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Quantifying the spatial implications of future land use policies in South Africa

–Reshaping a city through land use modelling-

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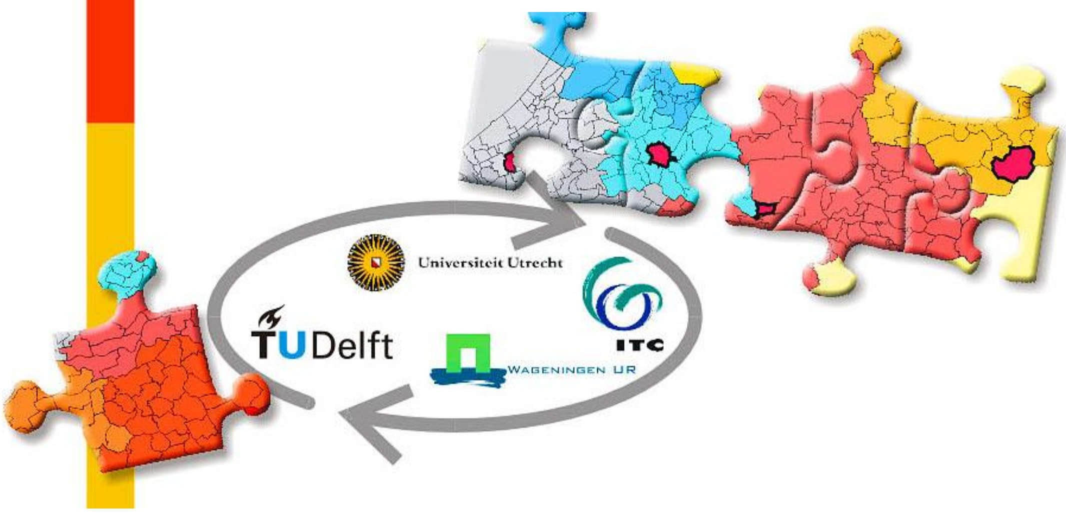

Quantifying the spatial implications of future land use policies in South Africa

–Reshaping a city through land use modelling-

Thesis submitted in partial fulfilment of the degree - Master of Science in

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Abstract

Land use policies have a definite and lasting impact on the way that cities grow, however, the change in land use only gets observed many years later. As such, it is difficult for policy and decision makers to observe and quantify the implications of their land use policies and strategies and what it might or might not mean for a city's landscape a decade or more from now.

Johannesburg is a case in point with many of the previous apartheids policies resulting in a city that is characterised by low densities, long commuter times and stark income and social inequalities (specifically between the northern and southern parts of the city). The South African government has stressed that bold policies and interventions need to be implemented to reshape the spatial inequalities of the past.

This research study sets out to investigate the consequences of the city's proposed policies. The Dyna-Clue model was used to compare the spatial impact of two different scenarios, thus answering the question whether the proposed policies will restore the city's inequality by the year 2030. The first scenario labelled the 'As-IS Scenario' assumes unconstraint spontaneous growth that continues along the same trajectory as the past decade while the second 'Policy-Led Scenario' looks at the implementation of land use policies and strategies that will restrict growth, densify transport corridors and invest in low cost housing in accessible locations.

The results of these two scenarios are evaluated based on a set of indicators to test which scenario produces the best outcome given the high rate of urbanisation and migration predicted for the city. The results are based on the two scenarios' influences on 1. Spatial inequality, 2. Density patterns and 3. Commuter distances.

It became clear within the study that if the government continues along the same trajectory as the past decade (AS-IS scenario) that the city will be inundated with informality by 2030. The city will see increased levels of spatial income inequality by providing more economic opportunities to already wealthy northern suburbs while restricting the bulk of the lower-income households to the southern parts of the city. The city will continue to be characterised by low densities and a large sprawled extent.

Adopting the governments proposed policies positively influences the unequal provision of economic opportunities by providing more economic opportunities to the southern suburbs of the city. Implementing densification corridors and restricting development outside the urban development boundary will see a 14% reduction in urban extent and an increase of 3 dwelling units per hectare compared to the AS-IS scenario. The vast amount of lower-income households will still dominate the southern half of Johannesburg and even with this drastic policy intervention segregation in both the southern and northern parts of Johannesburg will stay evident.

Acknowledgements

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1. Introduction and context

What we decide today will inherently shape and affect our cities years from now…

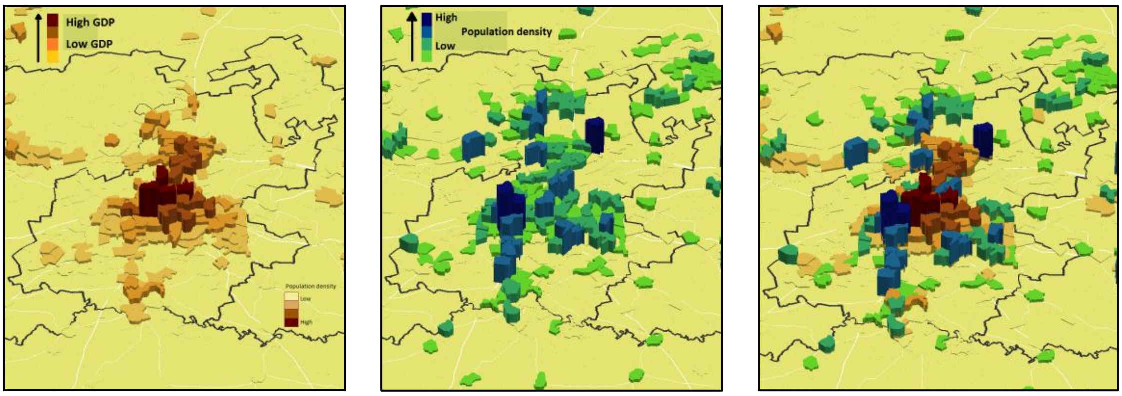
1.1 Background

Land use policies have a definite and lasting impact on the way that cities grow and expand, however the change in land use only gets observed long past the implementation date of these policies. As such, it is difficult for policy and decision makers to observe and quantify the implications of their land use policies and strategies and what it might or might not mean for a city's landscape a decade or more from now.

In South Africa the past apartheids policies are a case in point, with many of the policies resulting in unintended consequences that are currently affecting the livelihoods of its citizens and economy. The influence of past apartheids land use policies (such as the Urban Areas Act of 1923 or the Group Areas Act of 1950) are clearly evident in the land use patterns of South Africa's urban and rural spaces. These apartheids land use policies have left a legacy of sprawled, low density, two tier cities. The ideology behind these two tier cities was the geographical separation of people by race, one race living in houses built by the market while the other race was subjected to living under a socialist system with government land ownership (Bertaud 2001). These policies resulted (even though not directly intended) in cities having an unequal spatial design. This is reflected in stark income inequalities and a geography that separated its people from the economy creating high operational costs, population dispersion and long commuter times.

"Apartheid planning consigned the majority of South Africans to places far away from work, where services could not be sustained, and where it was difficult to access the benefits of society and participate in the economy." (The Presidency 2011)

Inequality is deeply entrenched within South Africa's city landscape and none of the planners could have foreseen the negative results and consequences that their ideological policies and land use regulations would produce. Figure 1.1 demonstrates the dispersion of population and the separation of people from economic activity within South Africa's biggest economic and population hub - Gauteng. Gauteng is the largest labour market in South Africa providing the majority of economic opportunities to South African citizens. It is also the host province for the case study area – the Johannesburg metropolitan municipality (Figure 1.2).



Economic distribution in Gauteng **Population distribution in Gauteng** **Comparison**

Figure 1.1: Gauteng province - Disparity between the economic and population densities.

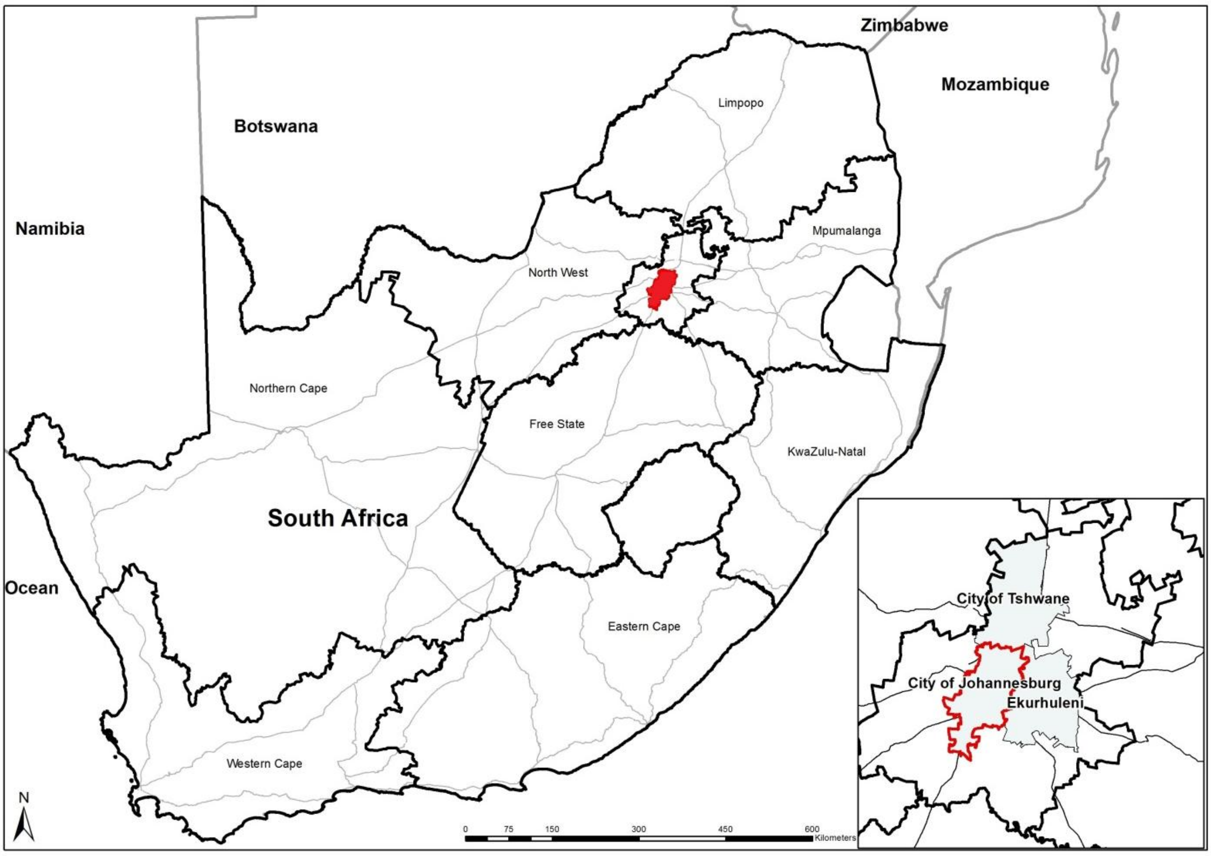


Figure 1.2: Johannesburg's location within Gauteng

When the new government regime took post in 1994 there was a strong urge to break down the apartheids geography legacy and reshape the South African cities through land use reform policies. These policies were meant to densify and compact cities, provide sustainable public transport and provide equal employment opportunities to its people (The Presidency 2011).

18 years later and South African cities are still fragmented and dispersed and people are still commuting long distances to reach employment opportunities. The poor are still located on the peripheries of the cities and in some cases this were exacerbated further by new low cost government housing projects.

Cities whose development are driven by demand are normally more ideal as they result in a logical organisation of space that allows employment and population to be organised in an acceptable spatial manner (Bertaud 2001). However, in South Africa the large backlogs in housing and infrastructure services forced government to take action by investing in large infrastructure ventures to alleviate backlog figures. These demands were met by providing houses on cheaper vacant open land on the peripheries of cities, yet again reinforcing the geographical segregation of the poor. These investment patterns are making the poor poorer by subjecting them to longer commuting times and thus excluding them from the formal economy.

Although South African urbanisation rates are slightly less than other African countries, it's still projected that 7.8 million people will migrate to South African cities by the year 2030 (The Presidency 2011). With an already large housing and service delivery backlog these totals will just add to the load and will put even more pressure on low income housing and service delivery needs.

Government has in response to these challenges stated that bold measures needs to be taken to reshape the ineffective and unequal settlement patterns. The presidency has urged that policies need to be enforced that will change the development patterns of South African cities by 2030. Some of these measures include limiting urban sprawl by enforcing higher densities in cities, investing in public transport and developing along specific development corridors. It is safe to say that looking at the implications of past policies that the new policies might go unnoticed in practice but might have unintended consequences on the land use of cities.

1.2 Johannesburg as case study area

Johannesburg (as part of South Africa's main economic hub) is a good example of where unintended land use policies affected its city's landscape dramatically. Johannesburg is one of a few cities where density patterns are inverted (Figure 1.3), resulting in an increase in density with distance away from the city's business district. This resulted in Johannesburg being a sprawled low density city with average commuting distance of 25km from residence to place of work (Bertaud 2001).

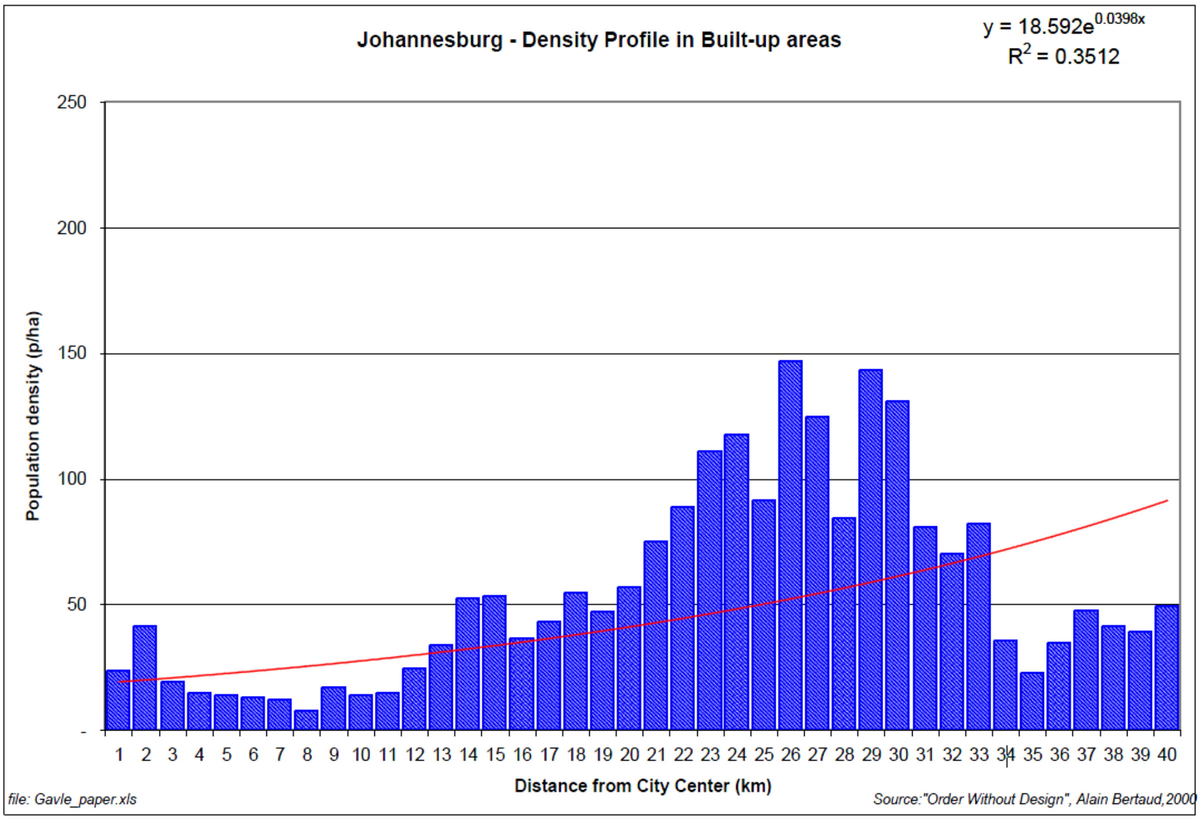


Figure 1.3: Johannesburg density profile. Extracted from Bertaud (2001) p.9.

The level of urbanisation and migration predicted for Johannesburg will place enormous pressure on the social, economic and infrastructure services of the city. The Johannesburg metropolitan council has constructed the growth management strategy (GMS) together with their spatial development framework (SDF) that reveals the spatial plan, policies, land use regulations and large government investment projects planned to reshape and alter the course of the city's spatial geography. Land use and policy regulations as well as incentives and large infrastructure investments are used as the main tools to influence the spatial structure of the city. The GMS and SDF identifies several key strategic nodes, corridors and policies to ensure that growth takes place in dedicated areas in order to reach desired density figures. History however teaches us that endeavouring to redesign a city through land use regulations and policies can have unpredictable and undesirable side effects.

"*Cities can be irreversible changed as most of the consequences will only be observed and quantified well into the future*" (Bertaud 2001).

Global Insight, an independent economic and demographic modelling consultancy, has recently predicted the population of Johannesburg (under a high growth and migration scenario) to increase from 3.8 million people in 2011 to 5.8 million people in 2030, they're also predicting that households will dramatically increase from 1.3 million households to nearly 2.2 million households.

Given these demographic changes projected for the city it is crucial to plan for the growth anticipated over the next two decades in order to shape and change the city's landscape for the better. In order to determine the effectiveness and spatial implications of these policies we need to turn to a spatial modelling solution.

1.3 What the research will address

Given the South African governments urge to reshape cities through bold policies, this research study will investigate the consequences of the proposed policies through making use of modelling tools, methods and techniques to support planners and policy makers in quantifying the spatial implications of their policy plans. The research will explore the use of urban land use change models and techniques to measure and anticipate the possible effects that the government's bold policies might have on the city's landscape.

Urban land use change models can be conceptual, statistical or mathematical representations of reality. These models are capable of simulating dynamic spatially explicit land use changes and patterns. South Africa is posing very specific development challenges that need to be taken into account when choosing to model this complex city landscape. Some of these include the urbanisation rate, the occurrence of informal settlements on vacant undeveloped land, the back-yard shack phenomena, government's active role in large infrastructure investment and the socio-economic and spatial inequalities the country is faced with. The question arises whether current land use models can be adapted to model the complex land use patterns and driving forces in a developing country such as South Africa. The research will focus on the monitoring and evaluation of what-if scenarios, thus simulating future land use and by evaluating the emerging spatial patterns.

1.4 Research Definition

1.4.1 Research objective

The objective of this research study is to through the use of land use models investigate, quantify and compare the long-term spatial consequences that the various planning policies will have on the City of Johannesburg's landscape. The policy outcomes should be quantified and compared based on their ability to reduce spatial inequality, densify the city and address the Apartheids planning legacies. These results will be crucial in quantifying unintended land use patterns as a result of adopting new land use policies.

1.4.2 Research question

The main research question that this study will try to answer is; "What will the long-term spatial impact (land use change) on the city of Johannesburg be if the government continues along the same path as the past two decades or if proposed high density & strategic infrastructure development land use policies are implemented? Thus, will the proposed land use policies restore and adequately change the land use patterns of the city by 2030?

1.4.3 Sub – research question

The following sub research questions are proposed in order to answer the main research question:

1. What are the theories and building blocks that underlay urban land use change models and which methods and techniques are currently available and being used to model urban land use policy scenarios?
2. What are the unique land use patterns and trends observed in the case study area and what are the driving factors that determine urban land use development and changes in Johannesburg, South Africa?
3. Which urban land use models are suitable for customization and adaptation for modelling land use policies in South Africa based on the model's purpose, data needs and scale of implementation?
4. How must the chosen urban land use model be adapted/amended in order to simulate land use change in South Africa under various policy scenarios?
5. How accurate is the model's results and what are some of the limitations of the chosen methodology?
6. How do the policy scenarios affect the Johannesburg land use patterns?

1.5 Scope and novelty of research

Although the research will take cognisance of cities as complex systems, it will not try to model the cities' complex interactions between markets, economy and ecology. This study is not aimed at predicting urban land use change but is aimed at monitoring and evaluating *what-if* scenarios; simulating future urban land use change for the purpose of evaluating emerging spatial patters. The research study will be applied to explore the influence that various policies will have on the future land use patterns of the city of Johannesburg. The study will also make use of external modelling predictions concerning economic and demographic forecasting.

Land use modelling is not a new concept with numerous examples of models being implemented and validated for use in developed countries. Land use models, implemented for areas in developing countries, have added a new thinking direction by including more multifaceted social problems such as informal economies and informal settlements but still lack a deeper understanding of the unique driving forces that changes these land use patterns.

South African cities have lots of similarity to developed countries but also face many similar challenges of developing countries such as poverty, income disparities, informal settlements and backyard shacks. Academic references to land use model development in South Africa is extremely limited. The study will directly contribute to and enhance the understanding and working of these models in the South African context and will contribute to a new and developing field of science within South Africa. Internationally the study will contribute by adding knowledge to the way urban land use models operates in a developing context. The study will contribute to understanding the influence that unique challenges such as informal settlements, backyard shacks, government provision of housing and developing patterns have on the land use patterns of developing countries.

Land use policies have a direct impact on people's livelihoods and information is needed to support policy debates and influence decisions through scientific evidence (Jantz et al. 2004). Simulation of growth and change of urban land use patterns and the ability to quantify the effects that policies and policy makers have on the land use patterns allows decision makers to make much better informed decisions between conflicting policy scenarios (Koomen and Stillwell 2007).

1.6 Structuring the research

Figure 1.4 provides an overview of the flow of research activities as well as the delineation of the various chapters for reporting on the research. The main research question was broken down into smaller research deliverables and the following section will explain the approach in answering the various sub-research questions.

Sub-research question 1: What are the theories and building blocks that underlay urban land use change models and which methods and techniques are currently available and being used to model urban land use policy scenarios?

This research question will be answered based on a literature study on the available theories in land use modelling. The section will look at the building blocks of a land use model, the various classes of models and modelling techniques available and their successful implementation. The outcomes will be discussed in chapter 2. This section will also feed into and have an influence on the model comparison described in Chapter 4 (Figure 1.4).

Sub-research question 2: What are the unique land use patterns and trends observed in the case study area and what are the driving factors that determine urban land use development and changes in Johannesburg, South Africa?

This research question will focus on selecting the main drivers of urban land use change and development in the chosen case study area based on the following approach:

1. A review of historical development patterns and past drivers of land use change.
2. The current spatial form of Johannesburg and its unique development problems.
3. The future trends and scenarios envisioned for the Johannesburg area.

The outcomes will be discussed in chapter 3 and the empirical analyses of the driving forces are tested in chapter 5. The formulation of the policy scenarios (Figure 1.4) will also be described in detail in chapter 3.

Sub-research question 3: Which urban land use models are suitable for customization and adaptation for modelling land use policies in South Africa based on various modelling criteria?

This question requires a three-step approach to answer:

1. The model requirements, specifications and criteria needs to be established in order to determine what a suitable model should look like based on the policy scenarios, the outputs required and the specific case study area.
2. A comparative review of chosen models will be conducted. The chosen models will be compared against each other for their ability to model and provide the outputs as defined in the modelling criteria.
3. Shortcomings of the chosen model will be identified and included as possible ‘advances’ to be made in the model in order to simulate the policies in a developing country.

The outcomes of this research question will be discussed in chapter 4. The exploration of the case study area (chapter 3) and the literature review (chapter 2) will feed into and contribute to the completion of this research question (Figure 1.4).

Sub-research question 4: How must the chosen land use model be adapted/amended and applied in order to simulate land use change in South Africa under various policy scenarios?

This section will focus on the adaptation of the model for application in developing countries. Applied research will be conducted to model the various policy scenarios. The steps involved in this section are:

1. Address the model shortcomings in order to make it capable of simulating land use change in the developing metropolitan city of Johannesburg.
2. Sourcing, preparing and populating the model with the required data.
3. Running the model for the various scenarios.

The outcomes of this sub-research question will be discussed in chapter 5. This research question is reliant on the completion of chapters 2, 3 and 4 that serves as the foundation work (Figure 1.4).

Sub-research question 5: How accurate is the model's results and what are some of the limitations of the chosen methodology?

This step includes a sensitivity analysis of the modelling results as well as listing the various constraints identified when using the chosen model. The outcomes of the sensitivity analyses will be captured in chapter 5 while the modelling constraint will be included in chapter 6.

Sub-research question 6: How will the modelling outputs be compared to determine the most suitable policy scenario? How do the policy scenarios affect the Johannesburg land use patterns?

This section will focus on analysing and quantifying the various policy scenarios influences on the case study area based on a set of indicators developed to compare the differences of the various modelling outputs. The various indicators and the modelling results will be presented in chapter 6 and the effects on the policy scenarios will be discussed in chapter 7.

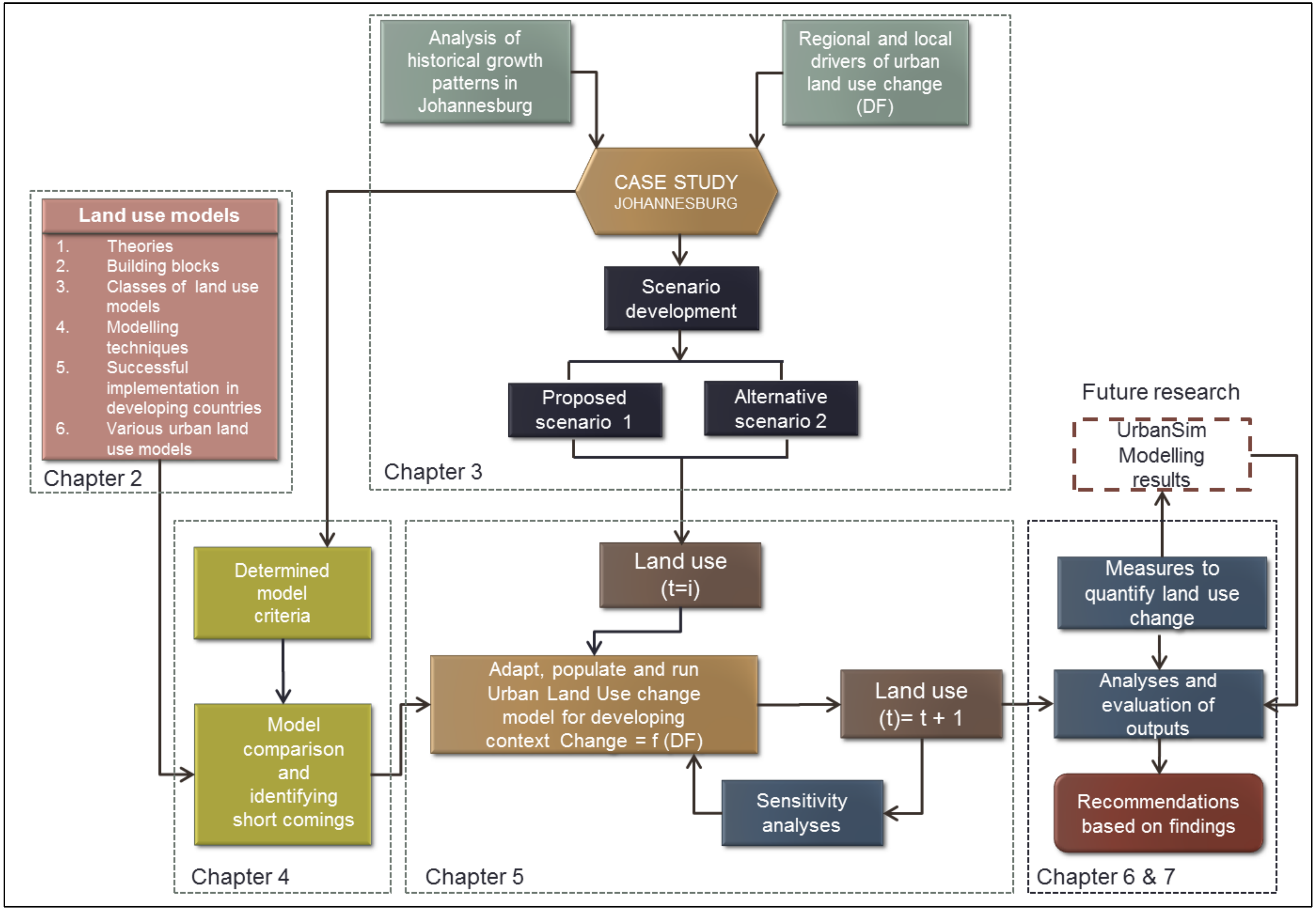


Figure 1.4: Research methodology and chapter breakdown

2. Urban land use models

The following sections provide an overview of the building blocks and theories of urban land use change modelling and will look at the various methods and techniques available to model urban land use change.

2.1 Introduction to modelling

Models are simplifications of reality, an abstract of the real world made with the purpose to study, understand and explore links and phenomena's. Models are built for a specific purpose to perform a very specific task. Models are a contained controllable version of the real world system being modelled, offering the ability to study the behaviour of the system under various inputs, scenarios and pressures. In order to model a system, comprehensive knowledge and understanding of the systems linkages and workings are required.

Casti (1994) describes the concept behind modelling (Figure 2.1) as a two-way mapping process through which desired characteristics in a real world system (**R**) are encoded into algorithms contained in a modelling system (**M**). The modelling system (**M**) can then be used to simulate various scenarios, the results in turn are decoded into meaningful indicators that allow the modeller to observe phenomena from the real world system (**R**).

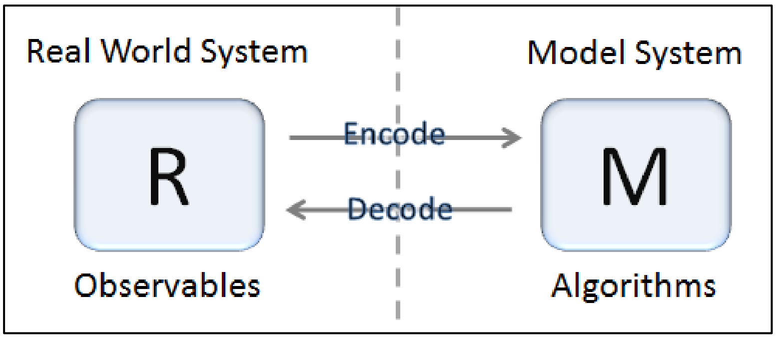


Figure 2.1: Modelling systems. Adopted from (Casti 1994).

For the purpose of this study simulation will refer to the act of imitating the behaviour of a systems characteristics and linkages, scenarios will refer to the construction of alternative futures and indicators will be the term used for describing the proxies used to measure the state of objects.

Modelling a specific real world system will be influenced by various factors, these include; 1.The specific system or sub-system being modelled, 2. The modeller's theoretical background (economist, market expert, mathematician, geographer etc.), 3. The modellers view on how the system works, 4. The purpose of the model and 5. The dynamic nature of the system (the influence of space and time) (Verburg et al. 2004).

2.2 Background to Urban land use models

Land use modelling is not a new concept and has been in the academia for several decades, making its debut in the late 50's but only receiving international attention since the 80's (Sui 1997). Throughout the years various models based on different modelling techniques and theories have been conceptualised, developed and applied. The first generation of these models theorized cities as simple systems, systems capable of being represented as aggregated static models, linear and deterministic in nature and driven by prediction and allocation rules. The second generation models introduced dynamic models capable of modelling the complex interrelated structure of cities through rule based chaotic and self-organizing principles (Sui 1997). These second generation models also started to explore the spatial consequences of decision making in complex systems (Engelen et al. 2003). The urban environment is a complex system with various interplays between sub-systems and endeavouring to model this system will be a multifaceted interdisciplinary exercise.

Parket et al. (2003) stresses the point that complex systems (such as the built environment) are too complex to model in its whole and that clear model boundaries need to be defined when starting the modelling process. Verburg et al. (2004) explain these models best by stating that land use change models are tools, designed to analyse the causes and consequences of land use change and to understand the functioning of the land use system for the purpose of supporting land use planning and policy. Both papers of Wadell (2002) and Koomen and Stillwell (2007) stress this point and emphasize the value that urban land use change models have in informing policy makers. Veldkamp and Lambin (2001) also argue that the biggest advantages of land use models lays in its ability to model likely future outcomes based on the present scenarios and events. Creating an urban land use change model that aim at testing alternative futures and capable of representing the key processes, links and complexities involved, will need to be done in an integrated, spatially-explicit, temporal and multi-scale manner.

Urban land use change modelling incorporates a variety of land use categories as inputs, utilises land use theories as the underpinning of the model, base assumptions of land use change on various internal/external driving forces and applies these techniques in various types of modelling tools. The outputs normally being measured in either the quantity (amount) of land use change taken place or the geographical areas these change took place in. Thus, answering the research questions as set aside in Chapter 1 requires an in-depth understanding of the models building blocks (what the model is made up of), the theories used in models, the system being modelled, the relevancy of the model to the research question and the various tools, methods and techniques available for use.

2.3 Theories used in explaining land use change

Various land use models have been developed and adopted to represent the complex inter-disciplinary field of land use change. Land use change modelling, due to its interdisciplinary nature draws from several disciplines and multiple theories on land use change. Briassoulis (2000) gives a detailed account of the theories used in land use change by grouping these theories into the three main traditions of;

1. Urban and Regional economic theory,
2. Sociological and political economy theory and
3. Human-nature theories.

Briassoulis (2000) explains that the urban and regional economic theories adopts an economic approach to land use change where the costs of utilities are taken into account (e.g land owners making decisions based on maximising their expected returns from their land). An example of one of the more extensively used theories in this category is the Bid-rent theory (a geographical economic theory that explains land prices based on distance to a city's CBD). Spatial interaction theories (such as the Lowry gravity models) are also good examples of regional economic theories.

Sociological and political economy theories originate in the field of social sciences and places emphasis on human behaviour, social networks and socio-cultural interactions. Theories used from this discipline to explain land use change and patterns ranges from behaviourist theories (such as the multiple nuclei theory), planning theories to core-periphery theories (Briassoulis 2000).

Human-nature theories take a 'total systems' approach and explain land patterns based on a much broader global perspective. One of the broader theories included here are e.g the global-environmental change theory (Briassoulis 2000).

The previous section gave an indication of several of the disciplines that contributes to our understanding of the complex environment of land use change. It is an indication of the interdisciplinary nature of studying this subject and should be taken note of when endeavouring in such an exercise.

2.4 Building blocks of a land-use model

Veldkamp and Fresco (1996a) first described the concept of land use change as an interaction between space, time, biophysical factors (constraints) and human decision making such as demographic and economic factors. Agarwal et al. (2000) uses this concept together with the rational that land use models utilise space (geographical location) and time as the basis for the interaction of human choices (agricultural practices, urbanisation etc.) in what is describes as the three critical dimensions of land use change modelling dynamics. These three dimensions of space, time and human choice also need to be considered together with the importance of scale and model complexity.

Scale is an important factor when considering land use change modelling as various problems presents themselves differently across various scales, what might seem to be irrelevant locally can turn out to be of global significance. The importance of scale and hierarchy when modelling a system is emphasized throughout the literature.

When modelling land use change the significance of space in relation to its resolution and extent is also of great importance. The resolution of space refers to the smallest unit of analysis incorporated in the model. The resolution needs to accurately represent the special characteristics of that space (geographical area) being modelled. This will also depend on the hierarchical scale being used for the model (e.g. global, regional, local etc.). The extent refers to the total area covered and considered necessary for modelling land use change dynamics. The spatial scale needs to be carefully selected when choosing to model land use change as this will have a significant impact on the model requirements as well as model outputs (Agarwal et al. 2000).

When modelling a dynamic land use change system it's important to incorporate temporal scale and duration. Temporal scale refers to the smallest time steps (e.g. day, month, year etc.) needed to accurately observe the land use change while the temporal duration refers to the length(period) needed to observe various changes (Agarwal et al. 2000). Land use is constantly being changed by human needs and environmental processes. These changes and competition for land between the two forces happens through time and space and thus adds a dynamic (temporal) and geographical (spatial) complexity to the modelling process (Briassoulis 2000).

Agarwal et al. (2000) aside from arguing the importance of space, time, human choice and scale, also argue the importance of a scale structure in terms of 'agents' and 'domain' in human decision making. 'Agents' refer to the individual agents within a model making decisions while domain describes the specific institutional and geographic context in which the agent acts. Actors (such as Government and individual land owners) have the greatest impact on land use change and it's therefore essential that their decision making on how they will influence the land use be incorporated in the model directly or indirectly.

Another study conducted by Verburg et al. (2004) argues that the most critical factors to look at when constructing a land use change model are;

1. The Level of analysis (top-down or bottom-up approach when modelling),
2. Cross-scale dynamics (influence of various drivers on specific scales),
3. Driving factors (the drivers of land use change),
4. Spatial interaction (how land use classes cluster together),
5. Neighbourhood effects (the influences of the neighbouring cells) and
6. Temporal dynamics (the effect of time).

2.5 Classification of land use change models

Various academic classifications exist for describing land use change model characteristics and types. Briassoulis (2000) classifies and describes models according to 1. Statistical and econometric models, 2. Spatial interaction models, 3. Optimization models and 4. Integrated models. Lambin et al. (2000) categorises land use models in a very similar manner into five predominant categories namely; 1. Empirical-statistical models, 2. Stochastic models, 3. Optimisation models, 4.Dynamic (process based) simulation models and 5. Integrated modelling approaches.

Statistical and econometric models:

These modelling techniques were some of the earliest applied to land use models dating back to the 1960's. Statistical techniques and equations are used to describe a specific sub-system of the entire complex system. These techniques are applied to more simple mathematically solvable problems that try to link land use change with specific determinants. These models are descriptive in nature explaining land use as a function of selected determinants. These statistical models are based on the notion that land use change is the result of interactions and changes in the environment and socio-economic drivers, used to reveal correlations and associations between variables (Briassoulis 2000).

