explain how the patterns of the growth take place. The result show that the built-up area will increase relatively at a constant rate from 7.79km^2 in 2010 to 11.56km^2, 15.26km^2, and 18.96km^2 by the year 2020, 2030, and 2040 respectively. The pattern of the growth in the study area follows the 2010 layout having more of densification type of development for the first two periods while it tends to be slightly expansion type of development on the available land by the 2030 continuing to evolve entirely as expansion sort of new development by the year 2040 stretching out from the existing built-up at an average annual growth rate of 6.85%. The development appeared to be pushed by the slope and available wetlands. The presence of minor roads seems to be the most influential factor than other factors over time. For the scenarios development the demand for the trend growth scenario was calculated based on growth in the building footprint for the period 2004 -2010. It is found that the built-up area will increase by the year 2020 to about 3.78km^2, 5.03km^2, and 2.91km^2 for the trend growth, low growth, and high growth scenarios respectively. In all scenarios, it was observed that much of the available open spaces and wetlands in the study area are placed under boundless pressure, with the increase in the built-up contributing to the increase in the imperviousness of the land surface.

6.2. Conclusions

Analysing and modelling trends of LCC at certain defined geographic section in parts of urban region is suitable. This can be used to improve understanding of the phenomena of the change at micro-scale and to contribute to the process of decision making for urban planners and managers to be able to forecast and ultimately mitigate and/or reduce risks of flooding associated with the increase in impervious land surfaces at the defined geographic province. The proposed analysis and modelling of the LCC is found to be sufficient and reliable to investigate trends of the LCC and to predict the location of built-up land cover and the driving forces attributed to the changes in the ULCA of Kampala city. Hence, the results of the analyses are sufficiently enough to investigate and predict the impacts of the increase in impervious surfaces on the increase in rates of surface water run-off in the study area. However, spatial data availability and quality are crucial factors for successful analysis of the phenomena of the LCC. The availability of the VHR imagery can contribute to overcome the problem of data scarcity in this regard in order to obtain accurate and more reliable results. For this case study, the two VHR imageries available for the study area have significantly helped to maintain the data quality and consistence to obtain the more reliable results. On the other hand, spatial scale (cell resolution) and spatial extent (spatial level of analysis) has significant influence on the outcome of the analysis and modelling. Thus, the results of the analysis and the model are only valid for the specific spatial and temporal scale, and spatial extent. Careful consideration of the variation in the spatial scale and spatial extent is therefore vital if the model is intended for similar application in the other parts of the city or somewhere else. Moreover, LRM can help to analyse trends of LCC and urban development process through time alongside the driving forces responsible for the change. However, the outcome of the model is highly sensitive to the change in the temporal and spatial resolution, and spatial extent. Therefore, identifying the optimal scale at which the models perform best is very important to obtain reliable results for specific study area and applications.

6.3. Further research directions

- To repeat analysis of the land cover in the study area for the same period by incorporating information about the land cover data that are obtained only from the two VHR imagery by the same method of data extraction or additional datasets of good quality, instead of using the building footprints and roads data that are obtained from other sources.

- To repeat the analysis of the land cover in the study area for different time steps by incorporating datasets of good quality.

- To repeat the LRM analysis of the driving forces by incorporating socio-economic factors and additional set of the physical driving factors at the same spatial and temporal scale for the study area.

- To repeat LRM for the same study area to examine the influence of changing spatial resolutions on parameter estimation and prediction of the outcomes and, thus, to determine the optimal scale of analysis at which the model perform best by using another alternatively robust statistical approaches that are available.

- To investigate the various growth scenarios based on computing the demand for land in relation to the actual and recent population data.

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8. APPENDIXES

Appendix-(A)

Table 8-1: List of data and data sources used

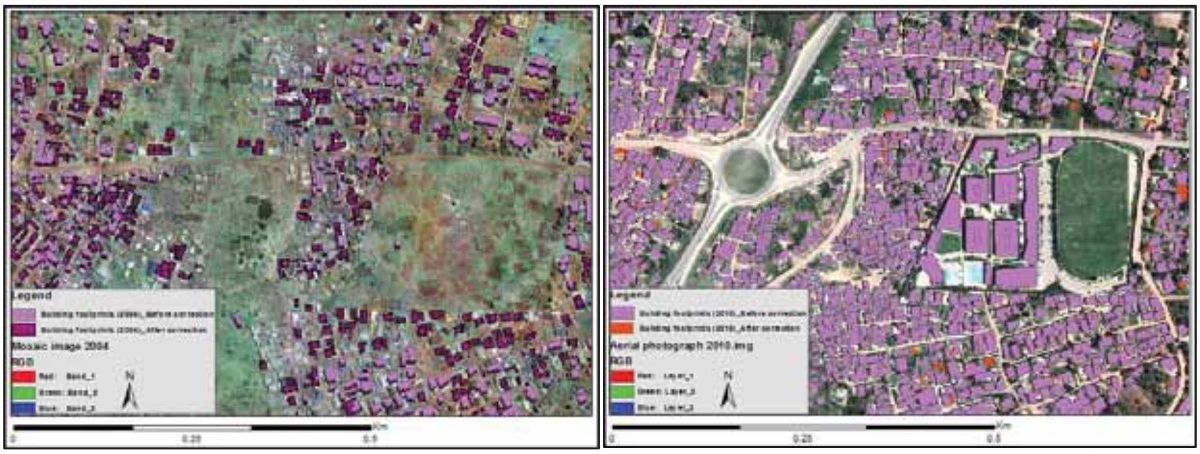
File name	Data type	Format	Year	Descriptions	Data sources
All_admin*	polygon	Vector	-	Administrative boundary with all administrative levels	ITC/ Richard Sliuzas
Buildings_04 *	polygon	Vector	2004	Building footprints	ITC/ Richard Sliuzas
A_structure*	polygon	Vector	2010	Building footprints	ITC/ Richard Sliuzas
Roads_93_TOPO*	line	Vector	1993	Road layer derived from topographic map data	ITC/ Richard Sliuzas
All_roads_04*	line	Vector	2004	Road layer	ITC/ Richard Sliuzas
KDMP_10yr*	line	Vector	10yrs flood lines	10 year flood level lines extracted and merged (Rivers/streams)	ITC/ Richard Sliuzas
kampala_2010_arcs*	Raster	Image	2010	Aerial photograph	ITC/ Richard Sliuzas
mosaic_2004warp	Raster	Image	2004	Mosaic image	ITC/ Richard Sliuzas
parishes_kampala2_ A_region*	polygon	vector	2010	Land use map	Dr. Shuwab Lwasa
kampala_demARCs*	Raster	tiff	2010	0.5x 0.5 meter pixel size DEM	ITC/ Richard Sliuzas
CBD	polygon	vector	2012	CBD	Google earth 2012
Market_Center	polygon	Vector	2012	Market centres	Field survey & Google earth
CensusAnalyticalRep ort*	Pdf	Table	2002/ 2012	Population data	UBOS/KPDP
Probable_drving_Fa ctors	Microsoft Word 2010	Text/ Table	2012	Lists of probable driving factors (Questionnaire)	Field survey & Literature/Expertise

