MODELLING LAND USE AND LAND COVER CHANGE IN THE WESTERN CAPE PROVINCE

by

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Declarations

I, Petronella Chenayi Tizora declare that the dissertation, which I hereby submit for the degree Master of Science in Geoinformatics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

I declare that:

1) I obtained the applicable research ethics approval.
2) I have observed the ethical standards required in terms of the University of Pretoria's Code of ethics for researchers and the Policy guidelines for responsible research.

Signed: PTizora……………………

Date: 06 February 2018……

Abstract

The Western Cape Province is currently faced with population growth, declining household sizes, increasing household numbers, high levels of migration, urbanization and escalating development pressures. These factors have consequently triggered changes in land use and land cover (LULC) and incited issues such as urban sprawl, marginalization of the poor, limited public access to resources, land degradation and climate change. Furthermore, the issues surrounding LULC in the Province emanate from past inequities in access to land coupled with unsustainable land use practices. This poses a challenge to the government which strives for a sustainable nation that safeguards democracy by providing basic access to services, managing limited resources and advancing effective and efficient integrated planning whilst maintaining ecosystem functions. Understanding drivers of LULC change and how various factors influence LULC is important in meeting this challenge.

Models which integrate and evaluate diverse factors of LULC change can be used to guide planners in making more informed decisions and achieving a balance between urban growth and preservation of the natural environment. The implementation of these models at a regional scale is however very limited in South Africa. LULC change models are valuable if their structures are based on deep knowledge of the system under investigation and if they produce credible results. This study therefore investigates the suitability of LULC change models in simulating LULC changes at a regional scale by quantifying changes in LULC in the Western Cape Province, determining the driving factors of LULC changes and exploring and implementing a regional land use change model.

An investigation of changes in LULC was conducted by integration of a desktop study of LULC maps using the 1990 and 2013-2014 South African National LULC datasets; document analysis; and expert opinion in the form of semi-structured interviews with municipality town planners. An adapted Driver-Pressure-State-Impact-Response (DPSIR) Framework was used to analyse and present LULC changes in the study area. A literature review was conducted in shortlisting of models and further evaluations involved analysis of the models using selection criteria which focused on the model’s relevance to the study area, linkage potential to other models or software, transferability, user friendliness, data requirements and cost.

The results of this study show that LULC changes in the Western Cape Province are driven by political, economic, technological, demographic, environmental and cultural factors which must be considered in strategies and policies in future planning to avoid detrimental impacts on the environment whilst maintaining socio-economic benefits. These factors were integrated in a hybrid model that was successfully implemented in the study area by combining Dyna-CLUE and Markov concepts. The hybrid model produced probability maps and simulation maps for the years between 1990 and 2014. Validation of the simulated maps was conducted using both visual and statistical analysis and the results indicated that the simulated maps were in good agreement with the validation map. Data availability was observed as the main drawback which influenced both the implementation of other suitable models and the accuracy of simulated maps. This study however contributes to the understanding of driving factors of LULC change and implementation of LULC change models at a regional scale in the South African context. Knowledge derived from this study can be used by planners as a guide to effectively gauge the impacts that planning policies and other driving factors might have on future LULC patterns in the Western Cape Province.

Key words

Land Use, Land Cover, LULC Change, Driving Factors, DPSIR, LULC Change Modelling, Dyna-CLUE, Markov

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1. INTRODUCTION

1.1 BACKGROUND OF THE PROBLEM

The world has been experiencing rapid urban population growth at unprecedented rates over the past decades. According to the 2014 Revision of World Urbanization Prospects, 30% of the world's population was urban in 1950 and it is estimated that in 2050, 66% of the world's population will be urban (United Nations, 2014). Further analysis indicates that by 2050, population growth and urbanization will increase the world's urban population by 2.5 billion people and 90% of this increase will be concentrated in Africa and Asia (United Nations, 2014). The prospect of living in urban areas is often associated with better infrastructure, access to jobs and better health, education and social services. Such perceptions lead to rapid rural to urban migration which contributes to urban population growth and increases the demand on housing and other urban land uses. If not managed and properly planned, urban growth can lead to serious issues such as inadequate infrastructure, environmental degradation, urban sprawl and housing and transport shortages which all have negative effects on the environment. In a South African context, the Western Cape Province has been experiencing rapid and inappropriate developments in biodiversity areas, mostly due to urban growth.

The State of the Environment Outlook Report for the Western Cape Province reveals that the Province is experiencing significant population growth, decreased household sizes, increasing household numbers, high levels of migration, urbanization, infrastructure development, mining pressures and agriculture expansion and intensification (Maree and Van Weele, 2013). These trends have consequently triggered changes in LULC and incited issues such as urban sprawl, marginalization of the poor, limited public access to resources, land degradation and climate change. Furthermore, the issues surrounding LULC in the Province emanate from past inequities in access to land coupled with unsustainable land use practices (Maree and Van Weele, 2013). This poses a challenge to the government which strives for a sustainable nation that safeguards democracy by providing basic access to services, managing limited resources and advancing effective and efficient integrated planning whilst maintaining ecosystem functions (DEAT, 2008).

Understanding drivers of LULC change and analysing how various factors influence LULC is important in meeting this challenge. Tools which integrate and evaluate diverse factors of LULC change can be used to guide planners in making more informed decisions and hence achieve a balance between urban growth and preservation of the natural environment. Some countries have created and adapted such tools as computer models which can assist in exploring the consequences of policies, human behaviour and other drivers on LULC patterns.

Computer models are essential tools which can assist humans in making more informed decisions through supplementation of existing mental modelling capabilities (Costanza and Matthias, 1998). Verburg et al. (2004b) describe LULC change models as "tools to support the analysis of the causes and consequences of land use changes in order to better understand the functioning of the land use system and to support land use planning and policy." LULC change models are currently being implemented mostly in developed countries and being used for planning decisions. However, there seems to be limited evidence of research and implementation of these models in South Africa. There is need to assess and analyse LULC change models applicability and suitability in developing countries to come up with appropriate or new models that better address a particular land use system.

1.2 STUDY AREA

The study area for this research is the Western Cape Province which is the fourth largest province in South Africa and covers 10.6% (129 462 square kilometres) of the country's total land surface (Maree and Van Weele, 2013). According to Statistics South Africa, approximately 11.3% of South Africa's total population currently resides in the Western Cape and migration into the region from other provinces and countries is expected to continue in the near future (Stats SA, 2014).

The province occupies a unique position in relation to other provinces and comprises of natural landscapes (long scenic coastline, mountain ranges, coastal and inland plains) and favourable climate which together with other factors such as employment opportunities attracts migrants from other provinces (mostly Eastern and Northern Cape) and countries.

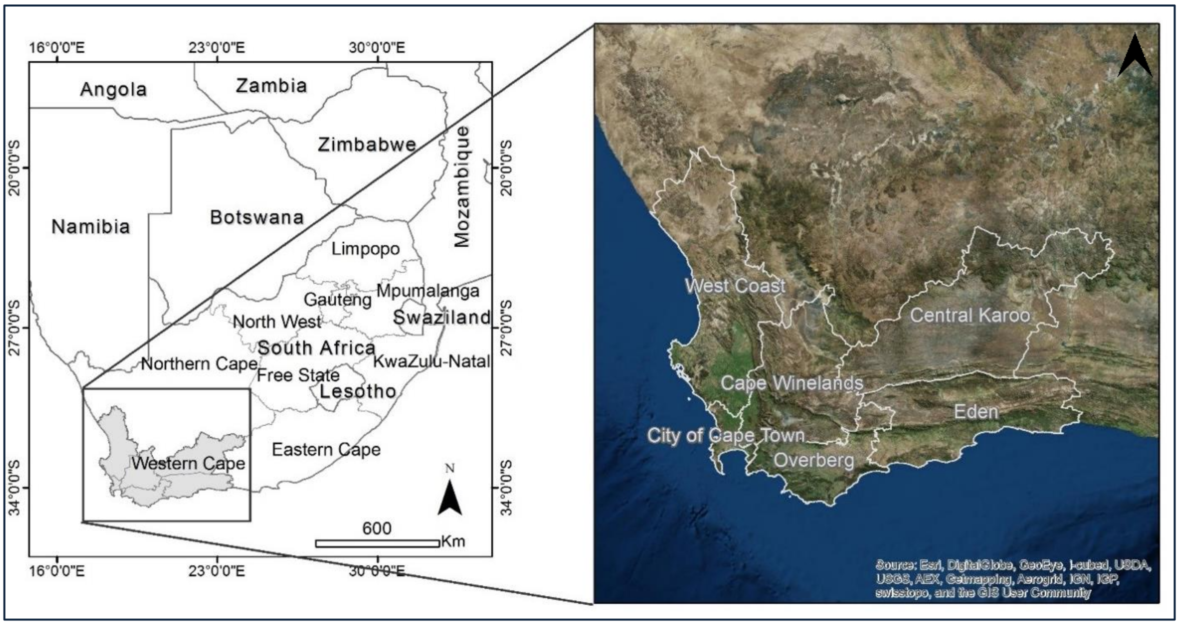


Figure 1-1: Western Cape Province location in relation to Africa and South Africa

Most migration into the Western Cape Province occurs along coastal areas and in agricultural areas which coincide with infrastructure development. According to Statistics South Africa, migration into the Western Cape increased from about 278 000 to 321 000 between 2001 and 2011 (Stats SA, 2014). The high rates of migration into the province contribute to population growth (Figure 1-2) and urban expansion which leads to pressure on resources and inevitable land use changes.

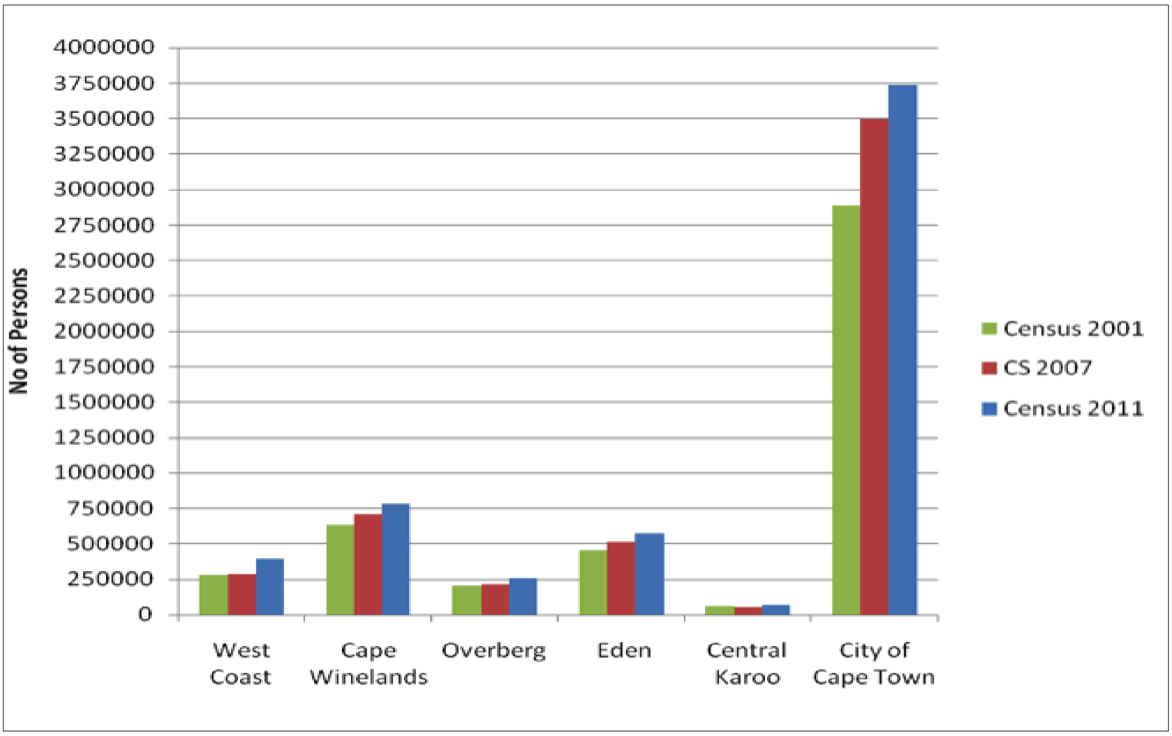


Figure 1-2: Population Growth in Western Cape (StatsSA, 2013)

Urbanization in the Western Cape region is very high and expected to increase in future. Overcrowding and huge shortages in housing and service delivery (waste removal, water and sanitation) are major issues in the Province. The Western Cape Department of Human Settlements estimated a housing backlog of about 409 827 in 2010 (DHS, 2010). Table 1-1 shows housing backlogs in each district municipality. Such backlogs, coupled with continued in-migration, results in the growth of informal dwellings with characteristics of poor living conditions such as lack of access to basic services. Furthermore, informal dwellings are located in unsuitable places which are often close to natural features such as wetlands and natural open space and, hence, contribute to environmental degradation.

Table 1-1: Housing Backlogs per District Municipality in the Western Cape Province (DHS, 2010)

District Municipality	Total Existing Housing Backlog
West Coast	15 876
Central Karoo	2 522
Eden	35 380
Overberg	17 427
Cape Winelands	38 522
City of Cape Town	300 100
TOTAL	**409 827**

Besides the issues associated with urbanization, population growth in the Western Cape Province also contributes to an increase in pressure on natural resources such as land. The agricultural sector is a major contributor to the economy of the province and is a crucial employment generator. However, expansion of agricultural activities has a negative impact on the environment if it occurs at the expense of Critical Biodiversity Areas (CBA's). An analysis by the Department of Agriculture, Forestry and Fisheries (DAFF) 2011 field boundary dataset indicates that there was cultivation expansion of approximately 53 600ha between 2000 and 2006, and 30% of this expansion was in CBA's (Pence, 2014). The Western Cape Province is therefore faced with a challenge of weighing urban development against agricultural expansion and protection of biodiversity areas.

1.3 PROBLEM STATEMENT

A diverse array of LULC change models have been developed, implemented globally and recommended as important in making land use decisions, yet the implementation of such models is limited in South Africa. This poses a challenge to regions such as the Western Cape Province where, similar to other growing provinces in developing countries, there is evidence of rapid and unplanned development in environmentally sensitive areas and policies are being implemented without estimation of the impacts of changes in land use.

This study will investigate the effectiveness and suitability of LULC models in simulating LULC change and supporting land use planning at a provincial scale in a South African context. The research will involve exploring the major driving forces of land use change in the Western Cape Province, selecting a model which can be adapted to simulate LULC change in this region and running the model with relevant data to test if the model is suitable. The question which this study seeks to answer is: Are there any regional LULC change models which can be adapted to a South African context, to simulate LULC change and hence assist as tools in supporting land use planning?

1.4 RESEARCH QUESTIONS

The following research questions arise from the above problem statement.

1) What are the driving factors of LULC development and change in the Western Cape Province?
2) Which LULC change models have been developed and implemented at a regional scale?
3) Which regional LULC change models can be customised for use in a South African context?

1.5 RESEARCH AIM AND OBJECTIVES

1.5.1 Research Aim

The overall aim of the study is to understand the factors which drive LULC change in the Western Cape Province and to explore LULC change models which can be adapted to the study area.

1.5.2 Research Objectives

The following goals will be undertaken to achieve the above aim:

1) To quantify changes in LULC in the Western Cape Province between 1990 and 2014.
2) To determine the driving factors of LULC change in the Western Cape Province.
3) To explore the current regional LULC change models and select a LULC change model which can be adapted to the Western Cape Province.

1.6 SIGNIFICANCE OF THE RESEARCH

The Gauteng City-Regional Observatory (GCRO) recently reviewed international and South African initiatives currently being used to monitor and simulate urban spatial change. The research categorized international urban models as “land use transportation (LUT), cellular automata, urban system dynamics, agent based models and spatial economics models” (Wray et al., 2015). It was however noted that a majority of South African modeling projects do not fall in the above listed categories and are “primarily Geographic Information Systems (GIS)-based and/or linked to spread sheets containing demographic or housing projections”(Wray et al., 2015). This therefore raises a gap in research on projects that attempt to simulate future LULC scenarios at a regional scale in South Africa.

A review of academic literature has revealed that no attempts have been made to implement LULC change models at a provincial level in South Africa. This is however a significant scale to analyze models as most factors which drive LULC change (e.g. governance) operate at this level. LULC changes operating at provincial levels have significant impacts on regional scale issues such as climate change and food security. Furthermore, processes which contribute to LULC change do not operate in isolation, various factors operate at different scales and there is need to analyze higher level processes which influence LULC change. This study will therefore fill the gap of LULC change models at a provincial scale in a South African context.

Part of the work in this thesis was peer reviewed and presented at the 7th Planning Africa Conference 2016-Making sense of the future: Disruption and Reinvention. The title of the Conference Paper is “Land Use and Land Cover Change in the Western Cape Province: Quantification of Changes & Understanding of Driving Factors” (Tizora et al., 2016). The audience, which comprised of town planners were interested in maps which highlighted LULC changes and gave positive feedback on the results of the LULC change assessment. Contributions of this study will be of interest to town planners and researchers because it will:

- Augment the existing practical and theoretical knowledge base on LULC development and change.
- Infuse more knowledge on drivers of LULC change and LULC change models.
- Fill in the knowledge gap by running models and recommending adaptable LULC change models to a developing country at a regional scale.

1.7 LIMITATIONS

This study is aimed at identifying LULC change models which can be adapted to a South African context at a regional scale and which can use the driving factors that affect the Western Cape Province. It does not include the LULC dynamics of other regions and the possible model inputs, assumptions or outputs which are applicable to other regions or provinces in South Africa.

This study also involves the identification of major social, economic and political factors which can drive significant changes in LULC; however, the incorporation of such factors into identified models may be limited by the availability of data. Simulation of real world events by models depends on data and assumptions applied. In some cases, the data may be available but not at the required scale and this may pose a challenge in accurately testing models. The quality, scale and availability of data will therefore have an impact on the implementation of the models and simulation results.

1.8 RESEARCH METHODS

This section will explain the methods which will be used to answer research questions and subsequently achieve the aim of the research.

1.8.1 LULC Drivers

Question 1. What are the driving factors of LULC development and change in the Western Cape Province?

Answering this question will involve determining the driving factors of LULC change by examining historical development patterns and exploring the current state of LULC change by reviewing literature on factors which influence land use decisions in the Western Cape Province. Policies such as Provincial Spatial Development Framework (PSDF) which determine future LULC change will also be reviewed.

Interviews will be conducted to further supplement the secondary literature on historical and current drivers of LULC change and to determine important factors which will influence future change. The interview participants will be municipality town planners and their responses will be based on their past experiences and knowledge on current land issues in the region. The questions will focus on why LULC change has been taking place in the region, what future changes are likely to occur and what is driving LULC change. The findings of driving factors of LULC change obtained from literature search and the interview will be very significant in this study as they determine the data needs of the research.

1.8.2 Regional LULC Models

> Question 2. Which LULC change models have been developed and implemented at a regional scale?

LULC change models will be identified using web and literature searches. The models will further be narrowed down and compared based on their characteristics such as data and resource requirements, information which the model produces and model strengths and limitations. This information will be obtained from reviews by researchers who have explicitly focused on categorizing and analyzing models of land use change. Further details of the individual models will be acquired from publications which explain specific functionalities and applications of the models.

1.8.3 Regional LULC Model Selection

> Question 3. Which regional land use change models can be customized for use in a South African context?

The main purpose of exploring land use change models is to select a model which can be used in South Africa at a regional scale. Selection criteria will be used to select the most suitable model. The following will be conducted after selecting a suitable model:

- Collection of data requirements for the selected models;
- Population of models with relevant data; and
- Simulating LULC changes and validating simulation results.

1.9 CHAPTER OVERVIEW

This thesis is made up of seven chapters that focus on achieving the purpose of this research and answering research questions. A summary of the chapters is provided below.

Chapter two will form the theory base of this research and provide a literature review on land use change modelling. This chapter will cover driving factors of land use change, major concepts important in land use change modelling and classification or categorization of land use change models.

Chapter three describes the methods used in achieving research objectives and provides an outline of data gathering and analysis processes.

Chapter four will discuss the results of the desktop study of land use changes and driving factors identified from interviews and document analysis.

Chapter five will describe selected models in terms of their characteristics including modelling techniques, data inputs and data outputs.

Chapter six will explain the model implementation and validation of results.

Chapter seven will provide the study conclusions, recommendations and possible future work.

2. THEORETICAL BACKGROUND

This Chapter provides a literature review of LULC change modelling. The first section of the literature review will explain the concepts; land, land use and land cover. LULC change and factors which influence or drive LULC change will be reviewed from both a local and international perspective. This will be followed by theory on LULC change models and concepts or issues which are important in LULC change modelling. Thereafter a summary of the most popular land use model classification techniques will be provided based on published literature. The last section of the literature review will present current South African academic modelling projects.

2.1 LAND USE AND LAND COVER

2.1.1 Land

The United Nations Convention to Combat Desertification documentation defines land as, “the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system” (United Nations, 1994). A more holistic definition of land is provided in the Food and Agriculture Organization (FAO) Land and Water Bulletin 2, where land is described as “a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)” (Sims and Sombroek 1997).

2.1.2 Land Use

The terms land use and land cover are often used interchangeably, though they have different meanings. Land use is the purpose for which land is used whereas land cover refers to the physical characteristics of the surface of the land. A formal description by FAO states that land use is “the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it” (Kutter and Neely, 1999). Chapter 1 of the Spatial Planning and Land Use Management Act No 16 of 2013 (SPLUMA) defines land use as “the purpose for which land is or may be used lawfully in terms of a land use scheme, existing scheme or in terms of any other authorisation, permit or consent issued by a competent authority, and includes and conditions related to such land use purpose." This definition is however not entirely correct as people can take de facto control of land and use it for various purposes which may not align with any land use scheme or authorisation. The use of land is therefore uncertain, does not end at political boundaries and can be both legal and illegal (Cooper, 2014)

Land use systems exist when different land uses are systematically linked through temporal interactions e.g. crop rotation or spatial relations. Figure 2-1 shows the relationship between land cover, land use and land function, where land function is the capacity of land to provide goods and services (Verburg et al., 2009).

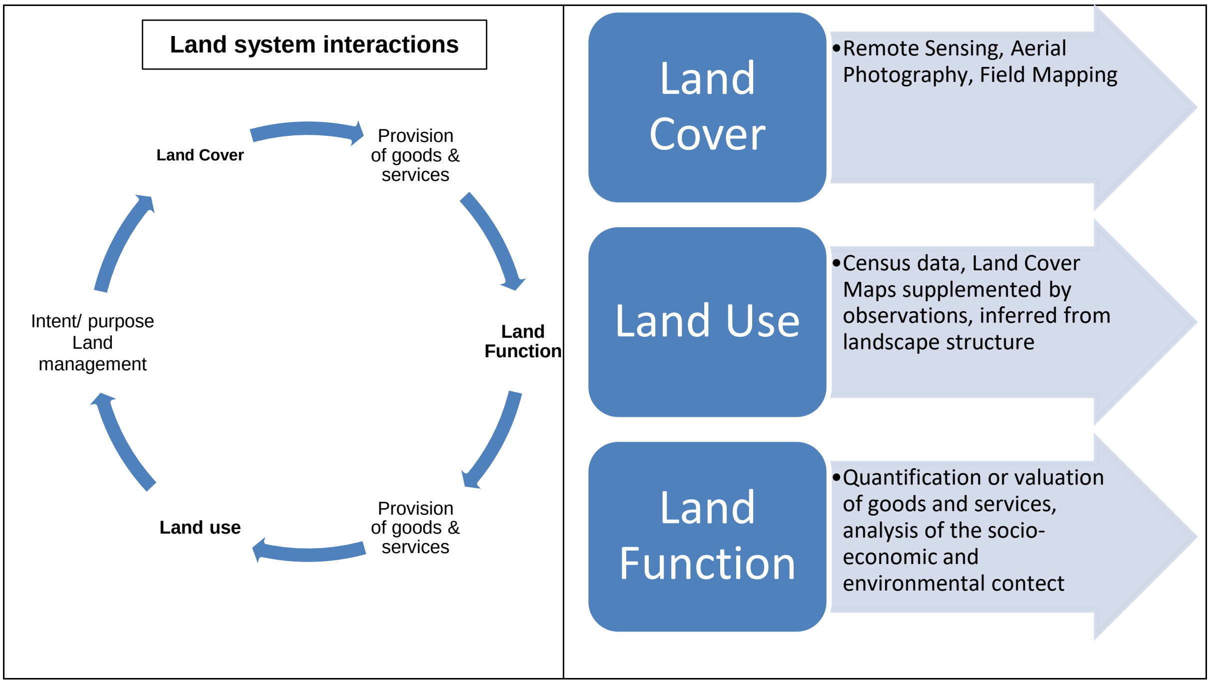


Figure 2-1: Land Use, Land Cover and Land Function relationships and data collection methods(Verburg et al., 2009).

As illustrated in Figure 2-1 land function is linked to land cover, implying that changes in land cover contribute to changes in provision of goods and services (Verburg et al., 2009). Mapping and quantification of land functions is useful in determination of hotspots of investment opportunities. However, the term land function is not very popular in South Africa, although it obviously informs planning which influences zoning. Cooper et al. (2014) differentiate planning, zoning and land-use and stress that planning should determine zoning, which in-turn determines land-use.

2.1.3 Land Cover

According to Turner et al. (1994), “Land cover is the biophysical state of the earth’s surface and immediate subsurface.” Land cover therefore includes quantity and types of all features over the earth such as vegetation, water, soil, artificial surfaces, etc. The difference between land use and land cover is demonstrated by Turner et al. (1994) as illustrated in Table 2-1. Turner et al. (1994) further add that land use involves the intent or purpose for which land is utilized. A different aspect, “biophysical manipulation” is also described as the manner which humans treat land to achieve intent e.g. the planting of grass for pasture.

Table 2-1: Distinguishing Land Cover and Land Use [adapted from (Turner et al., 1994)]

Land Cover				
				
Non biotic Construction	Forest	Grassland	Cropland	Wetland
Land Uses: Purpose				
				
Logging	Grazing	Agriculture	Wildlife Preserve	City/Town
Biophysical Manipulation				
Clear cutting	Grass Planting & Fertilising	Mounding	Culling for	Drain groundwater

Land use and land cover are obviously linked; however, it should be noted that a single land cover can support multiple land uses and vice versa. For instance, a land cover e.g. grassland can support many land uses such as grazing and recreation and a single land use may also take place on various land covers. Land cover can be determined by analysing remotely sensed images such as satellite images or aerial photos whilst land use and land use change will require additional socio-economic data and methods to determine the activities occurring on the landscape (Ellis and Pontius, 2007). Verburg et al. (2009) agree with this and state that unlike land cover, land use is not directly observable though it can be inferred from activities such as grazing or structural landscape elements e.g. logging roads. This study is conducted at a regional scale therefore the data that will be used in analysis and modelling will be a combination of data obtained from satellite imagery and socio-economic data. The term LULC will therefore be used to refer to land use and land cover in this study.

2.2 LULC CHANGE AND DRIVERS

2.2.1 International Review of Drivers of Land Use Change

LULC change involves a conversion from one LULC to another or intensification of the present or current LULC (Turner et al., 1994). The changes in LULC are determined by how individual landowners, communities, businesses and governments control land use and make decisions on how to use land. Such decisions are influenced by the interactions between socioeconomic factors such as population and environmental factors (e.g. topography and climate) which vary at different scales (Lambin and Geist, 2007). (Briassoulis, 2000) confirms this and further clarifies that environmental drivers do not have a direct impact on land use change but impacts land cover change which in turn influences land managers decisions.

LULC change can therefore be modelled as a function of socio-economic and environmental factors. These factors are often referred to as ‘driving factors’. The driving factors of LULC change are also categorised as either proximate or underlying, where the former are direct modifications by individuals at a local scale such as individual farms and the latter are indirect changes which occur at a regional scale (Lambin and Geist, 2007).

Proximate driving factors are usually caused by human activities such as infrastructure and agriculture expansion whereas underlying factors are caused by complex interactions between social, political, demographic and environmental variables (Lambin et al., 2001). According to Lambin et al. (2001), proximate causes can be categorised into three broad categories of agricultural expansion, wood extraction and infrastructure expansion whose activities or variables are demonstrated in Figure 2-2.

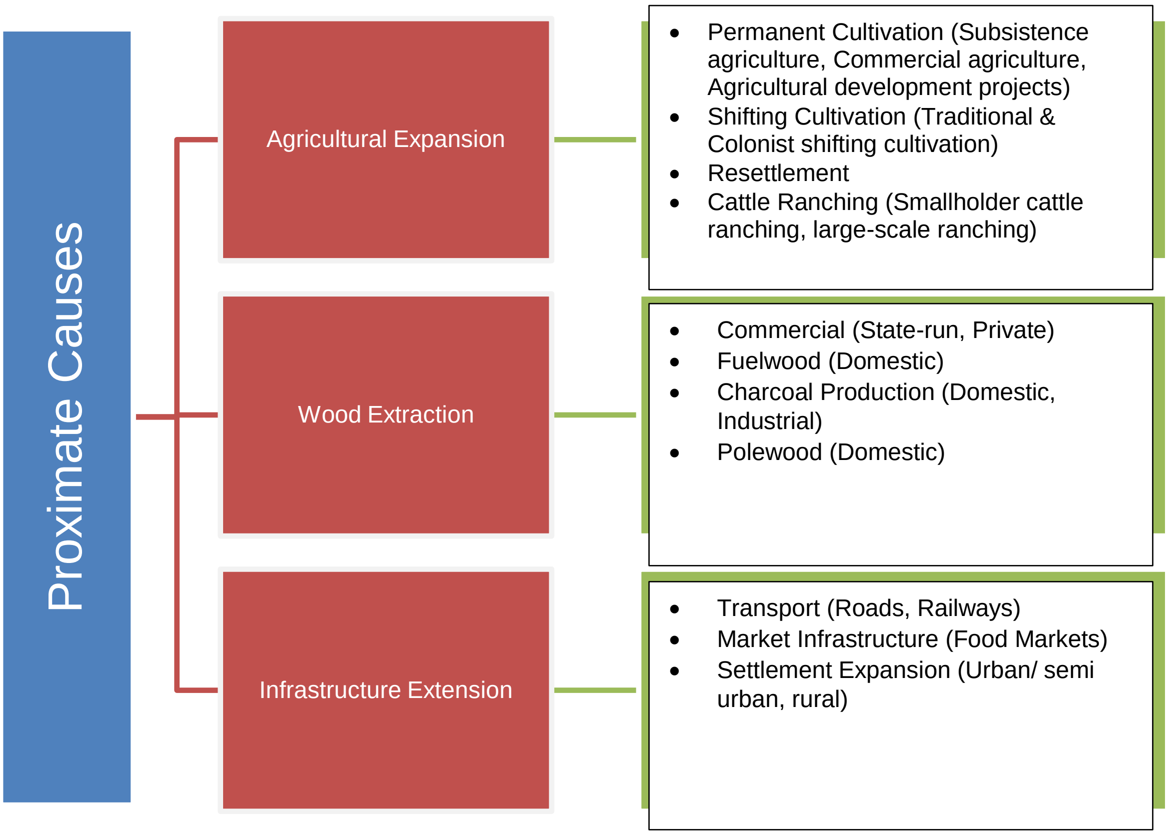


Figure 2-2: Proximate causes of LULC change and their variables (adapted from (Lambin et al., 2001)).

Briassoulis (2000) describes underlying driving forces as socio-economic drivers which comprise of demographic, economic, institutional factors, technological and cultural or socio-political. These components of underlying driving forces are further explained by Lambin et al. (2001) and summarized in Figure 2-3 below.

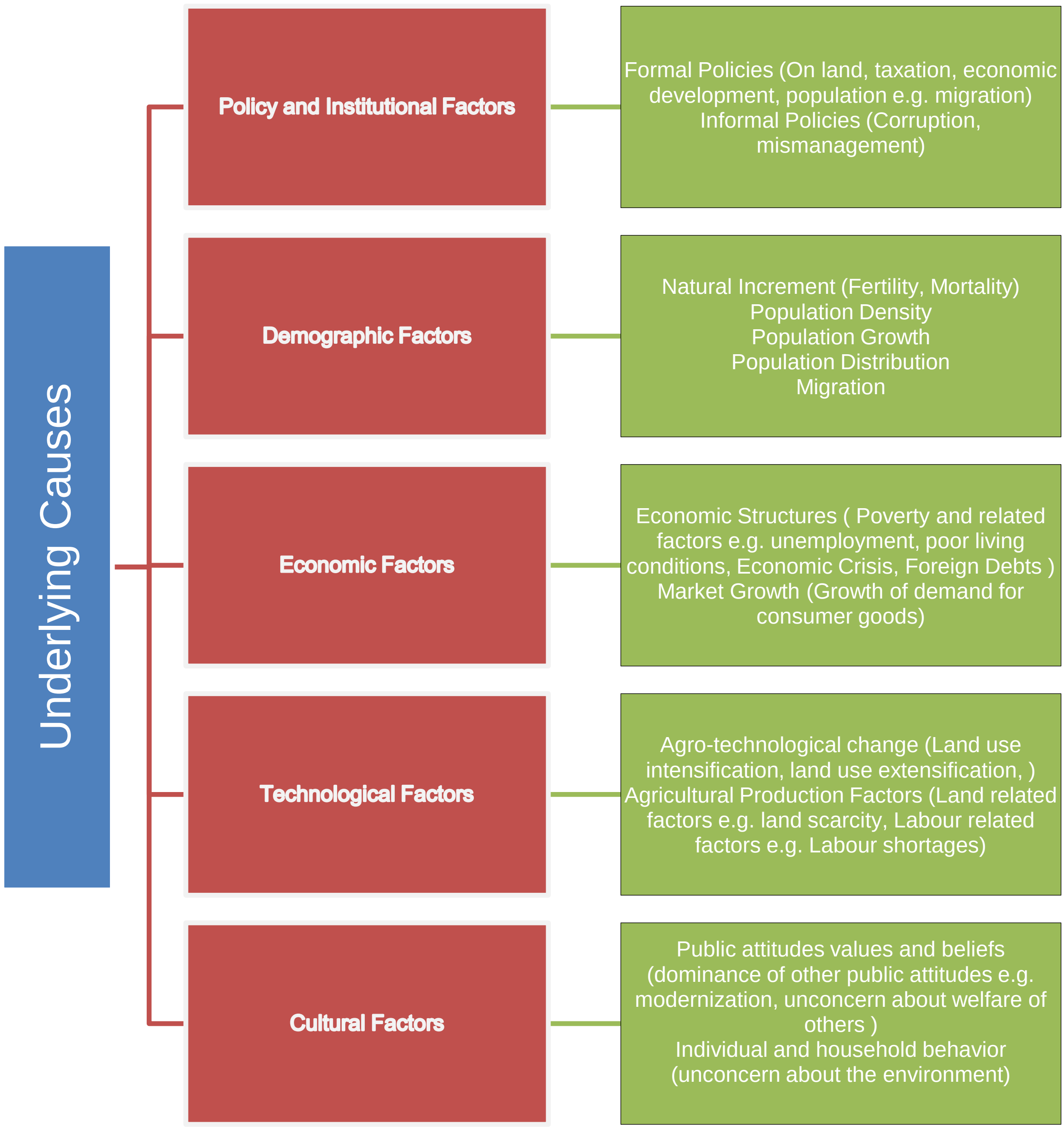


Figure 2-3: Underlying causes of LULC change and their variables [adapted from (Lambin et al., 2001)]

2.2.2 South African Review of Drivers of LULC

This section of the literature review covers drivers of LULC change in South Africa. The focus will be on underlying causes which consist of political, demographic, economic, technological, cultural and environmental variables. This is because unlike proximate factors, underlying factors operate at regional levels which coincide with the scale of this study.

2.2.2.1 Political Factors

Various legislation and policies play a significant role in stirring LULC change in South Africa. The political apartheid history of South Africa is partially responsible for the current spatial patterns in the country; therefore policies are a crucial factor when reviewing land use changes. The Group Areas Act 41 of 1950 divided South Africans into different racial groups where a greater percentage of the land was for the white minority, whilst the majority blacks were confined to smaller homelands. The use of land in previous homelands has had significant impacts on land cover, land use and livelihood options (Hoffman, 2014) and post-apartheid South Africa faces challenges which emanated from inequalities. Apartheid not only racially separated people, but also led to inequality in housing, geographic location, environmental landscape and distribution of facilities (Spinks, 2001).

