A Geospatial modelling approach to simulating the impact of future planning policies on the City of Tshwane

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Abstract

Many researchers believe that no matter what path a country takes towards economic development the end result will lead to urbanisation. Rapid urban growth will have a major influence on the social, economic and political dialogue over the next few decades. The planning policies that are implemented in cities influence where urban growth will take place. In order for a government to implement effective policies they first need to establish what the possible effects of these policies could be. Land use change models have proven to be effective decision support tools when it comes to determining the effects of planning policies. The aim of this paper is to simulate urban growth for the City of Tshwane over the next 30 years under the Compaction and Densification Strategy policy currently in the process of implementation. This policy aims to reduce the effect of urban sprawl by promoting urban densification. It became clear from the results that the implementation of the Compaction and Densification Strategy could lead to the development of a more compact City of Tshwane. Under the Compaction and Densification Strategy, most of the development will take place within a 25km radius of the Central Business District and around major routes, metropolitan- and urban cores. This leads to most of the development taking place around the existing infrastructure instead of taking place where there is no established infrastructure.

1. Introduction

Many researchers believe that no matter what path a country takes towards economic development the end result will lead to urbanisation (City of Tshwane, 2015b). The World Bank (2016) estimated that 50 percent of the global population lived in urban areas in 2016 and this number is expected to increase to 69.6 percent by 2050 (World Bank, 2016). In South Africa alone the proportion of people living in urban areas increased from 52 percent in 1990 to 62 percent in 2011 (World Bank, 2016) and is expected to continue this trend throughout the next couple of decades (Le Roux et al., 2018). This rapid urban growth will have a major influence on the social, economic and political dialogue over the next few decades.

Urban growth can manifest in two forms namely urban sprawl or urban densification. Urban sprawl is defined by the Oxford dictionary as the uncontrolled expansion of urban areas. Brueckner (2000) defines it as the excessive spatial growth of cities. Urban densification on the other hand is

the process of developing urban areas to be more compact and efficient in terms of infrastructure and sustainability. Urban densification is implemented in many cities in an attempt to neutralize the effects of urban sprawl (Haaland & van den Bosch, 2015). Originally urban development in South Africa took place in the form of urban sprawl, but over the last decade or so the development strategy of many South African cities changed to encourage urban densification (Du Plessis & Bonzaaier, 2015).

This has also been the case for cities within the City of Tshwane where the Compaction and Densification strategy (CDS) is being implemented in order to encourage densification within the municipality. The aim of the CDS is to achieve an efficient, integrated, stimulating, sustainable and liveable city with high quality environments. CDS aims to achieve this by minimising the cities footprint; reducing the destruction of agricultural land; encouraging the use of public transport; aiding in pedestrianisation; reducing inequality and creating a marketable city. The CDS is described as not being an end in itself, but a means to achieve an efficient, integrated and sustainable city (City of Tshwane, 2005).

Even with well-designed planning policies there is still a great uncertainty to how areas will develop under these policies and what impact these developments will have on the environment and our everyday lives (Le Roux & Augustjin, 2017; Chaudhuri & Clarke, 2013). Land use change models have proven to be effective decision support tools in determining the effects that planning policies will have on development. Land use change models are computer simulation tools that can be used in understanding the drivers of change.

There are currently multiple land use change models available to simulate the growth of urban areas. These models can be divided into two main categories based on the type of approach that was used to develop the model. These categories are descriptive and prescriptive models. Descriptive models are used for the simulation of current land use systems or to simulate future land use change. Prescriptive models are used to identify the optimised land use formation that will result in obtaining the specified objectives (Verburg et al., 2004).

While urbanisation and population growth affects the magnitude of urban growth, how the urban growth manifests is largely affected by the development strategies implemented. Before a new development strategy is implemented, the effects that it will have first need to be established. It is not known how the City of Tshwane will develop under the Compaction and Densification Strategy. In order to know this, the effects of the development strategy on the change of an urban area like the Tshwane need to be tested using a tool like a land use change model. This research paper attempt to identify the most appropriate land use change model to model urban growth for Tshwane. This model is then used to simulate urban growth for the City of Tshwane over the next 30 years under the Compaction and Densification strategy.