All the data are geo-referenced to the same geographic coordinate system; (GCS) Clarke1880 = Arc_1960_UTM_Zone_36N, D_Arc_1960 (Datum), Clarke_1880_RGS (Spheroid). *File name as it does obtained from the data sources metadata

Appendix-(B)

Figure 8-1: Partial view comparing the existing and updated building footprints

a) The mosaic image 2004 (right) and the aerial photograph 2010 (left)

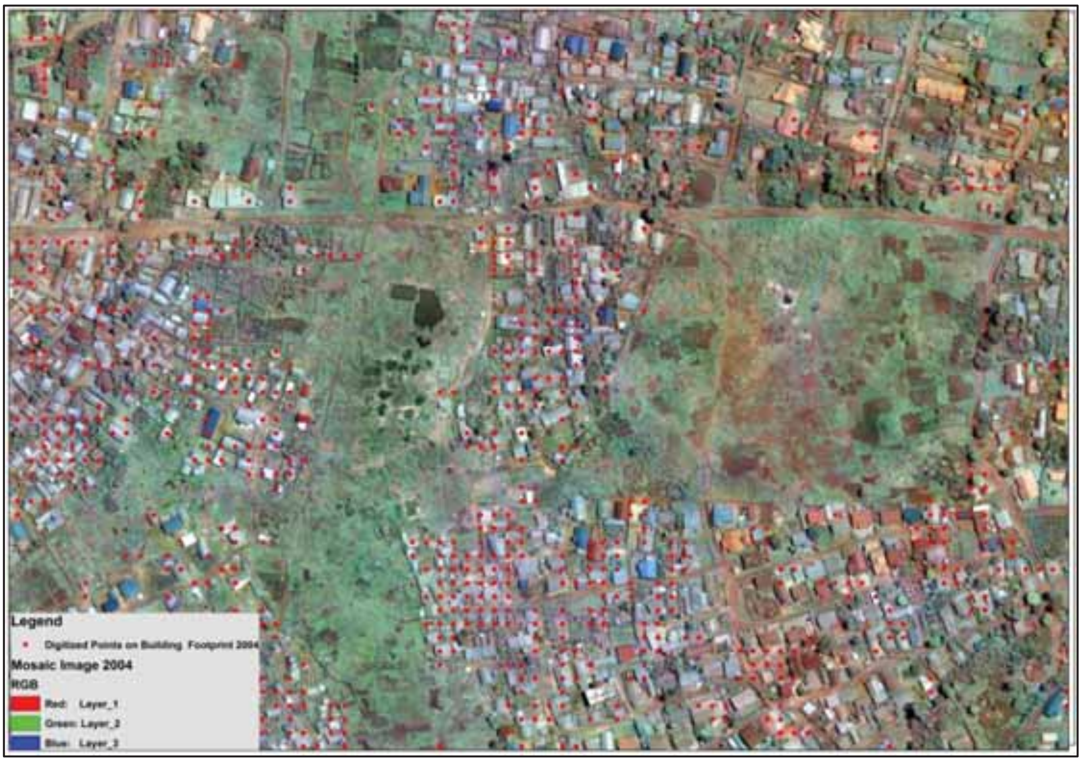


b) Building footprints extracted; the dark colours 2004 in the (right) and 2010 in the (left).

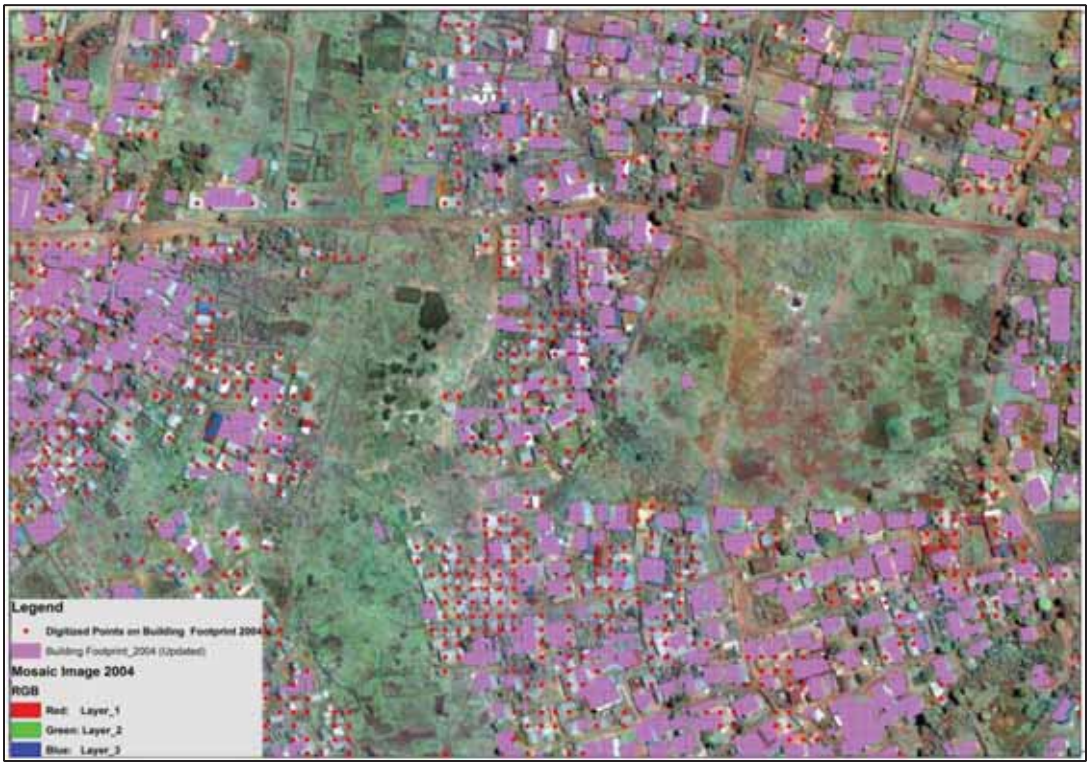
c) Building footprints 2004 and 2010 before updating (right) and after updating 2010 (left)