Post-apartheid policies and legislation were introduced with the aim of transforming apartheid spatial patterns into regions of “equity, integration and sustainability” (Rubin, 2008). However, past spatial patterns have been replicated by government’s incentives such as the Reconstruction and Development Program (RDP), which has seen settlement construction on the urban periphery with limited access to resources (Van Donk, 2008). This is mostly due to the unavailability of affordable well located land and the need to address housing backlogs (Van Donk, 2008). This issue is further discussed under economic factors in this chapter.

Geist and Lambin (2002) categorized political and institutional factors into formal and informal policies where formal policies result in intended LULC change whereas informal policies are “misdirected policies” that result in unintended LULC changes. The sections below focus on the categories of political and institutional factors which influence land use decisions in South Africa.

Formal Policies

This section of the political factors will focus on the spheres of government, policies and issues related to planning, which influence LULC change.

The South African Constitution of 1996 sets the laws of how government operates and provides for the establishment of three spheres of government as National, Provincial and Local (Table 2-2).

Table 2-2: South Africa Spheres of government (ETU, 2007)

SPHERE	LEGISLATURE	EXECUTIVE	ADMINISTRATION
NATIONAL	Parliament	President & Cabinet	Directors General & departments
PROVINCIAL	Provincial Legislature	Premier & Executive Council	Heads of Department & staff
LOCAL	Municipal Councils	Mayor & Mayoral Committee	Municipal Manager, HoDs & staff

These three spheres are accorded legislative authority as described in Sections 43, 44, 104 and 156 of the Constitution and Section 40(1) states that they "are distinctive, interdependent and interrelated" (South Africa, 1996) and responsible for land use and spatial planning in South Africa. The functional areas which are directly related to planning are listed in Schedules 4 and 5 of the Constitution of South Africa as provincial planning, municipal planning, regional planning and development and rural and urban development (Van Wyk, 2010). The Constitution however does not provide for the meanings of these functional areas, leading to inappropriate developments and conflicts between the three spheres.

Van Wyk (2010) argues that planning as outlined in the Constitution consists of various functional areas which are administered by all three spheres of government. He contends that the shared responsibilities by the three spheres over the functional areas bring about overlaps, conflicts and confusion in land decision-making processes. These problems are further exacerbated by Sections 100 and 139 of the Constitution; which authorise the national and provisional governments to intervene in municipal obligations. Van Wyk (2010) supports this argument by citing several court decisions dealing with the scope of the functional areas that relate to planning.

In a discussion document by the South African Cities Network on "important legal issues for provincial legislation dealing with Spatial Planning and Land Use Management", Berrisford and De Visser (2012) support this argument when they allege that the Constitution was not fully definitive in the terms listed in Schedules 4 and 5 concerning land use and spatial planning. They furthermore maintain that “there are other functional areas in schedules 4A and 5a which are relevant to land use planning i.e.; housing, agriculture, and environment”. Provincial government has authority over these functional areas, hence exercise of power overlaps with municipalities. However, the Spatial Planning and Land Use Management Act No 16 enacted in 2013 (SPLUMA) addresses these issues. It clearly states the categories of spatial planning as municipal planning, provincial planning and national planning.

Local Municipal Planning

According to the Constitutional Court judgement in a matter between , MACCSAND PTY Ltd AND OTHERS V. CITY OF CAPE TOWN AND OTHERS (2010) 4217/09 and 5932/09;

> … Planning in the context of municipal affairs is a term which has assumed a particular, well-established meaning which includes the zoning of land and the establishment of townships. In that context, the term is commonly used to define the control and regulation of the use of land.

Municipal planning is therefore the most detailed planning as it caters for local and district levels of planning. According to SPLUMA Section 5(a0), “municipal planning includes the compilation, approval and review of integrated development plans and regulation of land use within municipal area where the nature, scale and intensity of the land use should not affect the provincial planning mandate of the provincial government or the national interest” (South Africa, 2013). Municipalities are also required to have a hierarchy of plans ranging from a broad strategic municipality plan to a detailed plan where there is assigning of land use rights (Forbes et al., 2011). These plans consist of the following: “Long Term Development Strategy; Integrated Development Plan; Spatial Development Framework; Land Use Schemes (Forbes et al., 2011) and are illustrated in Figure 2-4 and briefly explained below.

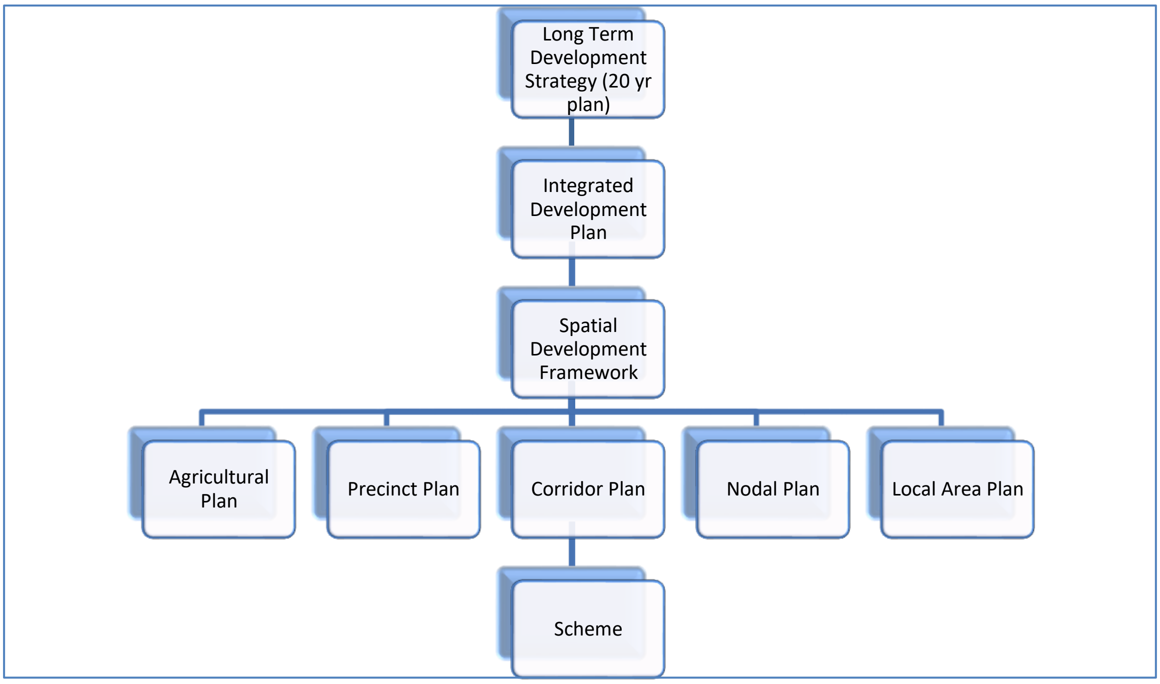


Figure 2-4 : Conceptual Hierarchy of Plans adapted from Forbes et al., (2011).

- Long Term Development Strategy (LTDS) – This is the Municipality's schedule unfolding their strategy for accomplishing its development goals for a period of twenty years and beyond. It is directly related to the Integrated Development Plan (IDP), providing an extended strategy for carrying out the IDPs. It should be contained within the framework of the IDP but is however usually viewed as a self-contained plan.
- Integrated Development Plan – This is a statutory requirement for the Municipal Council in terms of Chapter 5 of the Municipal Systems Act, 2000. Part 1 (1) of the Chapter stipulates that;

> "... A municipality must undertake developmentally-oriented planning so as to ensure that it –
> a) Strives to achieve the objects of local government set out in Section 152 of the Constitution;
> b) Gives effect to its developmental duties as required by Section 153 of the Constitution; and
> c) Together with other organs of state contribute to the progressive realization of the fundamental rights contained in Sections 24, 25, 26, 27 and 29 of the Constitution."

Section 153 (a) and (b) of the Constitution of the Republic of South Africa demands that a municipality "manage its administration and planning processes to give priority to the basic needs of the community, and to promote the social and economic development of the community and participate in national and provincial development programmes" (South Africa, 1996)

The Municipality Act, in Chapter 5 Part 2, requires that the IDP be reviewed and updated annually, and as indicated above, is regulated by and is intertwined with the long term development strategy (South Africa, 2000). "This strategic plan for the development of the municipality should link, integrate and co-ordinate various sector plans taking into account proposals for the development of the municipality, align the resources and capacity of the municipality for the implementation of the plan, form the policy framework and general basis on which annual budgets are set and in addition must be compatible with both national and provincial development plans" (Forbes et al., 2011).

- Spatial Development Framework – Spatial Development Framework (SDF) is a statutory requirement set out in Chapter 26(e) of the Municipal Systems Act. It is the principal strategic planning instrument which must include basic guidelines for land use management system for the municipality and it must include provisions in Section 26(g) to (i) (South Africa, 2000).
- Scheme – These are planning schemes or land use schemes prepared in terms of the Provincial Ordinance Act which serve to uphold development administration within a municipality.
- Other Non-Statutory Plans – Non-statutory plans fall between SDF and schemes and include a Spatial Development Plan, a Sector Plan, a Local Area Plan, a Nodal Plan, a Corridor Plan, a Precinct Plan, etc. They give an interpretation of the SDF over a specific geographical area.

Provincial and National Planning

The Constitution gives concurrent power to both national and provincial spheres in dealing with functional areas listed in Schedule 4. According to SPLUMA, Provincial planning is responsible for monitoring municipalities' compliance with the SPLUMA act and compilation of provincial spatial development framework whilst national planning involves compilation of spatial development plans and policies, including a national SDF (South Africa, 2013).

The following are the most common or important post-apartheid legislation that control land use and spatial planning in South Africa:

- **Constitution of South Africa No 108 of 1996** – Outlines the responsibilities of each sphere of the government (South Africa, 1996).
- **Municipal Systems Act No 32 of 2000** – Sets out legislation that enables municipalities to uplift their communities and ensure provision of access to essential services. Chapter 5 of this Act requires municipalities to adopt an Integrated Development Plan (IDP) which consists of a Spatial Development Framework (SDF) which "which must include the provision of basic guidelines for a land use management system for the municipality" (South Africa, 2000).
- **Development Facilitation Act No 67 of 1995 (DFA)** – Development Facilitation Act (DFA) 67 of 1995 aims "to introduce extraordinary measures to facilitate and speed up the implementation of reconstruction and development programmes and projects in relation to land; and in so doing to lay down general principles governing land development throughout the Republic; to provide for the establishment of a Development and Planning Commission for the purpose of advising the government on policy and laws concerning land development at national and provincial levels" (South Africa, 1995). This act however permitted developers to apply for development approvals from tribunals, leading to possible inappropriate land use and conflicts associated with parallel authority (Van Wyk, 2010). Parts V and VI of this act have been declared unconstitutional by the Constitutional Court and the Spatial Planning and Land Use Management Act (SPLUMA) of 2013 addresses issues which arose from DFA and clearly explains categories of spatial planning at municipal, provincial and national levels.

  Spatial Planning and Land Use Management Act no 16 of 2013 (SPLUMA) – National Legislation that was passed in 2013 and provides for a framework for planning i.e. development principles; SDF's at provincial, national and municipal levels; and Land use schemes (South Africa, 2013). Section 4a of the Act articulates that the spatial planning system in South Africa consists of the spatial development frameworks which must be prepared and adopted by national, provincial and municipal spheres of government. Section 21 of SPLUMA further endorses LULC modelling by outlining contents which must be included in municipal spatial development frameworks. Section 21c), regulates that a

Municipal spatial development framework must "include a longer term spatial development vision statement for the municipal area which indicates a desired spatial growth and development pattern for the next 10 to 20 years;" (South Africa, 2013). Section 21d) maintains that a Municipal SDF must "Identify current and future significant structuring and reconstructing elements of the spatial form of the municipality, including development corridors, activity spines and economic nodes where public and private investment will be prioritised and facilitated." (South Africa, 2013). Section 21f) further states that Municipal spatial development framework must Include estimates of economic activity and employment trends and locations in the municipal area for the next five years (South Africa, 2013).
SPLUMA therefore supports and regulates LULC and LULC modelling in South Africa and provides guidelines for spatial planning and land use management.

Forbes et al., (2011) further listed the following as other legislation which affect land use in South Africa: "Housing Act No 107 of 1997; National Environment Management Act No 107 of 1998 (NEMA) and associated acts i.e. NEM: Protected Areas Act, 2003; NEM: Biodiversity Act, 2004; NEM: Air Quality Act, 2004; NEM: Integrated Coastal Management Act, 2008; NEM: Waste Act, 2008; National Heritage Resources Act No 25 of 1999; Promotion of Administrative Justice Act No 3 of 2000; Planning Professions Act No 36 of 2002; Social Housing Act of No 16 of 2008; National Land Transport Act 5 of 2009". The legislation listed above influences land use by either encouraging land use changes or preventing changes. An example is National Environmental Management: Protected Areas Act No 57 of 2003 which prevents changes by regulating and restricting activities in protected areas.

Informal Policies

Informal policies can be in the form of corruption, mismanagement of land and unintended LULC changes which results from misdirected policies (Geist and Lambin (2002). The existence of policies can become irrelevant if there are influential people or foreign powers that are corrupt and interested in land developments. The South African Corruption Watch defines corruption as "the abuse of public resources or public power for personal gain" (Corruption Watch, 2015).

The Transparency International survey conducted in 2013 reveals that one in five people around the world reported that they paid a bribe in land services (Hardoon and Heinrich, 2013). The presence of corruption in land use leads to decision making which is driven by biased interests and unfair policies. Corruption in land use is critical in post-conflict communities and countries such as South Africa where efficient land management is crucial in rebuilding and reconstructing the country (Hardoon and Heinrich, 2013).

Corruption occurs at both administration and policy levels where administrative corruption involves paying bribes in property registration, changing or forging title deeds or obtaining favourable land use plans whilst political corruption comprises of actors such as government officials at both local and national levels; land investors; developers; and individuals with political and economic power who aim to gain control of the country's resources (Arial et al., 2011).

Political corruption is a result of opportunities which arise from development projects and land transactions e.g.:

> … when state-owned lands are privatised or leased, zoning or construction plans are approved, large-scale land acquisitions by investors are negotiated, and land is expropriated for government (or government-related) projects (Arial et al., 2011).

The challenge with corruption, especially at political level, is that it is difficult to document and prosecute, since the acts and policies which drive it may fall within the laws of the country. Acts such as SPLUMA consist of Sections which allow for abuse of authority e.g. Section 55 gives the Minister permission to exempt a piece of land or an area from provisions of the Act.

2.2.2.2 Demographic Factors

Various literature has pointed out that it is not the number of people that leads to pressure on land use, but rather aspects of population composition and distribution such as household size, migration and urbanization. These factors are explained in the following sections, including their implications (particularly in housing) and interactions with government policies.

- **Migration and Urbanization in South Africa**

A combination of political, social, economic and demographic factors drives internal and international migration in South Africa. Migration is however not a new phenomenon in Southern Africa and has a much larger history. International migration involves movement across national boundaries, whereas internal migration involves movements within the same country.

International Migration

International migration into South Africa is currently triggered by poverty, deteriorating economic conditions and political instability in neighbouring countries. According to a report by Stats SA on documented immigrants in South Africa, the largest number of foreign permits were issued to Zimbabwean nationals followed by Nigeria in 2013 (StatsSA, 2013). The illustration below (Figure 2-5) shows the distribution of various permits issued to the top ten foreign country nationals in South Africa in 2013.

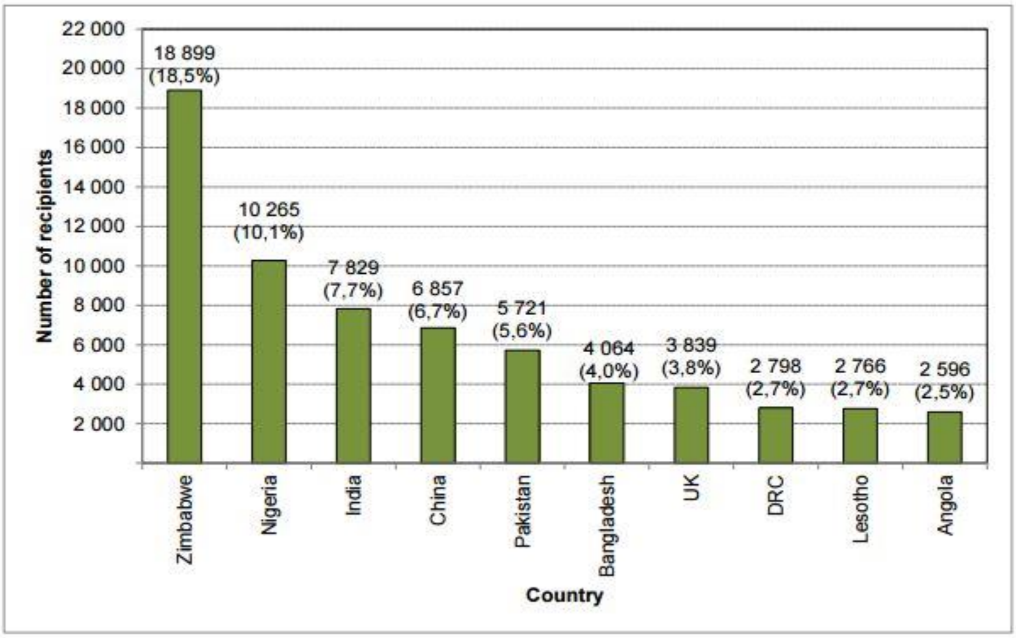


Figure 2-5: Distribution of Temporary Residential Permits issued by Home Affairs in 2013 (StatsSA, 2013).

The documentations on migration produced by StatsSA are however based on immigration statistics by Home affairs which are calculated from permits issued and does not include undocumented or illegal cross-border migrants. There is also no information on the common cross-border migrants from Mozambique, Malawi, Lesotho, Swaziland, and Botswana even though the number of migrants from these SADC countries is on the rise. It is estimated that there are between one and five million Zimbabweans residing in South Africa since 2000 and these comprise of "politically persecuted refugees, economic migrants (from professionals to unskilled persons), humanitarian migrants (including unaccompanied children), traders, shoppers and transit migrants" (Polzer, 2008). Current international migration trends in South Africa indicate that the bulk of migrants are concentrated in urban areas in Gauteng (46.8%) and Western Cape (13.4%) (Stats SA, 2007).

Internal Migration

Internal migration in South Africa is mostly characterised by temporary circular migration and permanent migration to urban areas (Fauvelle-Aymar, 2014). Circular migration involves movement to places of work or education whilst permanent residence remains in the rural or peri-urban setting (Kok and Collinson, 2006). Internal migration in South Africa significantly increased after the new government of South Africa introduced laws that allowed freedom of movement to South Africans as opposed to Group Areas Act 41 of 1950 which have already been discussed. Better employment opportunities, access to better health, education and other services and reunion with family members are some of the reasons why people migrate in South Africa. Figure 2-6 below shows that the greater proportion of internal migrants moves to metropolitan cities and secondary cities, whilst small towns or rural areas have a high out-migration.

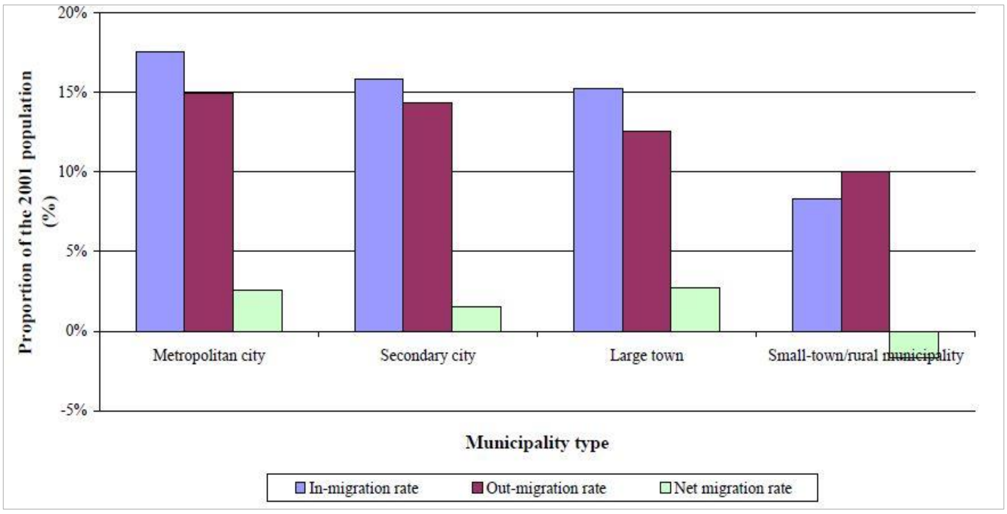


Figure 2-6: Migration rates for different municipality types in 2001 (Todes et al., 2010)

Effects of Population Growth and Urbanization

The structure of urban areas or cities is made up of the following pillars: economic development nodes e.g. business & industrial sites; housing developments e.g. residential, private ; public transport networks; infrastructure networks e.g. water and sanitation (Turok, 2014). An increase in population and urbanization leads to pressure on these four pillars resulting in serious issues such as poverty, under serviced informal housing and land degradation.

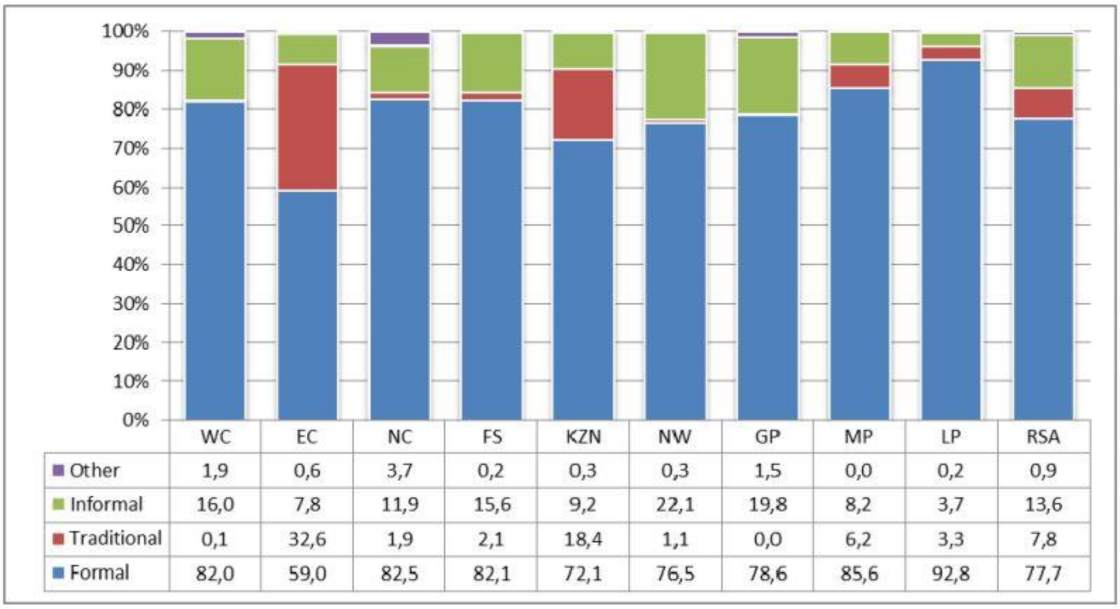
Increased effects of urbanization are evident in South Africa’s housing and transport sectors where the demand for housing in urban areas is continuously increasing yet there is no affordable land close to places of business and work, thus resulting in low-cost housing, shacks in peri-urban areas and expensive transport costs (Turok, 2014).

- **Declining Household Size**

Besides migration, declining household sizes in South Africa also contribute to growth and land-use issues. According to a study by UNISA, the average household size in South Africa declined from 4.48 in 1996 to approximately 3.69 in 2005 (Van Aardt, 2007). The number of households in South Africa is increased by migrating youth and single mothers who contribute to the increase in shacks in urban areas (Van Zyl et al., 2008) which leads to an increase in pressure on infrastructure and services.

Informal Housing/Background Shacks

Informal housing is a common feature in urban areas of most developing countries and remains a challenge as such settlements are continuously increasing due to rapid urbanization and population growth. South Africa is not an exception in this subject as most population living in urban areas are currently living in appalling conditions which are not easily accessible to work. Figure 2-7 below shows that in 2013, the North West (NW), Gauteng and Western Cape Provinces had the highest concentration of informal dwellings in the country.



	WC	EC	NC	FS	KZN	NW	GP	MP	LP	RSA
Other	1,9	0,6	3,7	0,2	0,3	0,3	1,5	0,0	0,2	0,9
Informal	16,0	7,8	11,9	15,6	9,2	22,1	19,8	8,2	3,7	13,6
Traditional	0,1	32,6	1,9	2,1	18,4	1,1	0,0	6,2	3,3	7,8
Formal	82,0	59,0	82,5	82,1	72,1	76,5	78,6	85,6	92,8	77,7

Figure 2-7: Percentage of houses that live in formal, traditional and informal dwellings by Province (Stats SA, 2013).

According to the General Household Survey (GHS) conducted by Stats SA, there has been an increase from 73.7% to 77.7 % in formal dwellings and a 0.4% increase in informal dwellings between 2002 and 2013 (Stats SA, 2013). The number of people living in informal settlements therefore remains very high despite the introduction of subsidised low cost housing, therefore implying that the government is failing to address the effects of urban growth.

- **Population Density**

South African cities have low average population densities as compared to cities (refer to Table 2-3) with similar characteristics in other countries (South African Cities Network, 2014).

Table 2-3: Population density of Cities in the World (Derived from Demographia 2009 by (South African Cities Network, 2014))

High income countries	**Density (population/km^2)**	**Middle & low income countries**	**Density (population/km^2)**	**South Africa**	**Density (population/km^2)**
Asia	7000	India	15000	Cape Town	3950
Japan	4200	China	7350	EThekwini	3500
Western Europe	3150	Russia	4900	Tshwane	2750
Canada	1600	Rest of Asia	8100	Johannesburg & Ekurhuleni	2500
Australia	1450	Africa	8150	Nelson Mandela Bay	2100
United States	1100	South & Central America	6250		
Average	**3100**	**Average**	**8292**	**Average**	**2960**

Densification in South Africa is occurring on the periphery with informal settlements and subsidised housing developments instead of urban nodes where there are abundant resources. Cities in South Africa therefore experience reverse mode densification resulting in inefficient use of land, fragmentation, increased travel times and expenses, densification in marginal areas and higher infrastructure costs (Ewing and Mammon, 2008)

2.2.2.3 Economic & Technological Factors

Economic factors can be in the form of taxes, investments, access to capital, markets, cost of production and transportation, technology and subsidies (Barbier, 1997). Land managers are stimulated by these economic factors. In addition, they are also motivated by profitability and feasibility of a particular land use. Economic factors, combined with institutional and technological factors play a significant role in land use change. For example, giving farmers access to capital and markets and agricultural technology can encourage agriculture expansion and conversion of land.
According to the Department of Agriculture, Forestry and Fisheries, the number of commercial farms in agriculture has declined from approximately 120 000 in 1950 to about 29 000 currently and there has also been a corresponding increase in average farm size (DAFF, 2015). This has consequently led to less reliance on manual labour (leading to job losses) and an increase in capital assets such as mechanisation.

- **Land Markets and Demand**

“Land Markets are mechanisms by which rights in land and housing, either separately or together, are voluntarily traded through transactions such as sales and leases. These transactions may take place on the formal land market, or may happen through informal channels such as informal land developers”(Palmer et al., 2009). In a land market developers search and scramble for land. When demand for a particular piece of land increases, its value also increases leading to demand and supply; where demand is triggered by increase in population, household development projects, and availability and access to credit funds (Palmer et al., 2009).

Heavy competition for land exists between the private and public sectors, where the main objective of the private sector is to accumulate as much profit from the land as they can generate, but is reluctant to participate in delivery of affordable housing projects. Therefore, if land is accessed by the private sector they will allocate it mostly to office parks, shopping malls, high income generating development projects, etc.

Consequently, government incentives such as RDP Housing settlements are in urban peripheries where land is available and affordable for government to purchase. This then leads to extended travel time and increased transport costs for people seeking employment and services in the CBD, where resources are concentrated. In a paper on settlement planning and urban transformation, Turok (2014) addresses how settlement location decisions and investment by private and public sectors could be improved to achieve a more integrated urban form. He describes peripheral locations as "poverty traps" characterised by longer travel times, increased government transport subsidies, high carbon emissions and limited access to services (Turok, 2014).

However, Venter et al. (2004) contend that there are both costs & benefits in different types of locations and stress that the relationship between household location and transport expenditure is not just a function of distance from the CBD, but other factors such as proximity to other development nodes, lifestyle choices are also relevant. In another study conducted by Venter et al. (2004) residents located on peripheral locations had far better access to employment opportunities than expected due to the existence of development nodes in diverse areas. Venter et al. (2004) add that distant locations often offer livelihood resources such as land for agriculture and have potential to access resources in future as the city expands outwards.

- **NIMBY**

NIMBY stands for "Not in My Back Yard", and is often sited together with LULU's (Locally-Unwanted-Land-Uses) and PIBBY (Put it in Black's Backyards). It is used to describe the individuals or citizens that are in opposition of proposed new developments which are within their neighbourhood (Ibitayo, 2008). This opposition is mostly triggered by fear that property values would be lowered.

A typical example would be a case where the government intends to build RDP houses in a low-density suburb where they believe beneficiaries will have equal access to markets and services whilst the government also benefits by reducing backlogs in housing delivery. NIMBIES would then oppose it by objecting that this will lead to reduced property values and have an adverse effect on their quality of life.

NIMBY is further empowered by policies such as the Development Facilitation Act (Section 4(a)) which endorses NIMBIES to oppose the establishment of low income housing projects in their neighbourhood (Rubin, 2008). However, Section 57 in SPLUMA foresees the potential impacts of NIMBY and stresses that development cannot be hampered solely based on property value (South Africa, 2013). It is therefore imperative to note that economic factors are evidently intertwined with political factors.

2.2.2.4 Cultural Factors

Besides political, demographic, technological, environmental and economic factors, various cultural factors also play an important role in land use change. Cultural factors encompass beliefs, attitudes, values and perceptions of land managers which have an impact on land use decisions (Lambin and Geist, 2007). Historic heritage sites such as the Castle of Good Hope which is one of the oldest building in South Africa that was a fort for protection around 1666, have become the centre of community life and its use has been reinvented over the years. The awareness of land managers on possible consequences of land use decisions depends on their personal histories and information available to them, and these are often linked to political and economic factors (Lambin and Geist, 2007).

2.2.2.5 Environmental Factors

Environmental factors are biophysical factors which “define the natural capacity or predisposing environmental conditions for land use change, with the set of abiotic and biotic factors – climate, soils, lithology, topography, relief, hydrology and vegetation” (Lambin and Geist, 2007). The interactions between environmental variables and human activities influence land use change e.g. relief determines the extent which machinery can be used and rates of erosion. Steep slopes are difficult to operate modern farm machinery and subject to erosion thus limiting exploitation. Changes in land uses such as agriculture are influenced by environmental factors e.g. climate (rainfall, wind, temperature) and soil conditions.

- **Soil**

Fischer et al. (2002) identified constraints for physical and chemical properties of soil which are essential for land exploitation as terrain-slope, soil depth, soil fertility, soil chemical, soil texture, soil drainage. Soil loss, compaction, poor drainage, salinisation and acidity are classified as soil degradation; which is common in former South African homelands and contributes to land abandonment by farmers (Gibson et al., 2005).These former homelands, now known as "communal areas" are mostly occupied by black South Africans who engaged in livestock and crop production for personal consumption and informal markets (Wessels, 2005).Communal areas are characterized by overstocking, soil erosion, excessive wood harvesting, and high population and are generally perceived as degraded (Hoffman and Todd, 2000). Land degradation is one of South Africa's critical environmental issues which is linked to food security, urbanization and climate change.

- **Water Availability**

The availability of water resources influences land uses such as agriculture and activities associated with it. Agriculture and crop irrigation are the dominant users of water in South Africa but still face challenges of water scarcity and uneven and unreliable rainfall with only about 450 mm per year compared to the world average rainfall of 860 mm per year. South Africa has about 3-4% high potential agricultural land but faces competition from other land uses such as residential, industrial developments and mining and this is further exacerbated by other factors such as water availability and climate change.

All the factors which have been discussed above require an understanding of how individuals and governments make land use decisions and how the various factors interact in specific contexts to influence land use change. These factors will be further explored in the Western Cape Province and verified using experts in land use planning. The following section of the literature review will focus on theory on land use change models and model classification.

2.3 LULC CHANGE MODELLING

(Verburg et al., 2004b) describe LULC change models as:

> … tools to support the analysis of the causes and consequences of land use changes in order to better understand the functioning of the land use system and to support land use planning and policy.

Various LULC change models have been developed and successfully applied in countries such as USA to assist in understanding land use dynamics and to simulate future LULC.

Heistermann et al. (2006) define a LULC model as “a tool to compute the change of area allocated to at least once specific land use type.” This is based on the fact that LULC models have the ability to determine the amount of land used at a particular location, where LULC changes will occur and in analysis of drivers of LULC change (Heistermann et al., 2006).

The development of LULC change models has been influenced by three essential issues which are: the need for policy and planning, the availability of data and theoretical developments from diverse fields with different approaches and perspectives on what should be modelled (Batty, 2008)

Simulation of future LULC involves the integration of multiple disciplinary perspectives, testing of assumptions, development of frameworks for empirical data collection, creation future system scenarios and testing the effects of policies on the land use system (Robinson et al., 2007). (Veldkamp and Lambin, 2001) support this and emphasize on LULC change models ability to test future land use systems states through scenario building based changes in selected variables.

According to Verburg et al. (2004b), the following concepts are essential when modelling LULC change: level of analysis, cross-scale dynamics, driving forces, spatial interaction and neighbourhood effects, temporal dynamics and level of integration. These concepts are briefly explained below.

2.3.1 Concepts in Land Use Change Models

2.3.1.1 Level of Analysis

Social sciences disciplines mostly study models at a micro-level whereas natural sciences focus on macro levels using GIS and remote sensing (Verburg et al., 2004b). Micro-level model can be categorised into multi-agent and micro-economic models where multi-agent models involve simulation of "decision-making by individual agents of the land use change explicitly addressing interactions among individual" (Verburg et al., 2004b). On the other hand, micro-economic models are based on economic models where there is an assumption that land use decisions are made by individuals who own land and use of land is based on highest returns. Models designed at a macro level have the ability to analyse socio-economic and environmental factors and an example is the IIASA for China (Verburg et al., 2004b), however some macro-levels such as the CLUE focus on the spatial analysis of the land use system.

2.3.1.2 Cross-scale Dynamics

Scale is "the spatial, temporal, quantitative, or analytic dimension used by scientists to measure and study objects and processes"(Evans et al., 2003). Concepts of extent and resolution are often used to understand scale. In land use modelling, spatial extent refers to the total size of the geographical area being modeled and resolution is concerned with the precision in measurement e.g. size of raster cell (Agarwal et al., 2002). Scale determines how land use patterns are measured and also impacts the driving forces in a land use model (Jantz and Goetz, 2005).

2.3.1.3 Driving Forces

As explained in section 2.2, driving factors of land use change can be categorised into bio-physical and socio-economic factors. The scale of analysis influences the dominance of driving factors on the land use system. The selection of driving factors of LULC change and quantification of relations between driving forces and LULC change are important in model implementation (Verburg et al., 2004b).

Selection of driving factors is determined by the theories and assumptions which make up the model and the extent of the study area. Larger extents cover a larger area and are characterized by diverse LULC patterns therefore there will be a larger range of driving factors (Verburg et al., 2004b). Relationships between LULC and driving forces can be quantified using theories and physical laws e.g. econometric models, empirical methods and expert knowledge e.g. cellular automata models (Verburg et al., 2004b).

2.3.1.4 Spatial Interaction and Neighbourhood Effects

This concept is based on the fact that land uses patterns exhibit spatial relationships and is commonly incorporated in cellular automata models (Verburg et al., 2004b). It is most likely that some land uses may be located closer to each other e.g. Urban expansion can occur where there is an existing urban area and at the same time other land uses are better further from each other e.g. industrial land use would preferably be located a distance away from residential areas.