2. Case study: City of Tshwane

2.1 City of Tshwane current landscape

City of Tshwane is 1 of 8 metropolitan municipalities in South Africa and is located in Northern Gauteng. The municipality was established in December 2000 after the first general local government elections. In 2011 Tshwane was merged with the Metsweding District to reduce the number of municipalities within the Gauteng province. Tshwane is one of the largest metropolitan municipalities in South Africa and consists of 7 spatial development regions, 13 cities/towns and 107 wards. (City of Tshwane, 2015a).

The structure of cities in South Africa is very different compared to those of other countries. This is in part due to the lasting effect of the planning strategies that were implemented during the apartheids era. This has resulted in distorted spatial patterns in many South African cities that has led to many problems such as the dispersion of economic and social opportunities (Du Plessis and Boonzaaier, 2015).

There are primarily 4 different housing classifications within Tshwane. These classes are (1) Residential housing, (2) Informal housing, (3) Townships and (4) Villages. The City of Tshwane has also divided the city into 5 density zones. These 5 zones are (1) Concentration zones which consists of high density zones as well as transit promotion zones, (2) Linear zones which consist of development corridors and activity spines, (3) Suburban densification zones which are the low to medium densities, (4) Low density zones and (5) Rural density zones (City of Tshwane, 2013).

2.2 City of Tshwane development strategies

Since the end of apartheid focus has been put on solving the segregated spatial patterns created during the apartheids era. The National Urban Development Framework proposed that one intervention could be the densification of urban areas and that densification could be a catalysts in solving some of the problems associated with segregated spatial patterns in South African cities (Du Plessis and Boonzaaier, 2015). In 2004 the City of Tshwane set in motion a project with multiple phases that aim to encourage density in the city. The first phase of this plan was the Macro Perspective on Residential Densities and Compaction in Tshwane. In this phase information was gathered on different trends and approaches that were used across South Africa as well as other countries to implement urban densification. The second phase was creating the Tshwane Compaction and Densification Strategy that would from a densification point of view addresses the structural composition of the area. The strategy does not provide a detailed proposal for densification but rather provides guidelines for densification (City of Tshwane, 2005; City of Tshwane, 2013).

In 2011 Tshwane started the process of creating 7 Regional Spatial Development Frameworks for the area. These frameworks needed to support the Metropolitan Spatial Development Framework that was established in 2012, the City Development Strategy, the Compaction and Densification Strategy created in 2005 and lastly the Open Space Framework. These 7 frameworks are continually being updated to ensure the development of a sustainable and well planned Tshwane

(City of Tshwane, 2005; City of Tshwane, 2013). In 2013 Tshwane released its 2055 vision that provides strategies that aims to create a Tshwane that is liveable, resilient and where all residents have access to a high quality life and social, economic and political freedom. In this 2055 vision, combatting sprawl and encouraging densification still forms one of the guiding principles (City of Tshwane, 2015b).

3. Land use change model evaluation

Land use change models offer a unique opportunity to study complex land use interactions (Jantz et al, 2004). Land use policies can have a direct and lasting impact on a country's spatial legacy and therefore it is argued that planners need to understand the 'unintended' consequences of the impacts of their spatial policy (Le Roux & Augustjin, 2017). Land use change models offer the unique opportunity to study the system as a whole and provide opportunities to explore evaluate and visualize alternative futures (Veldkamp & Lambin, 2001). These models also offer the ability to generate scientific evidence to support policy debates in order to evaluate spatial emerging patterns. These planning support tools can advise decision makers and promote awareness as to possible long term spatial implications (economic and environmental) of current land use policies. These models are best used to monitor and evaluate 'What-if' scenarios (Le Roux & Augustjin, 2017).