Most of these techniques are used for regional and national zonal analysis, static in nature, not based on sound theoretical guidance and focussed on modelling quantitative aspects of land use change. Well known modelling representations and techniques include; linear regression models, economic models, multinomial logit models and canonical correlation analysis models. These models are good for prediction of landuse change but poor in explaning patterns and relations between the variables as spatial data under correlation and regression models suffers from autocorrelation and multicollinearity. Spatially explicit, discreet statistical models are an exception to the above in that they are based on theories, quasi-static, able to be applied to more local scales and capable of adding qualitative aspects of land use change (Briassoulis 2000).

Econometric models according to Briassoulis (2000) are mostly indirect models, modeling determinates of land use change (e.g population growth) and then converting this back to the estimations of land use required for that specific determinined.

Spatial interaction models:

Spatial interaction models depict spatially explicit models that represent the interactions of human activities in space. These models take both the qualitative and quantitative interactions into consideration thus allowing a deterministic view of human behaviour. Spatial interaction models are concerned with origin destination modelling. Distance from original (e.g. population) and destination (employment opportunities), their locations and their size play a crucial role in the qualitative and quantitative modelling (Briassoulis 2000).

These models are based on the law of gravity in physics and utilises social physical theories. They are also static or quasi-static in nature. Some of the more noticeable applications include; potential models, opportunities models and gravity/spatial interaction models (Briassoulis 2000).

The main aim of these models is to model flows between origin and destination and the likely changes they will expect if either the interactions change or the origin/destination land uses change. Distance between origin and destination as well as the relative size of each supply/demand alternative plays a crucial role, this distance with size gravity declining is also called 'impedance effect of distance'. Due to its nature these models are restricted to one pair of land use at a time (Briassoulis 2000).

Optimization models:

These include programming models such as linear, dynamic and hierarchical models. Other techniques such as multi-criteria decision making and utility-maximization models are also included in this category (Briassoulis 2000).

Integrated model:

The models in this class uses techniques such as; Econometric-type models, gravity-spatial interactions base, Lowry types, input-output based models and simulation model that's based on various spatial scales.

2.6 Modelling techniques available

Modelling techniques for constructing land use models include spatial interaction models, spatial input-output models, discrete choice models, rule based models, optimisation models, computation models and agent based models. Parker et al. (2003) describes modelling techniques as driven by either 1.Equations, 2.Statistics, 3.Expert knowledge, 4.Systems, 5.Cellular Automata, 6.Hybrid or 7.Agent based techniques. The following section will explain two of the most relevant techniques that underlie most of the urban land use change models currently in practise; 1. Cellular Automata techniques and 2. Agent based techniques.

Cellular automata models

Cellular automata (CA) are a technique used within many urban land use change and growth models. CA are based on a uniform matrix of two-dimensional cells that's governed by 1. Transition rules, 2.Neighbourhood, 3. A cell state, and 4. Time. CA models have the capability to simulate complex dynamic systems through time (e.g. at each time interval various transition rules will apply to cells to change their cell states) (Parker et al. 2003). CA models can be geographically explicit and can easily be coupled with GIS and other geographical explicit models. CA models are easy to implement and adopt as they are simplistic in nature. CA models represent urban systems as a bottom-up process where land use change is the result of cumulative neighbourhood growth and transitions. These models have been applied in studies that looked at urban sprawl, residential growth, population dynamic, economic activity, employment, urbanisation, land use change and region growth (Torrens, 2012).

CA models are however limited in their capability to incorporate human decision making and choices and cannot represent the decision made between actors and their environment (Parker et al. 2003). CA models are difficult to calibrate (though models such as Sleuth have made significant progress on this) and the bottom-up modelling process excludes any regional or global influences (although models such as Clue-S have made strides in overcoming these shortfalls).

Agent base models

Agent based models (ABM) have the ability to incorporate agents (e.g households, government) as individual and collective decision makers. ABM simulates interactions between agents and their environment. ABM has the capability to model human decision making and behaviour in a spatially explicit manner and are capable of capturing emergent phenomena's (such as self-organisation and chaos theories). These models focus on providing frameworks for studying and understanding very specific aspects of urban systems. ABM is flexible and can be applied on a disaggregated level (Parker et al. 2003). The adaptive and learning capability of these individual agents allows the model to experiment with emergent behaviour.

Quantifying and justifying agent behaviours in an ABM is a time consuming and data hungry exercise. Applications of ABM techniques (e.g. UrbanSIM) require significant customisations of the model and strong programming experience is required. The interdependencies between agents and their environment also require the modeller to have a thorough understanding of the agents involved in the systems and their behaviour patterns.

Both CA and AB models requires interdisciplinary knowledge to construct an urban land use change model. Both models have the capability to model complex systems and both models can be spatially explicit. The application and customisation of CA models are however much simpler than AB models. CA models require less data and time to construct and populate and is supported through numerous examples in literature.

CA and AB model implementation in developing countries

Implementation and examples of modelling techniques in urban land use change models in developing countries are limited. Many of the models that have been applied in developing countries have omitted the growth of informality which is central to most of the developing countries. Most of the models focus on the growth of the urban environments and predicting urban sprawl (Barredo, 2004; Watkiss, 2008). Sietchiping (2004) has done extensive work on the modelling of informality in urban systems through the use of CA models and GIS with examples of applications in Tanzania and Cameroon. Urban land use change modelling for developing countries (specifically the incorporation of elements such as informality, policy interventions and the lack of planning) still has a long way to go.

3. Johannesburg as case study

Johannesburg, a predominantly urbanised city, is the financial capital of Gauteng, the economic hub of South Africa and the largest contributor to the country's gross domestic product (GDP). According to Statistics South Africa (2010), Johannesburg contributes 14% of South Africa's GDP and provides employment opportunities both formal and informal to 1.36 million people, 11% of the national employment figure. Johannesburg is one of six metropolitan municipalities and is home to 3.7 million people in approximately 1.3 million households. The city occupies a large geographical area (extent) of 1645 km² roughly 30km X 60km. The city has a complex spatial history that has been the result of many policies including those from the Apartheids era.

Understanding the spatial form of a city, how a city originated and what drove development in certain directions are important factors to understand when modelling spatial growth in a city. Past development patterns and the current spatial form provides clues to unlocking the possible future growth and expansion of a city. The following section will provide insight into the case study areas past, present and future state in order to determine the various regional and local drivers responsible for growth in the city.

3.1 Johannesburg's past development patterns

Given the importance of the development of the city, it is imperative to understand that Johannesburg's complex development patterns could be ascribed to mainly three defining elements:

1. The cities location on the Witwatersrand mineral basin
2. Past political policies
3. The many restructurings the city experienced since the end of Apartheid

3.1.1 The Witwatersrand mineral influence

Johannesburg's unlikely location (not near a harbour or large river) owes its existence to the discovery of gold in 1886 that sparked a gold rush and in-migration of settlers to the region. Within 9 years the city was the biggest in the country surpassing Cape Town the primary city for nearly 240 years (Beavon 1997).

Figure 3.1 shows the population growth of the city from a miner's camp in 1886 to 80 000 people in 1895, [1]250 000 in 1914, half a million in 1936, 1.6 million in 1970, [2]2.6 million in 1995 to 3.7 million inhabitants in 2010.

[1] Data Source: Centre for housing rights and evictions, 2005

[2] Data Source: Quantec 2010 regional indicators (downloaded 2012)

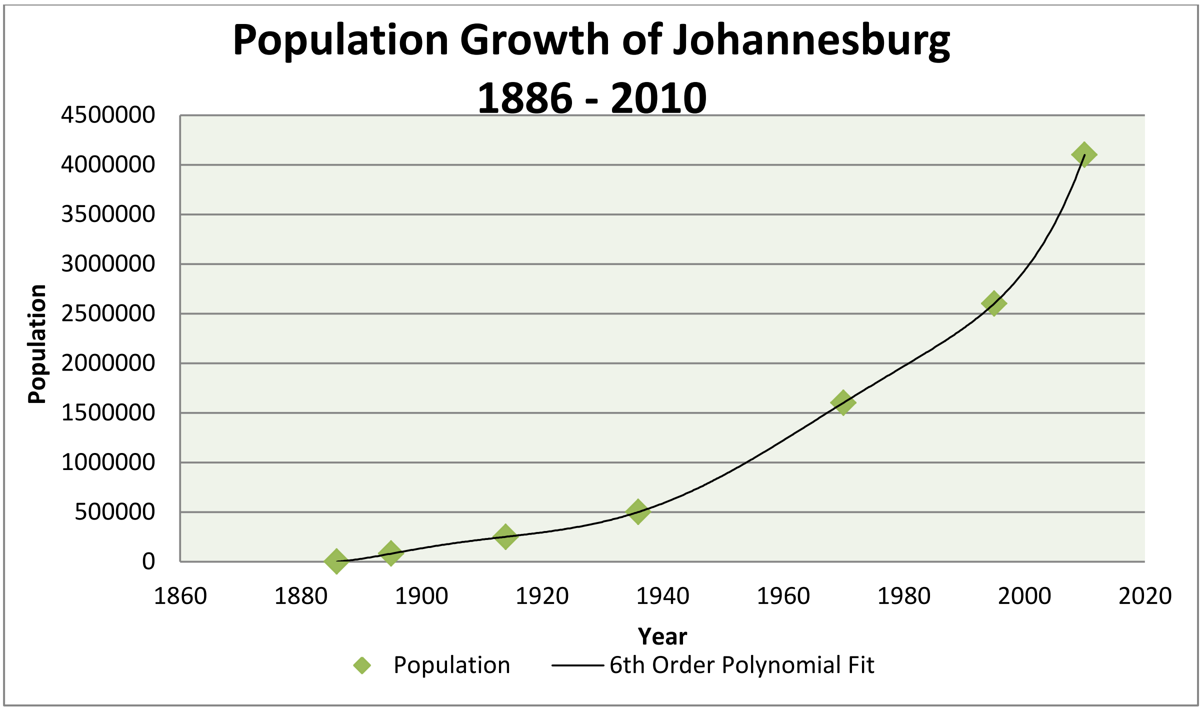


Figure 3.1: Growth of Johannesburg from 1886 - 2010

Johannesburg's location on the mineral rich Witwatersrand basin ensured its economic growth in the primary sector up until 1950. Johannesburg's prosperous economy and the 60 km gold reef (spanning from Krugersdorp in the west to Springs in the east) saw numerous new towns being established along the east-west gold reef (C.O.H.R.E 2005). In the early 1950's one in three people were employed in the primary mining industry, by 1970 a shift towards secondary manufacturing industries resulted in only one in eleven people being employed in the mining industry and by the early 1990's seven out of ten people were employed in the tertiary sector (Beavon 1997).

3.1.2 Past political policy influences

Johannesburg's past political policies have shaped the city to one of spatial segregation. The city was effectively divided into two main economies, those being market led in the north and the government designed areas of the south (Bertaud 2001). The most influential of these policies are briefly mentioned below to provide an indication of the major role that government and their policies played and are playing in the city's landscape today.

The spatial segregation of both wealth and race emanated even before the establishment of the city when the Kruger Republic's Gold Law (1885) banned black ownership and occupation of reserved mining land. The city subsequently saw its first spatial segregation in 1904 when attempts were made to move non-whites to Klipspruit (suburb in present day Soweto) 35km south west of the city, only allowing legal residence in the city in mining compounds or servant quarters in white suburbs. Klipspruit was the first of many [3]townships that later formed the city of South Western Township, today better known as Soweto (C.O.H.R.E 2005).

[3] Townships in the South African context refers to urban living areas specifically designed for non-white residents from the late 19th century to the end of Apartheid, these areas were far removed from the city CBD.

In 1918 the population was already past a quarter of a million and there was a severe lack of housing for the many black African and migrant labour workers. Wealthy Africans could purchase land in closer townships laid out in Alexandra (North of the Central Business District (CBD)) or Sophiatown (West of the CBD) while poorer labour workers had to commute from the periphery townships or reside in backyard shacks in closer townships (C.O.H.R.E 2005).

In 1923 the Urban Areas Act was put forth which confined Africans even more to townships, only Africans with urban employment were allowed legal options for tenure in the city. A decaying urban centre saw more slums and higher densities occupying the city centres and as a result the 'Slum act of 1934' came about and forced eviction of slum dwellers out of the city's CBD. Housing options were provided to the evicted white poor while the evicted black Africans were forced to settle in newly established townships like Sophiatown or Orlando (suburb in present day Soweto - again 30km south of the CBD) (C.O.H.R.E 2005). The lack of housing delivery in suitable locations forced many labour workers to move to townships or occupy backyard shacks. This increased densities in townships placed enormous pressure on housing backlogs and service delivery in these areas.

In 1939 the industrial sector boomed due to the manufacturing role played by South Africa in the Second World War. This resulted in an increase in demand for labour workers, drawing even more African labour workers to the city and densifying the townships resulting in a housing backlog of 42000 units. Government responded slowly by providing housing options in new townships located in modern day Soweto. There was already a clear spatial segregation of race and income. The wealthy white suburbs to the north of the city centre and the labour force workers confined to the south west and other defined townships (C.O.H.R.E 2005).

When Apartheid came about in 1948 measures were put in place to confine non-whites to the peripheries of the city. The new Government responded to the large housing backlog by providing housing in faraway located areas on the peripheries of the cities. One of the most noticeable of the past policies implemented by the Government was the 'Group Areas Act of 1950' that confined specific racial groups to specific areas. This act was arguably the biggest driver of spatial segregation. Leaseholds or rental tenure where put in place in Johannesburg for non-whites and no ownership of land was permitted (C.O.H.R.E 2005) . The inner city together with all the Freehold townships (with the exception of Alexandra north of the CBD) were cleared out and re-zoned for exclusive white residential use. Indians where restricted to Lenasia south of present day Soweto and coloureds to the Eldorado Park and Ennerdale Townships. Townships where laid out without being economically viable, far removed and dependent on white economies in the inner city and northern suburbs (C.O.H.R.E 2005).

When influx control was abandoned in 1986 this resulted in a mushrooming of informal settlements in better located areas closer to economic opportunities. Black people moved into the city centre while whites moved out to the nearby northern suburbs (C.O.H.R.E 2005) resulting in many commercial activities as well as office space moving to the North in established economic nodes constructed during the 1970's (e.g. the nodes of Sandton, Eastgate and Rosebank). The inner city (CBD) was in a state of decay until 1999 when the city responded with a series of inner city regeneration strategies (Beavon 1997).

3.1.3 Restructuring policies after Apartheid

The collapse of influx control in the late 1980's allowed many labour workers to move to the inner city and nearby areas in search of closer accommodation to better livelihoods and employment opportunities. The Government's struggle to eradicate the housing backlog and to provide accommodation closer to economic activities resulted in a dramatic increase of 190 informal settlements by 2005 in the Johannesburg metropolitan area (C.O.H.R.E 2005).

The new Government focused on providing housing opportunities to all (specifically the delivery of [4]RDP Government housing to lower income previously disadvantaged groups) but struggled to deliver these opportunities close to the economic centres. As most of the land was quite expensive nearer to the economic nodes the Government had to settle on lower priced available land mostly located on the periphery of the city, segregating the poorer communities and bounding them to long commuter distances (e.g. Diepsloot on the Northern periphery of the City).

With the end of apartheid the city's boundaries were extended and amalgamated several times with the inclusion of eleven previous local authorities into a new Greater Johannesburg Transitional Metropolitan council in 1995. This now included seven previously white affluent local authorities (e.g. Santon and Randburg) and four poorer black authorities (e.g. Soweto and Alexandra). The boundaries again changed in 2000 into the Greater Johannesburg Metropolitan Council that combined thirteen (an additional two) previous local authorities (now including Midrand to the North). The change in boundary meant that apart from the Johannesburg CBD there were several economic nodes (each the CBD of their own previous local authority) included into one metropolitan administration. This resulted in a polycentric city with various economic nodes. Suburban sprawl between these nodes have morphed the city to a sprawled urban space (Beavon 1997).

[4] Reconstruction and Development Programme (RDP) is a South African socio-economic policy framework that was implemented in 1994 to address the shortfall in social services.

3.2 Johannesburg's current spatial form

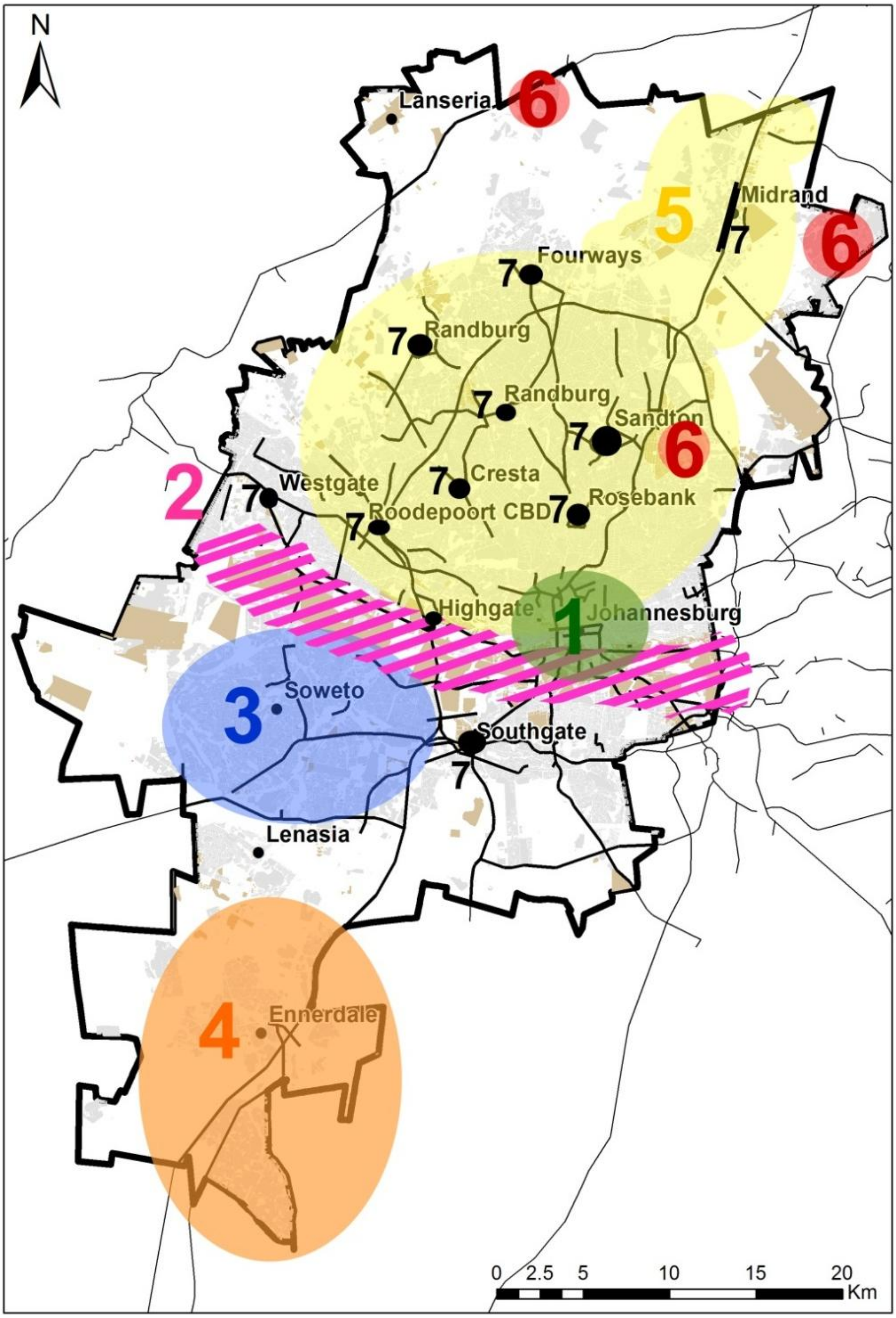


Figure 3.2: Johannesburg's current spatial form. (Adopted from: JHB Growth Management Strategy (GMS) and City of Johannesburg (2011))

Figure 3.2 above provides an overview of Johannesburg's current spatial form. The various areas indicated are:

1. Inner city: This area is still considered the main economic node and CBD of the Johannesburg metropolitan municipality. Government has spent many resources since 1999 through the inner city regeneration strategy to keep private investment focused and to better the livelihoods of its residence. (Johannesburg 2011)
2. Mining and manufacturing ridge: This area separates the city into a wealthy low density north and a densely populated poor south. This belt is a major constraint in promoting integration in the city. (Johannesburg 2011)
3. Soweto: The policy driven nature of the southern townships scared off commercial investment and resulted in Soweto (the home of 36% of Johannesburg's population) only holding 2% of all commercial floor space in the metropolitan. Most of these residences are dependent on the inner city (1) or various other economic nodes (7), resulting in long commuter trips to work. Soweto's land market is picking up and there are numerous economic opportunities within this urban agglomeration. Due to the long commuter trips, the residence is heavily dependent on rail and mini bus taxis to transport them from residence to work. (Johannesburg 2011)
4. Orange farm: Located far removed from any economic opportunities roughly 45km south of Johannesburg's CBD with a population of roughly 1million. Many of the residence are living in either Government built RDP housing or informal settlements and as a result the area has no formal functioning land market. The residences are also dependent on the northern economies of the city and rely heavily on rail and minibus taxis for transport. (Johannesburg 2011)
5. Affluent northern suburbs: These areas are characterised by a strong and vibrant market led economy. These low-density sprawled suburbs are dependent on private vehicles as means of transport. These areas are the result of decentralisation of commercial activities (7).
6. Former townships: Such as Diepsloot, Alexandra and Ivory Park are subjected to extreme densities in many areas exceeding 150 dwelling units per hectare (du/ha). The areas have been upgraded by Government housing investments but have grown enormously in size due to backyard shacks and informal settlements. (Johannesburg 2011)
7. Economic nodes: The city consists of various major, higher, medium and lower order economic nodes. The multiple economic nodes pose competition for the inner city (1) and are major producers of the city's economy and are the main attractors of employment opportunities. Many of these nodes where previous CBD's of previous local authorities.

3.2.1 Johannesburg's population and income disparities

The amalgamation of the various local authorities resulted in a segregated city with the mining and industrial belt dividing the city into an affluent north and a deprived south. North of the mining belt (with the exception of Alexandra township) was now characterised by a strong economy, several economic nodes, high income groups and low population density while the south were characterised as deprived with high population densities, little economic opportunities and predominantly low income groups. The dependency of the southern and periphery townships on the northern economies results in long travel distances and residence spending a large percentage of their income on transport. (Johannesburg 2011)

Figure 3.3a shows the higher densities in the CBD as well as the former townships of Alexandra, Soweto and Orange farm in the south, Diepsloot to the north and Ivory Park in the northeast. The higher density areas are also the areas that coincide with the lowest income levels (Figure 3.3b) and are subsequently the areas hosting the city's most back-yard shacks and informal settlements. These areas (with the exception of Alexandra) are also the areas that are furthest removed from the city's various economic nodes and are heavily dependent on public transport.

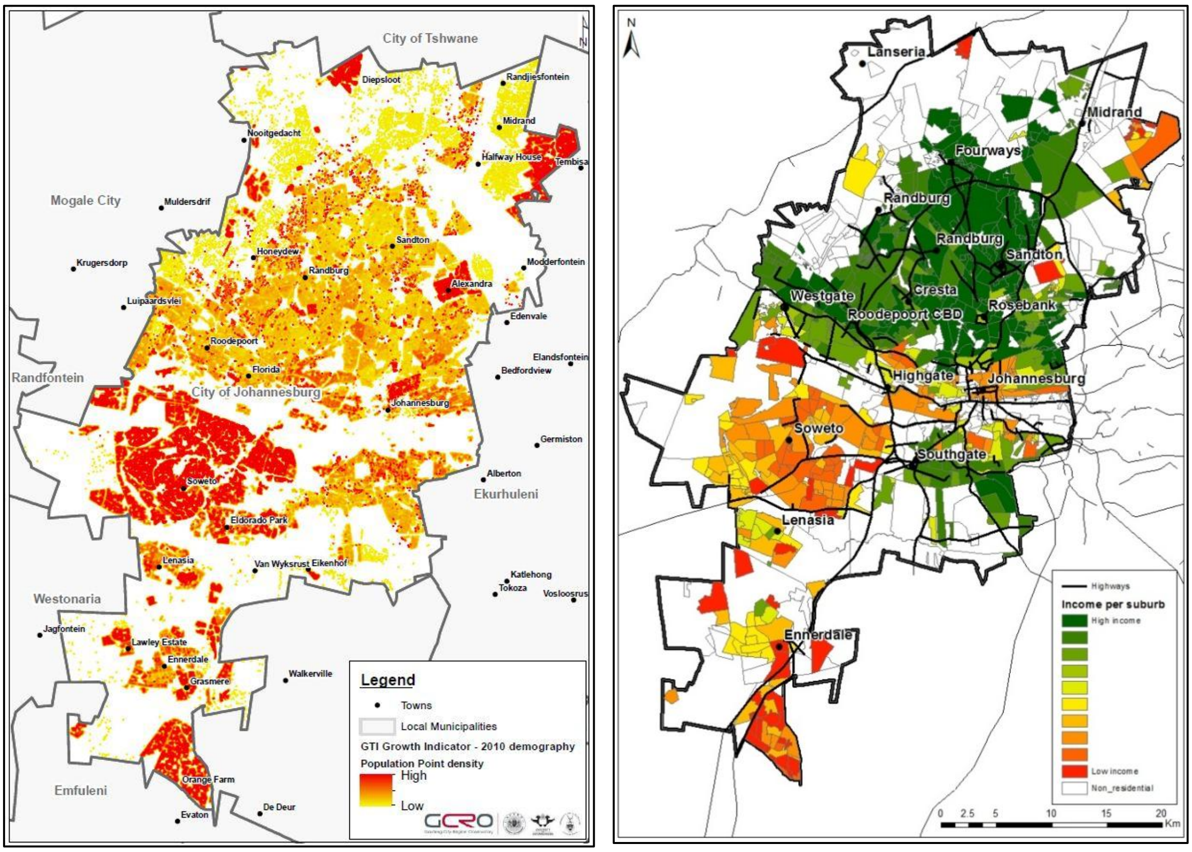


Figure 3.3: a) Population density (source: GCRO website) and b) income distribution (source: Knowledge factory).

3.2.2. Various types of residential housing and land use

The following section will look at Johannesburg's current spatial form in terms of the residential housing provided in the city. Johannesburg's residential housing can be divided into primarily three classes:

1. Formal housing driven by the market economy that consists of low, medium and high-rise housing
2. Informal housing that consists of informal settlements or backyard shacks
3. Government provided low cost housing that is a policy intervention

Formal housing

Figure 3.4 below shows the three types of formal housing in the city. Low-rise housing (Figure 3.4a) is typical suburban houses with a density varying from 2 dwelling units (du) /hectares (ha) to 15 du/ha. These areas are identified by one house on a parcel (Erf). The densities of housing differ based on income groups and tend to be homogeneous throughout a specific suburb. These types of housing are also subjected to becoming gated communities (a crime reduction mechanism where in a community gates the neighbourhood off and controls access of non-residents). This has a dramatic impact on the landscape of the city as these areas are very hard to convert to other types of land use or higher densities. Medium-rise housing (Figure 3.4b) is clustered housing with higher densities. These include security complexes with town houses, duets, sectional title and duplex housing. High-rise housing (Figure 3.4c) is defined as blocks of flats or hostel accommodation with significant higher densities than clustered housing.

Figure 3.4 Residential types of formal housing. a) Low-rise, b) Medium-rise, c) High-rise. (Source: Google Earth, 2012)

Informal housing

Informal housing can be categorised as either informal settlements or backyard shacks (see Figure 3.5 below). Figure 3.5a shows the typical aerial view of an informal settlement. These types of housing experienced a rapid increase specifically with the fall of apartheid when many new labour workers and people previously banned from occupying residences in the city migrated to the city in search of a better livelihood. The subsequent housing demand and government's failure to keep up with the housing backlogs resulted in many new informal settlements leaping up on vacant land, occupying land illegally throughout the Johannesburg city. Huchzermeyer (2006) points out that informal settlements are seen as a human needs-led development, where people settle themselves on available (many times unsafe) locations that meet their social and physical needs. The city of Johannesburg estimates that [5]800 000 people are living in 189 informal settlements throughout the metropolitan area. The city states that 103 of these townships are deemed not suitable for [6]in-situ upgrade and needs to be re-located to other suitable sites.

Backyard shacks (Figure 3.5b) while not a new phenomenon for the South-African landscape has increased in great numbers in the past decade. Increase in backyard shacks could be attributed to people wanting to benefit from services (water, electricity, sanitation) already put in place in formal developments. With the current service delivery backlog people tend to prefer living in an informal shack in the yard of a formal residential development, paying rent to the owner for the land and the services rendered. Figure 3.6 provides an example of the growth of backyard shacks from 2000 – 2010 in the Diepsloot area in the northern most part of the Johannesburg metropolitan area. The initial development was a Government RDP housing project developed to eradicate housing backlog and accommodate people that were evicted from environmentally unsafe areas in densely populated townships such as Alexandra. These developments include the provision of services such

[5] Source: City of Johannesburg (2011) & GMS

[6] In-situ upgrade refers to the upgrade of an informal settlement to a formal settlement on the current location while the residence resides in the area.

as electricity, water and sanitation and are thus ideal for the development of backyard shacks. The subsequent growth and infilling of these areas with informal shacks are clearly observed throughout the years. These areas can have a significant impact on service delivery as there is a total undercount of the amount of households and people requiring service delivery. Older single dwellings suburbs with declining incomes and newer Government social housing are prone to becoming more dense through infilling of informal shacks.

Figure 3.5: Informal housing. a) Informal settlements, b) Back-yard shacks (Source: Google Earth, 2012).

Figure 3.6: Backyard shacks growth from 2000-2010 in Diepsloot (Source: Johannesburg (2011) and GTI 2012)

Government low cost housing

This medium density low-income formal housing is a Government driven response to the severe housing backlogs. State funded and supported housing includes RDP and social housing. The previous figure 3.6 shows an example of Government RDP housing before informal densification took place. Income category separates it from the formal housing market. These Government subsidised RDP housing stock have been historically (due to apartheids legislation) and in practice (due to cheaper land) been provided on the periphery of the cities.

3.3 Johannesburg's future trends and proposed spatial scenarios

As previously stated the Presidency has urged that policies need to be enforced that will change the development patterns of our cities. Answering the main research question about the long-term spatial impacts (land use change) predicted for the city of Johannesburg can only be answered by understanding the past drivers of change, the current form of the city and the proposed future envisioned for the municipality. The previous two sections gave a background into the past drivers of change and the current spatial form whereas this section will explore the Government and municipal plans envisioned for the municipality's future. A clear understanding is thus needed around the specific policies and the future growth patterns envisioned for Johannesburg. The section will outline the projected future growth patterns as well as two policies that will be put to the test to determine their effect on the land use patterns of Johannesburg.

3.3.1 Johannesburg's future growth patterns (2030)

Demographic trends

The macro economic and demographic trends of the cities were determined by an independent consultant agency called Global Insight. The demographic growth trends were determined based on a cohort-component demographic model. The model uses five primary factors to determine its future population totals for the city. Global Insight (2011) bases their main calculation for the macro trends on:

$$Population\ (Pt+1) = Pt + Bt - Dt + It - Et \quad (1)$$

In Which;

Pt: Depicts the size of the population in the base year,

Bt: Depicts the number of births occurring between the base and projected years,

Dt: Depicts the number of deaths occurring between the base and projected years.

It: Depicts the immigrants arriving in the country between the base and projected years, and

Et: Depicts the emigrants leaving the country during the base and projected years.

Based on the projected macro demographic trends it is estimated that the Johannesburg city will have a positive population growth (Figure 3.7).

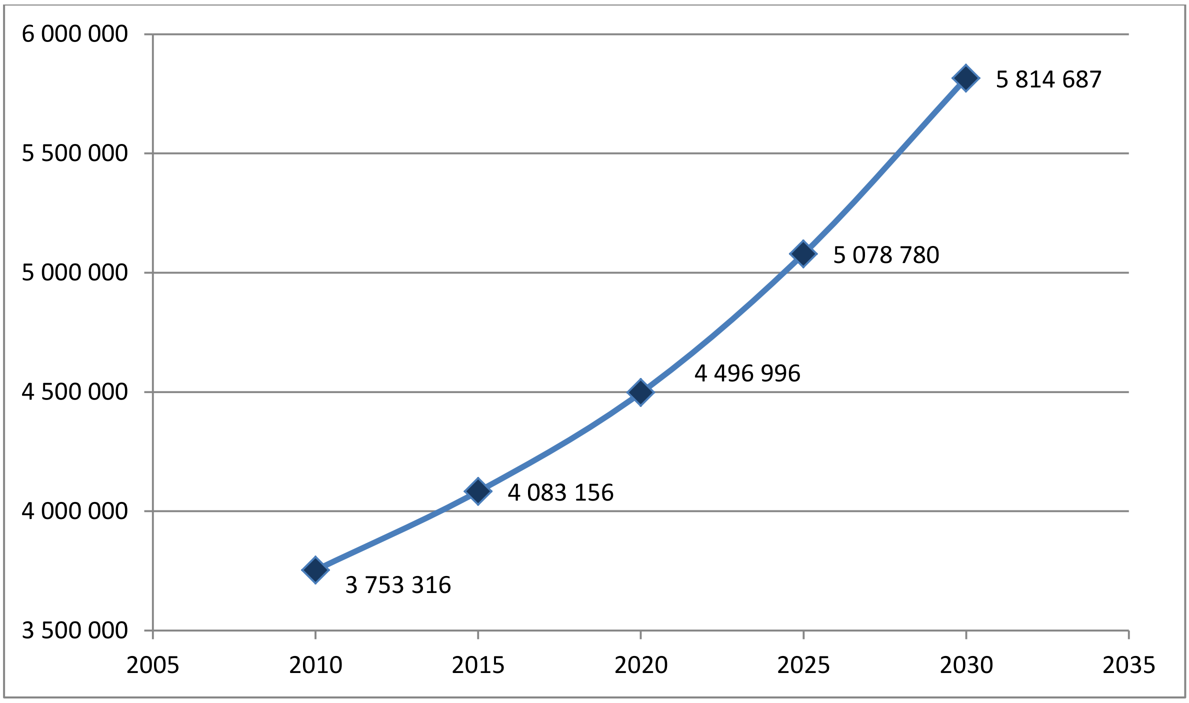


Figure 3.7: Projected population figures (Global Insight (2011)).

The significant increase in population is the result of the in-migration, urbanisation and the natural growth of the population. This increase in population and the fact that household sizes are decreasing will result in an enormous demand for houses that will directly influence the land use of the city. Failure of the Government to provide low-cost subsidised housing to the poor will result in an even bigger backlog of houses and an increase in both informal and backyard shacks throughout the city.

Economic trends

It is projected that the economy of Johannesburg will experience a positive growth which will affect the employment opportunities as well as the 'attractiveness' of the city to people in search of a better livelihood. Global Insight (2011) figures project a growth in employment in the tertiary services and a decline in both primary and secondary employment (Table 3.1). The table displays the percentage of employment in the economic sector (e.g. primary, secondary) in relation to the total employment in the city (e.g. Primary employment would contribute to 1.47% of the total employment figure in 2010 and will decrease to providing less than 1% in 2030).

Employment Share	2010	2015	2020	2025	2030
Primary	1.472858	1.29905	1.160921	1.056002	0.972956
Secondary	23.02222	22.49966	22.03286	21.65235	21.34969
Tertiary	75.50492	76.20129	76.80622	77.29165	77.67735

Table 3.1: Projected employment (jobs) per economic sector (Global Insight (2011)).

3.3.2 Johannesburg's future land use policies

Scenario planning provides great benefits to policy-makers. Creating and testing various scenarios allow decision makers to explore and test the possible implications that various policies might have on the city's landscape. Two scenarios are proposed for testing and exploration in the case study area, an 'AS-IS Scenario' and a 'Policy-Led Scenario'. The Policy-Led Scenario is the result of the

Johannesburg city's Growth management strategy while the 'AS-IS' Scenario is a current trend scenario to validate the model.

Scenario 1 – AS-IS Scenario

This scenario should represent unconstrained spontaneous growth. The scenario is a look into Johannesburg's possible future if the current trends, patterns and investment priorities continue along the same trajectory as the past. The following assumptions will be applied in this scenario:

1. Government provided subsidised housing is fixed to the Governments land budget; there is thus a limited amount of housing stock being built for the lower-income earners.
2. Vacant land is primarily considered for Government housing delivery due to the price constraints associated with redevelopment of already established areas.
3. Informal settlements should be considered for upgrading to Government housing before relocation is considered.
4. Informality and backyard shacks are not managed appropriately and allowed to continue to surface.
5. No development constraints are applied. No Urban development boundary (UDB) or large protected areas are implemented.
6. Growth continues along the past development patterns specifically the influence of the strong economy in the north.
7. Infrastructure investments are constrained to the current large investments underway.

Based on speculation it is estimated that the scenario will result in the following land use patterns that will be tested and measured in chapter 6:

1. A sprawled low density city due to the amount of space available for development
2. Low densities in accessible areas due to governments fixed budget
3. High densities on the periphery of the city in government provided housing
4. Long commuter times for lower income groups
5. Commercial investment bias in the northern part of the city
6. Backyard shack growth in closer accessible formal lower-income areas (a result of housing backlogs and high demand for lower-income housing)
7. Increase in informal settlements in all vacant accessible land closer to employment opportunities

Scenario 2 –Policy led municipal vision

This scenario assumes a very radical planning approach; it experiments with policy ideas and visions and looks at what it would take to create the 'utopia' picture of what planners believe is necessary in order to drastically reshape the spatial inequalities of the city. The Government in its National Development Plan (2030) sets out to break down the apartheids legacy by densifying and compacting cities, providing sustainable public transport and providing employment opportunities to all its citizens. The redevelopment of the city is envisioned through land use reform policies and strategies. One of these proposed strategies is called the Growth Management Strategy (GMS) of 2011. The strategy defines public transport corridors based on the Bus Rapid Transport (BRT) routes, the Gautrain stations and the Metrorail stations and states that densification should take place and are earmarked in support of these areas. The strategy emphasises the fact that low-income housing should be integrated into the city and not further marginalised. The following principles will apply:

1. Limiting urban sprawl through the adoption of an Urban Development Growth Boundary (UDB) of 2002.
2. Densifying key priority areas (preferable accessible nodes) through land use policies (zoning) and incentives.
3. Densifying transport corridors to ensure a sustainable and efficient transport system.
4. Investing in key infrastructure in specified development corridors. This should 'pull' the market as well as increasing the economic linkages between regions.
5. Investment of housing opportunities specifically for lower income groups should be done in closer proximity to employment and economic nodes, thus providing Government low-cost housing in key access areas.
6. Investing in residential lower income housing in the northern suburbs in accessible transport corridors by densifying low-rise housing.
7. Encouraging investment in commercial activity in the southern suburbs
8. Protecting environmentally sensitive nature areas.