Appendix-(C)

Figure 8-2: Partial view indicating the process of digitizing the missed building footprints 2004.

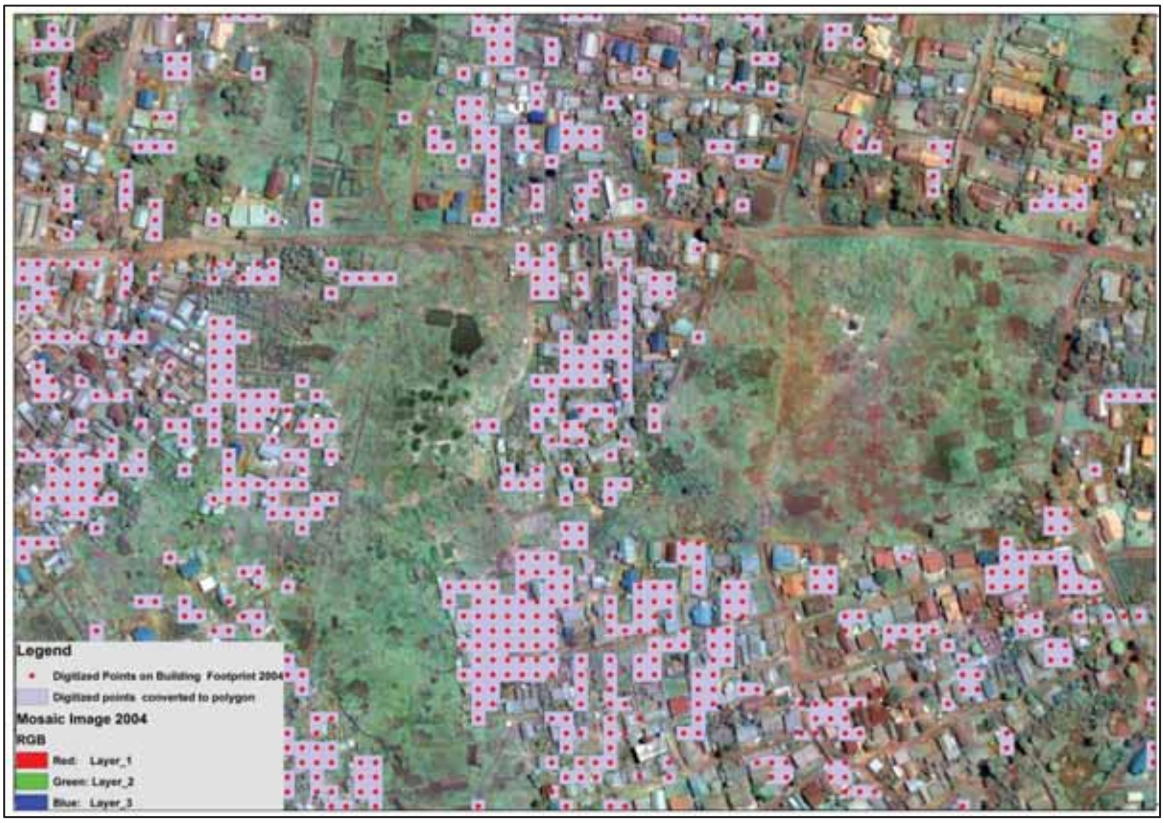


a) Extracted points that are on the building footprints of the image 2004



b) Extracted points and the building footprints of the image 2004

Figure 8-3: Comparing the converted polygon with the existing and missed built-up on image.