2.3.1.5 Temporal Dynamics

Time-scale is an important concept in modelling land use change as land use decisions are made based on short-term and long term dynamics (Verburg et al., 2004b). Models such as CLUE and SLEUTH implement temporal dynamics and the initial land is used to determine land use changes which might occur.

2.3.1.6 Level of Integration

This concept involves the integration of different sub-systems either by loosely linking individual analysed and modelled sub-systems or focusing on interactions between subsystems (Verburg et al., 2004b). According to (Verburg et al., 2004b), most models are currently based on concepts of a certain field and integration of other methods and techniques other disciplines is limited though this is essential in developing improved simulation algorithms.

2.3.2 Categorizing Land Use Change Models

Many researchers provide an overview of land use change models by categorising or classifying models based on different factors. The most popular classifications are by (Agarwal et al., 2002); based on a three-dimensional framework of space, time, decision-making; Lambin et al. (2000); (Briassoulis, 2000) who categorised models according to the modelling traditions which they belong; and Heistermann et al. (2006) who classified 18 models into geographic, economic and integrated categories. However, significant progress in land change models has occurred since the above reviews. Recent literature which updates and classifies land use change models is by Silva and Wu (2012) who grouped models into six benchmarks of modelling approaches, levels of analysis, spatial scales, temporal scales, spatial dimensions and planning tasks. Popular modelling approaches and categories mentioned above are briefly described below.

Agarwal et al. (2002) reviewed models by searching databases for a comprehensive list of models then short-listed 19 models based on their spatial, temporal and human decision-making characteristics. The following model types were covered: Markov models, logistic function models, regression models, econometric models, dynamic systems models, spatial simulation models, linear planning models, nonlinear mathematical planning models, mechanistic GIS models, and cellular automata models. The review involved model classification into the above categories and identification of model strengths and weaknesses, variables and capabilities. Appendix 1 illustrates the 19 models which were reviewed by Agarwal et al. (2002) .

Lambin et al. (2000) categorized land use change models as follows: empirical-statistical models, stochastic models, optimisation models, dynamic simulation models and integrated models. These classes of models are briefly explained below.

2.3.2.1 Empirical-statistical Models

Empirical-statistical models use multiple linear regression techniques to analyse changes in land use patterns and select important drivers of land use change (Veldkamp and Lambin, 2001). These models can predict land use change intensity in the immediate past and only valid in predicting land use changes which are represented in the calibration dataset (Veldkamp and Lambin, 2001).

2.3.2.2 Stochastic Models

These models are mostly based on transition probability models. Stochastic models provide descriptions of processes that move in sequential steps through a set of states, where the system states are the amount of land covered by different land uses (Lambin et al., 2000). Estimation of transition probabilities are based on a sample of transitions taking place at a particular time interval and such models depend on recent past observed transitions therefore their applications are limited to land-use intensification (Lambin et al., 2000).

2.3.2.3 Optimisation Models

Optimisation models originate from economics and are designed to optimize specific objectives of interested users and are used for decision making. Some of the categories of optimisation models are linear programming, dynamic programming and utility maximization models (Briassoulis, 2000).

2.3.2.4 Dynamic Simulation Models

Dynamic simulation models are also known as process models as they attempt to simulate processes which induce land use and land cover change. They are based on the assumption that spatial and temporal patterns of land use are influenced by the interaction of socio-economic and environmental processes (Lambin et al., 2000).

2.3.2.5 Integrated Models

Integrated models are made up of a combination of other modelling capabilities using an approach that is best at answering the research question (Lambin et al., 2000). These models are also known as hybrid models and are mostly large-scale models.

Briassoulis (2000) also categorised and described models based on underlying theories, purposes of the model, levels of analysis and types of land used being modelled. According to Briassoulis (2000) the following are the main categories of models: statistical and econometric models, spatial interaction models, optimization models, integrated models, natural sciences-based models, GIS-based models and Markov chain-based models. These models are briefly explained in Table 2-4.

Table 2-4: Main categories of land use change models adapted from Briassoulis (2000)

Category	Characteristics	Representative Models
Statistical & Econometric Models	• Mostly comprise of linear regression models. • Econometric models estimate changes in some determinants of land use e.g. population and then converts estimates to land use requirements.	• Linear Regression Models • Econometric Models • Multinomial Logit Models • Canonical Correlation Analysis Models
Spatial Interaction Models	• Based on the law of gravity in Physics • Involves modeling of interactions or movements caused by human activities e.g. migration. • Interactions between land use types are derived from interactions of human activities. • Land-use change is modeled based on accessibility changes and changes in origin and destination zones.	• Potential Models • Intervening Opportunities Models • Gravity Models
Optimization Models	• Aim to produce solutions which optimize decision-makers objectives. • Mostly used in land use planning applications	• Linear Programming Models • Dynamic Programming Models • Goal Programming • Utility-Maximization Models • Multi-Objective Models
Integrated Models	• Relate interactions, relationships, and linkages between two or more components of a spatial system to land use and land use changes. • Mostly large-scale models: from urban to global spatial levels	• Econometric-Type Integrated Models • Gravity & Lowry Integrated Models

Category	Characteristics	Representative Models
		• Simulation Integrated Models i.e. Urban Level| Regional Level | Global Level • Input-Output-Based Integrated Models
Other Modelling Approaches	• Natural Sciences modelling approaches originate from disciplines such as ecology, forest science, soil science, and environmental science and mostly focus on bio-physical factors of land use change without incorporating socio-economic, institutional, political factors. • Markov modelling belongs to the analytical methods of stochastic processes and combined with GIS to for visualizing and projecting the probabilities of land use change. • GIS-Based Modelling focuses visualization and spatial analysis and modelling.	• Markov Modelling of Land Use Change • GIS-Based Modelling of Land Use Change • Natural-Sciences-Oriented Modelling Approach

Heistermann et al. (2006) reviewed and compared 18 modelling approaches at a continental to global scale and classified them into geographic, economic and integrated models. These classifications and examples of available models are briefly explained below:

2.3.2.6 Geographic Land Use Models

Geographic land use models are concerned with land attributes, land use suitability and location. The existence of remote sensing data and Geographic Information Systems has significantly contributed to the development of these models which mostly operate at a local to regional scale. Heistermann et al. (2006) further classified geographic land use models into empirical-statistical models, DINAMICO EGO and rule based or process based models.

2.3.2.7 Economic Land Use Models

These models are based on economic theory where there is an assumption allocation of resources is dependent in the profits expected. Land is therefore allocated based on returns which are expected under various uses (Heistermann et al., 2006). Demand and supply are therefore the main drivers of land use change in these models.

As briefly explained above, economic models address demand and supply, which implies that they are limited to representing price mechanisms and are not adequate in capturing spatial aspects whilst geographic models have strengths in spatial determination of land use (Heistermann et al., 2006). Integrated models make up for the shortcomings of the disciplines of economics and those of geography by coupling economic optimization models with tools that allow for spatial evaluation and land resources allocation (Heistermann et al., 2006).

2.4 SOUTH AFRICAN MODELLING INITIATIVES

A study undertaken by GCRO revealed that LULC modelling and simulation of future LULC is limited in South Africa. A summary of significant projects on LULC modelling is illustrated in Appendix 2. In contrast to the identified South African modelling projects, this study focuses on identifying LULC change models which can be adapted to South Africa at a regional scale to simulate future LULC. The research will contribute to the understanding of drivers of LULC change and LULC change models in a South African context, add to the gap in knowledge of LULC change models implementation at a regional scale.

This Chapter provided the theory base of this research. The first section of this literature review explained the concepts of land, land use and land cover. This was followed by literature on LULC changes and factors which influence LULC changes from both local and international perspectives. Theory on LULC change models and concepts or issues which are important in LULC change modelling were covered together with a summary of the most popular land use model classification techniques. The last section of the literature review provided a list (Appendix 2) of modelling initiatives and proved that there is a gap in research on modelling LULC at a regional scale.

3. METHODOLOGY

This study was conducted using a mixed methods research methodology which integrated a quantitative and qualitative approach to better understand LULC changes and their drivers. Detection and analysis of drivers of LULC changes was conducted through a desktop study of LULC maps using Geographical Information Systems (GIS), interviewing municipality town planners, document analysis and adapting of the DPSIR framework. The desktop study of LULC maps was used to analyse LULC changes and this addressed the objective to quantifying changes in LULC in the Western Cape Province. Interviews with municipality town planners (section 3.2.1) accompanied with reviews of documents were the methods used to determine driving factors and their impacts. An adapted Driver-Pressure-State-Impact-Response (DPSIR) framework was used to report and organize findings of the interviews into grouped themes presented as components of the framework. The sections below describe the sources of data, data analysis, population sample, research instrument and ethical considerations relating to this study.

3.1 REMOTE SENSING DERIVED LULC DATA

3.1.1 Available LULC data

Analysis of LULC change in the study area was based on directly comparable LULC datasets of 1990 and 2013/14 obtained from the Department of Environmental Affairs (DEA). These datasets cover the whole country at a 30m spatial resolution and are known as the 1990 South African National Land Cover Dataset (35 Classes) and the 2013/2014 South African National Land Cover Dataset (72 Classes). These datasets were created by GEOTERRAIMAGE (GTI) using similar mapping techniques and incorporate both land-cover and land-use data which are referred to as "Land-Cover". The 1990 dataset was derived from multi-seasonal Landsat 5 imagery which was acquired between 1989 and 1991 whereas the 2013/14 dataset was generated from Landsat 8 imagery acquired between 2013 and 2014. Land-use classes such as settlements, plantations, mines and cultivated land were acquired from other sources (GEOTERRAIMAGE, 2014). The table below lists other alternative LULC datasets in South Africa.

Table 3-1: Available LULC datasets in South Africa (adapted from Ngcofe and Thompson, 2015)

NLC layer/mapping product	Imagery	Method
NLC 94	1994-1995 Landsat imagery	Manual interpretation off 1:250 000 paper-image maps & recapturing as digital vector dataset consisting of 31 land cover classes.
NLC 2000	2000-2001 Landsat imagery	Generated from digital imagery using per-pixel classifiers consisting of 45 land cover classes.
NLC 2005	Provincial 2000-2009 SPOT imagery and 2005 Landsat where no data existed.	Specifically produced for UN-FAO, consisting of 5 land cover classes.
SANBI_NLC_2010	Provincial land cover datasets between 2007 and 2011 combined with NLC 2000	Produced by South African National Biodiversity Institute for national spatial biodiversity assessment for the year 2010. This dataset consists of 8 land cover classes.

The NLC 94 and 2000 datasets are the major alternative datasets in South Africa, however, these were created using different methods and are not directly comparable to any other datasets. The NLC 94 had a minimum mapping unit of 25ha with 31 land cover classes whilst the NLC 2000 had minimum mapping unit of 2 ha and 45 land cover classes (Fairbanks et al., 2000). The process of converting these datasets to a comparable state with the 1990 and 2013/14 datasets would involve numerous computations and probably yield unsatisfactory results, since the NLC 1994 and 2000 datasets had an accuracy of 79.4% and 65.8% respectfully. It was therefore preferable to utilize the available, more accurate and directly comparable 1990 and 2013/2014 datasets.

3.1.2 Data Processing & Software

The 1990 and 2013/14 LULC datasets were reclassified or grouped into 11 classes for easy analysis and assessment of LULC changes. The South African Land Cover Classification System for remote sensing applications was the adopted scheme in reclassifying the datasets. The classes are summarized below.

Table 3-2: LULC reclassification based on Thompson's standard land cover classification scheme (Thompson, 1996)

LULC Class	LULC included	Description
Forest and woodland	Forest, Woodland	Natural / semi-natural indigenous forest dominated by tall trees and where canopy heights are > 5m
Thicket	Thicket, High fynbos, bushland	Natural / semi-natural / bush dominated areas, where canopy heights are between 2-5m

LULC Class	LULC included	Description
Shrubland and low fynbos	Shrubland, low fynbos	Natural / semi-natural grass dominated areas where tree / bush canopy densities are < 20%
Grassland	Grassland	Natural / semi natural grass dominated areas. Includes sparse bushland and woodland areas.
Forest plantations	Forest plantations mature trees, young trees, temporary clear-felled stand	Planted forestry plantations used for growing commercial timber tree species.
Waterbodies	Permanent water, Seasonal water	Areas of open surface water which can either be natural and man-made.
Wetlands	Wetlands	Wetland areas that are primarily vegetated on a seasonal or permanent basis. The vegetation can be either rooted or floating. Wetlands may be either daily (i.e. coastal), temporarily, seasonal or permanently wet and/or saturated.
Barren lands	Bare rock / soil, Degraded land	Non-vegetated donga and gully features, typically associated with significant natural or man-induced erosion activities along or in association with stream and flow lines.
Cultivated land		Commercially cultivated fields used for crop production.
Urban / built up	Commercial, Industrial, Residential, Informal, Schools	Areas containing built-up structures, commercial, administrative, health, transport, various residential, schools and sports grounds
Mines and quarries	Mine bare, mine semi-bare, mine buildings	Mining activity footprint

Reclassification was done in ArcMap 10.3.1 using Reclassify function from Spatial Analyst. LULC change detection, quantification and analysis were performed in Land Change Modeler (LCM) 2 for ArcMap. LCM requires input of land cover maps with matching classes, legend and characteristics. LCM only accepts LULC maps as byte or integer images with identical values and legends, where the legends begin with 1 and sequential. Furthermore, the land cover maps must have identical rows and columns with X and Y extents. ArcMap 10.3.1 was therefore used to process the LULC datasets prior to analysis in LCM. A Clip function in ArcMap was performed using the

Western Cape Province and individual district municipalities' shapefiles from Municipal Demarcation Board (MDB) as mask datasets. This was followed by a Copy Raster function to set resolution and convert the LULC images into a format required by LCM. The workflow in data processing in ArcMap is illustrated in the flowchart below.

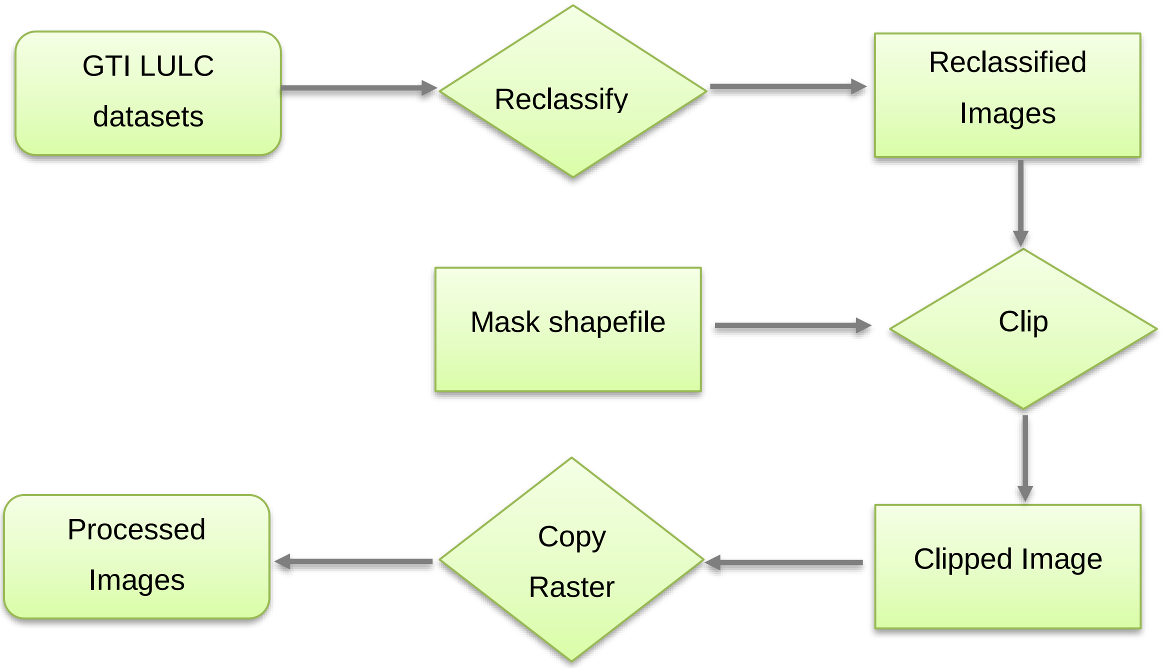


Figure 3-1: Flowchart illustrating data processing in ArcMap 10.3.1

LCM requires two LULC maps between two time periods in order to perform change assessments. After processing data in ArcMap, an assessment of LULC change was conducted using the processed 1990 and 2013/14 LULC datasets as input parameters. Three types of graphs between the two input LULC datasets were generated. The first graph gives an indication of gains and losses for each LULC class. The second graph shows net changes by category or class. This is calculated by adding gains and subtracting losses from the earlier LULC dataset (1990). The third type of graph examines the contributions to changes experienced by a single LULC due to other various LULC classes hence showing contributors to net change.

3.2 LULC Change Qualitative Analysis

3.2.1 Population Sample

The research population for this study comprised of municipality town planners and IDP managers in the Western Cape Province. Participants were selected per district municipality and they had to be aware of land use issues within their district. In cases where a district representative was absent, an available town planner was selected from a local municipality within the district.

3.2.2 Research Instrument

Annum (2015) refers to research instruments as tools used in collection of data, such as interviews, questionnaires, observations and document readings. Semi-structured interviews were conducted to gain knowledge of LULC issues in the study area and to collect primary data from interaction with planners. This method was selected as it allowed exploration of issues relevant to the concerned municipality. The interviews were both face-to-face and telephonic and data was collected by transcribing and digital audio recording. Participants were informed of the nature of the research and a consent form was emailed and explained to them prior to the interviews. An interview guide (refer to Appendix 3: Interview guide) consisting of key themes was constructed. However, there was no strict adherence to the interview guide and probing was used to explore new paths emanating from the respondent's answers and to obtain detailed information on a subject of discussion which the researcher had no prior knowledge.

Data collected from interviews was validated, corroborated and supplemented by relevant LULC change documentation. The Western Cape Provincial Spatial Development Framework (SDF), individual municipalities SDF's, Growth Potential Study of Towns, State of the Environment Reports and various legislation and policy documents related to land use e.g. Spatial Planning and Land Use Management Act (SPLUMA), were obtained from the internet and examined to retrieve relevant LULC information.

3.2.3 Ethical Considerations

Identifying drivers of land-use change in the Western Cape required interaction with municipality town planners to understand how land-use decisions are made and how socio-economic, political and environmental factors interact to influence these decisions. Various ethical issues regarding to collecting information, seeking consent, providing incentives, sensitive information, harm and confidentiality must be considered in relation to participants (Kumar, 2009). The following section addresses how ethical issues were handled in the research.

- **Informed Consent**

The participants were informed prior to the interviews, of the purpose of the research, how they were to participate, why the information was necessary and why they were selected. A consent form was emailed to all participants and the researcher also read out and explained contents of the consent form before undertaking the interviews. A written consent was therefore obtained from participants.

- **Privacy, Confidentiality and Anonymity**

The researcher acknowledges that sharing information about participants for purposes other than the research is unethical. Furthermore, confidentiality and anonymity is maintained by ensuring that participant names or any identifying information is excluded in documentations.

- **Voluntary Participation**

Participants were informed of the purpose and nature of the research as a master's research project and they were not forced to engage in the interviews. The informed consent letter also included a section were the participants were informed of their right to withdraw their contributions during the interview.

3.2.4 Driver-Pressure-State-Impact-Response (DPSIR) Framework

The DPSIR is an analytical framework which can be used to organize, report and illustrate the effects of human activities on the environment. This framework was developed by the European Environmental Agency in the 1990s and has since been applied in environmental research projects to support planning decisions (Kristensen, 2004). The DPSIR framework was adapted in assessing LULC changes in the study area in-order to present various aspects and issues which emerged from interviews and document readings.

3.3 MODEL SELECTION

As observed from the literature outlined in section 2.3.2, various categories or classifications of LULC change models have been identified by different researchers. The diversity of these categories is due to differences in scientific disciplines, model objectives, modelling techniques, theoretical backgrounds, research questions and scales of application. Verburg et al. (2006) argue that despite the availability of a wide range of modelling approaches, there is no single approach that is superior to model land use. They further allege that the selection of a model is highly dependent on the research or policy questions that need answers, the availability of data and the characteristics of the study area. Based on this notion, the selected LULC change models for this research should firstly address the issue of scale as implied by the research questions in section 1.4.

The main aim of this research is to investigate whether there are any regional LULC change models which can be adapted to a South African context and be used to simulate LULC change and hence assist as tools in supporting land use planning. "Regional" in this context denotes a coarse resolution for an area with a large extent i.e. at Provincial level. Recent literature which updates and classifies land use change models to include benchmarks of spatial scales is by Silva and Wu (2012) who grouped models into spatial scales ranging from local scales to regional scales. Regional models were identified as GEOMOD2 (Pontius et al., 2001), LEAM (Deal, 2001), METROPILUS (Putman, 2013), SPARTACUS (Lautso, 2003) and TRANUS (De La Barra, 2001). Spatial scales however differ depending on the author's understanding of scale. Some models such as UrbanSim are classified by some authors as regional models, yet they are also capable of simulating land use at local scales. Silva and Wu (2012) further identified multi-scale models as CLUE (Verburg et al., 2001;Veldkamp and Fresco, 1996), CVCA (Silva et al., 2008), DG-ABC (Silva and Wu), ENVIRONMENTAL EXPLORER (White and Engelen, 2000) , SLEUTH (Silva and Clarke, 2002) and UrbanSim (Waddell et al., 2003). Most of the models listed have limited documentation hence no concrete definitions of spatial scales are provided leading to classifications based on the developers' description of the model. Based on this line of argument, the initial selection of models was based on the design approach i.e. the structure of the model.

The two main structures of models were identified in literature as top-down and bottom-up models. Top down-models originate from landscape ecology, are pattern oriented and based on remote sensing data (Castella and Verburg, 2007). These models are used when aggregate rate of land use change can be determined for the region as a whole through statistical or mathematical formulation (Verburg, 2006). In contrast, bottom-up models describe actors of land use change and their interaction with the environment as illustrated in Figure 3-2. Actors are in the form of individuals and institutions such as farmers, land owners, communities, government bodies and property management agencies. Bottom-up models are often referred to as agent-based models (Castella and Verburg, 2007) which consist of agents as autonomous decision making entities; an environment which agents interact; rules defining the interaction between agents and the environment; and rules determining the sequence of actions in the model (Parker et al., 2002).

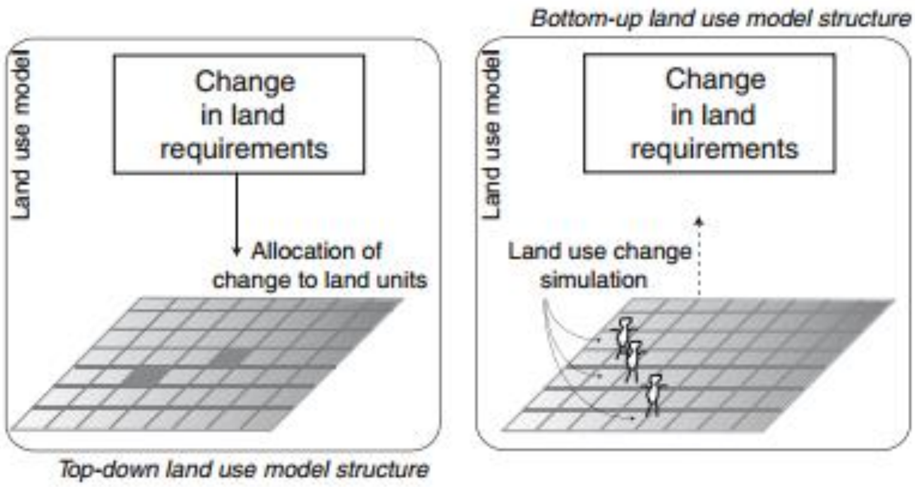


Figure 3-2: Top-down and Bottom-up land use model structures [adapted from (Verburg, 2006)]

According to Verburg (2006), selection of either a top-down or bottom up modelling approach depends on the extent of analysis and the dominating land use change processes operating in the area under investigation. Top-down approaches are adequate when land use changes are influenced by regional factors whilst bottom-up approaches are sufficient when land use changes are steered by local processes. Top-down models mostly make use of remote sensing and census data as main inputs. Examples of top-down models are CLUE (Veldkamp and Fresco, 1996), CLUE-s (Verburg et al., 2002), Environment Explorer (White and Engelen, 2000), DINAMICA (Soares-Filho et al., 2002) and CA_Markov (Eastman, 2012). On the other hand, bottom-up models require extensive field-work in collection of information on agents' behaviour and formulation of rules which determine interaction with the environment. A popular bottom-up model that incorporates local drivers of land use change is the SLEUTH model.

Whilst there are various models that exclusively implement top-down or bottom-up approaches, some models combine these approaches to create hybrid models. An example is Dyna-CLUE, a hybrid model by Verburg and Overmars (2009) which agricultural and urban dynamics are determined by a top-down approach and semi-natural land use is determined by local processes. The Dyna-CLUE model was also implemented in the City of Johannesburg by Le Roux (2012) to quantify spatial implications of future land use policies. Besides using different modelling concepts for different land uses, hybrid models can also be implemented by combining different approaches e.g. agent-based decisions that include cellular neighbourhood models, using different approaches for different scales and by integrating different modelling frameworks (National Research Council, 2014). The main advantage of hybrid models is in overcoming limitations of individual modelling approaches and taking advantage of their strengths (National Research Council, 2014). This research therefore implemented a hybrid model which combined different modelling approaches.

The two hybrid models which were shortlisted were Cellular Automata (CA) and Markov which will be referred to as CA_Markov/; and Dyna-CLUE and Markov. These models were chosen based on a multitude of publications and literature which suggests their wide applications in various topics in different regions and countries. CLUE application examples are in tropical deforestation (Verburg and Veldkamp, 2004;Wassenaar et al., 2007), land degradation (Lesschen et al., 2007), land abandonment (Verburg and Overmars, 2009). Joint CA_Markov applications which combine CA with Markov include deforestation policy interventions (Adhikari and Southworth, 2012), coastal transitions (Shirley and Battaglia, 2008) and vegetation dynamics (Mobaied et al., 2011).

3.3.1 Model Selection Criteria

After completing the initial selection of models, the final step was to assess whether the models met a set of requirements for them to effectively model LULC change in the study area. The set of requirements was in the form of a list of modelling criteria created based on knowledge of area the under study together with a selection guide extracted from a report by the Environmental Protection Agency (EPA, 2000). The following are the requirements:

Relevance: A relevant model must model and project outcomes for scenarios that relate to the community and its needs. Relevance is determined by the LULC changes which will be evaluated and questions or issues to be addressed. For this study, it was observed that LULC changes were mostly due to political, economic, demographic and environmental drivers. A relevant model must therefore be able to incorporate these drivers and output transition maps for each LULC category.

Linkage Potential: Linkage potential is concerned with whether the model can be linked to other models or GIS presentation software. A model with high linkage potential will allow data outputs to other models or software for further analysis or presentation. This is important since a hybrid model is the best method to model LULC changes.

Transferability: This is the ability of the model to be transferred or applied to environments other than the one for which it was developed. Some models may have been designed for specific environments or regions, leading to intensive efforts in adapting them to other areas.

User Friendliness/ Ease of use: Some LULC change models may require technical expertise to operate, calibrate and interpret results. A complex or sophisticated model is of no use as it might take too much time to understand it and its data outputs. A person with knowledge of GIS should find the model relatively easy to use.

Data Requirements: Many LULC change models are data intensive and require certain data to function. In some instances, the data can be available or might require significant time and resources to obtain. A model may therefore be constrained by the availability of data. The performance of the model is therefore influenced by the quality and scope of available data (Batty and Howes, 2001).

Cost: This is the amount required to acquire and maintain the model, calculated using the purchase price and additional hardware and software computer requirements. Models which are part of a consulting service and not available for direct purchase will not be considered. A free downloadable model would be the best model, though those which are available at a reasonable cost or with an academic licence will be considered.

A summary of selected models and how they match the criteria described above is provided in Chapter 5.

4. LAND USE AND LAND COVER CHANGES

This Chapter presents the history of LULC changes which were observed in the Western Cape Province between 1990 and 2014. This Chapter consists of two Sections which provide qualitative and quantitative results obtained from the desktop study, interviews with municipality town planners and document analysis. The Chapter concludes with an adapted DPSIR LULC change framework for the Western Cape Province.

4.1 DESKTOP QUANTITATIVE ANALYSIS OF LULC CHANGES

This section presents the results of desktop quantitative analysis of reclassified maps of 1990 and 2014. These maps indicate LULC changes in the Western Cape Province (Figure 4-1). Individual district municipalities maps were also created based on clip extents of the municipality vector mask datasets.

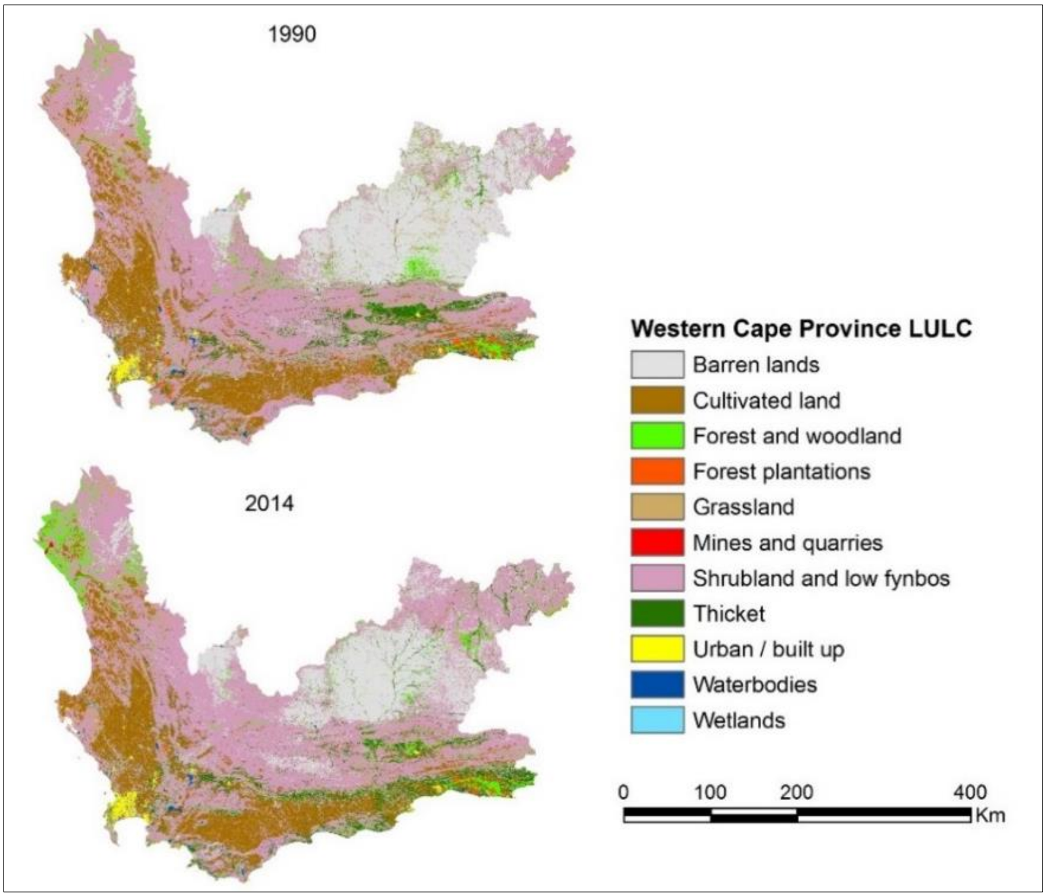


Figure 4-1: Western Cape Province LULC maps for years 1990 and 2014

LULC change is presented in graphical form in Figure 4-2, where gains are green and losses in purple for each LULC category.

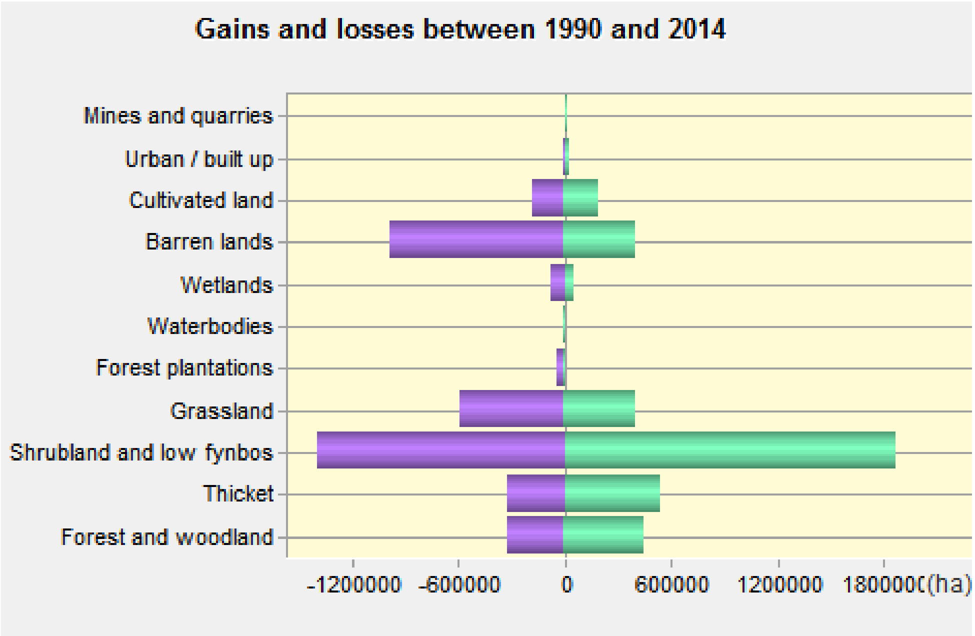


Figure 4-2: Western Cape Province gains and losses in each class between 1990 and 2014

Table 4-1 shows the net area change in hectares and percentage changes for individual LULC classes between 1990 and 2014 in the Western Cape Province. The quantified results indicate that the Western Cape Province has experienced considerable changes in LULC. Based on the LULC datasets used; there has been a provincial decrease in forest plantations, grasslands, wetlands, and barren lands over the past 24 years. Contrary to these decreases, there have been increases in urban/built up, mines and quarries, water bodies, woodlands, thicket and shrubland.

Table 4-1: Western Cape LULC area, net change and percentage change between 1990 and 2014

Class Name	1990 Area (ha)	2014 Area (ha)	Net Change (ha)	% Change
Forest and woodlands	462 583.44	593 923.68	131 340.24	28.39
Thicket	590 777.55	794 971.53	204 193.98	34.56
Shrubland and low fynbos	6 143 518.44	6 610 854.06	467 335.62	7.61
Grassland	706 820.4	519 442.47	-187 377.93	-26.51
Forest plantations	120 180.51	81 228.42	-38 952.09	-32.41
Waterbodies	55 190.52	55 987.02	796.5	1.44
Wetlands	143 738.46	108 163.71	-35 574.75	-24.75
Barren lands	2 776 498.47	2 198 310.12	-578 188.35	-20.82
Cultivated land	1 949 069.34	1 969 208.91	20 139.57	1.03
Urban / built up	103 646.97	116 667.45	13 020.48	12.56
Mines and quarries	6 184.53	9 451.26	3 266.73	52.82

The highest percent gain is in mines and quarries although the Western Cape Province is generally not popular in mining, with mining activities mostly concentrated in the West Coast district municipality. Mining activities are predominantly characterised by sand mining resulting from construction pressures. The mining sector however has a low contribution to the Province's GDP and sand mines result in loss of surface productivity and undesirable visual impacts. Other net gains between the two time periods were in forest and woodland and thicket LULC classes. The net increase in thicket could be a result of mapping errors or inaccuracies due to spectrally similar woody vegetation classes such as indigenous forest, woodland and shrubland.

The highest net percent loss is in plantations LULC class, giving an indication that there has been a decrease in plantations over the past 24 years. The decrease in plantations in the Western Cape Province was mostly due to the Government's forestry exit policy and fires in the region. In 2001, the Cabinet decided to decommission about 44 793 hectares (ha) of forestry plantations in the Western and Southern Cape to convert the land to agriculture, human settlements and conservation within a 20-year period from 2001.