Based on speculation it is estimated that the scenario will result in the following land use patterns that will be tested and measured in chapter 6:

1. A compacted city
2. Higher densities in more accessible location
3. Increase in economic opportunities and access to southern suburbs
4. Increase in accessibility to employment for lower income households
5. Government invest in low cost housing in more accessible locations

Figure 3.8 below provides an overview of the city of Johannesburg's GMS of 2011.

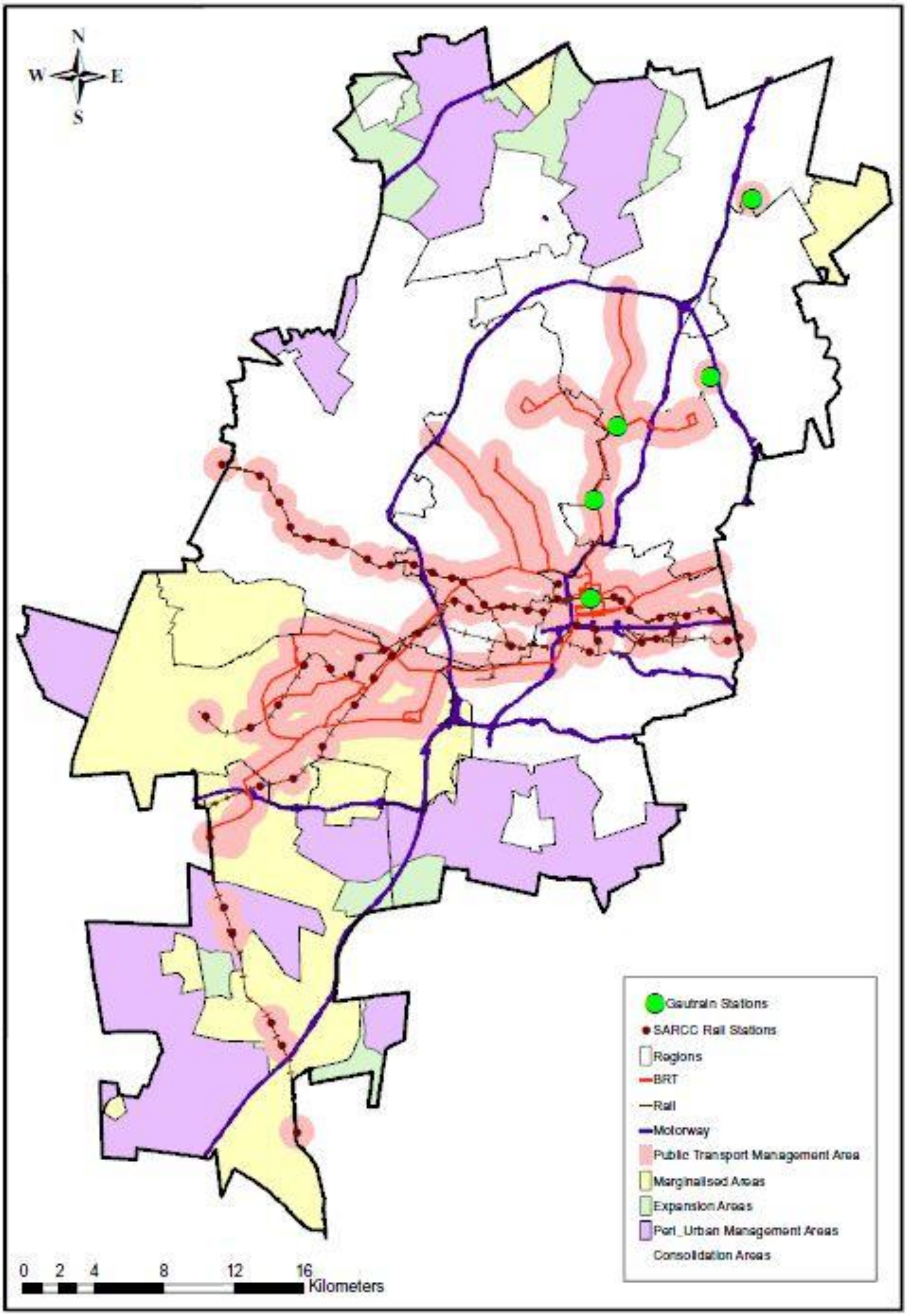


Figure 3.8: Densification corridors, growth boundaries and excluded areas of the GMS. (Source: City of Johannesburg (2011))

4. Choosing a land use change model

Various land use change models exist and have been developed to simulate future land use and policy scenarios. The five most popular literature comparisons that have been done on land use models are:

1. Agarwal et al. (2000) provides a comprehensive comparison of nineteen different land use models with relation to their spatial, temporal and decision making complexity
2. Verburg et al. (2004) discusses six descriptive land use change models with the purpose to describe the various features of land use change models that modellers should take into consideration
3. Wainger et al. (2007) compares a vast number of models (twenty four) with relation to their ease of use, ability to model quantity of growth, availability, technical expertise etc.
4. Pontius et al. (2008) experimented with nine popular models and did comparative studies based on their simulated results
5. Haase and Schwarz (2009) provides a comprehensive review of nineteen urban land use models from four different methodologies (spatial economics, system dynamics, cellular automata and agent based) and analysed their capability to model the human decision making sphere

From each one of these studies it is clear that various models exist that have been developed, applied and tested throughout various countries. It is also clear that each one of these models where designed for a very specific purpose, location and application in mind. From the models reviewed that have been applied in developing countries, no comparative literature is available on their adaptation to simulate specifically the urban development challenges (e.g. various formal and informal residential classes). Most of the models that simulate informality are newly created models not available in the main stream for adaptations (Section 2.6). Many of these models focussed on the simulation of informality and excluded the various formal development land use classes.

From the various comparative literature studies and reviews available on land use change models, two of the most widely used academically well-cited cellular automata models were chosen based on their applications and perceived value for modelling the urban environment in a developing context. The Dyna-Clue and Sleuth models were chosen, as both models have been applied in various cities and countries including developing countries and their use in urban growth studies are strongly supported through literature. Even though both models have not been implemented to simulate the various land use classes in the developing context, the literature made it clear that both models have been applied in a wide number of applications and have sufficient supporting documentation. Both models are based on sound statistical and mathematical theories and techniques can simulate land use change on a yearly basis and offers the modeller the opportunity to define the required spatial resolution for the specific study area.

A comparative study between these two land use models will be conducted to define the most suitable land use model for the respective case study area. The models will now be compared based on their ability to simulate urban growth for various developing land use classes in the developing context.

Comparative process

The comparative study is done through:

1. Setting up the required modelling criteria for the case study area (section 4.1)
2. Describing through literature reviews the two models' main characteristics and their ability to adhere to the modelling criteria set aside above. This is done by looking at the individual models based on (section 4.2):
    a. The required input data, the modelling methods used and the output requirements
    b. The advantages and disadvantages of choosing the specific model
3. Choosing the most suitable model based on the comparison (section 4.3)

4.1 Modelling criteria for the Johannesburg case study

The modelling criteria specification is an important step in the modelling process as this will outline the minimum set of requirements that the model should adhere to in order to execute the research study effectively. Based on a clear understanding of the case study and the various modelling needs required to adhere to the policies set aside in Chapter 4.3, a series of criteria where developed to compare the various models for their suitability to answer the research question. The main modelling criteria that will form the basis of the model and that are essential for the case study area are:

Model input requirements:

The following input requirements are of importance when choosing the desired model:

1. The input data should be easily obtainable, no fieldwork or data acquisition should be considered when populating the model.

Model process characteristics:

The following modelling characteristics in terms of how the model functions are necessary:

1. Drivers of change: The model should be able to incorporate the various human, biophysical and socio-economic drivers of land use change. The model should also allow for each one of these drivers to be applicable in the transition rules of individual land use types.

2. Incorporation of external models: Future demand for land use is dependent on the projected figures of how the economy and population will grow. It is thus essential that the model should allow for the incorporation of existing socio-economic model outputs.

3. The model should be able to evaluate the various policy scenarios.

4. Dynamic change: Spatial change is not linear and needs to be considered in a dynamic context. Thus dynamic feedback loops (temporal dynamics) should be applied.

5. Competition between land uses: The model should take into account the competition between land use types.

Model output requirements:

The following criteria are critical to the model as these will be used to measure the policies against one another. The model should be able to simulate the effects that the three policies/regulations will have on the land use change in terms of:

1. Densities: The model should be able to model residential densities and whether or not various suburbs, nodes or strategic corridors will densify under specific conditions.

2. Accessibility: The model should be able to simulate the effect that the policies will have on the travel distance from residential land uses to the city's economic centres.

3. Land use types: The model should be capable of simulating various types of land uses e.g. commercial, industrial, mining, residential, nature etc.

4. Residential land use types: The model should have the capability to simulate various types of residential land use e.g. formal, informal, backyard shacks etc.

6. Social housing: The model should also be capable of simulating the growth of Government's social housing. As these types of housing are a direct policy intervention and not market related.

4.2 Model characteristics

The following section provides an overview of the Dyna-Clue and Sleuth land use change models. The section looks at each model in terms of their general modelling approach (inputs, processes and outputs). The section concludes by discussing the advantages and disadvantages of choosing each model with relation to the capability of the models to adhere to the modelling criteria set aside in the above section.

4.2.1 Dyna-Clue

The Dyna-Clue (Dynamic conversion of land use and its effects on small regional scale) model is one of the most used allocation models in the planning field; it is theoretically sound and documented in various well cited literature papers. Its capability to simulate conversions of multiple land uses and it applicability in scenario analysis (Verburg and Overmars 2009) makes this a highly suitable model to consider for the study area at hand. Clue has been adopted in various European countries and has been applied in developing countries such as the Philippines (Verburg et al. 2002), China (Chen 2009; Rui 2010) and Vietnam (Castella and Verburg 2007). The Dyna-Clue 2.0 model (2006) will be considered for this case study, and can be obtained from the website of The Institute for Environmental Studies at: http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/Clue/index.asp.

Spatial data input

Table 4.1 shows the spatial datasets that should be prepared in map format for input into the various model settings. The inputs refer to figure 4.1.

Land use maps (SD1)	Current land use map of base year. Trend maps for conversion matrix
Locational driving factors (SD2)	Biophysical and socio-economic datasets
Spatial policies and restrictions (SD3)	Policy protected areas and location specific preference areas for land use types.

Table 4.1: Spatial data inputs

Non-spatial data inputs

In addition to the spatial data the model also requires non-spatial data inputs as shown in table 4.2.

Policy scenarios (NSD1)	Two policy scenarios that feed into the land use demand and conversion matrix.
Regional driving factors (NSD2)	Regional drivers influence the land use demand. These include demographic and economic models.
Expert knowledge (NSD3)	Additional source of data for determining land use conversions and elasticity values.

Table 4.2: Non-spatial data inputs

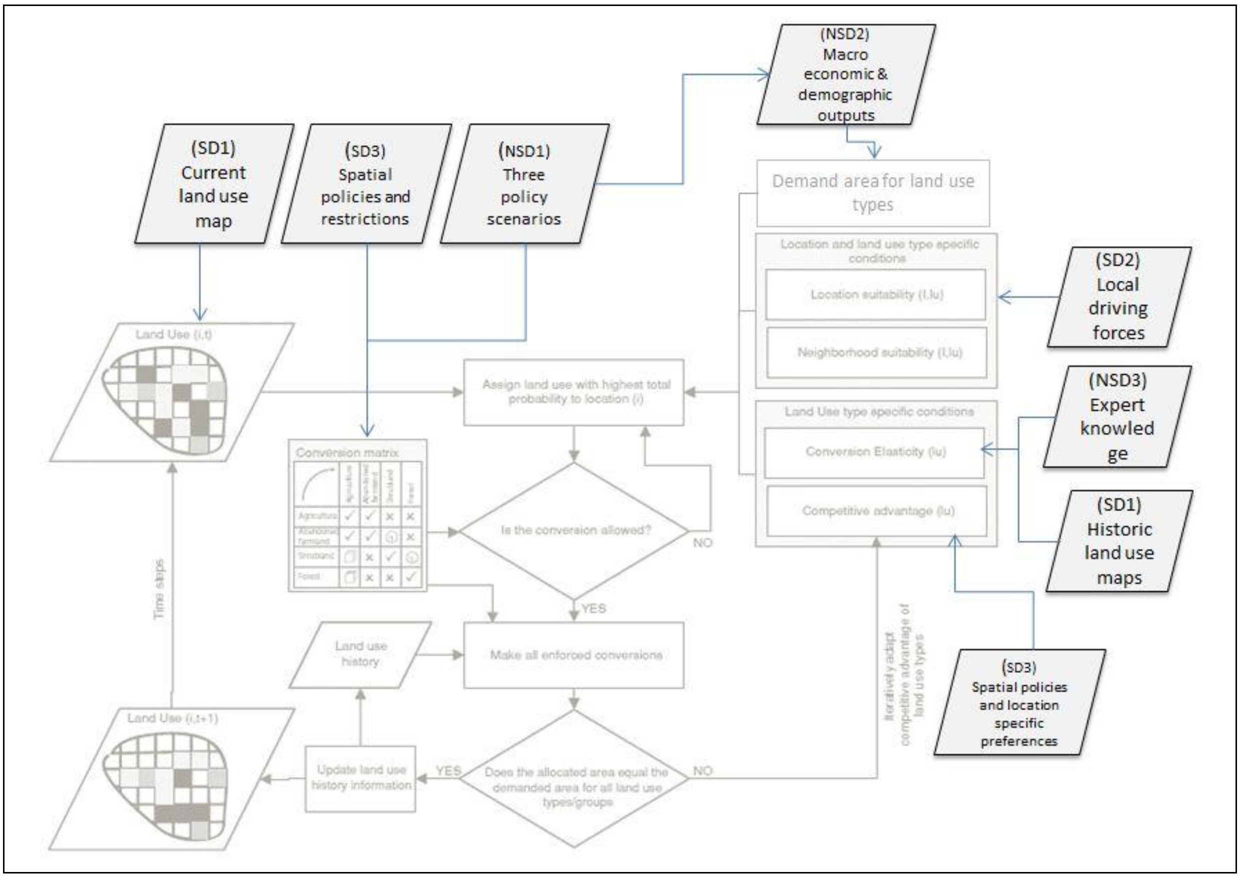


Figure 4.1: Input data for the allocation procedure of Dyna-Clue model. Adopted from Verburg and Overmars (2009).

Modelling process

Dyna-Clue is a spatially explicit land use change model that is based on 1. Empirical analyses, 2. Spatial analysis and 3. Dynamic modelling (interaction between space and time). The model is capable of simulating complex land use change systems and separates driving factors of quantity of change (amount of change) from location of change.

Dyna-Clue consists of two sub-models (Figure 4.2); a non-spatial demand component and a spatial allocation model (Verburg et al. 2002). The non-spatial demand module is an aggregate input that calculates the area demand per land use for the various land use classes. These inputs are obtained from regional drivers of change (e.g. population and economic dynamics) and can be derived either from simply trend extrapolations or external complex demographic and economic models or from development policies that are then converted into demand per land use for the model. The spatial allocation model translates these calculated demands into land use changes at various locations in the study area through utilising a series of driving forces (e.g. biophysical and socio-economic) and conversion rules (Verburg et al. 2002).

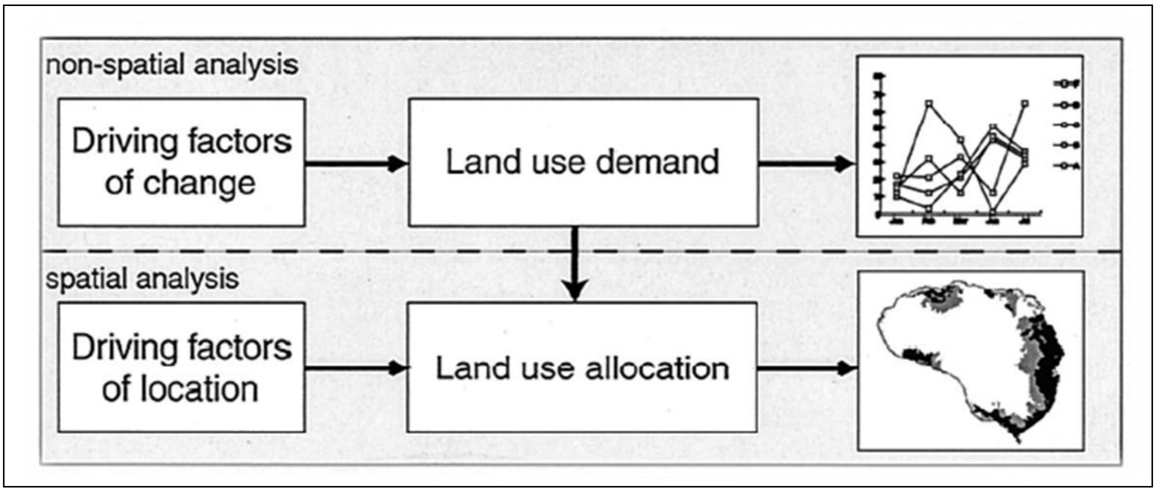


Figure 4.2: Sub-models in the Clue land use model (Verburg, Soepboer et al. 2002)

Land use allocation process

The spatial allocation of land use is dependent on four factors:

1. Location suitability – a process of determining the preference of land use suitability through actual land use patterns and local driving forces of change.
2. Conversion rules – the transition rules for various land use types to change into other land use types.
3. Spatial policies and restrictions – protected areas, restriction areas and development areas.
4. Land use demand – calculated from the non-spatial demand module.

The land use change allocation is an iterative process that consists of four primary steps (Figure 4.3):

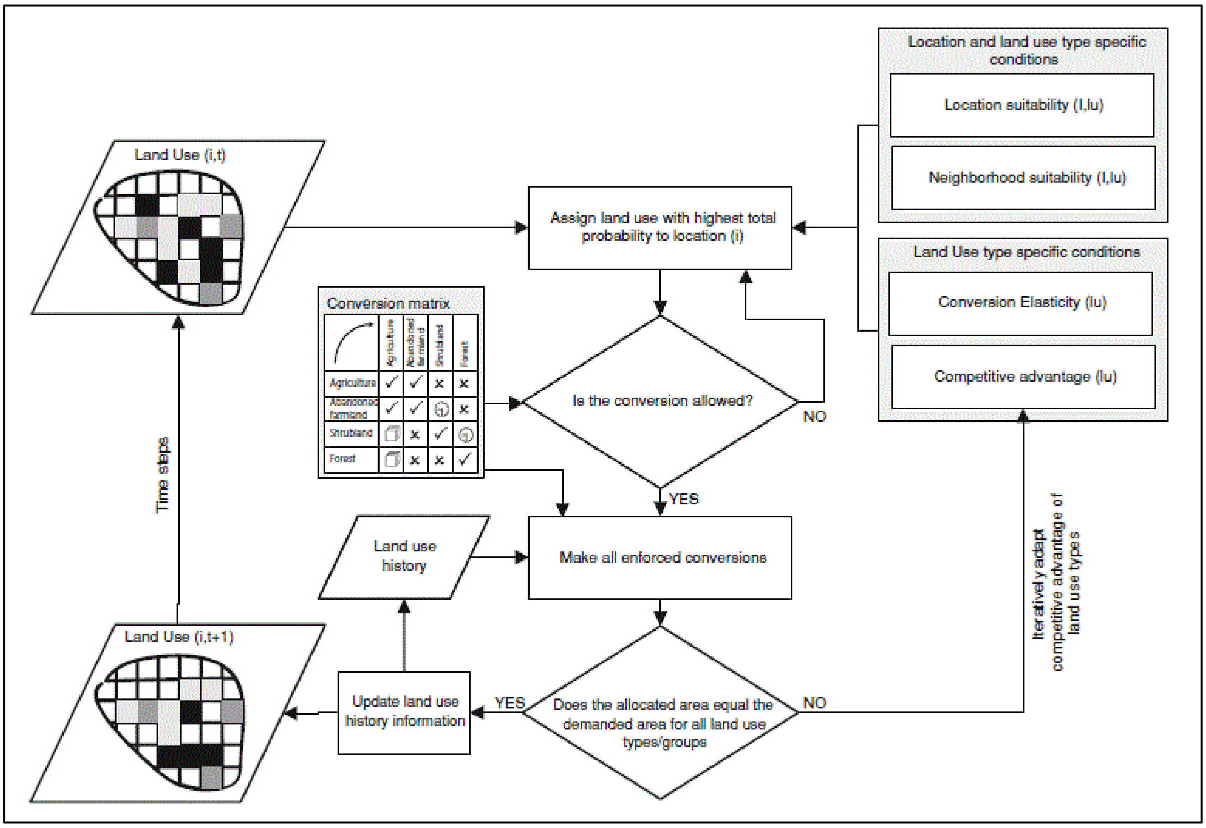


Figure 4.3: Allocation procedure (Verburg and Overmars 2009)

Step 1: Calculating the total change potential

The Dyna-CLUE model allocates land use changes with discrete time steps. In each time step (t) land use changes (lu) are allocated to the locations (i) that are most likely to change according to the different input parameters. Verburg and Overmars (2009) defines the highest total probability *($Ptot_{i,t,lu}$)* of change to be determined through;

$$Ptot_{i,t,lu} = Ploc_{i,t,lu} + Pnbh_{i,t,lu} + Comp_{t,lu} + ELAS_{lu} \quad (2)$$

Where

$Ploc_{i,t,lu}$: The location suitability is the probability (P_i) of a specific cell being dedicated to a specific land use type. It is calculated by determining the relation between land use types and a set of driving forces (X) of change through a step wise logistic regression process, where the probability of a cell is determined through (Verburg, Soepboer et al. 2002):

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} \dots \dots \dots . . + \beta_n X_{n,i} \quad (3)$$

$Pnbh_{i,t,lu}$: Neighbouring cells might influence the centre cell depending on the impact specified by the modeller.

$Comp_{t,lu}$: Location specific preference maps can be used to indicate the preference for a specific land use type at a certain location. The location suitability and neighbourhood influence can be overruled as this adds a competitive advantage to a land uses location.

$ELAS_{lu}$: The costs of conversion of the current land use type. High values indicate a higher cost of conversion and thus a higher probability that the land use will stay unchanged.

Step 2: Checking if conversion is allowed

In this step the model checks whether the conversion is allowed based on the conversion rules set up by the various spatial policies and restrictions. These include the conversion matrix which specifies if land use types may change into other land use types as well as restricted areas that restricts conversion of specific land use types on specific located areas e.g. residential development outside the urban development boundary etc. Conversions can also be forced after a specific time elapsed.

Step 3: Controlling allocated land use area against demands calculated

The allocated land area per land use type needs to be equal to the demands specified by the non-spatial sub-model. As long as the demand and allocation area differs, the model will iterate.

Step 4: Assigning a land use type to a specific cell

When the allocation and the demand are equal the time series are saved (Land use = t+1) and the next years simulation is started.

Model outputs

The simulation results are exported per year to ascii format. The ascii files are then converted to raster format in GIS software and displayed per simulation year. The outputs will display the land use type and the specific locations where these land use types are located.

Advantages/Disadvantages of using Dyna-Clue

The following section relates to Dyna-Clue's capability to adhere to the modelling criteria (inputs, processes and outputs) set aside in Section 4.1. The advantages and disadvantages of using Clue for the modelling of urban land use change in the Johannesburg case study area are:

Modelling criteria	Dyna-Clue's (+)Advantages and (-)Disadvantages
Readily available input data	+ The model input requirements are flexible and many of the datasets are readily available for the case study area. - The preparation of the demand inputs can be time consuming and is reliant on external models
Incorporate human, biophysical and socio-economic drivers of land use change	+ The model has the capability of incorporating both regional (demographic & economic) and local driving forces of change (biophysical and socio-economic) + The modeller can include as many driving forces per land use type as deemed necessary + The model also has the capability of including human choices (human driving forces) by allowing the simulation of policy scenarios through a series of policy alternatives
Incorporation of external models for economic and demographic projections	+ External demographic and economic models can be used and coupled with the model to calculate and verify the future land use demands
Modelling policy scenarios	+ The Dyna-Clue model is very applicable in simulating various policy scenarios
Dynamic change through temporal feedback loops	+ Capable of simulating at a yearly temporal scale with dynamic feedback loops
Competition between land uses	+ Models competition between multiple land uses based on suitability of land use for a specific land use type + Also includes the use of preference maps for specific land use types
Density modelling	+ Quantity (amount) of change is determined through the non-spatial demand model - Quantity (density) of land use types at specific locations is not a direct output of the model
Accessibility and road modelling	+ Accessibility can be done external to the model - The model does not make provision for the modelling of growth in linear features and therefore cannot model future land use of roads or railways directly
Multiple land use types	+ The model is capable of simulating multiple individual land use types simultaneously
Multiple residential breakdown (e.g. formal and informal)	+ Can be done by introducing more land use classes - No documented literature examples of multiple classes of residential land use types
Modelling income for lower order residential land use types	+ Can be done by introducing more land use classes - No documented literature examples of this breakdown
Other	+ User can define spatial resolution + The model takes cognisance of a bottom-up and top-down approach, instead of the normal bottom-up CA process.

Table 4.3: Dyna-Clue functionality in relation to the case study requirements

4.2.2 Sleuth

The Sleuth model is a CA model that is widely applied and accepted in both academia (with 32 major studies documented in literature) and in practise (with over a 100 applications worldwide) (Clarke 2008). Various well cited papers (Silva and Clarke 2002; Jantz et al. 2004) emphasize the suitability and adoptability of the model for the use in urban growth studies.

The model has been applied in various cities throughout the United States (Jantz et al. 2004) and other countries such as Portugal (Silva and Clarke 2002), Brazil (Leao et al. 2004), Italy (Caglioni, Pelizzoni et al. 2006), Oman (Al-Awadhi 2007), Egypt (Abd-Allah 2007), Australia (Liu and Phinn 2004), China (Wu wt al. 2009) and South Africa (Watkiss 2008). The model has proven throughout the various applications to be portable and adaptable in many contexts. Sleuth 3.0 Beta version will be investigated for use. It is an open source 'c-language' programme obtainable from the research website of project Gigalopolis on http://www.ncgia.ucsb.edu/projects/gig/.

Data inputs

Sleuth is an abbreviation for the six input layers required to run and populate the urban growth model; Slope, Land use, Exclusion, Urban extent, Transportation and Hillshade.

Slope – To implement topographical constraints and introduce suitability of flatter areas.

Land use – Not obligatory but used by the coupled Deltatron land use model, needed for land use change modelling when considering different land use classes.

Exclusion – This layer is used to introduce areas that are prohibited from urbanisation. This layer is also used when modelling policies.

Urban extent – This layer indicate the urbanised (built-up) area and should be available for at least four time periods.

Transportation – The model requires two different time stamp transport layers.

Hillshade – This layer is only used as a background and positional reference, it is not used in the modelling process.

Modelling process

The Sleuth model is characterised by three phases: 1. Data preparation, 2. Calibration and 3. Projection. The Sleuth model consists of two sub-components; an urban growth model (UGM) that focuses on simulating urbanisation and a coupled land use change model called Deltatron that focuses on the simulation of various land use type changes. Most applications of the Sleuth model use the UGM subcomponent as they focus on the modelling of urban/non-urban transition. The following section will explain the processes of the two sub-components.

Urban Growth Model (UGM)

Transition of non-urban to urban cells takes place through a series of growth rules (Table 4.4). The model has the capability to simulate four types of urban growth dynamics: 1. Spontaneous growth, 2. Diffusion, 3. Edge growth and 4. Road-influenced growth. These growth types are controlled through five growth coefficients that rule the behaviour of the cells and form the core of the Sleuth model: 1. Dispersion, 2. Breed, 3. Spread, 4. Slope resistance and 5. Road gravity (Jantz et al. 2004).

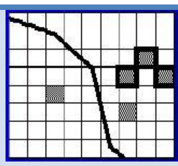
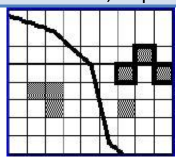
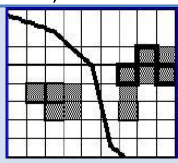
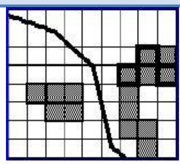
Growth cycle order	Growth type	Controlling coefficients	Summary description	Example
1 (t=0)	Spontaneous	Dispersion	Randomly selects potential new growth cells (random urbanization of pixels)	 f (diffusion coefficient, slope resistance)
2	New spreading centres	Breed	Growing urban centres from spontaneous growth (emergence of new urbanizing centres)	 f(spontaneous growth, breed coefficient, slope resistance)
3	Edge	Spread	Old or new urban centres seed additional growth. Most common type of development. (Expansion on the urban edges)	 f(Spread coefficient, slope resistance)
4 (t=t+1)	Road-influenced	Road-gravity dispersion, breed	Newly urbanised cell spawns growth along transportation network (road network influence)	 f(breed coefficient, road_gravity coefficient, slope resistance, diffusion coefficient)

Table 4.4: Growth rules in Sleuth (Table extracted from Jantz, Goetz et al. (2004) p.254 and images extracted at Project Gigalopolis http://www.ncgia.ucsb.edu/projects/gig/index.html)

The five coefficients are responsible for the urbanization of cells and needs to be carefully calibrated by comparing simulated land cover change to historically observed data (Jantz et al. 2004). Calibration is done through running a series of least square regression measures between the seed (initial condition) year and the final (observed) year. Various measures are then applied to determine the spatial fit between the 2 years in order to derive the control parameters (coefficients) of growth.

The calibration process is normally conducted through a tree step refinement process of starting the calibration (goodness of fit) on a course resolution (four times the actual model resolution), refining it to a medium resolution (two times the model resolution) and finally calibrating the model to the actual resolution resulting in a fine scale calibration (Dietzel and Clarke 2004).

An additional growth rule that influences the static growth coefficients is called the 'Self Modification' rule. This rule is brought in to simulate population dynamics more accurately (e.g. rapid growth spurges). Critical high and critical low values of growth are set up in the file parameter and when these are exceeded a boom or bust cycle kicks in (Silva and Clarke 2002). In these instances the growth coefficients are adapted to reflect the boom/bust cycle (Figure 4.4).

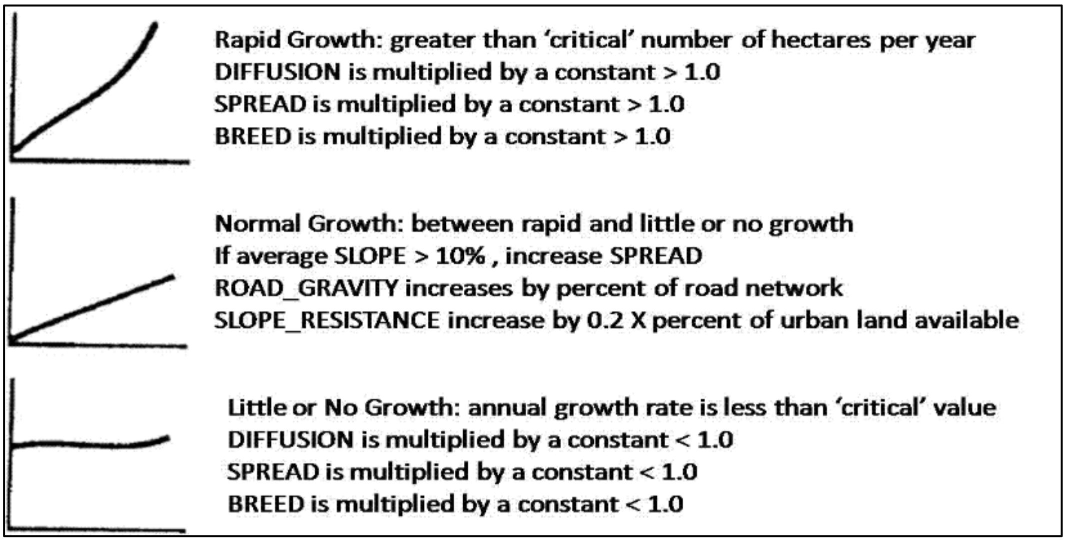


Figure 4.4: Sleuth self-modification rule (http://www.ncgia.ucsb.edu/projects/gig/About/gwSelfMod.htm)

Using a series of Monte Carlo (MC) simulations for each year and the parameters defined in the calibration process the coefficients are applied to the seed (current) year and projected into the future through a series of growth cycle (Figure 4.5).

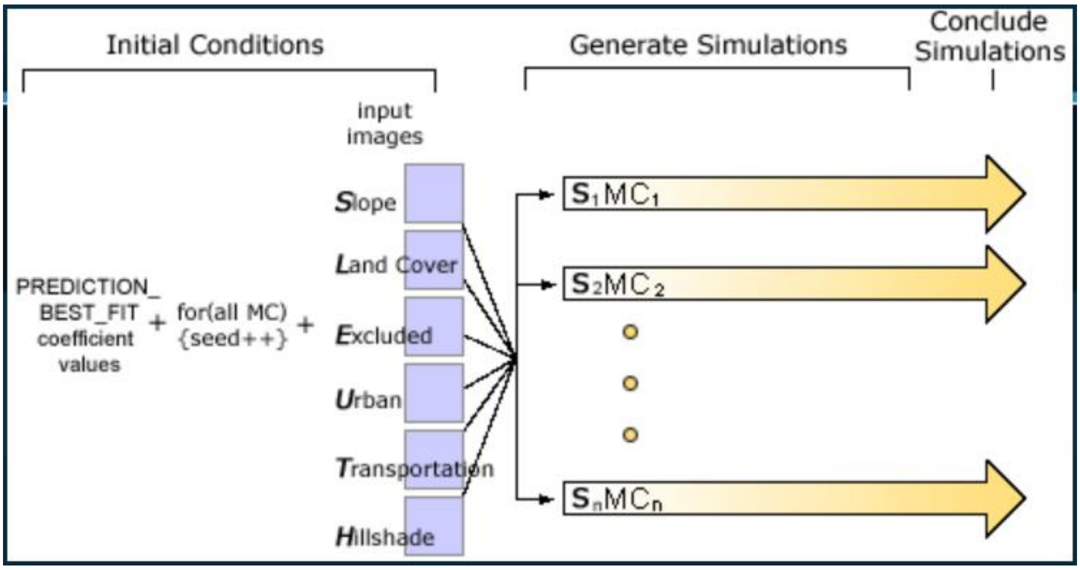


Figure 4.5: Sleuth prediction process (http://www.ncgia.ucsb.edu/projects/gig/About/bkStrPrediction.html)

Deltatron model

Land use/cover change modelling is determined through the Deltatron model. This subcomponent is responsible for modelling the transition of non-urban land uses. This sub-model's function is not well documented according to Jantz et al. (2004) and acts as a black box for modellers.

Model outputs

Sleuth generates GIF's as outputs that need to be converted into a GIS format such as TIFF's before the data can be displayed and analysed. The Sleuth model produces yearly probability maps of urbanization per cell.

Advantages/Disadvantages of using Sleuth

The following section relates to Sleuth's capability to adhere to the modelling criteria (inputs, processes and outputs) set aside in Section 1. The advantages and disadvantages of using Sleuth for the modelling of urban land use change in the Johannesburg case study area are:

Modelling criteria	SLEUTH (+)Advantages and (-)Disadvantages
Readily available input data	-The model requires various historical input layers many of which are not readily available in the case study area (e.g. four historical extent layers of build-up and two transportation layers). The inputs are fixed and extracting these from satellite imagery will be time consuming.
Incorporate human, biophysical and socio-economic drivers of land use change	+ The model has built in 'demographic' drivers of change - The build in demographic drivers of change are all based on historical patterns and trends and not possible future scenarios. - Model does not account for economic drivers of land use change - The model does not account for human choice interventions e.g. Zoning, Social housing interventions or government investments. - The model is restricted to predefined growth rules that govern the model's behaviour; therefore adding additional drivers of change is not possible. The limitations of not incorporating these socio-economic drivers of change are a big disadvantage in this specific case study area.
Incorporation of external models for economic and demographic projections	- No external modelling outputs are taken into consideration. As growth rates are calculated internally this limits the model's capability of incorporating external well defined population and economic scenarios.
Modelling policy scenarios	+ Allows the incorporation of a restriction layer - The restriction layer input is the only primary function to implement policies, thus the model is very limited in simulating alternative policies
Dynamic change through temporal feedback loops	+ Capable of simulating at a yearly temporal scale + The 'self-modification rule' allows for non-linear growth
Competition between land uses	- The competition between land use types in the Deltatron model is not documented well enough to understand how it deals with competition of land use types.
Density modelling	- Not possible as the model merely simulates urban and non-urban land use classes. -Incorporating a density proxy into the model would require significant programming or the coupling of a new model
Accessibility modelling	+ Euclidean distance can be easily derived from the modelling outputs - The model does not make provision for the modelling of growth in linear features and therefore cannot model future land use of roads or railways directly
Multiple land use types	+ The Deltatron model has the possibility of simulating various non-urban land use types
Multiple residential breakdown (e.g. formal and informal)	- The model is not designed to separate classes within the built-up category - Due to the limited flexibility in altering the driving forces it would not be possible to simulate the growth of informal settlements without extensive programming. - No examples where found where the Sleuth model was directly altered to simulate both formal and informal simultaneously. There are however a couple of Phd studies that aimed to do this but either ended up building new models based on CA principles (Sietchiping 2004) or failed completely in modelling informality (Abd-Allah 2007).