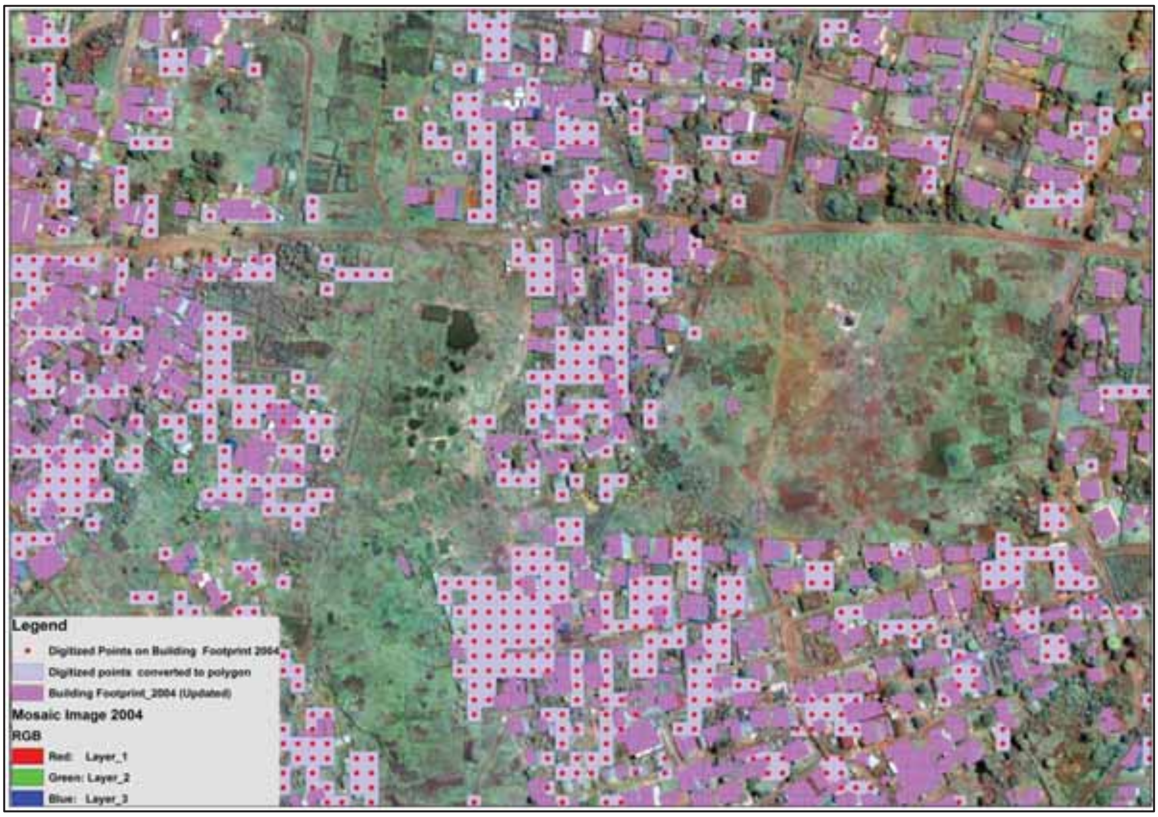
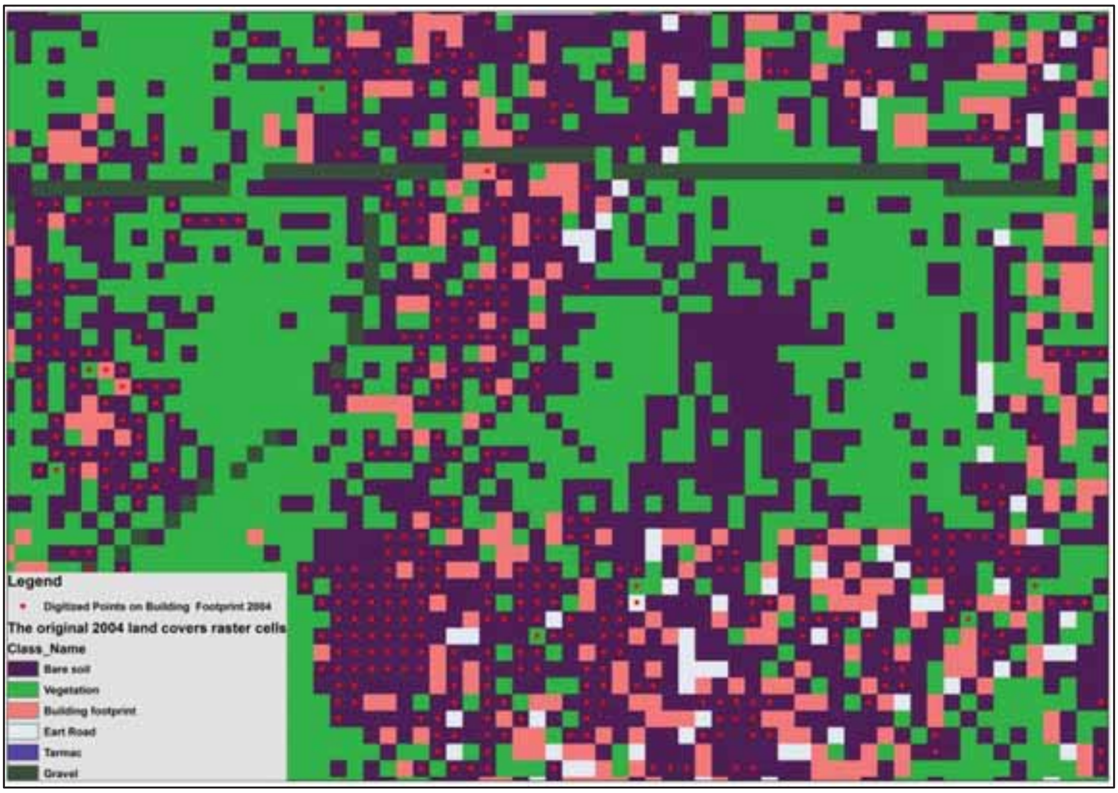
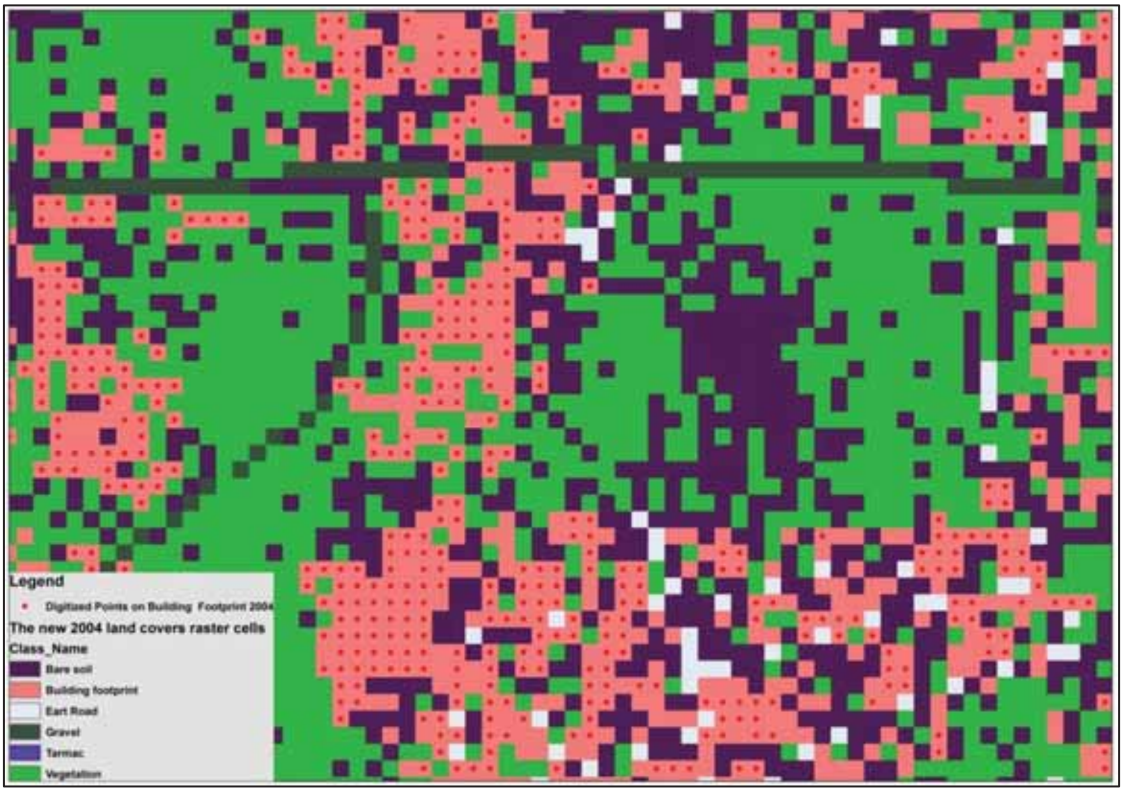