The rationale behind this was that the plantations were not economically viable at that time; accompanied with concerns of plantations invasion of protected areas and catchments. Government however partially reversed 22 402ha back to plantation forestry following studies and recommendations by the Department of Water Affairs and Forestry in 2008 (Wilgen, 2015). There has been no significant increase in plantations since no initiatives were implemented following the reversal by Cabinet in 2008 (De Beer et al., 2014). An indication of the actual losses of forest plantations to other LULC classes between 1990 and 2014 is illustrated in Figure 4-3.

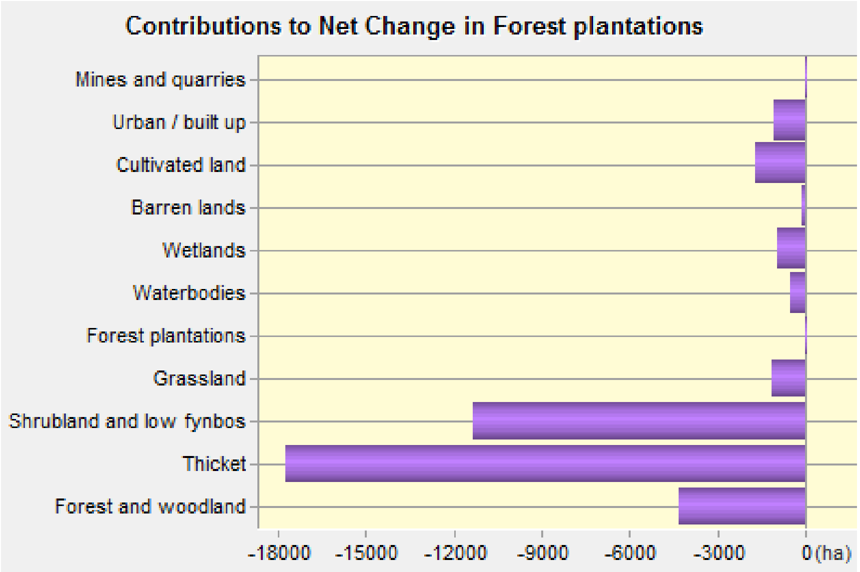


Figure 4-3: Contributions to net change in forest plantations by other LULC classes

The LULC change results also indicate that there has been a provincial increase in urban or built up areas with about 12% and a 1% increase in cultivation. An assessment of the individual district municipalities in the Western Cape Province however provides a clearer picture of the actual LULC changes and shows that the increase in urban areas in the past 24years is concentrated in the Cape Metropolitan area and the adjacent Cape Winelands district municipality. Despite the 1% provincial increase in cultivation, the Cape Metro has experienced 3 728 hectares loss (-8.49%) in cultivation to other LULC classes.

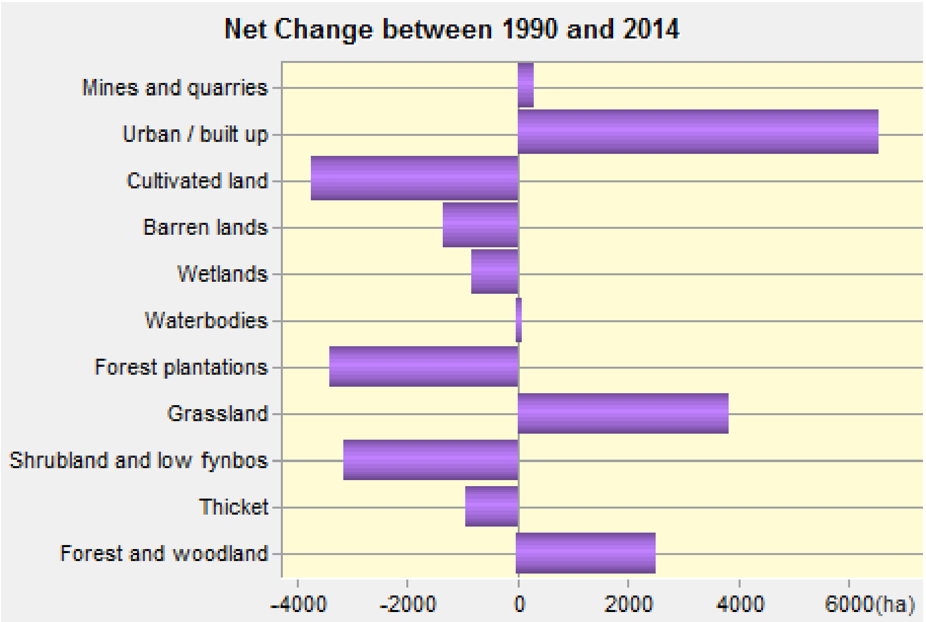


Figure 4-4: Cape Town Metro net change between 1990 and 2014

Further analysis of net changes in LULC in the Cape Metro indicate that the most increase occurred in the urban LULC class which experienced gains at the expense of cultivated land (216 ha), shrubland and low fynbos (5 315 ha) and plantations (463 ha). This increase is largely due to urbanization and migration amongst other factors which will be discussed in the driving factors section.

4.2 QUALITATIVE ANALYSIS USING THE DPSIR FRAMEWORK

The following sections provide a summary of LULC change qualitative results obtained from interviews with municipality town planners. The findings from the interviews are organized into themes which are presented using components of the DPSIR framework illustrated in Figure 4-5. The DPSIR framework is used to highlight the relationship between human activities and land use change. Drivers are social, economic, demographic changes in societies, including consumption, lifestyle and production patterns. These forces lead to human activities and processes which exert pressure on land resources resulting in various states of the environment. The change in state of the environment has consequences which are indicated in the framework as impacts that elicit responses. Responses are actions by individuals, society and the government to prevent and adapt to negative impacts (Gabrielsen and Bosch, 2003). The arrows between components of the DSPSIR framework represent causal chains which show sequential processes that link causes of problems with their effects (Smeets and Weterings, 1999).

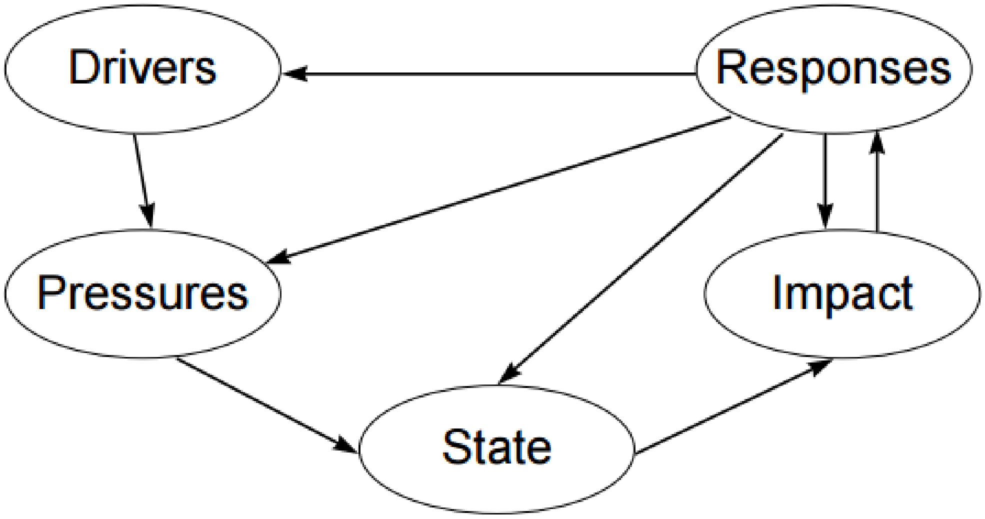


Figure 4-5: The DPSIR Framework Smeets and Weterings (1999)

This chapter will conclude with an adapted DPSIR LULC change framework for the Western Cape Province.

4.2.1 Driving Factors of LULC Change

This research identified both underlying and proximate driving factors of LULC change in the study area. Proximate factors are infrastructure expansion, agriculture and expansion and whilst underlying factors are political, economic, technological, demographic, environmental and cultural factors. Underlying factors will be explained in detail as they are relevant to the scale of the study. A summary of all determined factors is provided in Figure 4-6.

4.2.1.1 Political Factors

As outlined in the literature review on drivers of land use change, legislation and policies play a significant role land use changes in South Africa. Current legislation on land use planning in the Western Cape Province is regulated by all three spheres of government, in accordance with the South African Constitution of 1996. National legislation relevant to planning is outlined in section 2.2.2.1. Provincial and municipal policies must be aligned with national legislation and policies. Land use change is influenced by policies which can either encourage or hinder developments. An example of such a policy is the Urban Edge policy, which demarcates outer limits of urban development by defining the Urban Edge and Coastal Edge line. The Urban Edge line is meant to prevent urban sprawl and to protect natural resources boundaries whilst the Coastal Edge serves to protect coastal regions. The Urban Edge policy is in accordance with the Western Cape Provincial Spatial Development Framework (PSDF) and the National Environmental Management Act No. 107 of 1998. If properly implemented, this means future developments in demarcated areas will be restricted.

4.2.1.2 Economic Factors

The economic development of the Western Cape Province has strong links with agri-processing, tourism and gas sectors; which the government intends to prioritize. The rationale behind this is that high potential sectors promote job creation and inclusive growth therefore resources can be channelled towards them instead of focusing on all sectors (WCG, 2015a). This agrees with the Western Cape Provincial Strategic goal of creating opportunities for growth and jobs.

Agri-processing currently has a GVA of R12 billion with 79 000 formal jobs in the Western Cape Province. The Western Cape Government projections under a high growth scenario estimates a 126% increase in GVA to R26 billion in 2019 with 100 000 more jobs (WCG, 2015b). Opportunities in growth acceleration in agri-processing have been identified as market growth through market promotion and access, logistics and infrastructure and industrialisation of the agri-processing sector. Interviews with municipality town planners revealed the prevalence of pluriactivity by farmers in the form of farm accommodation, wine tasting, farm tours and other non-agricultural activities, thus indicating linkages between economic sectors of agriculture and tourism. The tourism sector currently contributes 17 billion in GVA and 204 000 formal jobs in the province. High growth scenarios estimate an increase in GVA by 65% (R28 billion) in 2019 and a further 120 000 jobs (WCG, 2015b).

The oil and gas industry is another sector which the Western Cape Government intends to prioritize. This sector comprises of major ports located in Saldanha Bay in the West Coast district, Cape Town and Mossel Bay in Eden. The Saldanha Bay port is expected to expand development in the oil and gas sector and has been designated as an Industrial Development Zone (IDZ). The IDZ is expected to generate approximately 25 000 jobs and attract investments over a period of 20years.

4.2.1.3 Demographic Factors

The Western Cape Province is one of the most urbanised provinces in South Africa, with a rapidly growing population. Population growth is due to natural increase together with inflows of people from other regions through international, internal and temporary circular migration. Stats SA (2014) estimates internal or inter-provincial migration at 344 830 people into the Western Cape Province between 2011 and 2016. Internal migration into the province mostly originates from the neighbouring Eastern and Northern Cape Provinces and is due to perceptions of better employment opportunities, access to better health, education and other facilities. More than 80% of the population and economic activity in the province is concentrated in the City of Cape Town and the neighbouring Cape Winelands which are characterized by rapid urbanization which leads to informal settlements expansion with high crime, poverty and basic services shortages (Maree and Van Weele, 2013).

Population growth and decreased household sizes have led to higher demands for housing space in the Western Cape Province. Continued in-migration, limited funding to address housing backlogs and shortage of well-located land for housing contributes to the increase in informal settlements and backyard housing. Demographic factors are therefore very significant in driving land use change.

4.2.1.4 Environmental Factors

The effects of climate changes are evident in the Western Cape Province where extreme weather conditions in form of droughts, heat waves and floods are prevalent. This poses a challenge to the agricultural sector which must increase food production to cater for the expanding population. The most challenging factor in agricultural productivity in the Western Cape Province is water availability. The decline in rainfall has led to reduced crop production, low profits and farm conversions to other land uses. The impact of climate change on the agriculture sector also adversely affects other sectors that rely on agriculture for key inputs. Furthermore, very hot and dry conditions in the Province trigger fires which are partially responsible for loss of plantations.

4.2.1.5 Technological Factors

Environmental factors discussed above have led to a decrease in number of farms and consolidation of farm units to achieve economies of scale. Consolidation of farms implies less reliance on labour and increased mechanization which results in job losses. Farm worker issues have been reported in agricultural rural districts in the Cape Winelands due to job losses resulting from mechanization.

4.2.1.6 Cultural Factors

As outlined in the literature review, cultural factors are concerned with people's beliefs and attitudes towards land use. Interviews with municipal town planners revealed that land use decisions in the Western Cape Province are in the hands of the mayor, council, politicians, institutions, developers together with limited influence of the public.

Lack of knowledge and understanding of the impacts of certain land uses can adversely affect both the environment and economy.

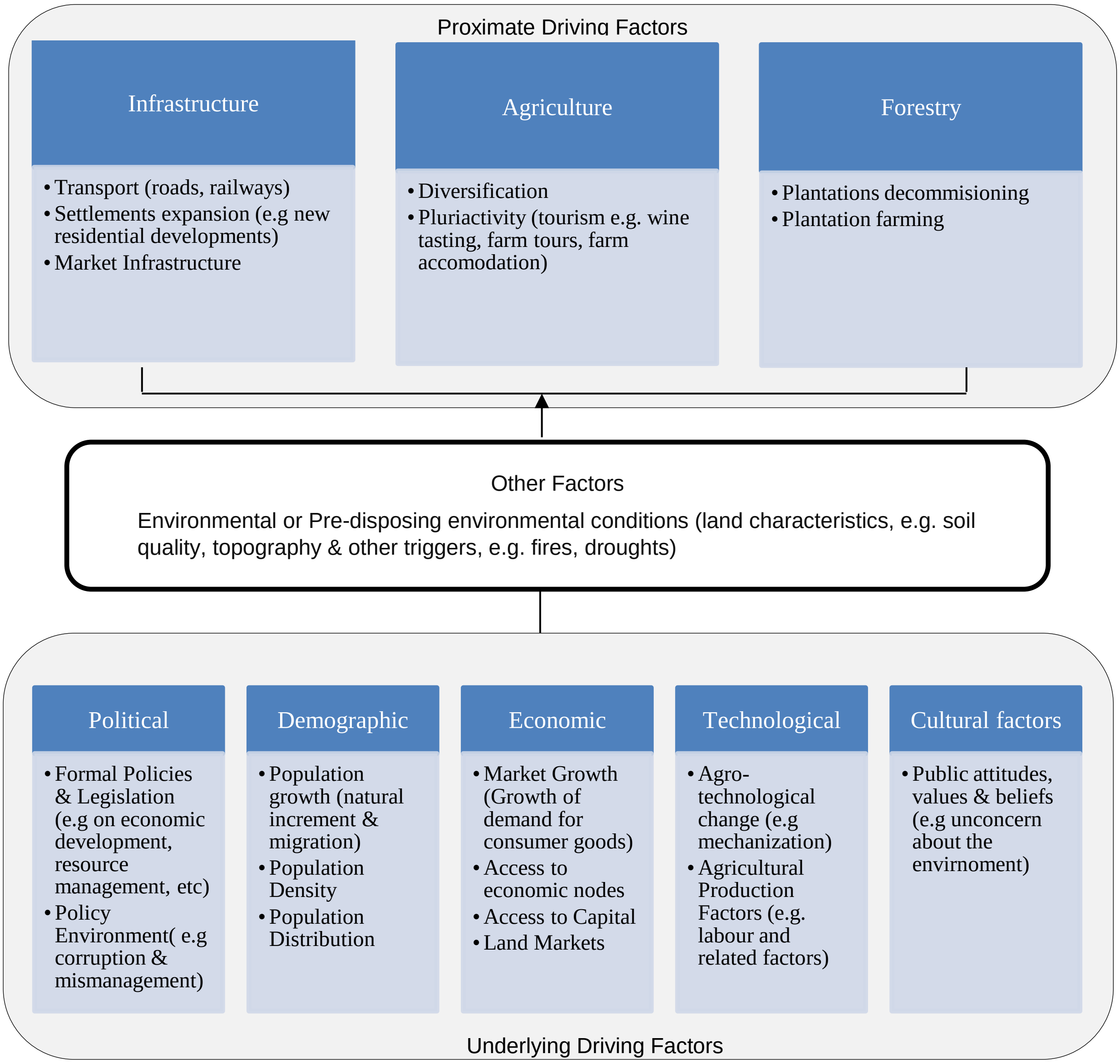


Figure 4-6: Driving Factors of LULC change in the Western Cape Province [adapted from Geist and Lambin (2002)]

4.2.2 Pressures

The political, economic, technological, demographic, environmental and cultural factors discussed lead to human activities which exert pressure on land resources. The most prominent pressures emerge from sectors with high economic development opportunities which occur in the Cape Metropolitan, Eden and West Coast district municipalities. These sectors have been identified in the Provincial Environmental

Review and Outlook as agriculture, tourism and industry sectors (WCG, 2015a), which interact with other associated sectors and promote LULC change. Pressure from agriculture is in the form of land, water availability and chemicals. The agricultural sector attracts both inter-provincial and circular temporary migrants within the province, which exerts pressure on transport, housing and services. Tourism in the Western Cape Province has increased pressure on infrastructure development.

Development pressures in the province are also influenced by institution research projects and partnerships with the government. Examples are Agri-hubs by the Department of Rural Development and Land Reform (DRDLR); port developments by Transnet and the Department of Economic Development and Tourism (DEDT); and plantation decommissioning by South African Forestry Companies Limited (SAFCOL). Institutions conduct studies and make recommendations which push government to approve changes, especially if the impacts align with government objectives.

4.2.3 State

LULC change drivers coupled with pressures on resources affect the state of land in the Western Cape Province. The change in state of land has clearly been demonstrated with the results presented from the desktop analysis which shows the changes that have taken place in LULC between 1990 and 2014. LULC maps also show that most infrastructure developments are concentrated along the coastline, in the City of Cape Town and in core agricultural towns. Based on the interview respondents, most land use changes and associated impacts occur in agricultural, tourism and industry related areas.

Agriculture takes up the majority of land in the Western Cape Province (2.5million ha) and past trends indicate a decrease in croplands in the Central Karoo District with a contrasting increase in vineyards in the Western region (Maree and Van Weele, 2013). The decrease in agriculture is due to land capability and water availability where the latter is a common restraining factor in the province. The increase in tourism has put a demand on residential, transport and other infrastructure, particularly in coastal areas where developments are taking place in the form of holiday homes, residential accommodation, hotels and other tourism associated activities. Transnet and DEDT research on industrial opportunities has resulted in port developments and the initiation of the Saldanha bay Industrial Development Zone (IDZ).

4.2.4 Impacts

The change in state of land use has both positive and negative consequences. Agriculture promotes food security, job creation, economic stability, inputs to other industries amongst other advantages. However poor farming practices, overgrazing and land clearance can lead to erosion and land degradation. Droughts and declining farming profitability have led to pluriactivity as farmers engage non-agricultural activities in order to supplement their income. If more profitable, this could contribute to farm exits and change in land use. The conversion of plantations to other land uses has led to job losses and dried trees from clear-felling have fuelled fires leading to biodiversity loss.

The perception of the Western Cape as a better province in terms of employment and access to basic services has led to in-migration leading to pressure on transport, accommodation and other essential facilities. This consequently leads to congestion, increased crime, informal settlements, backyard housing, urban sprawl, infrastructure developments and other issues which negatively impact the environment. Pressure from the tourism industry has led to various developments close to the coast and road upgrading to improve connectivity between areas. The N1, N2 and N7 highways together with other roads will need upgrading to facilitate connectivity between tourism and other economic hubs.

The Saldanha Bay IDZ is expected to provide employment and various economic opportunities to different industries in future and Transnet has proposed iron-ore infrastructure expansion which will be an economic benefit and is also aligned with government infrastructure development goals (WESGRO, 2015). However the upgrading and expansion of iron ore terminal requires sediments dredging which leads to marine disturbance, pollution and coastal erosion (Clark et al., 2015). Other impacts of the development of the IDZ include developments of new roads, sewage works, powerlines, residential and other infrastructure. The increased attention of the West coast area will attract employees of various skills levels leading to a high demand in housing and increased property prices.

4.2.5 Response

Responses are actions which the society or government undertake as a result of detrimental impacts which can take place at stages between driving factors and impacts in the DPSIR framework. Such responses in the study area have been in the form of policies and monitoring projects. An example is the monitoring of the state and changes of ecosystem functioning of the Saldanha Bay and Langebaan Lagoon by the establishment of the Saldanha Bay Water Quality and Forum Trust (SBWQFT) (Clark et al., 2015). The SBWQFT produces annual reports on activities which affect the bay such as industrial development, dredging, and coastal erosion in order to identify and mitigate negative impacts to the environment (Clark et al., 2015).

4.2.6 Adapted DPSIR Framework

LULC aspects and issues which emerged from interviews with municipality town planners and document readings were grouped into themes of Driving Factors, Pressures, State, Impacts and Responses. An adapted DPSIR framework for LULC change in the Western Cape Province is presented in Figure 4-7. This framework was developed to structure and subsequently summarise qualitative findings on drivers of land use change.

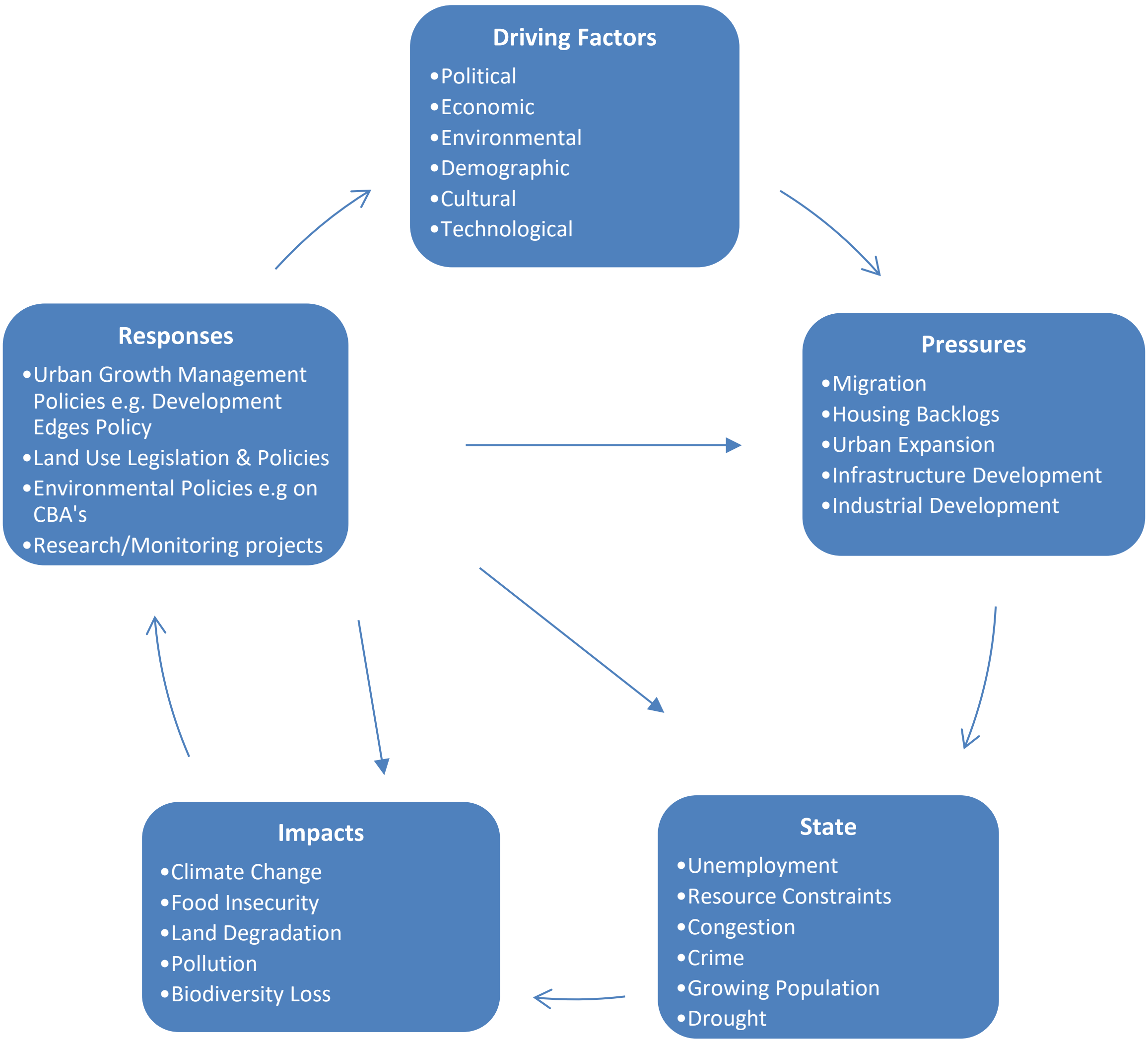


Figure 4-7: DPSIR Framework for LULC change in the Western Cape Province

5. SUMMARY OF SELECTED LULC CHANGE MODELS

This Chapter provides a summary of the shortlisted LULC change models. Concepts behind the Markov, CLUE and CA modelling approaches will be discussed and the models will be described in terms of their characteristics including modelling techniques, data inputs and data outputs. Each description will conclude with the strengths and limitations of the model in relation to the selection criteria presented in Section 3.3.1. The purpose of this Chapter is to evaluate whether the initially selected models will be applicable in the study area.

5.1 Markov

Markov models were named after a Russian mathematician, Andrey Markov and are a class of stochastic processes with limited memory (Maes, 2013). The use of Markov chains as models evolved from social and economic science research in the 1950s (Iacono et al., 2012) and early proposals of using Markov chains for modelling land use change include that of Burnham (1973);(Bourne, 1971) and applications by Muller and Middleton (1994);(Turner, 1987). Recent applications of Markov seek to overcome the limitations of the model by integrating Markov concepts with other models or simulation techniques to create hybrid models. Arsanjani et al. (2013) designed a hybrid model consisting of Markov, logistic regression and cellular automata to analyse suburban expansion in Tehran Metropolitan. Mishra and Rai (2016) used Multi-Layer Perceptron (MLP) and Markov chains to for prediction of future land use and land cover scenarios in Bihar, India.

- **Markov Characteristics**

Markov chain models are random processes that undergo transitions in a system comprised of discrete states and possess the Markov property (Coolen, 2009). The Markov property in land use change is when future use of land at time (*t+1*) can be predicted solely based on the immediately preceding state of land use at time (*t*) and not the sequence. The probability of land use changing to the next state at time (*t+1*) depends only on the most recent state (*t*), which can be defined as:

$$P(X_{t+1}|X_0, \cdots, X_t\ ) = P(X_{t+1}|X_t) \quad (1)$$

LULC from one period of time to another is cross tabulated and used to create a transition probability matrix, which forms the basis for future predictions (Eastman, 2012). Markov requires two LULC images from different time periods and uses them to generate a transition probability matrix, transition areas matrix and conditional probability images (Eastman, 2012). These are explained below

- A transition probability matrix shows the probability of a LULC category changing to every other category. This matrix is generated from cross tabulation of the 2 input images adjusted by proportional error of 0.15, based on an assumption that LULC maps are 85% accurate (Eastman, 2012).
- The transition areas matrix indicates the number of pixels that are expected to change from each LULC type to every other LULC type over the next time-period (Eastman, 2012). The transition area matrix is calculated by multiplication of each column in the transition probability matrix by the number of cells of the corresponding land use in the later image as shown in the equation below.

$$X_{t+1} = P_{ij} \text{ x } X_t \quad (2)$$

where

$$P_{ij} = \begin{pmatrix} P_{11} & P_{12} & P_{1n} \\ P_{22} & P_{22} & P_{2n} \\ P_{n1} & P_{n2} & P_{nn} \end{pmatrix}$$

And the following condition is met:

$$\left(0 \leq P_{ij} < 1 \; and \; \sum_{J=1}^{N} P_{ij} = 1, (i, j = 1,2 \ldots n)\right)$$

Where, X_t is the system state at time (t); $X_{t+1}$is the state of the system at time $(t + 1)$ and P_{ij} is the transition probability matrix.

- Conditional probability images are based on the transition probability matrix and express the probability that each LULC type will be found at each location in the next time frame.

Based on the above discussion, Markov can calculate future land use demand by representing all the possible directions of land use change among all land use categories. However, Markov does not account for spatial relationships but this can be overcome by integrating it with cellular automata to allow transition probabilities of pixels to be a function of neighbouring pixels. Moreover, Markov assumes transition probabilities of land use types to be a constant value implying that factors that led to land use changes between the initial time periods will still operate in future at the exact same rate. This is however not realistic as drivers of LULC change are bound to change depending on various conditions that will be taking place. Weaknesses of Markov can therefore be overcome by integrating it with other modelling approaches or models such as CA or Dyna-CLUE. The strengths and limitations of Markov in relation to the selection criteria described in Section 3.3.1 are presented in Table 5-1 below.

Table 5-1: Markov Strengths and Limitations in relation to selection criteria

Selection Criteria	Advantages and Disadvantages
Relevance	✓ Markov can depict the direction of LULC change hence it is very useful in analysing future land use demands. Future projections on LULC patterns can therefore be calculated using population growth, migration and economic growth patterns. χ Markov assumes that the factors that produced changes will continue in future. This is not usually the case. This can be overcome by using Markov with Dyna-CLUE to incorporate other driving factors. χ In Markov, land use at a certain location is only influenced by the previous state of land use and not the surrounding land uses. However, spatial dimension can be added by incorporating cellular automata models.
Linkage Potential	✓ The results of Markov, in the form of transition maps can be easily understood by decision-makers. ✓ Markov transition matrices can be used in models such as CA and CLUE to provide a framework for analysis of future land use demands.
Transferability	✓ There are no modifications required when using the software.
User Friendliness	✓ Markov models are relatively easy to use and with knowledge of GIS and statistics. ✓ Markov can simplify complex processes of land use change in the form of transition probability matrices, making it an easy sketch planning tool.
Data Requirements	✓ Markov models are generally not data hungry. The only data input required are historical land use or land cover images for two time-periods.
Cost	✓ Markov is available as a module in TerrSet. A student licence was obtained for $49 for the purposes of this research. The general licence for TerrSet is between $425 and $1 250.

5.2 Cellular Automata

Cellular Automata (CA) were developed by Ulam and Von Neumann in the 1940s and have become one of the most popular modelling approaches in land use and land cover modelling. A cellular automaton consists of identical cells that are located in a two or three-dimensional grid, a set of discrete states, a neighborhood, transition rules and time steps (Shiffman, 2012). Every cell has a state which represents a spatial variable e.g. land use. Transition rules determine the state of a cell based on its current state and the state of its neighbours. The neighborhood is a set of adjacent cells that influence the state of a particular cell. In land use change, cells that are more distant in the neighborhood will have a smaller effect on the state of a particular cell. Typical neighborhood configurations of two-dimensional CA are illustrated in Figure 5-1. Time steps are the temporal dimension in which a cellular automaton exists (Liu, 2008).

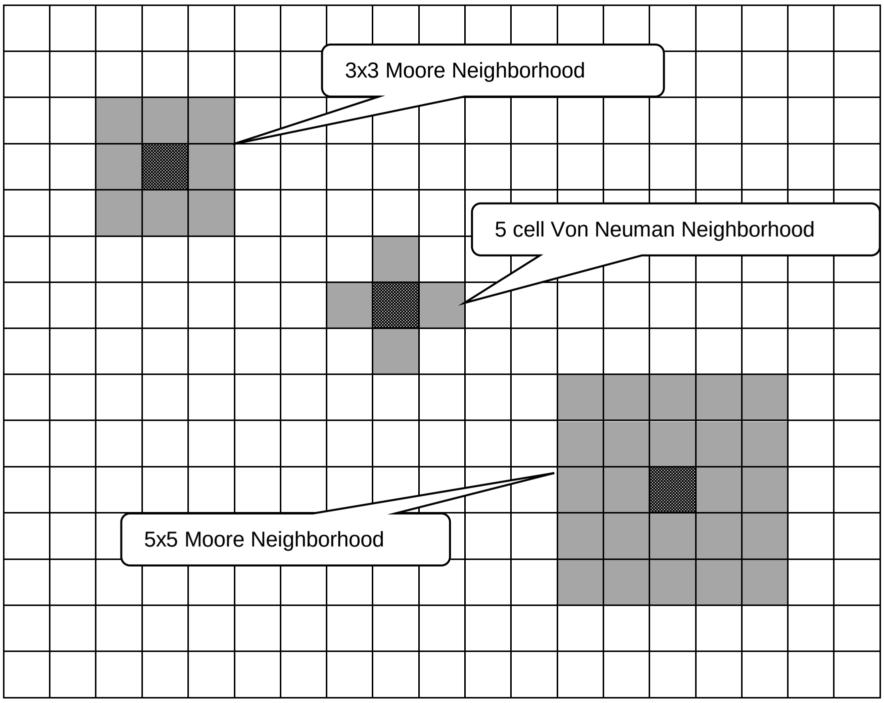


Figure 5-1: Cellular Automata neighbourhoods [adapted from (De Smith et al., 2007)]

The strengths and limitations of CA in relation to the selection criteria in section 3.3.1 are presented in Table 5-2 below.

Table 5-2: Cellular Automata Strengths and Limitations in relation to selection criteria

Selection Criteria	Advantages and Disadvantages
Relevance	✓ CA adds spatial dimension to Markov by integrating neighborhood effects using a contiguity filter.
Linkage Potential	✓ CA in IDRISI takes inputs of transition areas and suitability maps which can be created by other software. ✓ The results of CA, in the form of a prediction maps can be easily understood and input in GIS software for visualization.
Transferability	✓ There are no modifications required when using the software.
User Friendliness	✓ CA models are relatively easy to use and with knowledge of GIS analysis.
Data Requirements	✓ Markov models are generally not data hungry. The data inputs required are historical land use or land cover images for two time periods.
Cost	✓ CA is available as a module in TerrSet. A student licence was obtained for $49 for the purposes of this research. The general licence for TerrSet is between $425 and $1 250.

5.3 CA_Markov

CA_Markov combines the concepts of CA, Markov, Multi-Criteria Evaluation (MCE) and Multi-Objective Land Allocation (MOLA) and is found within IDRISI GIS Analysis tools in TerrSet software. The first step in CA_Markov involves the comparison of two historic land use maps to calculate the quantity of change for each land use category. Markov creates a transition probability matrix and conditional probability images, as described in section 5.1. The next step is predicting the location of change based on the concepts of a suitability maps and contiguity. Suitability maps determine the suitability of each pixel to transition to any land use at a specific time. These suitability maps can be generated by MCE using socioeconomic and other variables together with conditional probability images produced by Markov. The suitability maps are then further weighted using a CA contiguity filter. CA functionality is used to convert Markov into a spatially explicit model as it implements the 1st law of Geography by using a contiguity rule: where a pixel that is close to a specific LULC category is most likely to change to that category as compared to a pixel that is further. The definition of nearby is determined by a spatial filter which the user specifies. CA_Markov in TerrSet requires number of iterations to enable establishment of the number of time-steps that will be used for simulation. Each land use is considered for each time step and competing land uses are solved using MOLA procedures.

CA_Markov was however not implemented in this study despite its attractive advantages. This was due to data limitations since CA_Markov would require 3 sets of LULC maps i.e. input 1990 and 2000 maps and a 2010/2014 map as a validation map. The only datasets that were available and readily comparable were the 1990 and 2013/14 LULC data. This study therefore implemented Dyna-CLUE model with Markov modelling approaches.

5.4 Dyna-CLUE

CLUE (Conversion of Land Use and its Effects) is a multi-scale land use and land cover change model that was created by Veldkamp and Fresco (1996) to simulate past changes and to explore future scenarios in land use changes. Applications of the CLUE models vary from small regions to continents and different versions e.g. CLUE,

CLUE-CR, CLUE-s, Dyna-CLUE and CLUE-Scanner have been implemented globally. Dyna-CLUE was the selected version for this research.

- **Dyna-CLUE Model Structure**

The CLUE model has two distinct modules i.e. a non-spatial demand module and a spatially explicit module (Figure 5-2). The non-spatial demand module calculates the aggregate area change for all land use categories whilst the spatial analysis module translates demands into land use changes at different locations using a set of driving forces and transition rules (Verburg and Overmars, 2009). In this study, the demands will be calculated using the Markov model described in section 5.1.