Modelling income for lower order residential land use types	- Not possible for same reasons listed above.
Other	+ Well documented implementations in various developing countries + User can define spatial resolution + Due to extensive calibration, high confidence levels of accuracy can be provided - The model uses a long and tedious calibration process, and many literature papers refer to this step in the modelling process of Sleuth to be very time consuming and depended on accurate historical data (Jantz et al. 2004; Clarke 2008) - Can model urbanisation but not redevelopment - Only bottom up approach (local properties) not top-down (global/regional properties) taken into consideration.

Table 4.5: Sleuth functionality in relation to the case study requirements

4.3 Model comparison

Based on the 4.1 Modelling criteria for the Johannesburg case study area together with the comparison of the advantages and disadvantages of the two land use change models it was decided that Dyna-Clue offers the best base model to work with. Table 4.6 below provides the comparison of the two models based on their ability to adhere to the model requirements needed. The advantages (+) and disadvantages (-) are summarised as depicted in the previous section and the table provides an indication of how the models compare, (+) indicate that the model is able to handle these requirements effortlessly, (-) indicates that the model will need substantial programming to alter the model. Where both (+) and (-) are present it indicates that the model can handle the criteria with some additional adjustments or that a loosely coupled separate model is needed for the required functionality.

Modelling criteria	Dyna-Clue	Sleuth
Readily available input data	+ -	-
Incorporate human, biophysical and socio-economic drivers of land use change	+	-
Incorporation of external models for economic and demographic projections	+	-
Modelling policy scenarios	+	+ -
Dynamic change through temporal feedback loops	+	+
Competition between land uses	+	-
Density modelling	+ -	-
Accessibility and road modelling	+ -	+ -
Multiple land use types	+	+
Multiple residential breakdown (e.g. formal and informal)	+ -	-
Modelling income for lower order residential land use types	+ -	-

Table 4.6: Comparison of models against case study requirements

What sets the Dyna-Clue model apart from the Sleuth model is its flexibility in its input requirements and the fact that most of the data requirements for the Dyna-Clue model are already readily available from the Johannesburg municipality. Dyna-Clue is also capable of incorporating external model outputs and can simulate socio-economic, biophysical and human drivers of change where Sleuth is limited in this regard.

Sleuth is limited in its incorporation of policy scenarios where Clue is geared towards understanding implications of future policies and its influence on the land use patterns. Dyna-Clue is thus much more suitable for the modelling of land use change and provides the most flexibility for incorporating various types of land use classes. Dyna-Clue has the capability to indirectly model quantity of change (densities) due to its flexibility in specifying land use classes. Both models need to be exported and loosely coupled with alternative software to analyse accessibility. The Dyna-Clue model is set up to take notice of the competition between land use classes specifically when policy makers decide to intervene with priority areas.

It is clear from the comparison that the Dyna-Clue model is capable of handling all model criteria as set aside in section 4.1, there are however a couple of noticeable drawbacks that needs to be attended to in order to adapt the model for the specific case study. This will be addressed in Chapter 5.

5. Adapting, Populating and Running Dyna-Clue

This chapter addresses the adaptation of the model to suit the modelling requirements of the Johannesburg city. The chapter also covers the data preparation phase, how the model was populated and the running and sensitivity analyses of the model.

5.1 Adapting the Dyna-Clue model for implementation

Based on the technical review of how the Clue model operates (Section 4.2.1) and its comparison with the modelling criteria, it's evident that the model falls short of some of the key modelling criteria previously specified. The specific shortcomings (specified as disadvantages in the critical review table) that need to be addressed are:

1. Density constraints: The model assigns one land use class to a specific cell and it's therefore not possible to directly model the density of houses per cell making the simulation of policies geared towards densification difficult.
2. Choice of land use classes: The land use classification chosen for the model is of significant importance as the classes will be used to compare the various scenario outcomes.
3. Static infrastructure modelling: Clue cannot model the growth of linear features, making the simulation of roads difficult. The model is also not capable of directly modelling or measuring the accessibility of residential land use classes to economic opportunities. How can these limitations be addressed in the model?

The following sections will discuss the shortcomings one by one and indicate how these will be addressed in the modelling process.

5.1.1 Modelling Density

Housing densities per cell are not a direct output of the model and it's therefore not possible to directly model the effect that policies will have on the city's density. Also the inability of the model to include two land use classes in the same raster cell makes it difficult to simulate the mix of informal and formal housing. There are two popular ways in which to include residential density modelling in a CA model:

1. Representing land use as a percentage of a cell

2. Representing a land use as a cell

The first is to model the land uses separately by assigning actual residential densities per raster cell, however in CA a raster cell can only be assigned one value and therefore it's not capable of modelling two land uses in the same layer. As such, two separate simulation runs would have to be undertaken (e.g. formal and informal) and the results should then be combined through map algebra into one output layer to represent the number of households per cell or the percentages mix of formal and informal (Figure 5.1).

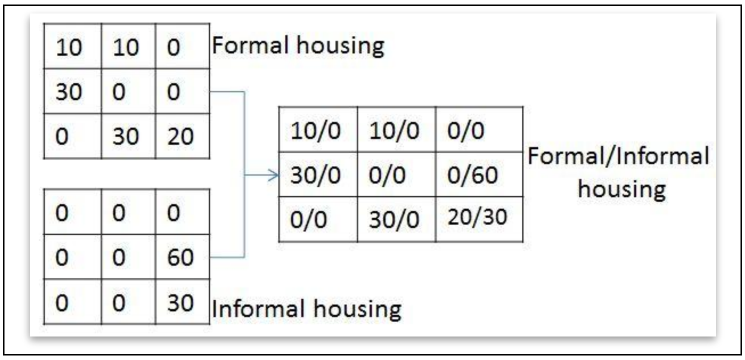


Figure 5.1: Directly modelling formal and informal densities per cell

Modelling land uses separately in layers and combining the layers at the end of the simulation process is not ideal as this eliminates the strength of the Dyna-Clue model to calculate the competition between land uses. The Dyna-Clue model was specifically designed to model the effects of land use on a small scale, thus representing each raster cell in the model as a unique type of land use.

A second consideration for modelling the residential densities would be to use land use types as a proxy for densities. Beardsley (2009) describes how the UPlan model makes use of density factors when modelling in a CA environment. Unique residential types can then be classified (according to densities) separately and modelled in competition with one another. An advantage of this modelling approach is that it allows the incorporation of various other types of housing deemed necessary to be modelled separately for comparing and analysing the various scenario outputs. E.g. Instead of providing proxies for low, medium and high densities, other residential land uses (e.g. Government low cost housing and back-yard shacks) can now be included in the model (Figure 5.2).

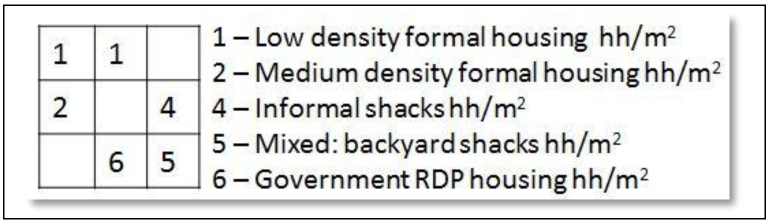


Figure 5.2: Land use as a proxy for residential densities

Low cost housing is a Government driven response to the current housing backlogs in the lower income categories and a response to eliminating the growth of informal settlements. This low cost housing is a Government driven interventions and develops differently from the other types of market-led response housing. In order to measure the inclusion of low cost Government housing into the city, it should be modelled as a separate class with its own set of driving forces and transition rules.

5.1.2 Creating an innovative land use typology

Land use is a general term used to describe how land is being used by humans and the socio-economic activities that take place on the parcel of land (ESPON 2011). Deciding which land use classes to incorporate in the land use change model is an important step as these classes should be representative of the study area and have the capability to answer the research question presented.

When deciding on a land use typology the following criteria were taken into consideration:

1. The classes should represent the function of the land use and must be representative of the case study area as described in Section 3.2 (e.g. formal residential, informal residential, commercial, industrial, mining etc.).
2. The function of residential land use classes should act as a proxy for household density, thus representing the intensity or concentration of activities on a specific parcel (e.g. low, medium, high density).
3. The inclusion of Government low cost housing into the city is a critical component in the cities growth management strategy and their accessibility should be measured to determine the progress that Government has made. Consideration should therefore be given to include the income attribute into the typology as one of the critical scenario outputs of the model is to measure the inclusion of low-income social housing into the city.

Due to the land use typology criteria specified, it is clear that just using normal functional land use classes (e.g. Residential, Commercial, Industrial, Mining etc.) will not be sufficient in answering the research questions; specifically those aimed at the policies (densification corridors and inclusionary low-cost housing). It's evident that a more nuanced urban land use typology is required.

Three important categories are mentioned when defining land use in the specific case study area. The first is the land use function or activity that takes place on the land, the second is the intensity with which the activity occupies the land (Rodrique et al. 2009) and the third is an additional income attribute. Combining these three categories into one land use typology can provide a solution for linking densities (intensity) and income classes to a specific function of land use.

In order to combine the nature of land use (function), the level of accumulation (intensity) and the income attribute, an analysis process (Annexure A) was followed. Ten land use classes of which six are residential land uses were defined. The Dyna-Clue's limitation to incorporate only ten land use classes limited the scope of expanding these classes to cover a more comprehensive classification. Densities were calculated after the land use typology was applied to the case study area. The densities were calculated on the amount of dwelling units per land use class. This was done by dividing the amount of dwelling units on a specific land use type by the area in hectares that made up that land use type in the case study area.

$$Dwelling\ density\ per\ land\ use = \frac{Dwelling\ units\ (du) per\ land\ use\ type}{Area\ (hectare) per\ land\ use\ type} \qquad (4)$$

The results of the suggested three-layered typology are represented in Table 5.1 below.

Land use typology and (code)	Dwelling (Household) density per land use type
Commercial (0)	n/a
Other (1)	n/a
Industrial (2) Mining and Manufacturing	n/a
Open (3) Vacant and small holdings	0.53
Low density residential (4)	5.69
Medium density residential (5)	13.73
High density residential (6)	46.22
Mixed formality (7)	31.82
Informal settlements (8)	31.02
Government housing (9)	18.35

Table 5.1: New land use typology and associated densities

These ten land use classes together with their associated residential densities will be used when defining the demand figures for the various typologies. Figure 5.3 below shows the spatial representation of the nuanced ten class typology.

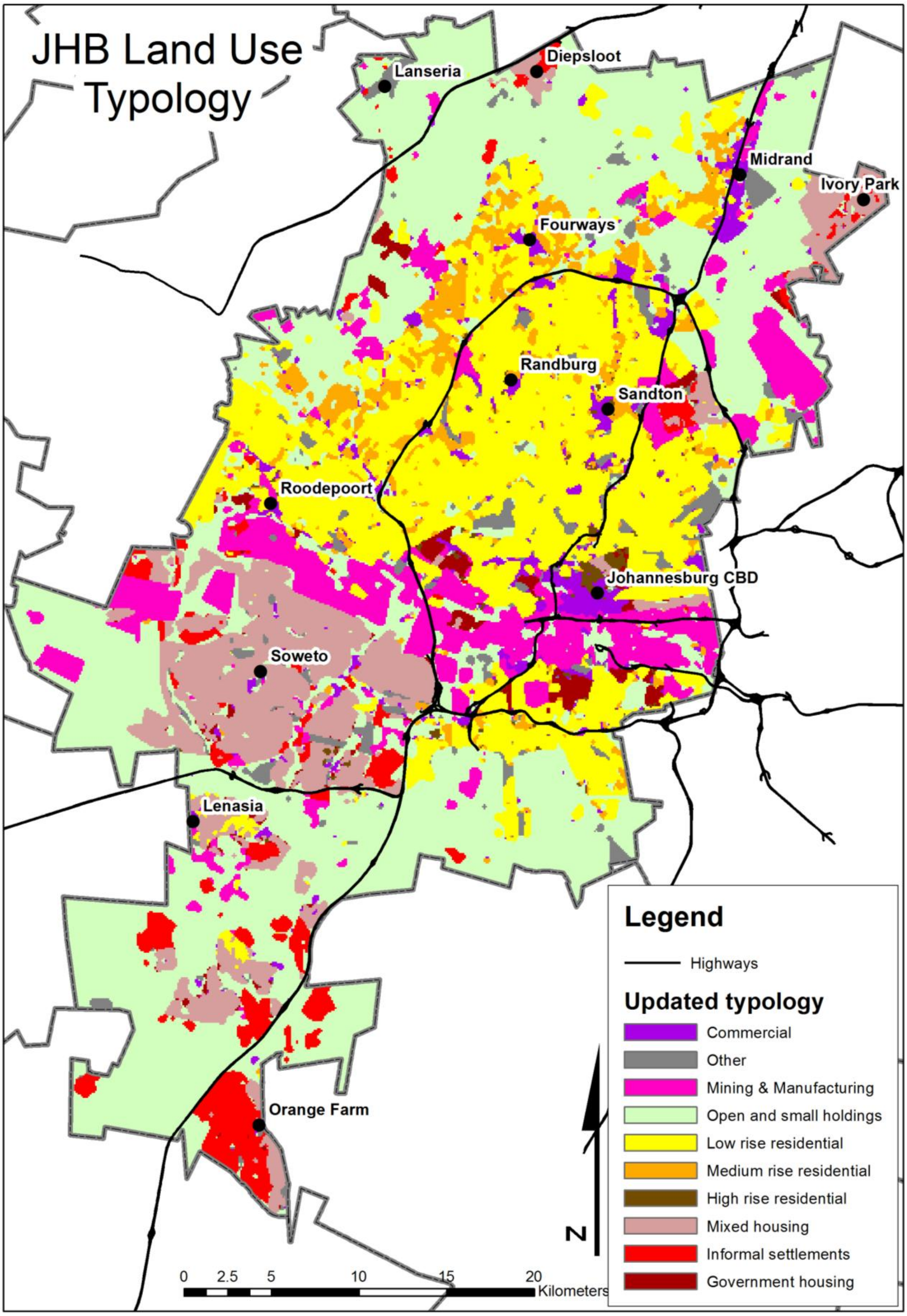


Figure 5.3: Nuanced land use typology

5.1.3 Dealing with static infrastructure modelling

The constraints of accessibility modelling and the inability of the model to simulate linear features are two important issues to consider in the Dyna-Clue model. These constraints can be overcome by:

1. Inability to simulate linear features: Roads are classified within the static 'Other' land use class and can therefore not be modelled to grow. Roads and accessibility to roads and networks is an important driver of local land use change. Various land use classes are attracted to road networks and it is therefore important that this layer is incorporated in the model. The model however allows for various drivers of change as input into the model. A new road layer set will thus be used and included as a driver of land use change but will not be modelled in terms of growth.

2. Accessibility modelling: One of the modelling output requirements was to be able to measure the travel time; access from residential areas (specifically low-income housing) towards the economic centres. This can be done through a loose coupling with ArcGIS Network analyses. Using the outputs of the simulation results and a separate road network, accessibility can be calculated externally to the model as part of the policy comparative measures.

3. Infrastructure growth: Focussing on infrastructure investment is one of the key policies that will be modelled. How will the implementation of e.g. the new Bus Rapid Transport (BRT) system, new economic hubs in the south and the new Gautrain railway and stations be taken into consideration? It is proposed to incorporate these investments through spatial preference maps (referred to in Section 5.2.3) and through local drivers of change (referred to in Section 5.2.4). Spatial preference maps can be used to indicate the corridors and nodes next to these rails, transport systems and stations that will be dedicate/zoned for 'High residential' use only. Preference maps can be scheduled as an event at a specific time and location in the Dyna-Clue model. Using drivers of land use change can also support this process. Various land use types can be attracted to these infrastructure developments. Specific infrastructures that will be included as 'drivers of change' are:

   3.1. New Gautrain stations,

   3.2. New BRT routes and the

   3.3. New planned commercial hubs for the South.

5.2 Populating the model

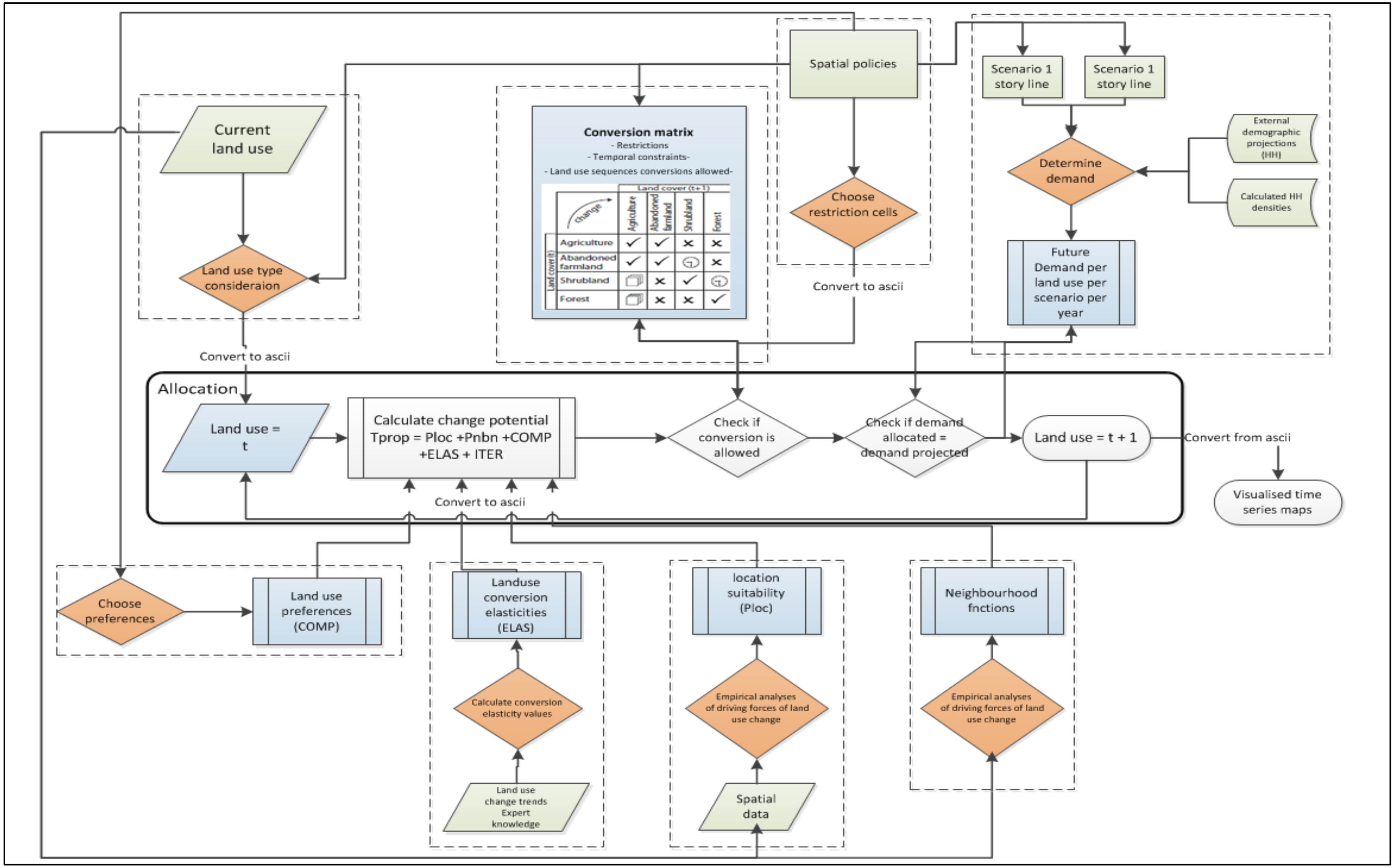


Figure 5.4: Modelling overview (Adopted from Verburg and Overmars (2009))

Figure 5.4 above provides an overview of the adapted model that will be utilised for the simulation process. The following sections will describe the various components of the model and will focus on how the data was prepared and populated into the model. The various sections that will be discussed are 1. Land use demand calculations, 2. Spatial policy restrictions, 3. Location preferences, 4. Drivers of land use change, 5. Neighbourhood factors and 6. Conversion rules.

5.2.1 Determining/predicting land use demand

The model requires a set of demand values per land use class. These demand values are the projected growth anticipated (or as part of a policy simulation) per land use class for the future. Land use demand figures per land use type are calculated on a regional level for a case study area. The most common method to determine these demands is either through extrapolation of land use trends from the recent past or through coupling macro demographic and economic models (Verburg et al. 2004). The case study will make use of projected household control totals produced by an external demographic model. This section translates the external demographic model outputs (Section 3.3.1) together with the two defined policy scenarios (Section 3.3.2) into demand figures for the model. The model requires a series of input values for the two scenarios that indicates demand per land use for each forecasted year. Calculating these demand figures should be done based on the adequate raster resolution for the model. It was decided based on the modelling constraint and an analysis on the impacts of various cell resolutions (Annexure B) that a 100m cell resolution should be satisfactory for the modelling approach. It is important to understand that the demand section is the non-spatial allocation that is aimed at 1. Linking the external demographic projections and 2.Outlining the demand figures for the two policy scenarios.

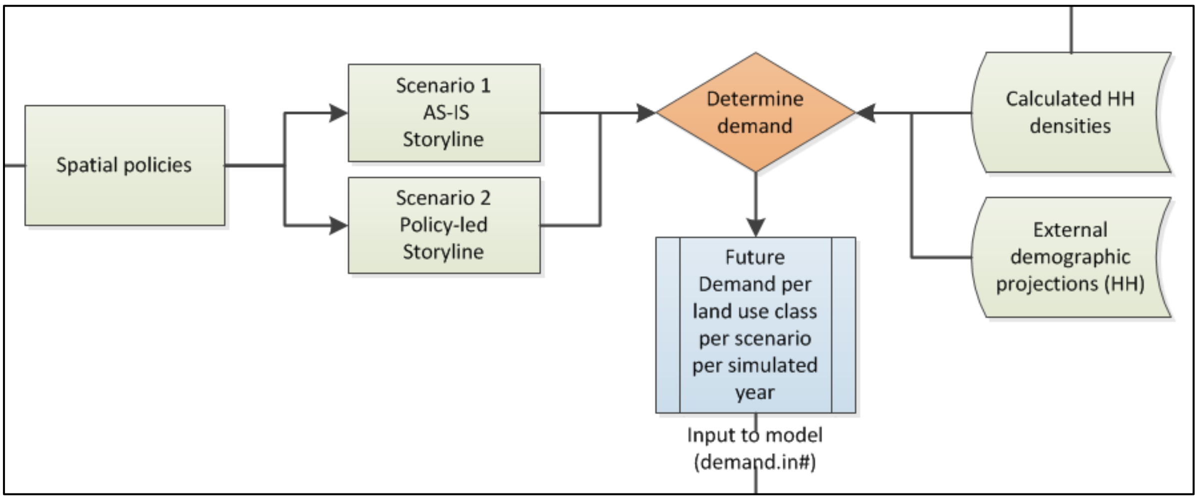


Figure 5.5: Calculating demand figures for populating the model

Scenario 1 – Spontaneous growth (As-Is Scenario)

This scenario will explore the impacts on the Johannesburg metropolitan landscape if the government continuous along the same trajectories as the past decade. Government housing is constricted to a budget and thus only minimum Government housing (same percentage as current) on cheaper available vacant land will be provided. Densification will take place primarily through new development (infilling) and to a lesser extent redevelopment. Due to the already large housing backlog and a projected increase in backlogs due to the constraints on the Government's budget, more informal and mixed use housing will surface. No Urban development boundary (UDB) is applied and as such mostly vacant land on the periphery of the city will be utilised for development.

Calculating demand figures

Based on the projected households figure for 2030 (described in Section 3.3.1) and the densities per land use type calculated in section 5.1 the demand Table 5.2 was created to reflect the land use demand figures for the AS-IS Scenario. The table shows for each land use type the amount of hectares that it occupies in 2007 and the amount of hectare it should occupy in 2030. The total number of households in the two years should correlate to the actual and projected figures (Section 5.3.1), the household figure per individual land use type is the result of the density per land use multiplied by the amount of hectares. To align the cell space available with the demand figures, a slight adjustment was made to fit the demand with the space available.

Land use	2007 extent Hectares (HA)	House-holds (HH) 2007	% HH	Land use change	2030 extent (HA)	2030 adjusted extent (HA)	(HH) 2030	% (HH)
(0)Commercial	4568	-	-	+30%	5938	5930	-	-
(1) Other	4436	-	-	0	4436	4436	-	-
(2) Manu - facturing + Mining	15326	-	-	-10%	13793	13780	-	-
(3) Small holdings + Open land	69039	36628	3.14	-70%	20712	20700	10988	0.50
(4) Low rise	37579	213688	18.34	+25%	46974	46970	267110	12.16
(5) Medium rise	7627	104754	8.99	+200%	22881	22870	314261	14.30
(6) High rise	708	32726	2.81	+100%	1416	1400	65453	2.98
(7) Mixed	16949	539378	46.29	+50%	25424	25400	889823	40.50
(8) Informal	6397	198432	17.03	+197%	18999	18987	569973	25.94
(9) Govern-ment	2164	39707	3.41	+100%	4328	4320	79414	3.61
Total	**164793**	**1165313**	**100**		**164901**	**164793**	**2197021**	**100**

Table 5.2: Land use demand calculations for 2030

Applying demand figures in model

Land use demand figures are needed for each year that should be considered in the simulation process. In order to project the growth curve between the initial (2007) and projected (2030) households the same growth curve as the input external demographic model (Figure 3.7) were used. Figure 5.6 below represents the input values for the model, the growth trend are quite linear between the initial and projected year, it is deemed acceptable as it is based on the official projection figures of Global Insight (2011).

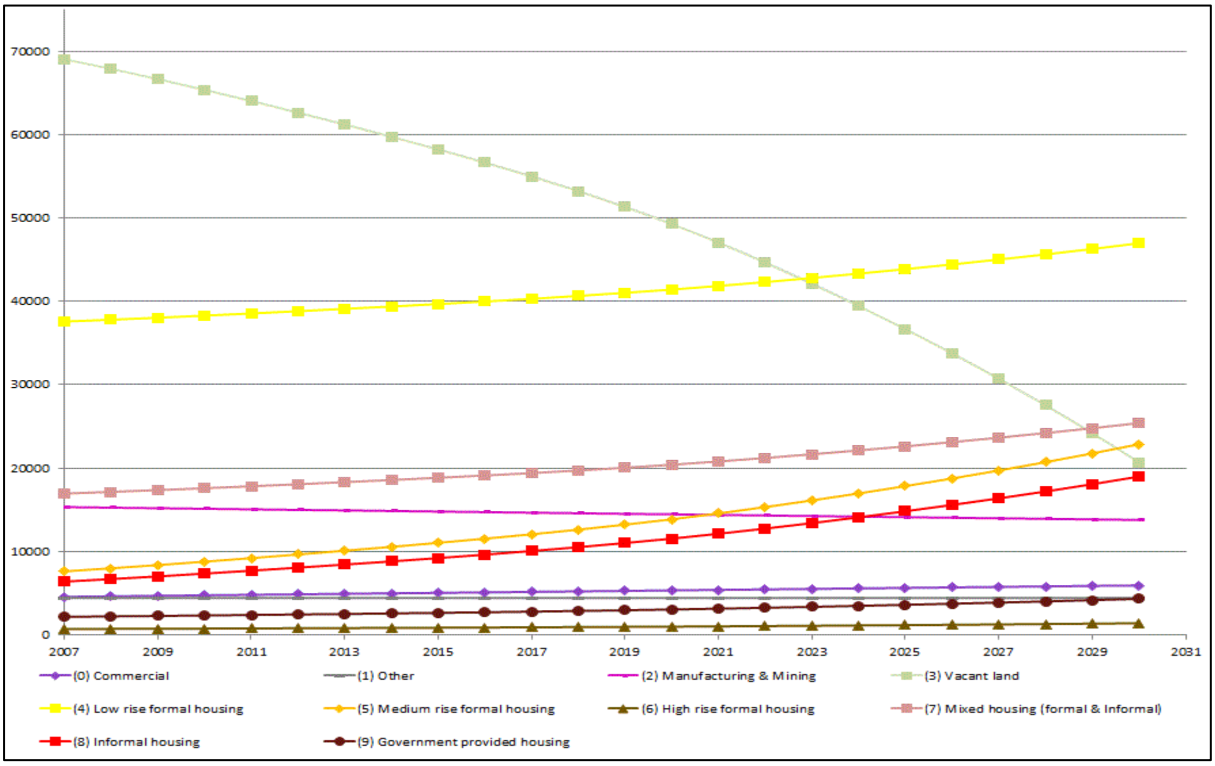


Figure 5.6: Regional land use demands per land use class for the AS-IS Scenarios

Scenario 2 – Policy-led vision

This scenario assumes a very radical planning approach; it represents the 'utopia' picture of what planners believe is necessary to drastically reshape the spatial inequalities that was created in the Johannesburg metropolitan through apartheids planning. The scenario explores what the city would look like if spatial restrictions and preferences are enforced and if government realises the eradication of informal settlements by providing housing to all the poor in accessible locations. The scenario encourages investment in commercial activity in the southern suburbs of Johannesburg, places emphasis on compacting the sprawled city by applying a UDB and redevelops lower density residential accessible locations into higher residential densities.

Calculating demand figures

The total amount of households in the initial (2007) and projected (2030) years again correlates to the actual and projected figures (Section 3.3.1). Table 5.3 below depicts the demand figures for the policy-led scenario.

Land use	2007 extent Hectares (HA)	House-holds (HH) 2007	% HH	Land use change	2030 extent (HA)	2030 adjusted extent (HA)	(HH) 2030	% (HH)
(0)Commercial	4568	-	-	100%	9136	9136	-	-
(1) Other	4436	-	-	0	4436	4436	-	-
(2) Manu - facturing + Mining	15326	-	-	-50%	7663	7663	-	-
(3) Small holdings + Open land	69039	36628	3.14	-50%	34520	37537	19895	0.83
(4) Low rise	37579	213688	18.34	-40%	22547	22547	128292	5.83
(5) Medium rise	7627	104754	8.99	220%	24406	24406	335094	15.25
(6) High rise	708	32726	2.81	970%	7576	7576	350162	15.93
(7) Mixed	16949	539378	46.29	50%	25424	25424	808992	40.48
(8) Informal	6397	198432	17.03	100%	0	100	3182	0
(9) Govern-ment	2164	39707	3.41	1100%	25968	25968	476513	21.68
Total	**164793**	**1165313**	**100**		**161675**	**164793**	**2122131**	**100**

Table 5.3: Land use demand calculations for 2030

Applying demand figures in model

In order to project the growth rate between the initial (2007) and projected (2030) households, a linear trend was used. Due to the decline in low-rise residential, vacant land, commercial and manufacturing it was not suitable to apply the same growth trend as in the AS-IS Scenario. Figure 5.7 below represents the input values into the model.

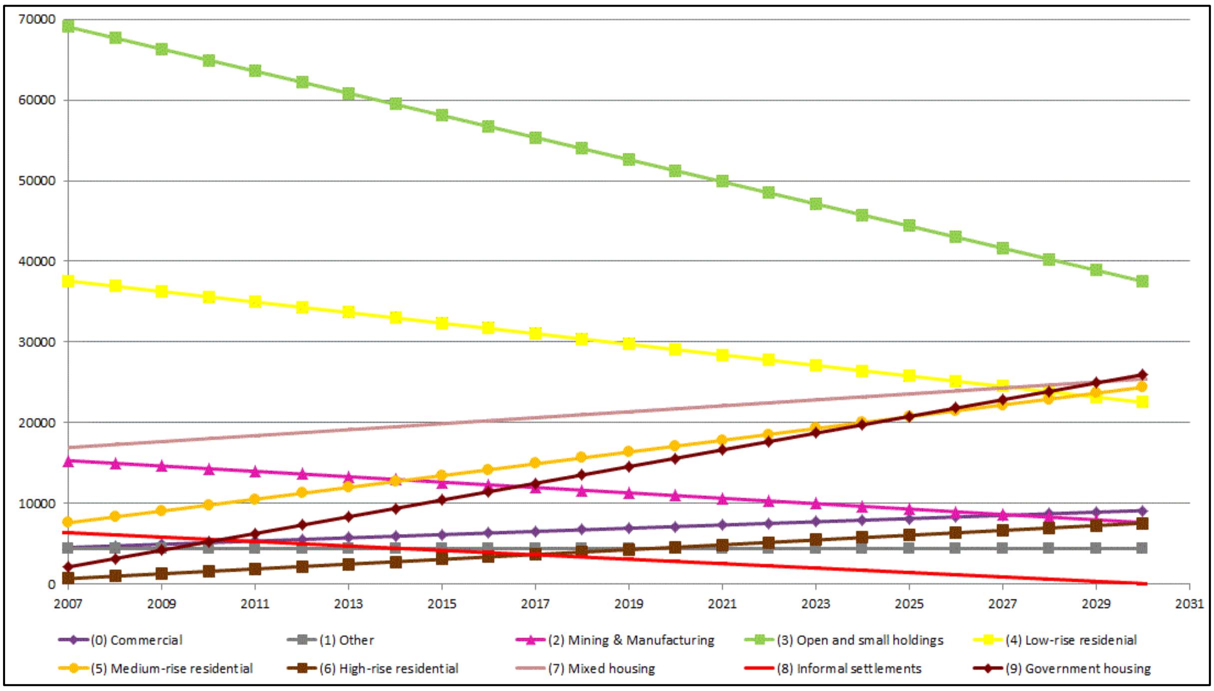


Figure 5.7: Regional land use demands projected per land use class for the Policy-Led Scenario

5.2.2 Spatial Policies

This section will define the spatial policies that restrict land use change and development in the Johannesburg metropolitan area. Two separate restriction layers where created for the two policy scenarios. 'Region_nopolicy.fil' is used in the AS-IS Scenario and allows conversion throughout the metropolitan area. 'Region_udl.fil' is the restriction file used in the Policy-Led scenario. This restriction layer makes use of the urban development boundary (UDB) and two potential nature parks as proposed by the Johannesburg metropolitan municipality in their GMS, 2012 (Figure 3.8). The Policy-led scenario is a strict planning implementation scenario and as such the areas in red (figure 5.8a) are excluded from any development.

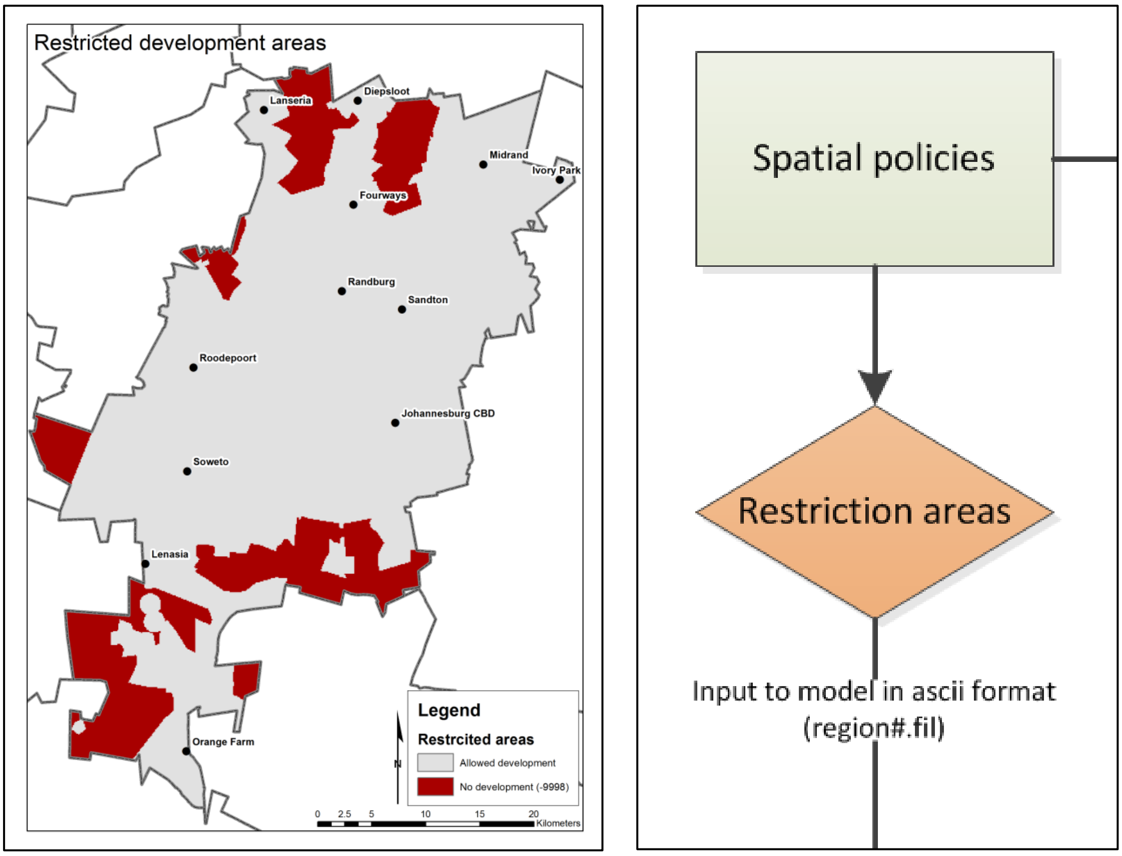


Figure 5.8: a) Area restriction file - Region_udl.fil, b) Preparation of the restriction files for the model

5.2.3 Location preference

This section will describe the location preference areas of various land use classes. These preference areas are scenario specific and applicable per land use class. Preference areas for the AS-IS Scenario are based on past observations, current land use policies and plans that are captured in the municipalities spatial development plans. Preference areas for the Policy-Led Scenario are identified development areas based on the transport and development corridors specified in the city's GMS.

