PROJECTING THE FUTURE GROWTH OF SOUTH AFRICAN SETTLEMENTS

DEVELOPING A CONCEPT MODEL FOR TOWN GROWTH FORECASTING IN SOUTH AFRICA

WORKSTREAM 3: RESEARCH REPORT

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1 INTRODUCTION

This report explores the potential shifts and development trajectories of South African settlements and attempts to determine the future growth and decline of settlements across South Africa to relate these directly to the changes projected in climate variability. This report is one of two reports that cover the objectives of Workstream 3 of the Green Book.

The main objectives of Workstream 3 are to:

1. Profile neighbourhoods/towns/settlements according to their social, economic, physical, environmental vulnerabilities as well as the mechanisms in place to makes these neighbourhoods/towns/settlements more resilient (coping capacity); and to
2. Project the growth and decline of towns/settlements to 2030 & 2050 in order to understand the pressures associated with the development trajectories of these towns.

This document covers the second objective through conceptualising and developing a growth/decline model for estimating growth and decline trajectories of settlements in South Africa. This research forms part of a larger risk analysis of settlements across South Africa (Figure 1) and focusses on the current and future vulnerability of settlements with regards to their social, economic, physical, environmental and institutional make-up.

Spatially explicit population data are important in scenario-driven assessments of climate change impacts on for example, the spatial distribution of land use, demand for food and water, energy usage and emissions, climate disasters and climate-induced vulnerability (Jones, 2014; Jones & O’Neill, 2016). Understanding the impacts of climate change on people and the environment requires an understanding of the dynamics of climate, the environment in terms of land use/land cover changes and socio-economic changes (Bierwagen, Theobald, Pyke, Choate, Groth, Thomas & Morefiel, 2010). Spatial population projections are thus an integral component when determining the potential exposure and vulnerability of a population to hazards, both natural and man-made, and increasingly for assessing the potential consequences of global climate change (Jones & O’Neill, 2016).

Most publically available future population estimates are at a global scale and are non-spatial in nature at a national scale. In order to provide planning support that is sensitive to the local context, local projections are required (Gaffin, Rosenzweig, Xing & Yetman, 2004). The growing volume of research on climate change risk and vulnerability, especially at a community level, has stimulated the need for more detailed and reliable population data in order to obtain relevant local-scale population projections for evaluating changes in population exposure and vulnerability that result from changes in climate.

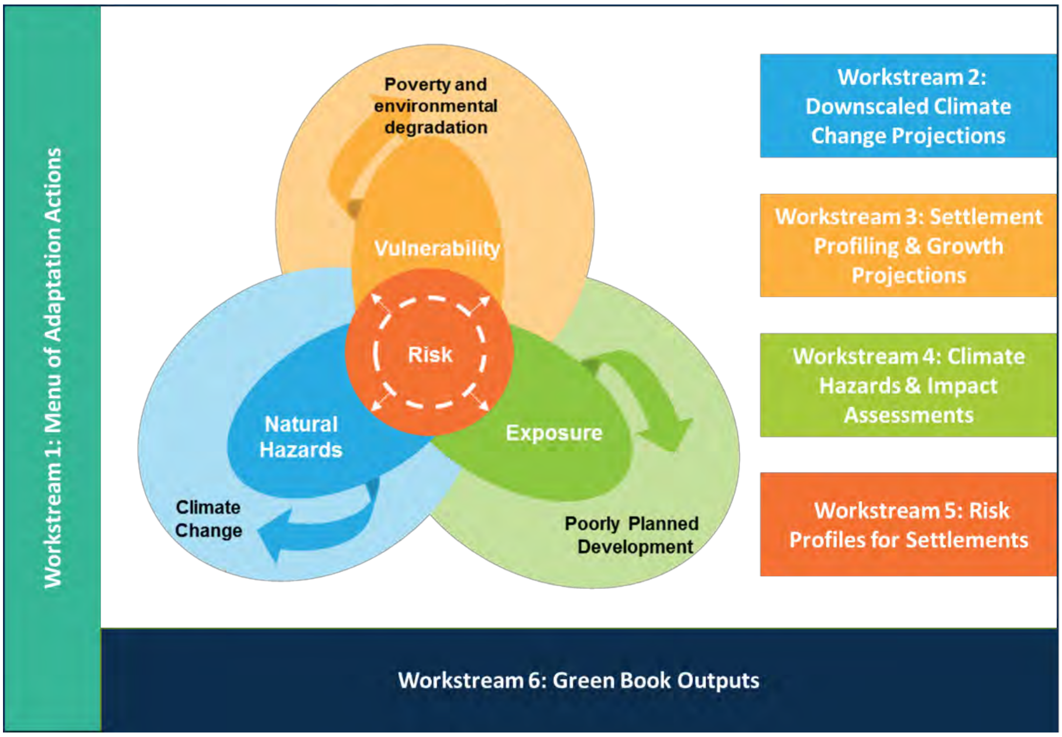


Figure 1: Conceptual framework for risk profiling in the Green Book

The main objective of this research is predicting demographic change on a settlement scale in South Africa by downscaling district municipality demographic population projections of 2030 and 2050 based on a population potential grid. The report outlines the development of such a population disaggregation model and the first round results showing growth and decline of South African Settlements to 2030 and 2050.

This report covers the following:

a) A literature overview of integrated town growth models and techniques
b) The conceptual model design and implementation
c) Input data and data methodology
d) Model results and findings
e) Shortfalls and the way forward

1.1 Research Design

The research followed five tasks and several sub-tasks to meet the final objective of predicting demographic change on a settlement scale. Figure 2 depicts the flow of research from conceptualization to publication.

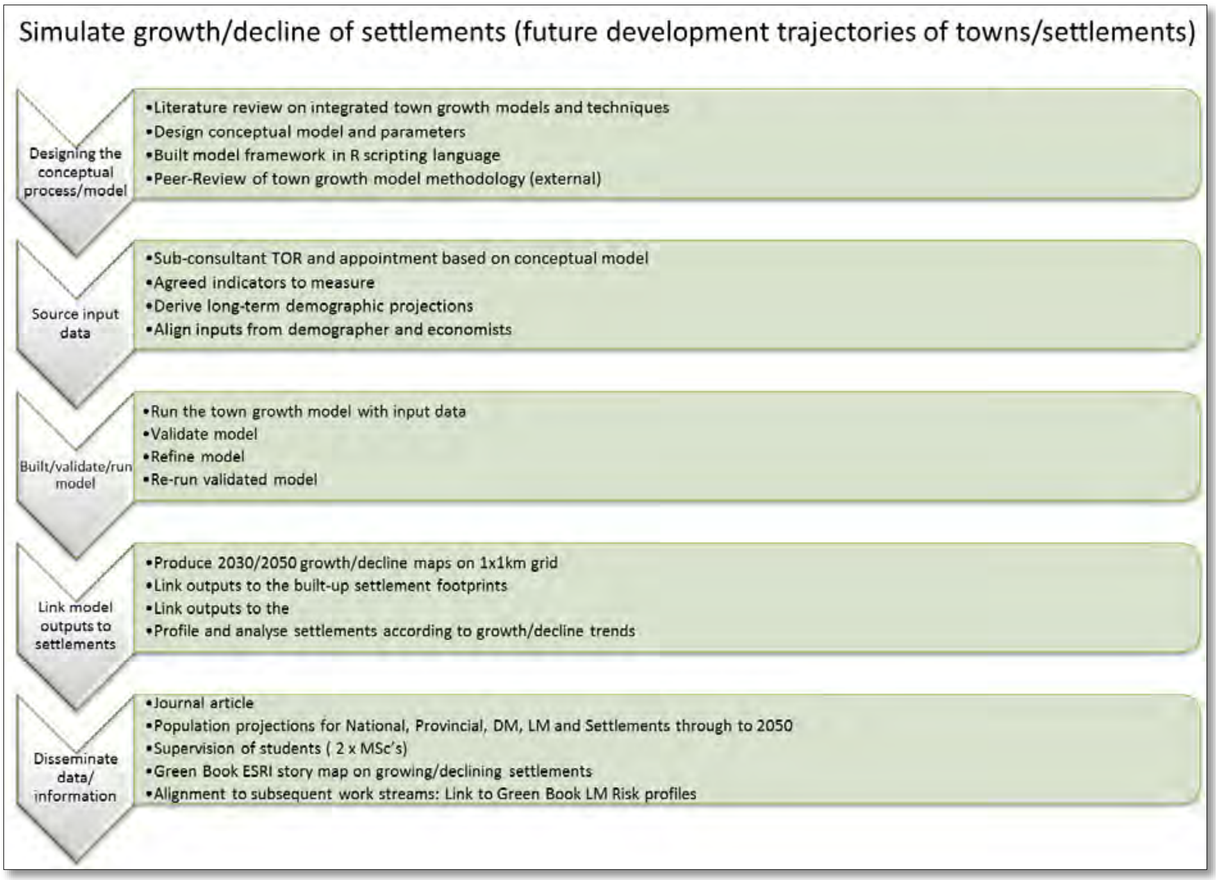


Figure 2: Research design and associated tasks

1.2 Outputs generated to meet the objective

As part of meeting the final objective several research outputs were generated for the Green Book project, these include:

- Working document (peer-reviewed): Projecting the growth/decline of SA settlements,
- Settlement growth/decline model written in R scripting language,
- Geodatabase with population projections for national, provincial, district and local municipalities as well as settlements through to 2050,
- Green Book ESRI story map showing growing/declining cities across South Africa,

- Population projections featured as part of the municipal risk profiles on the Green Book online platform, and
- Peer-reviewed journal article.

The outputs generated by this workstream have been used by:

- The team developing the National Spatial Development Framework (NSDF)
- The South African Cities Network (SACN)
- The working group overseeing the National Framework for Climate Services (NFCS)

2 A FRAMEWORK FOR INCLUDING POPULATION DYNAMICS IN CLIMATE CHANGE STUDIES

2.1 Differentiating between population projections, estimates and forecasts

Spatially disaggregated data are important for understanding urban spatial structure. Population growth has a direct impact on the future demand for food, water, housing, education and services, to name a few (Jones, 2014). Knowledge about past population growth can be integrated into information about future population shifts which is fundamental for informing future policy and decision making. The availability of accurate demographic data, both historical and forward-looking, is therefore at the heart of most urban and regional planning activities (Isserman, 1984; Li, 2010).

It is important to note that there are differences between **population estimates**, **projections** and **forecasts**. *Population estimates* are statistics about the population based on data sampled during a particular reference period, whereas *population projections* are an indication of future population size if the underlying assumptions about future patterns of change really occur. The assumptions about future patterns of change need not be based on modelling values of past and current patterns of change. Projections differ from *forecasts* which are underpinned by historical values used in predicting future values (ABS, 2018).

There is a tendency to incorrectly use population projections as inputs in demography instead of population forecasts (Isserman, 1984). Projections are subjective; therefore the assumptions or scenarios on which they have been formulated should be clearly stated. It is good practice for projections to be finalized through an expert group process where the underpinning assumptions are critically examined. In forecasting, the theoretical and modelling skill of the forecaster have an effect on the margin of error of the forecasts. Therefore, forecasting requires careful consideration of the context, data and validation sample accuracy during the model building stage. When forecasting population important considerations include knowledge about the social and economic history of the area, time periods of significant events or shifts in the population (trend extrapolation-based models), birth and death rates (component models), employment and labour force dependency rates (economic models), and various socioeconomic variables which are typically required in simultaneous models (Isserman, 1984).

3 LITERATURE REVIEW

3.1 Global population data

There are a number of examples of spatially explicit projections of future population that have been developed at global, continental and city scales (Grübler et al., 2007; Gaffin, Rosenzweig, Xing & Yetman, 2004; Bengtsson, Shen & Oki, 2006). Considerable work has also been done globally to improve the quality and availability of gridded population data. Examples include: the Global Rural Urban Mapping Project (GRUMP)[1] which makes available population count and density estimates for the years 1990, 1995 and 2000; LandSCAN[2] which is an archive of population count estimates for the years 1998, 2000-2016; the Gridded Population of the World series which is now in its fourth version (GPWv4), making available population count and density estimates for the years 2000, 2005, 2010, 2015, and 2020 (CIESIN, 2017); and WorldPop[3] which has in its archive gridded population data for the years 2000-2020. GPWv4 population count and density gridded data were inputs in the process of producing WorldPop population counts and density grids (Lloyd et al., 2017). The spatial resolution of these global population data is typically 1x1 km, except for WorldPop where users can also obtain 100x100 m resolution data. Generally, the sources of data for these web-based geoportals are country-specific censuses, surveys, satellite imagery and other supportive geospatial layers.

[1] http://sedac.ciesin.columbia.edu/data/collection/grump-v1 [Accessed: 23/05/2018]
[2] https://landscan.ornl.gov/ [Accessed: 23/05/2018]
[3] http://www.worldpop.org.uk/ [Accessed: 23/05/2018]

Previously forecasts and projections of future global population were only available at country level, or even more coarsely, at regional/continental level. An area of research and development has emerged in the downscaling of future population projections and forecasts in order to estimate population size at high spatial resolution. This is a rapidly growing area of interest and currently there is no convergence in terms of methodologies, and the projections span relatively short time horizons (Gaffin, Rosenzweig, Xing & Yetman, 2004; Balk, Brickman, Anderson, Pozzi & Yetman, 2005, Lloyd et al., 2017).

Little theoretical work has been done within developing countries to develop spatially explicit population projections at a scale fine enough to do settlement-level analysis for an entire country (Hachadoorian, Gaffin & Engelman, 2011). While the top-down approach of downscaling from country/continental level projections and forecasts of population growth accounts for the macro-level redistribution patterns (Chi & Marcouiller, 2011), its shortcoming is that local subtleties can be missed if there are no additional calibration steps for incorporating local expert information about expected changes in demographic patterns. Limitations with global super-resolution population mapping efforts, such as WorldPop, stem from limited spatial coverage and resolution and acquisition period misalignment of input data (Lloyd et al., 2017). It is recommended that accuracy at the subnational scale be improved through assimilation of local information because having only generalised views of future population distribution trends across multiple regions is of limited use in local decision making (McKee, Rose, Bright, Huynh & Bhaduri, 2015).

The majority of existing large-scale spatially explicit population projections are constructed using simple linear scaling techniques or population trend extrapolation (Hachadoorian, Gaffin & Engelman, 2011; Balk, Brickman, Anderson, Pozzi & Yetman, 2005). Linear scaling techniques are straightforward, and reflect future trends and patterns using only current birth, death and migration rates as the basis for spatial prediction (Jones & O'Neill, 2013). Trend extrapolation models look at the individual cell and project population change as either the total population change per cell or the change in the share of growth per cell (McKee, Rose, Bright, Huynh & Bhaduri, 2015; Hachadoorian, Gaffin & Engelman, 2011). A shortcoming of methodologies that follow this line of thought is that they assume, by definition, that the future population structure will conform to the current spatial structure of the population (Jones & O'Neill, 2013; McKee, Rose, Bright, Huynh & Bhaduri, 2015).

3.2 Spatial disaggregation of population data

Spatial data disaggregation involves transforming data from larger spatial units to smaller spatial units, and is an important area of research in geospatial modelling and analysis. The concept of spatial data disaggregation involves a source zone and a target zone. The source zone refers to the spatial unit for which we have information (e.g. irregular spatial administrative boundaries), and the target zone refers to the spatial unit for which the information is needed, such as regular raster grid (Li, 2010).