Figure 8-4: Comparison of land cover 2004 before and after digitizing the missed built-up in raster.





Appendix-(D)

Table 8-2: Summary of lists of driving factors of LCC /land use change based on literature

	Probable driving force	Literature
Site specific characteristics	Slope	(Cheng & Masser, 2003; De Koning et al., 1998; Dubovyk et al., 2011; Hu & Lo, 2007; Huang et al., 2009; Van Dessel et al., 2008); Key informants;
	Zoning status of the land	(Cheng & Masser, 2004; Huang et al., 2009; Schneeberger et al., 2007; Verburg, Schulp, Witte, & Veldkamp, 2006)
	Master plan	(Schneeberger et al., 2007; Verburg, Schulp, et al., 2006)
	Suitability of the land location for development	(Hu & Lo, 2007; Schneeberger et al., 2007; Verburg, Schulp, et al., 2006);Key informants
Neighborhood characteristics	Proportion of undeveloped land in the surrounding area	(Bürgi & Turner, 2002; Cheng & Masser, 2003; Dubovyk et al., 2011; Hu & Lo, 2007);Key informants
	Proportion of urban land in the surrounding area	(Bürgi & Turner, 2002; Cheng & Masser, 2003; Dubovyk et al., 2011; Hu & Lo, 2007; Li & Yeh, 2004; Verburg, Schulp, et al., 2006);Key informants
	Spatial policies, such as protected area and conserved land	(Hersperger & Burgi, 2009; Schneeberger et al., 2007);Key informants
Proximity characteristics	Distance to major roads	(Cheng & Masser, 2003, 2004; De Koning et al., 1998; Hu & Lo, 2007; Schneeberger et al., 2007)
	Distance to minor roads	(Cheng & Masser, 2003; Schneeberger et al., 2007);Key informants
	Distance to industrial sites	(Cheng & Masser, 2003; Dubovyk et al., 2011; Schneeberger et al., 2007);Key informants
	Distance to minor city centers	(Cheng & Masser, 2003, 2004; Hu & Lo, 2007; Liu, Li, Shi, Zhang, & Chen, 2010; Schneeberger et al., 2007; Verburg et al., 2002);Key informants
	Distance to rivers/ streams	(Cheng & Masser, 2003; De Koning et al., 1998; Verburg et al., 1999; Verburg et al., 2002; Verburg, van Eck, et al., 2004);Key informants
	Distance to market center	.(Hu & Lo, 2007; Schneeberger et al., 2007; Verburg et al., 1999);Key informants
	Distance to urban center	(De Koning et al., 1998; Dubovyk et al., 2011; Hu & Lo, 2007; Schneeberger et al., 2007; Verburg, van Eck, et al., 2004)
	Distance to bus stops	(Schneeberger et al., 2007);Key informants

Appendix -(E)

Table 8-3: Template of questionnaire sheet

Name:____________________________________date________________

Occupation/Profession________________________positon/duty________________

Address:____

City: ______________________state____________________________

Telephone:______________________Email:__________________________

Rating scale			
Very significant	= 5	Insignificant	= 2
Significant	= 4	Very insignificant	= 1
Neutral	= 3	Not Assigned	= 0

Question: 1 Scenarios for land cover changes

Trend population growth: the assumption that the population continuous to grow at the current growth rate. **Low population growth:** the assumption that the current growth rate will be controlled or lowered by some factors. **High population growth:** the assumption that the population growth rate continuous to grow exponentially.

Directions: Please make your choice of each of the lists scenarios of land cover change aimed to be developed based on the assumption of the aforementioned growth rate to predict future land cover change location (in the next 5-15 years) in the Lubigi catchment. Check the box under respective rows to make your choice.

Scenarios		Yes	No	Remarks
Assumptions	Trend population growth			
	Low population growth			
	High population growth			
				Please specify and also indicate rate of importance if others exist.

Question: 2 Probable driving force of land cover changes.