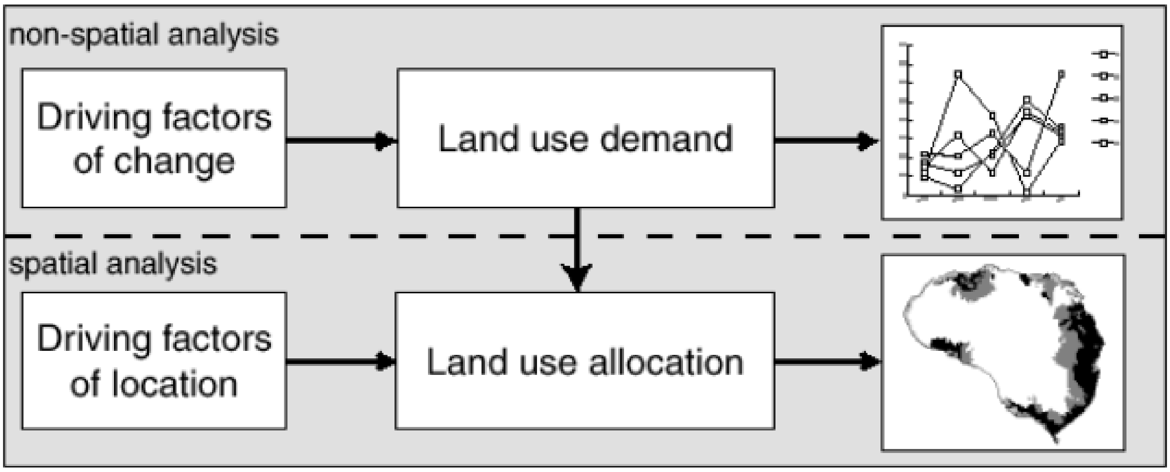


Figure 5-2: The CLUE modelling procedure

The Dyna-clue model requires the following as inputs; spatial policies and restrictions; land-use type specific conversions; land use requirements (demands) and location characteristics. Spatial policies indicate areas where land use changes are restricted by policies. These policies must be in the form of maps showing areas where the policies will be implemented e.g. national parks. Land-use type conversion settings are temporal simulation dynamics that indicate possible and impossible conversions amongst land use categories. Conversion settings are in the form of conversion elasticities and transition matrices, where the former are concerned with reversibility of land use change and the latter are transition matrices between land uses. Land use requirements are calculated at aggregate level using by extrapolation of trends of land use change of the recent past into the near future (Verburg, 2010). Location characteristics are concerned with the expectations of land use changes to occur at places that have specific characteristics i.e. locations with the highest preference.

Preference is determined by drivers of land use and calculated with the following equation:

$$R_{ki} = a_k X_{1i} + b_k X_{2i} + \ldots\ldots \qquad (3)$$

Where R is the preference of assigning location *i* to land use *k*, $X_{1,2\ldots}$ are environmental and socio-economical characteristics of location *i* and a_k and b_k are the impacts of characteristic on preferences for land use *k*. After inputs are provided, allocation procedure is calculated as illustrated in Figure 5-3.

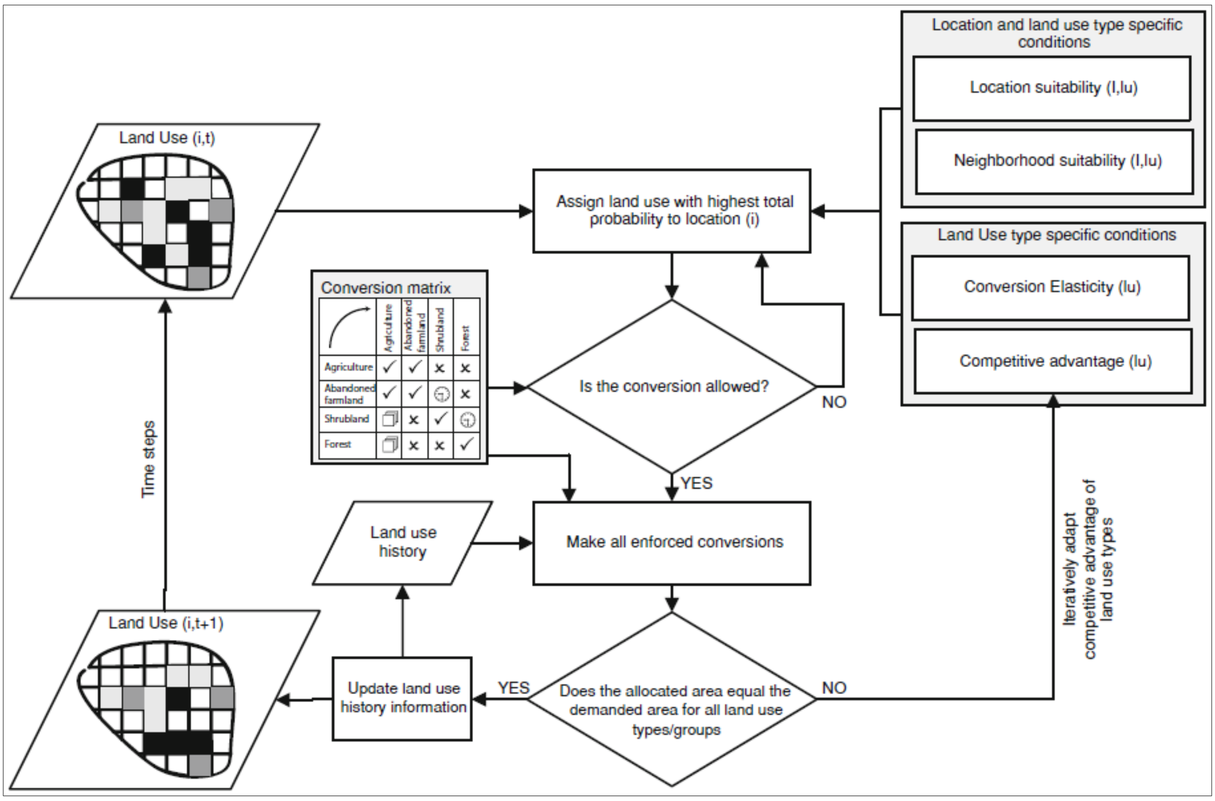


Figure 5-3: Dyna-CLUE Allocation procedure [adapted from (Verburg and Overmars, 2009)]

Allocation procedure involves the determination of cells that are permitted to change by excluding cells such as protected areas and from further calculations. According to Verburg and Overmars (2009), for every grid cell or location (*i*) at time (*t*), the highest total probability ($Ptot_{i,t,lu}$) is calculated for every land use (*lu*) by summation of the location suitability ($Ploc_{i,t,lu}$), neighborhood suitability ($Pnbh_{i,t,lu}$), conversion elasticity ($Elas_{i,t,lu}$) and competitive advantage ($Comp_{t,lu}$). This can be described in the equation below:

$$Ptot_{i,t,lu} = Ploc_{i,t,lu} + Ploc_{i,t,lu} + Elas_{i,t,lu} + Comp_{t,lu} \quad (4)$$

Where, location and neighborhood suitability are determined by empirical methods, expert knowledge and analysis of neighborhood interactions. Conversion elasticity measures the costs of conversion from one land use to another, where high elasticity indicates high conversion costs and implies a higher probability of the land use to remain the same. Competition advantage is calculated iteratively for all land use categories by comparing the total allocated area to land use requirements (demand). The value of competitive advantage is increased when allocated area is smaller than demand and decreased when allocation exceeds demand. Iteration ends when allocation is equal to demand, then the map is saved and calculations for the next time-step begin (Verburg and Overmars, 2009;Verburg, 2010). The strengths and limitations of Dyna-CLUE in relation to the selection criteria in section 3.3.1 are presented in Table 5-3.

Table 5-3: Dyna-CLUE Strengths and Limitations in relation to selection criteria

Selection Criteria	Advantages and Disadvantages
Relevance	✓ The model is relevant to the case study area as it allows the incorporation of drivers of land use change. Unlike other models, Dyna-CLUE can take regional drivers of land use change and has no limitations on the number of drivers which can be included. ✓ The model can also simultaneously model multiple land uses. ✓ The model can simulate multiple policy scenarios.
Linkage Potential	✓ Dyna-CLUE allows inputs from other models; therefore, Markov transition matrices can be used to provide land use demands.
Transferability	✓ There are no modifications required.
User Friendliness	χ The model is difficult to implement without prior knowledge of advanced spatial analysis.
Data Requirements	✓ Data inputs are flexible χ Land use demand inputs depend on other models.
Cost	✓ The model can be downloaded free of charge from http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/Clue/index.aspx

As outlined in summaries of land change models described above, all the models are capable of modelling land use changes in the case study area. These models however have limitations which can be overcome by combining their strengths and integrating them into hybrid models. The hybrid model which was selected and implemented in the study area is Dyna-CLUE and Markov. The implementation of this model in the case study area is explained in Chapter 6.

6. MODELLING LULC CHANGES

This Chapter provides the steps that were undertaken in implementing the Dyna-CLUE model with Markov concepts in the Western Cape Province. A modelling framework which gives an overview of the model that was adapted for simulation of LULC changes is first presented in Figure 6-1. This is followed by sections which describe the different components of the model, data preparation and model population. The Chapter concludes with presentation of outputs of the model and validation of Dyna-CLUE simulated maps.

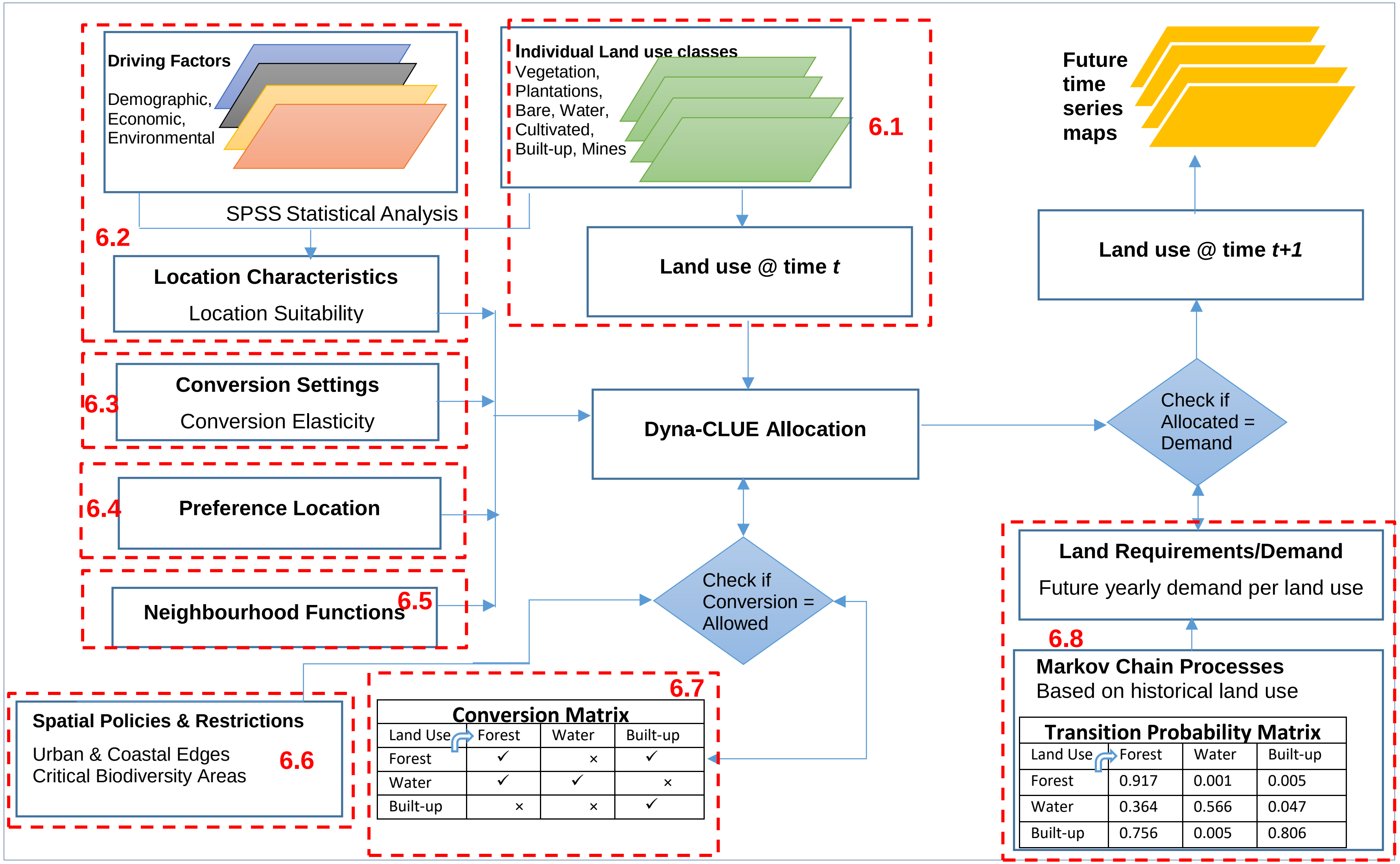


Figure 6-1:Dyna-CLUE modelling framework for the Western Cape Province [adapted from Verburg and Overmars (2009), Le Roux (2012) and (Le Roux et al., 15 March 2015)]

6.1 INPUT LULC DATA

The 1990 LULC map was used as the base map and year 2013/14 LULC map was used to validate the results predicted by the model. ArcMap 10.3.1 was used to clip the 1990 and 2013/14 national LULC maps using the Western Cape Province as the mask dataset. The maps were then reclassified and codes 0, 1, 2, 3, 4, 5, 6 were assigned to vegetation, plantations, water, bare, cultivated, built-up and mines respectively (Figure 6-2, Figure 6-3). The rationale behind Reclassification to 7 classes listed above was to simplify LULC classes and decrease processing time in modelling. The reclassified LULC maps were converted to ASCII format as required by Dyna-CLUE and code "cov_all.0" was assigned to the 1990 LULC map.(Le Roux, 2012)

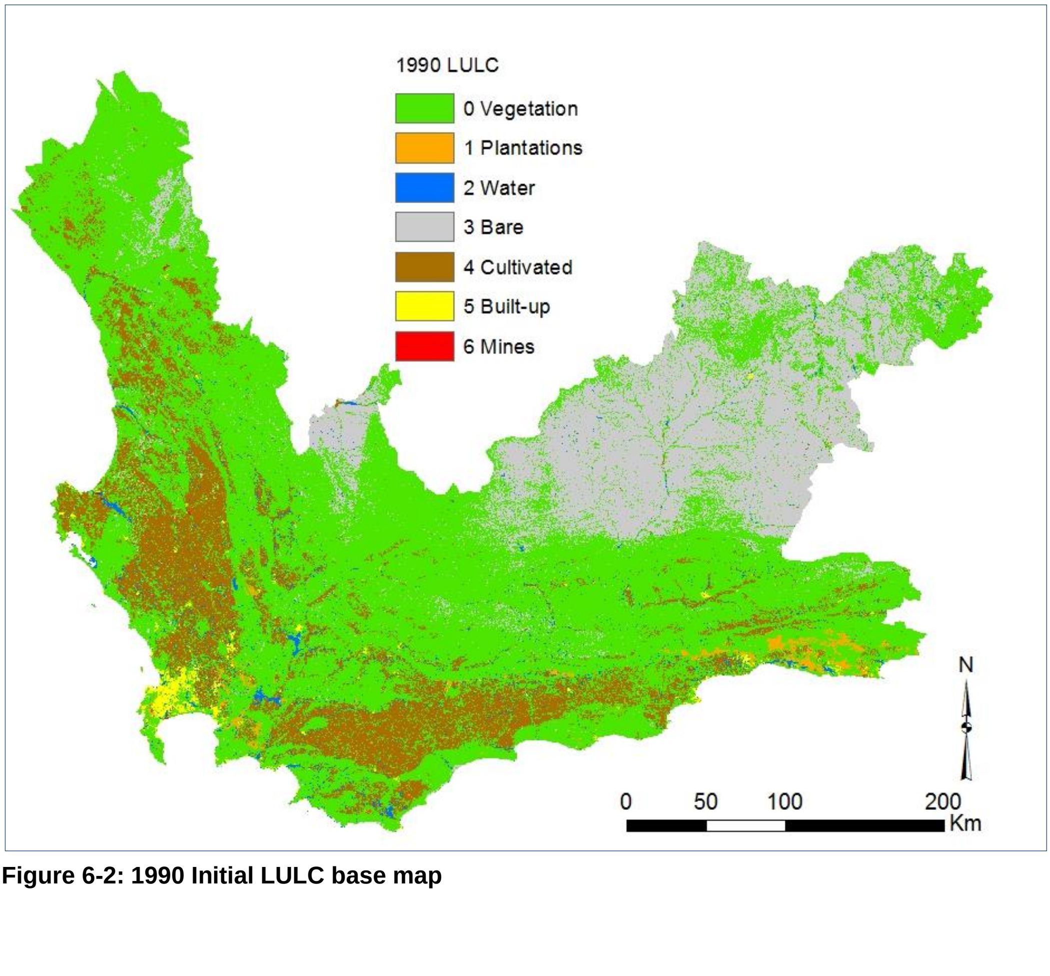


Figure 6-2: 1990 Initial LULC base map

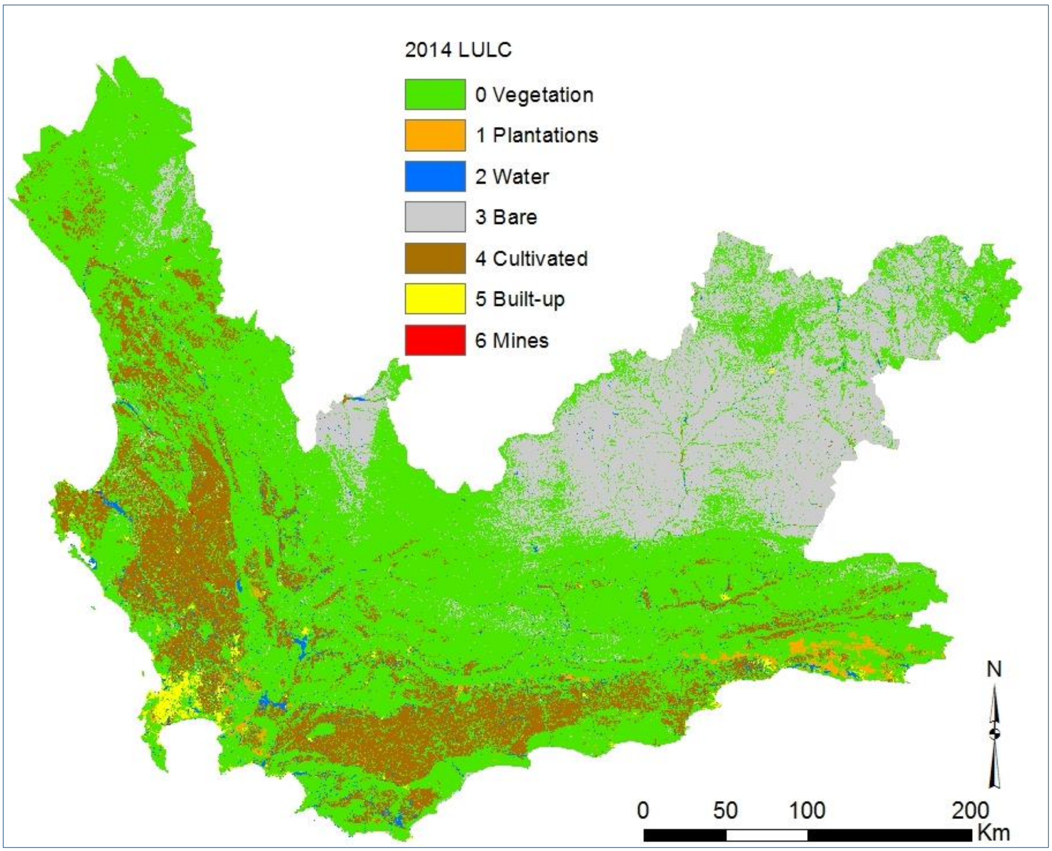


Figure 6-3: 2014 validation map

- **Modeling Resolution**

The size of the Western Cape Province was too large for high-resolution modelling with the source data being 30X30m resolution. The input data was therefore resampled to a 1x1km (100ha) resolution to reduce size and speed up data processing. This study was conducted at regional scale and LULC changes and modelling at this scale can be represented using a larger raster cell size or lower resolution. Given the scale of the study, it was not necessary to conduct the study at a high resolution which would show greater detail. When observed at a finer resolution, built-up areas would be made up of residential areas and offices blocks which would be relevant if the study was conducted at local municipality level. At a regional/provincial scale, LULC is more homogeneous and larger raster cell sizes can be used for quicker display, processing and storage with minimal effects along urban edges.

- **Maps of Individual LULC classes**

Dyna-CLUE requires maps of individual classes as input data in the root folder where the program is installed. Individual land-use classes were therefore extracted from the

1990 base map using “Extract by Attributes” tool in ArcMap. Model builder was used to iterate the extracted land-use classes and perform raster resampling to 1x1km as illustrated below.

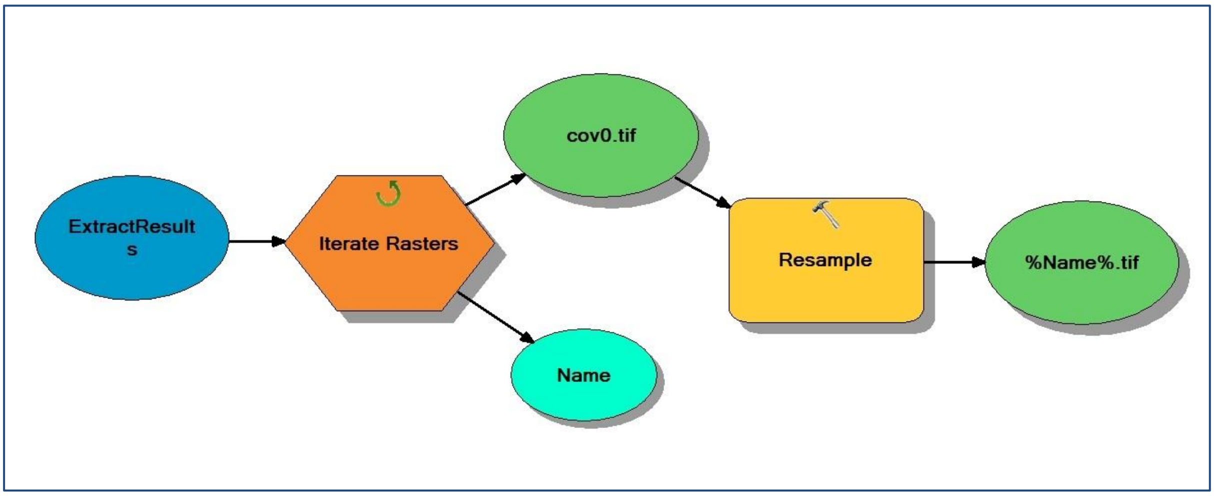


Figure 6-4: Model to iterate extracted land-use classes and resample to 1x1km resolution

The resampled LULC classes were then exported to ASCII format and codes cov1_0.0, cov1_0.1, cov1_0.2, cov1_0.3, cov1_0.4, cov1_0.5, cov1_0.6 were respectively assigned to land use classes Vegetation, Plantations, Water, Bare, Cultivated, Built-up and Mines as illustrated in Figure 6-5.

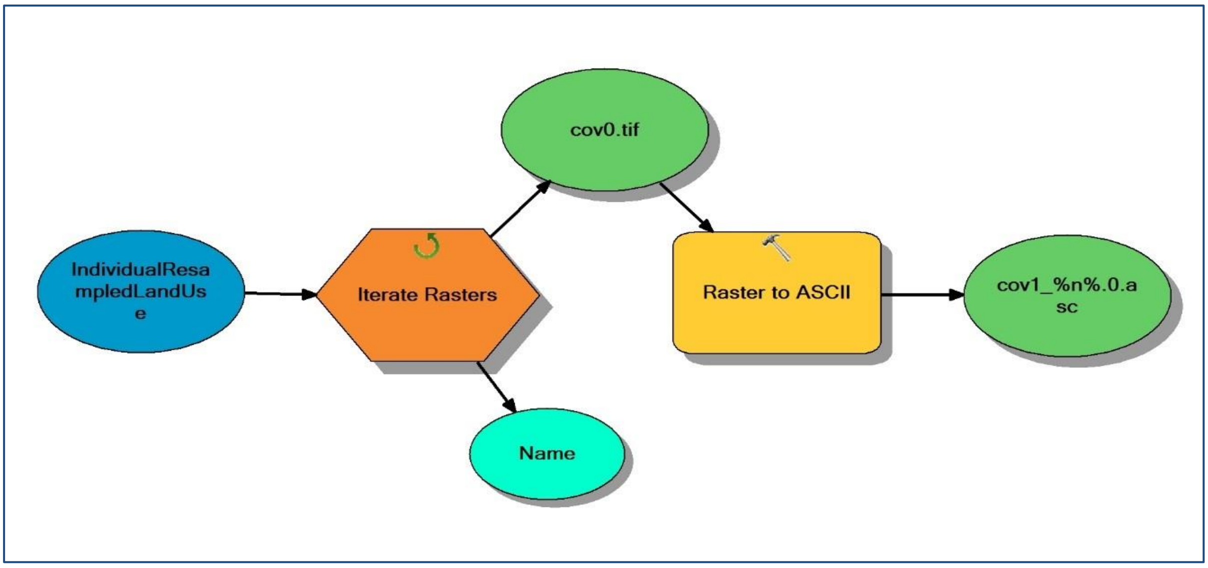


Figure 6-5: Model to iterate resampled land-use classes and convert to ASCII format

The processed individual land use maps are illustrated in Figure 6-6.

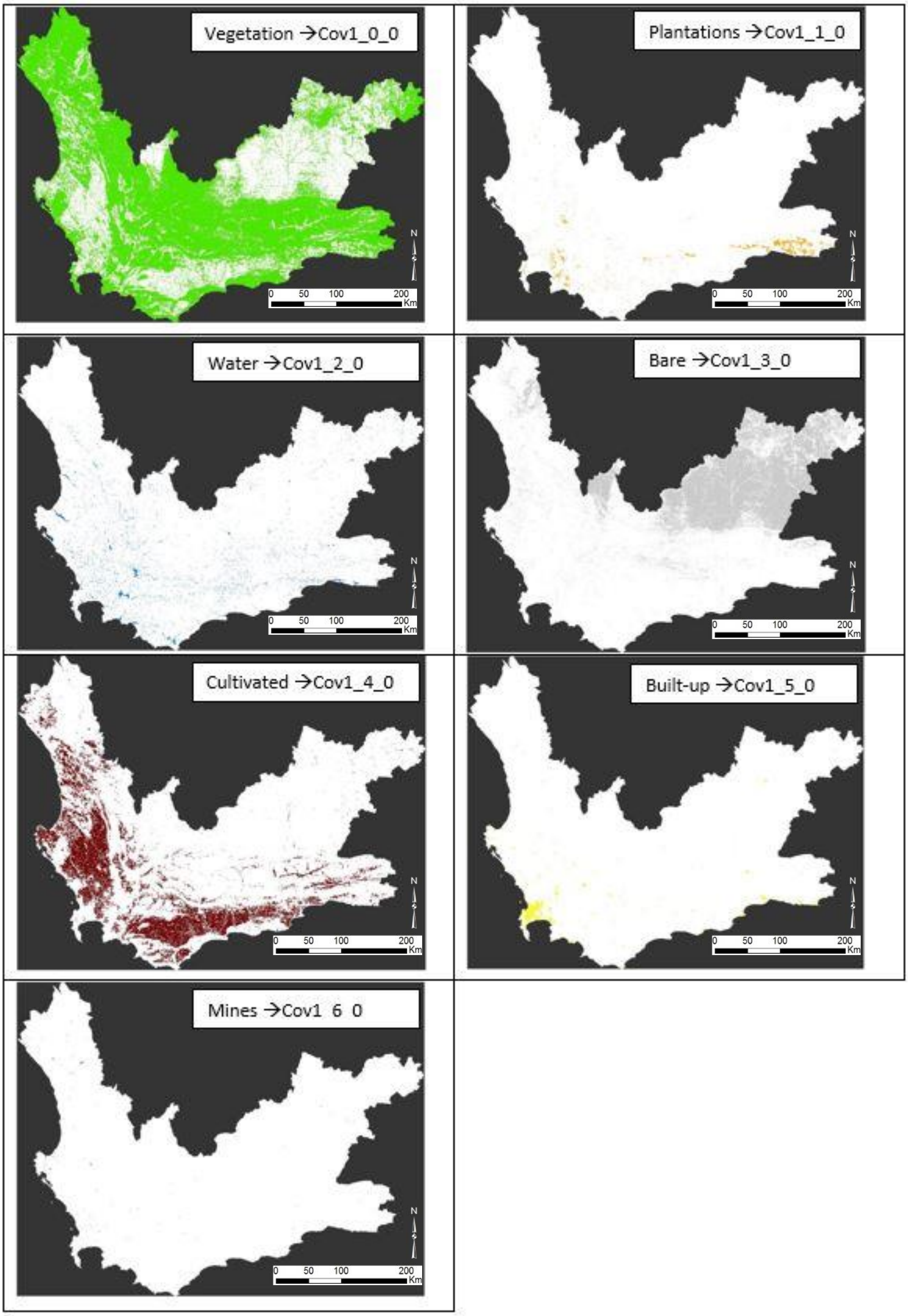


Figure 6-6: 1990 Individual LULC maps

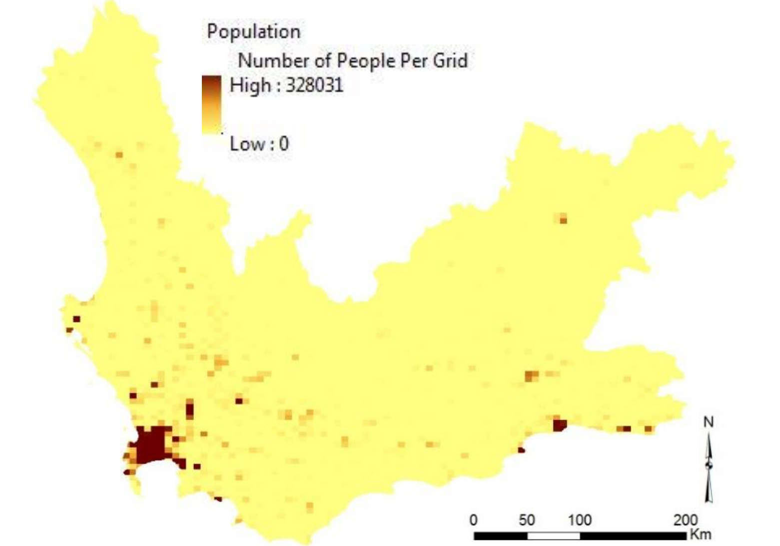
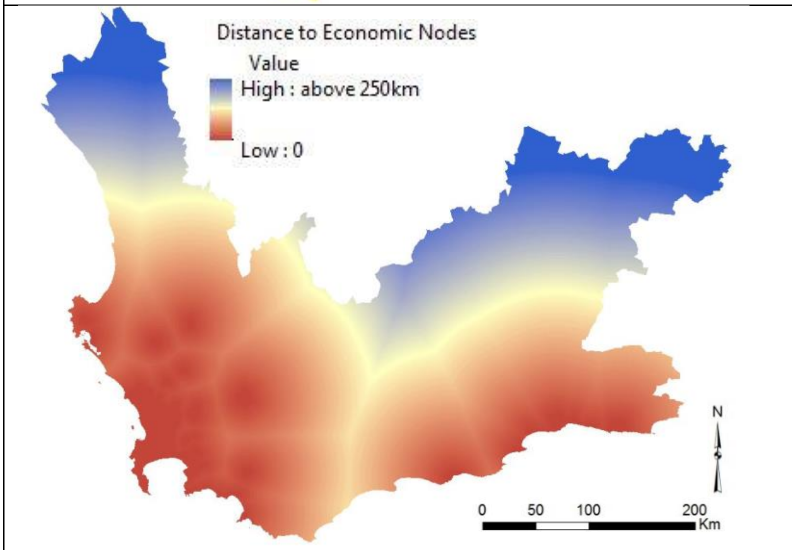
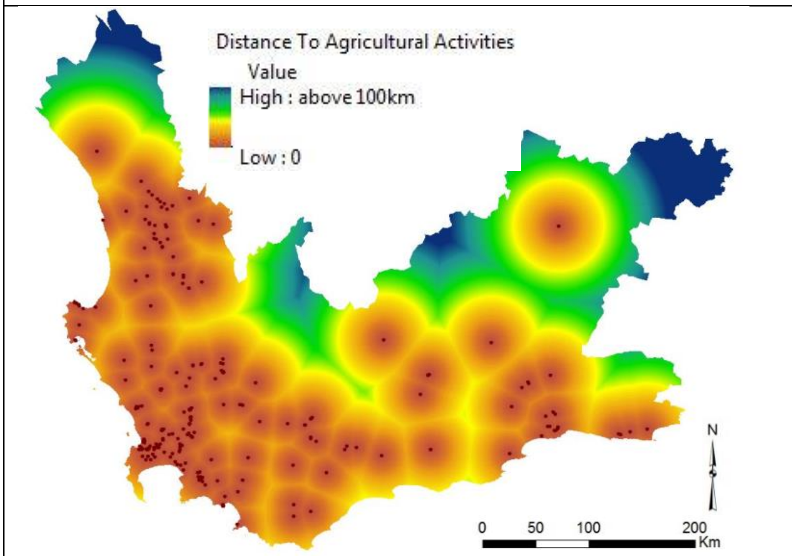
6.2 LOCATION CHARACTERISTICS

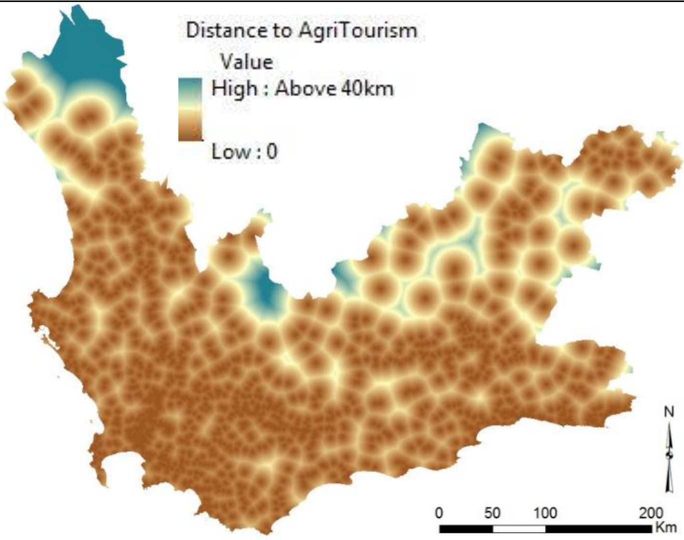
Location characteristics are determined by location preference of a land use, calculated through logistic regression models which indicate the preference of a specific land use based on quantification of its relationship or correlation with explanatory factors. After preparing maps of individual land use types, explanatory variables were created in ArcMap. The explanatory variables were based on the drivers of LULC change explained in section 4.2.1. The most significant driving factors which were considered in modelling were identified as:

- Demographic factors: Population growth in the study area is due to natural increase and in-migration. Population growth and decreased household sizes have led to higher demands for housing space in the Western Cape Province. Continued in-migration, limited funding to address housing backlogs and shortage of well-located land for housing contributes to the increase in informal settlements and backyard housing
- Environmental: The effects of climate changes are evident in the study area where extreme weather conditions in form of droughts, heat waves and floods are prevalent. This poses a challenge to the agricultural sector which must increase food production to cater for the expanding population. The most challenging factor in agricultural productivity in the Western Cape Province is water availability. The decline in rainfall has led to reduced crop production, low profits and farm conversions to other land uses. The impact of climate change on the agriculture sector also adversely affects other sectors that rely on agriculture for key inputs.
- Economic: The economic development of the Western Cape Province has strong links with agri-processing, tourism and gas sectors. These sectors attract investments and developments which lead to further in-migration and land use change.

Based on the above summary, the driving factors which were included in the modelling exercise were population, distance to economic nodes, distance to agricultural activities, distance to agri-tourism and land capability. Other relevant factors were not included due to data availability. These driving factors and the sources of data used are briefly explained in the table below.