However, transferring known socio-economic data from large spatial units to smaller spatial units does not simply involve evenly subdividing the data between the smaller target zones because spatial data are naturally heterogeneous, and aggregated data inherently mask spatial distribution (Li, 2010; Li, Corcoran, Pullar, Robson & Stimson, 2009). Within an aggregate spatial unit (e.g. provincial boundary), the distribution of the population is not evenly spread; instead population is concentrated in and around towns and cities forming denser urban nodes, and dispersed amongst sparser rural landscapes. This gives rise to the modifiable areal unit problem, a classical problem in geographical data analysis (Li, 2010).

Methods for deriving spatially disaggregated population estimates can be subdivided into two categories, namely data-driven approaches (areal interpolation methods) and theory-driven approaches (multivariate statistical models) (Li, 2010; Wu, Qiu & Wang, 2005). Within both approaches, further distinctions can be made between models that only use census enumerator area population, and those that model the allocation of population data to smaller geographic units using supplementary socio-economic ancillary information (Hachadoorian, Gaffin & Engelman, 2011).

Data-driven approaches derive the spatial structure of data from known source zone data (typically using census population data as the input) and apply interpolation or disaggregation techniques to obtain a refined population surface. By comparison, theory-driven approaches use statistical and mathematical modelling to infer relationships between population distributions and space based on regional economic and urban geography theories to estimate the total population for an area, for example, the correlative relationship between the distribution of population and socio-economic variables (Li, 2010; Wu, Qiu & Wang, 2005). It is common to find that population size is correlated in some measure to economic activity. Population largely determines the size and type of the labour market consumer, as well as its purchasing power. The production of population estimates is therefore as important as that of producing economic indicators.

Early efforts to spatially disaggregate population to a continuous gridded surface used areal interpolation independently, or in combination with a **dasymetric modelling approach**. Dasymetric modelling is comparable to areal interpolation but supplements the interpolation process with ancillary spatial data. These methods are discussed in more detail below (Bhaduri, Bright, Coleman& Urban, 2007).

Tobler's pycnophylactic areal interpolation is a special case of areal interpolation, and is widely referenced in spatial data disaggregation literature. The underlying assumption of pycnophylactic areal interpolation is based on **Tobler's first law of geography**, namely that **'everything is related to everything else, but near things are more related than distant things'.** In this way, this method assumes a smooth density function that takes into account the effect of adjacent source zones while preserving the overall volume (pycnophylactic property) of the original data (Li, 2010; Wu, Qiu & Wang, 2005). The volume-preserving characteristic of interpolation models is necessary if the accuracy of the model is to be determined.

To improve model output, **areal interpolation** has been used in conjunction with a dasymetric modeling approach, a cartographic process that involves using geospatial or remote sensing ancillary data to assist population interpolation (Gaughan, Stevens, Linard, Patel & Tatem, 2015; Li, 2010; Wu, Qiu & Wang, 2005).

Population distribution is not an isolated phenomenon, but is influenced by a range of different natural and socio-economic factors that vary at global and regional scales. Models that statistically estimate population density can be considerably improved by incorporating ancillary data about the natural and socio-economic features that inform population distribution (Wu, Qiu & Wang, 2005; Li, 2010).

Ancillary data can be grouped into two categories based on their function. On the one hand, ancillary data have been used in the literature to identify areas more likely to become developed based on accessibility factors such as distance to CBD, main roads, sites and infrastructure services, as well as to inform population density predictions based on land use, land cover and settlement extent data (McKee, Rose, Bright, Huynh and Bhaduri, 2014; Linard, Gilbert & Tatem, 2011; Li, 2010; Adeel, 2010). On the other hand, ancillary data have been used to define uninhabitable areas as well as areas prohibited from future development, including data on national parks, forests and protected land; water; perennial ice; wetlands; mountainous areas (slope and altitude); airport boundaries; federal defence sites; golf courses; parks and cemeteries (McKee, Rose, Bright, Huynh and Bhaduri, 2014; Wu, Qiu & Wang, 2005). Using only the latter, binary dysametric modelling uses a binary land use classification (populated or not populated) as the ancillary data to aid in interpolation (Li, 2010).

The fine level of detail in ancillary datasets is important if the data are to improve the overall accuracy of the model. In general, if ancillary data are to improve the accuracy of a gridded output population distribution model, ancillary data must have a finer spatial resolution than the input census data (Bhaduri, Bright, Coleman& Urban, 2007; Gaughan, Stevens, Linard, Patel & Tatem, 2015).

In the Florida 2060 report (Zwick & Carr, 2006), a 2060 population distribution scenario for the state of Florida, USA was developed using an **urban suitability analysis**. Future population was spatially distributed to areas from the highest to the lowest urban suitability. This urban suitability surface was created in order to distribute population projections until 2060 and was based on incorporating existing population as an attractor of future growth and including factors such as road density, development infrastructure and proximity to main roads, urban centres, open water and coastlines.

In a similar study, Theobald (2005) developed the **spatially explicit regional growth model** (SERGoM), incorporating a number of physical and socio-economic variables that relate historical growth patterns and accessibility to urban and protected areas in order to forecast housing density.

There are also **more complex multivariate statistical techniques** that model the change in population distribution by incorporating variables that seek to explain the statistical relationship between population counts and associated variables (McKee, Rose, Bright, Huynh & Bhaduri, 2015).

A number of **location theories** also seek to explain the spatial and statistical relationships between population distribution and the major factors that influence location choice and economic activities. Population geography is the study of changing population distribution, growth, composition, and migration and seeks to theoretically explain population patterns caused by spatial patterns and processes (Li, 2010). Based on these theories, regional economics try to explain the associated relationships between land use patterns and population change, while central place theories place population in a hierarchy of urban places where the movement of population, businesses, and goods are determined by the associated costs and city sizes. Similarly, spatial diffusion theories argue that population growth tends to spread outwards from a city centre to surrounding area, implying that population growth is spatially auto-correlated (Chi & Marcouiller, 2011).

The **location theory** has become an important theoretical basis for the geographical locations of population and economic activities, and seeks to identify the factors that influence the location of the individual activities (Li, 2011). Based on Li's study (2011), some key factors are widely recognised as forming major economic and spatial processes that organise activities in space. These include spatial demand (area of market), transportation cost, land use supply, accessibility, land value and economies.

Regression models exploit ancillary data to improve population estimation accuracy (Li, Pullar, Corcoran & Stimson, 2007). Land use classes define the purposes for which humans exploit land, and are closely linked to people's activities. In more complex regression models, land use has been used as an effective proxy for population distribution, where a land use class is used to deduce valuable information about the levels of urbanisation on a piece of land (Bhaduri, Bright, Coleman& Urban, 2007; Li, Pullar, Corcoran & Stimson, 2007). Regression models are grounded by the assumptions that population densities vary according to land use, but population densities per land use are homogeneous (Gaughan, Stevens, Linard, Patel & Tatem, 2015).

Regression models range from simple (incorporating only a few land use classes), to complex (incorporating a multitude of different land use classes). **Three-class dasymetric modelling** makes distinctions between the densities of three residential land uses classes. Mennis (2003) distinguished between non-urban low-density residential and high-density residential land uses, whereas a similar study by Langford (2006) distinguished between rural, suburban and dense residential land use classes. In general, complex models yield more accurate results, but incorporating a high number of variables into a model increases the potential level of skilled analysis as well as the theoretical guidance required (Wu, Qiu & Wang, 2005).

Langford (2006) notes that in his study, the benefits of a three-class dasymetric model over a binary model were inconclusive. However, in their more recent comparative study of spatial disaggregation techniques for population estimation, Li, Pullar, Corcoran and Stimson (2015) compared the overall accuracy of **binary dasymetric modelling**, **three-class dasymetric modelling**, **globally fitted regression modelling** and **locally fitted regression** modelling for modelling the population in Queensland, Australia. Based on their findings, three-class dasymetric modelling produced the most accurate results.

A number of authors have used **logistic regression** for modelling urban growth processes. Abebe (2011) used logistic regression modelling to examine and explain informal settlement expansion over 20 years from 1982–2002 and densification over the period 1992–1998, in Dar es Salaam, Tanzania, while Cheng and Masser (2003) presented a spatial data model of urban growth in Wuhan City, China between 1993–2000. Cheng and Masser (2003) determined that the major determinants of urban growth in Wuhan City, China were urban road infrastructure and developed area extent.

Kernel-based interpolation methods are also widely used to estimate the probability of the population distribution based on the distance to the population centre. These models allocate population based on the **exponential distance decay function**, using the centroid of a source zone as a control point. A window is positioned over each control point, and in turn the source zone population is allocated to grid cells falling inside the window using a unique weighting based on the distance decay function between the source zone centroid and the grid cell (Li, 2010).

3.3 Gravity models

The gravity model, a commonly used tool in spatial interaction modelling, is arguably the most straightforward areal interpolation technique that is used for mapping population growth (McKee, Rose, Bright, Huynh & Bhaduri, 2015; Jones & O'Neill, 2013), and more extensively for modelling and analysing population mobility patterns between countries and between regions within countries (Simini, González, Maritan & Barabási, 2012; Poot, Alimi, Cameron & Maré, 2016; Ramos, 2016).

Gravity models, which were conceptualized from Newton's laws of gravity and gravitational potential by urban geographers, seek to describe the movement of people from areas of low potential to attractor nodes which are areas of high potential. Therefore, they've been used to summarise the spatial distribution of the population of an area over time (Pueyo, Zuniga, Jover & Calvo, 2013; McKee, Rose, Bright, Huynh & Bhaduri, 2015). The implementation of the gravity model for future spatial population projection is based on the assumption that people tend to live in or close to cities and that existing populations attract additional population (an assumption substantiated by historic and currently observed urbanisation patterns). In this way, when people relocate, they tend to move towards areas that are well connected with urban nodes (Liao, Wang, Meng & Li, 2010; McKee, Rose, Bright, Huynh & Bhaduri, 2015).

A refined gravity model, often referred to in the literature as the IIASA methodology, was developed by the International Institute for Applied Systems Analysis (IIASA) to downscale generalised global population projections to a continuous gridded surface (Grübler et al., 2007). The IIASA model allocates projected urban and rural population change to grid-cells according to a **population potential surface**, where the potential for each grid-cell is calculated as a **distance-weighted measure of the population in nearby cells** (Jones & O'Neill, 2013). Population potential models are a specialised type of gravity model (McKee, Rose, Bright, Huynh & Bhaduri, 2015).

While there is extensive use of gravity models because they are simple to implement, flexible and effective for summarizing complex spatial patterns, the use of population potential to allocate projected population spatially is limited for applications at small scale because it inherently enforces a sprawling pattern of spatial development across all regions (Jones & O'Neill, 2013; Jones, 2014).

In a critical assessment of the IIASA method, Jones (2014) highlights five characteristics that negatively affect the accuracy of its spatial population distribution outcomes, namely: (1) the distance decay function limits the range of spatial development patterns that are possible, and sprawling patterns are most widely observed; (2) the model is vulnerable to border effects, specifically along coastlines; (3) The model creates unrealistic spatial patterns between urban and rural boundaries caused by the urban/rural classification distinction, affecting the overall pattern of projected urbanisation; (4) population loss is incorrectly allocated (and models often encounter challenges when data sets include negative or zero values) and (5) without the incorporation of ancillary data, population can be allocated to areas unsuitable for human development.

As a way to mitigate many of its spatial limitations, Jones and O'Neill (2013) modified the IIASA method by introducing parameters into their model that account for varying socio-economic assumptions, using historical data to reflect past spatial development trends and adding an exclusion mask to prevent population allocation in areas unsuitable for human development.

3.4 Agents of population change

The manner in which settlements are distributed across space is a dynamic reflection of the relationship and interaction between population, development and the environment. Cultural, political and geographical forces as well as temporal and spatial influences affect population dynamics and drive population change (National Population Unit, 2001; Chi & Ventura, 2011a; Entwisle, 2007).

In the context of urban geography, population change (growth or decline) is an inevitable phenomenon influenced by a variety of factors. These factors can be categorised into a number of broad components posited to impact population growth patterns, including demographic characteristics, socio-economic conditions, transportation accessibility, biophysical conditions and natural amenities, as well as policies related to land use and development, with each component having many potential influential factors (Chi & Marcouiller, 2011; Chi & Ventura, 2011a). Spatially and temporally, population change occurs in response to changes in the influential factors at a certain location in time (Chi & Ventura, 2011b).

Similar to the broad motivational categories identified by Chi and Ventura (2011a), Jones (2014) argues that people choose to live in places they deem to be attractive. Although the definition of attractiveness is individually subjective, locational choices are linked to economic factors such as economic opportunity and transportation infrastructure, social factors such as proximity to family and the presence of social amenities, as well as the intangible attachments people have to certain places (Jones, 2014).

In their attempt to explain population growth, Chi and Marcouiller (2011), further refined the factors influencing where people live into four indices, demographics (measure of the local demographic characteristics), liveability (measure of the social and economic conditions), accessibility (measure of the access to transportation and community infrastructure), and development potential (the measure of the potential for land conversion and development), respectively. Chi and Marcouiller (2011) also note that population growth patterns are determined jointly by a variety of factors, and not one component (be it economic conditions or natural amenities) can be generalised to determine the trend of the population-redistribution processes. In developing African countries, urban spatial expansion is driven by various geographical and socio-economic factors (Adeel, 2010). The rapid population increase in developing countries is usually a dominant factor, but accessibility also plays a major role in stimulating the spatial growth of settlements. A combined description of influential factors that determine people's movements and locational choices are depicted in Table 1.

Table 1: Factors influencing where people live (Sources: Murdock (1991); Chi & Marcouiller (2011); Chi & Ventura (2011a); Jones (2014); Li, (2010))

Components influencing population change	Influential factors
Demographic characteristics	Population size and change: • Total number of people in the population • Exponential rates of change for the total population Population density Population composition (age, sex, race/ethnic, and household composition) Population distribution (relative to potential housing sites, or competing settlement locations) Average household size Special populations (institutional populations such as military personnel, students, prison populations) Population processes (fertility, mortality and migration): • Number of births • Fertility rate • Number of deaths • Survival rates • Life expectancy at birth • Number of migrants

Components influencing population change	Influential factors
Socio-economic conditions	Employment/unemployment rates Crime rates Income Population with high school education Population with bachelor's degree Housing units using public water Seasonal housing Real estate values (cost of land/land rent) Workers in retail industry Workers in agriculture industry Proximity to family Presence of social amenities Community values
Transportation and accessibility	Public transport availability Transportation cost Road and highway density Anticipated future change in local transportation networks Accessibility: • Proximity to central cities • Proximity to airports • Proximity to major highways

Components influencing population change	Influential factors
Biophysical conditions and natural amenities	Physical size of the area Climate Physical features of the area: • Flood plain or flood-prone zones • Forest coverage • Water coverage • Wetland coverage • Open space • Lengths of lakeshore/riverbank/coastline • Slope • Area with any other topographical features making settlement difficult Public land coverage: • Golf courses • Parks • Cemeteries • Game/nature reserves Viewshed
Land use and development	Government policy Location of built-up areas Land use patterns and policies: • Population density • Housing unit density • Dominant land use type • Dominant housing type • Land use plans • Zoning, regulatory restrictions or tax-exempt lands Built amenities: • Shopping opportunities • Eating/drinking establishments • Built attractions • Recreational sites

3.5 Migration as a driver of population change

The main components of population change are births, deaths and migration. Migration, in contrast to the other processes of demography, is a complex and dynamic process (Weeks, 2012), and it has been argued that as the third component of population change, migration does not receive enough focus. This is in part due to the complexities that migration analysis poses when compared to the other two components (Stats SA, 2015).