Directions: Please indicate the significance level of each of the lists driving factors of land cover change (for the past 5-15 years) in the Lubigi catchment if any by giving rating value as indicated below. Check the box under respective rows to make your indications.

	Probable driving force	5	4	3	2	1	0	Remarks
Site specific characteristics	Slope							
	Zoning status of the land							
	Master plan							
	Suitability of the land location for development							
								Please specify and also indicate rate of contribution if others exist.
Neighbourhoods characteristics	Proportion of undeveloped land in the surrounding area							
	Proportion of urban land in the surrounding area							
	Spatial policies, such as protected area and conserved land							
								Please specify and also indicate rate of contribution if others exist.
Proximity characteristics	Distance to major roads							
	Distance to minor roads							
	Distance to industrial sites							
	Distance to minor city centres							
	Distance to rivers/ streams							
	Distance to market centre							Please specify and also indicate rate of contribution if others exist.
	Distance to bus stops							
Very significant = 5; Significant = 4; Neutral = 3; Insignificant = 2; Very insignificant= 1; Not Assigned= 0								

Question: 3 possible available developable land locations in the parishes of Lubigi catchment.

Directions: Please give significance level of where possible future land for development (in the next 5-15 years) is available (expected to happen) with in each of the lists of parishes in the Lubigi catchment given below, if exist by giving rating value in the same way as indicated above. Check the box under respective rows to make your indications.

	Parishes Name	5	4	3	2	1	0	Remarks
1	BUKOTO I							
2	BUKOTO II							
3	BWAISE I							
4	BWAISE II							
5	BWAISE III							
6	KAMWOKYA I							
7	KAMWOKYA II							
8	KANYANYA							.
9	KAWEMPE I							
10	KAZO							
11	KIKAYA							
12	KYEBANDO							
13	MAKERERE I							
14	MAKERERE II							
15	MAKERERE III							
16	MAKERERE UNIVERSITY							
17	MULAGO I							
18	MULAGO II							
19	MULAGO III							
20	WANDEGEYA							

Q1. In which parishes do you think the growth much will take place in the next 5- 15 years? Why?

Q2. In which parishes do you think much developable land is available for the next 5- 15 years? Why?

Q3. In which parishes do you think much protected land is available for the next 5- 15 years? Why?

Very significant = 5; Significant = 4; Neutral = 3; Insignificant = 2; Very insignificant = 1; Not Assigned = 0

Appendix-(F)

Table 8-4: Rated responses of the key informants (Probable driving force of land cover changes)

Driving Factors	5	4	3	2	1	Total Respondent	Rating Score
Slope	2	5	1	1	3	12	3.2
Zoning status of the land	2	2	2	3	3	12	2.8
Master plan	1	1	4	3	3	12	2.5
Suitability of the land location	6	2	3	1	-	12	4.1
Proportion of undeveloped land	4	3	-	3	2	12	3.3
Proportion of urban land	5	5	1	-	1	12	4.1
Spatial policies	-	1	-	3	8	12	1.5
Distance to major roads	10	2	-	-	-	12	4.8
Distance to minor roads	3	3	3	3	-	12	3.5
Distance to industrial sites	2	3	1	3	3	12	2.8
Distance to minor city centres	3	5		2	2	12	3.4
Distance to rivers/ streams	2	1	3	1	5	12	2.5
Distance to market centre	5	5	-	1	1	12	4.0
Distance to bus stops	2	2	2	-	6	12	2.5

Table 8-5: Rated responses of the key informants (possible available developable land locations)

Parishes Name	5	4	3	2	1	Total Respondent	Rating Score
Kanyanya	4	6	-	2	-	12	4.0
Kikaya	5	3	2	-	2	12	3.8
Kyebando	1	7	4	-	-	12	3.8
kazoo	1	5	5	-	1	12	3.4
Bwaise III	3	2	3	3	1	12	3.3
Mekerere II	1	4	3	4	-	12	3.2
Bwaise II	3	2	2	3	2	12	3.1
Mekerere III	3	3	1	2	3	12	3.1
Mekerere I	1	4	3	2	2	12	3.0
Mulugo III	2	5		1	4	12	3.0
Kawempe I	1	4	3	1	3	12	2.9
Bukoto II	2	1	4	3	2	12	2.8
Kamwokya II	2	2	3	2	3	12	2.8
Kamwokya I	-	4	3	3	2	12	2.8
Mulugo I	3	2	1	-	6	12	2.7
Bukoto I	2	1	3	2	4	12	2.6
Bwaise I	-	3	3	4	2	12	2.6
Mekerere university	2	1	4	-	5	12	2.6
Wandegeya	-	5	2	-	5	12	2.6
Mulugo II	1	3	1	2	5	12	2.4

Table 8-6: Rated responses of the key informants (Expected Scenarios for land cover changes)

Scenario type	Yes	No	Total no of respondents
Trend population growth	7	5	12
Low population growth	1	11	12
High population growth	11	1	12