Implementing an already existing model will save time and development work and offers the opportunity to build on a solid knowledge base of years of development experience (Le Roux & Augustjin, 2017). However land use change models vary enormously according to their purpose, location and application for which they were built (Veldkamp & Lambin, 2001; Le Roux & Augustjin, 2017). When choosing a suitable model one has to consider a series of factors e.g. the number of land use classes the model can accommodate, the models ability to link external models, the support offered by the developers, the accessibility of the software, the resource requirements and factors such as data requirements needed to run the model (Agarwal et al, 2000; Verburg et al, 2004; Le Roux & Augustjin, 2017).

3.1 Determining models to be evaluated

Therefore currently available land use change models were evaluated against a predefined list of requirements in order to identify the most suitable land use change model. In order to execute the research objective 5 main project requirements were identified, these requirements included; (1) the ability to simulate urban growth, (2) previous successful implementations in a South African context, (3) the model has to be either open-source or freely available, (4) the input data required by the model had to be readily available or easily obtainable and (5) the outputs provided by the model needed to be transparent enough to allow further analysis and processing.

Based on the above criteria and a thorough literature search 4 land use change models were identified for evaluation, these included:

(1) SLEUTH (http://www.ncgia.ucsb.edu/projects/gig/index.html) a cellular automata model with previous applications in the City of Cape Town (Watkiss, 2008) and the City of Tshwane (Van Heerden et al., 2018), (2) *What if?* (http://www.whatifinc.biz/) a geospatial GIS based planning support system with application in Johannesburg Metropolitan Municipality (Dos Santos, 2014), (3) Dyna-Clue (http://www.ivm.vu.nl/) a hybrid system model with applications in Johannesburg (Le Roux & Augustjin, 2017), Western Cape Province (Tizora et al., 2018) and Frances Baard District Municipality (Le Roux et al., 2015) and (4) UrbanSim (http://www.urbansim.com/) an agent based model with applications in the Metropolitan cities of Nelson Mandela Bay, eThekwini, Ekurhuleni, Johannesburg and Tshwane (Le Roux, 2013; Coetzee et al., 2014; Waldeck & van Heerden, 2016). Figure 1 shows the location of known land use change modelling studies that were performed in South Africa using the specified four land use change models.