Migration is a direct response to the inequalities in opportunities and hardships faced by different communities across space, with most migration theories maintaining that migration is primarily motivated by economic factors (Dudley, Poston & Bouvier, 2010). People migrate from areas of less development and fewer opportunities, to areas of greater development and more opportunities, and the economic factors that motivate migration are classified as push or pull factors (National Population Unit, 2001; Mhloyi, Taruberekera & Lemba, 2013; Thet, 2014). The decision to migrate is therefore not an isolated process and is influenced by the cultural and social context in which an individual lives (Weeks, 2012).

In a study on cross-border migration in Europe, Dennett (2014) concluded that migration tends to occur more between regions with larger GDP and unemployment discrepancies, and that the effect is most noticeable at the extremes, where the inequality is greatest. However, it should be noted that the relationship between GDP, unemployment and migration is far from linear, and the prediction of movement flows can therefore not be done in isolation (Dennett, 2014).

The flow of people in and out of an area has a direct effect on the social and economic structure of communities. In Southern Africa, populations are dynamic and population mobility high, with South Africa receiving large numbers of migrants from across the region (Stats SA, 2012b). Reasons for immigration include economic, political and social factors. In South Africa, the migration of people and families both within and across the national borders has become a commonplace but contentious issue, strongly influencing changing national population distributions and dynamics (National Population Unit, 2001; Stats SA, 2015). Compared with the rest of Africa, South Africa is also a significant contributor to global international migrant statistics, known for the immigration of its citizens to more developed counties like the United Kingdom, Canada and Australia, with an annual net immigration of 247 000 to such countries between 2000 and 2010 (Phillips, 2006; Stats SA, 2015).

Weeks (2012) argues that internal migration can change population size and distribution at a subnational level far more rapidly than either mortality or fertility. Internally, South African migration is largely urban-ward, dominated by the rural-to-urban type often associated with unemployment and poor living conditions, where young adults often choose to relocate to urban areas in search of work and increased opportunities. Chi & Marcouiller (2011) noted that the most important economic factors that influence the migration of the working age population are income and employment. This is consistent with the argument that people are attracted by better educational or work opportunities or simply moving for better access to services and pleasure, the perceptions of living in developed urban centres, while they are pushed away from rural areas because of poor economic conditions and lack of amenities (National Population Unit, 2001; Mhloyi, Taruberekera & Lemba, 2013; Reed, 2013; Stats SA, 2015). Step migration from smaller cities to larger metropoles is also a common trend, and migration to peri-urban areas has become increasingly important in some parts of KwaZulu-Natal (Reed, 2013). Migration is not always a choice, and forced migration resulting from conflicts, political policies (e.g. Apartheid’s policies in South Africa) and industrial downscaling (especially in the mining industry) has also become a contributory factor to changing national population dynamics (National Population Unit, 2001).

4 A METHODOLOGY FOR LONG-TERM SETTLEMENT-SCALE POPULATION FORECASTS

4.1 The modelling framework

The settlement growth model in Figure 3 can be described as a methodology for producing high spatial resolution population projections. Two scenarios are considered for each period, namely medium-growth and high-growth scenarios. The immediate use of these downscaled population projections is in profiling climate change risk and vulnerability to guide the selection of suitable adaptation options for planning climate resilient human settlements. As shown in Figure 3, the settlement scale population projections have been aggregated from the 1x1 km grids of population projections. The availability of the gridded population dataset enables assessments of expected changes in the spatial distribution of people within each settlement. The core modelling components are the demographic model which produces the long-term projected population values at the national, provincial and local municipal scales, as well as the population potential model, a gravity model that is used to disaggregate/downscale the population projections, resulting in 1x1 km resolution projected population grids for 2030 and 2050.

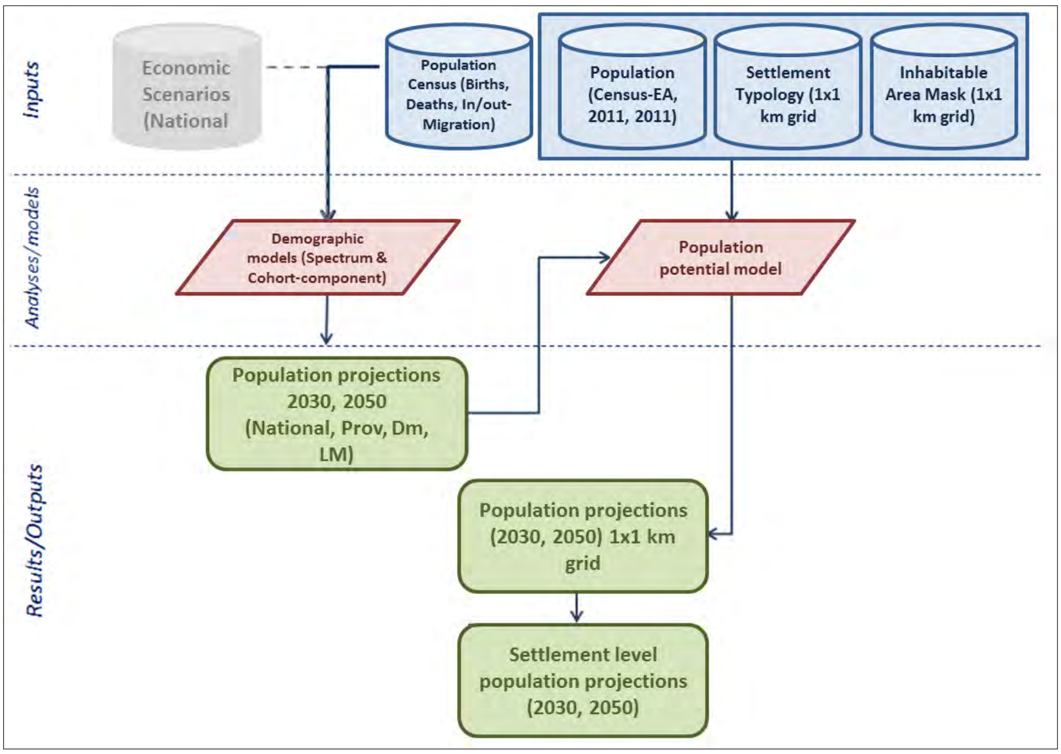


Figure 3: A conceptual model for settlement-scale population projection using census, topography, land cover/use and economic data as inputs

4.2 Derivation of long-term demographic control totals

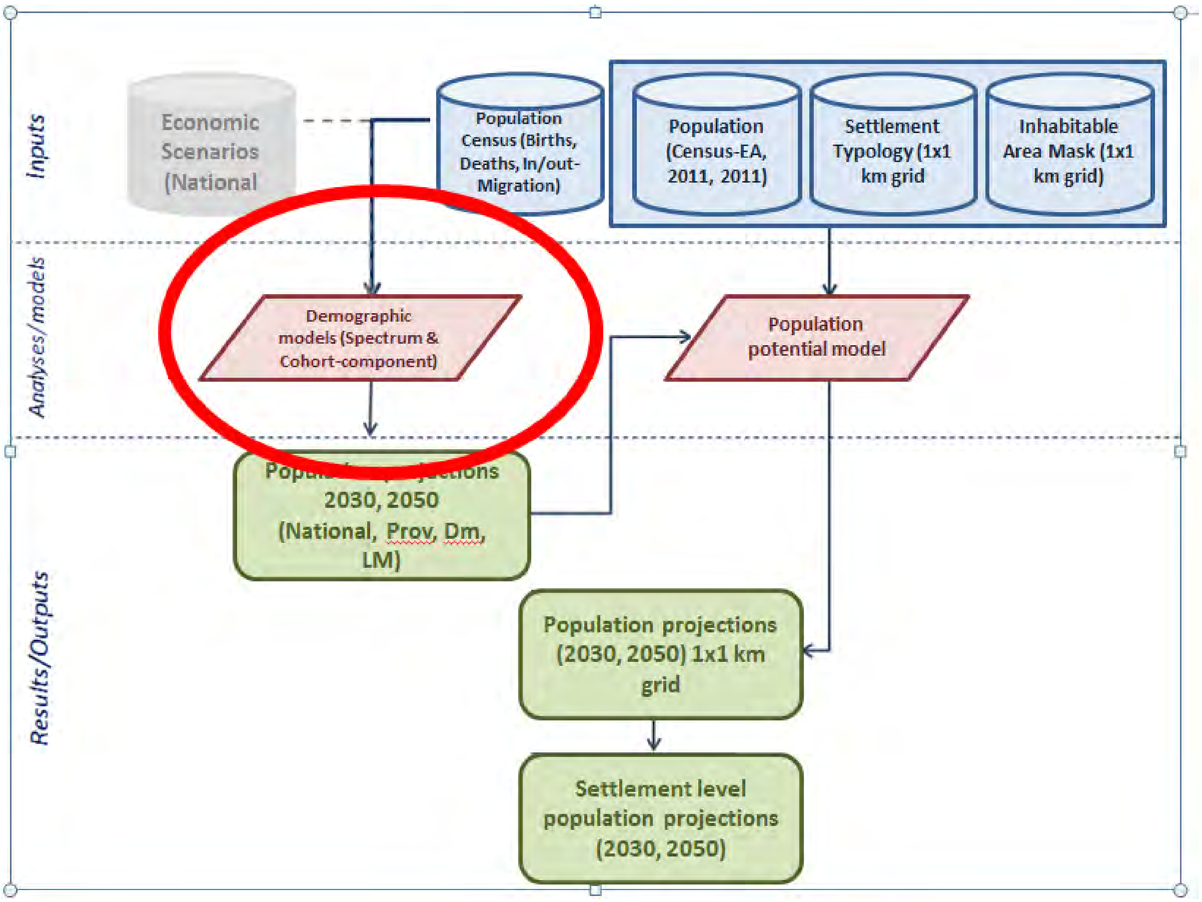


Figure 4: Conceptual model for settlement-scale population projection using census, topography, land cover/use and economic data as inputs, highlighting the demographic modelling phase.

4.2.1 Methodology

The section distinguishes between two separate methodologies used in the demographic projections. These are:

(a) Projection of the national population by using the SPECTRUM system;

(b) Provincial projection by applying a UN sub-national method of cohort-component projections (United Nations, 1992). The software for these projections was written in JMP script language (JSL) developed by the SAS institute Inc.

New versions of the SPECTRUM program incorporate new survey results on HIV/AIDS and the effect on mortality and fertility levels.

4.2.2 National projections (SPECTRUM system)

4.2.2.1 Models for population projection

The SPECTRUM software package, developed by Avenir Health (previously the Futures Institute), are applied separately for the four population groups. The SPECTRUM Policy Modelling System consolidates previous models into an integrated package containing seven components. Only two of these components are used to project the South African population at national level. These components are **Demproj**, a program to make population projections using the cohort component method and **AIM,** a program to project the consequences of the HIV/AIDS epidemic. SPECTRUM version 5.47 was used in this analysis. An important input of **AIM** is the HIV prevalence of the South African population.

Our knowledge of the HIV/AIDS epidemic in South Africa is based primarily on the prevalence data that have been collected annually from pregnant women attending public antenatal clinics (ANC) since 1990. These data have been used to obtain national estimates of HIV prevalence among the adult population and to determine epidemic trends over time.

To obtain a national epidemic curve, the Estimation and Projection Package (EPP), which has been incorporated into SPECTRUM, were applied using HIV prevalence data for the period 1990–2013.

This data however produced biased estimates of general population HIV prevalence because only a select group of people (i.e. pregnant women attending public health services) are included in the sample. Firstly, HIV prevalence among women who attend public health services is generally estimated to be higher than prevalence among those who attend private health services. Secondly, HIV prevalence among pregnant women is likely to be different than the prevalence among the general adult population. Some adjustments were made to correct for these biases in the estimates. Results from HSRC surveys on HIV/AIDS were helpful in this regard.

SPECTRUM additionally requires time-series data for the total fertility rate (TFR), life expectancy (not taking HIV/AIDS into account) and international migration. The number of adults receiving anti-retroviral treatment is a very important variable in the AIM part of SPECTRUM. The demographic component of the projections is based on the cohort-component approach.

4.2.2.2 Assumptions of DemProj

The demographic model in SPECTRUM, known as **DemProj**, is a computer program for making population projections for countries or regions. The program requires information on the number of people by age and gender in a base year, as well as current year data and future assumptions about the TFR, the age distribution of fertility, life expectancy at birth by sex, the most appropriate model life table, and the magnitude and pattern of international migration. This information is used to project the size of the future population by age and gender for as far as 150 years into the future.

Linking DemProj with other modules in SPECTRUM makes it possible to examine the demographic impact of AIDS (AIM), the family planning service requirements to achieve demographic and health goals (FamPlan), the costs and benefits of family planning programmes and the socioeconomic impacts of high fertility and rapid population growth (RAPID).

DemProj was first produced in 1980. Since then, it has been used by a large number of planners and researchers around the world. It has been updated from time to time in response to comments and suggestions from users.

This current release incorporates a number of new features in response to these comments. DemProj (and the entire SPECTRUM system) is designed to produce information useful for policy formulation and dialogue within a framework of easy-to-use computer programs.

4.2.2.3 The Base Population

Although census data for 2011 and the community survey data for 2016 are available, the base year for the projections are still 1985 (before the first cases of HIV/AIDS were reported in 1991) and the aim is to reach the total numbers of Census 2011 and the Community Survey in 2016.

4.2.2.4 Fertility assumptions

The Total Fertility Rate (TFR) is the number of live births a woman would have if she survived to age 50 and had children according to the prevailing pattern of childbearing at each age group. It is not an average of the number of live births for currently living women. Rather, it is a synthetic measure that expresses the current level of fertility in terms of the average number of live births that would occur per woman if the current age-specific fertility rates remained constant and all women survived to age 50.

Estimates of the TFR are available from a number of sources. The best sources will be national fertility systems and population censuses. The registration of births in South Africa is administered by the Department of Home Affairs (DHA) and published by Stats SA when data are available. The latest information on the number of live births recorded in the South African birth registration system is 2015. The reporting of live births is shown by year of registration (the year in which the birth was registered) and occurrence year (the year in which the birth occurred).

To estimate the TFR it was necessary to determine the number of births per women in the five year age groups (e.g. 15-19, 20-24, 25-29 and so on till 45-49). This was obtained from the birth registration system. Furthermore the number of women in each of the above mentioned age-groups was required. The number of women can only be obtained from a census or projection. For the census years 2001, 2011 and to a lesser extent for the Community Surveys in 2006 and 2016, such data are available. In the years in between the Censuses and the Community Surveys the midyear estimates should be used. To estimate the population numbers using calculated TFR, one would normally run the projection several times and try to match the numbers of adjusted births (adjusted for late and under registration) from the birth registration system.

In these projections the procedure mentioned above was followed for the years 2001 to 2016. For the last year (2050 in this case) a TFR was assumed and then interpolated between these values to fill in the intervening years. Interpolation may be done for any interval of time. In this projection two end TFRs were set, namely a higher level that correspond to a high international migration assumption and a slightly lower end value for the lower migration assumption.

4.2.2.5 Mortality assumptions

Life expectancy at birth is the average number of years a person can expect to live based on the age-specific death rates for a given year. This is the calculated life expectancy at birth. When AIM is not being used, then this number will be the same as the input life expectancy. However, if AIM is used, then the calculated life expectancy will (as in this study) include the impact of AIDS-related deaths, and will therefore be different from the input life expectancy. Statistics from the South African civil registration system are the only national source of information on mortality and causes of death. 2015 was the latest data available and was released in February 2017.