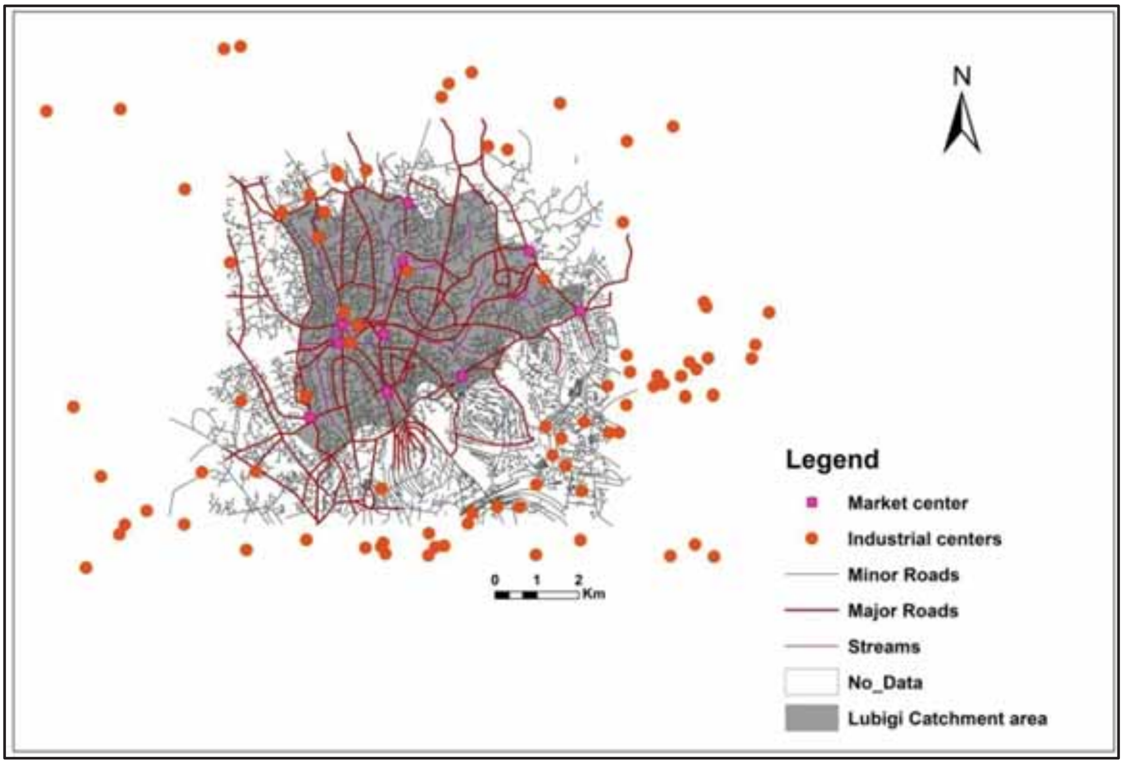
Appendix-(G)

Table 8-7: Lists of key informants

No	Key informant	Institution	Position
1	Baker Sengendo	KCCA	PDC/ Bwasie-II
2	Godwin Othieno	KCCA	Physical Planner
3	John Kisembo	KCCA	PDC/Bwasie-III
4	Kisembo Teddy	Mekerere University	Student/Geography department
5	Kuyiga Maximus	KCCA	Environmentalist/Kwamepe
6	Lutaaga Hassan	KCCA	PDC/ Bwasie-I
7	Mpanga Musassa	KCCA	PDC/ Mekerere-III
8	Nakoko Emmanuel	Mekerere University	Student/Ministry of lands
9	Nalule Harriet	Mekerere University	Student/Geography department
10	Nambassi Moses	Mekerere University	Student/Geography department
11	Prince Kanaakulya	KCCA	PDC/ Mulago-II
12	Shuwab Lwasa (Dr.)	Mekerere University	Lecturer/Geographer

Appendix-(H)

Figure 8-5: Consideration of neighbourhood effect for proximity characteristics



Appendix-(I)