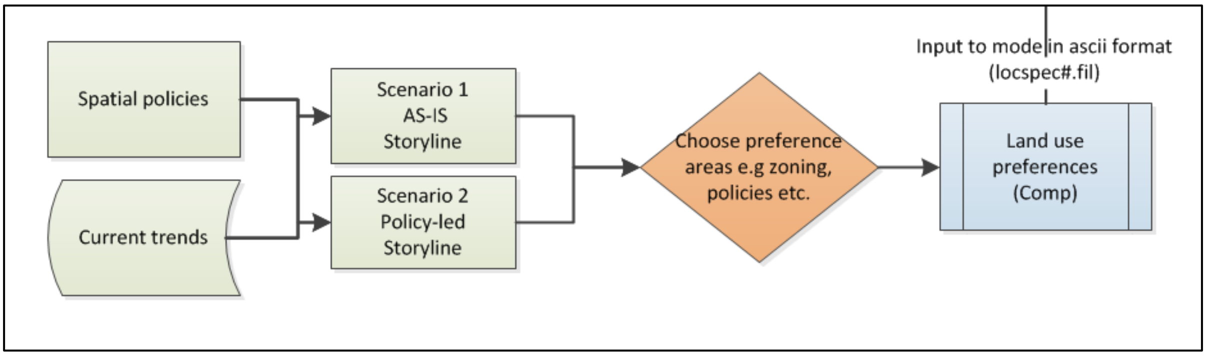


Figure 5.9: Calculating the locational preference areas for input into the model

AS-IS Scenario location preference areas

Preference areas are only considered for the mixed residential, informal settlements and government subsidised housing. Land use development can be described through neighbourhood and regression analyses but the three classes mentioned here do not adhere to conventional development patterns. The reasoning are:

1. Preference to mixed housing. Mixed housing can only take place under specific conditions and on specific locations; these include low-rise residential lower income and government subsidised housing areas. All current (2007) areas that were characterised by one of these two land use classes are considered for conversion to mixed use. As the model progresses through time more options will become available as more government housing gets build (Figure 5.10a).

2. Preference to informal housing: Informal settlements can only develop on vacant land and as such all vacant land is deemed preferable for new informal settlements (Figure 5.10b).

3. Government subsidised housing: Government subsidised housing is a response to the backlogs in housing delivery. These housing initiatives are currently build where the demand is present and where available vacant land or informal settlements are located. The city's spatial development plan indicates areas that are deemed feasible for these developments. These areas are on the periphery of the city were lower priced municipal land is available and where the current demand (informal settlements) are located. Figure 5.10c depicts the areas that were either defined by Government as potential development sites (in their spatial development plans) or are areas of possible upgrading (e.g. informal settlements).

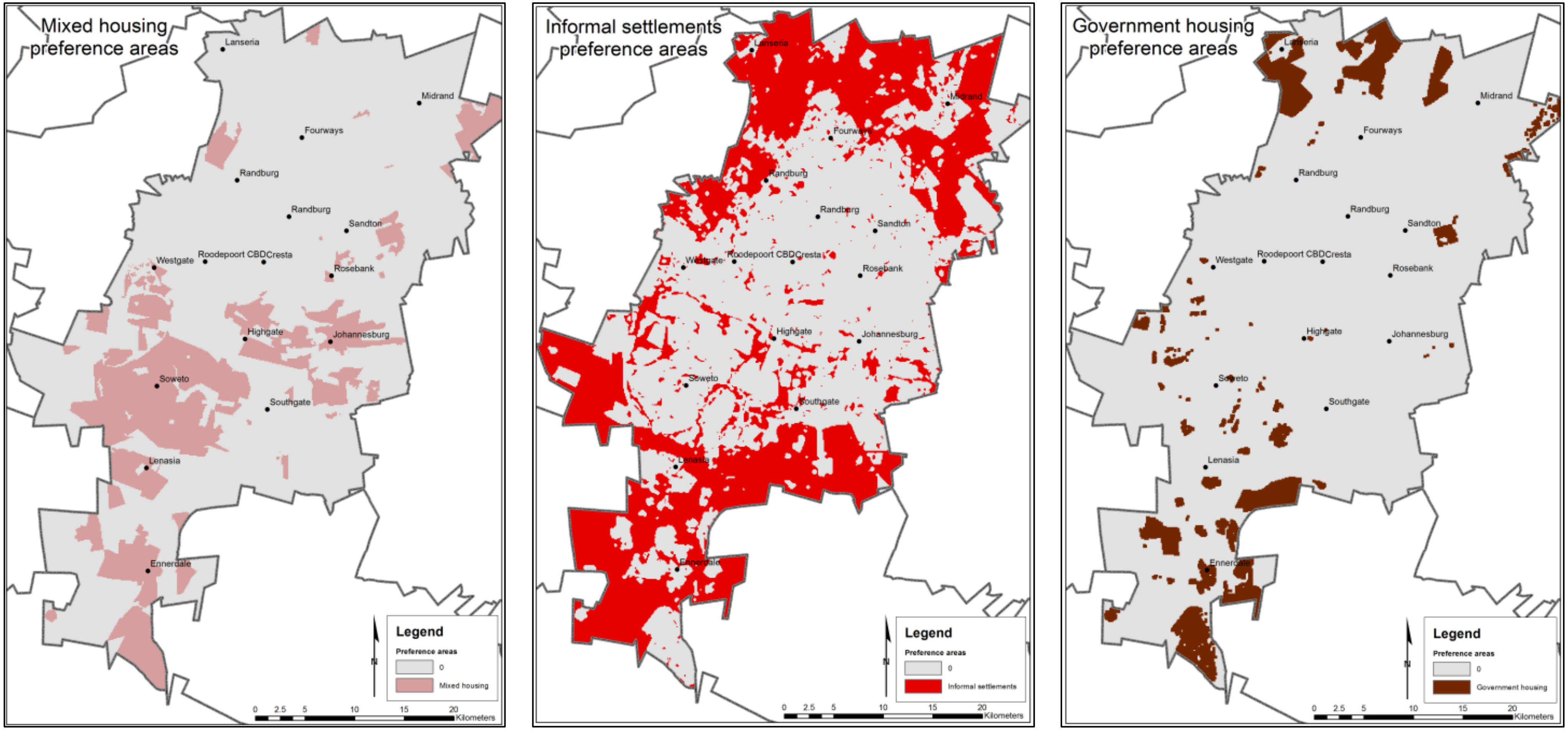


Figure 5.10: Location specific preference areas. a) Preference areas for mixed housing, b) Preference areas for Informal settlements and c) Preference areas for Government housing

Policy-Led Scenario location preference areas

This scenario is aimed at densifying and compacting the city according to the Johannesburg's municipal GMS. The preference areas set for this scenario is mixed use, government subsidised housing and commercial areas. Informal preference areas are not included as the scenario assumes complete eradication of informal settlements through the provision of accessible Government housing. The higher income areas can't be managed by direct intervention like the state planned housing but can be governed through restriction policies; these are considered through the inclusion of the restriction layer in the previous section. The reasons for including the preference areas are:

1. Preference to mixed housing. Due to the specific nature of this type of development the preference areas will stay the same as in figure 5.10a.

2. Preference to government subsidised housing: Preference are set to the GMS transport management corridors. These transportation management corridors due to their accessibility were identified in the GMS as corridors of higher density development. Areas include a 1km buffer from the Gautrain stations, BRT lines and the Metrorail stations, these areas were defined by the municipality and included as is in the study (Figure 5.11a).

3. Preference to commercial activity: Preference to the south of the mining divide is encouraged as this will ensure better accessibility to employment for the lower income groups. The areas included for consideration of development are areas with little commercial activity located in high demand areas. Figure 5.11b depicts the identified nodes that should be encouraged for additional economic investment.

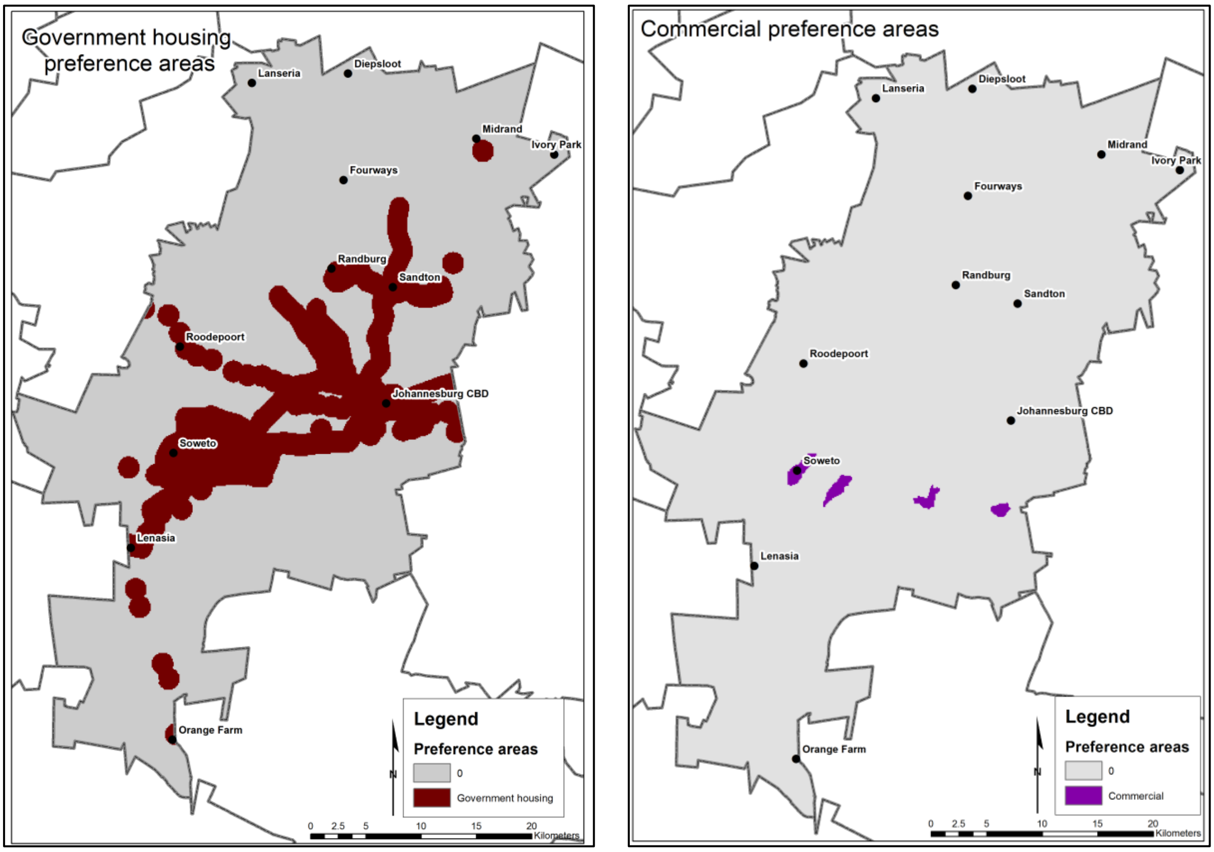


Figure 5.11: a) Government preference areas, b) Commercial preference areas

5.2.4 Analyses of drivers of land use change

Developing a realistic land use change model must contain the inclusion of the most important drivers or actors of land use change (Veldkamp and Lambin 2001). The model should consider the effect that various driving forces and processes will have on different scales of the model. The literature distinguishes between two main scales of driving forces of land use change, those that affect land use from a global/regional perspective and those drivers that influence various spatial allocations of land use change on a local scale. Both regional and local driving factors have a significant effect on the land use and the potential changes thereof. The following section will look at the regional and local drivers of change as well as the influence of neighbourhood characteristics.

Regional drivers of change

Agarwal et al. (2000) argue that land use change is driven by demography, technology, the economy, political and social institutions, culturally determined attitudes, beliefs and behaviour and information and its flow. *Zondag and Borsboom-Van Beurden* (2009) refined and narrowed these drivers to five primary drivers of land use change on a global/regional scale to 1. Political, 2. Economic, 3. Cultural, 4. Technological and 5. Natural factors. Hersperger et al. (2010) emphasised the role that direct interventions such as policies and laws will have on the land use change of a region.

The Johannesburg metropolitan context

Looking at Johannesburg and South Africa's past development patterns (Section 3.1), the current spatial form (Section 3.2) and local knowledge acquired, a couple of drivers (hypothesis) of land use change were identified. These factors are seen as possible regional drivers that can change the growth patterns of land use in the Johannesburg metropolitan area.

The most significant regional drivers of change are seen as:

1. Demographic growth is projected based on in-migration, urbanisation and natural growth. This is arguable the most significant driver of land use change as it directly results in more household demand. Population growth and decrease in household size automatically create a new demand for residential space and new areas needs to be developed to satisfy this demand.
2. Housing backlogs and service delivery backlogs are a result of government not keeping up with the demand in lower income classes due to natural growth or in-migration. A shortage in supply of lower income classes is speculated to be the biggest drivers of both city slums and backyard shacks.
3. Political policies (land use policies) affect and will continue to affect land use patterns. These policies either restrict the development of certain land uses in areas or encourage the development thereof in specific areas (e.g. Government strategic investment strategies).
4. The economic growth of Johannesburg is also a big attracter of new development and investment. The in-migration into Johannesburg metropolitan area could, to a large degree, be explained by the opportunities provided (or believed to be provided) by a strong economic sector.

Implementation in model through scenarios

The regional drivers of change have a direct influence on the land use type demand figures. As such these regional drivers where included and discussed in the demand calculations as control totals (demographic growth) and scenarios (backlogs and political policies).

Local drivers of change

While the regional drivers covered the demographic, economic and political drivers of change this section will look at the bio-physical drivers of change that influence the spatial distribution of land use allocation.

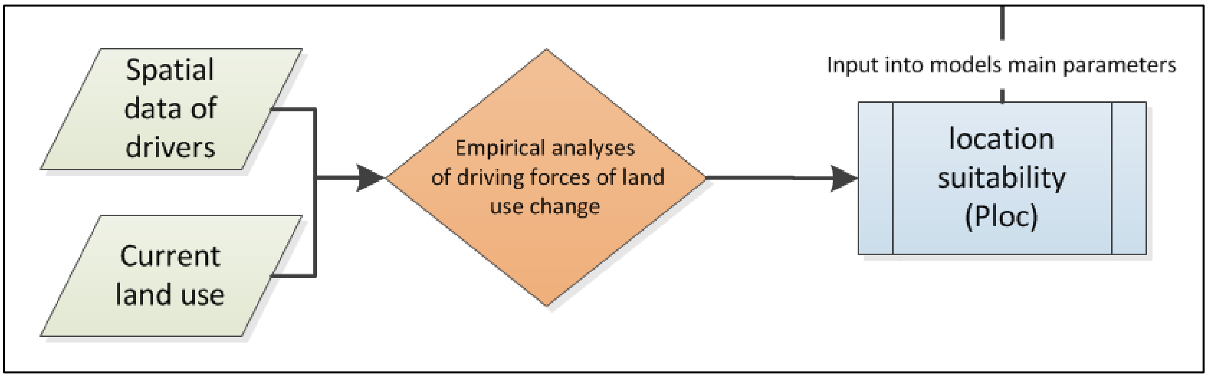


Figure 5.12: Calculating the local drivers of change

The Johannesburg metropolitan context

Defining the major drivers of land use change in South Africa should be considered in the context of the current land use categories. Using expert knowledge and visual interpretation a series of potential drivers (hypotheses) of change where defined. The set of driving factors selected are:

Driving factor	Explanatory factor
1	Distance to main feeder routes
2	Distance to highways
3	Distance to infrastructure development (Gautrain stations)
4	Distance to new infrastructure development (BRT bus lanes), only influential for the first 2km
5	Distance to main economic hubs (commercial)
6	Distance to main shopping centres
7	Distance to metrorail stations
8	Distance to mining and manufacturing activities
9	Distance to informal housing

Table 5.4: Driving forces of land use change

All distances where calculated in Euclidean distance and measured in kilometres. The various driving factor maps that where created as input into the model can be viewed in Figure 5.13 below.

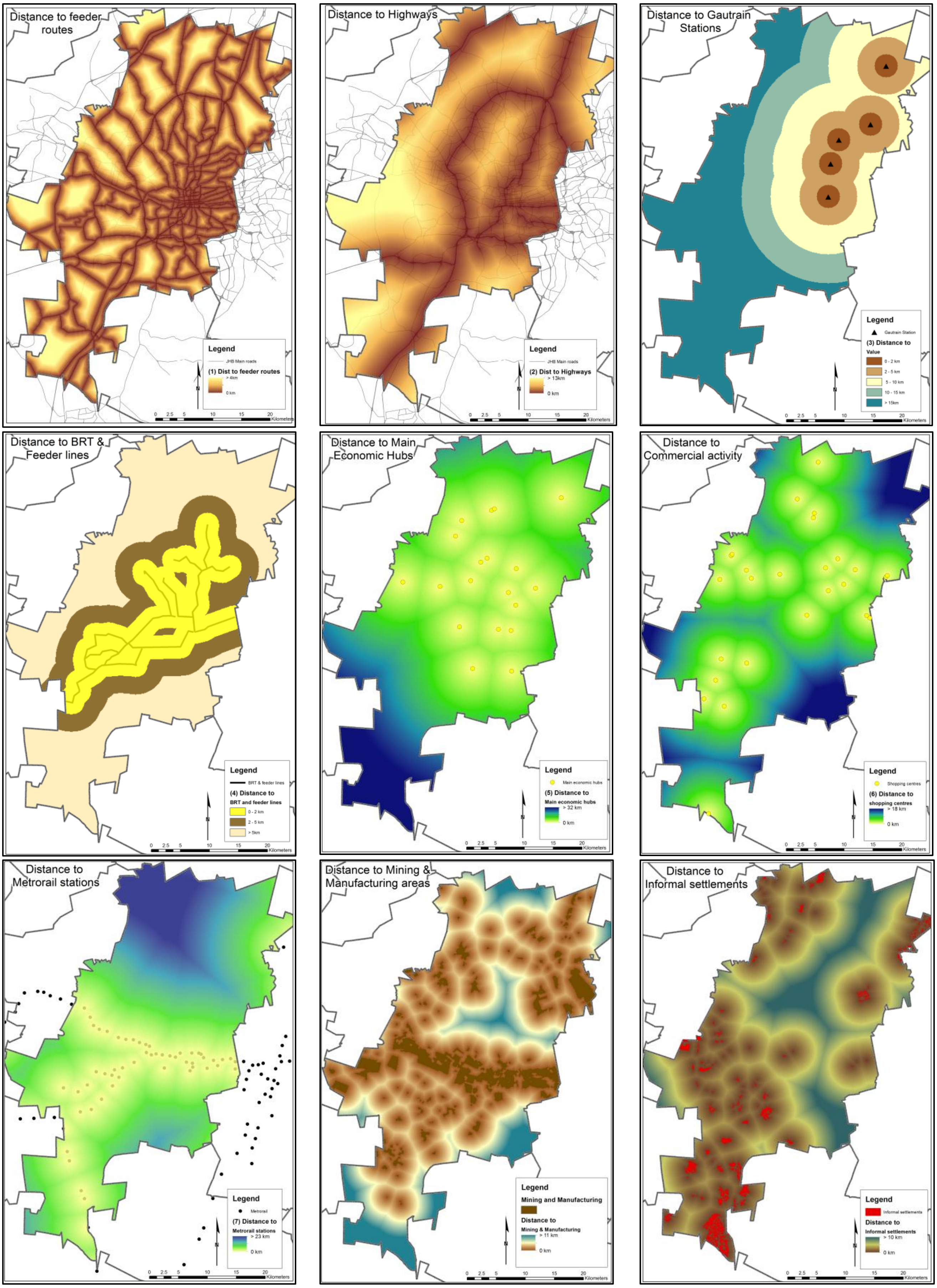


Figure 5.13: Potential driving factors of land use change

Based on the potential driving (explanatory) factors, various hypotheses were set up to test for their potential influence on a land use class (Table 5.5). In the table ($-\beta_n$) means that the lower the distance to the specific land use class, the higher the probability while ($+\beta_n$) means lower the distance to the specific land use class, the lower the probability.

Hypotheses for testing	Commer-cial (0)	Industrial (2)	Low-rise (4)	Medium-rise (5)	High-rise (6)
1 Feeder routes	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)	-
2 Highways	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)
3 Gautrain stations	($-\beta_n$)	-	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)
4 BRT bus lanes	($-\beta_n$)	-	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)
5 Economic hubs	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)
6 Shopping centres	($-\beta_n$)	-	($-\beta_n$)	($-\beta_n$)	($-\beta_n$)
7 Metrorail stations	-	-	-	-	($-\beta_n$)
8Mining and manufacturing	($-\beta_n$)	-	($+\beta_n$)	($+\beta_n$)	-
9 Informal housing	($+\beta_n$)	-	($+\beta_n$)	($+\beta_n$)	-

Table 5.5: Hypothesis of land use change

Mixed housing (7) will not be tested as it is not subjected to local driving forces as these classes only have the capability to develop on lower income low rise formal structures or Government build low cost housing (covered in section 5.2.3). Informal housing (8) is driven by primarily the availability of vacant land and the effect of neighbourhood factors and is therefore not tested here. Government housing (9) is also not subjected to local drivers of change as these interventions are directly implemented in the city space through policies and direct investment.

Other driving factors that would have been beneficial to include but that were not considered due to data constraints are:

1. Land prices: This factor can have an influence on the distribution of the various income groups.
2. Gated communities: These areas form pockets of spaces in low and medium density residential housing that will be very difficult to convert to other land use types.
3. Land ownership: This will affect the rate at which land gets released for development; also the management thereof can result in informal occupation.
4. Labour intensive employment: The distances to these areas can influence the distribution of the lower income earners.
5. Geological unstable areas: Many informal settlements in the south of the city are located on these areas. It provides a hazard for the residents in these areas.

Testing and implementation in the model

The next step was to test the various hypotheses through making use of logistic regression analyses. Logistic regression is used to analyse and quantify the relationship between the driving forces and the various land use types. The logistic regression analyses is used to estimate the coefficients ($\beta_{\text{-values}}$) of the logit model used in creating the location potential of cells to be dedicated to a specific land use type (Verburg et al. 2002).

The table below depict the results from the step wise regression analyses that were performed to select only the most relevant factors from the larger group of drivers defined in the previous section. The factors that added no significant value to the model where excluded from the table.

The ROC value indicates the goodness of fit of the logistic regression model and is also indicated in the table below. The closer the ROC value to 1 the better the fit of the logistic regression model; the closer the value to 0.5 the more random the occurrences of a specific land use type are. The ROC values presented below indicates the logistic regression model performance and the values derived in this case study are an indication that the model has a very good distinguishable ability with all values greater than 0.8.

Driving factors	(0) Commercial	(4) Residential low rise	(5) Residential medium rise	(6) Residential high rise
	β-values	β-values	β-values	β-values
(1) Main feeder routes	-0.003	-0.0006	-0.0003	-0.001
(2) Highways	-0.00016	-0.00008	-0.0001	-
(3) Gautrain stations	-0.00006	-	0.00003	-0.00009
(4) BRT and feeder routes	-0.00002	-0.00004	-0.00013	-0.0001
(5) Economic hubs	-0.00008	-0.0003	-0.0003	-0.00025
(6) Shopping districts	-0.00002	-0.0002	-0.0002	-
(7) Metrorail	-	-	-	-0.00014
(9) Informal housing	-	+0.0003	+0.00025	-
Constant	**-1.218**	**0.184**	**-2.398**	**-2.192**
ROC values	**0.84**	**0.88**	**0.825**	**0.87**

Table 5.6: Regression results

Neighbourhood factors

Verburg et al. (2002) explains that the conversion of land use classes can be partially explained by the influence of the immediate neighbours of a specific class. Neighbourhood influences are deemed important for commercial facilities due to their clustering characteristics and deemed important for residential development due to the attractor role that already put in place services have to offer. Land use conversion is thus more likely to occur next to already established land uses of the same type.

This section will consider and quantify the influence that neighbourhood cells have on various land use classes.

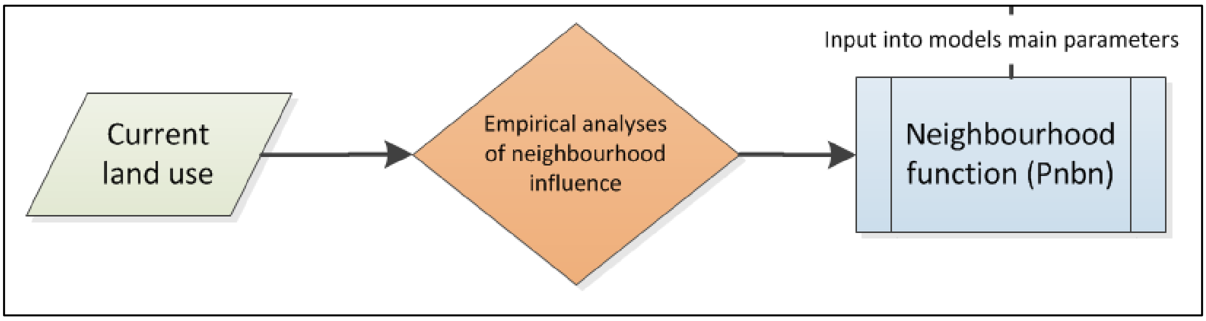


Figure 5.14: Calculating the neighbourhood influence

The Johannesburg metropolitan context

The following case study specific hypotheses will be tested for their neighbourhood influences on each other;

1. The neighbourhood influence of commercial on commercial ($+\beta_n$)
2. The neighbourhood influence of low rise residential on low rise residential ($+\beta_n$)
3. The neighbourhood influence of medium rise residential on medium rise residential ($+\beta_n$)
4. The neighbourhood influence of high rise residential on high rise residential ($+\beta_n$)
5. The neighbourhood influence of informal on informal ($+\beta_n$)

Testing and implementation in the model

The neighbourhood of a specific land use class location can now be calculated by the enrichment factor (F) which is a measure of the occurrences of a specific land use class in the neighbourhood of a location relative to the occurrence of this land use type in the study area as a whole. Verburg (2002) defines this as:

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

In which:

- $F_{i,k,d}$ characterizes the enrichment of neighbourhood d of location i with land use type k;
- $n_{k,d,i}$ is the number of cells of land use type k in the neighbourhood with size 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.

In order to calculate the relation between the probability of a location and its enrichment factors a logit model similar to the driving forces calculation in the previous section is used. The model will be populated with the $\beta_{\text{-values}}$ from the regression equation, the neighbourhood window (sphere of influence) and the relative influence strength of each of the various window cells. Table 5.7 below provides the regression results. For detail maps of the various enrichment factors used in the regression analyses please refer to Annexure C.

Land use classes	(0)Commercial	(4) Residential low rise	(5) Residential medium rise	(6) Residential high rise	(8) Informal settlements
(0)Commercial	1.11	-	-	-	-
(4) Residential low rise	-	1.953	-	-	-
(5) Residential medium rise	-	-	1.541	-	-
(6) Residential high rise	-	-	-	0.077	-
(8) Informal settlements	-	-	-	-	.917
Constant	**-3.640**	**-1.839**	**-3.171**	**-5.488**	**-3.303**

Table 5.7: Regression results of the neighbourhood factors

The influence of setting the weights was done through an iterative process by visual interpretation of historical growth patterns in the next section. Due to the uncertain method followed in deriving these weights of neighbourhood setting a sensitivity analyses was performed to test the influences that these weights have on the model (Section 5.4.3).

5.2.5 Conversion rules

Elasticity conversion

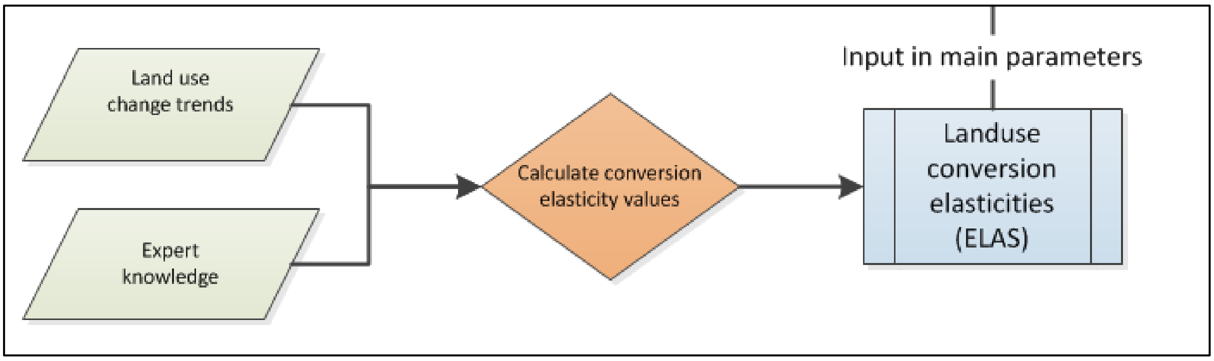


Figure 5.15: Calculating elasticity values

The elasticity conversion is a value between 0 and 1 that indicates the reversibility of a land use type. 0 would indicate a land use that is easily reversible, thus it can be deleted and added at the same time in the model where 1 would indicate typically a land use with a high investment cost that will not change easily as long as there are adequate space available to cover the land use demands (Verburg et al. 2002).

The Johannesburg metropolitan context

Figure 5.16 below shows the most significant patches of growth for the commercial, industrial, residential and informal land use classes. The 2007 land use typology used as the initial simulation year was created with datasets not available in 2001. The changes could therefore not be distinguished between the various residential classes. From the total change in the Johannesburg metropolitan areas it was observed that 95% of all land use change that happened between 2001-2007 were changes from vacant open land to various other land use types, thus only 5% of changes happened between the non-vacant land use types. Of the 95% vacant changes observed these can be attributed to: 1. Commercial with 7%, 2. Other with 5%, 3. Industrial with 9%, 4. Residential with 71% and 5. Informal with 8%.

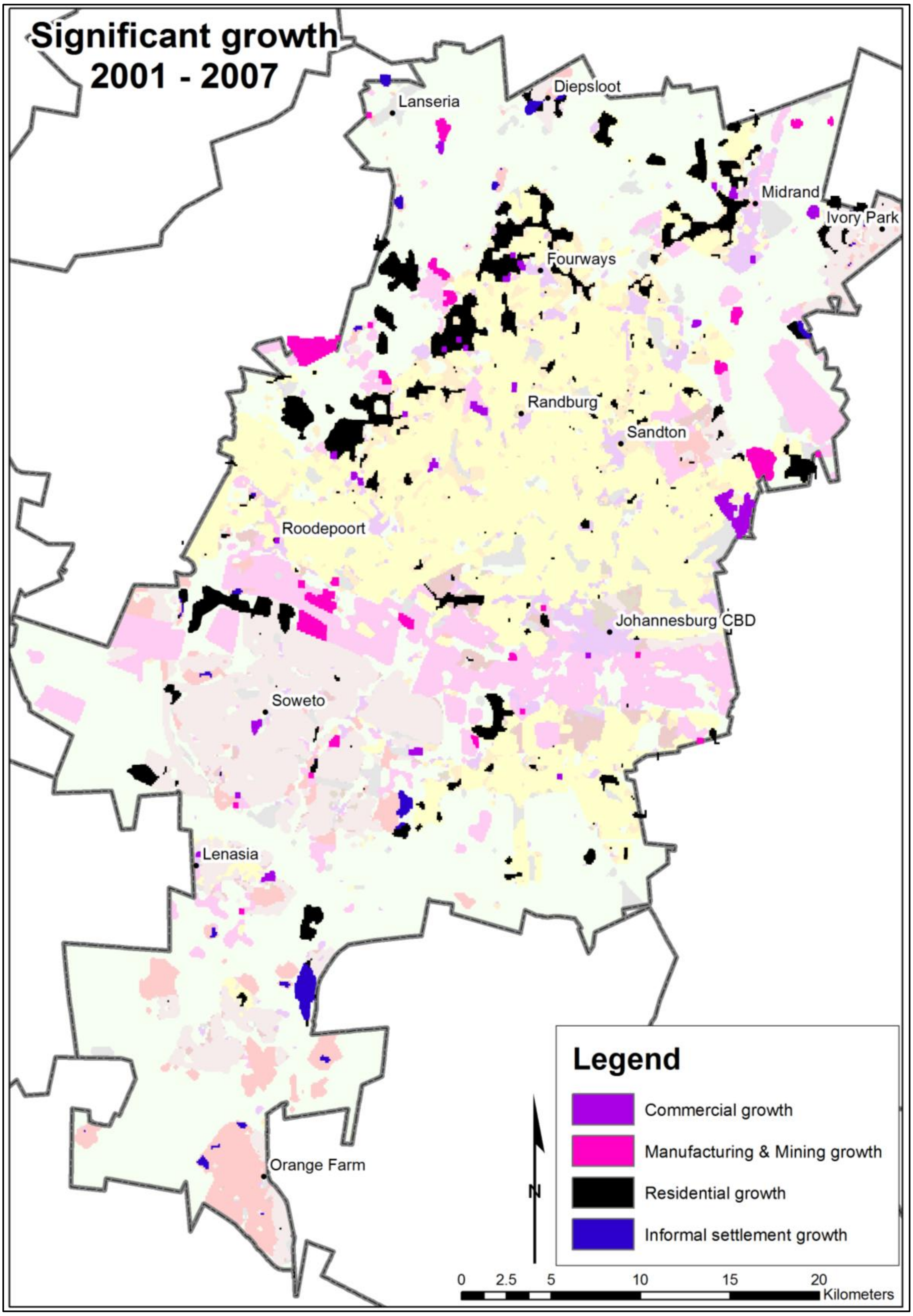


Figure 5.16: Significant land use change 2001-2007

It is clear that as long as there is adequate land available, higher investment land is less likely to be converted. As the land use trend data was insufficient to quantify the past development trends, expert knowledge were used to populate the elasticity values (Table 5.8).

Land use class	Elasticity values As-IS Scenario	Elasticity values Policy-Led Scenario
0 Commercial	0.8	0.8
1 Other	1	1
2 Manufacturing and mining	0.8	0.8
3 Open and small holdings	0.4	0.2
4 Low rise residential housing	0.7	0.6
5 Medium rise residential housing	0.7	0.7
6 High rise residential housing	0.8	0.8
7 Mixed housing	0.5	0.5
8 Informal settlements	0.2	0.1
9 Government housing	0.7	0.7

Table 5.8: Elasticity values

As these are based on visual interpretation and expert knowledge a detailed sensitivity analyse was performed in Section 5.4.1. The table assumes that higher investment infrastructure such as commercial, manufacturing and mining and high-rise housing will be much more stable in the model. Land use classes such as low-rise residential, medium-rise residential and government housing also requires significant investment but less than the previous classes mentioned and is therefore also relatively stable but less so than the higher investment classes. Informal settlements are temporary structures that need to be removed and formalised at some stage therefore making it a very instable class.

Land use conversion matrix

This section will explain the various land use changes that are possible within the metropolitan areas. The conversion matrix allows a progressive time step change to take place between land uses. Some of the land uses e.g. Open (3) can be converted into any other land use type while some land uses e.g. Mixed housing (7) have to follow a specific development sequence (informal settlements (8) can be redeveloped to government housing (9) that over time changes into mixed housing (7)).

Implementation in the AS-IS scenario

The following assumptions where made for modelling purposes in the AS-IS Scenario. These are based on 1. Changes observed in the period 2001-2007 and 2. Expert knowledge as changes could not be quantified between the various residential classes as explained above.

1. Commercial change (0): Likely to stay the same or alternatively change to higher density formal housing with an equal investment value. It’s unlikely that these land uses will change to lower density housing.
2. Other change (1): These are excluded from the model as the land use class is static in the model.
3. Manufacturing and mining (2): Likely to change to higher density residential land uses or higher investment classes such as commercial. Unproductive mining ground could be utilised by the Government for subsidised housing.

4. Vacant and small holding (3): Likely to change to any land use class.
5. Low rise residential (4): Likely to change to any other land use class except informal (as formal structure are already in place) and Government housing (as the as-is scenario excludes this as a possibility due to Government housing primarily being the response to informality and backlogs).
6. Medium rise residential (5): Same as above and also excludes low rise residential (densities will not decrease if demand increases, also investment made in medium rise buildings will exclude this possibility)
7. High rise (6): Same as above but excludes medium rise and mixed housing(mixed housing only possible under specific conditions)
8. Mixed housing (7): Ideal investment possibilities for higher densities as higher densities already obtained through informality. Changes possible to commercial, manufacturing and high rise residential.
9. Informal settlements (8): Government responds to informality with Government housing, thus this land use class will be changed via policy intervention and investment to Government housing.
10. Government housing (9): Due to the Government's investment this class is only capable of change to either high rise residential, commercial or alternatively be densified by informality and change to mixed housing.

Implementation in the model

	(0)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
(0)	1	0	0	0	0	0	1	0	0	0
(1)	0	0	0	0	0	0	0	0	0	0
(2)	1	0	1	1	0	1	1	0	0	1
(3)	1	0	1	1	1	1	1	1	1	1
(4)	1	0	0	1	1	1	1	1	0	0
(5)	1	0	0	1	0	1	1	1	0	0
(6)	1	0	0	1	0	0	1	0	0	0
(7)	1	0	0	0	0	0	1	1	0	0
(8)	1	0	0	1	0	0	0	0	1	1
(9)	0	0	0	0	0	1	1	1	0	1

Table 5.9: Conversion matrix

As these tables were based on visual interpretation, limited quantifiable data and expert knowledge a detailed sensitivity analyse was performed in Section 5.4.2.

Implementation in the Policy-Led scenario

The only significant changes from the AS-IS Scenario is:

1. Commercial land use (0) will not change to high rise. It is assumed that commercial activity provides the bulk of the employment and that access to these hubs are critical. These hubs cannot be deleted.

2. Low rise residential land use (4) can be replaced by Government housing. The policy is geared towards redevelopment and densification. Optimal low-rise areas will easily change to Government housing.