Life expectancy at birth is calculated from a Life Table. Normally the table has as input age-specific mortality rates (m(x)) in the Life Table. Mortality rates are calculated by dividing the number of deaths in a specific age group by the population number in that age group. We experienced the same problem as with the TFR. We wanted to use the survival ratios from the Life Table to project the population, but population data are only available from the projection. To convert data from the civil registration system to a Life Table and from that determine a life expectancy is therefore not direct.

As in the case of the TFR the projections were run several times and we tried to match the number of adjusted deaths (adjusted for late and under registration) from the death registration system.

4.2.2.6 International migration assumptions

Migration is nearly always the most difficult component of any population projection. In many instances, the actual number of recent migrations is not well known and future migration trends can be very difficult to predict.

Several methods can be used in conjunction with one another to evaluate the level of migration when data are available. When complete data or estimates believed to be reliable on births and deaths are available, a simple balancing equation may be used to evaluate a possible level of net migration between two censuses. The equation is as follows:

$$P_n = P_0 + B - D + M_{in} - M_{out}$$

Where:

P_0	=	Population in the Base Year
B	=	Births during the interval
D	=	Deaths during the interval
M_{in}	=	In-Migration
M_{out}	=	Out-Migration

This simple equation assumes complete registration of births and deaths and equal coverage of the population at both censuses. Since all censuses vary in their coverage, the resulting amount of net migration cannot be absolutely accurate but it can assist in evaluating some order of magnitude of migration.

This approach resulted in two separate scenarios (high growth and medium growth) and differed based on their in and out migration assumptions and is shown in Figure 5 in comparison to population projections acquired from the World Bank, United Nations (United Nations, 2015) and Population Reference Bureau (Population Reference Bureau, 2016). The results were discussed by a panel of experts and migration assumptions were tested with national and international migration experts.

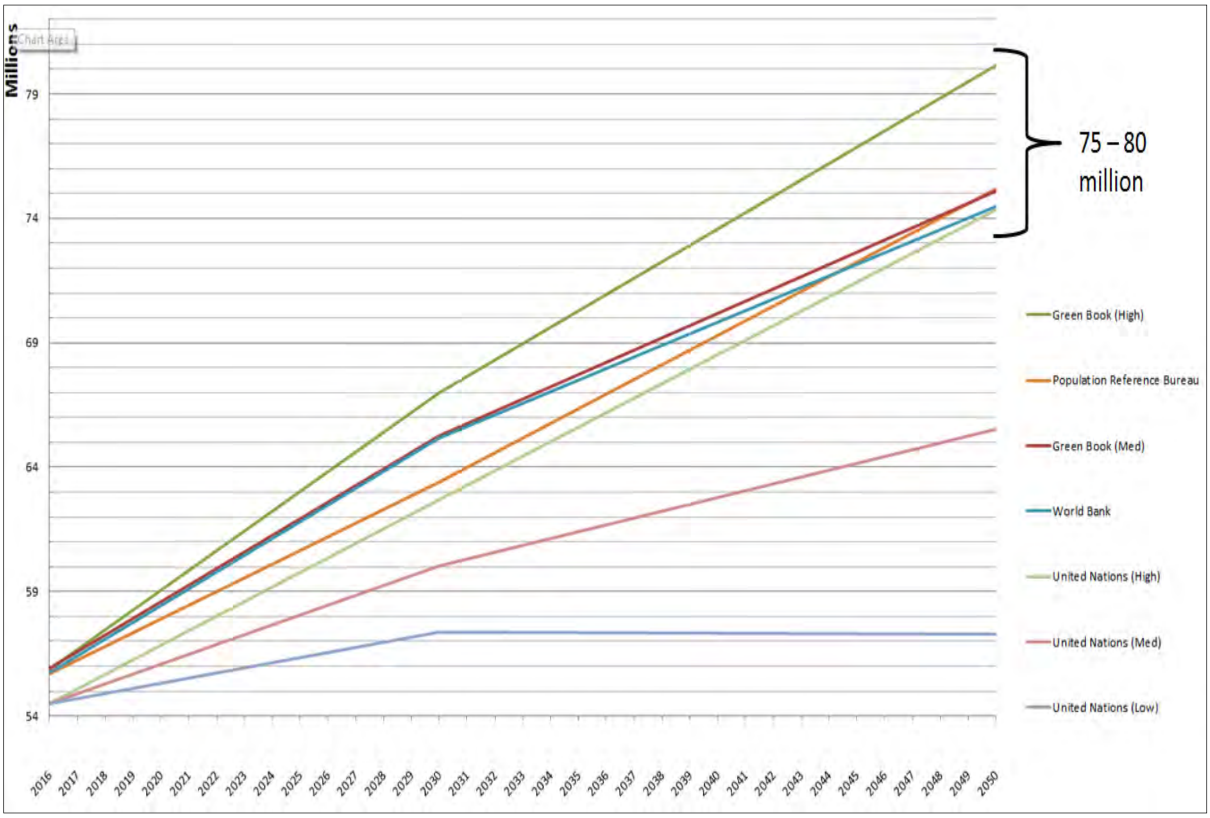


Figure 5: National level population projections based on the SPECTRUM SYSTEM

4.2.3 Provincial projections (Cohort-component method)

4.2.3.1 Overview

When projections for all the regions of a country are desired and the appropriate data are available, a multi-regional approach should be considered, as this is the only way to guarantee that the total migration flows between regions will sum to zero, or to the assumed level of international migration (United Nations, 1992). Developed by Willekens and Rogers (1978), these methods have not been widely used in developing countries, largely due to the lack of adequate migration data and the difficulty of applying these methods.

Multi-regional methods require the estimation of separate age-specific migration rates between every region of the country and every other region, and such detailed data are rarely available. Although it is possible to estimate some of the missing data (see Willekens et al., 1979), the task of preparing data can become overwhelming if there are many regions. If there are only a few streams, however, the multi-regional method is the best method to use. In South Africa, 2 448 (9x8x17x2) migration streams are derived if the multi-regional model is applied in calculating migration streams by age group (17 in total) and sex for each province. The number of streams increase dramatically if this approach is followed for the 52 district and metropolitan municipalities, namely to about 90 000.

4.2.3.2 The age-structure of the provinces

The base from which a population projection is done is very important as it has a big effect on the outcome of a projection. It also forms the base from which the provincial fertility and mortality rates were adjusted in this study.

For the preparation of the 2001 age-structures of the provinces, two sources of data were used, namely (a) the provincial 2001 Census populations by age and sex (on 2016 boundaries); (b) the projected South African population by age and sex. Using these sources of data, the 2001 base age structures of each of the nine provinces by gender is determined by applying an iterative process. Five iterations were enough to obtain stable populations.

4.2.3.3 Calculation of migration rates from the 2011 Census

For sub-national areas, migration is often the major determinant of population growth and can also be seen as the most difficult component of growth to forecast accurately as migration rates are subject to much greater volatility than either fertility or mortality rates.

To determine flow patterns a census or large survey is usually the only source of data and the two procedures most frequently used for measuring internal migration are:

a) Procedures based on questions on censuses or surveys intended to detect migration.
b) Procedures based on other population characteristics such as age-structure and places of birth.

As special questions in Census 2011 were now available, it was decided to follow the approach in (a) above, in this study. These questions were used to determine the usual residence and previous residence of every person during the census or survey period. In the case of the census the targeted previous residence was exactly ten years.

To convert the response to these migration questions to migration rates per thousand of the population in specific age groups, the following steps were followed:

a) Determine the usual province of residence of each person at the time of the census or survey.
b) Determine the previous province of residence.
c) If the usual province of residence and the previous province of residence were the same, then the person is classified as a non-migrant.
d) If the usual province and previous province are different the direction of the migration stream is determined.
e) Cross tabulate usual and previous province (see Table 2 below).
f) Cross tabulate age (five-year age groups) with usual province for every previous province (see Table 3).

We were now ready to convert the migration information obtained from Census 2011 to migration rates per thousand of the population. This was done by using two sets of information, namely the cross-tabulations of previous and usual provinces for the total population and by age groups. Table 2 below presents migration movements between the provinces. To illustrate the procedure, only the female movements are given in this table. Take note that the data in Tables 2 to 4 is only given to illustrate the procedure and might differ from the data in the projection.

Table 2: Total female movement between provinces: 2001-2011 (percentages)

Prov In 2001	Province in 2011								
	EC	FS	GT	KZN	LIM	MP	NC	NW	WC
EC	94,12	0,2748335*	1,50	1,00	0,11	0,16	0,06	0,40	2,38
FS	0,32	95,04	2,53	0,33	0,18	0,25	0,25	0,77	0,50
GT	0,34	0,30	96,57	0,54	0,49	0,41	0,08	0,55	0,72
KZN	0,22	0,10	1,47	97,55	0,08	0,21	0,02	0,09	0,27
LIM	0,06	0,08	3,48	0,10	95,21	0,62	0,03	0,31	0,10
MP	0,12	0,19	2,88	0,37	0,63	95,32	0,05	0,26	0,20
NC	0,33	0,87	1,39	0,22	0,20	0,15	93,36	1,01	2,46
NW	0,18	0,36	3,53	0,16	0,41	0,19	0,44	94,49	0,26
WC	0,69	0,13	0,84	0,24	0,07	0,08	0,27	0,09	97,58

* This FS cell has more decimal places in order to illustrate the calculations in Table 2.

From Table 2 it is observed that for example 94,12 % of the population of the Eastern Cape reported that they were living in the same province in 2001 and 2011. This however did not indicate that they did not move at all as the census question did only focus on the last move. Of those that moved, 2,4 % moved to Western Cape, 1,5 % to Gauteng and smaller proportions to other provinces.

Next, the age distribution of the out-migrants from each province to every other province needs to be determined. The results of these analyses are given in Table 4 to illustrate the out-migration of the female Eastern Cape population to the other eight provinces. To complete the analyses eight similar tables (not shown here) were also constructed.

Table 3 does not show the volume of migration, but only indicates the age distribution of the migrants. It is clear from this table that the highest percentage of migrants are found amongst those in the age group 15–24. For example in Gauteng about 45% of the out-migrants were from the age group 15–24 years. It is therefore clear that the information in both Tables 2 and 3 must be used to calculate out-migration rates per thousand of the population. An Eastern Cape example of such a calculation is given in Table 4.

Table 3: Total female movement between provinces by age: 2001-2011 (percentages distribution)

Age group	Province in 2001							
	FS*	GT	KZN	LIM	MP	NC	NW	WC
Births after 2001	0,060519991	0,0557	0,0626	0,0747	0,0820	0,0706	0,0810	0,0567
0-4	0,078544898	0,0524	0,0635	0,0836	0,0676	0,0879	0,0650	0,0638
5-9	0,075486126	0,0483	0,0628	0,0494	0,0646	0,0855	0,0406	0,0652
10-14	0,120166048	0,1073	0,1291	0,0922	0,1145	0,1257	0,0814	0,1325
15-19	0,187786760	0,2446	0,2402	0,1598	0,1768	0,1299	0,1979	0,2448
20-24	0,151846187	0,2126	0,1682	0,1638	0,1745	0,1327	0,2059	0,1823
25-29	0,107712475	0,0982	0,0881	0,1355	0,1168	0,0850	0,1320	0,0867
30-34	0,071444177	0,0638	0,0612	0,0857	0,0768	0,0729	0,0882	0,0543
35-39	0,049705047	0,0436	0,0428	0,0593	0,0462	0,0579	0,0531	0,0381
40-44	0,029495303	0,0266	0,0261	0,0379	0,0233	0,0519	0,0252	0,0241
45-49	0,019008084	0,0151	0,0176	0,0198	0,0157	0,0276	0,0102	0,0154
50-54	0,011361154	0,0095	0,0112	0,0097	0,0094	0,0257	0,0066	0,0110
55-59	0,011033428	0,0075	0,0095	0,0097	0,0105	0,0140	0,0047	0,0091
60-64	0,008302381	0,0051	0,0057	0,0044	0,0073	0,0084	0,0025	0,0060
65-69	0,006663754	0,0033	0,0055	0,0052	0,0050	0,0098	0,0022	0,0043
70-74	0,005571335	0,0031	0,0025	0,0044	0,0046	0,0065	0,0018	0,0025

75-79	0,003604981	0,0019	0,0020	0,0026	0,0029	0,0042	0,0008	0,0018
80+	0,001747870	0,0013	0,0013	0,0024	0,0017	0,0037	0,0010	0,0013
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

* The FS column has more decimal places in order to illustrate the calculations in Table 3.

Table 4: Calculation of "scaled" migration rates (out-migration of Eastern Cape females to the Free State in the period 2001 to 2011)

Age in 2001	EC Female Population in 2001	Percentage distribution of migrants: the EC to the FS (from Table 2)	Estimated migrants	Scaled migration rates
	(1)	(2)	(3)=(1)*(2)	(4)=(2) * scale factor
Births after 2001		0,060519991		0,00194
0-4	387 164	0,078544898	30 410	0,00251
5-9	446 561	0,075486126	33 709	0,00242
10-14	450 993	0,120166048	54 194	0,00384
15-19	403 541	0,187786760	75 780	0,00601
20-24	305 412	0,151846187	46 376	0,00486
25-29	253 482	0,107712475	27 303	0,00345
30-34	199 671	0,071444177	14 265	0,00229
35-39	182 789	0,049705047	9 086	0,00159
40-44	182 212	0,029495303	5 374	0,00094
45-49	153 021	0,019008084	2 909	0,00061
50-54	127 907	0,011361154	1 453	0,00036
55-59	108 174	0,011033428	1 194	0,00035
60-64	119 473	0,008302381	992	0,00027
65-69	91 015	0,006663754	607	0,00021
70-74	61 401	0,005571335	342	0,00018
75-79	35 740	0,003604981	129	0,00012
80+	31 958	0,001747870	56	0,00006
Total	3 540 514	1	304 177	
Calculated total out-migration rate			304 177 / 3 540 514 = 0,0859132	
Desired total out-migration rate (from Table 1)			0,002748335	
Scale factor			0,002748335 / 0,0859132 = 0,03198967	

These out-migration rates for the Eastern Cape females to the Free State will be used in the cohort-component projections. For each of the nine provinces, sixteen tables of the format of Table 3 were created.

4.2.3.4 Provincial fertility rates

The following steps were used to obtain a set of age-specific fertility rates for each province to be used in the provincial cohort-component projections:

a) Analyses of the recorded live births datasets (for the period 1998 to 2014) were done to adjust for late registration and completeness. The number of births in the age groups 15 to 49 were obtained. This was done for each province.
b) The total number of births generated from the provinces were then compared with the total number of births in the RSA projection. Proportional adjustments were made if necessary and TFRs calculated by applying the births to the specific provincial 15-49 age structure.
c) Using these adjusted TFRs and age-specific fertility rates as well as survival ratios, the number of births and the 0–4 projected population were obtained. The projected 0–4 year and 5–9 year populations were checked for consistency. Provision was made to adjust the TFR manually if inconsistencies were found.
d) The process above was repeated if inconsistencies were found in (c).