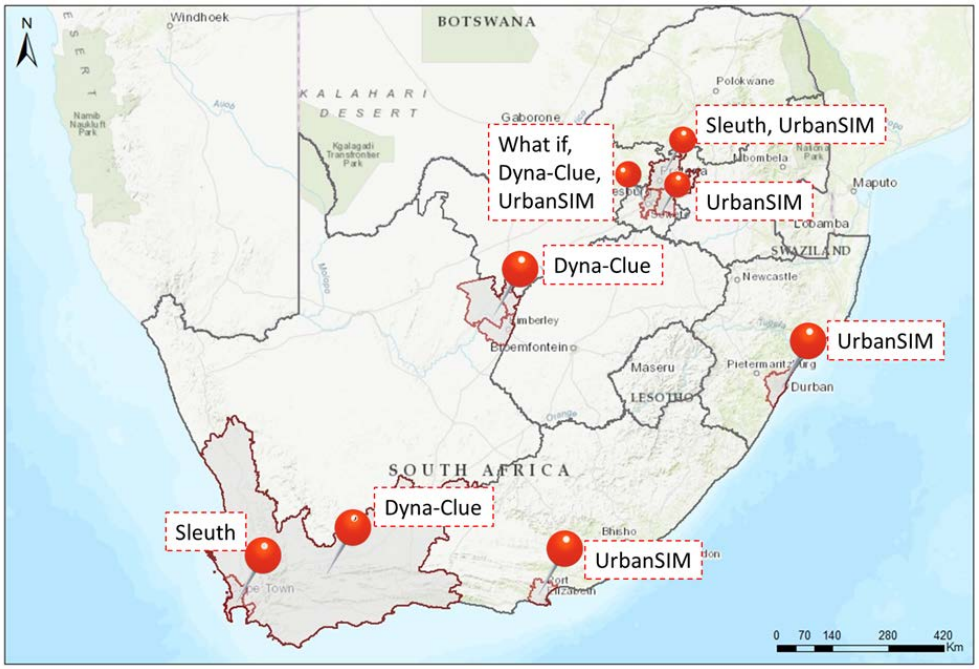

Figure 1. Previous land use change modelling studies in South Africa

3.2 Criteria list

Evaluating the above 4 models consisted of 20 different sub-criteria that addressed the 5 requirements mentioned above. The criteria chosen to evaluate the models consisted off; (1) Relevancy to project, (2) Model costs, (3) Model provides support, (4) Technical expertise required, (5) Data requirements, (6) Accuracy, (7) Resolution, (8) Temporal capabilities, (9) Versatility, (10) Linkage potential, (11) Public accessibility, (12) Transferability, (13) Third party use, (14) Ability to simulate densities, (15) Extensibility, (16) Transparency, (17) User friendly, (18) Flexible data requirements, (19) Measure of goodness of fit and (20) Hardware.

Given the objective of the study and the various criteria that were considered, *What if?* was identified as the most suitable model for simulating urban growth in the City of Tshwane. This model was primarily chosen due to its ability to simulate densities, its flexibility with input data

requirements, its user friendliness, data substitution options, transparency and linkage potential. What sets the *What If?* model apart from its competitors is the fact that it provides a useful knowledge management environment that makes use of evidence based science to allow users to see the implications of future policies and its influences on the land use patterns (Klosterman, 1999; Pettit, 2008).

3.3 Overview of *What If?* model

What If? is a GIS based planning support system developed by Klosterman (1999) that enables a user to integrate social, economic and environmental datasets. A user can generate multiple planning scenarios in which the communities involvement and their perceptions of what needs are important is considered. It makes use of the bottom-up modelling approach that focuses on the processes and entities and use these two things to develop the system in order to synthetically produce output data that allows for prediction. This is done by firstly dividing up the study area into uniform analysis zones (UAZ's) and then using these zones along with alternative policy choices and regional conditions to allocate projected land use demands. The UAZ's are areas within the study area that are homogeneous in all the aspects that are considered in the model. *What If?* projects future growth by balancing the demand and supply of land that is appropriate for different uses at different locations (Pettit, 2008). Three sub models are used to establish the planning support system part of the model. These sub models are the suitability, demand and allocation models.

The main datasets that are required is (1) Land use maps that are used as the basis for the simulation, (2) Development plans that specifies where development should take place, (3) Suitability analysis layers that are used to determine the suitability of land for development, (4) Display layers that are used to create end result maps that are easier to interpret, (5) Infrastructure control layers that specify areas where development is only allowed to take place if a certain infrastructure is present, (6) Land use control layers used to show the effects that certain development plans will have, (7) Growth pattern layers used to specify the order in which growth allocation will take place, (8) Sub area boundary and (9) Population data layer that is used to project the residential population and housing.

4. Implementation of *What If?* Model

4.1 Datasets used

In order for growth projections to be made by *What If?* requires 9 main datasets that can each consist of multiple sub layers.

Table 1. Data used

Datasets	Sub layers	Data Custodian
Land use maps	Land use for 2000 and 2016	GeoTerra Image
Development plans	Density layers	City of Tshwane
Suitability analysis layers	Slope	DIVA-GIS
	Protected areas	SANBI
Display layers	Roads for 2000 and 2016	City of Tshwane
Infrastructure control	Mobility spines	City of Tshwane
	Mobility roads	City of Tshwane
	Activity spines	City of Tshwane
	Activity street	City of Tshwane
Land use controls	Management zones	City of Tshwane
	Development areas	City of Tshwane
Growth pattern layers	25 km buffer around CBD	
	200m buffer around roads	
Sub-area boundary layer	2011 Municipal wards	City of Tshwane
Population data layer	2011 Census data	StatsSA