3. Mixed housing (7) can change to higher rise residential housing. The policy is geared towards eradication of informality, these mixed use housing should thus be capable of redevelopment.

4. Government housing (9) can be redeveloped to commercial (0) land uses due to its optimal locations next to transport routes.

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(0)	1	0	0	0	0	0	0	0	0	0
(1)	0	0	0	0	0	0	0	0	0	0
(2)	1	0	1	1	0	1	1	0	0	1
(3)	1	0	1	1	1	1	1	1	1	1
(4)	1	0	0	0	1	1	1	1	0	1
(5)	1	0	0	0	0	1	1	1	0	0
(6)	1	0	0	0	0	0	1	0	0	0
(7)	1	0	0	0	0	1	1	1	0	0
(8)	1	0	1	1	1	1	1	0	1	1
(9)	1	0	0	0	0	1	1	1	0	1

Table 5.10: Conversion matrix

5.3 Running the model

The model takes all the relevant inputs specified in the previous section and allocates land use change based on the change potential formula. The various components that will be considered in the allocation formula are:

$$Ptoti,t,lu = Ploci,t,lu + Pnbhi,t,lu + Compt,lu + ELASlu \qquad (6)$$

Where:

$Ploc_{i,t,lu}$: Is the location suitability calculated in Section 5.2.4

$Pnbh_{i,t,lu}$: Neighbouring cells defined in Section 5.2.4

$Comp_{t,lu}$: Location specific preference maps defined in Section 5.2.2

$ELAS_{lu}$: Conversion settings defined in Section 5.2.5

To calculate the change potential, a summary of the input layers used per land use type is provided in table 5.11 for the AS-IS Scenario and table 5.12 for the Policy-Led scenario.

AS-IS Scenario

Land use	0	1	2	3	4	5	6	7	8	9
Location specific preference (Compt)	-	-	-	-	-	-	-	yes	yes	yes
Local drivers of change (Ploc)	yes	-	-	-	yes	yes	yes	-	-	-
Neighbourhood influence (Pnbh)	yes	-	-	-	yes	yes	yes	-	yes	-

Table 5.11: AS-IS Scenario inclusion layers

Policy-Led Scenario

Land use	0	1	2	3	4	5	6	7	8	9
Location specific preference (Compt)	yes	-	-	-	-	-	-	yes	-	yes
Local drivers of change (Ploc)	yes	-	-	-	-	yes	yes	-	-	-
Neighbourhood influence (Pnbh)	yes	-	-	-	-	yes	yes	-	-	yes

Table 5.12: Policy-Led Scenario inclusion layers

Based on these specified inputs and formulas the change potential maps are now calculated to evaluate the influence that the neighbourhood, drivers and preference areas have on the potential of the land use changes. Below is an example of the results of the change potential formula for the two policy analyses for the Medium-rise land use class, a full set of maps can be viewed in Annexure D.

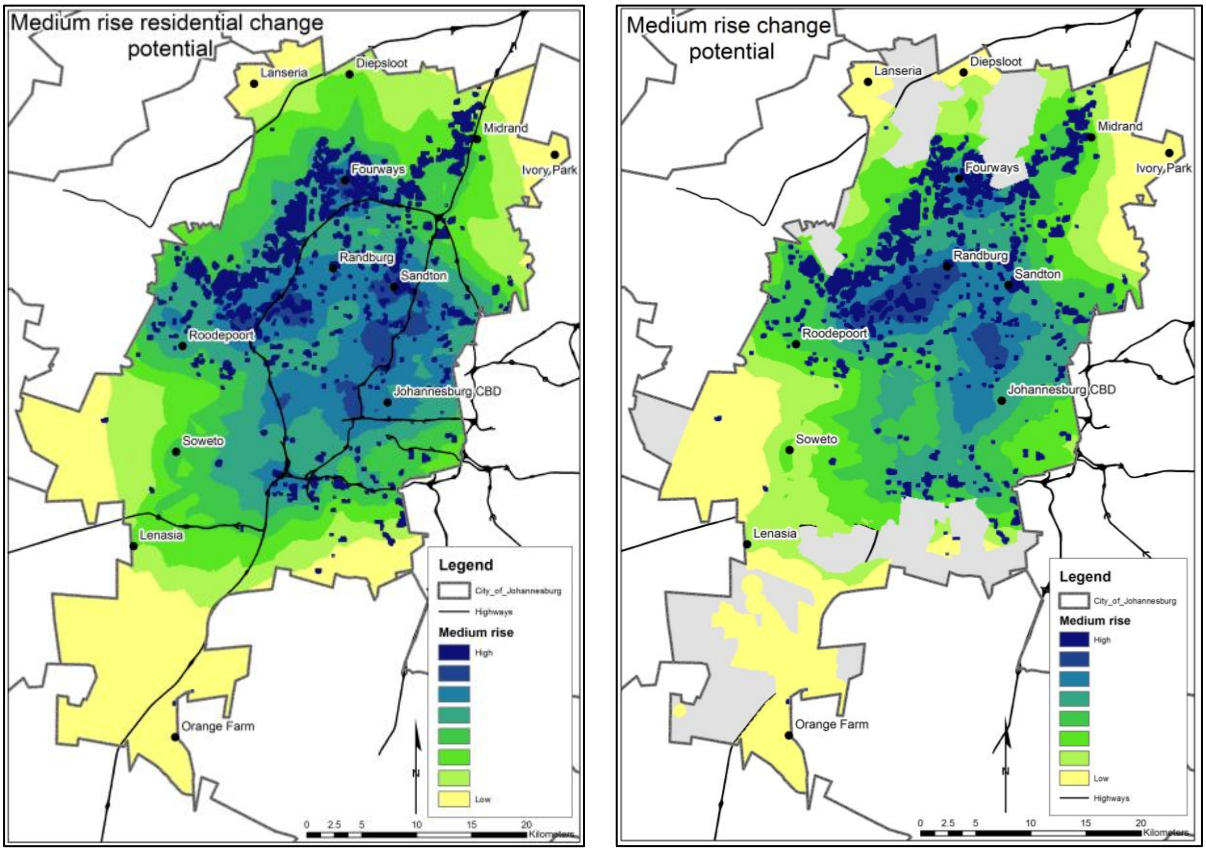


Figure 5.17: Examples of potential maps for the Medium-rise residences. a) As-IS Scenario, b) Policy-Led Scenario

5.4 Sensitivity analyses

Saltelli (2008) defines sensitivity analyses as a study to define the influence that uncertainty and variation in the inputs of a model will have on the output of the modelling results. Saltelli (2008) describes this as: "…*a technique for systematically changing variables in a model to determine the effects of such changes*".

Due to the uncertainty associated with the input layers of the conversion elasticities, conversion matrix and the weights of the neighbourhood functions, it is useful to determine the sensitivity of the model towards variations in these input layers. The crude method of OAT (One-factor-At-a-Time) will be used in the sensitivity analyses. The OAT method is an iterative process of changing one input factor at a time and observing the results. Only the AS-IS Scenario will be tested for its sensitivity as this method should simulate reality based on past trends and development patterns. The influence of the OAT method will be measured based on the change percentage observed. The change percentage will be a percentage of change between the normal simulation and the sensitivity run.

$$Change\ percentage = \frac{\Delta n}{N} * 100 \qquad (7)$$

Where;

- Δn is the total number of changed cells in the study area
- N is the total number of cells in the study area

The following sensitivity analyses will be run to test the models robustness.

Input setting	*Original model*	*Sensitivity run1*	*Sensitivity run2*
Conversion elasticities	AS-IS Scenario	0.1 decrease on all values	0.1 increase on all values
Conversion Matrix	AS-IS Scenario	All conversions allowed	-
Neighbourhood weight	AS-IS Scenario	Low neighbourhood weights assigned	High neighbourhood weights assigned

Table 5.13: Various changes proposed for the OAT sensitivity analyses

5.4.1 Sensitivity analyses on Conversion elasticities

The sensitivity analysis for the conversion elasticities looks at the influence that increasing or decreasing the elasticity values will have on the modelling results. Table 5.14 below depicts the changes that will be tested.

Land use classes	*Original model*	*Sensitivity run1 - 0.1 decrease on original model*	*Sensitivity run2 – 0.1 increase on original model*
0	0.8	0.7	0.9
1	1	1	1
2	0.8	0.7	0.9
3	0.4	0.3	0.5
4	0.7	0.6	0.8
5	0.7	0.6	0.8
6	0.8	0.7	0.9
7	0.5	0.4	0.6
8	0.2	0.1	0.3
9	0.7	0.6	0.8
Change percentage	-	9.72%	8.46%

Table 5.14: Sensitivity input values

More than 50% (61% for sensitivity run1 and 40% for sensitivity run2) are differences within the mixed housing, informal settlements and Government provided housing classes. All three of these classes are not driven by local drivers of change but location specific areas.

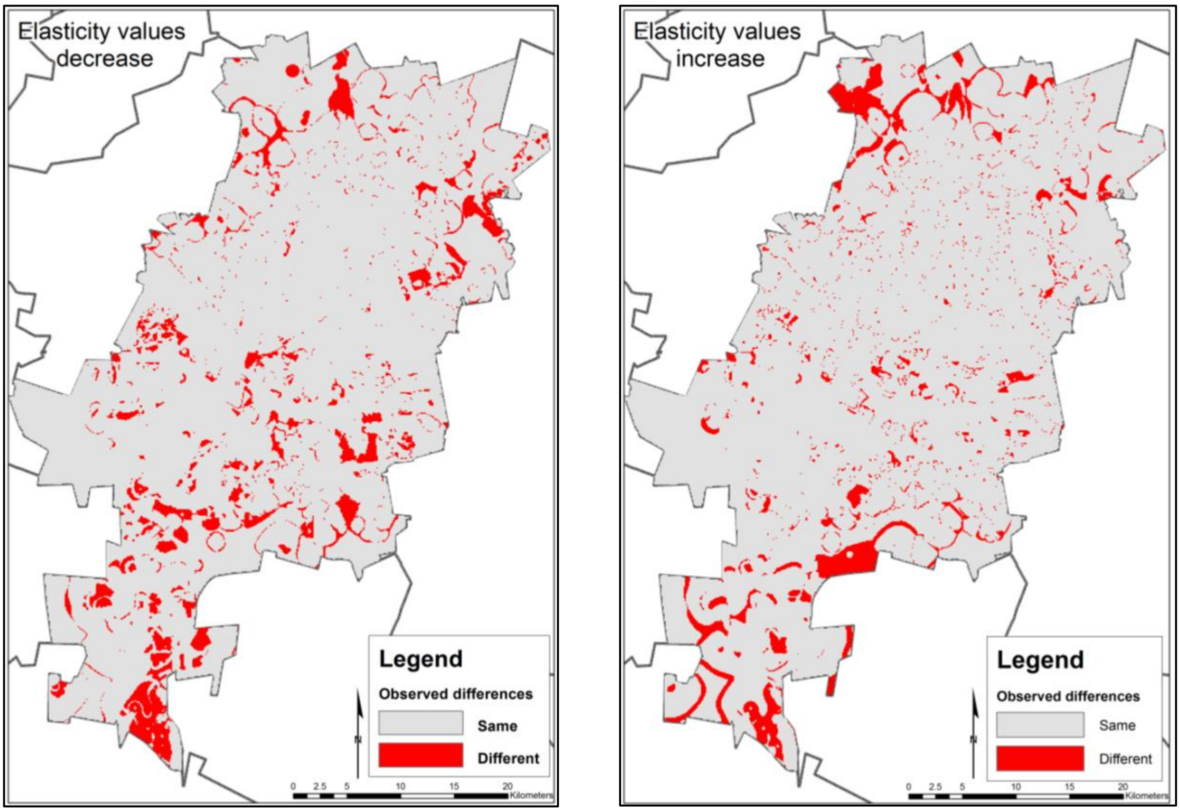


Figure 5.18: Changes observed in an OAT method on elasticity values

5.4.2 Sensitivity analyses on Conversion matrix

One analysis in is which all conversions were allowed was performed to test the sensitivity of the model.

Land use classes	*Original model*	**All conversions allowed**
Change percentage	-	13%

Table 5.15: Sensitivity analyses results for the conversion matrix

Allowing thus all conversion to take part in the model will result in a 13% difference. Figure 5.19 below depicts the spatial allocation of the changes observed when altering the input parameters.

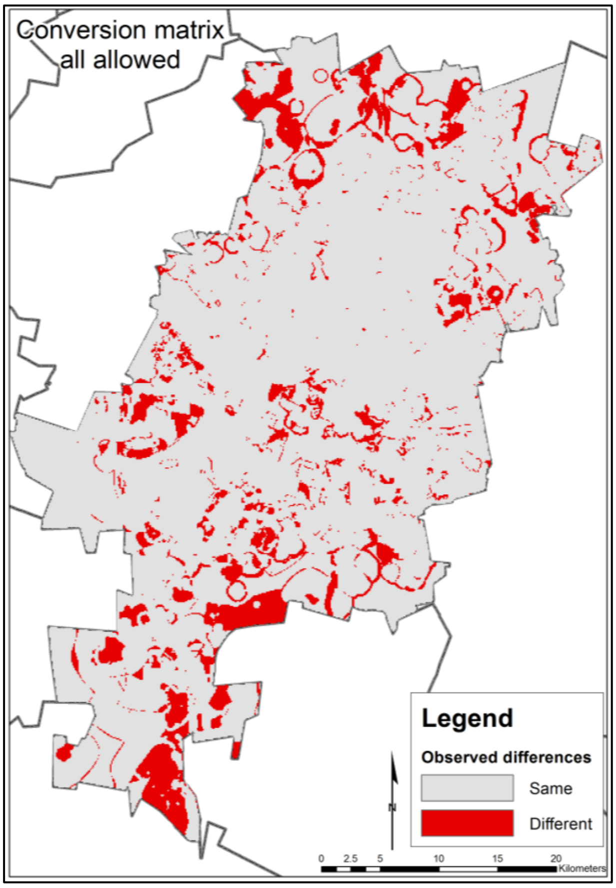


Figure 5.19: Spatial results of the OAT method for the conversion matrix

5.4.3 Sensitivity analyses on Neighbourhood weights

The sensitivity of the neighbourhood weights where tested through the use of high and low values. The table and figure below depict the changes observed.

Land use classes	***Original model***	**Low neighbourhood weights assigned**	***High neighbourhood weights assigned***
0	0.3	0.2	0.5
4	0.3	0.2	0.5
5	0.2	0.1	0.4
6	0.5	0.3	0.7
8	0.5	0.3	0.7
Change percentage	-	14.87%	6.9%

Table 5.16: Neighbourhood weights

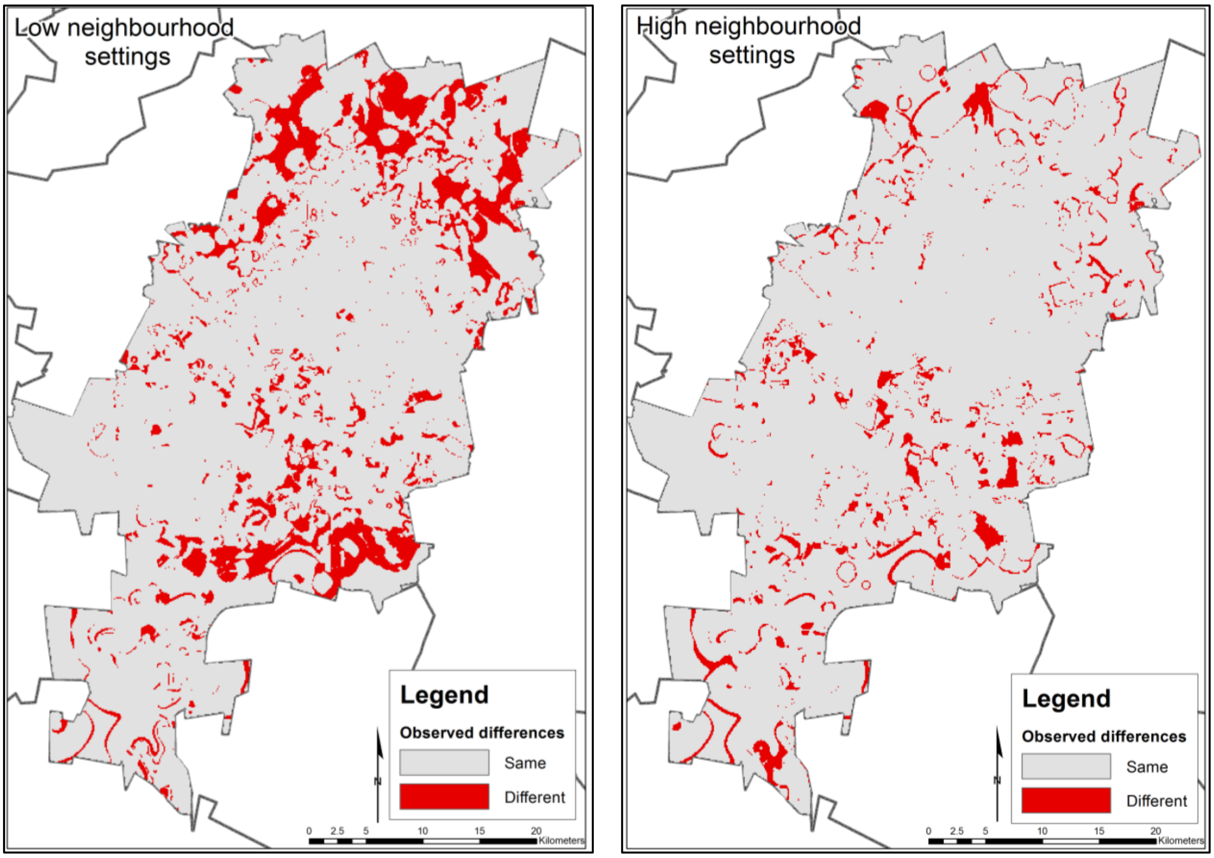


Figure 5.20: Results of using the OAT method on the neighbourhood functions

Conclusion

From the sensitivity analyses it can be concluded that the model is the most sensitive to low neighbourhood weights. The influence of the neighbourhood weights on the model is thus noticeable enough to ensure that the right weights are assigned. Even though neighbourhood factors were calculated with regression analyses, the influence (weight) of the neighbourhood in the land use potential calculation is not rigorous enough and deserves more attention. The model is not very sensitive to the elasticity values and the changes observed are relatively small, however research is needed to determine how to calculate these values from historical datasets. Aside from the sensitivity analyses a validation experiment with historical data would have been ideal. Starting the modelling process at a much earlier initial year and simulating over a decade or more and then fine tuning the model based on observations will greatly add to the validity of the model. However the past land use data (specifically supporting datasets such as the backyard shacks and informal layers) are not available making a past historic validation process impossible.

6. Results

Johannesburg is characterised by spatial inequalities, low densities and long commuter distances. Government has stated that bold new measures are needed to reshape the cities landscapes and as such two scenarios have been developed and modelled using the Dyna-Clue model to test the effects that implementing these policies will have on the city's landscape. The first AS-IS scenario tests the effect of continuing along the same trajectory as the past decade while the second Policy-led scenario test various municipal planning initiatives and thinking. The simulated scenario outcomes were evaluated based on a set of indicators to evaluate which scenario produces the best results given the high rate of urbanisation and migration predicted for the city. Results are produced based on a set of indicators to test the two scenario influences on 1. Spatial inequality, 2. Density patterns and 3. Commuter distances. The various indicators that will be tested are:

1. Spatial inequality (Section 6.1):
   1.1 Wealth segregation
   1.2 Distribution and quantity of economic nodes and centres
   1.3 Spatial allocation of demand (Growth patterns and trends)

2. Density patterns (Section 6.2):
   2.1 Amount and location of change (Urban sprawl)
   2.2 Densification of transport management nodes (transport sustainability)

3. Commuting distances (Section 6.3):
   3.1 Access to public transport

6.1 Measuring spatial inequality

Measuring spatial inequality will be done based on 1. Determining the wealth segregation, 2. Determining the effect of the policies on the distribution and quantity of the economic centres and 3. A visual interpretation of the spatial patterns and trends observed.

6.1.1 Wealth segregation

The wealth segregation between the cities affluent north and deprived south has been discussed in length. Measuring thus the effect of the policies on the distribution of wealth is done by subdividing the city into a northern and southern section (Annexure E) and calculating the amount of households per land use type in each segment. Table 6.1 below shows that in 2007 the majority (61%) of all households in the city lived within the southern part of Johannesburg and that 91% of the southern households are considered lower-income earners (Mixed, informal and government low cost housing) while the majority of the households in the north (67%) are higher income earners (formal residences). The AS-IS Scenario will stay largely the same with 60% of households falling in the southern parts of the city of which 90% households will be in the lower-income category. The Policy-Led scenario ensures that more people resides in the north (48%) compared to the 39% of 2007. The Policy-Led scenario will lead to almost an equal amount of higher income earners (51%) and lower income earners (49%) present in the north but the southern part of the city will see slightly more higher income earners (22%) compared to the 10% projected for the AS-IS scenario.

Household classes	Base year north	Base year south	AS-IS Scenario north	AS-IS Scenario south	Policy-led Scenario north	Policy-led Scenario south
Formal Households (HH) (classes 4,5,6)	320503	67302	479957	137569	517343	244847
% HH of section	67	9	54	10	51	22
Mixed housing (HH)	98665	494445	262325	670845	230475	738535
% HH of section	21	67	29	51	23	66
Informal settlements (HH)	35760	156150	113190	474570	2580	7140
% HH of section	8	21	13	36	0.3	0.6
Government provided (HH)	21762	17780	34679	43505	267728	132919
% HH of section	5	2	4	3	26	12
% HH in North vs. South	39	61	40	60	48	52
Total HH	**1212367**		**2216640**		**2141567**	

Table 6.1: Household breakdown

6.1.2 Distribution of economic nodes

The effect of the policies on the distribution and quantity of the economic activity will be evaluated separately based on northern and southern segments of the city (Annexure E). The quantity of commercial activities were measured based on the amount of hectares, patch sizes and amount of households per economic hectare. The inequality and the spatial heritage of the Apartheids planning is clearly evident from table 6.2 which indicates that in 2007 4.5 times the amount of commercial hectares are available in the northern affluent parts of the city compared to the south. Comparing the quantity of commercial activity with the household distribution even deteriorates the pictures as 61% of the population are distributed in the southern suburbs of Johannesburg. The AS-IS scenario paints a very gloomy picture as both the population distribution (40% north vs. 60% south) and commercial distribution (80% north vs. 20% south) stays largely unchanged from the 2007 situation. The Policy-Led scenario betters this picture as more people are projected to live in the north (48%) as well as more economic activity projected for the south (33%). Even though commercial activity will slightly increase in the south, this will not keep up with the households' projected growth in the south.

	2007 Base year north	2007 Base year south	AS-IS Scenario north	AS-IS Scenario south	Policy-led Scenario north	Policy-led Scenario south
Commercial land (HA) % of Total Commercial land	3757 (82)	815 (18)	4651 (80)	1151 (20)	4600 (67)	2297 (33)
Commercial patches	312	143	325	144	371	221
Households % of Total Commercial land	476689 (39)	735677 (61)	890152 (40)	1326489 (60)	1018125 (48)	1123441 (52)
HH per Com HA	127	903	191	1152	221	489

Table 6.2: Economic node quantity and distribution

6.1.3 Spatial allocation and demand

Figure 6.1 below displays the spatial allocation results of the two policy scenarios in relation to the initial base year of 2007. The most visible differences observed in the growth patterns are; 1. The sprawled nature of the city in the AS-IS Scenario, 2. The large amount of the informal settlements to the south in the AS-IS Scenario, 3. The amount of economic activity projected for southern Johannesburg in the Policy-Led scenario, 4. The location of high-rise residences in the Policy-Led Scenario 5. The location of government low cost housing on the periphery of the city in the AS-IS scenario and 5. The location of government low cost housing next to the transport corridors in the Policy-Led scenario. In both scenarios the preference of higher income residences can be observed in the north. The AS-IS scenario paints a disheartened picture for informality in the city if the Government is faced with budget constraints, the city will see much more informality in the southern part of Johannesburg that will segregate the wealth of the city even more. The forced investment of the Government housing into the accessible transport corridors in the Policy-Led Scenario is a response to the low income housing demand but focussing these investments into prime corridors will restrict the development of higher income housing and as a result, many of the high-income developments will be pushed towards the outskirts of the city. The complete set of spatial allocation maps for five year intervals for both scenarios can be viewed in Annexure G.

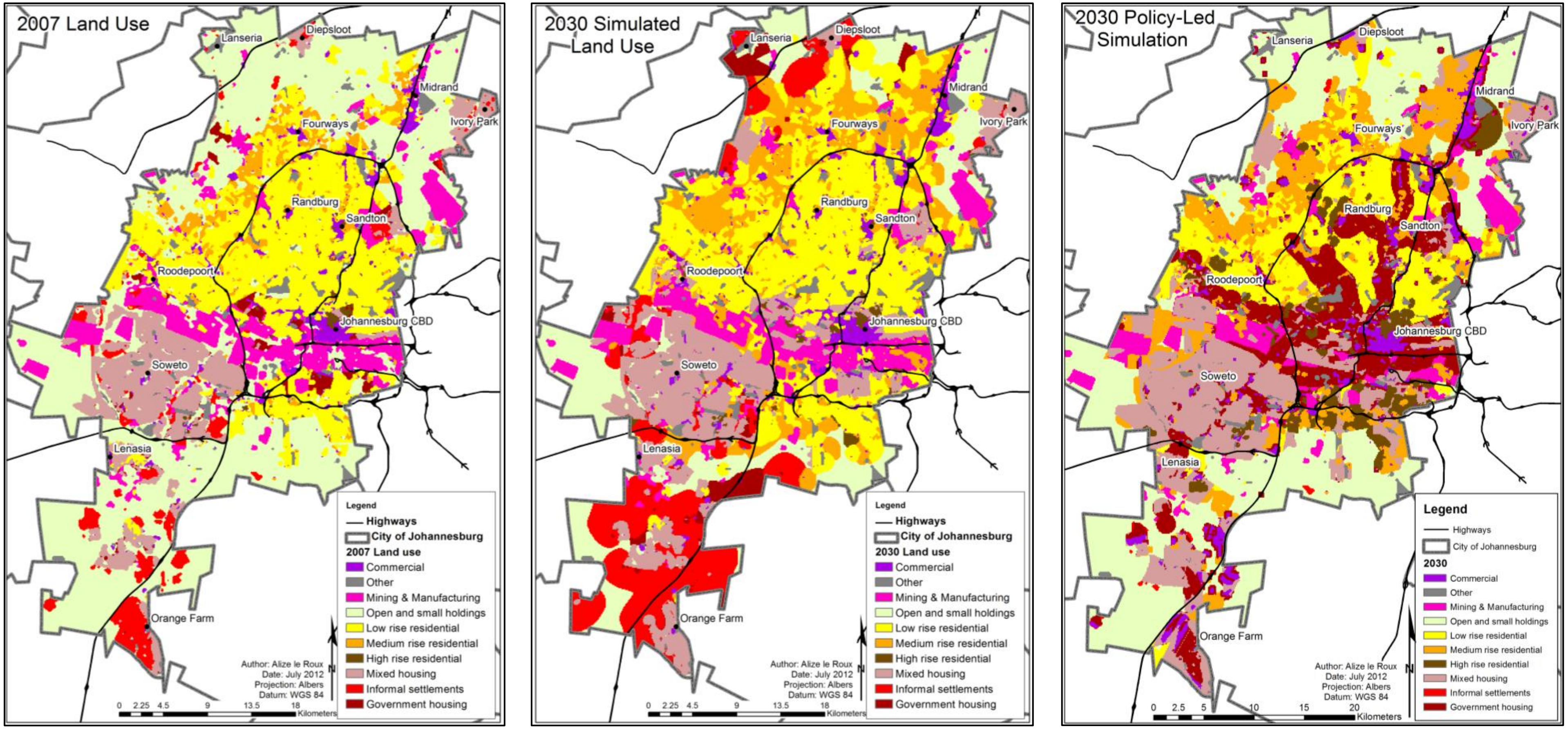


Figure 6.1: a) Initial 2007 year, b) AS-IS Scenario and c) Policy-Led scenario.

In the AS-IS Scenario there is a clear vacant space available between Midrand (higher income investment) in the north of Johannesburg and the Ivory park lower income areas in the north-east. The higher income households prefer areas located further away from these informal settlements (depicted in Section 5.2.4) and as such locate on the western side of the highway (Figure 6.1b). The presence of enough land available for development encourages this behaviour even further. Figure 6.2 below shows simulated 2007, 2012 and 2030 maps together with satellite imagery of actual development between 2007 and 2012. The yellow and orange areas on the satellite image in 2012 shows areas of low-rise and medium-rise residential development, the purple areas depict commercial growth and the green areas indicate future growth. These patterns are also observed by the simulated results.

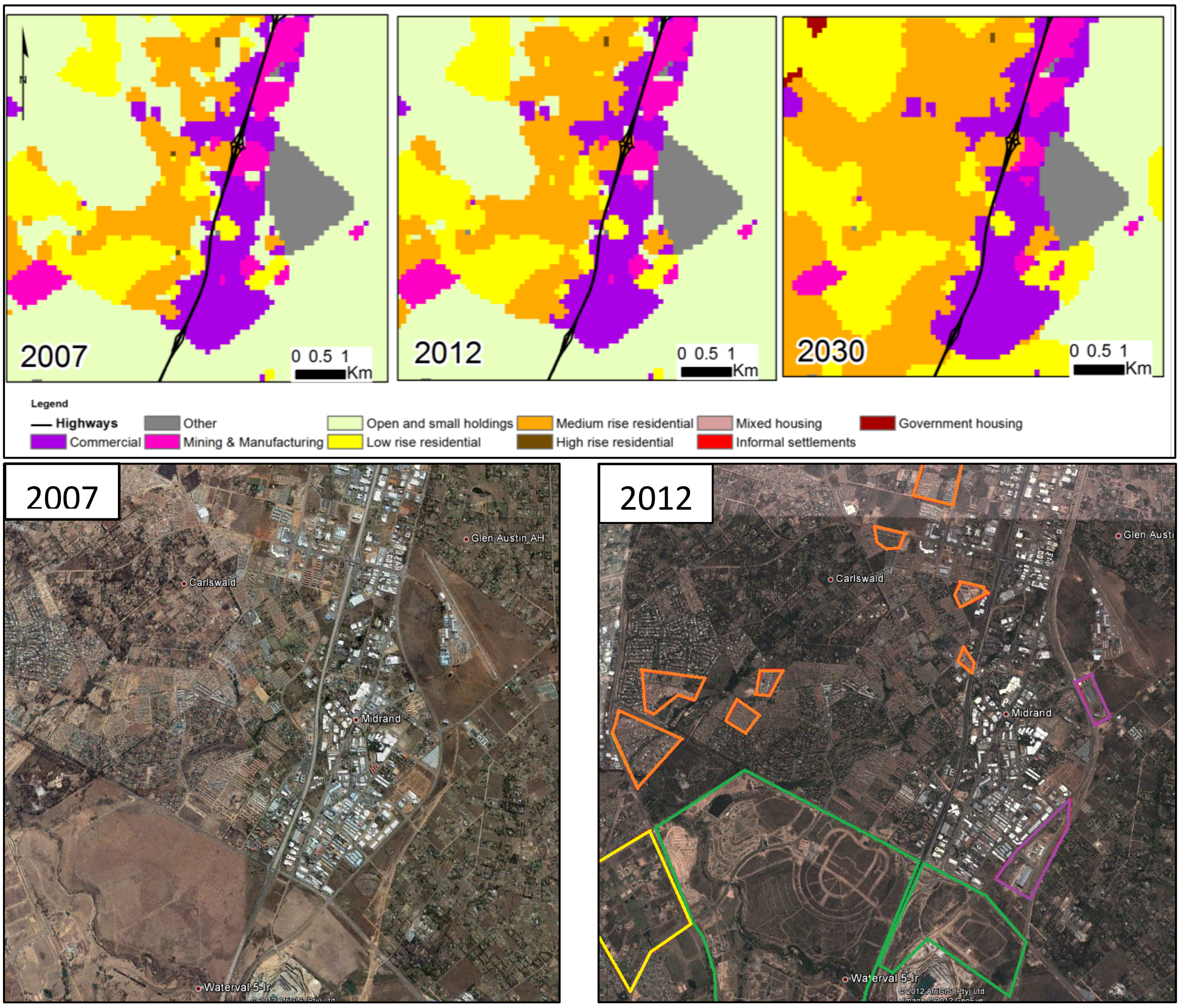


Figure 6.2: Midrand growth 2007 – 2012 (2007 image from DigitalGlobe and 2012 image from GeoEye, both obtained from Google earth)

The transition phases of informal settlements via government housing to mixed housing are also observed throughout both models. Two noticeable areas of transformation are the far south (Orange farm) and the Alexandria area (East of Sandton). Figure 6.3 below provides a satellite image of the Alexandra settlement. To the west is the manufacturing areas and low and medium rise residential areas and to the east Government housing that has been converted into mixed housing through the infilling of backyard shacks.

Figure 6.3: Satellite image of Alexandra and surrounding areas (2012 GeoEye image obtained from Google).

Figure 6.4 indicate the transformation of an informal settlement (Alexandra) to a mixed housing (formal and informal) development in the AS-IS Scenario. In 2007 and 2010 Alexandra is characterised by informality. From 2015 to 2025 these informal areas are replaced or upgraded by Government subsidised housing and by 2030 the Government housing will have converted into mixed housing (informal backyard shacks on formal properties).

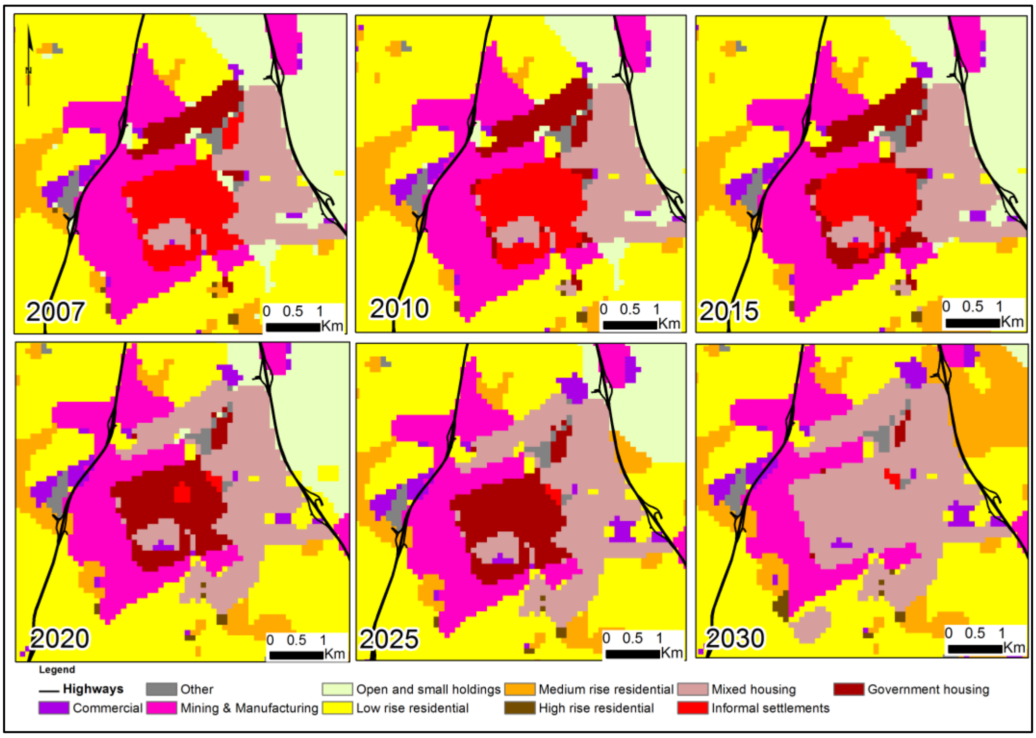


Figure 6.4: Transition sequence of lower income areas, informal settlements to mixed housing.

The growth projected in the AS-IS scenario south of the mining divide (in the south-eastern corner of the metropolitan areas) provides a very positive outlook for the city. Higher income residential development would attract more markets and more job opportunities will become available in this region. This area could provide an ideal opportunity for the marginalised areas to become more integrated into the city. However, the municipality is pushing for the implementation of a UDB (as indicated in the Policy-Led Scenario) that would limit investment in this specific area. Figure 6.5 below depicts the normal AS-IS scenario and the same AS-IS scenario but with the inclusion of the UDB to determine the influence of growth in this specific area if the development boundary is enforced.