4.2.3.5 Provincial survival ratios

The following steps were used to obtain a set of survival ratios for each province to be used in the provincial cohort-component projections:

a) Analyses of the Mortality and Causes of Death datasets from 1998 to 2014 (the latest available) were done to adjust from late registration and completeness.
b) The numbers of male and female deaths calculated for each province were then compared with the total number of male and female deaths in the RSA projection respectively. Proportional adjustments were made where necessary.
c) Age-specific mortality rates (m(x)) were then calculated.
d) Using the m(x) rates, life tables for both males and females and for each province were calculated.
e) Life expectancies at birth as well as survival ratios by age can be read from the obtained life tables (see the shaded areas in Table 5 below). The survival rates are now available to be used in the projection.

An example of the calculations for the female population follows the steps as described above and is given in Table 5 and 6. Take note that the data in Tables 5 and 6 are only given to illustrate the procedure and might differ from the data in the projection.

The first step is to compare the total number of deaths for all the provinces with the number of deaths for RSA. In this example the total number of RSA deaths was 294 666 and the deaths by province total 333 314. The adjusted deaths (for each age group in a province) are calculated by applying an adjustment factor of 0,884049274 (294 666 divided by 333 314). The adjusted deaths are given in column 4 in the table below. The second step is to calculate the m(x)-values for each age group based on the adjusted number of births. Life tables for each province and sex can know be constructed. This is done by applying the LTMXQXAD spreadsheet in PAS. The survival ratios read from the constructed life tables and which will be used in the projection, are given in the last column of Table 5 and 6 (shaded).

Table 5: Calculation of female survival ratios for provincial projections

	Age category	Population in 2001	Deaths	Adjusted		Survival ratios	
				Deaths	m(x)	Categories	Values
		(1)	(2)	(3)	(4)		(5)
EC	0	69 939	5884	5 202	0,0744	Birth	0,9177
	1-4	317 225	3140	2 776	0,0088	0- 4	0,9745
	.	.	.	.	.	.	.
	80-84	21 446	3316	2 932	0,1367	75-79	0,5717
	85+	10 512	2484	2 196	0,2089	80+	0,3913
	EC Total		52111	46 069	LE=56,3		
FS	0	31 344	2960	2 617	0,0835	Birth	0,9068
	1-4	122 286	1486	1 314	0,0107	0- 4	0,9688
	.	.	.	.	.	.	.
	80-84	7 209	1165	1 030	0,1429	75-79	0,5549
	85+	4 782	1161	1 026	0,2146	80+	0,3794
	FS Total		23263	20 565	LE=53,6		
GT	0	85 909	6578	5 815	0,0677	Birth	0,9256
	1-4	318 539	2670	2 360	0,0074	0- 4	0,9783
	.	.	.	.	.	.	.
	80-84	15 073	2248	1 987	0,1319	75-79	0,5851
	85+	9 722	2248	1 987	0,2044	80+	0,4008
	GT Total		51045	45 127	LE=58,4		
KZN	0	110 491	12655	11 188	0,1013	Birth	0,8851
	1-4	464 769	7959	7 036	0,0151	0- 4	0,9563
	.	.	.	.	.	.	.
	80-84	20 673	3592	3 176	0,1536	75-79	0,5260
	85+	11 800	2998	2 650	0,2246	80+	0,3591
	KZN Total		93169	82366	LE=48,4		
LIM	0	61 848	5311	4 695	0,0759	Birth	0,9159
	1-4	273 599	2808	2 482	0,0091	0- 4	0,9735
	.	.	.	.	.	.	.
	80-84	17 848	2782	2 459	0,1378	75-79	0,5688
	85+	11 932	2833	2 505	0,2099	80+	0,3892
	LIM Total		40481	35 787	LE=55,9		

Table 6: Calculation of female survival ratios for provincial projections (continued)

	Age category	Population in 2001	Deaths	Adjusted		Survival ratios	
				Deaths	m(x)	Categories	Values
		(1)	(2)	(3)	(4)		(5)
MP	0	43 463	4310	3 810	0,0877	Birth	0,9017
	1-4	171 468	2274	2 010	0,0117	0- 4	0,9660
	.	.	.	.	.	.	.
	80-84	7 503	1235	1 092	0,1455	75-79	0,5476
	85+	4 384	1077	952	0,2172	80+	0,3742
	MP Total		26865	23 750	LE=52,3		
NC	0	12 576	842	744	0,0592	Birth	0,9355
	1-4	48 485	321	284	0,0059	0- 4	0,9828
	.	.	.	.	.	.	.
	80-84	2 427	344	304	0,1253	75-79	0,6038
	85+	1 820	408	361	0,1982	80+	0,4140
	NC Total		6201	5 482	LE=61,2		
NW	0	36 840	3215	2 842	0,0772	Birth	0,9144
	1-4	140 356	1483	1 311	0,0093	0- 4	0,9728
	.	.	.	.	.	.	.
	80-84	7 284	1142	1 010	0,1386	75-79	0,5664
	85+	5 319	1268	1 121	0,2107	80+	0,3875
	NW Total		22997	20331	LE=55,5		
WC	0	43 634	2018	1 784	0,0409	Birth	0,9564
	1-4	168 864	587	519	0,0031	0- 4	0,9909
	.	.	.	.	.	.	.
	80-84	8 708	1067	943	0,1083	75-79	0,6526
	85+	6 439	1328	1 174	0,1823	80+	0,4489
	WC Total		17183	15190	LE=67,6		
		Total prov deaths		333315			
RSA	0	38 653					
	1-4	17 511					
	.	.					
	80-84	16 244					
	85+	15 487					
		RSA Total deaths = 294 666					
		Adjustment factor = 294 666 / 333 315 = 0.88404					

4.2.3.6 Provincial cohort-component calculations

The format that explains the cohort-component method used to project the provincial populations is shown in Table 7 below. This table and Tables 8 and 9 are only given to illustrate the procedure and might differ from the data in the projection. The Eastern Cape female population will be used in this discussion (as before).

Table 7: Projection of the Eastern Cape female population (part 1)

Age	Population 2001	Survival ratio (Table 4,col 5)	Age specific fertility	Migration rates (per thousands of population) to:							
				FS (Table 3)	GT*	KZN	LIM	MP	NC	NW	WC
Births after 2001	426 668	0,9177		0,00194	0,00952	0,00567	0,00106	0,00154	0,00055	0,00393	0,01649
0-4	387 164	0,9745		0,00251	0,00895	0,00575	0,00118	0,00127	0,00069	0,00316	0,01854
5-9	446 561	0,9908		0,00242	0,00826	0,00570	0,00070	0,00121	0,00067	0,00197	0,01895
10-14	450 993	0,9878		0,00384	0,01833	0,01170	0,00131	0,00215	0,00099	0,00396	0,03849
15-19	403 541	0,9802	0,0609	0,00601	0,04179	0,02177	0,00226	0,00332	0,00102	0,00962	0,07114
20-24	305 412	0,9742	0,1380	0,00486	0,03634	0,01525	0,00232	0,00328	0,00104	0,01000	0,05298
25-29	253 482	0,9696	0,1644	0,00345	0,01678	0,00799	0,00192	0,00219	0,00067	0,00641	0,02520
30-34	199 671	0,9645	0,1431	0,00229	0,01090	0,00555	0,00121	0,00144	0,00057	0,00428	0,01579
35-39	182 789	0,9579	0,0994	0,00159	0,00745	0,00388	0,00084	0,00087	0,00045	0,00258	0,01107
40-44	182 212	0,9476	0,0436	0,00094	0,00455	0,00237	0,00054	0,00044	0,00041	0,00123	0,00701
45-49	153 021	0,9305	0,0162	0,00061	0,00258	0,00160	0,00028	0,00029	0,00022	0,00049	0,00449
50-54	127 907	0,9049		0,00036	0,00162	0,00101	0,00014	0,00018	0,00020	0,00032	0,00318
55-59	108 174	0,8693		0,00035	0,00128	0,00087	0,00014	0,00020	0,00011	0,00023	0,00264
60-64	119 473	0,8217		0,00027	0,00087	0,00052	0,00006	0,00014	0,00007	0,00012	0,00175
65-69	91 015	0,7580		0,00021	0,00057	0,00050	0,00007	0,00009	0,00008	0,00011	0,00125
70-74	61 401	0,6754		0,00018	0,00054	0,00023	0,00006	0,00009	0,00005	0,00009	0,00073
75-79	35 740	0,5717		0,00012	0,00033	0,00018	0,00004	0,00005	0,00003	0,00004	0,00052
80+	31 958	0,3913		0,00006	0,00022	0,00011	0,00003	0,00003	0,00003	0,00005	0,00036

* The calculations of the migration rates to the other provinces as well as the age specific fertility rates are not given in this document

The main steps in deriving provincial mid-year population estimates for South Africa are as follows.

4.2.3.7 Calculate the number of out-migrants (5 years and older)

Whereas a projection for a single region involves multiplying the population at the first time-point in each five-year age group by a survival rate to obtain the survivors to the next five-year age group at the second time-point, a multi-regional projection involves a compound survival rate which specifies the probability of surviving and being in a particular region at the second time-point. A compound survival rate is the product of the survival rate and the out-migration rate(s) to each of the other provinces. The number of out-migrants from province A to each of the other provinces is then defined as:

$$OUT^{AB}_{t+5,x+5} = P^{A}_{t,x} * S^{A}_{t,x} * MR^{AB}_{t,x}$$
$$OUT^{AC}_{t+5,x+5} = P^{A}_{t,x} * S^{A}_{t,x} * MR^{AC}_{t,x}$$

$$OUT^{AI}_{t+5,x+5} = P^{A}_{t,x} * S^{A}_{t,x} * MR^{AI}_{t,x}$$

Where:

$S_{t,x}^{A}$ is the survival ratio of province A, age group x, first projection period

$MR_{t,x}^{AB}$ is the migration rate of province A to province B, age group x, first projection period

$MR_{t,x}^{AC}$ is the migration rate of province A to province C, age group x, first projection period

$MR_{t,x}^{AI}$ is the migration rate of province A to province I, age group x, first projection period.

The migration rate is defined as the number of migrants per thousand of the population in a specific age group.

4.2.3.8 Calculate the number of survivors by province (5 years and older)

For survival in the same province, the compound rate is the survival rate times one minus the sum of the out-migration to the other provinces. That is, the survivors (those that have not died or migrated) for people in age group x+5 and period t+5 of province A are obtained by using the following formula:

$$SUR_{t+5,x+5}^{A} = P_{t,x}^{A} * S_{t,x}^{A} * (1 - MR_{t,x}^{AB} - MR_{t,x}^{AC} - MR_{t,x}^{AD} - ....MR_{t,x}^{AI})$$

Where:

$P_{t,x}^{A}$ is the population of province A, age group x, first period; and the other symbols are defined as before. The number of survivors in each of the other provinces is calculated in the same way.

Applying the formulas in sections 4.1.3.7 (calculate the number of out-migrants (5 years and older)) and section 4.1.3.8 (calculate the number of survivors by province (5 years and older)) and using the data in Table 7 will result in the number of out-migrants as set out in Table 8. The calculations in Tables 7 and 8 will have to be repeated for all the other female populations in the other provinces (not shown). The same format, except for the fertility assumptions, is used for the male populations.

Table 8: Projection of the Eastern Cape female population (Part 2)

	Survivors in EC	Number of out migrants to:								In-migrants To EC*	Projected Population 2006
		FS	GT	KZN	LIM	MP	NC	NW	WC		
0-4	375 618	758	3 729	2 221	414	603	217	1 540	6 457	6 351	381 969
5-9	361 426	947	3 377	2 169	445	479	260	1 192	6 995	6 358	367 784
10-14	424 812	1 066	3 655	2 522	310	535	296	872	8 384	5 772	430 584
15-19	409 509	1 711	8 166	5 212	584	958	441	1 764	17 147	6 874	416 383
20-24	333 477	2 377	16 530	8 611	894	1 313	403	3 805	28 139	7 487	340 964
25-29	260 022	1 446	10 812	4 537	690	976	309	2 975	15 763	7 997	268 019
30-34	229 897	848	4 122	1 964	472	538	165	1 575	6 194	6 650	236 547
35-39	184 488	441	2 099	1 069	233	277	110	824	3 041	4 493	188 981
40-44	170 063	278	1 304	679	147	152	79	452	1 938	2 912	172 975
45-49	169 644	162	786	409	93	76	71	212	1 210	1 907	171 551
50-54	140 882	87	367	228	40	41	31	70	639	1 312	142 194
55-59	114 932	42	188	117	16	21	23	37	368	884	115 816
60-64	93 488	33	120	82	13	19	10	22	248	636	94 124
65-69	97 798	27	85	51	6	14	7	12	172	327	98 125
70-74	68 791	14	39	34	5	6	6	8	86	134	68 925
75-79	41 389	7	22	10	2	4	2	4	30	57	41 446
80+	32 900	3	10	5	1	1	1	2	16	27	32 927
Total	3 509 136	10 247	55 411	29 920	4 365	6 013	2 431	15 366	96 827		3 569 314

* To obtain the in-migrants to the EC, similar calculations were done for all the other provinces.

4.2.3.9 Calculate the number of in-migrants (5 years and older)

The number of in-migrants to province A (see second last column in Table 6) is obtained by adding the out-migrants from the other provinces (B to I) to province A, that is:

$$IN^{A}_{t+5,x+5} = OUT^{BA}_{t+5,x+5} + OUT^{CA}_{t+5,x+5} + OUT^{DA}_{t+5,x+5} + \ldots\ldots\ldots + OUT^{IA}_{t+5,x+5}$$

4.2.3.10 Projected population (5 years and older)

The projected provincial population of A in each age group aged 5 years and older (see last column in Table 6) is simply the sum of the survivors in province A and the number of in-migrants to province A, namely:

$$P^{A}_{t+5,x+5} = SUR^{A}_{t+5,x+5} + IN^{A}_{t+5,x+5}$$

4.2.3.11 Calculate the number of births and survivors aged 0–4 years

Annual births are estimated by applying the age-specific birth rates assumed for each province to the number of women in each of the reproductive age groups. This step is done separately for the present and the date 5 year previous. The results are averaged and then multiplied by five to obtain the total number of births in the five-year projection interval. Applying the sex ratio at birth will result in the number of male births. The female births are obtained by subtraction. The projected 0–4 population (see first entry in the last column of Table 8) is calculated by applying the formula in sections 4.2.3.7 to 4.2.3.10 to the number of male and female births respectively.

This projection process can be repeated for further time intervals and the assumed levels of mortality, fertility and migration can be altered for each projection period, if desired. **Based on the above this resulted in the population projections in Table 9 below.**

Table 9: Output provincial population projections (in million) for 2016, 2030 and 2050, medium and high scenario

	2016		2030		2050	
	Med	**High**	**Med**	**High**	**Med**	**High**
EC	6,89	6,93	7,93	8,13	9,02	9,56
FS	2,75	2,77	2, 86	2, 94	2, 99	3, 16
GT	13,39	13,48	16,67	17,14	20,30	21,79
KZN	10,91	10,99	12,85	13,19	14,75	15,80
LIM	5,71	5,75	6,59	6,76	7,09	7,57
MP	4,30	4,33	5,11	5,24	5,91	6,26
NC	1,19	1,19	1,31	1,34	1,39	1,47
NW	3,97	3,99	4,55	4,61	5,12	5,48
WC	6,23	6,27	7,41	7,58	8,53	9,02
Total	**55,33**	**55,70**	**65,27**	**66,99**	**75,10**	**80,14**

4.2.4 District municipality projections (Cohort-Component method)

4.2.4.1 The age-sex structures of the base populations

The base age/sex structures of the district councils were determined through an iteration process and using the following datasets:

- The projected 2001 provincial populations by sex and five-year age groups (2016 boundaries);
- The district and metropolitan municipality populations for Census 2001 by age and sex (2016 boundaries).