Table 6-1: Description of driving factors and their data sources

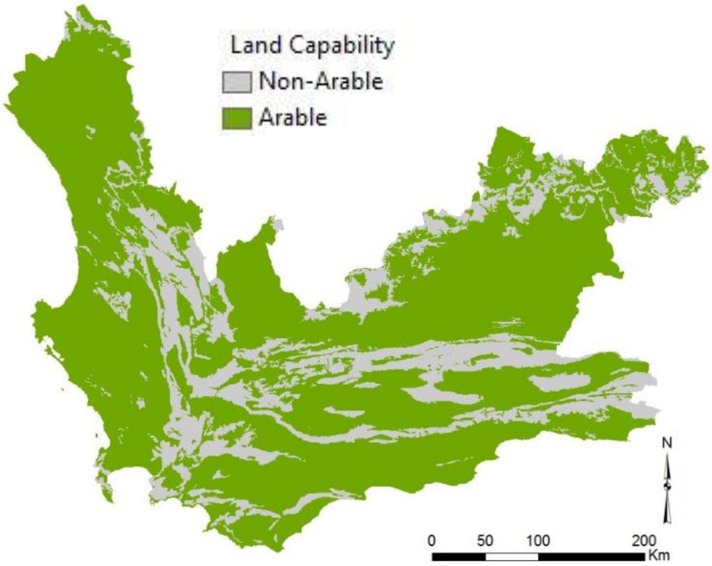
	**Population** The population data used was based on small area layer (SAL) which was created by combining all enumerator areas (EAs) with population of less than 500 with adjacent EAs within the same subplace. **Data Source** StatsSA
	**Distance to Economic Nodes** Economic nodes are towns or settlements with high growth potential. These areas were extracted from the Growth Potential Study of the Western Cape Province **Data Source** Department of Environmental Affairs & Development Planning
	**Distance to Agricultural Activities** This dataset consists of agri-processing locations in the Western Cape Province. **Data Source** Department of Agriculture



Distance to AgriTourism

This datasets shows locations where agriculturally based areas incorporate tourist activities such as accomodation, camping, restaurants, wine tasting, farm tours, etc.

Data Source
Department of Agriculture



Land Capability

Land capability gives an indication of the most intensive long-term use of land and indicates some limitations associated with different land use classes. This dataset incorporates the effects of climate, soil and terrain features inorder to determine the best use of land.

Data Source
Department of Agriculture

The above driving factors were then converted from raster to ASCII format using ArcToolbox Conversion Tools. A file conversion program that comes with Dyna Clue software was used to convert ASCII grids of all the individual land uses and their driving factors into a tabular file. This file was then input into SPSS to quantify correlations between land uses and driving factors. Table 6-2 below shows the various hypothesis that were tested to find the influence of explanaory factor on land use classes. A negatice β-value means that the lower the distance to a specific land use class, the higher the probability and a positive β-value means the lower the distance to a land use class, the lower the probability. In instances which do not concern distance e.g. Population, a negative β-value means the higher the value, the higher the probability and a positive β-value means the lower the value, the lower the probability.

Table 6-2: Hypothesis of land use changes

	(1) Plantations	(3) Bare	(4) Cultivated	(5) Built-Up
	β-values	β-values	β-values	β-values
(0) Distance to Agricultural activities			-	-
(1) Distance to Economic Nodes	+	+	-	-
(2) Population	-	+	-	-
(3) Land Capability	-	-	-	-
(3) Distance to Agritourism			-	-

Logistic regression is a common method in to calculate the coefficients (β-values) of the logit model which are used to find the probability of a certain cell being allocated a land use type, given a set of driving factors (Verburg et al., 2002). Stepwise regression was therefore used to select relevant driving factors and variables with no significant influence on land use patterns were excluded from the final regression equation. The regression results are presented in Table 6-3 including ROC values which indicate the goodness of fit. ROC values close to 0.5 indicate a random model whereas values close to 1 indicate a perfect fit. The ROC values presented in Table 6-3 show that the model is generally good, with the majority of values being above 0.8. Cultivated land-use has a ROC of 0.64, this value needs to be improved in future by incorporating more accurate driving factors which have a stronger correlation with the land-use.

Table 6-3: Stepwise regression results

	(1) Plantations	(3) Bare	(4) Cultivated	(5) Built-Up
	β-values	β-values	β-values	β-values
(0) Agri-Processing	-	-	0.00015	0.0001
(1) Economic Nodes	0.0001	0.0001	-	-
(2) Population	-	-	-	0.0016
(3) land Capability	-	-	0.0001	-
Constant	-10.762	3.207	-3.173	-3.372
ROC Values	0.864	0.817	0.644	0.92

6.3 CONVERSION SETTINGS

Conversion elasticity gives an indication of conversion costs from one land use type to another and is assigned a value between 0 and 1. A high elasticity value (close to 1) indicates a high cost of conversion and a consequently higher probability of the land use type to remain at the same location (Verburg and Overmars, 2009). The determination of conversion elasticities for implementation of Dyna-CLUE model in the study area was based on analysis of land use history data, visual interpretation and expert knowledge. The values assigned are illustrated in Table 6-4 below.

Table 6-4: Land use conversion elasticities

Land Use	Elasticity Value
Vegetation	0.1
Plantations	0.1
Water	0.7
Bare	0.1
Cultivated	0.4
Built-Up	0.7
Mines	0.6

High conversion elasticity values were assigned to built-up and water land use types, given their low probabilities to be converted to other land use type whereas low conversion elasticity values were allocated to vegetation and bare land due to their higher likelihood to be converted to other land use types. Vegetation, plantations and bare land uses were assigned a conversion elasticity of 0.1 since they are unstable and can easily be converted to another class. Cultivated land use was assigned a conversion elasticity of 0.4 which is higher than the previously mentioned classes since cultivation requires a higher investment and is thus more stable. Mining was allocated a conversion elasticity of 0.6 because it requires a greater investment than cultivated land use class and is therefore more stable.

6.4 PREFERENCE LOCATION

Land use types can have location specific preferences due to spatial policies or research initiatives which can be implemented through SDF's and municipality plans. In the case of the Western Cape Province, the mining land use was assigned location preferences based on mining potential data created by the South African National Biodiversity Institute (SANBI). SANBI (2005) determined mining potential at a national level based on the accuracy of deposit mapping, its size and commodity types. The attributes of this dataset consist of mining potential of areas ranging from 0 (low potential to 100 (high potential). Mining potential was included in the model by increasing the probability of mining land use in locations with a high potential for mining to occur. A file coded locspec6.fil which contains a map with preferred mining locations was created in ArcMap and added as input to the model (Figure 6-7).

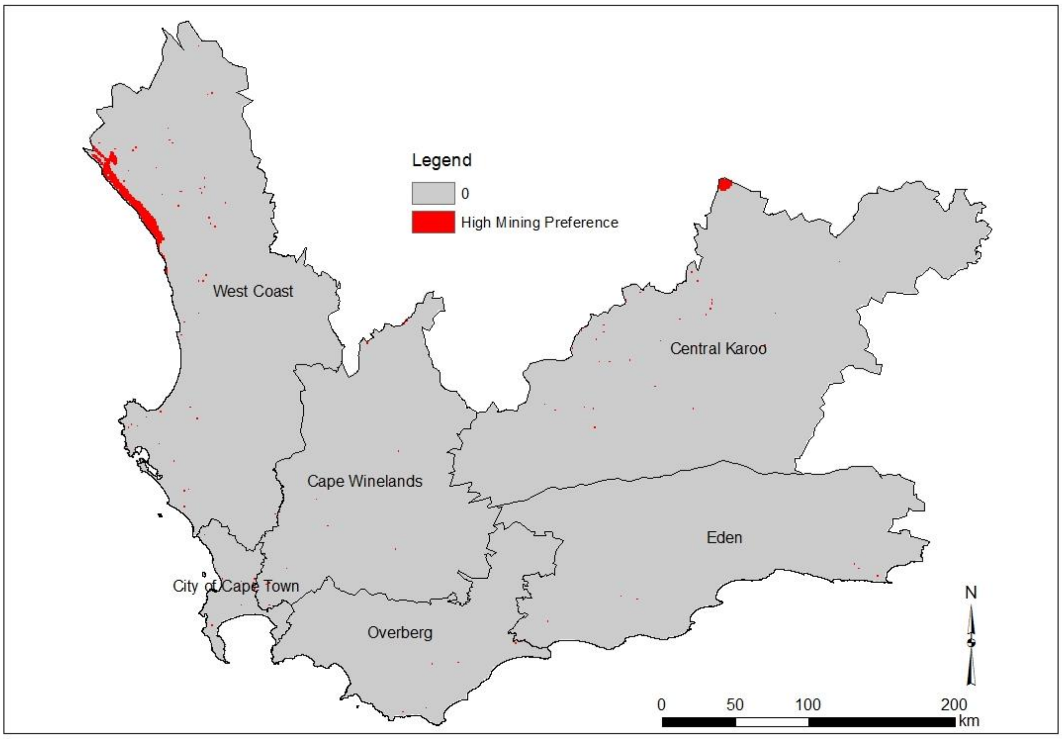


Figure 6-7: Location specific preference areas for mining

6.5 NEIGHBOURHOOD INFLUENCE

According to the first law of geography by Tobler (1970), “everything is related to everything else, but near things are more related than distant things”. This law plays a significant role in understanding spatial interactions in LULC dynamics and forms an important component of land use change models. In land use change models, this implies that a land use transitions will most likely cluster next to a similar established land use types. Verburg et al. (2004a) characterised the location of a neighborhood by defining an enrichment factor which is defined by the occurrence of a land use type in the location’s neighbourhood relative to its occurrences in the whole study area. The enrichment factor can be defined by the equation:

$$F_{i,k,d} = \frac{n_{k,i,d}/n_{d,i}}{N_k/N} \quad (5)$$

Where:

$F_{i,k,d}$ is the enrichment of neighbourhood *d* of location *i* with land use type *k*.

$n_{k,i,d}$ is the number of cells of land use type *k* in the neighbourhood *d* of cell *i*.

$n_{d,i}$ is the total number of cells in the neighbourhood.

N_k is the number of cells with land use type k in the whole raster.
N is the total number of cells in the raster.

Enrichment factors were calculated for built-up and mines land use types using the focal statistics function in ArcMap. As proposed by Verburg et al. (2004a), analysis of the explanatory influence of enrichment factors through logistic regression was performed to assess the relevance of enrichment factors.

6.6 SPATIAL POLICIES AND RESTRICTIONS

Spatial policies and restrictions are defined by specific pixels that are not allowed to convert to any other land use type. Restrictions that constrain developments in the Western Cape Province are implemented in response to biodiversity threats due to conversions of the natural environment to man-made landscapes. Such restrictions aim to support biodiversity and ecosystem fuctioning and are in the form of political factors i.e legislations, policies and plans at national and provincial levels. Examples of national legislations are the National Environmental Management Act 107 of 1998 (NEMA) and the Biodiversity Act 10 of 2004 (NEMBA); Provincial legislations include the Western Cape Nature Conservation Board Act 15 of 1998 and at municipality level, restrictions are implemented in SDF's.

Two restriction layers were used in the Western Cape Province model to show the impact of two different scenarios. The first scenario permits land use conversions throughout the province, as an AS-IS scenario and is coded 'region_nopolicy.fil'. This scenario was created from the initial 1990 base map by reclassification of all the land use classes and assigning them with code 0 to show that all convesions are allowed. The second scenario is a Policy-Led scenario where the restriction file excludes national parks from conversions as illustrated in Figure 6-8.

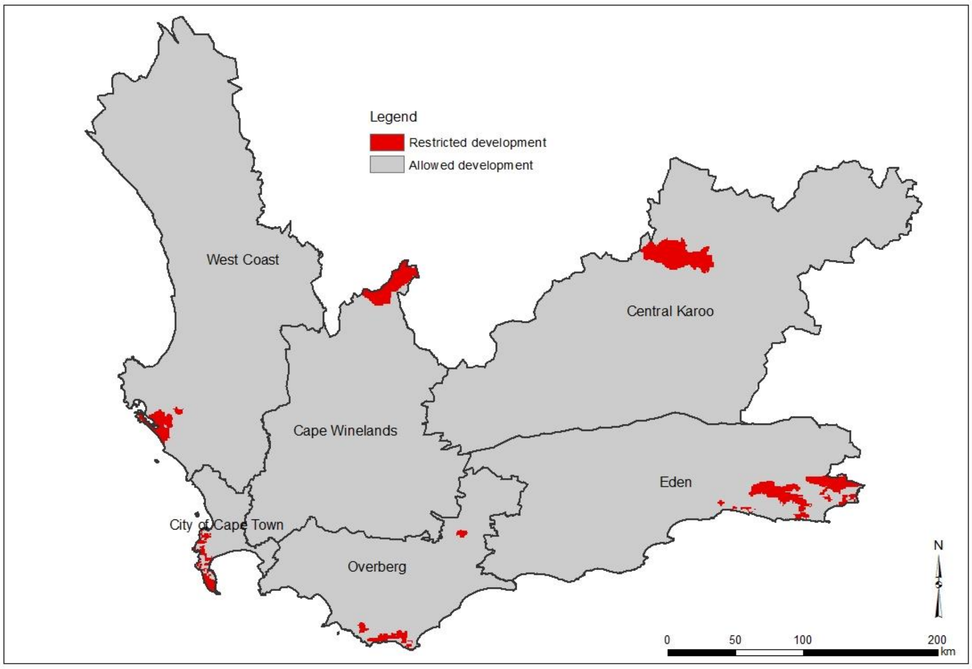


Figure 6-8: National parks restriction areas

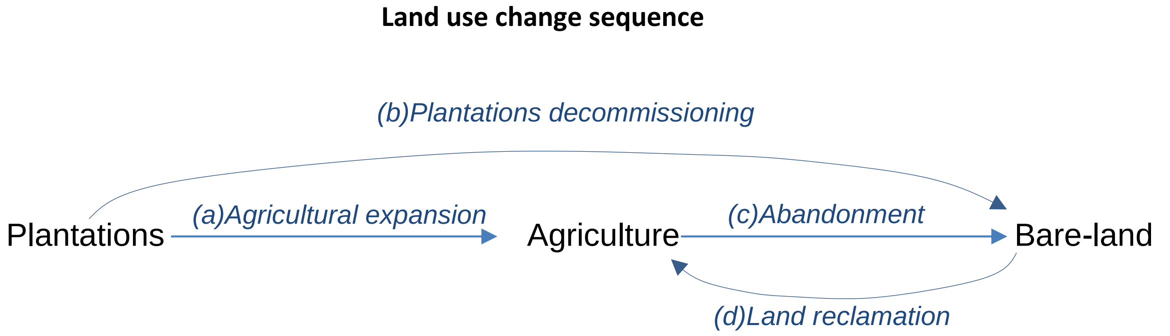
As mentioned in Section 4.2.1.1, the Urban and Coastal Edge Policy will most likely lead to restrictions on future developments in demarcated areas in the Western Cape Province. Urban and Coastal edges were not included as a restriction layer in this model due to the unavailability of a comprehensive Provincial dataset. The dataset is still being updated in various local municipalities and will be an important restriction layer for the prediction of future land use patterns.

6.7 CONVERSION MATRIX

Dyna-CLUE specifies land use type conversion settings in a conversion matrix. The purpose of the conversion matrix is to:

- Define to what other land use type the initial land use is permitted to be converted or not.
- Indicate the number of years a land use type at a specific location should remain unchanged before conversion to another land use type.

Below is an illustration of a hypothetical land use change sequence translation into a land use conversion matrix.



Land use conversion matrix

Land Use	Plantations	Agriculture	Bare-land
Plantations	✓	✓ (a)	✓ (b)
Agriculture	×	✓	✓ (c)
Bare-land	×	✓ (d)	✓

Where:

✓ Possible conversion
× Impossible conversion

Figure 6-9: Translation of a hypothetical land use sequence into a land use conversion matrix [adapted from (Verburg, 2010)]

The conversion matrix used in the Western Cape Province was determined using previous trends i.e. analysis of changes between 1990 & 2014 using land change modeler for ArcMap. The results of the analysis are illustrated in Table 6-5, where the conversions are from rows to columns, "1" represents possible conversions and "0" shows impossible conversions. In the case of plantations, the table also gives an indication of the number of years plantations remained stable before the forest exit policy was implemented. The figure "1 12" in the plantations row consists of "1" and "12", where "1" indicates a possible conversion from plantations to other land uses and "12" represents the time period before conversions began. Major changes in plantations began in 2002 after the forest exit policy was implemented therefore the table shows possible changes in the 12th year from 1990 (i.e. year 2002). The conversion matrix is saved in the root folder of Dyna-CLUE as "allow.txt".

Table 6-5: Conversion Matrix

	Vegetation	Plantations	Water	Bare	Cultivated	Built-Up	Mines
Vegetation	1	0	0	0	1	1	1
Plantations	1 12	1	0	0	1 12	1 12	1 12
Water	1	0	1	0	1	0	0
Bare	1	0	0	1	1	1	1
Cultivated	0	0	0	1	1	1	1
Built-Up	0	0	0	0	0	1	0
Mines	0	0	0	0	0	0	1

6.8 LAND REQUIREMENTS

The demand file was created based on the concept of Markov chain models. The Markov property in land use change is when future use of land at time (*t+1*) can be predicted solely based on the immediately preceding state of land use at time (*t*) and not the sequence. The probability of land use changing to the next state at time (*t+1*) depends only on the most recent state (*t*), which can be defined as:

$$P(X_{t+1}|X_0, \cdots, X_t\ ) = P(X_{t+1}|X_t) \quad (6)$$

Land use from the 1st time period (year 1990) was crosstabulated with year 2013/14 to create a transition probability matrix. Crosstabulation was conducted using the original datasets at 30x30m resolution to avoid loss of values due to resampling. Crosstabulation was conducted using IDRISI GIS Analysis Crosstab tool which is embedded in Terrset Software. The results of crosstabulation of pixels of land uses are shown in the table below.

Table 6-6: Pixel cross tabulation output indicating number of pixels that correspond to each combination of categories in the initial 1990 map and reference 2013/14 map

LULC	Vegetation	Plantations	Water	Bare	Cultivated	Built-Up	Mines	Tot1990
Vegetation	80490158	110201	430077	4472363	2019172	232991	63939	87818901
Plantations	494337	763742	19057	1616	41845	14537	205	1335339
Water	804772	2777	1242982	45958	103888	9398	546	2210321
Bare	10835973	515	45114	19888281	73914	6001	167	30849965
Cultivated	1883946	22893	79886	14846	19634853	15928	3974	21656326
Built-Up	118964	2332	5042	2170	5834	1017077	216	1151635
Mines	29540	78	1737	427	593	375	35967	68717
Tot2014	94657690	902538	1823895	24425661	21880099	1296307	105014	145091204

Below is the transition probability matrix which shows the probability that each LULC category will change to every other category.

Table 6-7: Transition probability matrix

LULC	Vegetation	Plantations	Water	Bare	Cultivated	Built-Up	Mines
Vegetation	0.917	0.001	0.005	0.051	0.023	0.003	0.001
Plantations	0.370	0.572	0.014	0.001	0.031	0.011	0.000
Water	0.364	0.001	0.562	0.021	0.047	0.004	0.000
Bare	0.351	0.000	0.001	0.645	0.002	0.000	0.000
Cultivated	0.087	0.001	0.004	0.001	0.907	0.001	0.000

Built-Up	0.103	0.002	0.004	0.002	0.005	0.883	0.000
Mines	0.430	0.001	0.025	0.006	0.009	0.005	0.523

The transition probabilities in the above table were used to create a transition areas matrix which indicates the number of pixels that are expected to change from each LULC type to every other LULC type over the next time-period. In this case, the next time-period is 24 years from year 2014. The transition area matrix was calculated by multiplication of each column in the transition probability matrix by the number of cells of the corresponding land use in the later image as shown in the equation below.

$$X_{t+1} = P_{ij} \text{ x } X_t \quad (7)$$

Where

$$P_{ij} = \begin{pmatrix} P_{11} & P_{12} & P_{1n} \\ P_{22} & P_{22} & P_{2n} \\ P_{n1} & P_{n2} & P_{nn} \end{pmatrix}$$

And the following condition is met:

$$\left(0 \leq P_{ij} < 1 \; and \; \sum_{J=1}^{N} P_{ij} = 1, (i, j = 1,2 \ldots n) \right)$$

Where, X_t is the system state at time (t); $X_{t+1}$is the state of the system at time $(t + 1)$ and P_{ij} is the transition probability matrix. After conducting the above process in excel, the following table shows the future number of pixels for each land use.

Table 6-8: Future predicted number of pixels and hectares for each LULC type

LULC type	Expected Areas (in pixels)	Expected Areas (in hectares)
Vegetation	98418338	8857650
Plantations	663559	59720
Water	1626884	146420
Bare	20624429	1856199
Cultivated	22194154	1997474
Built-up	1434978	129148
Mines	128863	11598
Total	145091204	13058208

The modelling approach implemented in this study involved an investigation of how identified driving factors related to historic LULC changes inorder to use the relationships to create a model that predicts future LULC patterns. This study therefore focused on utilizing the initial 1990 LULC map and components of the adapted model illustrated in Figure 6-1 to simulate transitions and hence produce a prediction map for the year 2014. It was necessary to first evaluate the ability of the predicted map in simulating the 2013/14 LULC reference map and to validate the models before performing future LULC predictions.

Land use demands between 1990 and 2014 were calculated using linear interpolation. These are presented in the graph below.

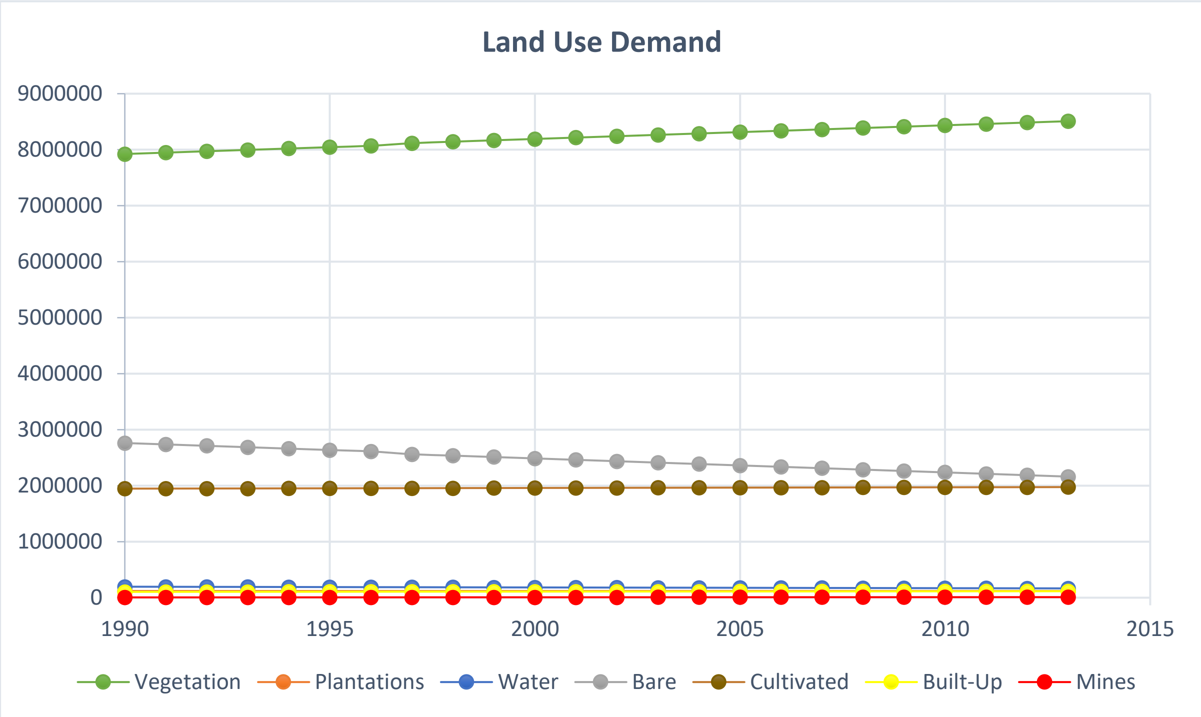


Figure 6-10: LULC demands from1990 to 2014

6.9 MODEL LAND USE ALLOCATION

The inputs explained in the sections above were used to run Dyna-CLUE and the main parameters used to configure the model were saved in the directory where Dyna-CLUE was saved as main.1(refer to Appendix 8.4). Land use was allocated based on the equation:

$$Ptot_{i,t,lu} = Ploc_{i,t,lu} + Ploc_{i,t,lu} + Elas_{i,t,lu} + Comp_{t,lu} \tag{8}$$

Where $Ptot_{i,t,lu}$= the highest total probability calculated for every land use (*lu*) for every grid cell or location (*i*) at time (*t*) by summation of:

$Ploc_{i,t,lu}$ - Location suitability explained in Section 6.2.

$Pnbh_{i,t,lu}$- Neighbourhood functions in described in Section 6.5.

$Elas_{i,t,lu}$- Conversion settings in Section 6.7.

$Comp_{t,lu}$- Preference location explained in Section 6.4.

The data inputs listed above were used to create probability maps for LULC allocations. The results of allocations for Built-up, Mines, Cultivation and Plantations LULC classes are presented in model outputs and validation section 6.10.1.

6.10 MODEL OUTPUTS AND VALIDATION

The Western Cape Dyna-CLUE model was run by selecting a scenario and demand file for the scenario. Each scenario generated 23 simulation maps for the years 1991 to 2014. The simulated maps had to be validated to find out how the model performed and reveal the accuracy of predicted maps. Due to unavailability of readily comparable LULC data at a provincial scale, the map used for validation was the 2013/2014 LULC map. Validation of the simulated map was performed using both visual and statistical approaches as endorsed by Pontius Jr and Chen (2006). However, an ideal validation would have included analysis of the simulated map of year 2000 but this was impossible due to unavailability of a readily comparable year 2000 reference map.

6.10.1 Visual Validation

The visual validation approach was conducted to quickly analyse spatial patterns which could otherwise be undetectable through statistical methods. The importance of visual map inspection is that it reveals some characteristics of maps that may be overlooked by directly performing statistical analysis on simulated maps (Visser, 2004). Based on this notion, visual analysis was performed between two sets of maps, that is, the initial 1990 LULC map and the 2013/2014 reference map and the 1990 LULC map with the simulated 2014 map (Figure 6-11).

Visual analysis was done using IDRISI crosstabulation with hard classification analysis. Hard classification analysis is used when pixels in maps belong to exactly one category without any partial membership to more than one category. The outputs of hard classification crosstabulation analysis of the two sets of maps were cross classification images which consisted of pixels that showed a combination of categories of the maps being compared. These images allowed visualisation of changes that occurred between each LULC category and every other LULC category/class. To simplify the visualisation analysis results, the output cross classification image from analysis of the 1990 LULC map and the 2013/14 LULC reference map was reclassified in ArcMap to show pixels where changes occurred and where there were no changes (top right of Figure 6-11). Similarly, the image at the bottom right of Figure 6-11 gives an indication of changes that occurred between the 1990 initial map and the 2014 AS-IS scenario simulated map. The 2014 Policy-Led scenario map was created using national parks (Figure 6-8) as the restriction area and slightly different parameters. The maps of actual LULC changes and simulated changes display some similarities in changes in LULC throughout the province, though there are a few differences.

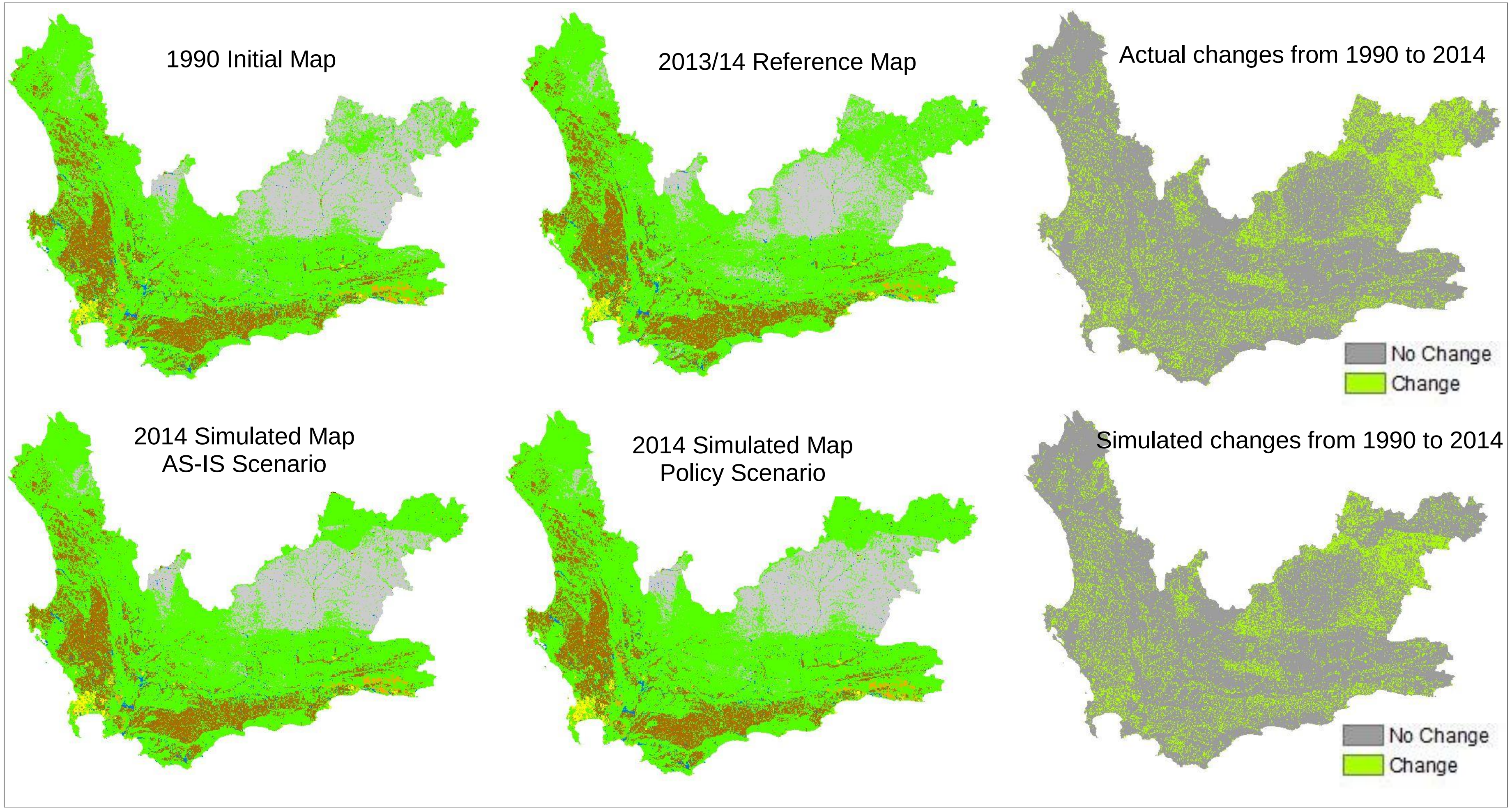


Figure 6-11: Visual analysis of the initial 1990 map, 2014 reference map and 2014 simulated maps

Individual LULC classes of mines, built-up and cultivation were also visually analysed to determine if allocation was correct or logical. This was achieved by first running the Dyna-CLUE model in 'Calculate probability maps' mode. The purpose of this step was to test whether the hypothesis for the driving factors and preference layers on each LULC type were correct.

6.10.1.1 Mining

As explained in section 6.4, the allocation of mines was based on location preferences (Figure 6-7) which were extracted from mining potential data. An overlay of the initial 1990 mining locations and the output probability map for mining land use in an AS-IS scenario is presented in Figure 6-12. As illustrated below, new mining locations are expected to occur in the West Coast District Municipality.

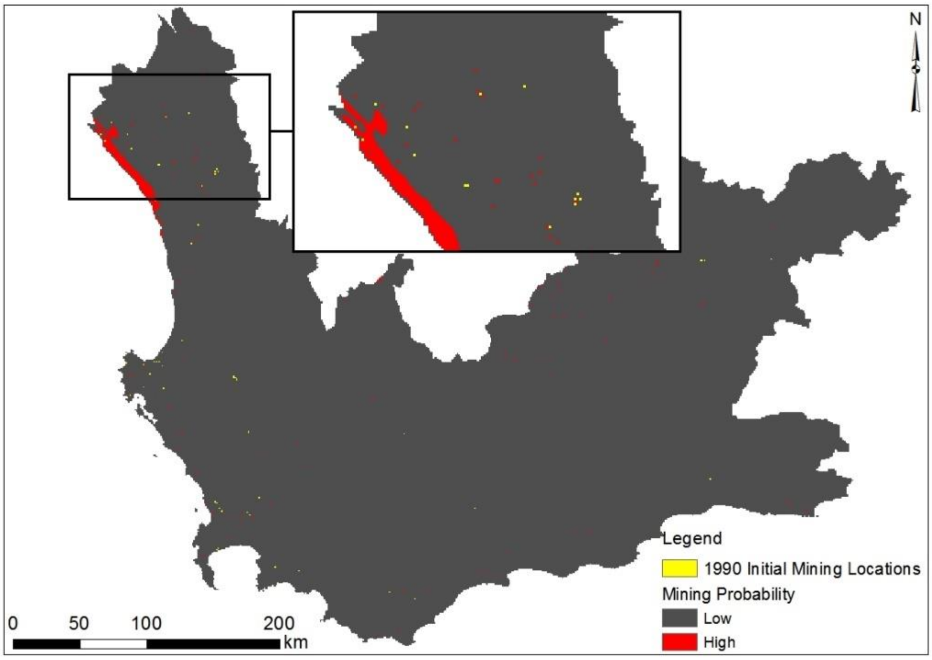


Figure 6-12: Output probability map for mining land use in a AS-IS scenario

The output probability map for mining land-use in a Policy-Led scenario gives an indication of restricted areas (parks) where mining allocations will not be allowed. This is illustrated in Figure 6-13. A comparison of the output probability maps of the two scenarios shows that allocations of mining land use were very similar. A similar trend was observed for built-up and cultivation land uses.

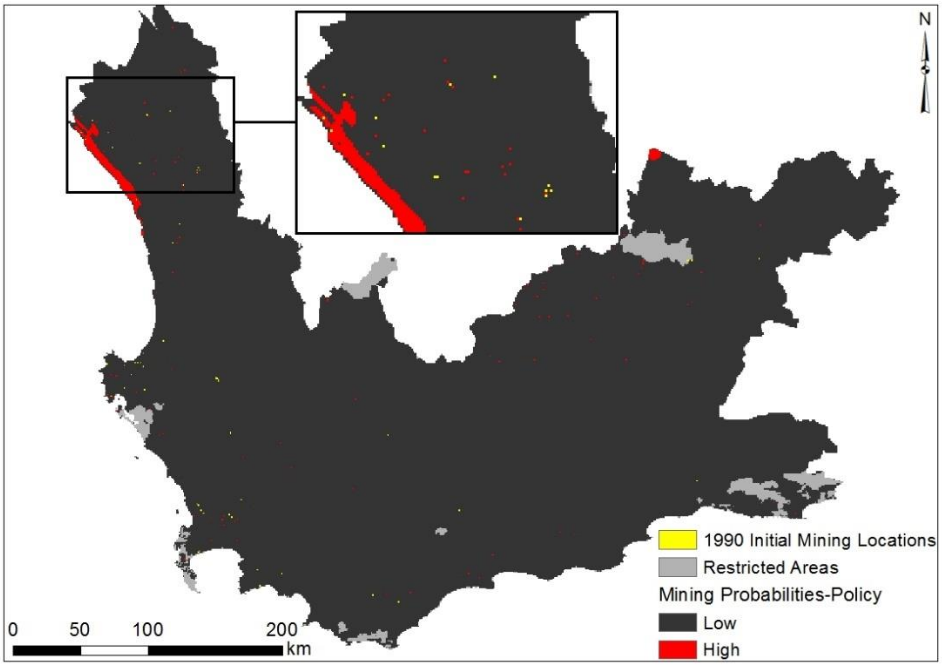


Figure 6-13: Output probability map for mining land use in a Policy-Led scenario

An overlay of the output probability map with the simulated mining class shows that most allocations were in areas with a high probability for mining (Figure 6-14). The simulated map also demonstrates new mining locations in the West Coast District Municipality. Most of the new mining locations are allocated correctly, since they correspond with preferred mining locations, though there are a few mines which were misplaced.