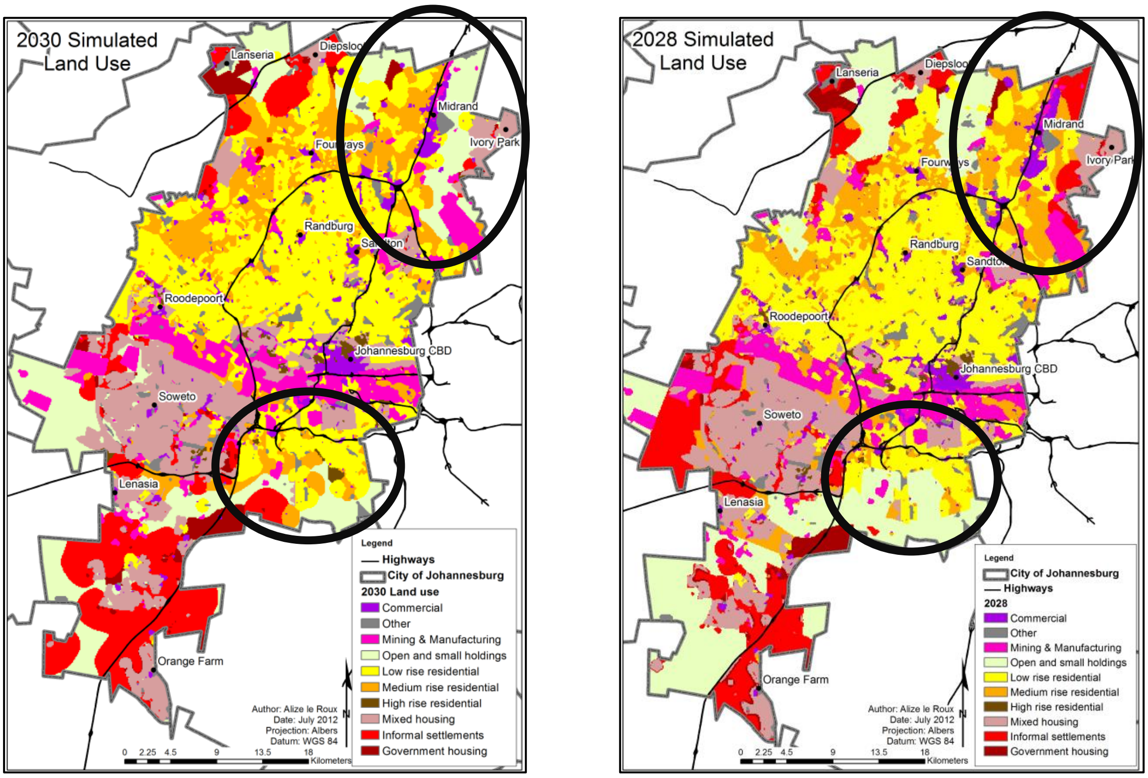


Figure 6.5: The influence of the UDB on the spatial patterns of the city. A) Without the UDB and B) With UDB

The figure clearly shows that by excluding the development in these south-eastern areas, the higher income development will be pushed towards the north where most of the higher income investment is already taking place. What is interesting to note now is that due to the limited space available (because of the UDB) the northern pattern of 'segregation' is forced to change and the higher income development will take place on the eastern side next to the Ivory park settlement (previously restricted to the western side). Including the UDB into the AS-IS Scenario will result in the city running out of land space in 2028. The inclusion of the UDB in the Policy-Led scenario together with higher densities forces higher income earners in higher densities towards the South-east as well as the northern link in Midrand (Figure 6.1c).

6.2 Measuring density

In order to compare the influence of the two scenarios on the density patterns of the city two indicators were measured; 1.Urban sprawl and the 2. Household densification of the transport management nodes.

6.2.1 Urban Sprawl

The effect of the policies on urban sprawl can be determined by calculating the total built-up area, the land consumption per capita and the percentage of new development in 2030. Table 6.3 below provides the results of the two scenarios and their influence on the city's built-up area as well as the land consumption per capita for the various residential classes.

JHB land area 164793 Hectare (HA)	2007 Base year	2030 AS-IS Scenario	2030 Policy-led Scenario
Built-up area (HA)	95 754	142 251	119 310
% Built-up area of total land	58.11%	86.32%	72.4%
Residential (classes 4-9) land consumption (HA)	71 424	118 007	98 963
Households (HH) in classes 4-9	1 128 685	2 179 901	2 186 032
HH per HA	15.8	18.5	22.1

Table 6.3: Built-up areas

From the result summary shown in table 6.3 it is clear that by implementing a UDB and forcing higher densities in accessible locations, the cities footprint will increase by 14.29% to 72.4% built-up areas. This is a small increase compared to the 86.32% built-up area (28.21% increase from the base year) predicted when no development boundary is applied. Densities will also be higher in the Policy-Led scenario resulting in 22.1 households per hectare compared to 18.5 households if no urban development boundary is applied. Table 6.4 below quantifies the extent to which development has taken place on vacant land. It is clear from the table that not applying any restrictions or policies will result in nearly double the amount of vacant land being converted to built-up areas.

2007 - 2030	AS-IS Scenario	Policy-led Scenario
Vacant to Vacant (Ha)	22 522	45 457
Vacant – Built-up (Ha)	46517	23583
% Vacant change to built-up	67.38%	34.16%

Table 6.4: Development of vacant land

6.2.2. Densification of the transport management corridors

This measure looks at the effect of the two scenarios on the sustainability of the Government defined transport management area (as described in Figure 5.11a). Higher densities within the transport management corridors will ensure greater sustainability of the public transport network. Table 6.5 below indicates that the majority of the land is occupied by low-rise (42%) and mixed-housing (30%) in the AS-IS Scenario. The Policy-Led Scenario indicates a shift towards the majority land being occupied by Government provided low cost housing (61%) followed by mixed housing (32%). The Policy-Led scenario will host 673 941 households in these preferred corridor areas compared to 514 420 if no policy intervention is made. In the AS-IS scenario the majority of the households are located in mixed housing, indicating that low-rise residential developments will convert into higher densities due to the optimal location of these areas. In the Policy-Led scenario the majority of the households are located in mixed and government low-cost housing (Figure 6.6).

Housing type	Initial year 2007 Hectares	% Land area of total residential land in corridors	2030 AS-IS Scenario	% Land area of total residential land in corridors	2030 Policy-Led Scenario	% Land area of total residential land in corridors
Small Holdings (3) (Ha)	3587	15	104	0.4	0	0
Low-rise (4) (Ha)	9745	42	9003	38	0	0
Medium-rise (5) (Ha)	1009	4	1933	8	1222	4
High-rise (6) (Ha)	347	2	531	2	681	2
Mixed housing (7) (Ha)	7012	30	10593	45	8980	32
Informal settlements (8) (Ha)	1122	5	1304	6	0	0
Government housing (9) (Ha)	554	2	120	1	16970	61
Total residential hectares	23376	-	23588	-	27853	-
Amount of Households	**376460**	**-**	**514420**	**-**	**673941**	**-**

Table 6.5: Amount of land (in hectares) in the various land use classes for the transport corridor

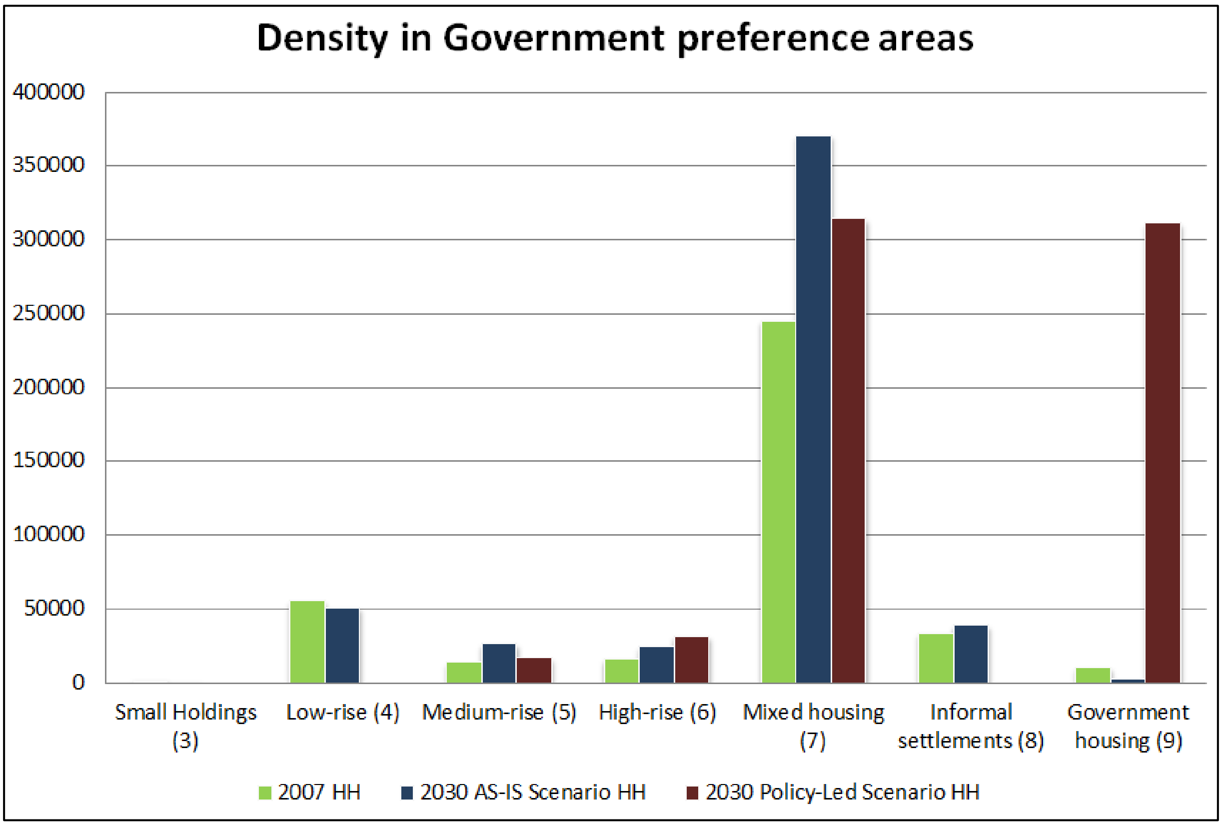


Figure 6.6: Households per land use class within the transport corridors

6.2 Measuring commuting distances

The following section will measure the access to various publicly provided transport systems. The effect of the policies on the access of households to public transport will be calculated through determining the amount of people within a set distance from the Gautrain stations, the BRT lines and the Metrorail stations. The access to Gautrain stations are based on a 5km radius whereas the access to BRT lines and Metrorail stations are based on a 2.5km radius. The assumption was made that for both the BRT lines (Bus routes) and the Metrorail stations a walking distance should apply, whereas for the Gautrain stations a slightly further driving distance can be assumed.

6.3.1 Household access to the Gautrain stations

Table 6.6 below displays the land area consumption per land use class within a 5km distance buffer around the various Gautrain stations. The land area was multiplied by the densities per land use class (Section 5.1.2) to derive the amount of households per land use class (Figure 6.7). From the table it is evident that the largest land area within the 5km buffer in the AS-IS scenario will be consumed by low-rise and small holdings (cumulatively 68%) whereas the Policy-Led scenario will results in an equal amount of land being occupied by both the higher income classes(44%) (Classes 4, 5 and 6) and lower income households (44%) (Classes 7 and 9). Translating these land areas into the amount of households (Figure 6.7) gives as a slightly different perspective. The As-IS scenario will see more of the higher income earners (56%) (land use classes 4, 5 and 6) having access to the stations whereas the Policy-led scenario will see the majority of household belonging to the government provided low cost housing (59%).

Housing type	2007 Base year (Ha)	2030 AS-IS Scenario(Ha)	% land area 2030 AS-IS	2030 Policy-Led Scenario (Ha)	% land area 2030 Policy-Led
Small Holdings (3)	7623	3005	13 %	2971	12 %
Low-rise (4)	11838	12624	55 %	5294	21 %
Medium-rise (5)	1624	3697	16 %	4030	16 %
High-rise (6)	415	484	2 %	1824	7 %
Mixed housing (7)	1196	3150	13.5 %	2737	11 %
Informal settlements (8)	312	83	0.4 %	0	0 %
Government housing (9)	320	20	0.1 %	8213	33%
Amount of residential land consumption (Ha)	**23328**	**23063**	**-**	**25069**	**-**
Amount of Households (HH)	**169939**	**259635**	**x 1.5 times**	**417836**	**x 2.5 times**

Table 6.6: Amount of land (in hectares) in the various land use classes

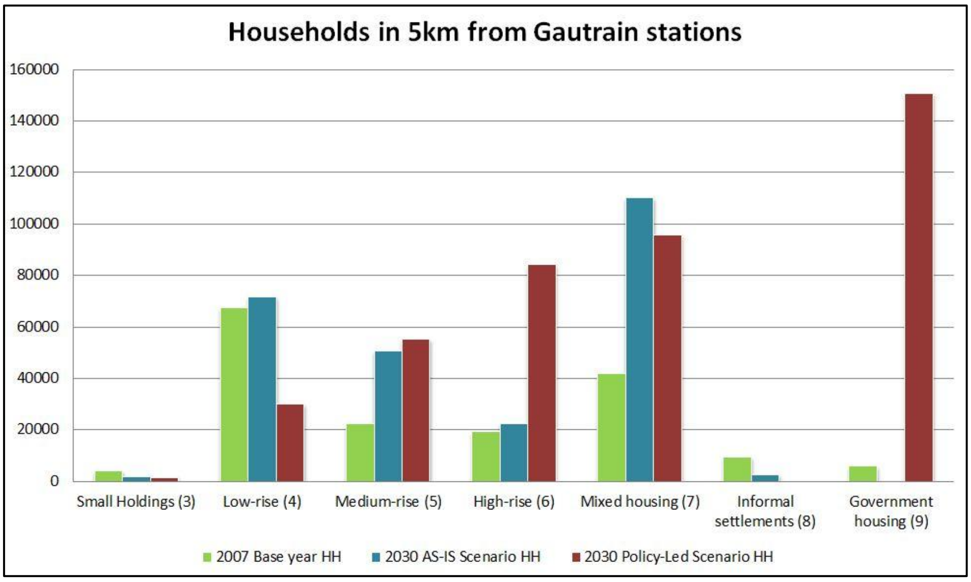


Figure 6.7: Households per land use class within 5km from Gautrain stations

6.3.2 Household access to the BRT lines

Table 6.7 below displays the land consumption of the different land use classes within a walking distance of 2.5km from the BRT lines. Implementing the various policies in the Policy-Led scenario will see an additional 200000 households having access to the BRT lines compared to the AS-IS Scenario. The majority of the households will fall within the mixed housing class for both scenarios. This can be attributed to the fact that the BRT lines runs through the Soweto township (mixed housing) that stays largely unchanged throughout the simulation years. So even though 59% of the land in the AS-IS Scenario is dedicated to higher income earners (class 4,5 and 6) the majority of household access is still obtained by the lower income earners.

Housing type	Base year (Ha)	2030 AS-IS Scenario (Ha)	% land area 2030 AS-IS	2030 Policy-Led Scenario (Ha)	% land area 2030 Policy-Led
Small Holdings (3)	5293	538	1.48	304	0.76
Low-rise (4)	17659	17509	48.29	7829	19.66
Medium-rise (5)	1826	3245	8.95	3131	7.86
High-rise (6)	528	746	2.06	2393	6.01
Mixed housing (7)	8984	13108	36.16	12047	30.24
Informal settlements (8)	714	1001	2.76	0	0.00
Government housing (9)	1061	108	0.30	14128	35.47
Amount of residential land consumption (Ha)	**36065**	**36255**	**-**	**39832**	**-**
Amount of Households	**508037**	**669691**	**x 1.3 times**	**879173**	**x 1.7 times**

Table 6.7: Amount of land (in hectares) in the various land use classes

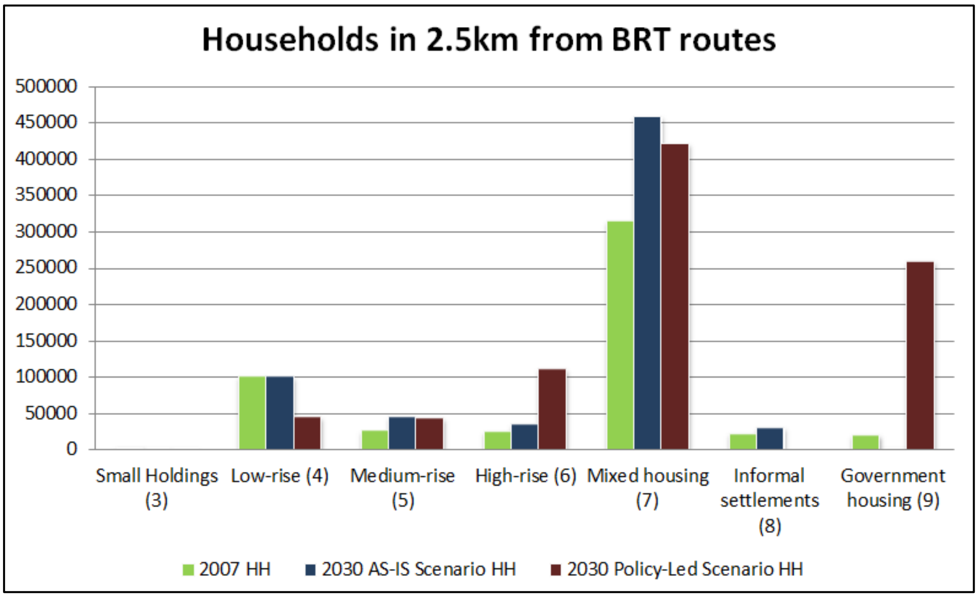


Figure 6.8: Households per land use class within 2.5km from BRT lines

6.3.3 Household access to the Metrorail stations

Table 6.8 below displays the land consumption of the different land use classes within a walking distance of 2.5km from the Metrorail stations. It can be observed that in both scenarios the low-rise residential housing will be redeveloped and replaced by lower-income classes. A lot of informality (both informal settlements and mixed housing) will be present in the AS-IS scenario whereas in the Policy-Led scenario all informal settlements will be replaced by government housing. Figure 6.9 clearly indicates that the majority of the households fall within the lower income earners (Classes 7, 8 and 9) for both scenarios.

Housing type	Base year (Ha)	2030 AS-IS Scenario (Ha)	% land area 2030 AS-IS	2030 Policy-Led Scenario (Ha)	% land area 2030 Policy-Led
Small Holdings (3)	8514	1098	3.74	2456	7.28
Low-rise (4)	7074	6638	22.6	2526	7.49
Medium-rise (5)	428	1853	6.31	1486	4.41
High-rise (6)	380	763	2.6	1707	5.1
Mixed housing (7)	9766	14662	49.91	14521	43.05
Informal settlements (8)	1910	4172	14.20	16	0.05
Government housing (9)	1119	192	0.65	11022	32.7
Amount of residential land consumption (Ha)	**29191**	**29378**	**-**	**33734**	**-**
Amount of Households	**487828**	**740900**	**x 1.5 times**	**825935**	**x 1.7 times**

Table 6.8: Amount of land (in hectares) in the various land use classes

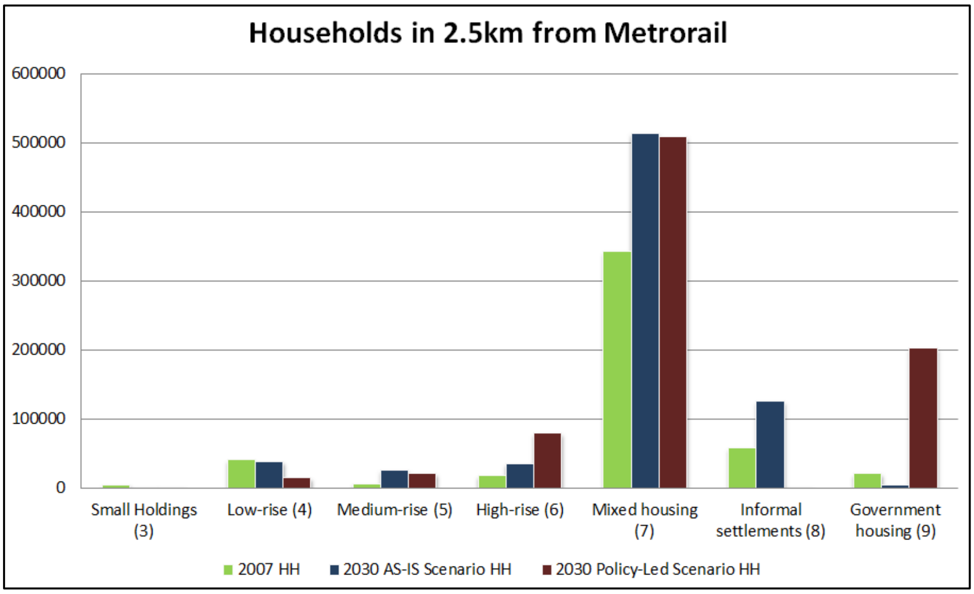


Figure 6.9: Households per land use class within 2.5km from Metrorail stations

In all three public transport cases, it is clear that both scenarios will lead to an overall increase in the amount of household access to public transport, however the Policy-Led scenario will allow a greater number of low-income earners to have access to the public transport systems.

7. Discussion and conclusion

7.1 Research process and results

The research study set out to investigate and determine the consequences and implications of proposed policy plans and spatial strategies. The study utilised modelling tools, methods and techniques to support planners and policy makers within the municipality to quantify and analyse the future spatial implications of the city's policy plans.

The unintended consequences of Apartheids land use policies and planning practises are clearly evident in Johannesburg's landscape. The Johannesburg metropolitan is wide spread with low population densities (15 dwelling units per hectare) resulting in long commuting distances. The city's spatial structure is characterised by stark social and income inequalities and this is noticeable in the large amount of lower-income households living in isolated areas on the periphery of the city. It is also visible in the income inequality of the southern suburbs of Johannesburg which are noticeable deprived from economic opportunities, hosting only 18% of the commercial hectares while accommodating 61% of the city's households (predominantly made up of lower-income households).

The South African government has as a response stressed that bold policies and interventions needs to be implemented to reshape the spatial inequalities of the past. The Johannesburg municipality has drafted policy plans and strategies to address the existing problems by 2030. To realise their targets they developed land-use reform strategies (such as the Growth Management strategy) mainly aimed at the enhancement of public transportation, densification of accessible transport nodes and corridors and the provision of low cost housing in accessible locations.

In addition to these planning policies the city is also expected to grow by 2miljion people and growth is expected in the tertiary employment sectors. Simulations were run using the Dyna-Clue model to evaluate two scenarios, a current AS-IS scenario that focusses on current trends and decision making in line with the past two decades and a Policy-Led scenario that examines the proposed strategies affects.

In order to compare the two scenarios and determine their consequences for the city's landscape three factors where analyses:

1. The effect of the policies on wealth and economic distribution
2. The effect of the policies on population density and its transport corridors
3. The effect of the policies on commuter distances

The analyses in chapter 6 showed that land use patterns that are associated with historically high levels of social inequality and spatial segregation will stay the same in the AS-IS scenario. The Policy-Led scenario will have a slightly more positive effect on the northern parts of Johannesburg but the south of Johannesburg will stay segregated to a large extent. The spatial inequalities of the income groups continue to be very prominent due to the exceptionally high level of clustering of various income groups. The Policy-Led scenario will result in more households residing in the north of the city, 48% compared to the 40% of the AS-IS Scenario. The Policy-led scenario also leads to a greater number of high income earners in the south, 22% compared to the 10% projected for the AS-IS scenario. The economic inequalities will stay unchanged for the AS-IS Scenario compared to the initial year as 80% of the commercial activity is provided in the north and only 20% in the south where 60% of the households are located. The Policy-Led scenario provides more economic opportunities (33%) in the south for 52% of the households. This policy thus positively influences the unequal provision of economic opportunities but still doesn’t correct the inequalities.

The influence of the UDB is also clearly visible as it restricts the growth of the city specifically towards the south in the Policy-Led Scenario. Applying a development boundary (such as the proposed UDB) will indeed have an influence on the sprawled nature of the city but will restrict development towards the south. Implementing the UDB will result in the city being 72% built-up in 2030 compared to the 86.32% predicted if no boundary is applied. The densities will also increase to 22.1 households per hectare in the Policy-Led scenario compared to the 18.5 households per hectare in the AS-IS scenario. However, the increase in density can also be ascribed to the higher densities in the form of government provided low cost housing and high-rise building used in the Policy-Led scenario.

The effect of the policies on the commuter distances indicated that both scenarios will lead to an overall increase in the number of household that have access to public transport but the Policy-Led scenario will allow a greater number of low-income earners to have access to the public transport systems.

From the analyses it became clear that if the government continues along the same trajectory as the past decade that the city will be inundated with informality by 2030. The city will see increased levels of spatial income inequality and will become even more sprawled. Adopting the government policies on densification and growth restrictions will see a more inclusive northern half of the city. However the vast amount of lower-income earners will still dominate a largely segregated southern half of Johannesburg and even with these drastic policy interventions segregation in the southern suburbs and areas such as Soweto, Orange farm, Diepsloot and Ivory Park will stay prevalent.

The answer to the main research question is now clear; “No, the proposed policy plans of the city of Johannesburg will not restore the spatial inequalities of past political agendas”. A more multi-dimensional, multi-level approach is thus needed. Mbuli (2008) puts emphasis on the fact that poverty alleviation can only be accomplished through rapid and broad-economic growth, investing in economic opportunities, job creation for the poor specifically in the small and medium enterprise sector, increasing expenditure in investment in human capital development and establishing of social networks. It is thus suggested that more policies need to be implemented and tested, specifically economic policies.

7.2 Model limitations, recommendations and way forward

The model proved to be well suited to simulate various classes of urban land use and was easily adopted to model a three-layer typology that included land function, density and income categories. The model was also adapted to simulate the growth of both formal and informal structures as well as policy interventions such as Government provided low cost housing. There are however a couple of limitations in the model that needs to be taken into account.

The model is dependent on external land use demand figures that specify the amount of hectares per land use class for the projected future. The control totals for the household growth were obtained from an external demographic model. The breakdown of these household control totals into land use classes was done based on the percentages observed in the base year (2007) and the specified scenarios that were tested. Land use classes such as commercial, mining and manufacturing were derived based on the projected employment growth in the primary, secondary and tertiary economic sectors (Table 3.1) (e.g. a decline in primary sector employment meant a decline in mining activity while a growth in tertiary employment resulted in growth in commercial land use). These assumptions directly influence the spatial allocation of the land use demand. The Johannesburg Dyna-Clue model only utilised economic employment figures and did not take into account other economic factors such as Government budget constraints, economic growth or fiscal spending. It is suggested that more rigorous investigation is needed to derive at the land use demand figures (e.g. investment in human capital can decrease the amount of low cost housing demand as these households move into the formal market economy).

Another limitation of the model is that land use demand cannot change dynamically in the model based on feedback of land constraints (e.g. if available land runs out, the model should have adjusted to build higher density residences instead of assuming it is not possible). This relates back to the problem of specifying the various land use demand figures externally to the model. It is proposed to overcome this by running multiple scenarios that test the effect of the variations within the household splits. Causal relationships are also not taken into account (e.g. implementation of restricted growth based on the UDB could potentially increase land prices due to availability that in turn could see higher densities and higher land prices as a results). Market responses of demand and supply are thus not taken into account.

Inclusion of government's low cost housing is subject to human drivers of change such as direct policy interventions and cannot be explained through regional or local spatial drivers of change. These decisions were included in the model through locational preference areas that directly influenced the locations of these housing types. A deeper understanding is needed on how the various other land use classes interact and are affected by these direct interventions of investment. More scenarios are thus needed to test the effect of the preferences areas on the growth of these land uses throughout the city.

It should be noted that the model was the most sensitive to the settings in the neighbourhood weights and a lack of data restricted the scientific rigour that was applied in dealing with this setting. Although sensitivity analyses were preformed it is suggested that a validation process between simulated and observed years should be conducted for a more accurate representation.

Engelen et al. (2003) highlights the fact that the urban environment is a complex system with interplays between sub-systems and that the modelling should endeavour to be a multifaceted interdisciplinary exercise. It is suggested that the modelling exercise should include expertise from a wider range of disciplines, including elements such as gated communities, land prices, land ownership, labour intensive employment locations and geological unsafe areas. This will greatly improve the interdisciplinary nature of the model.

Given the limited amount of urban land use change models available within developing countries it would be beneficial to compare the results of this CA model with results obtained by another modelling technique (e.g. UrbanSim an agent-based model currently being adopted by the CSIR to simulate urban growth in the developing context). This comparison will provide valuable insights into the effects of policy modelling in developing countries.

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Annexure A - Calculating a new land use typology

The classification of Table A1 below is based on the three principles of; land use functions, density and income. This multi-layered classification is not readily available and various steps where preformed in order to classify the Johannesburg land use accordingly. First step involved grouping all the functional land use classes together, thereafter the various residential classes were separated based on their densities and income classes. This classification was done utilising data from the GTI 2007 land use classes, the GTI 2007 growth indicators for formal and informal units and using the income classes per suburb obtained from Knowledge Factory and StatsSA 2007.

Land use class	**Data used in classification**	**Process used for classification**	**Current land occupation and brief summary of reason for including land use class**
Commercial (0)	GTI land use 2007	Select all commercial (1) properties	This class occupies 2.36% of the Johannesburg land area. It is critical when comparing the three scenarios in terms of access to employment.
Other (1)	GTI land use 2007 Cadastre 2007 Roads dataset 2011	Select all Services (14), Government (4), Unknown (17), Parks (8), Recreation (9) and Air transport (16) properties.	Includes layers considered static for the simulation. These areas are considered 'undevelopable' land.
Industrial Mining and Manufacturing (2)	GTI land use 2007	Select all Industrial (5) properties and Select all mining(6) properties	Manufacturing occupies 3.37% of the land use and the mining occupies 3.17% of the land area.
Vacant, Small holdings and open spaces (3)	GTI land use 2007	Select all small holdings (15) and open (7) properties. Roads where excluded from this layer.	This will be the primary land available for expansion of the urban environment.
Formal residential low rise (4)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Select all formal single dwellings, detached (11) properties. Exclude low income suburbs and exclude mixed formality area. Schools and community areas where included as part of this land use type.	This class is critical in determining the influence of policies on urban sprawl/compactness. The class density is slightly lower than normal due to the inclusion of educational and community services.
Formal residential medium density (5)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Select all formal cluster housing (10) properties. Exclude low income suburbs and exclude mixed formality area. Typically simplex, duplex, security estates or walk-ups. This class fills the gap between extreme low densities of single dwellings and the high densities found in city centres.	This higher density land use class includes simplexes, duplexes, duets and walk-ups. The class also contains community services and educational facilities. Schools and community areas where included as part of this land use type.
Formal residential high rise (6)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Select all formal high rise (12) properties. Apartments, hostels and flats.	Flats and apartment block, primarily located in the cities CBD or central economic nodes. Not a popular choice due to crime related activities associated with high density residential units. Older workers hostels also fall in this category although

			not located near the CBD or economic hubs.
Mixed use (7)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Where functional land use class is 'Residential' and where there is a presence of Informal structures or Backyard structures on the same erf.	These areas represent high densities and are a mix between formal and informal housing. These areas are typically characterised by formal residential areas that densify over time by means of informal backyard shacks.
Informal residential (8)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Where functional land use class is Informal (13). Areas without a formal structure occupying land illegally.	Hosts and estimated 200 000 households. No formal structure or services put in place.
Government low cost housing (9)	GTI land use 2007 GTI growth indicators 2007 Suburb Income 2007	Where Functional land use class is 'Residential', where no backyard shacks or informal dwellings are present and where suburb Income levels are below R9500 per household. This is the acceptable limit for state provided housing according to the Human settlements Atlas (2009).	Most of the Mixed formality transformed from this class. Mostly single dwellings or walk-ups with smaller dense units and low income earners (income below R9500p/month).

Table A1: Ten class land use typology development

Annexure B – Determining the raster resolution

In order to determine the ideal resolution for the modelling input analyses was done to determine the influence of various resolution scales on the accuracy of the models representation. The scales taken into consideration were a 10m, 50m, 100m and 150m resolution. It was decided to include the roads layer into the ‘other’ land use type classification to ensure that it is not modelled as ‘open’ or developable land (as specified in the original GTI land use dataset). Figure B1 provides a visual indication of the influences of the various conversion methods used while figure B2 provides a calculation of the influence that various scales and conversion methods have on the percentage of land use assigned to each land use type. The percentages are based on the amount of raster cells representing a specific land use type.

The land use type with the largest area within a cell gets assigned to a specific cell. Figure B1b is a 10m raster representation of the actual vector representation in Figure B1a. The 10m representation is by far the most visually pleasing and accurate (i.t.o cell representation). Unfortunately this will require 14.8 million cells within the Dyna-Clue mode. A more acceptable amount can be obtained by using 590000 cells at 50m resolution (figure B1c) or 164973 cells by using a 100m raster. However when this approach is followed the conversion of linear features (roads) to raster format introduces some visual disturbances as noted in figure B1c specifically the residential and commercial areas. An approach to try and assign priorities to non-road areas resulted in a much better visual representation (figure B1d) but the results when calculating the allocated cells result in an over calculation in available vacant land in the city.

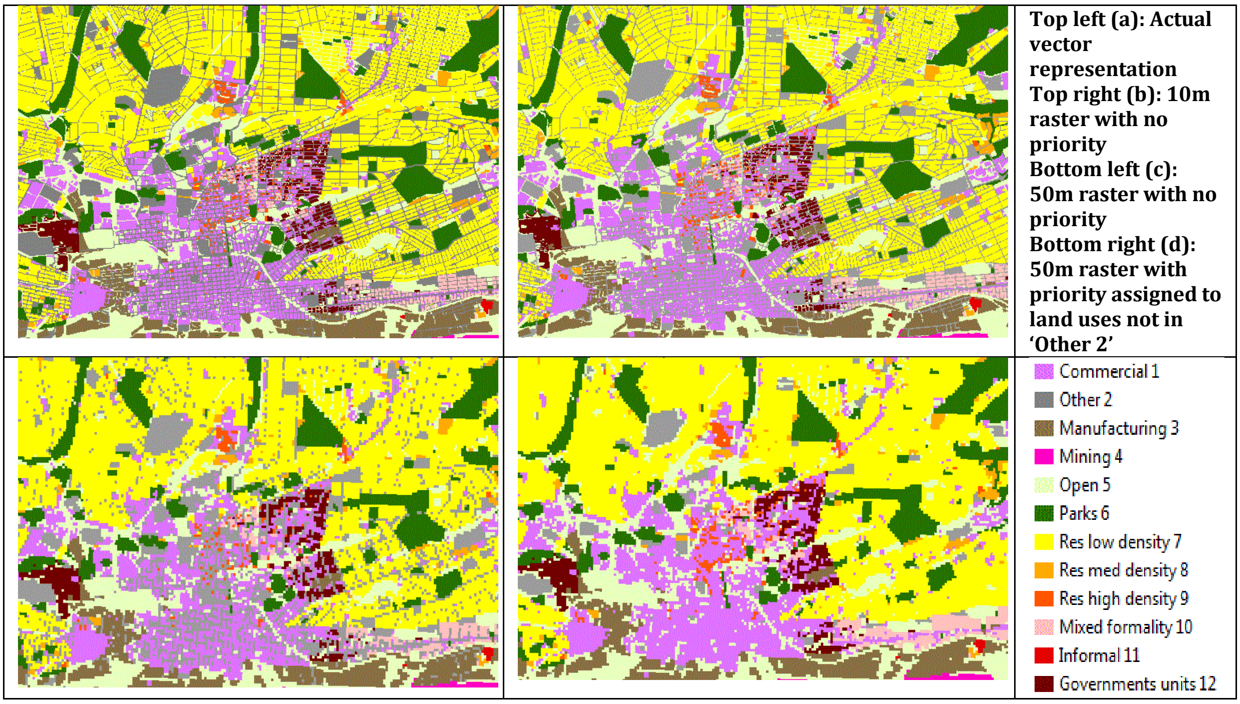


Figure B1: Visual influence of conversion methods

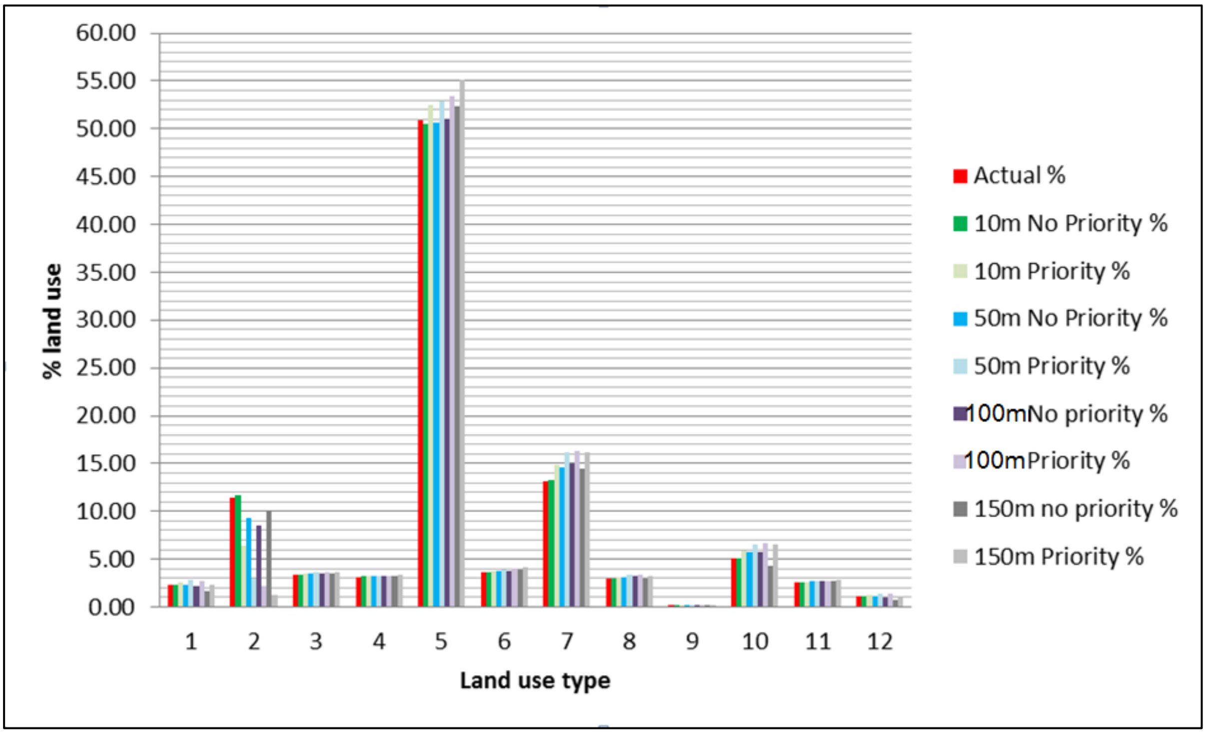
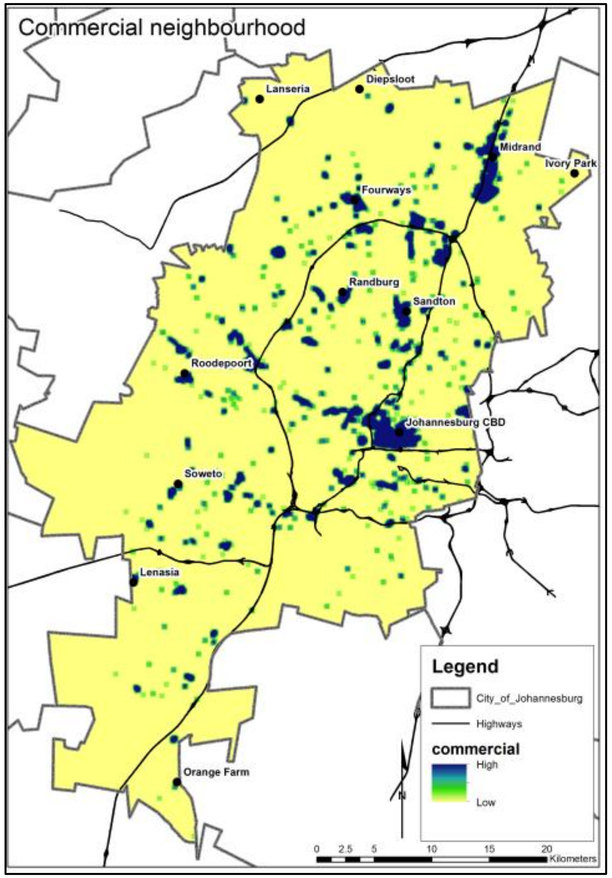
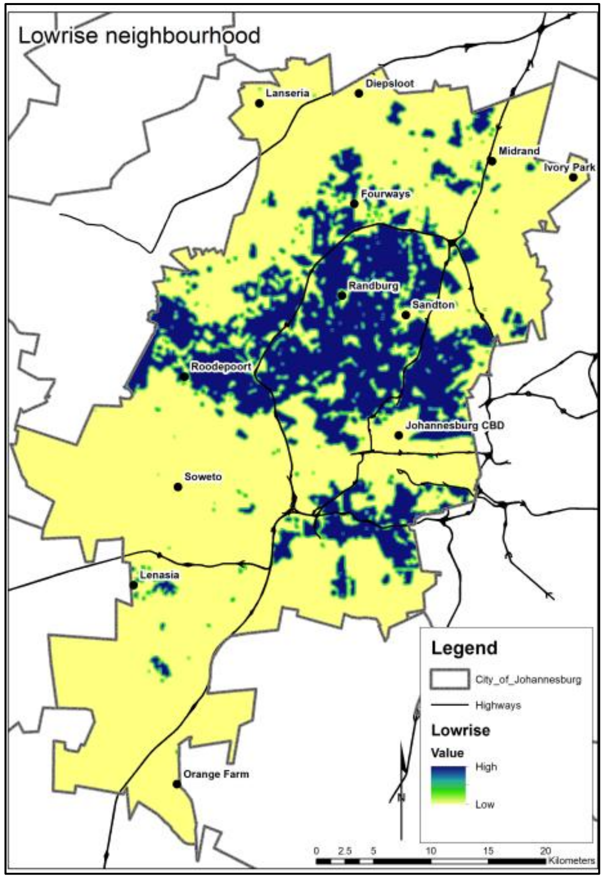


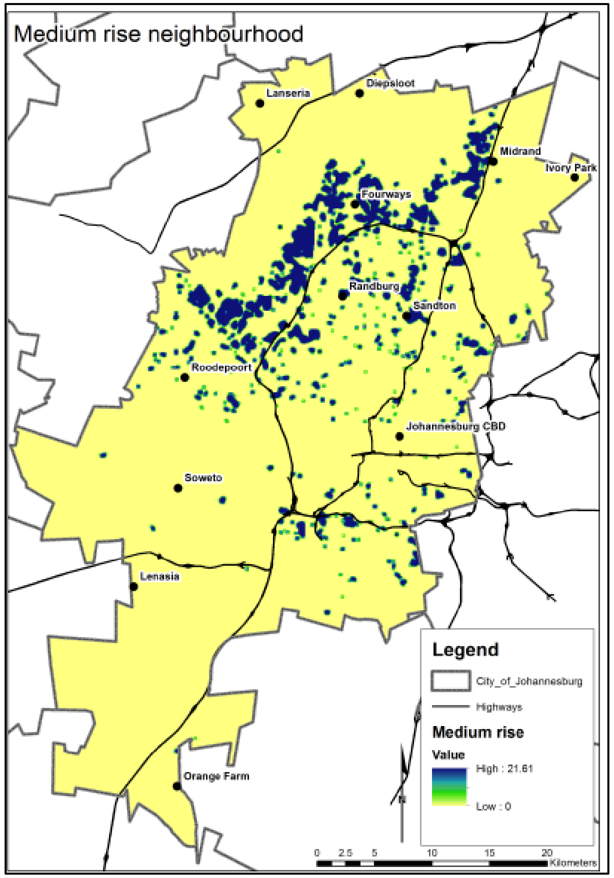
Figure B2: Area distortions of two conversion methods for four scales.