4.2.4.2 The migration trends between district and metropolitan municipalities

The same method was used as described in section 4.1.3.3 (calculation of migration rates from the 2011 census) for the provinces. The only difference is that the nine provinces are replaced with the 52 district and metropolitan municipalities. One hundred and four tables (52x2) of the format of Table 2 will have to be constructed and 5 304 (52x51x2) similar to Table 3. The same calculations as in Table 4 will also be followed to obtain scaled migration rates for each district or metropolitan municipality.

4.2.4.3 Fertility estimation of district and metropolitan municipalities

The following steps were used to obtain a set of age-specific fertility rates for each district municipality and each metropolitan municipality to be used in these cohort-component projections:

a) Analyses of the recorded live births datasets (1998 to 2014) were done to adjust from late registration and completeness. The number of births in the age groups 15 to 49 were obtained. This was done for each district municipality.
b) The total number of births generated from the district municipalities was then compared with the total number of births in that specific province. Proportional adjustments were made if necessary and TFRs calculated by applying the births to the specific district or metropolitan population 15-49 age structure.
c) Using these adjusted TFRs and age specific fertility rates as well as survival ratios, the number of births and the 0–4 projected population were obtained. The projected 0–4 year and 5–9 year populations were checked for consistency. Provision was made to adjust the TFR manually if inconsistencies were found.
d) The process above was repeated if inconsistencies were found in (c).

4.2.4.4 Mortality estimation of district and metropolitan municipalities

The following steps were used to obtain a set of survival ratios for each province to be used in the provincial cohort-component projections (see Table 4 with provinces replaced by district municipalities).

a) Only data from 2007 to 2014 were available on this level to do analyses of the Mortality and Causes of Death datasets to adjust for late registration and completeness.
b) The numbers of male and female deaths calculated for each municipality were then compared with the total number of male and female deaths in that specific province. Proportional adjustments were made where necessary.
c) Age-specific mortality rates (m(x)) were then calculated.
d) Using the m(x) rates separate life tables for males and females and for each district municipality were calculated.
e) Life expectancies at birth as well as survival ratios by age can be read from the obtained life tables. The survival rates are now available to be used in the projection.

4.2.4.5 The Cohort-Component district municipality projections

The same procedure as described in sections 4.1.3 to 4.1.11 for the provincial projections are also followed for the district municipality projections. The nine provinces should be replaced by the 52 district and metropolitan municipalities.

4.2.4.6 4.1.5 Long-term projections for local municipalities

It would be difficult to project local municipality population by using the cohort-component method. Mortality, fertility and migration data are in some cases not available and where available it is often of a poor quality. Migration data on this level can especially not be used.

Is was therefore decided to follow a different approach. One approach would be to identify the changes in the relative size of the municipalities by using data of the last 3 censuses and the 2016 Community Survey (CS2016). The growth rate between the censuses and the CS2016 would be another approach.

4.2.4.7 Calculation of numbers, rates and proportions

For each of the censuses in 1996, 2001, 2011 and the CS in 2016 the following were calculated by gender:

a) The population of each local municipality in relation to the total population (proportion);

b) The population of each local municipality in relation to the population of the largest metropolitan municipality (proportion);
c) The population of each local municipality in relation to the population of the district municipality in which the municipality belong (proportion);
d) Growth rate between 1996 and 2016;
e) Growth rate between 2011 and 2016;
f) Growth rate between 2001 and 2016;
g) Growth rate between 2001 and 2011;
h) Using the local municipality population numbers at the four dates.

4.2.4.8 Fitting a regression line to the numbers, rates and proportions

Using the proportions, rates and numbers calculated above, determine least-square regression lines with the four points available. Unless the data line up perfectly, any line that we use to model the relationship will have an error (called the residual).

The least-squares regression line can be defined as:
y = a + bx

Where:

$$b = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x}\bar{y}}{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}$$

and a = $\bar{y} - b\bar{x}$

(y = rates, percentages or numbers, x = years)

Using the two approaches in (a) and (b) above did not give results that can be used for this projection. A large number of local municipalities have populations that are very small in relation to the total population and to the largest metro. The result of the projections to 2030 and 2050 was negative proportion for a number of local municipalities. We therefore decided to only use (c) to (h) above in the analyses.

As would be expected, the outcome of the six approaches did differ for 2030 and 2050. To obtain a single estimate for each local municipality the following were done: Remove the highest and lowest estimate and calculate the mean value for the remaining four estimates.

This was done separately for each local municipality, which means that the chosen projection types might differ.

As was the case with the higher level projections, the total of all the local municipalities in a particular district municipality must add to the district municipality total.

4.2.4.9 4.1.5.3 Projection to 2030 and 2050 by age

Four broad age groups were used, namely 0-14 (child), 15-34 (youth), 35-64 (adult) and 65+ (elderly). This grouping is in line with those used by Stats SA.

The following steps were followed for this analysis:

a) Determine for 1996, 2001, 2011 and 2016 the proportional age distribution for each local municipality.
b) For each age-group separately determine a least-square regression line with the four points available. Do this analysis for males and females.
c) Project the proportions (the four age-groups separately) to 2030 and 2050 using the regression lines calculated in (b).
d) At the points of projections (2030 and 2050) the projected age proportions are combined. Make sure that the four age proportions add up to 1. If not, make proportional adjustments.
e) Apply the projected proportions to the projected local municipality populations in 2030 and 2050. The projected local municipality age numbers must however also add to the corresponding age groups in the district municipality projections. This can only be done by an iteration process. For this analysis about 6 to 7 iterations were enough to obtain stability.

4.2.4.10 Risks regarding long-term population projections

In the period 1960-1980 several long-term population projections were undertaken by Prof. Jan Sadie from Stellenbosch and researchers at the HSRC. All these projections did by far not reach the census counts in 2001 and 2011. Some of these projections were 10-15 million off the actual target. It must however be taken into account that most of these projections were done by hand calculations and it was only in the late 1970s that the researchers at the HSRC had computer facilities at their disposal. But even then, their long-term projections were found to be mediocre at best.

In the early years of demography in South Africa, projections were only done at national level and scenarios, especially with different fertility levels, were created. Lower level projections were only published from the ASSA models and the Mid-year estimates by Stats SA (from 2006). The latest ASSA model (ASSA 2008) only projected down to provincial level. Stats SA started publishing mid-year estimates for district and metropolitan municipalities from about 2011.

Not many demographers are willing to get involved in long-term projections, especially not at low level (district municipalities and below). They would argue that it is difficult to estimate the future fertility, mortality and migration levels 30 to 40 years from now. South Africa has a very high level of HIV prevalence and the HIV population reached about 8 million in 2016. This is about to increase in the future. Some long-term projections indicate that the country's death rate (which is now decreasing) might increase in the future. What will happen on lower levels? Fertility will probably decline in all parts of South Africa. It is however the estimation of migration trends that are very uncertain. The future trends of the inflow of international migrants, especially of African countries close to the South African borders, are to a large extent dependent on the economic and political stability in these countries. Internal migration numbers can only be obtained from the South African censuses and these data are normally outdated when it becomes available to researchers. The movement of people are obtained from a census based on information from 5 to 10 years before the census. Census data regarding migration are released on the earliest two years after a census. Researchers therefore must work with migration data that are at least 7 years old. This might be acceptable on provincial level but does not help much on district and local municipality level. The demarcation changes of local municipalities on a regular basis are also not favourable to estimates at that level.

The output population projection results from the SPECTRUM and Cohort-Component modelling exercise are illustrated in Figures 6 and 7, indicating the projected population (absolute and relative change) between 2011 and 2050 for both the medium and high population scenarios.

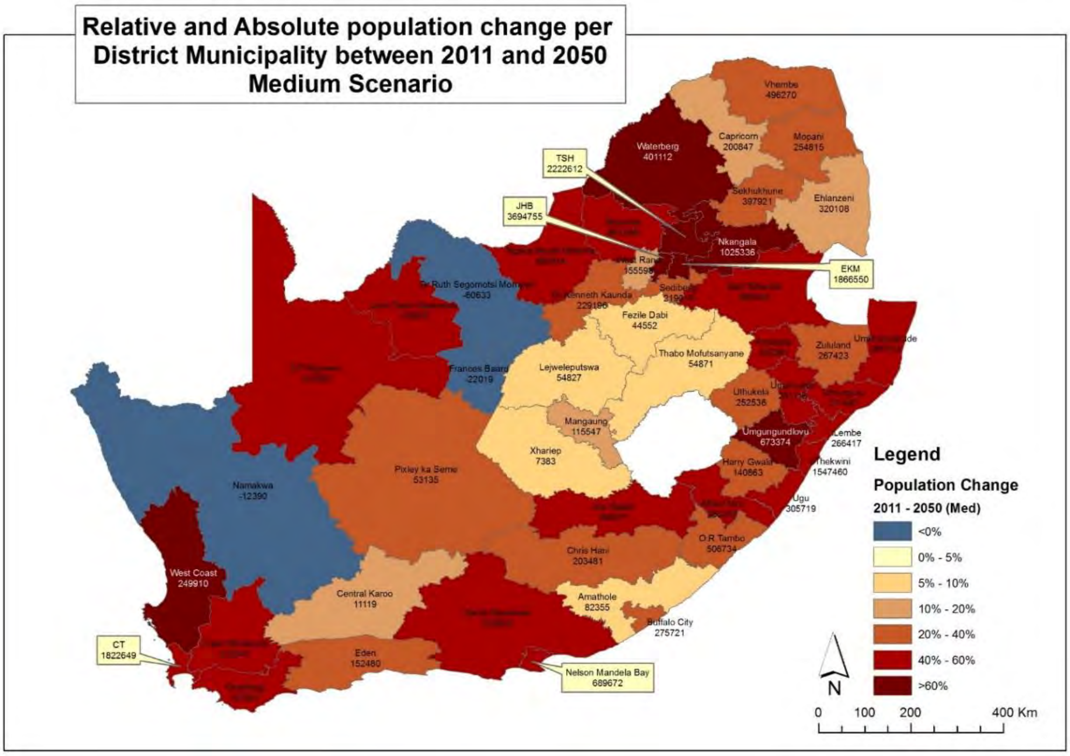


Figure 6: Relative and absolute population change per District Municipality between 2011 and 2050 (Medium Growth Scenario)

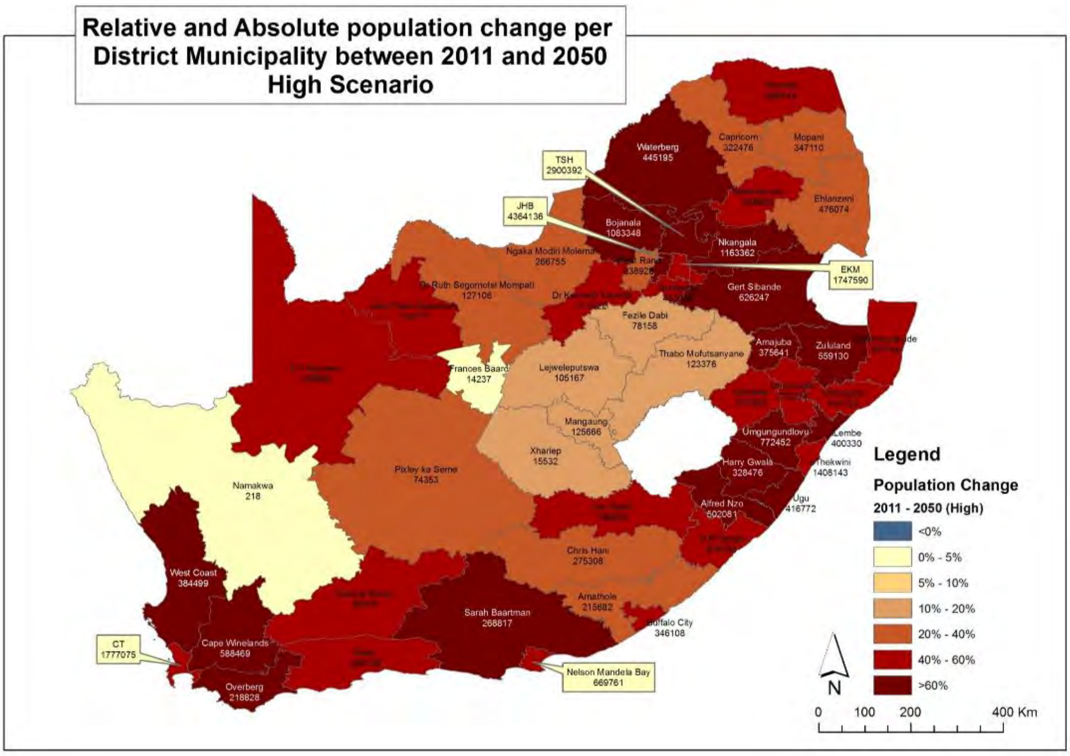


Figure 7: Relative and absolute population change per District Municipality between 2011 and 2050 (High Growth Scenario)

4.3 Spatial disaggregation of population projections through the potential model

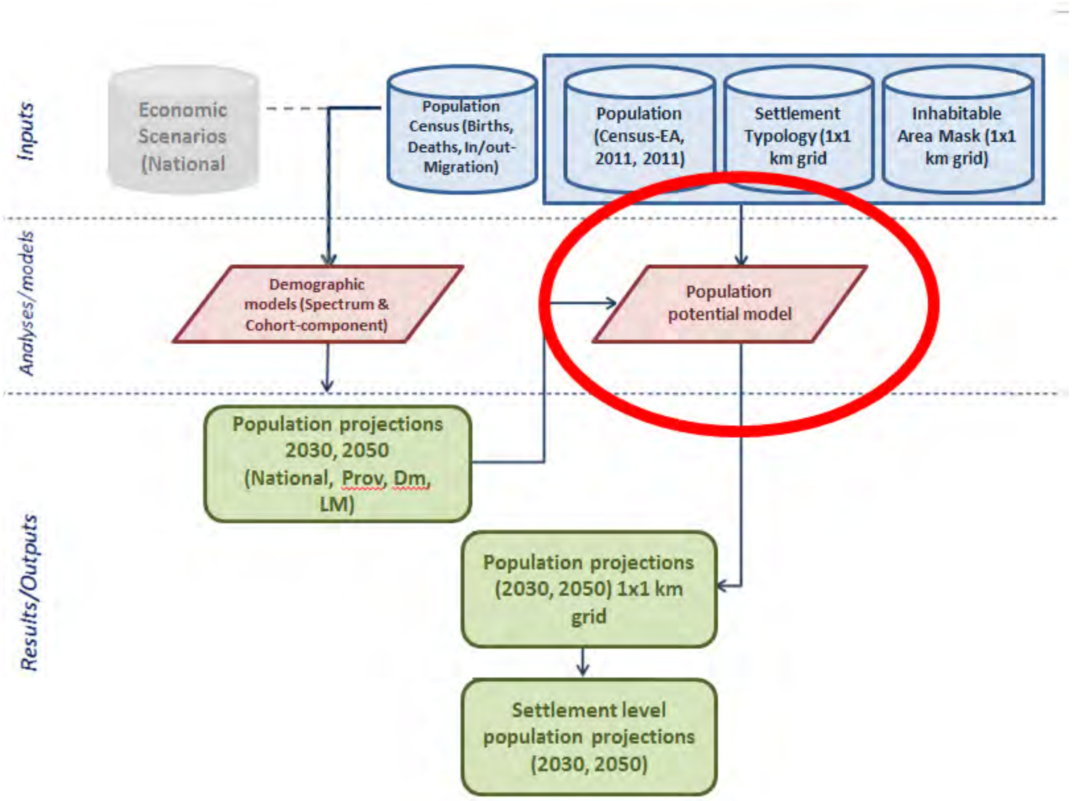


Figure 8: Conceptual model for settlement-scale population projections using census, topography, land cover/use and economic data as inputs, highlighting the population potential model.