4.2 Adapting the model

The *What If?* model is first used to simulate the land use for 2015. This is then used in the validation of the model before the future growth is projected to determine just how accurate the model is. The simulated land use for 2015 was compared to the actual land use of 2015. The accuracy of the *What If?* projections are very dependent on the amount of data that is provided for the model to use. The more data on the future developments that can be provided, the higher the accuracy of the projection will be. When the actual and simulated land use is compared it can be seen that *What If?* is accurate in terms of where the development might take place but it is not as accurate in terms of which land use type will develop where. *What If?* also under projects on the amount of development as more development took place than was projected.

After the model was validated it was then adapted in order to simulate the future growth. The model is made up of 2 programs, namely *What If? Set up* and *What If?*. The *What If? Set up* program is used to link the attributes in the Union file to each relevant subsection. The subsections are (1) Analysis option, (2) Land use information, (3) Suitability information, (4) Demand information (5) Allocation information and (6) Other information. Once this is done the *What If?*

program is used to specify the current, past and projected population as well as land use and employment.

This information is then used by What If's 3 main models: suitability, demand and allocation. Each of these models require certain input values that are used during the projection process. The suitability analysis model is used to provide the areas within the study area that are least to most suitable for development. This model makes use of weighted multiple criteria analysis (MCA) to assign the suitability. The demand model is used to calculate what the future demand for land will be. This model uses projected population and employment growth to determine the future demand. The last model is the allocation model which uses the information from the suitability and growth model to project the future growth. Here the future land use is assigned to the appropriate UAZ's based on suitability, size, growth patterns and lastly it also incorporates some random assigning of land. Different projection scenarios can be created by making changes to the parameters specified in each of the 3 modules.

5. Results and discussion

In order to clearly see how development will differ when the Compaction and Densification Strategy is implemented two different scenarios were simulated. The first scenario considers the development guidelines provided by the Compaction and Densification Strategy. The second scenario does not take these guidelines into consideration.

5.1 Analysing the urban growth

The simulation provides maps of the projected growth that have already been categorised according to the different land use types. Figure 2 show the projected growth map for Scenario 1 with an added image that is zoomed in on the area where most of the development occurred. When Figure 2 is inspected it is clear that densification definitely took place. A lot of the development took place around the current residential areas as well as within 25km of the CBD. Development also took place next to all the main routes that are located within this 25km area. These main routes are the activity spines and streets as well as the mobility spines and roads that were identified in the Compaction and Densification Strategy.