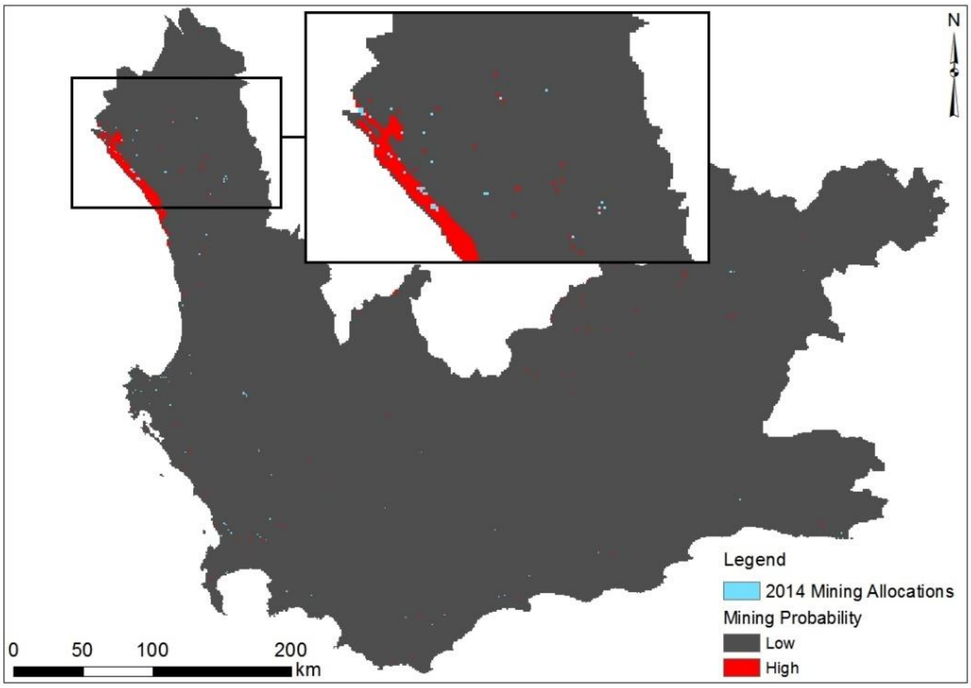


Figure 6-14: Overlay of mining probability with 2014 mining simulated map

A visual comparison of the simulated 2014 mining land use (Figure 6-14) with the 2013/14 mining reference layer (Figure 6-15) however paints a slightly different picture. The difference can be explained by the location preferences which were input into the model as the main dataset that influences the allocation of mines. The mismatch in the simulated and reference mining maps can be corrected by making use of actual land use plans which can be extracted from individual municipalities SDF's and IDP's. These datasets were not used in the Dyna-CLUE model due to time constraints as this would involve extensive editing since there is no standard method for capturing data across individual municipalities. It must however also be noted that certain traits such as illegal mining are difficult to monitor and can therefore lead to unexpected patterns in the mining land use.

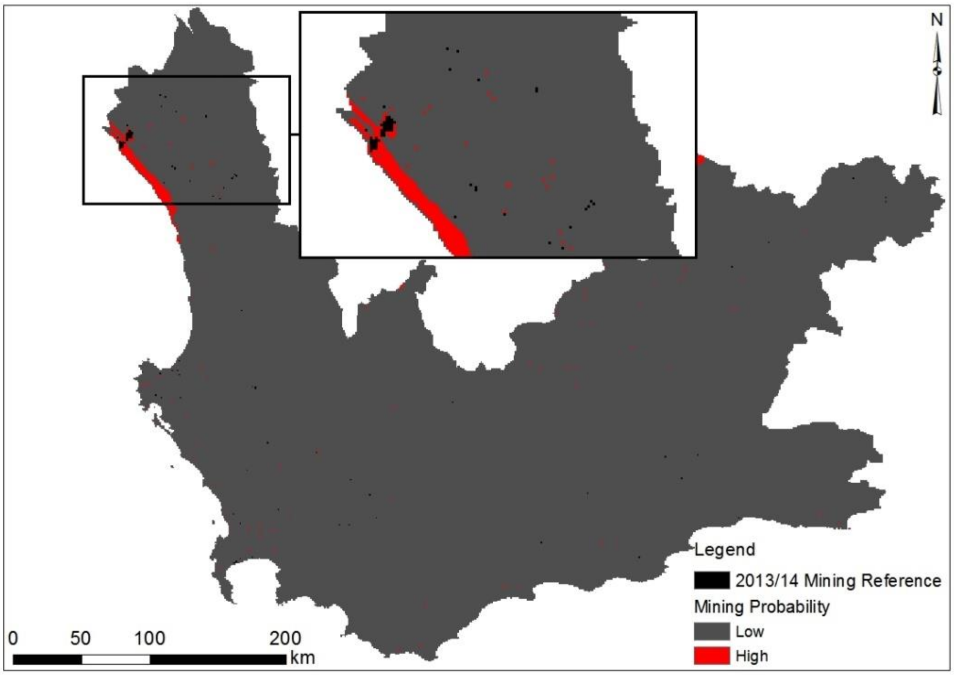


Figure 6-15: 2013/14 Mining reference map

6.10.1.2 Built-up

Allocation of built-up land use was based on population and agri-processing as input driving factors. The rationale behind this was that areas with a higher population or higher concentrations of agri-processing had a higher probability of attracting developments and expanding built-up land use. The output probability map for built-up areas in a AS_IS scenario is presented in Figure 6-16.

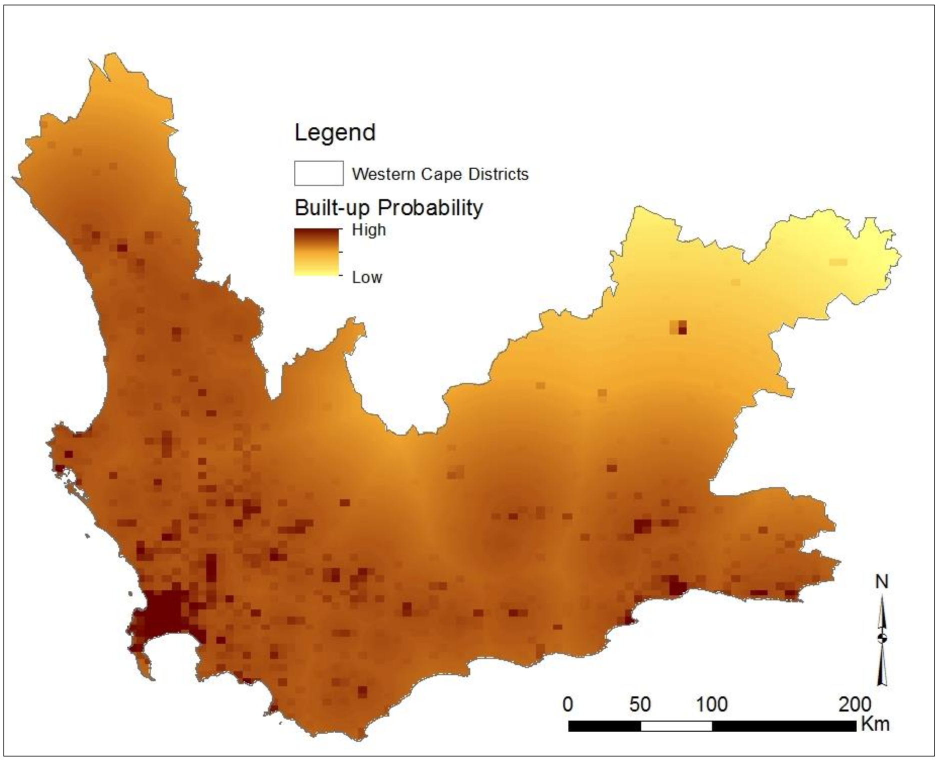


Figure 6-16: Output probability map for built-up areas

An overlay of the output probability map for built-up areas with the simulated 2014 built up map demonstrated Dyna-CLUE's ability to allocate locations based on input driving factors. This is illustrated in Figure 6-17 where the simulated built-up land use coincides with areas with a high probability for built-up land use

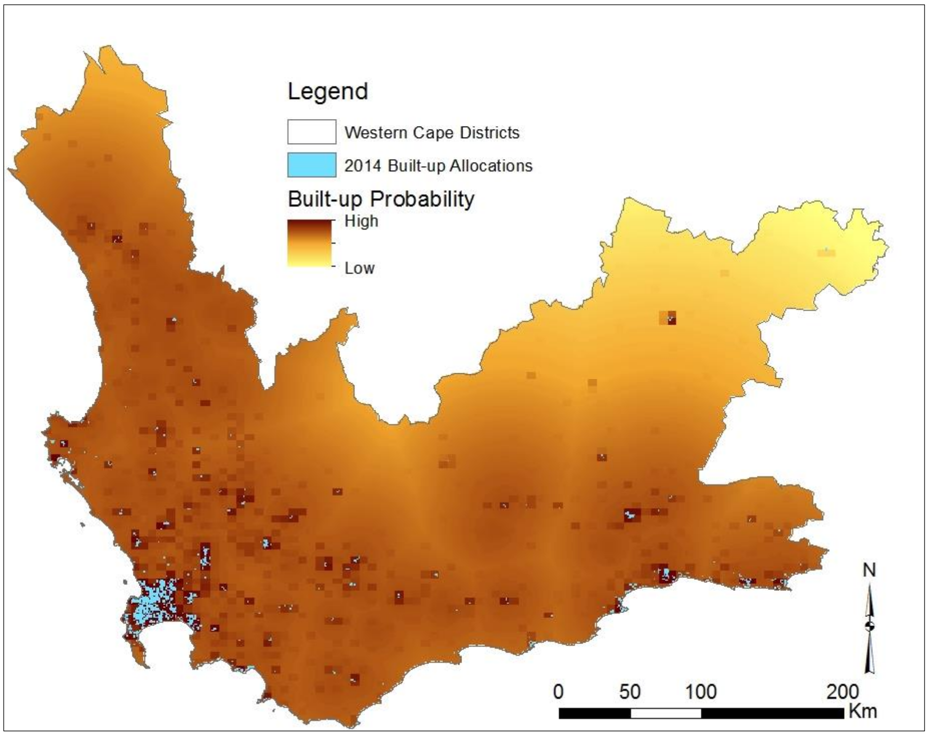


Figure 6-17: Overlay of built-up probability with 2014 built-up simulated map

The 2014 simulated map was compared with the 2013/14 reference map (Figure 6-18) for built-up areas and these maps showed similarities hence concluding that allocations by Dyna-CLUE were adequately represented.

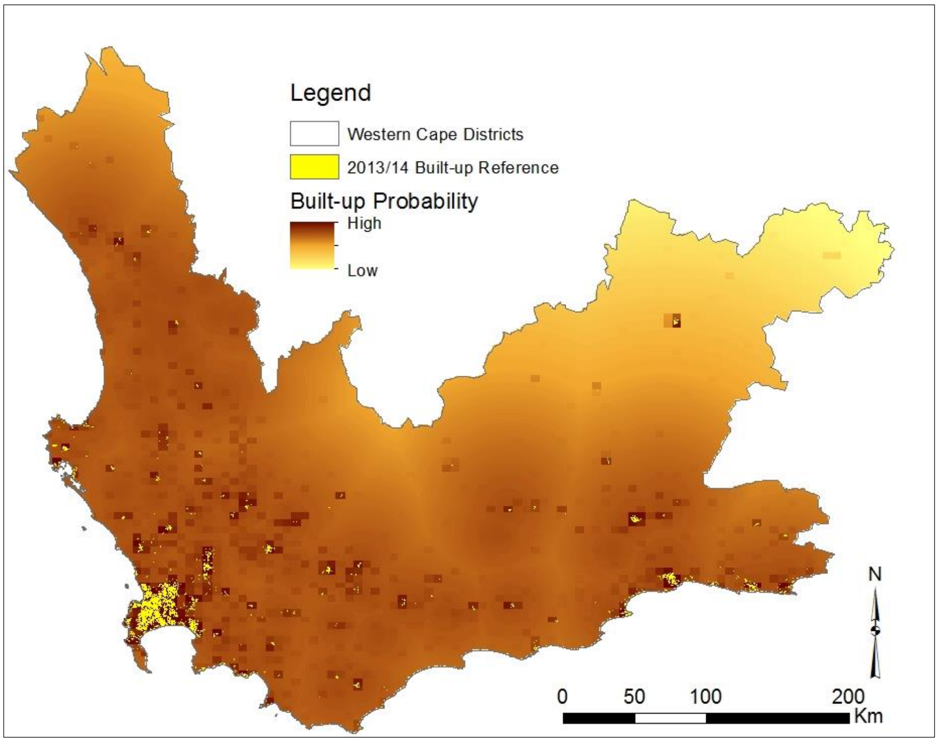


Figure 6-18: 2013/14 Built-up reference map

6.10.1.3 Cultivation

Cultivation allocation was based on input driving factors of agri-processing, distance to economic nodes and land capability. The output probability map with an overlay of the resultant simulated 2014 cultivation land use is illustrated in Figure 6-19. This map demonstrates Dyna-CLUE's ability to allocate cultivation land use in agricultural districts which have a high probability for cultivation to occur. The Central Karoo District Municipality has only a few cultivation allocations due its semi-desert conditions.

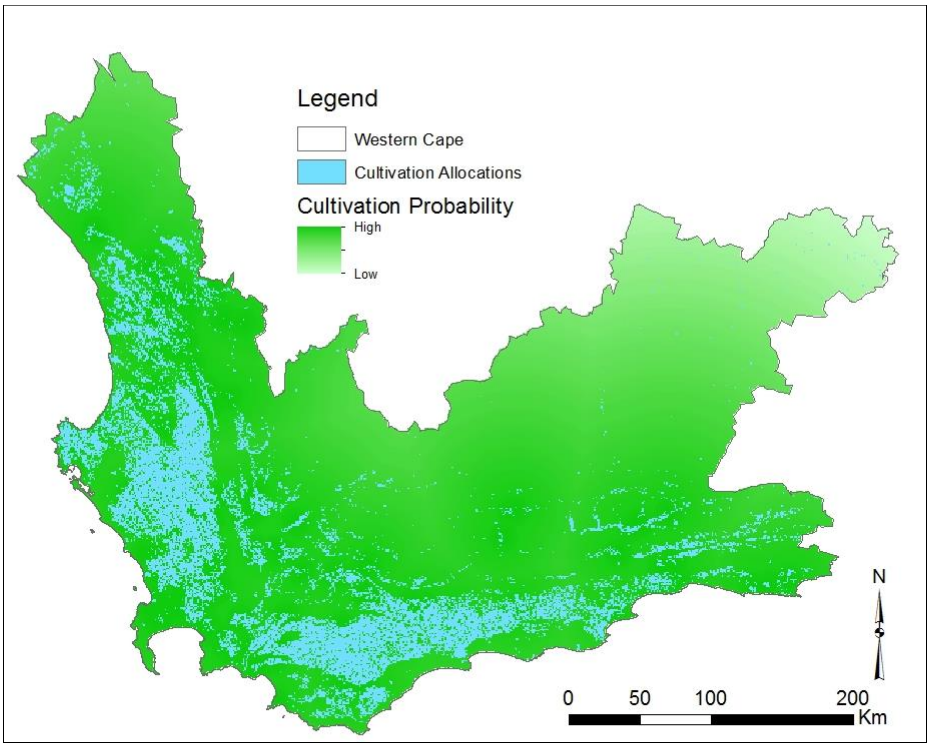


Figure 6-19: Overlay of cultivation probability with 2014 cultivation simulated map

The 2014 simulated map (Figure 6-19) was visually compared with the 2013/14 reference map (Figure 6-20) for cultivation and these maps showed similarities hence concluding that Dyna-CLUE adequately simulated LULC allocations.

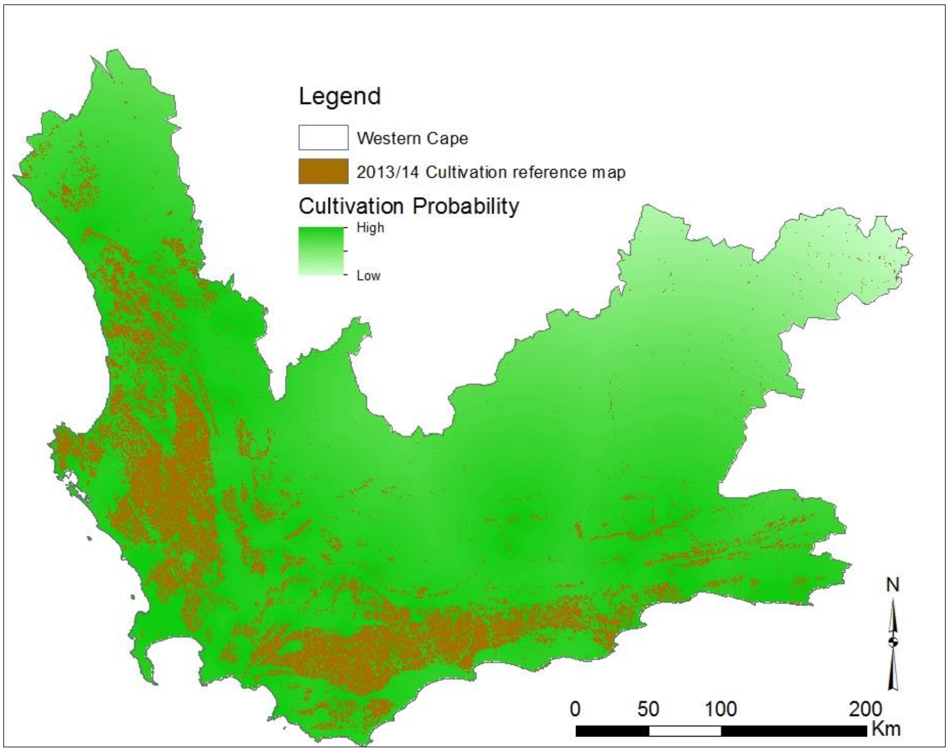


Figure 6-20: 2013/14 Cultivated reference map

6.10.2 Statistical Validation

The second approach conducted in validation of the simulated map was the statistical approach. The purpose of statistical validation was to find how well the 2013/2014 reference map agreed with the 2014 simulated map in terms of both quantity and location of cells in each category. The issues of quantity and location agreement in statistical validation of the Western Cape dyna-CLUE model were addressed using the VALIDATE module in IDRISI.

According to Pontius et al. (2008) statistical validation can involve examination of 1) the initial reference map at the first time period 2) the refence map at the subsequent time and 3) the simulated map of the subsequent time. Given these maps, the following three possible two-map comparisons can be undertaken in validation.

- Comparison between the reference map at the initial time with the reference map of the subsequent time-period. This type of comparison shows the actual observed LULC changes based on input reference maps and therefore gives a reflection of the dynamics of the landscape.
- Comparison between the reference map at the initial time with the simulated map indicates the model's predicted change which reflects the behaviour of the model.
- Comparison between the reference map at the second time-period with the simulated map characterises the accuracy of the prediction.

The third comparison was of main interest since it provided the accuracy of the simulated map. The VALIDATE module in IDRISI was therefore run for the entire study area with the 2013/14 LULC map as the reference map and the 2014 predicted LULC map as the simulated map. Outputs of the VALIDATE results were kappa statistics and components of agreement and disagreement which are explained in the following sections.

6.10.2.1 Kappa Statistics

Figure 6-21 shows the output graph generated by running VALIDATE using the 2013/14 LULC map as the reference map and the 2014 simulated map as the comparison map. As explained above, this comparison method is of main interest since it indicates the accuracy of the model at simulating LULC changes. The graph below shows traditional Kappa statistics, Kstandard, Kno and Klocation. Kstandard indicates agreement extent in terms of each category, Kno indicates overall agreement and is used to evaluate overall success of the simulation and Klocation shows agreement between reference and comparison map in terms of location of each category. Kappa statistics of 0 indicate an agreement due to chance and 1 indicates perfect agreement. The accuracies of the Western Cape model were Kno = 0.9001, Kstandard = 0.08528 and Klocation = 0.8623, indicating that the model is acceptable for future predictions.

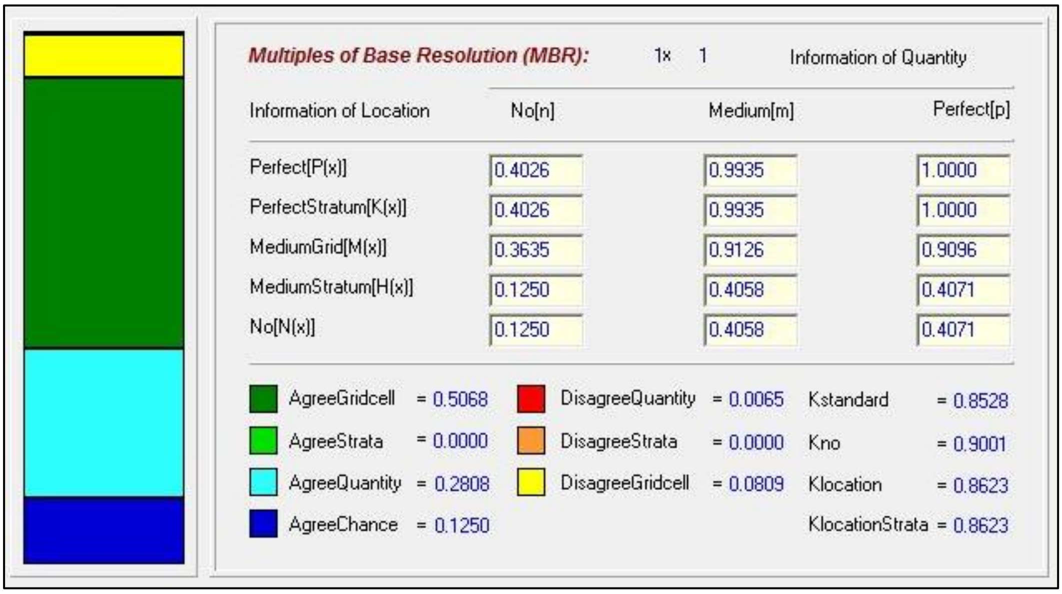


Figure 6-21: Validation results graph showing kappa statistics and components of agreement and disagreement for comparison of the reference 2013/14 map with the simulated 2014 map.

However after working with Kappa indices for over a decade, Pontius Jr and Millones (2011) discourage the use of the indices in model validation describing them as "useless, misleading, and/or flawed". Despite the wide application of Kappa indices by researchers in LULC change and remote sensing applications, this study follows the recommendations made by Pontius Jr and Millones (2011), disregards Kappa statistics and focuses on components of agreements and disagreements as the main statistical validation techniques.

6.10.2.2 Components of Agreement and Disagreement

The vertical axis of the graph in Figure 6-21 consists of components of agreement and disagreement, based on the similarities and differences between the reference 2013/14 map and the simulated map. The VALIDATE module computes seven statistical calculations which constitute the basis for components of agreement and disagreement (Pontius Jr and Chen, 2006). These seven calculations are denoted as N(**n**), N(**m**), H(**m**), M(**m**), K(**m**), P(**m**), and P(**p**); where the arguments in bold represent levels of information of quantity i.e.

1. **n** = no information
2. **m** = medium information
3. **p** = perfect information

The functions in capital letters indicate levels of information of location i.e.

1. N = no information
2. H = medium stratum-level information but no grid cell level information
3. M = medium stratum-level information and medium grid cell-level information
4. K = medium stratum-level information and perfect grid cell-level information
5. P = perfect stratum-level information and perfect grid cell-level information

A summary of the seven statistical calculations as described by Pontius Jr and Suedmeyer (2004) and Pontius Jr and Chen (2006) is presented in Table 6-9 below.

Table 6-9: Statistical calculations which constitute the basis for the components of agreement and disagreement (Pontius Jr and Suedmeyer, 2004) and (Pontius Jr and Chen, 2006)

Expression	**Description**
N(n)	Agreement due to chance.
N(m)	Agreement between reference map and a modified comparison map, where the modification is to randomize the locations of the raw cells within the comparison map.
H(m)	Agreement between the reference map and a modified comparison map, where the modification is to randomize the locations of the cells within each stratum of the comparison map.
M(m)	Agreement between the reference map and the unmodified comparison map. It is the proportion of grid cells classified correctly, which is the most commonly used measure of agreement between maps.
K(m)	Agreement between the reference map and a modified comparison map, where the modification is to rearrange as perfectly as possible the locations of cells within each stratum of the comparison map to maximize the agreement between the modified comparison map and the reference map.
P(m)	Agreement between the reference map and a modified comparison map, where the modification is to rearrange as perfectly as possible the locations of cells within the

	entire comparison map to maximize the agreement between the modified comparison map and the reference map.
P(p)	Perfect agreement, which is the agreement between the reference map and a map that has perfect information of both quantity and location. P(p) is always 1

6.10.2.3 Interpretation of Components

A summary of the components of agreement and disagreement expressed in terms of the seven statistical calculations explained above is presented in Table 6-10 below.

Table 6-10: Components of agreement and disagreement in terms of the seven statistical calculations (Pontius Jr and Suedmeyer, 2004) and (Pontius Jr and Chen, 2006)

Component	**Description**
Disagreement due to quantity	P(**p**)-P(**m**)
Disagreement at stratum level	P(**m**)-K(**m**)
Disagreement at grid cell level	K(**m**)-M(**m**)
Agreement at grid cell level	MAX [M(**m**)-H(**m**), 0]
Agreement at stratum level	MAX [H(**m**)-N(**m**), 0]
Agreement due to quantity	If MIN [N(**n**), N(**m**), H(**m**), M(**m**)] = N(**n**), then MIN [N(**m**)-N(**n**), H(**m**)-N(**n**), M(**m**)-N(**n**)], else 0
Agreement due to chance	MIN [N(**n**), N(**m**), H(**m**), M(**m**)]

Interpretation of components of disagreement are important in finding ways of improving the comparison map so that it agrees more with the reference map (Pontius Jr and Chen, 2006). Components of disagreement were therefore first interpreted before components of agreement. The disagreement due to quantity was calculated by subtracting P(m) from P(p) where, P(m) is agreement between the reference map and a modified comparison map and P(p) is perfect agreement as explained in Table 6-9. Based on the VALIDATE results presented in Figure 6-21, the disagreement due to quantity was 0.0065, which is close to 0. This value indicates the amount of disagreement associated with the fact that the 2014 simulated map failed to quantify each LULC category correctly. The disagreement at grid cell level was 0.0809. Grid level disagreement is the error associated with the fact that the 2014 simulated map failed to specify perfectly the correct locations of LULC categories. Strata disagreement was 0, which is logical since there was no strata image defined to include analysis by region. The overall disagreement was calculated by summation of quantity disagreement, grid level disagreement and strata disagreement, producing a total disagreement of 0.0874.

The VALIDATE module also calculated components of agreements which describe characteristics of agreement between the simulated 2014 map and reference map. The agreement due to chance was 0.1250. This agreement is achieved with no information on location or quantity and was used as the baseline to compare actual agreements. The agreement due to quantity was 0.2808 and this value is the additional agreement that the 2014 simulated map was accurate in terms of specifying the quantity of each LULC category. The agreement due to grid cell level location was 0.5068 (refer to Figure 6-21) and gives an indication of additional agreement that the 2014 simulated map was somewhat accurate in specification of grid cell level location of each LULC category. The overall agreement was calculated by adding agreement due to chance with agreement due to quantity and agreement due to grid cell level location. This overall agreement can also be deduced from the value of M(m) described in Table 6-9 as the agreement between the reference map and the unmodified comparison map. The overall agreement between the 2013/14 reference map and the 2014 simulated map was 0.9126, which indicates a good simulation.

Having performed visual and statistical analysis for the entire study area, analysis was also performed for a sample District Municipality. This was done to find out if the model was not biased since it is possible that agreements of quantity can be achieved due to a large persistence on the landscape. An example would be a 15% landscape change between the beginning and end time, which yields an 85% agreement for the entire study area. A model that simulates no change could therefore lead to an agreement of above 85%. The Cape Metro was chosen as the sample area to perform

VALIDATION since it is popular for having experienced rapid changes in LULC between 1990 and 2014. The results of the VALIDATION are illustrated in Figure 6-22 below and can be interpreted using Table 6-9 and Table 6-10.

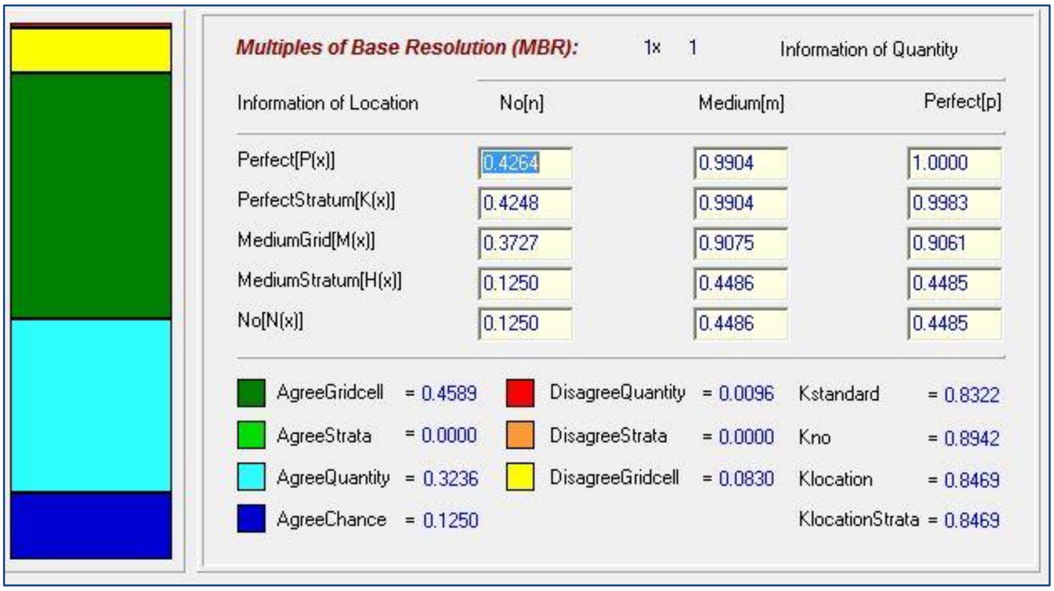


Figure 6-22: Validation results graph showing agreement and disagreement for comparison of the reference 2013/14 map with the simulated 2014 map for Cape Town Metro

The Kappa indices were ignored and validation results were based on the components of agreement and disagreement. The disagreement due to quantity was calculated by subtracting P(m) from P(p) where, P(m) is agreement between the reference map and a modified comparison map and P(p) is perfect agreement as explained in Table 6-9. Based on the VALIDATE results presented in Figure 6-22, the disagreement due to quantity was 0.0096, which is slightly more than the disagreement at a Provincial scale. This value indicates the amount of disagreement associated with the fact that the 2014 simulated map failed to quantify each LULC category correctly at District Level. The disagreement at grid cell level was 0.0830. Grid level disagreement is the error associated with the fact that the 2014 simulated map failed to specify perfectly the correct locations of LULC categories. Strata disagreement was 0, which is logical since there was no strata image defined to include analysis by region. The overall disagreement was calculated by summation of quantity disagreement, grid level disagreement and strata disagreement, producing a total disagreement of 0.0926.

The overall agreement at District level was calculated by adding agreement due to chance with agreement due to quantity and agreement due to grid cell level location. This gave a value of 0.9075 which was not very different from the overall agreement at Provincial level of 0.9126. Based both the statistical and visual validation results it was concluded that the simulation maps produced by Dyna-CLUE were in good agreement with the reference maps. This proves that the model is valid and can be used to predict future LULC patterns in the study area. An ideal model for predicting future LULC patterns can therefore be implemented by incorporating predicted figures of LULC derived from Markov as explained in Section 6.8, together with driving factors and relevant spatial policies such as the Urban and Coastal Edge Policy. Future LULC predictions were not included in this study due to time constraints since this would require obtaining more accurate datasets and extensive data editing. The validation above however proves that LULC models are applicable in a South African context and can be used to guide planners to effectively gauge the impacts that planning policies and other driving factors might have on future LULC patterns in the Western Cape Province.

7. CONCLUSIONS

The purpose of this study was to investigate the suitability of land use models in simulating LULC changes and supporting planning at a Provincial scale in South Africa. This Chapter provides conclusions of the research based on the findings from the previous Chapters. The sections below explain how the research objectives were achieved.

7.1 RESULTS DISCUSSION

Objective 1: To quantify changes in land use and land cover in the Western Cape Province between 1990 and 2014.

This was achieved by using GIS software to analyse LULC maps derived from remote sensing imagery. The LULC quantitative analysis results indicate that there were significant LULC changes between 1990 and 2014 characterised by declines in forest plantations, grasslands, wetlands, and barren lands. In contrast, urban/built up, mines and quarries, water bodies, woodlands, thicket and shrubland classes exhibited increases. Mines and quarries had the highest increase (52.82%) mostly due to the demand of sand from the construction industry. The highest loss was in plantations (-32.41%), owing to the government's exit policy which saw the decommissioning of plantations.

The LULC change results also show that there was a provincial increase in built-up areas with about 12% and 1.03% increase in cultivation. However, analyses of individual district municipalities LULC changes reveal that the increase in built-up areas was concentrated in Cape Metropolitan area and the adjacent Cape Winelands at the expense of cultivated land, shrubland and low fynbos and plantations. The increase in urban areas was due to rising infrastructure demands generated by population growth and the tourism industry. Explanations on the causes of changes in LULC were addressed by Objective 2 explained below.

Objective 2: To determine driving factors of land use change in the Western Cape Province.

CONCLUSIONS

The determination of driving factors of land use change in the Western Cape Province was accomplished by interviewing municipality town planners to obtain deeper insights on LULC change dynamics and adapting of the DSPIR framework. The findings indicate that LULC changes in the Western Cape Province are a result of diverse interrelated factors that operate at different scales. At a provincial scale, changes emerge from political factors through legislation and policies aimed at poverty alleviation, promoting access to basic services, reducing inequalities and promoting economic growth.

Patterns of LULC changes are consistent with nodes of economic growth which occur in the Cape Metropolitan, Eden and West Coast District Municipalities. The agriculture, tourism and industry sectors in these municipalities attract foreign investments leading to net in-migration from other provinces. Migration coupled with natural increase results in population growth which increases the amount and intensity of pressure exerted on resources and consequently changes the state of land.

Driving factors of LULC change were grouped into proximate and underlying causes as proposed by Geist and Lambin (2002). Based on interviews and document analysis, proximate causes were identified as infrastructure, agriculture and forestry changes and underlying causes as political, demographic, economic, technological and cultural factors. To understand these drivers, the DPSIR framework was adapted to show how driving factors lead to human activities which exert pressure on resources resulting in various states of the environment which have significant impacts and require responses. Strategies and policies based on responses to major drivers of LULC and their impacts are therefore recommended to avoid undesirable impacts of changes in LULC.

The results of Objectives 1 and 2 were compiled into a conference paper which was peer reviewed and presented at the 7th Planning Africa Conference 2016-Making sense of the future: Disruption and Reinvention. The session audience understood the project and gave positive feedback on the results of the LULC change assessment.

Objective 3: To explore current regional land use change models and select a land use change model which can be adapted to the Western Cape Province.

This objective was achieved by conducting a literature review on land use change models and selecting a model which could be adapted in the study area. Modelling approaches were combined into hybrid models. Two hybrid models which were shortlisted were Cellular Automata (CA) and Markov which was referred to as CA_Markov; and Dyna-CLUE and Markov. These models were shortlisted based on a multitude of publications and literature which suggests their wide applications in various topics in different regions and countries. The shortlisted hybrid models were further evaluated based on selection criteria which focused on the models relevance to the study area, linkage potential to other models or software, transferability, user friendliness, data requirements and cost. CA_Markov had very attractive advantages but could not be used due to unavailability of input LULC datasets. Dyna-CLUE model with Markov concepts was the hybrid model that was implemented in the Western Cape Province. Model validation was performed using both visual and statistical analysis and the results indicated that Dyna-CLUE and Markov had the ability to simulate land use changes in the study area. Markov was used to predict future LULC demands and these figures together with relevant driving factors can be used to predict future land use patterns. Based on this research it can therefore be concluded that, “Yes, regional models that can be adapted to a South African context exist and can be used to simulate LULC change and hence assist as tools to support Provincial planning.