The population projections being disaggregated by the potential model are outputs of a demographic model at national, provincial, district and local municipal levels as shown in Figure 8. The demographic model embeds information on crucial demographic processes such as fertility, mortality and migration which includes insights on economic trends since internal migration in South Africa (as in other developing nations) is influenced by access to better economic opportunities (De Haan, 2000, Kok et al., 2006, Todes et al., 2010).

Population *potential* is considered as a measure of the "attractive force" of a particular grid cell for further population growth (Grübler et al 2007). In this study separate population potential surfaces are used to allocate (projected) population change, but each is calculated using the existing population in each grid cell. Potential (v_i) for the i^{th} grid cell is defined as:

$$v_i = \sum_j^m P_j d_{ij}^{-q} \qquad (1)$$

P_j is the population of each grid cell within a pre-specified window around cell *i* and *d* is the geographic distance between pairs of grid cells. There are *m* grid cells in a window and the exponent *q* can range between 1 and 2.

It is known that the rate of change in population differs according to the type of settlement. To account for that characteristic, the population potential for urban areas is modelled differently to rural areas (Jones, 2014). The innovation on this aspect in methodology presented in Figure 2 is that settlement type heterogeneity is accounted for by modelling population potential for types of settlements defined by a settlement typology created for South Africa instead of the common rural-urban segmentation which is not a well suited descriptor for the settlement fabric found in South Africa. The settlement typology consists of eleven settlement types (Van Huyssteen et. al, 2015), but for the purpose of the model, these were condensed into four groups. For each settlement type a square window is set and in Table 10 the values for the lengths that are appropriate for this study are specified. The window dimensions are based on the rank of each settlement type and are related to the spatial extent that is typical of that settlement type. Alternatively, the bandwidth can be quantitatively optimized based on population data (Jones, 2014).

Table 10: Window sizes used in this study and the corresponding settlement types

SETTLEMENT TYPE	VALUE	WINDOW SIZE (in KM)
CITY REGION	*1*	*80*
CITY, REGIONAL CENTRE	*2, 3, 4, 5*	*50*
SERVICE TOWN, LOCAL NICHE TOWN	*6, 7*	*10*
HIGH DENSITY, DENSE, SPARSE RURAL AREAS AND RURAL NODES	*8, 9, 10, 11*	*5*

A challenge with the basic potential formula (Eqn. 1) is the exclusion of self-potential as a result of zero distance when i=j. One solution, that is used in this study is to use the distance from the boundary to the cell-centre for i=j. An alternative that was also considered was to use other distance-decay functions such as the exponential and Gaussian distance decay function as presented in Equation (2) and (3) respectively which reduces to 1 for the zero distance.

$$v_i = \sum_j^m P_j^a e^{-bd_{ij}} \tag{2}$$

The additional parameters a and b in Equation 2 represent the importance of local characteristics and the impact of distance on the contribution of nearby populations to the centre cell's population potential. Both parameters can be estimated using historical population data (Jones and O'Neill, 2013). The Gaussian distance decay function is commonly used in deriving the weights in geographic weighted regression (Fotheringham, 1981). The population potential model defined using this function is:

$$v_i = \sum_j^m P_j^a e^{-0.5\left(bd_{ij}\right)^2} \tag{3}$$

The additional parameters a and b represent the importance of local characteristics and effective distance bandwidth, similar to Equation 2.

With the potential model, national and subnational population projections can be disaggregated, but for brevity in Section 5 of this report, only the grid-level population projections which were downscaled from the district-level projections (based on a cohort-component demographic model) are presented. The gridded population potential surface is used to allocate projected population change at grid-level for settlement types ranging from city regions to high density traditional areas. The projected population at time $(t+1)$ from time t within each grid-cell i can be obtained from aggregate-level (national/municipal) population change $\left(P_N(t+1) - P_N(t)\right)$ as follows:

$$P_i(t+1) = P_i(t) + \left(\frac{v_i(t)}{\sum_{j=1}^N v_i(t)} \times \left(P_N(t+1) - P_N(t)\right)\right) \tag{4}$$

According to Jones (2012), the potential term which is used as a weight in Equation (4) is reduced from a term that would have required knowing the potentials at time $(t+1)$ by assuming the following mathematical equivalence,

$$\frac{v_i(t+1)-v_i(t)}{\sum_{j=1}^N (v_i(t+1)-v_i(t))} \approx \frac{v_i(t)}{\sum_{j=1}^N v_i(t)} \tag{5}$$

With the current increasing rate of urbanisation and minimal economic opportunities in deeply rural areas, allocating population growth using the potential surface seems implausible. These areas are anticipated to stagnate or decline in terms of population size, whereas the potential model is biased towards positive population change. Adding parameters to the potential function is one way in which declining population can be accommodated. In this study, population decline was incorporated at the demographic model level where certain municipalities were projected to have declining population sizes based on certain long-term social and economic scenarios. The disaggregation model in these sparsely rural areas was switched from the potential model to a *constant share of growth* (CSG) model (Wilson, 2015).

The CSG model distributes projected/forecasted population at some aggregate level (e.g. national or municipal) to grid cell i based on that cell's share of growth (g_i) during the base period t such that,

$$P_i(t+1) = P_i(t) + \left(g_i \times \left(P_N(t+1) - P_N(t)\right)\right) \quad (6)$$

Like the potential model, the CSG required aggregate-level population change projections/forecasts to be produced independently. Caution against this model is that it can generate implausible forecasts when the direction of change in population at the aggregate level is different to the direction of change at grid-cell level during base period. One can expect this effect to be reduced by considering subnational projections rather than national.

4.4 Preparation of the geospatial mask as a base dataset

When downscaling population projections to a high resolution grid, an important consideration is that population is not allocated to areas that are not habitable or where people are not allowed to live. In this study, the exclusion of such areas was achieved through geospatial masking. The process of creating a geospatial mask considered locations of protected nature and surface water, settlement types and current population locations, as well as elevation and the slope. Specifically, the geospatial mask had six input layers, namely, nature reserves, surface water, elevation, slope, and dwelling type and population from the SPOT building dataset (Figure 9).

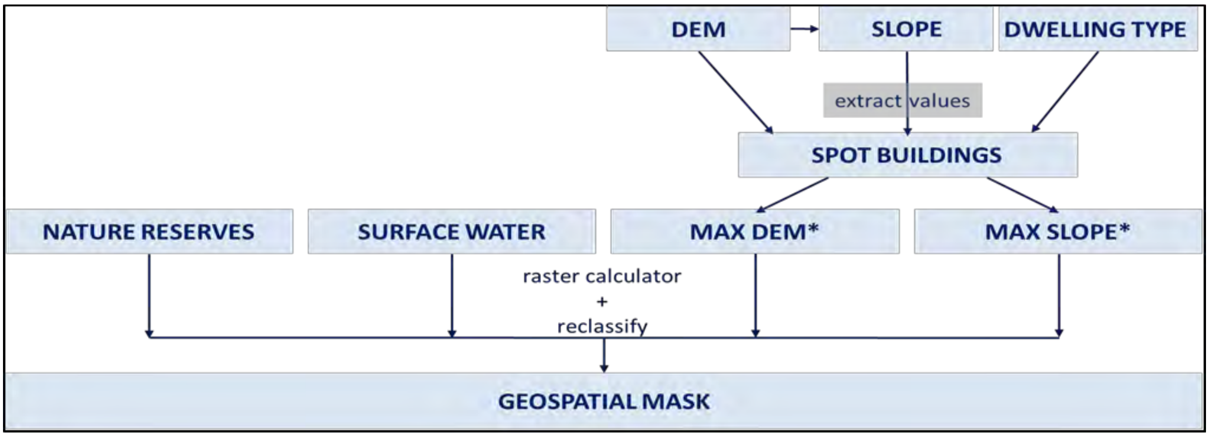


Figure 9: A conceptual model of the geospatial mask

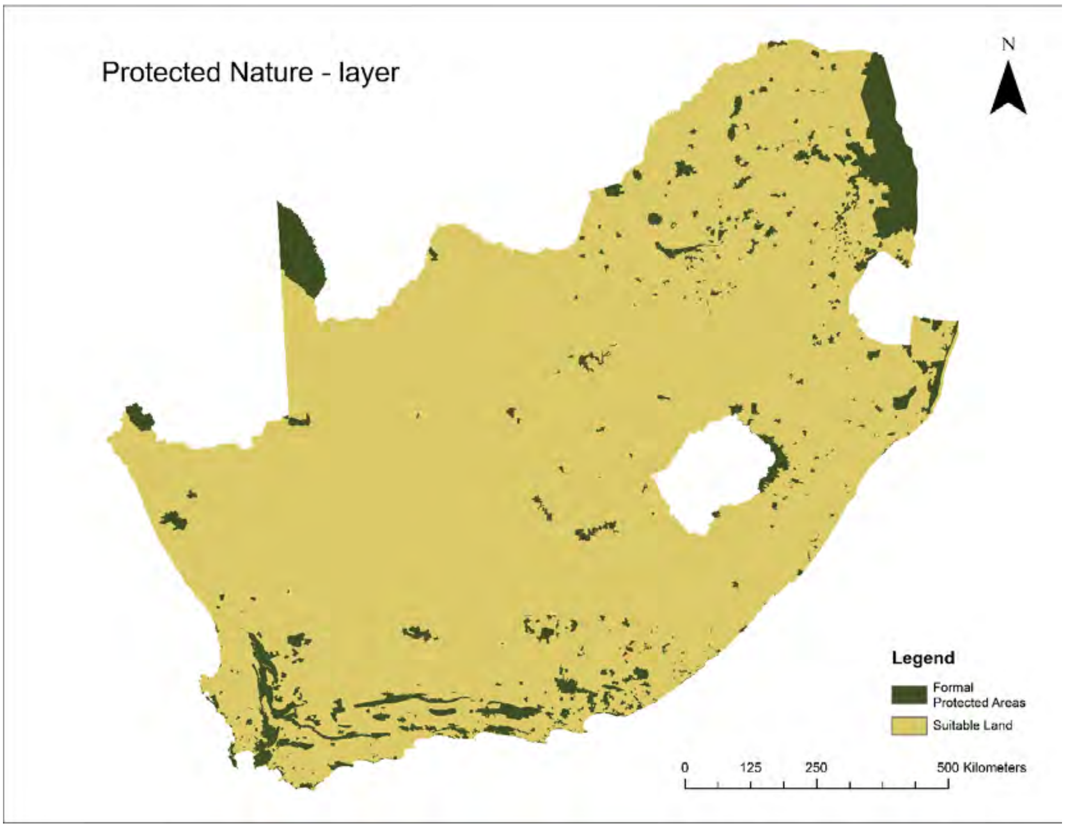


Figure 10: First input layer: Formal protected nature

The first input layer was a shapefile of the natural parks, accessible via the website of the South African National Biodiversity Institute (SANBI). This dataset includes all formal protected national park areas in South Africa (GIS Metadata). This shapefile was converted from polygons to a raster grid of 1 km by 1 km cells. The cells presenting the areas within the natural park were given value 0 and all others were given the value 1. If a cell has 50 % or more of its area in a formal protected area, it is classified as 0. Cells with less than half of their size or not at all in formal protected areas are classified as 1. Figure 10 shows this input layer, where all parks irrespective of their size were included and are shown in green on the map.

The second input layer used in the determination of areas suitable for settlement (Figure 11) was derived from the 2013-14 South African land cover raster and it represents all cells which have the biggest proportion of their area classified as surface water. This included cells classified as 'Water seasonal', 'Water permanent', 'Wetlands', 'Mines water seasonal' and 'Mines water permanent' were reclassified as value 0, while all other classes were assigned a value of 1.

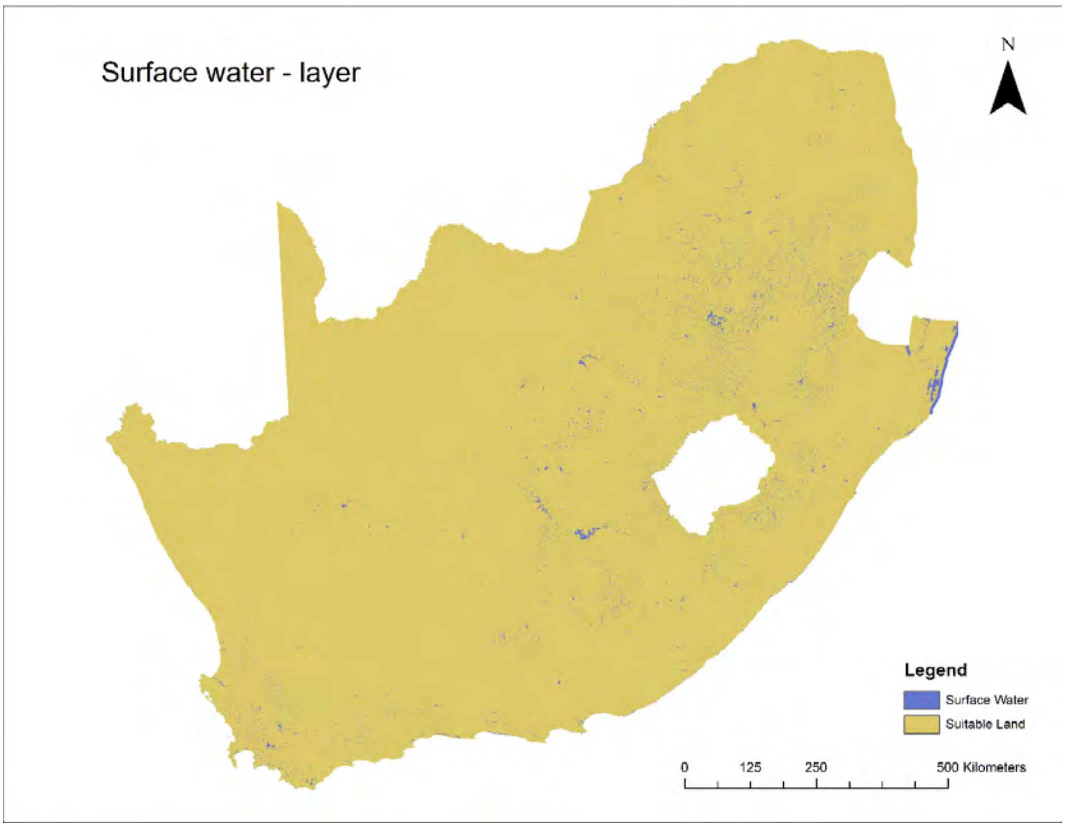


Figure 11: Second input layer: Surface water

The third and fourth input layers for excluding inhabitable areas for human settlements were elevation and slope which were calculated from the Digital Elevation Model (DEM) tiles that were downloaded from the United States Geological Survey (USGS) website (USGS & EROS Center, 2018). The tiles are ASTER imagery, with a resolution of 31 m by 31 m. Tiles necessary to cover the spatial extent of the country were mosaicked, resulting in an elevation raster for the whole of South Africa. The slope was calculated as the first derivative of the mosaicked elevation raster.