Figure 8-6: Suitability layer

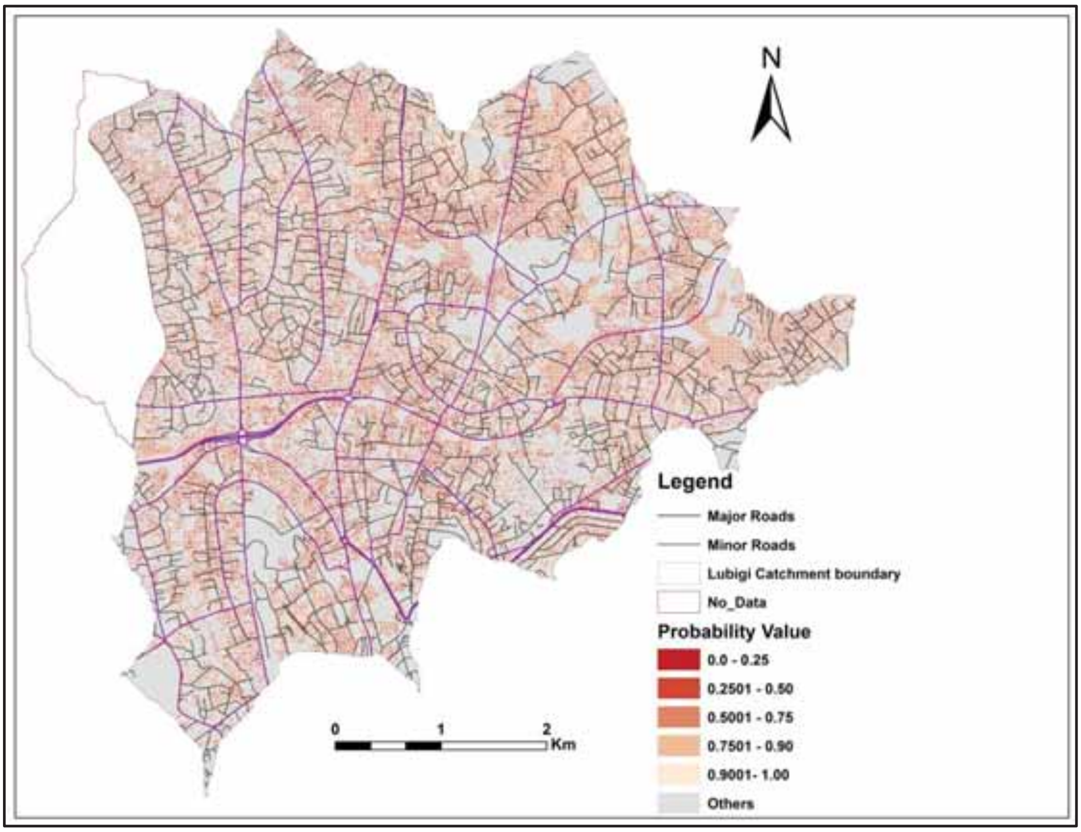


Figure 8-7: Land cover map for the Trend growth scenario 2020

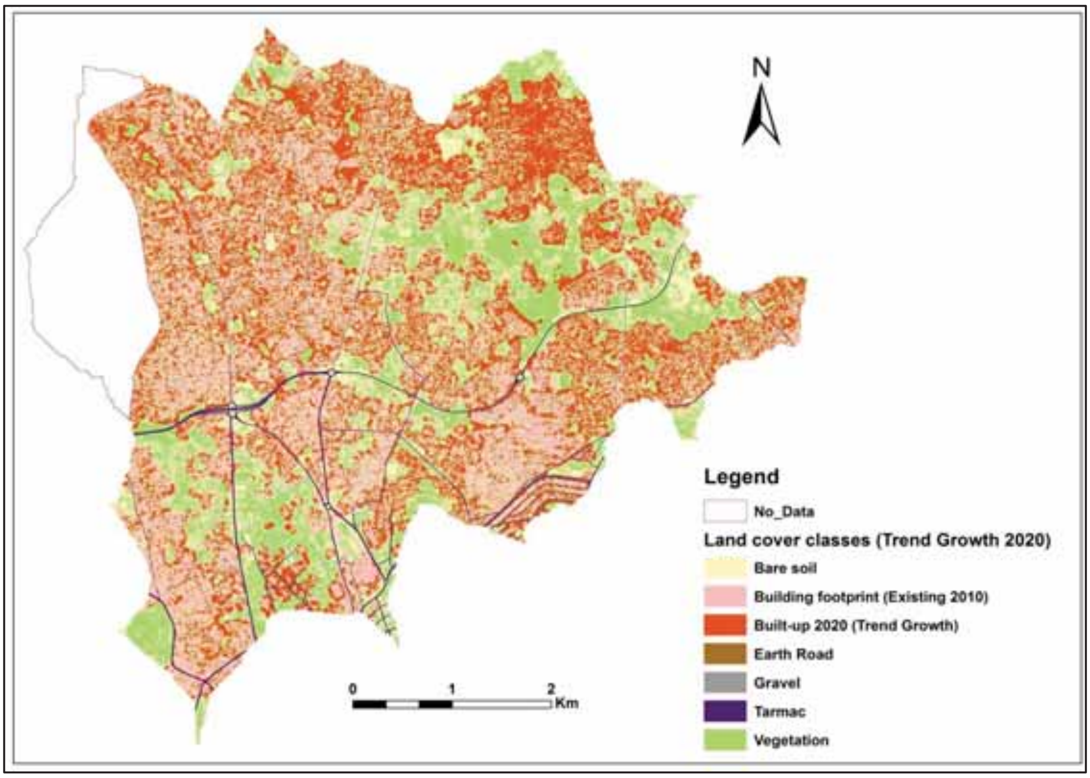


Figure 8-8: Land cover map for the Low growth scenario 2020

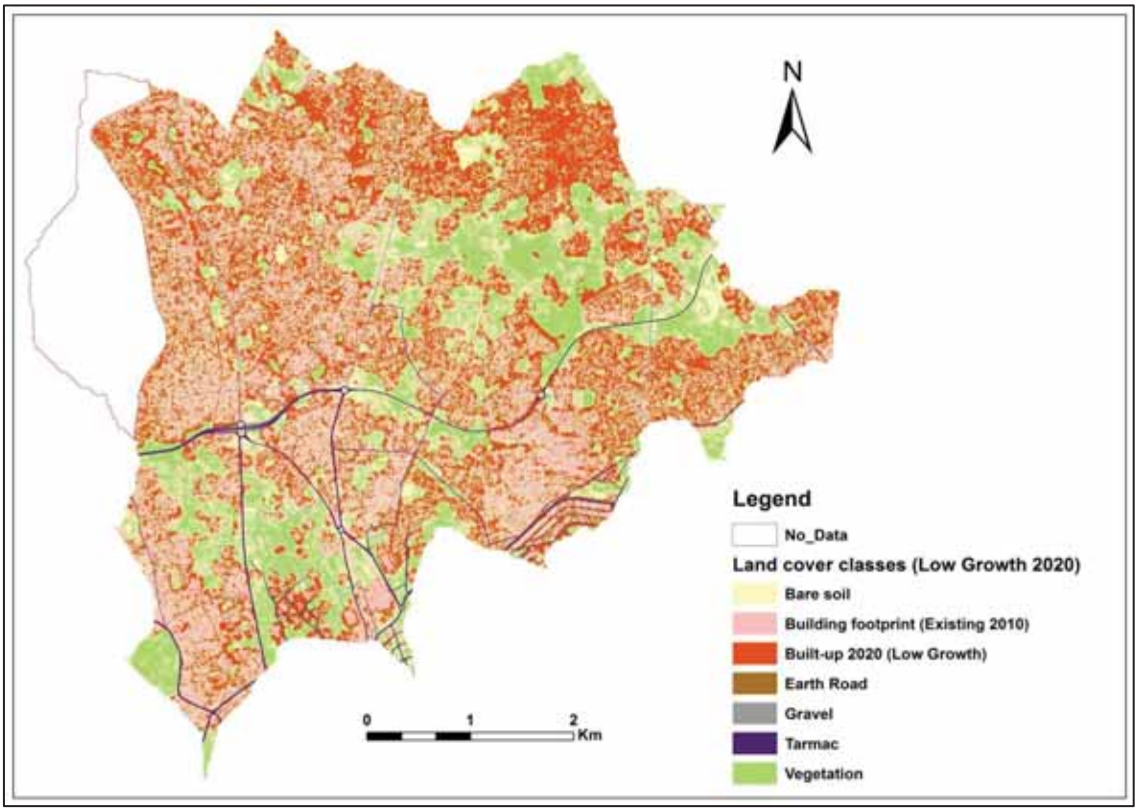


Figure 8-9: Land cover map for the High growth scenario 2020