7.2 RECOMMENDATIONS

This study proves that it is indeed possible to model LULC changes at a Provincial scale in South Africa. The results of the integration of Dyna-CLUE and Markov indicate that LULC patterns can be simulated based on knowledge of driving factors, land demand calculated from historical LULC and neighbourhood characteristics. Dyna-CLUE model with Markov concepts can be used to support future land use planning by incorporating policies which influence future land use e.g. The Western Cape Urban and Coastal Edge Policy. Further improvements to the model can also be made by using land use plans as inputs to enhance simulation results.

South Africa is a country where data sharing is still evolving. The unavailability of datasets limits the implementation of models as access is restricted since data is usually only commercially available. Open data is therefore recommended to both government and private institutions in order to support and encourage research and developments and to maximise data benefits to society.

Implementation of CA_Markov model was not possible due to the unavailability of input LULC datasets at shorter time intervals. South Africa generally lacks consistent and comparable LULC datasets at both local and regional levels. The Chief Directorate: National Geospatial Information (CD:NGI) of The Department of Rural Development and Land Reform is still in the process of conducting workshops with various organisations and government departments to develop a National LULC Classification System and Methodology. The purpose of this initiative is to ensure that land use datasets created at local, district and national levels are standardised and compatible. The author of this dissertation attended one of the workshops and observed that local municipality officials were not well represented though they are the key stakeholders in this process. As mentioned in Section 2.2.2.1, control of land in South Africa is at municipality level, therefore it is recommended that the NGI actively engages local municipalities to ensure successful development of standards and methodologies of National LULC Classification System.

7.3 FUTURE WORK

Future work on LULC change modelling using Dyna-CLUE model with Markov concepts in the Western Cape Province could focus on extending the model to perform future predictions. This can be achieved with the availability of LULC datasets at shorter intervals and more accurate driving factor data at a Provincial scale. Replication of this model in other Provinces is possible upon collection of relevant driving factors and the simulation results can be compared with other regions to find differences and similarities in LULC patterns.

8. APPENDIXES

8.1 Appendix 1: Land use models adapted from Agarwal et al. (2002)

Model Name/Citation	Model Type	Variables	Model Strength
1. General Ecosystem Model (GEM) (Fitz et al., 1996)	Dynamic systems model	Captures feedback among abiotic and biotic ecosystem components	Spatially dependent model, Can adapt resolution, extent, and time step to match the process being modelled
2. Patuxent Landscape Model (PLM) (Voinov et al., 1999)	Dynamic systems model	Predicts fundamental ecological processes and land-use patterns at the watershed level	In addition to the strengths of the GEM, the PLM incorporates several other variables that add to its applicability to assess the impacts of land management and best management practices
3. CLUE-CR (Conversion of Land Use and Its Effects – Costa Rica) (Veldkamp and Fresco, 1996)	Discrete finite state model	Simulates top-down and bottom-up effects of land-use change in Costa Rica	Multiple scales - local, regional, and national. Uses the outcome of a nested analysis, scale dependent land-use/land-cover linear regressions as model input, which is reproducible, unlike a specific calibration exercise
4. Area base model (Hardie and Parks, 1997)	Area base model, using a modified multinomial logit model	Predicts land-use proportions at county level	Uses publicly available data Incorporates economic (rent), and landowner characteristics (age, income) and population density Incorporates the impact of land heterogeneity
5. Mertens and Lambin (1997)	Univariate spatial models	Frequency of deforestation	Presents a strategy for modelling deforestation by proposing a typology of deforestation patterns
6. Chomitz and Gray (1996)	Econometric (multinomial logit) model	Predicts land use, aggregated in three classes: Natural vegetation, Semi-subsistence agriculture, Commercial farming	Used spatially disaggregated information to calculate an integrated distance measure based on terrain and presence of roads
7. Gilruth et al. (1995)	Spatial dynamic model	Predicts sites used for shifting cultivation in terms of topography and proximity to population centers	Replicable Tries to mimic expansion of cultivation over time
8. Wood et al. 1997	Spatial Markov model	Land-use change	Investigating Markov variations, which relax strict assumptions associated with the Markov approach

9. CUF (California Urban Futures) (Landis et al., 1998a)	Spatial simulation	Explains land use in a metropolitan setting, in terms of demand (population growth) and supply of land (underdeveloped land available for redevelopment	Underlying theory of parcel allocation by population growth projections and price, and incorporation of incentives for intermediaries developers, a great strength
10. LUCAS (Land-Use Change Analysis System) (Berry et al., 1996)	Spatial stochastic model	Transition probability matrix (TMP) (of change in land cover) Module 2 simulates the landscape change	Model shows process (the TPM), output (new land-use map), and impact (on species habitat), all in one, which is rare and commendable
11. Wear et al. 1998	Simple log weights	Predicts area of timberland adjusted for population density	Simple and powerful indicator of forest sustainability, of the impact of human settlement decisions on one forest function --its role as timberland
12. Wear et al. (1999)	Logit model	Predicts the probability of land being classified as potential timberland	Includes several environmental variables
13. Swallow et al. (1997)	Dynamic model	Simulates an optimal harvest sequence	The long time horizon, and the annual checking of present values under alternate possible states of the forest makes it a useful forest management tool for maximizing multiple-use values
14. NELUP (O'Callaghan, 1996)	General systems framework Economic component uses a recursive linear planning model	Explains patterns of agricultural and forestry land use under different scenarios	Uses land cover to link market forces, hydrology, and ecology in a environmental model of land use
15. NELUP - Extension (Oglethorpe, 1995)	Linear planning model at farm level	Maximizes income Profit is the dependent variable	Detailed farm-level model, with extensive calibration
16. FASOM (Forest and Agriculture Sector Optimization Model) (Adams et al., 1996)	Dynamic, nonlinear, price endogenous, mathematical programming model	Allocation of land in the forest and agricultural sectors	Incorporates both agriculture and forest land uses. Price of products and land is endogenous
17. CURBA (California Urban and Biodiversity Analysis Model) (Landis et al., 1998b)	Overlay of GIS layers with statistical urban growth projections	The interaction among the probabilities of urbanization, its interaction with habitat type and extent, and, impacts of policy changes on the two	Increases understanding of factors behind recent urbanization patterns
18. Clarke and Gaydos (1998)	Cellular automata model	Change in urban areas over time	Allows each cell to act independently according to rules, analogous to city expansion as a result of hundreds of small decisions

8.2 Appendix 2: South Africa urban modelling initiatives adapted from (Wray et al, 2013)

Model Name/Citation	Model Type	Description	Components
Shoko and Smit (2013)	ABM	Patterns and trends in land occupation change over time in a Cape Town informal settlement.	Physical and socio-economic factors
(Le Roux, 2012)	Cellular automata (Dyna-Clue)	An investigation into the consequences of the CoJ's current planning policies using the cellular automata Dyna-Clue mode.	Spatial data required include: land use maps, locational driving factors, spatial policies and restrictions. Non-spatial data inputs include: policy scenarios, regional driving factors such as macroeconomic and demographic factors
(Abutaleb et al., 2013)	Cellular automata	Cellular automata model by Dr Abu-Taleb to predict urban growth with the CoJ. The model will monitor the urban growth from 1995 to 2010, followed by an urban growth simulation to the year 2030.	Satellite imagery from Landsat for the years 1995 and 2010 used to generate land use/cover. IDRISI software utilised to combine the land use/cover, road network and slope variables to model the urban growth.
GITMC (CSIR, 2012b)	Econometric/microsimulation/ ABM	CSIR, in conjunction with UP, appointed by DRT to establish the GITMC with the aim of coordinating and integrating transport modelling for local and provincial governments in Gauteng	GITMC will build on the data and modelling created in the CSIR UrbanSim and MATSim simulation project to produce urban growth scenarios based on different infrastructure initiatives.
CSIR UrbanSim (CSIR, 2011; CSIR, 2012a; Waldeck, 2007)	Econometric/microsimulation/ ABM	Simulates urban growth 30 years into the future in eThekwini, Nelson Mandela Bay, Johannesburg and Gauteng, based on current spatial policy and investment decision	UrbanSim: choices of households and businesses in relation to property and services, developers as suppliers of services, and government provision of infrastructure and services.

8.3 Appendix 3: Interview guide

DRIVERS OF LULC CHANGE INTERVIEW GUIDE QUESTIONS

1. What are the most significant LULC changes that have occurred in this municipality in the last 20years?
2. Where did these changes occur and why in those particular locations?
3. When did the changes occur and why then?
4. Who is responsible for these changes?
5. What are the main reasons for these changes in LULC?
6. Have government policies played a role in LULC change?
7. What are the potential economic, social and environmental impacts of LULC changes?
8. What measures are being implemented or considered by your municipality to address these potential impacts?
9. Does your municipality use any population or economic growth projection tools; if so, is it in its own capacity/ consultants are hired to do it?
10. What do you think this municipality will look like in 10years?
11. What are the major factors affecting future LULC?

8.4 Appendix 4: Dyna-CLUE main parameters

Line	Description Format	AS-IS Scenario	Policy-Led Scenario
1	Number of land use types	7	7
2	Number of regions	1	1
3	Max. number of independent variables in a regression equation	2	2
4	Total number of driving factors	5	5
5	Number of rows	480	480
6	Number of columns	620	620
7	Cell area	100	100
8	xll coordinate	-382749	-382749
9	yll coordinate	-3876795	-3876795
10	Number coding of the land use types	0 1 2 3 4 5 6	0 1 2 3 4 5 6
11	Codes for conversion elasticities	0.1 0.1 0.7 0.1 0.4 0.7 0.6	0.1 0.1 0.7 0.1 0.4 0.7 0.6
12	Iteration variables	0 3 100	0 3 100
13	Start and end year of simulations	1990 2014	1990 2014
14	Number and coding of explanatory factors that change every year	0	0
15	Output file choice 1, 0, -2 or 2	3	3
16	Region specific regression choice 0, 1 or 2	0	0
17	Initialization of land use history 0, 1 or 2	1 5	1 5
18	Neighbourhood calculation choice 0, 1 or 2	0	0
19	Location specific preference additions	1 0 0 0 0.1 0 0 1	1 0 0 0 0.1 0 0 0.3
		0.05	0.05

9. REFERENCE LIST

Abutaleb, K., Taiwo, O.-J., Ahmed, F. & Ngie, A. 2013. Modeling urban change using cellular automata: the case study of Johannesburg, South Africa. *Life in a Changing Urban Landscape,* 1**,** 64.

Adams, D. M., Alig, R. J., Callaway, J. M., Winnett, S. M. & McCarl, B. A. 1996. *The forest and agricultural sector optimization model (FASOM): model structure and policy applications*, DIANE Publishing.

Adhikari, S. & Southworth, J. 2012. Simulating forest cover changes of Bannerghatta National Park based on a CA-Markov model: a remote sensing approach. *Remote Sensing,* 4**,** 3215-3243.

Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P. & Schweik, C. M. 2002. A review and assessment of land-use change models: dynamics of space, time, and human choice. *Gen. Tech. Rep. NE-297. Newton Square, PA. U.S. Department of Agriculture, Forest Service, Northeastern Research Station***,** 61.

Annum, D. G. 2015. *Research Instrument for data collection* [Online]. Available: http://campus.educadium.com/newmediart/file.php/1/giilmadstore/UgradResearch/ThesisWrit4all/files/notes/resInstr.pdf [Accessed 2 February 2016].

Arial, A., Fagan, C. & Zimmermann, W. 2011. Corruption in the Land Sector. IT Working Paper 04/2011, FAO and Transparency International.

Arsanjani, J. J., Helbich, M., Kainz, W. & Boloorani, A. D. 2013. Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion. *International Journal of Applied Earth Observation and Geoinformation,* 21**,** 265-275.

Barbier, E. B. 1997. The economic determinants of land degradation in developing countries. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 352**,** 891-899.

Batty, M. (2008) Fifty years of urban modelling: macro-statics to micro-dynamics. In: ALBEVERIO, S., ANDREY, D., GIORDANO, P, VANCHERI, A. (Eds.), The dynamics of complex urban system. PhysicaVerlag, Heidelberg, 1-20.

Batty, M. & Howes, D. (2001) Predicting temporal patterns in urban development from remote imagery. In: DONNAY, J.P., BARNSLEY, M.J., LONGLEY, P.A. (Eds.) Remote sensing and urban analysis. Taylor and Francis, London and New York, 185-204.

Berrisford, S. & De Visser, J. 2012. Important Legal Issues for Provincial Legislation dealing with Spatial Planning and Land Use: A Discussion Document. South African Cities Network (SACN).

Berry, M. W., Hazen, B. C., MacIntyre, R. L. & Flamm, R. O. 1996. LUCAS: a system for modeling land-use change. *IEEE Computational Science and Engineering,* 3**,** 24-35.

Bourne, L. S. 1971. Physical adjustment processes and land use succession: a conceptual review and central city example. *Economic Geography,* 47**,** 1-15.

Briassoulis, H. 2000. *Analysis of land use change: theoretical and modeling approaches. Web Book of Regional Science, Regional Research Institute, West Virginia University* [Online]. Available:

http://www.rri.wvu.edu/WebBook/Briassoulis/contents.htm [Accessed 20 January 2015].

Burnham, B. O. 1973. Markov intertemporal land use simulation model. *Southern Journal of Agricultural Economics,* 5**,** 253-258.

Castella, J.-C. & Verburg, P. H. 2007. Combination of process-oriented and pattern-oriented models of land-use change in a mountain area of Vietnam. *Ecological modelling,* 202**,** 410-420.

Chomitz, K. M. & Gray, D. A. 1996. Roads, land use, and deforestation: a spatial model applied to Belize. *The World Bank Economic Review,* 10**,** 487-512.

Clark, B. M., Massie, V., Laird, M., Biccard, A., Hutchings, K., Harmer, R., Brown, E., Dun, a. O. O., Makunga, M. & Turpie, J. 2015. The State of Saldanha Bay and Langebaan Lagoon 2015. Anchor Environmental Consultants.

Clarke, K. C. & Gaydos, L. J. 1998. Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. *International journal of geographical information science,* 12**,** 699-714.

Coolen, A. 2009. Markov Chains. Compact Lecture Notes and Exercises. Department of Mathematics. King's College London.

Cooper, A. K. 2014. Meta-language for land-use classification systems. *Presentation at the Workshop on the Development of an Interim Framework for the National Land Use Classification Standard, Methodology and Symbology for South Africa.* Protea Hotel OR Tambo International Airport, Kempton Park.

Cooper, A. K., Van Huyssteen, E., Das, S., Coetzee, M. & Mans, G. 2014. Assessment of spatial data infrastructures. *Town and Regional Planning,* 64**,** 65-75.

Corruption Watch. 2015. *What is corruption : Our definition of corruption* [Online]. Available: http://www.corruptionwatch.org.za/learn-about-corruption/what-is-corruption/our-definition-of-corruption/ [Accessed 15 November 2015].

Costanza, R. & Matthias, R. 1998. Using dynamic modeling to scope environmental problems and build consensus. *Environmental management,* 22**,** 183-195.

DAFF 2015. 2015/16 to 2019/20 Strategic Plan. *In:* DEPARTMENT OF AGRICULTURE FORESTRY AND FISHERIES (ed.). Pretoria.

De Beer, M. C., Cori, H., Längin, D. W. & Theron, F. 2014. The socioeconomic impact of the phasing out of plantations in the Western and Southern Cape regions of South Africa. *Southern Forests: a Journal of Forest Science,* 76**,** 57-64.

De La Barra, T. 2001. Integrated land use and transport modeling: the TRANUS experience. *Planning Support Systems: Integrating Geographic Information Systems, Models and Visualization Tools Eds RK Brail, RE Klosterman (ESRI Press, Redlands, CA) pp***,** 129-156.

De Smith, M. J., Goodchild, M. F. & Longley, P. 2007. *Geospatial analysis: a comprehensive guide to principles, techniques and software tools*, Troubador Publishing Ltd.

Deal, B. 2001. Ecological urban dynamics: the convergence of spatial modelling and sustainability. *Building Research & Information,* 29**,** 381-393.

DEAT 2008. A National Framework for Sustainable Development in South Africa

DHS 2010. An Evaluation of Existing Data Sources for Possible Consideration as Base Figures in the Calculation of the Housing Backlog in Western Cape Municipalities. Western Cape Provincial Government.

Eastman, J. 2012. IDRISI Selva Tutorial. *Idrisi Production, Clark Labs-Clark University*.

Ellis, E. & Pontius, R. 2007. Land-use and land-cover change. *Encyclopedia of earth*.

EPA 2000. A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns. *US Environmental Protection Agency, Office of Research and Development, Cincinnati, OH*, 21-26.

ETU. 2007. *The three spheres of Government* [Online]. Available: http://www.etu.org.za/toolbox/docs/govern/spheres.html [Accessed 21 September 2015].

Evans, T., Ostrom, E. & Gibson, C. 2003. Scaling issues in the social sciences. *Scaling in Integrated Assessment*, 75-106.

Ewing, K. & Mammon, N. 2008. *Cape Town DenCity Towards Sustainable Urban Form* [Online]. Available: http://planning.cityenergy.org.za/Pdf_files/south_africa_cities/city_of_capetown/Cape_Town_DenCity_Towards_Sustainable_Urban_Form.pdf [Accessed 26 September 2015].

Fairbanks, DHK., Thompson, MW., Vink, DE., Newby, TS., Van den Berg, HM & Everard, DA 2000, The South African Land-Cover Characteristics Database: A synopsis of the landscape. *SA Journal of Science*, vol. 96, no 2, pp. 69-82.

Fauvelle-Aymar, C. 2014. Migration and employment in South Africa : An econometric analysis of domestic and international migrants (QLFS (Q3) 2012). Johannesburg: African Centre for Migration and Society, University of Witwatersrand.

Fischer, G., van Velthuizen, H., Shah, M. & Nachtergaele, F. 2002. *Global agro-ecological assessment for agriculture in the 21st century: methodology and results*.

Fitz, H., DeBellevue, E., Costanza, R., Boumans, R., Maxwell, T., Wainger, L. & Sklar, F. 1996. Development of a general ecosystem model for a range of scales and ecosystems. *Ecological modelling,* 88**,** 263-295.

Forbes J, Moonsammy S, Patel Y, Moodley S, Mupariwa M. August 2011. "An introduction to municipal planning within South Africa, Version 1". Municipal Planning Capacity Enhancement Partnership of SALGA, SAPI and MILE. Durban, South Africa.

Gabrielsen, P. & Bosch, P. 2003. Environmental indicators: typology and use in reporting. *EEA, Copenhagen*.

Geist, H. J. & Lambin, E. F. 2002. Proximate Causes and Underlying Driving Forces of Tropical Deforestation *BioScience,* 52**,** 143-150.

GEOTERRAIMAGE 2014. 2013-2014 South African National Land-Cover Dataset. Data User Report and Metadata.

Gibson, D., Paterson, G., Newby, T., Hoffman, T., Laker, M., Henderson, C. & Pretorius, R. 2005. NATIONAL STATE OF THE ENVIRONMENT PROJECT.

Gilruth, P. T., Marsh, S. E. & Itami, R. 1995. A dynamic spatial model of shifting cultivation in the highlands of Guinea, West Africa. *Ecological modelling,* 79**,** 179-197.

Hardie, I. W. & Parks, P. J. 1997. Land use with heterogeneous land quality: an application of an area base model. *American Journal of Agricultural Economics,* 79**,** 299-310.

Hardoon, D. & Heinrich, F. 2013. Global Corruption Barometer 2013. Transparency International.

Heistermann, M., Müller, C. & Ronneberger, K. 2006. Land in sight?: Achievements, deficits and potentials of continental to global scale land-use modeling. *Agriculture, Ecosystems & Environment,* 114**,** 141-158.

Hoffman, M. T. 2014. Changing Patterns of Rural Land Use and Land Cover in South Africa and their Implications for Land Reform. *Journal of Southern African Studies,* 40**,** 707-725.

Hoffman, M. T. & Todd, S. 2000. A national review of land degradation in South Africa: the influence of biophysical and socio-economic factors. *Journal of Southern African Studies,* 26**,** 743-758.

Iacono, M., Levinson, D., El-Geneidy, A. & Wasfi, R. A Markov Chain Model of Land Use Change in the Twin Cities, 1958-2005. Proceeding of the 10th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, 2012. Citeseer, 10.345-350.2012.

Ibitayo, O. 2008. *NIMBYism. The Encyclopedia of Earth* [Online]. Available: http://www.eoearth.org/view/article/154752 [Accessed 20 January 2015].

Jantz, C. A. & Goetz, S. J. 2005. Analysis of scale dependencies in an urban land-use-change model. *International Journal of Geographical Information Science,* 19**,** 217-241.

Kok, P. & Collinson, M. 2006. Migration and Urbanisation in South Africa. Statistics South Africa. Pretoria. ISBN 0-621-36509-2.

Kristensen, P. 2004. *The DPSIR framework. 27-29 September 2004 workshop on a comprehensive/detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya* [Online]. Available: http://wwz.ifremer.fr/dce/content/download/69291/913220/file/DPSIR.pdf [Accessed 2 February 2016].

Kumar, R. 2009. Research methodology: a step-by-step guide for beginners. *Investigación Bibliotecológica,* 13.

Kutter, A. & Neely, C. 1999. The Future of Our Land: Facing the challenge. *FAO and UNEP, Rome*.

Lambin, E. F. & Geist, H. J. 2007. *Causes of land-use and land-cover change* [Online]. Available: http://www.eoearth.org/view/article/51cbed2f7896bb431f6905af [Accessed 20 January 2015].

Lambin, E. F., Rounsevell, M. & Geist, H. 2000. Are agricultural land-use models able to predict changes in land-use intensity? *Agriculture, Ecosystems & Environment,* 82**,** 321-331.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G. & Folke, C. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global environmental change,* 11**,** 261-269.

Landis, J., Zhang, M. & Zook, M. 1998a. CUF II: The Second Generation of the California Urban Futures Model. Berkeley, CA: UC Transportation Center, University of California.

Landis, J. D., Monzon, J. P., Reilly, M. & Cogan, C. 1998b. Development and pilot application of the California urban and biodiversity analysis (CURBA) Model.

Lautso, K. 2003. The SPARTACUS system for defining and analysing sustainable urban land use and transport policies. *Planning support systems in practice.* Springer.

Le Roux, A. 2012. *Quantifying the spatial implications of future land use policies in South Africa: reshaping a city through land use modelling.* University of Utrecht, The Netherlands.

Le Roux, A., Mokilane, P., McKelly, D., Van Huyssteen, E. & Mans, G. 15 March 2015. Technical input requirements to use the DYNA-CLUE model: The Frances Baard-Clue application. Prepared by CSIR for the Department of Rural Development and Land Reform.

Lesschen, J., Kok, K., Verburg, P. & Cammeraat, L. 2007. Identification of vulnerable areas for gully erosion under different scenarios of land abandonment in Southeast Spain. *Catena,* 71**,** 110-121.

Liu, Y. 2008. *Modelling urban development with geographical information systems and cellular automata*, CRC Press.

MACCSAND PTY Ltd AND OTHERS V. CITY OF CAPE TOWN AND OTHERS (2010. Western Cape High Court.

Maes, C. 2013. An introduction to theory of Markov processes mostly for physics students. KU Leuven, Belgium.

Maree, G. & Van Weele, G. 2013. State of Environment Outlook Report for the Western Cape Province.

Mertens, B. & Lambin, E. F. 1997. Spatial modeling of deforestation in southern Cameroon: Spatial disaggregation of diverse deforestation processes. *Applied Geography,* 17**,** 143-162.

Mishra, V. N. & Rai, P. K. 2016. A remote sensing aided multi-layer perceptron-Markov chain analysis for land use and land cover change prediction in Patna district (Bihar), India. *Arabian Journal of Geosciences,* 9**,** 1-18.

Mobaied, S., Riera, B., Lalanne, A., Baguette, M. & Machon, N. 2011. The use of diachronic spatial approaches and predictive modelling to study the vegetation dynamics of a managed heathland. *Biodiversity and conservation,* 20**,** 73-88.

Muller, M. R. & Middleton, J. 1994. A Markov model of land-use change dynamics in the Niagara Region, Ontario, Canada. *Landscape Ecology,* 9**,** 151-157.

National Research Council 2014. *Advancing Land Change Modeling:: Opportunities and Research Requirements*, Washington, DC: National Academies Press.

Ngcofe, L. & Thompson, M. (2015). *The status of land cover mapping in South Africa* [Online]. Available: http://www.ee.co.za/article/status-land-cover-mapping-south-africa-1994-2015.html. [Accessed 2 February 2015].

O'Callaghan, J. 1996. *Land use: the interaction of economics, ecology and hydrology*, Springer Science & Business Media.

Oglethorpe, D. 1995. Farm-level economic modelling within a river catchment decision support system. *Journal of Environmental Planning and Management,* 38**,** 93-106.

Palmer, D., Fricska, S. & Wehrmann, B. 2009. Towards improved land governance. *Food and Agriculture Organization of the United Nations, United Nations Human Settlements Programme, Rome, Italy*.

Parker, D. C., Berger, T. & Manson, S. M. Agent-based models of land-use and land-cover change. Proc. of an International Workshop, 2002. 4-7.

Pence, G. Q. 2014. Western Cape Biodiversity Framework 2014 Status Update: Critical Biodiversity Areas of the Western Cape. *Unpublished CapeNature project report. Cape Town, South Africa*.

Polzer, T. 2008. South African government and civil society responses to Zimbabwean migration. *South African Migration Project,* 22**,** 1-24.

Pontius Jr, R. G. & Chen, H. 2006. GEOMOD modeling. *Clark University*.

Pontius Jr, R. G. & Millones, M. 2011. Death to Kappa: birth of quantity disagreement and allocation disagreement for accuracy assessment. *International Journal of Remote Sensing,* 32**,** 4407-4429.

Pontius Jr, R. G. & Suedmeyer, B. 2004. Components of agreement between categorical maps at multiple resolutions. *Remote sensing and GIS accuracy assessment***,** 233-251.

Pontius, R. G., Boersma, W., Castella, J.-C., Clarke, K., de Nijs, T., Dietzel, C., Duan, Z., Fotsing, E., Goldstein, N. & Kok, K. 2008. Comparing the input, output, and validation maps for several models of land change. *The Annals of Regional Science,* 42**,** 11-37.

Pontius, R. G., Cornell, J. D. & Hall, C. A. 2001. Modeling the spatial pattern of land-use change with GEOMOD2: application and validation for Costa Rica. *Agriculture, Ecosystems & Environment,* 85**,** 191-203.

Putman, S. H. 2013. *Integrated Urban Models Volume 1: Policy Analysis of Transportation and Land Use (RLE: The City)*, Routledge.

Robinson, D. T., Brown, D. G., Parker, D. C., Schreinemachers, P., Janssen, M. A., Huigen, M., Wittmer, H., Gotts, N., Promburom, P. & Irwin, E. 2007. Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science,* 2**,** 31-55.

Rubin, M. 2008. LAND MANAGEMENT AND DEMOCRATIC GOVERNANCE IN THE CITY OF JOHANNESBURG. Urban Landmark.

SANBI 2005. Mining Potential.

Shiffman, D. 2012. *The nature of code: Simulating Natural Systems with Processing*, Version 1.0, self-published. ISBN 978-0985930806.

Shirley, L. J. & Battaglia, L. L. 2008. Projecting fine resolution land-cover dynamics for a rapidly changing terrestrial-aquatic transition in Terrebonne Basin, Louisiana, USA. *Journal of Coastal Research***,** 1545-1554.

Shoko, M. & Smit, J. 2013. Use of agent based modelling to investigate the dynamics of slum growth. *South African Journal of Geomatics,* 2**,** 54-67.

Silva, E. & Wu, N. 2012. Surveying models in urban land studies. *Journal of Planning Literature,* 27**,** 139-152.

Silva, E. A., Ahern, J. & Wileden, J. 2008. Strategies for landscape ecology: An application using cellular automata models. *Progress in Planning,* 70**,** 133-177.

Silva, E. A. & Clarke, K. C. 2002. Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal. *Computers, Environment and Urban Systems,* 26**,** 525-552.

Silva, E. A. & Wu, N. DG-ABC: An Integrated Multi-Agent and Cellular Automata Urban Growth Model.

Sims, D. & Sombroek , W. G. 1997. Negotiating a sustainable future for or land-Structural and institutional guidelines for land resource management in the 21st Century.

Smeets, E. & Weterings, R. 1999. *Environmental indicators: Typology and overview*, European Environment Agency Copenhagen.

Soares-Filho, B. S., Cerqueira, G. C. & Pennachin, C. L. 2002. DINAMICA—a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. *Ecological modelling,* 154**,** 217-235.

South Africa 1995. Development Facilitation Act No. 67 of 1995 Pretoria.

South Africa 1996. Constitution of the Republic of South Africa Act No. 108 of 1996.

South Africa 2000. Municipal Systems Act No. 32 of 2000. Cape Town: Government Gazette.

South Africa 2013. Spatial Planning and Land Use Management Act No.16 of 2013. Cape Town: Government Gazette.

South African Cities Network. 2014. *Sustainable Cities* [Online]. Available: http://sacitiesnetwork.co.za/wp-content/uploads/2014/06/chapter3_the_built_environment.pdf [Accessed 9 September 2015].

Spinks, C. 2001. *A New Apartheid?: Urban Spatiality,(fear Of) Crime, and Segregation in Cape Town, South Africa*, London School of Economics and Political Science, Development Studies Inst.

Stats SA 2007. Community Survey: Revised Version. Pretoria: Statistics South Africa.

Stats SA 2013. General household survey 2013. Pretoria: Statistics South Africa.

Stats SA 2014. Mid-year population estimates. Statistics South Africa.

Swallow, S. K., Talukdar, P. & Wear, D. N. 1997. Spatial and temporal specialization in forest ecosystem management under sole ownership. *American Journal of Agricultural Economics,* 79**,** 311-326.

Tizora, P., Le Roux, A., Cooper, A. K. & Mans, G. Land Use and Land Cover Change in the Western Cape Province: Quantification of Changes & Understanding of Driving Factors. 7th Planning Africa Conference 2016-Making sense of the future: Disruption and Reinvention, 2016 Sandton Convention Centre, Johannesburg, South Africa. South Africa Planning Institute (SAPI).

Tobler, W. R. 1970. A computer movie simulating urban growth in the Detroit region. *Economic geography,* 46**,** 234-240.

Todes, A., Kok, P., Wentzel, M., Van Zyl, J. & Cross, C. Contemporary South African urbanization dynamics. Urban forum, 2010. Springer, 331-348.

Transparency International. 2014. *Corruption Perceptions Index* [Online]. Available: https://www.transparency.org/cpi2014/results [Accessed 15 November 2015].

Turner, B., Meyer, W. B. & Skole, D. L. 1994. Global land-use/land-cover change: towards an integrated study. *Ambio (Sweden)*.

Turner, M. G. 1987. Spatial simulation of landscape changes in Georgia: a comparison of 3 transition models. *Landscape Ecology,* 1**,** 29-36.

Turok, I. 2014. Settlement Planning and Urban Transformation.

United Nations 1994. 1994 United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa(UNCCD).

United Nations 2014. World urbanization prospects: The 2014 revision.

Van Aardt, C. 2007. Population and Household Projections for South Africa by Province and Population Group, 2001-2021. Bureau of Market Research, University of South Africa.

Van Donk, M. 2008. *Consolidating developmental local government: Lessons from the South African experience*, Juta and Company Ltd.

Van Wyk, J. 2010. Parallel planning mechanisms as a" recipe for disaster". *PER: Potchefstroomse Elektroniese Regsblad,* 13**,** 214-234.

Van Zyl, J., Cross, C. & Donovan, M. 2008. Overview of the extent and nature of the unbundling of South African households and the implications thereof. *Paper Commissioned by The Presidency, South Africa*.

Veldkamp, A. & Fresco, L. 1996. CLUE-CR: an integrated multi-scale model to simulate land use change scenarios in Costa Rica. *Ecological modelling,* 91**,** 231-248.

Veldkamp, A. & Lambin, E. F. 2001. Predicting land-use change. *Agriculture, ecosystems & environment,* 85**,** 1-6.

Venter, C., Biermann, S. & Van Ryneveld, M. Low-cost housing location in South African cities: empirical findings on costs and benefits. rd Annual Southern African Transport Conference, Pretoria, South Africa, 2004. 12-15.

Verburg, P., De Koning, G., Kok, K., Veldkamp, A. & Priess, J. 2001. The CLUE modelling framework: an integrated model for the analysis of land use change. *Land use and cover change.*

Verburg, P. H. 2006. Simulating feedbacks in land use and land cover change models. *Landscape Ecology,* 21**,** 1171-1183.

Verburg, P. H. 2010. The Clue Modelling Framework. VU University Amsterdam, Institute for Environmental Studies.

Verburg, P. H., de Nijs, T. C., van Eck, J. R., Visser, H. & de Jong, K. 2004a. A method to analyse neighbourhood characteristics of land use patterns. *Computers, Environment and Urban Systems,* 28**,** 667-690.

Verburg, P. H., Kok, K., Pontius Jr, R. G. & Veldkamp, A. 2006. Modeling land-use and land-cover change. *Land-use and land-cover change.* Springer.

Verburg, P. H. & Overmars, K. P. 2009. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landscape ecology,* 24**,** 1167-1181.

Verburg, P. H., Schot, P. P., Dijst, M. J. & Veldkamp, A. 2004b. Land use change modelling: current practice and research priorities. *GeoJournal,* 61**,** 309-324.

Verburg, P. H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V. & Mastura, S. S. 2002. Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental management,* 30**,** 391-405.

Verburg, P. H., Van De Steeg, J., Veldkamp, A. & Willemen, L. 2009. From land cover change to land function dynamics: a major challenge to improve land characterization. *Journal of environmental management,* 90**,** 1327-1335.

Verburg, P. H. & Veldkamp, A. 2004. Projecting land use transitions at forest fringes in the Philippines at two spatial scales. *Landscape Ecology,* 19**,** 77-98.

Visser, H. 2004. The Map Comparison Kit: methods, software and applications. *RIVM report,* 550002005**,** 127.

Voinov, A., Costanza, R., Wainger, L., Boumans, R., Villa, F., Maxwell, T. & Voinov, H. 1999. Patuxent landscape model: integrated ecological economic modeling of a watershed. *Environmental Modelling & Software,* 14**,** 473-491.

Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M. & Ulfarsson, G. 2003. Microsimulation of urban development and location choices: Design and implementation of UrbanSim. *Networks and Spatial Economics,* 3**,** 43-67.

Wassenaar, T., Gerber, P., Verburg, P., Rosales, M., Ibrahim, M. & Steinfeld, H. 2007. Projecting land use changes in the Neotropics: The geography of pasture expansion into forest. *Global Environmental Change,* 17**,** 86-104.

WCG 2015a. Provincial Economic Review and Outlook 2015. *In:* TREASURY, W. C. G. P. (ed.). Cape Town.

WCG 2015b. Provincial Strategic Plan 2014-2019. *In:* PREMIER, D. O. T. (ed.).

Wear, D. N., Liu, R., Foreman, J. M. & Sheffield, R. M. 1999. The effects of population growth on timber management and inventories in Virginia. *Forest Ecology and Management,* 118**,** 107-115.

WESGRO 2015. 2015/2016 INVEST IN WESTERN CAPE A PERSPECTIVE ON INVESTMENT OPPORTUNITIES IN THE WESTERN CAPE.

Wessels, K. 2005. Monitoring land degradation in Southern Africa by assessing changes in primary productivity.

White, R. & Engelen, G. 2000. High-resolution integrated modelling of the spatial dynamics of urban and regional systems. *Computers, environment and urban systems,* 24**,** 383-400.

Wilgen, B. W. v. 2015. Plantation forestry and invasive pines in the Cape Floristic Region: Towards conflict resolution. *South African Journal of Science,* 111**,** 1-2.

Wray, C., Musango, J., Damon, K. & Cheruiyot, K. 2015. Modelling urban spatial change: a review of international and South African modelling initiatives.