From the above figure it is clear that the 'Other' land use type (2) (which includes the linear roads features) are the most inaccurate when translating the vector into raster format. It was decided given the model constraints that a 100m raster with priority will be used.

Annexure C: Neighbourhood factors







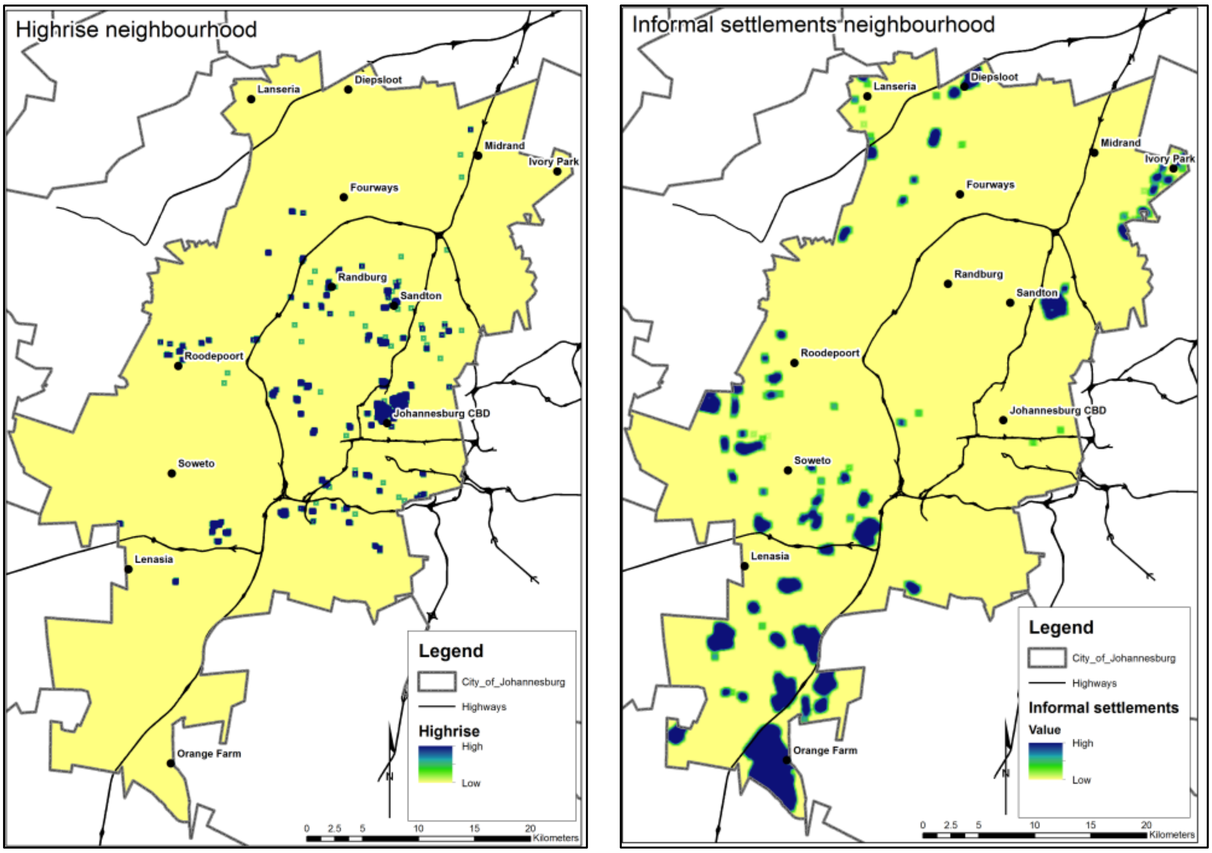
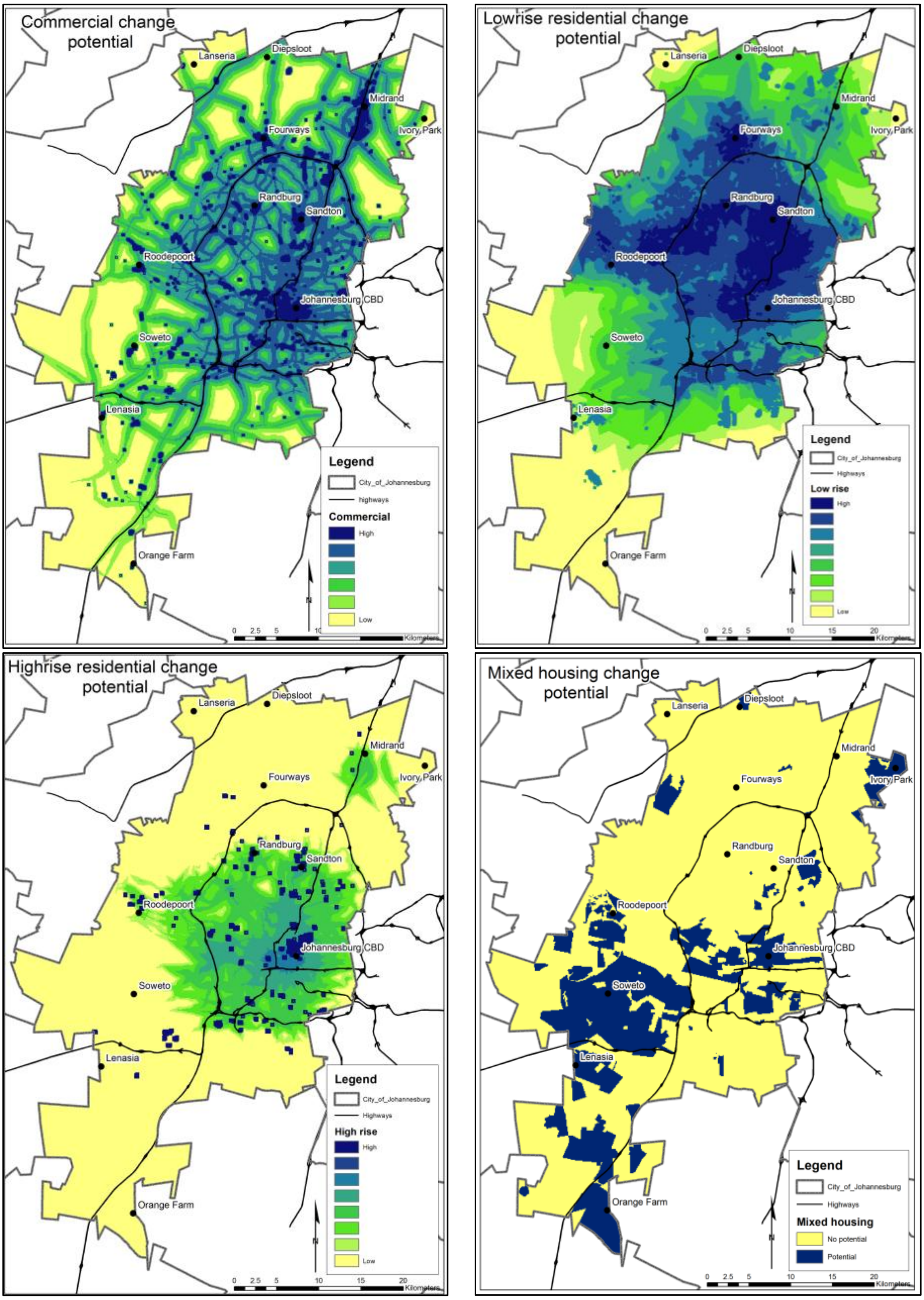


Figure C1: Neighbourhood factor maps

All neighbourhood enrichment maps where created with ‘focal statistics’ in ArcGIS using a rectangular window of 5.

Annexure D: Potential maps

AS-IS Scenario change potential



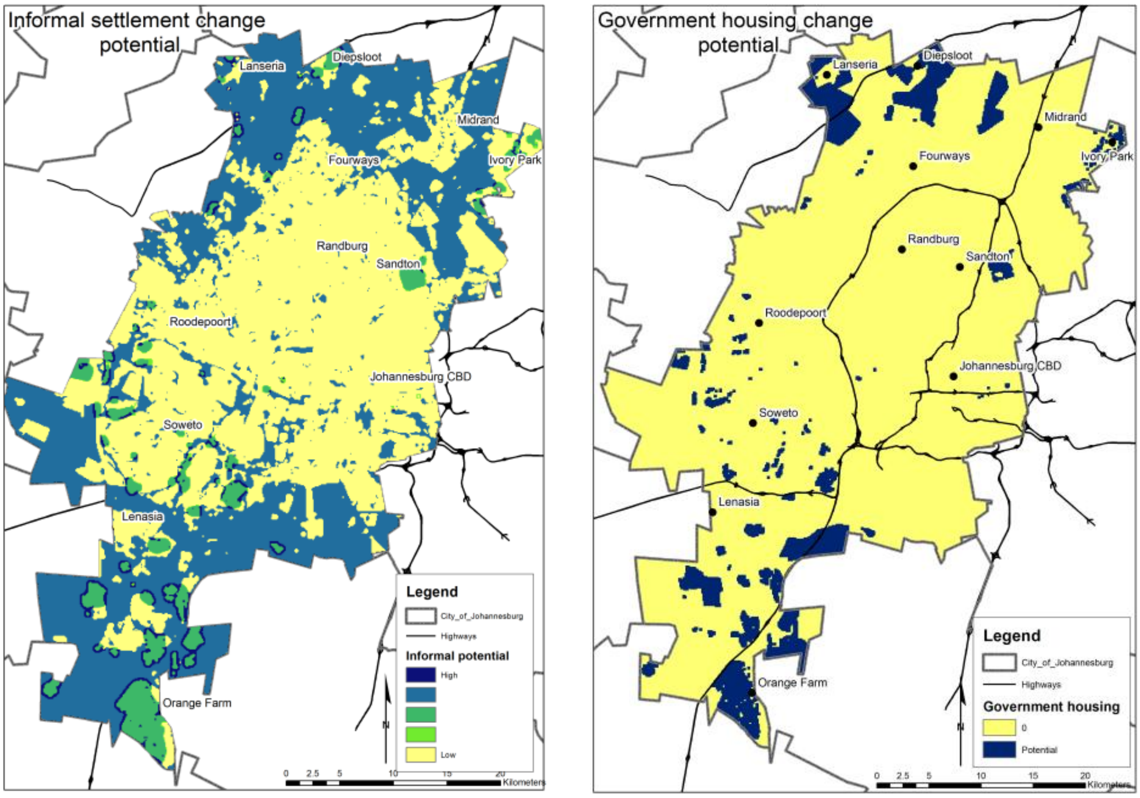
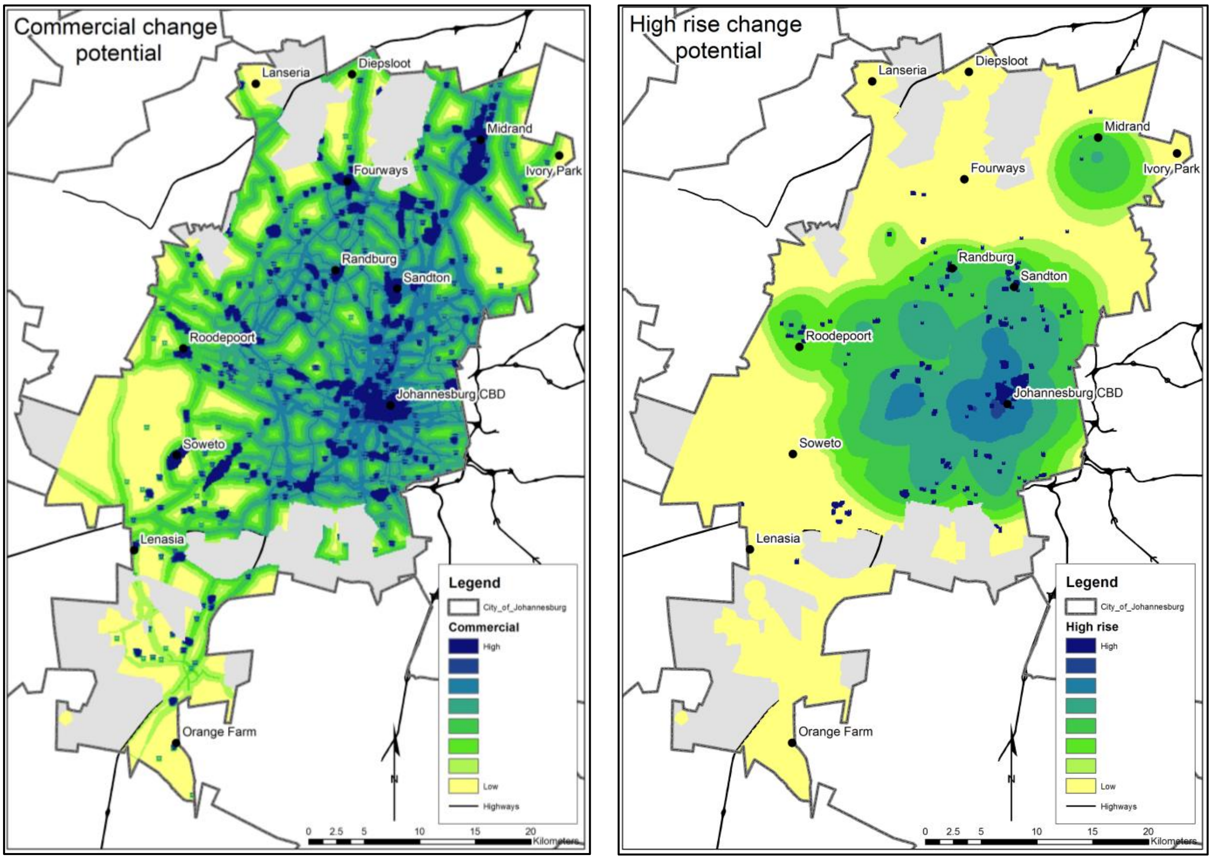


Figure D1: Change potential maps

Policy-Led Scenario change potential

Potential maps for Low rise residential (4) and Informal settlements (8) are not displayed due to the fact that the Policy-led Scenario depicts these two classes as declining in the scenario.



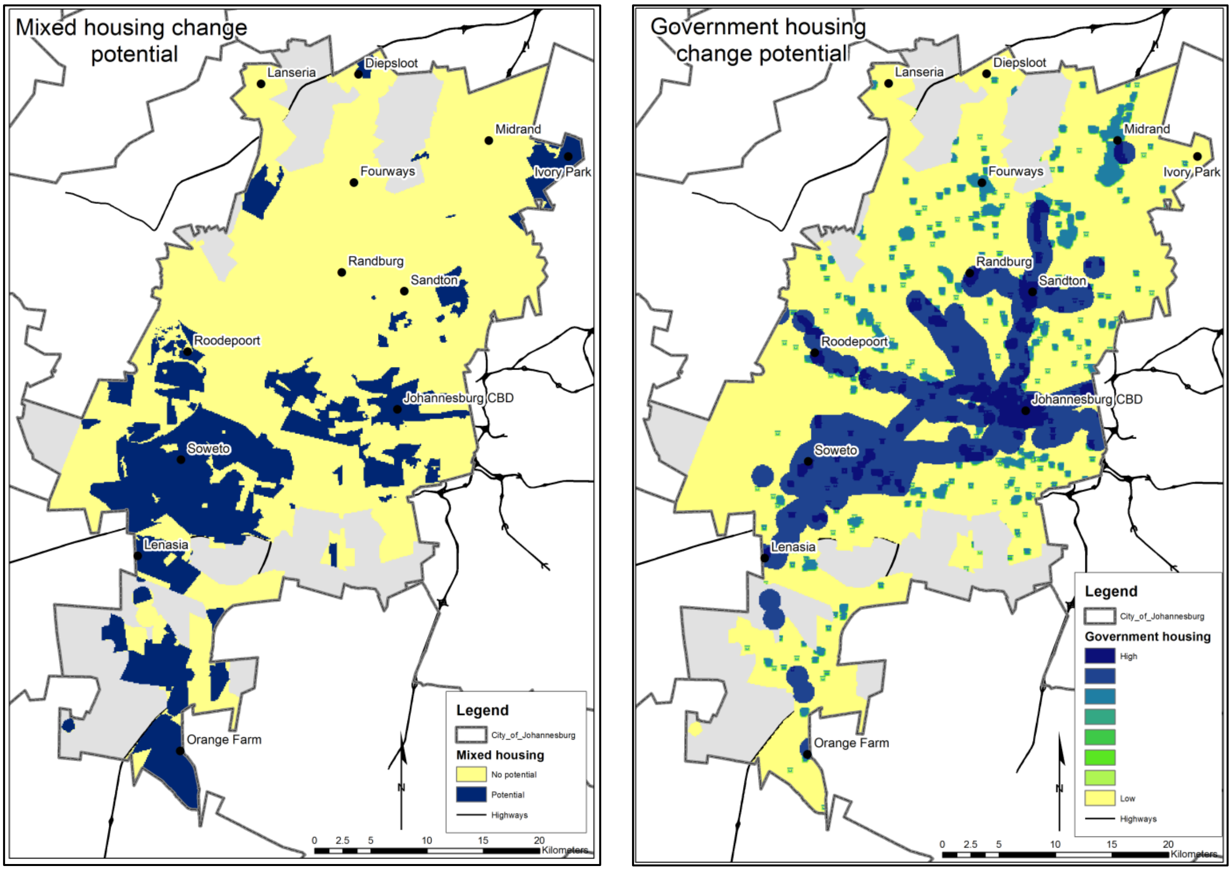


Figure D2: Change potential maps

Annexure E: Devision of Northern and Southern Johannesburg

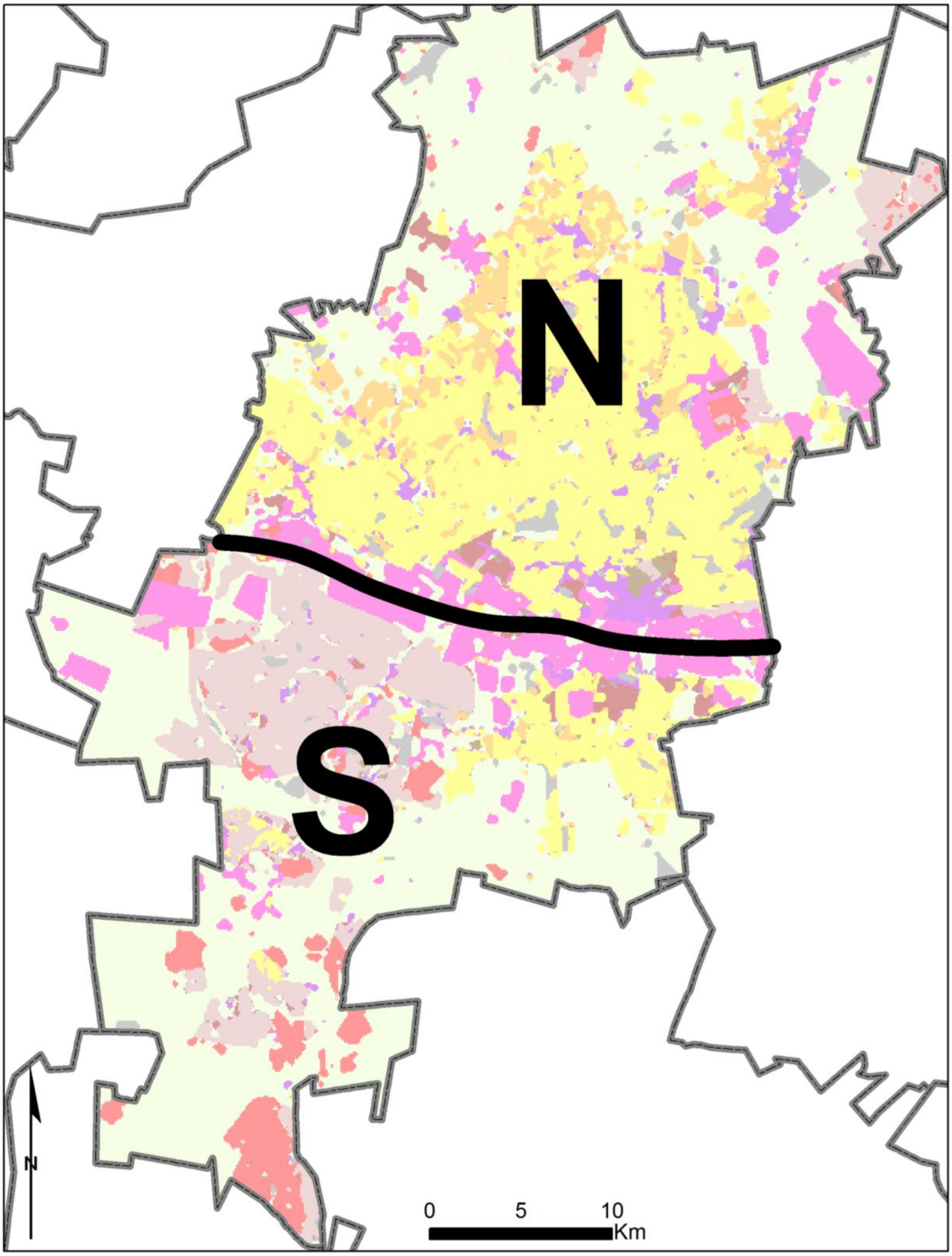
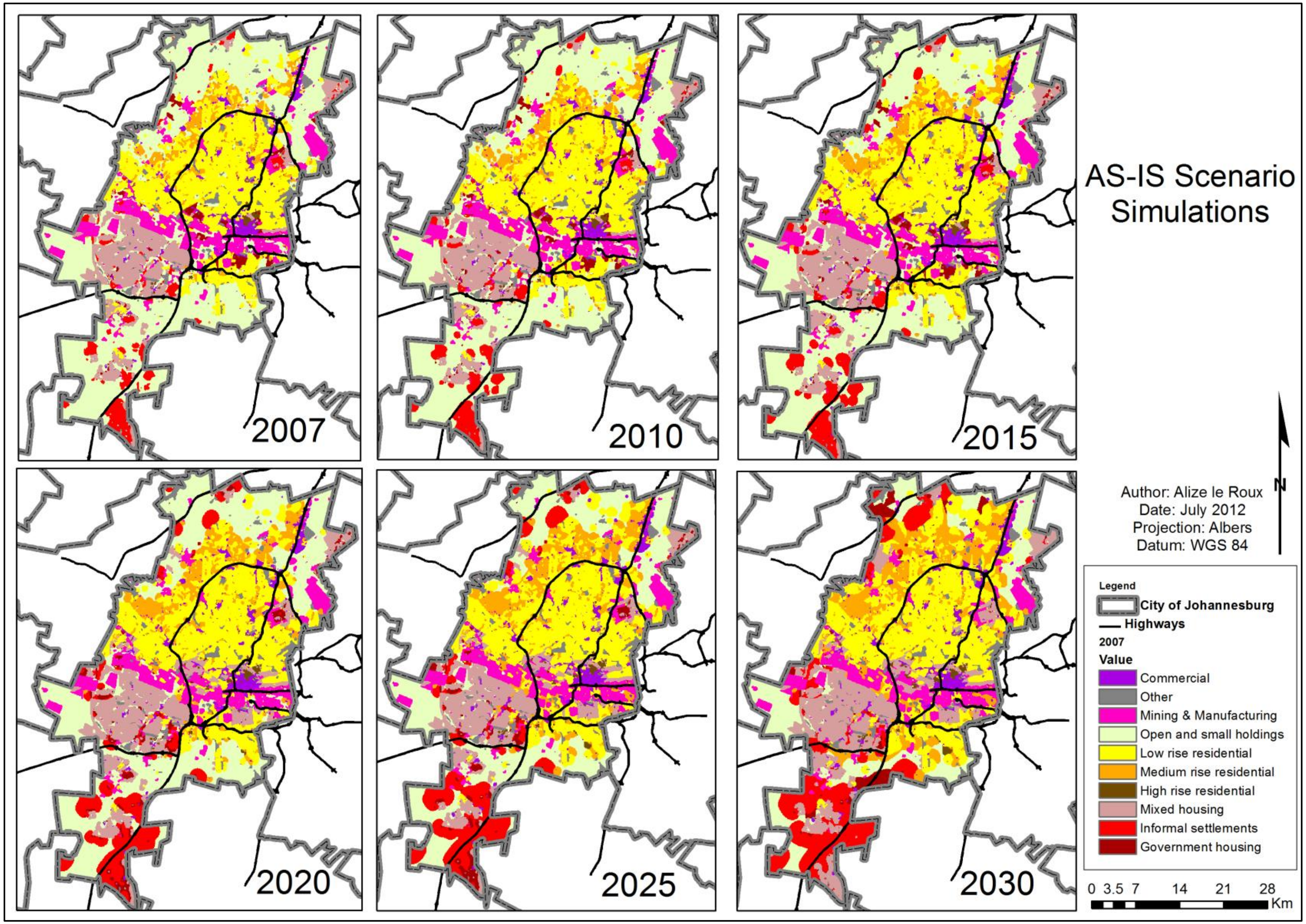


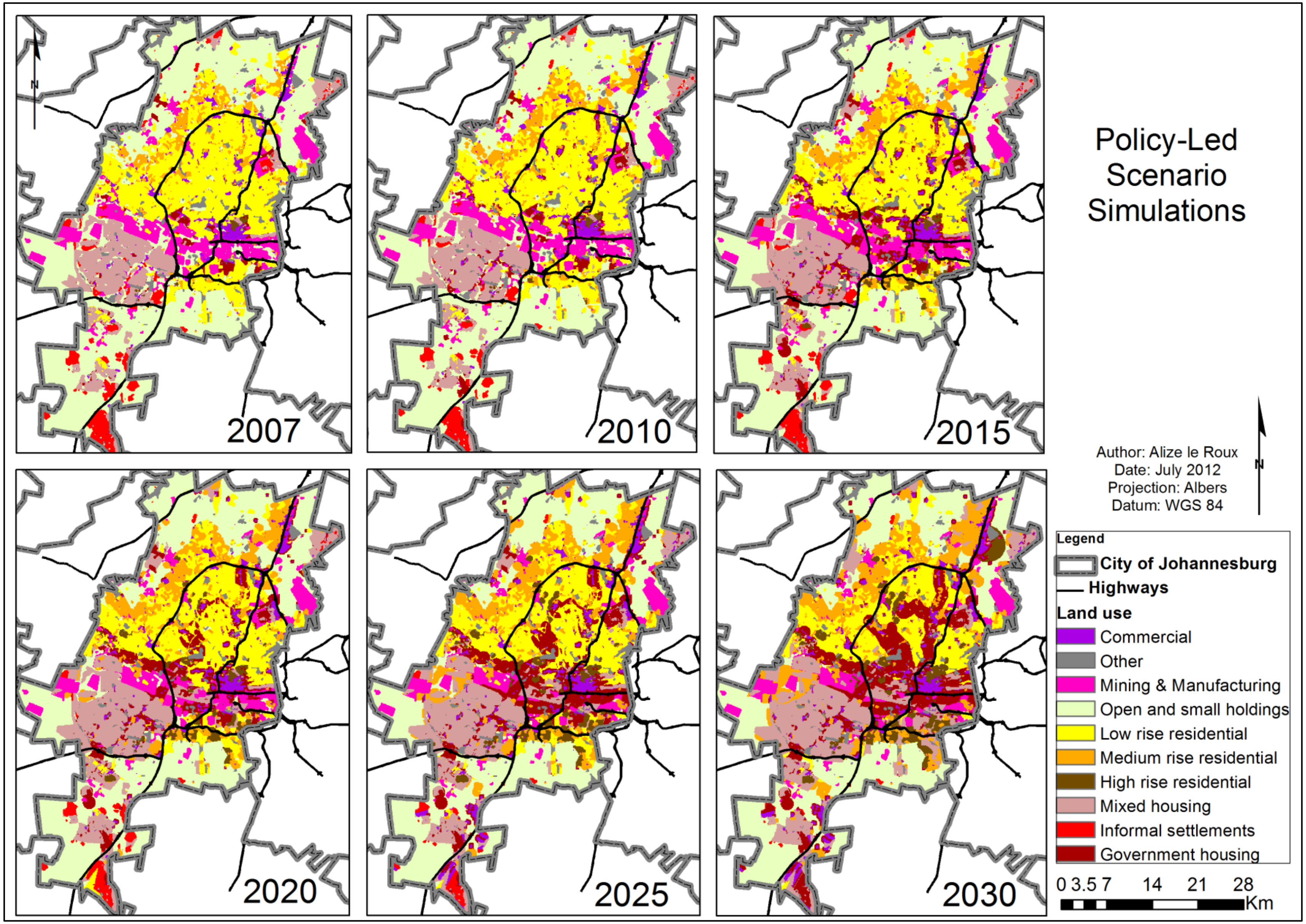
Figure E1: Division of Johannesburg's measurement unit.

Annexure F: Data sources used

Dataset	Description	Format	Feature	Year	Source
Roads	Feeder routes and Highways	Vector	Network set	2010	AfriGIS
Dwelling counts	Informal settlements and Backyard shacks	Vector	Points	2011	Geoterra Image (GTI)
Land use	Functional land use typology	Vector	Polygon	2007	Geoterra Image (GTI)
JHB Boundary	Local municipality boundary	Vector	Polygon	2009	Municipal demarcation board
Gauteng Boundary	Provincial municipality boundary	Vector	Polygon	2009	Municipal demarcation board
Economic distribution	GDP distribution per 50sqkm	Vector	Polygon	2011	CSIR, GAP
Population distribution	Population distribution per 50 sqkm	Vector	Polygon	2011	CSIR, GAP
JHB Spatial From	Image of various spaces within the metropolitan	GIF	-	2011	City of Johannesburg
Household income	Income distribution per suburb	Vector	polygon	2007	Knowledge factory, ClusterPlus
Backyard shacks growth	Time series satellite image of backyard shacks	GIF	-	2000-2010	GTI and City of Johannesburg
Various satellite images	Example satellite images used throughout the document	GIF	-	2007-2012	Google Earth
Gauteng station	Locations of the Gautrain stations	Vector	Points	2011	City of Johannesburg
BRT Lines	Bus rapid transport system lines	Vector	Lines	2011	City of Johannesburg
Metrorail stations	Location of all metrorail stations	Vector	Points	2011	City of Johannesburg
Growth Management Strategy (GMS) Layers	Government preference areas Public transport managment areas Expantion areas Urban development boundary	Vectors	Polygons	2011	City of Johannesburg
Economic hubs	Areas of significant economic activity.	Vectors	Polygons	2011	City of Johannesburg
Commercial activity	Regional shopping centres	Vectors	Points	2011	City of Johannesburg

Annexure G: Simulated land use change




2007
2010
2015
2020
2025
2030
Policy-Led Scenario Simulations
Author: Alize le Roux
Date: July 2012
Projection: Albers
Datum: WGS 84
N
Legend
City of Johannesburg
Highways
Land use
Commercial
Other
Mining & Manufacturing
Open and small holdings
Low rise residential
Medium rise residential
High rise residential
Mixed housing
Informal settlements
Government housing
0 3.5 7 14 21 28
Km

Annexure H: Main parameter settings

Line no.	Parameter input values	Description
1	10	Number of land use classes
2	1	Number of regions
3	7	Maximum number of driving factors for the regression equation with most variables present
4	9	Total number of driving factors considered for the study area
5	693	Number of rows of the input raster
6	504	Number of columns of the input raster
7	100	Cell area (m)
8	368448.85714027	X coordinate of the lower left corner of the input raster
9	-2884629.7554679	Y coordinate of the lower left corner of the input raster
10	0 1 2 3 4 5 6 7 8 9	Coding for the land use classes
11	0.8 0.4 0.7 0.7 0.8 0.5 0.2 0.7	Conversion elasticity's (between 0 and 1) for each of the land use classes specified in line 10.
12	0 5 15	Iteration variables. - (0) convergence criteria expressed as percentage - 5% deviation allowed between demand change and actual allocated change - 15% maximum deviation allowed between demanded changes and actually allocated changes
13	2007 2030	Start and end year of simulation
14	0	Number of dynamic driving factors
15	3	Output/input file choice. 3 indicates ArcGIS extensions used (*.asc)
16	0	No addition regions used, no addition drivers
17	1 5	Default values used for land use history
18	1	(1) Neighbourhood function on (2) To calculate the neighbourhood maps
19	1	(1) Preference area maps used for study and the relative weights assigned
20	0.07	Iteration parameter (stable setting)

Annexure I: Software utilised

Software and license	Function
ArcGIS desktop student edition 10.1 and CSIR license	GIS software, data preparation, analyses and visualisation.
SPSS Statistics 17.0 CSIR license	Statistical analyses package for regression analyses
Dyna-Clue 2.0 2006 Free-Ware	Land use change model
Photoshop Private license	Visualisation
Microsoft Excel 2010 student and CSIR license	Analyses and data preparation
Windows 7 professional 64 bit operating system	Operating system
Skype	Communication with supervisor
Dropbox	Data sharing with supervisor
Microsoft Word 2010 Student edition and CSIR license	Document writing