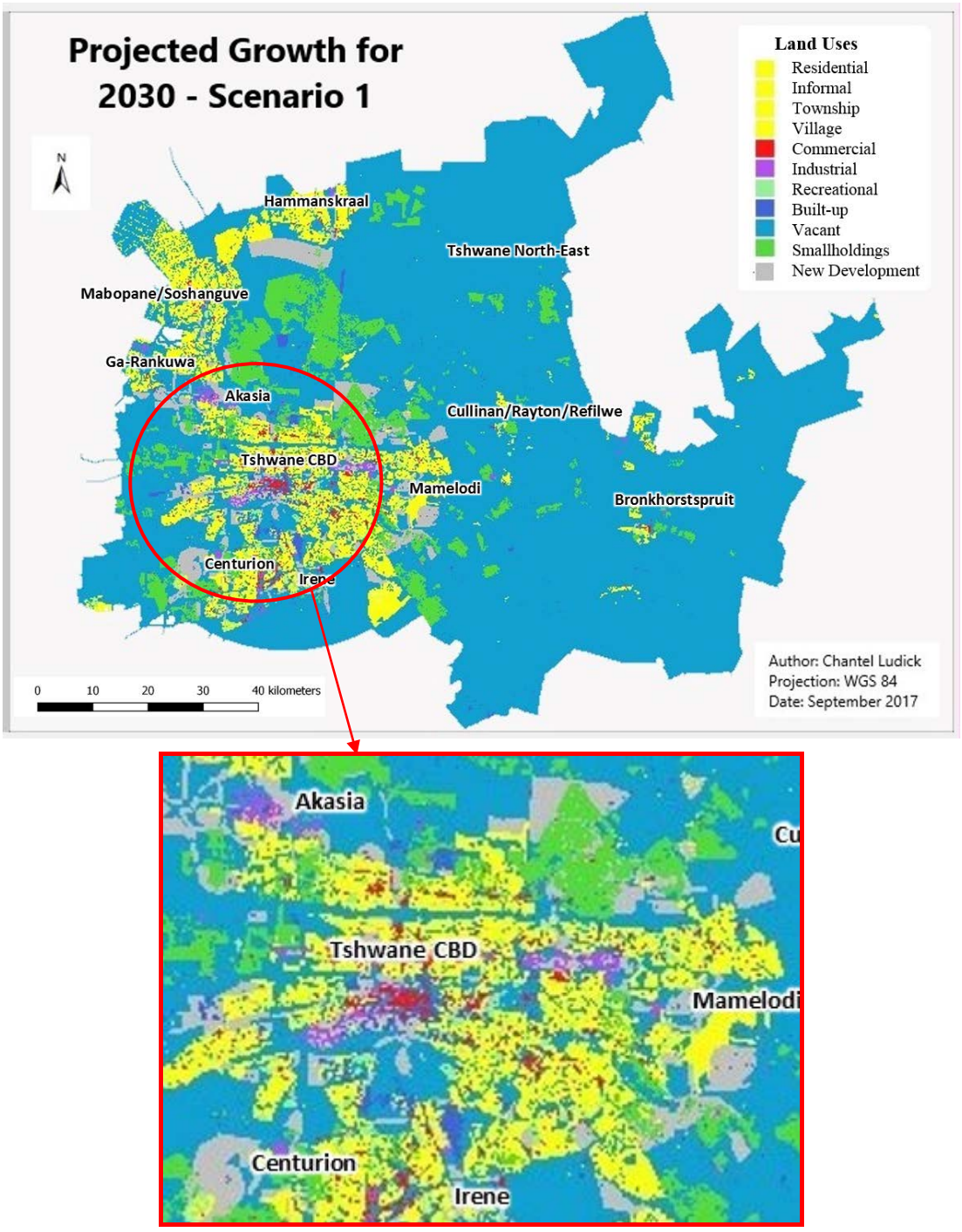

Figure 2: Output map for Scenario provided by *What If?*

Figure 3 shows the projected growth map for Scenario 2. With Scenario 2, when no development plan is specified, the development that occurred differs drastically from that of Scenario 1 as there was no densification and almost no development took place within the 25km area of the CBD as with Scenario 1. This is most likely because development can now take place wherever there is vacant land available. Without the implementation of the CDS, the likelihood of urban sprawl taking place increases. The development is more pronounced and clustered together in areas located in Tshwane North-East and the South Eastern part of Tshwane. Most of the development for a specific class took place in the same areas. This type of development might be possible for commercial, built-up and industrial, but the chances that all recreational areas will develop in the

same cluster is very low. The odd gaps within each of the areas of the development is where the slope was higher than its surrounding areas, therefore development did not take place there. Overall there is a lot less vacant land left than there was for Scenario 1.

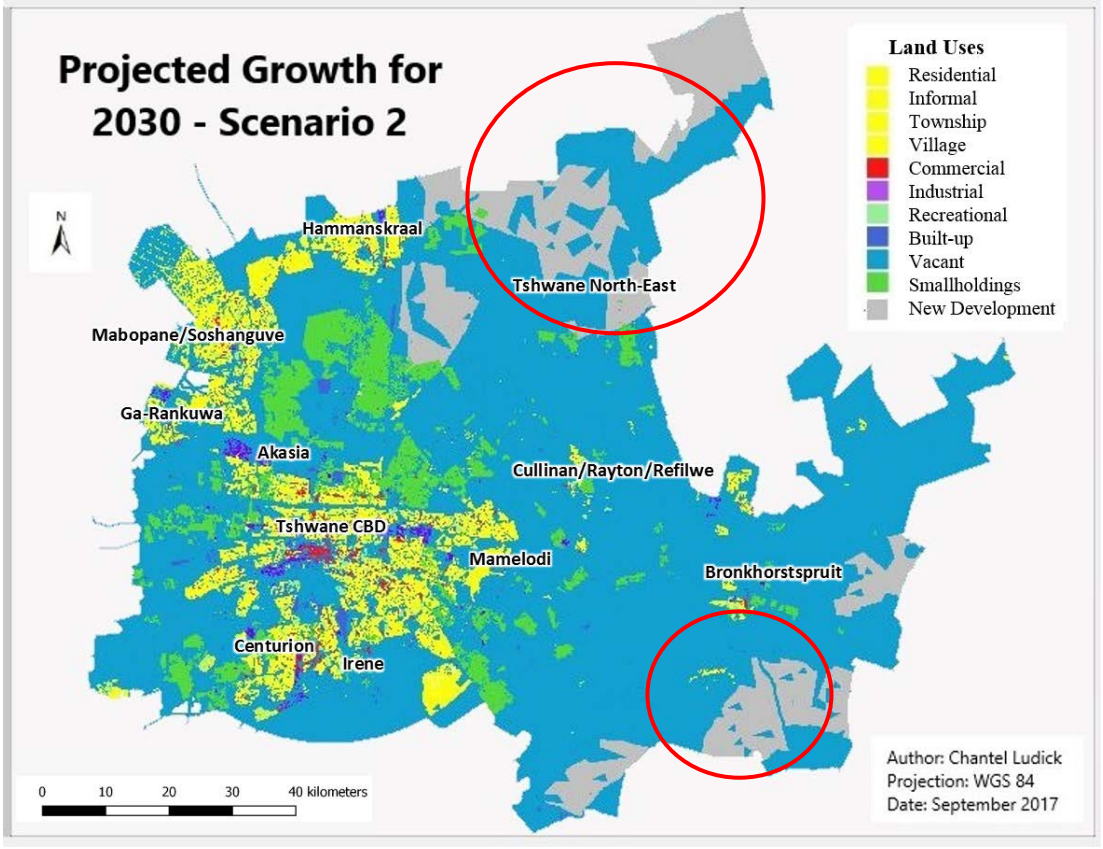

Figure 3: Output map for Scenario 2 provided by *What If?*

5.2 Analysing the densification

Since the focus of the project was to see if densification took place two types of densification namely building density and population density was calculated. The building densities were calculated as units per squared kilometre and the population densities as people per squared kilometre. With both these densities the change in density per ward was also calculated between 2015 and 2030. The following formulas were used:

$$\text{Building Density per Ward} = \frac{\text{Number of units}}{\text{Area of the Ward in km}^2} \quad [1]$$

$$\text{Change in Building Density per Ward} = \frac{\text{Number of units for 2030} - \text{Number of units for 2015}}{\text{Area of the Ward in km}^2} \quad [2]$$

$$\text{Population Density per Ward} = \frac{\text{Number of people}}{\text{Area of the Ward in km}^2} \quad [3]$$

$$\text{Change in Population Density per Ward} = \frac{\text{Population size for 2030} - \text{Population size for 2015}}{\text{Area of the Ward in km}^2} \quad [4]$$

5.2.1 Scenario 1

Out of the 107 wards located in Tshwane, 33 have shown a significant increase in building density. This includes wards located in the CBD, Akasia, Centurion and Mamelodi. Each of these 33 wards increased with around 200 units or more. The density for 3 of the larger sized wards in this area changed from having a density of between 7 and 106 units per km^2 to 107 to 228 units per km^2. These 3 wards include Ward 50 North of the CBD; Ward 91 East of Irene and Ward 4 South of Ga-Rankuwa.

In order to see all the wards that had an increase, whether this increase was significant or not, the changes in density between 2015 and 2030 was also studied. Many of the smaller wards around the CBD in areas like Akasia, Mamelodi and the CBD itself had a large increase in housing units. Others had a large increase possibly because they fell within the 25km area around the CBD where most of the densification occurred. There were also a few larger sized wards in Tshwane North-East where the areas had a smaller increase of between 3 and 19 units per km^2 which fell outside the 25km area around the CBD.

All of the 107 wards in Tshwane had an increase in population, but not all 107 showed significant growth. The wards where the most significant population growth took place is very similar to where the building densification took place. These are the wards that fall within the 25 km area around the CBD. With many of the wards in these areas the population increased from 441 – 1023 people per km^2 to 1024 – 1812 people per km^2 especially in the wards located in Centurion and around Mabopane and Soshanguve. There are also a few smaller wards in the area North of Bronkhorstspruit where the population increase was a lot smaller.

The change in population density between 2015 and 2030 confirms that there was population increases over the entire City of Tshwane. It also indicated that over the biggest part of City of Tshwane which includes Tshwane North-East, Cullinan, Rayton, Refilwe and Bronkhorstspruit the increase was between 20 – 326 people per km^2. If this increase is compared to other wards where the growth was between 601 – 988 people per km^2 or 988 – 1549 people per km^2, it cannot be seen as significant growth. The population growth that occurred in these areas probably took place in the areas within the ward where there were already established residential areas and these areas were just filled up.

5.2.2 Scenario 2

The densification for Scenario 2 is very different from that of Scenario 1. The increase in units are located across most of Tshwane, especially Tshwane North-East and the areas surrounding Bronkhorstspruit, and no longer mostly clustered around the CBD. There are only 11 wards out of the 107 that had a significant increase in the amount of units. Some of the most significant increases took place in Ward 79 East of Irene; Ward 49 and 99 in Tshwane North-East. Some of the smaller wards in these areas also had a significant increase. Once again this is very different to Scenario 1 where the densification took place in many wards, especially the smaller wards. Most of the

densification took place in wards that are located far from the CBD area. This indicates that without a development plan urban sprawl would continue in Tshwane.

The pattern of population increase for Scenario 2 is similar to that of the increase in building units. The most significant population increase took place in the larger sized wards in Tshwane North-East, these wards had an increase of 1663 – 2401 people per km^2 and there were a few smaller wards in this area that had an increase of 5312 – 9257 people per km^2. There was also a significant increase in a few of the South Eastern wards located around Bronkhorstspruit.

The difference in the population densities between 2015 and 2030 shows that like with Scenario 1, there was an increase of the population over the entire Tshwane. Even though the population increase also took place all over, the distribution of the population for Scenario 2 is very different to that of Scenario 1. The most significant change in density takes place in the areas within Tshwane North-East that were previously identified. These wards had an increase of 976 – 2451 people per km^2. Most of the other wards only had an increase of 22 – 973 people per km^2 which is not very significant compared to other larger increases.

6. Conclusion

The modelling results showed that under the Compaction and Densification Strategy, most of the development will take place within a 25km radius of the Central Business District and around major routes, metropolitan- and urban cores. This leads to most of the development taking place around the existing infrastructure instead of taking place where there is no established infrastructure. Overall the results confirm that the Compaction and Densification Strategy could be an effective strategy to combat urban sprawl in the Tshwane by increasing densification in the area.

The What If? model is geared towards providing the opportunity to reaching some understanding of what influence planning policies could have on the future structure of a city. The simple user interface of What If? makes it usable for those who do not have a programming background and that lack the technical expertise required by many other land use change models. One shortfall of the model is that compared too many other land use change models, *What If?* is very data intensive although the data that required is very basic and usually easily accessible datasets. Overall What If? has proved to be a valuable tool for simulating urban growth and holds great potential for similar studies.

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