Initially maximum elevation and slope in already built-up areas were considered as benchmarks for exclusion of areas unsuitable for building settlements based on the assumption that this would be a reflection of standards set by the building industry. This was done by extracting the elevation and the slope of every point in the SPOT building dataset (Eskom, 2012). The SPOT building dataset consists of points for all locations of buildings in South Africa and include a count of people that live in each building. Next to the elevation and slope, the type of settlement is added as an attribute to the SPOT building dataset. The type of dwelling is derived from the 2011 census enumeration area dataset (StatsSA, 2011). The SPOT buildings are classified as urban, rural or traditional settlements. The maximum elevation and slope was based on the urban and rural settlements. Traditional settlements were excluded because they are not bound to any building regulations in South Africa which limits the ability to derive a general geometric morphological description for them.

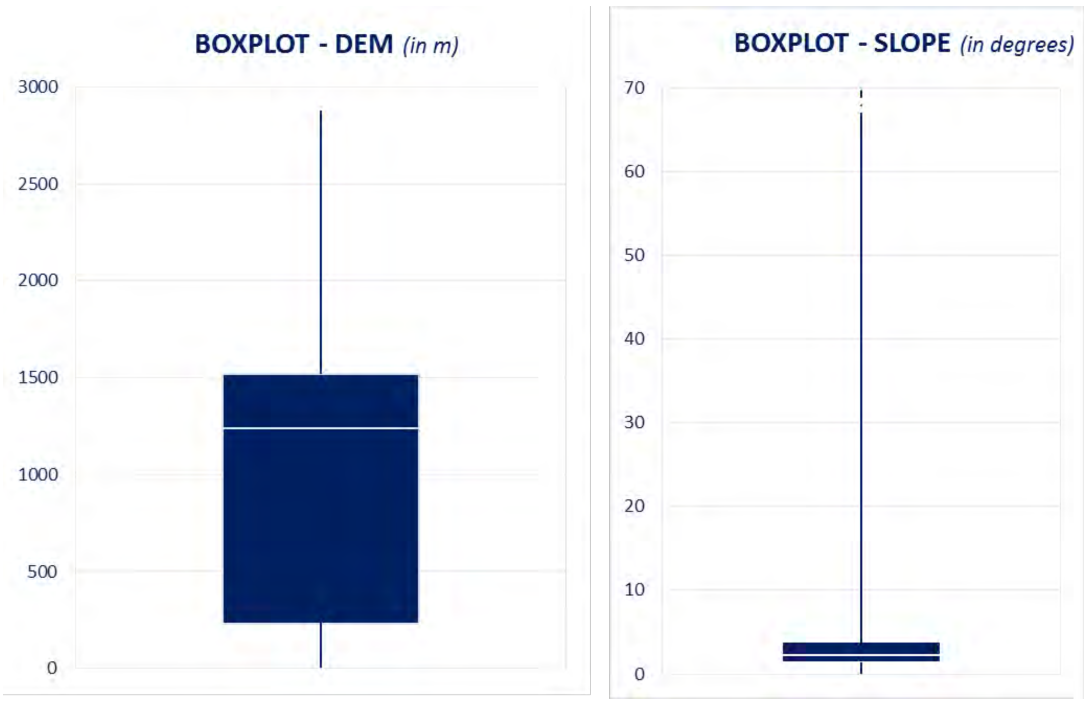


Figure 12: Boxplot describing the variability in elevation and slope derived from the DEM

The elevation boxplot in Figure 12 shows that about 75 % of the area has elevation that is below 1 500 m, but the maximum is nearly 3 000 m which indicates distribution asymmetry. The distribution of slopes exhibits a greater degree of skewness with the third quartile of nearly 4 ° (degrees) being very distant from the maximum of 70 °. Settlements that were found at heights above 2 700 m and slopes that are nearly 70 ° were viewed as extreme cases. Therefore, use of the maximum value criteria was aborted in favour of setting a threshold.

Elevation and slope thresholds were set as values where 99.9% of all urban and rural buildings were found. Table 11 shows the figures on which the box plots are based, including the threshold values at 99.9%, as well as the 99.5 and 99 percentiles. After defining thresholds for the maximum elevation and maximum slope, rasters were reclassified, assigning 0 to cells with raster values higher than the threshold and 1 to those with lower values.

Table 11: Statistics for the elevation and slope attributes from the 2011 SPOT building and DEM datasets

DEM (in m)	*URBAN-RURAL*	**SLOPE** (in degrees)
0	**MINIMUM**	0
2878	**MAXIMUM**	66.884
987.30	**MEAN**	3.147
1241	**MODUS**	2.314
615.96	**STANDARD DEVIATION**	2.814
1286	**IQR**	2.512
231	**Q_1**	1.362
1517	**Q_3**	3.874
1746	***99 %***	14.07
1771	***99.5 %***	16.307
1877	***99.9 %***	21.452

The threshold, when reclassifying the DEM raster to the third input layer, was set on 1 877 m and the result is shown in Figure 13. For the DEM raster, the map shows that the chosen threshold was high and there was only a small area restricted from future population growth based on the elevation.

The threshold for the slope raster was set to 21.452 °, as shown in Figure 14. Although this raster doesn’t restrict very large areas, this raster has very fine detail and shows the advantage of the fine scale of the final geospatial mask.

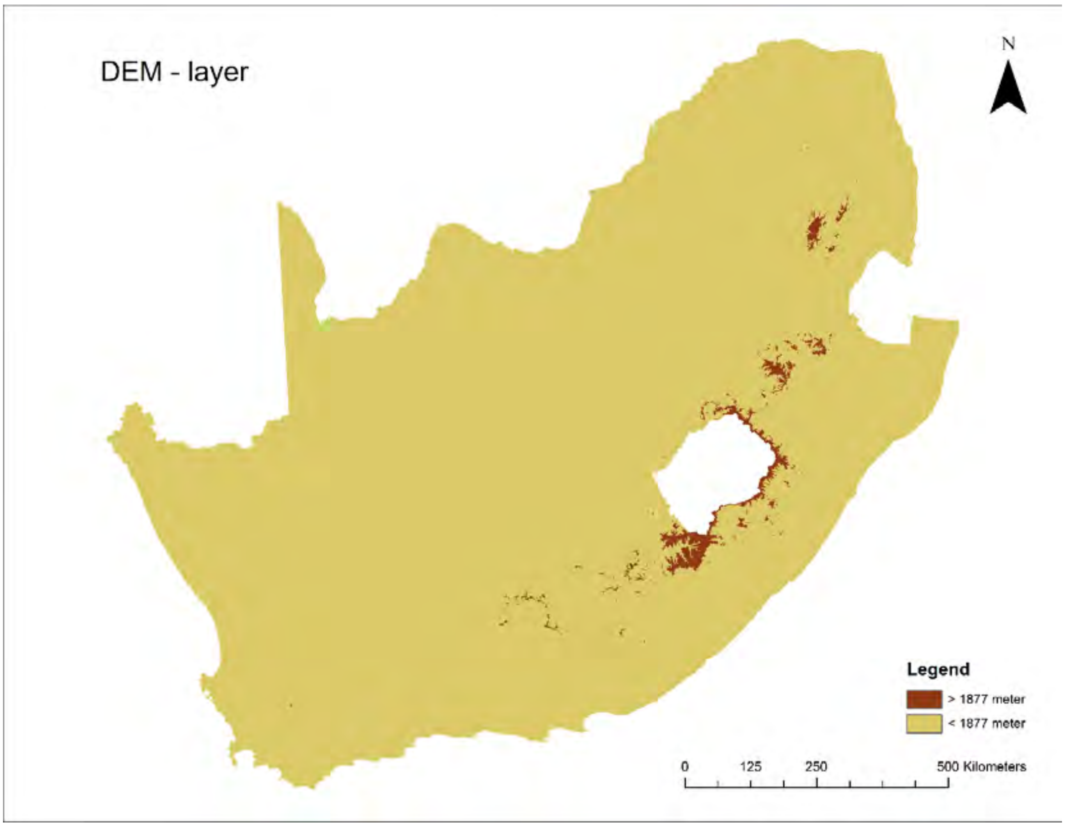


Figure 13: Third input layer: Elevation from the 30 m ASTER DEM

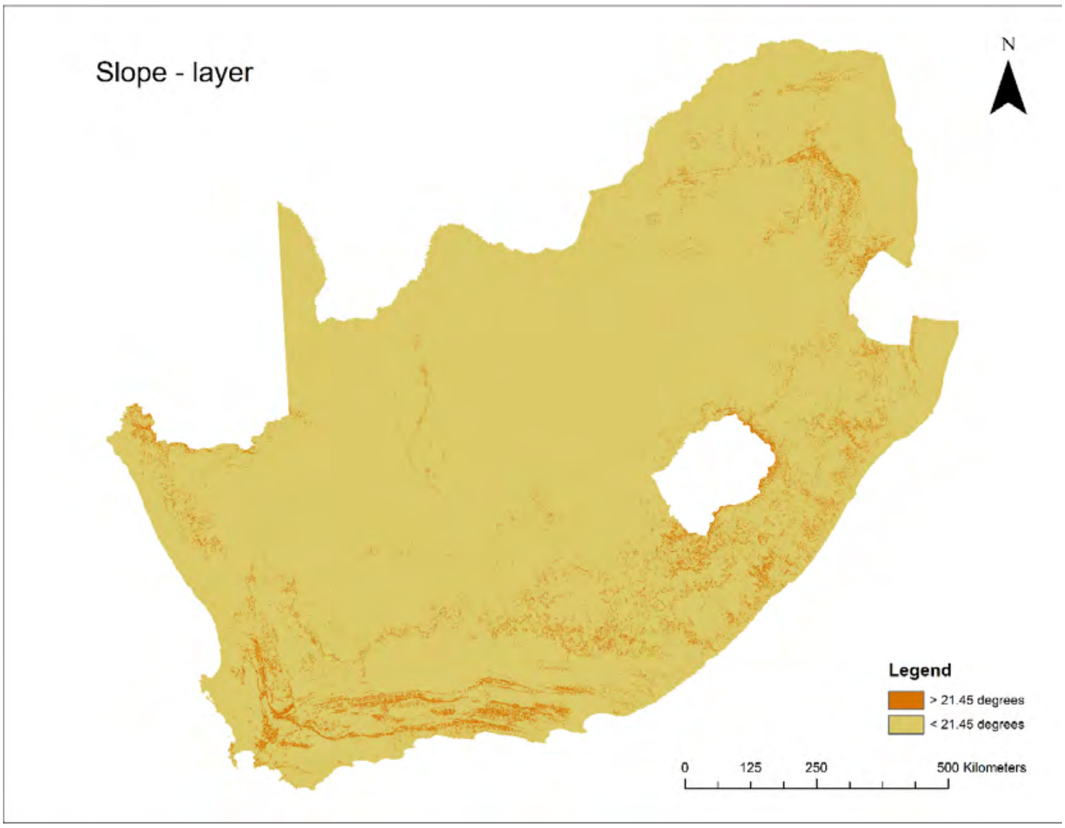


Figure 14: Fourth input layer: Slope from the 30 m ASTER DEM

The final result was created by adding the four rasters and reclassifying the output of the raster calculation. All restricted areas are combined and classified as 0, in Figure 15 called ‘Geospatial Mask’. The cells in the final raster with value 1, called ‘Suitable Land’ in the legend, do not have any one of the features restricted by the input layers. Those cells are not in formal protected areas, do not contain any water bodies, are not on a higher elevation level than 1 877 m above sea level and are not on a steeper slope than 21.45 °. In any other case, cells containing any water bodies, or are in a formal protected nature area and on an elevation level of 2150 m, are restricted from future population residence by this geospatial mask.

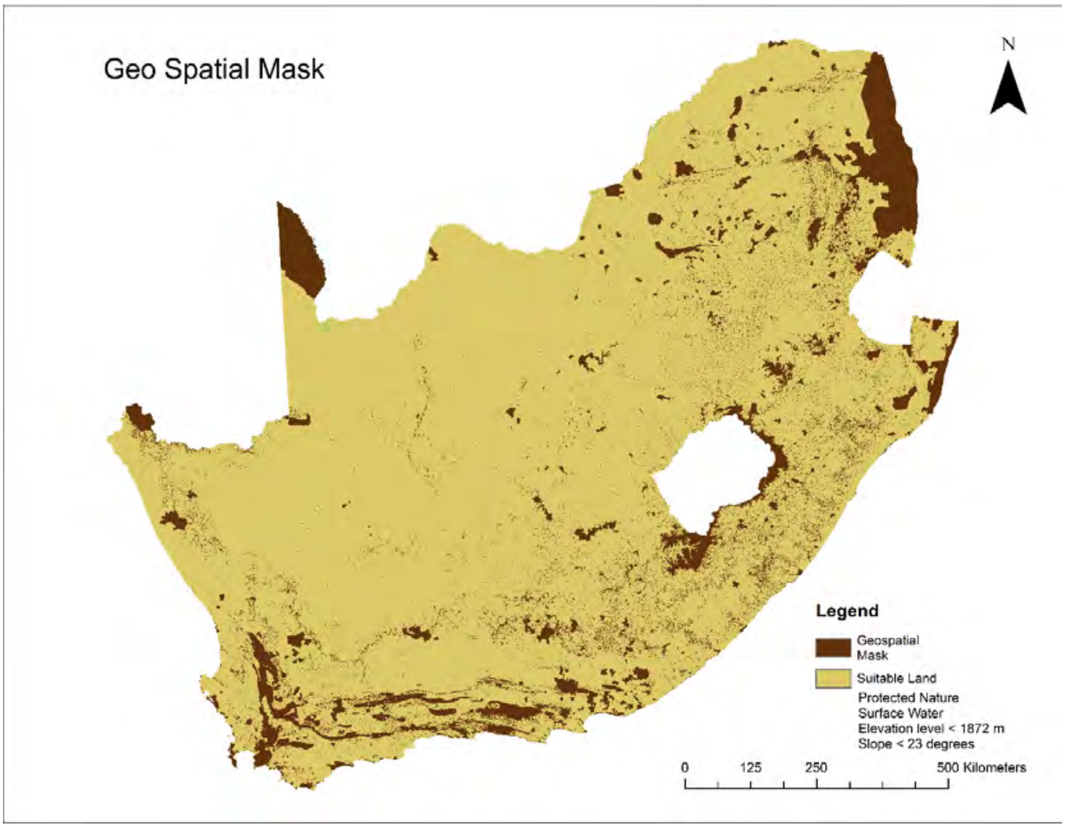


Figure 15: The final geospatial mask

5 SETTLEMENT-SCALE POPULATION GROWTH MODELLING RESULTS

The process of downscaling population projections produced by the demographic model consisted of implementing the potential model for grid-cells that were not masked and which belonged to a range of settlements from city regions to dense rural nodes. Subsequently, the constant share of growth model was used for the downscaling of projections in masked out areas with non-zero base year population and very sparse rural areas. The allocation in masked areas would still exclude water bodies and protected nature reserves, but areas that were excluded based on slope and elevation thresholds are typically the ones that had small numbers of people. The 2011 population which formed the basis of the potential grid was initially in the format of the SPOT building point dataset. It was converted into a raster grid of 1 km by 1 km using the dasymetric mapping method. Inputs that were used to delineate the application area for the potential model included the country's boundary and the geospatial mask whose creation was explained in Section 4.3., while the settlement typology defined the bandwidths for the allocation of potential. The population projections being downscaled are outputs of a demographic model where medium and high population growth scenarios were considered. The national projections are shown in Table 12.

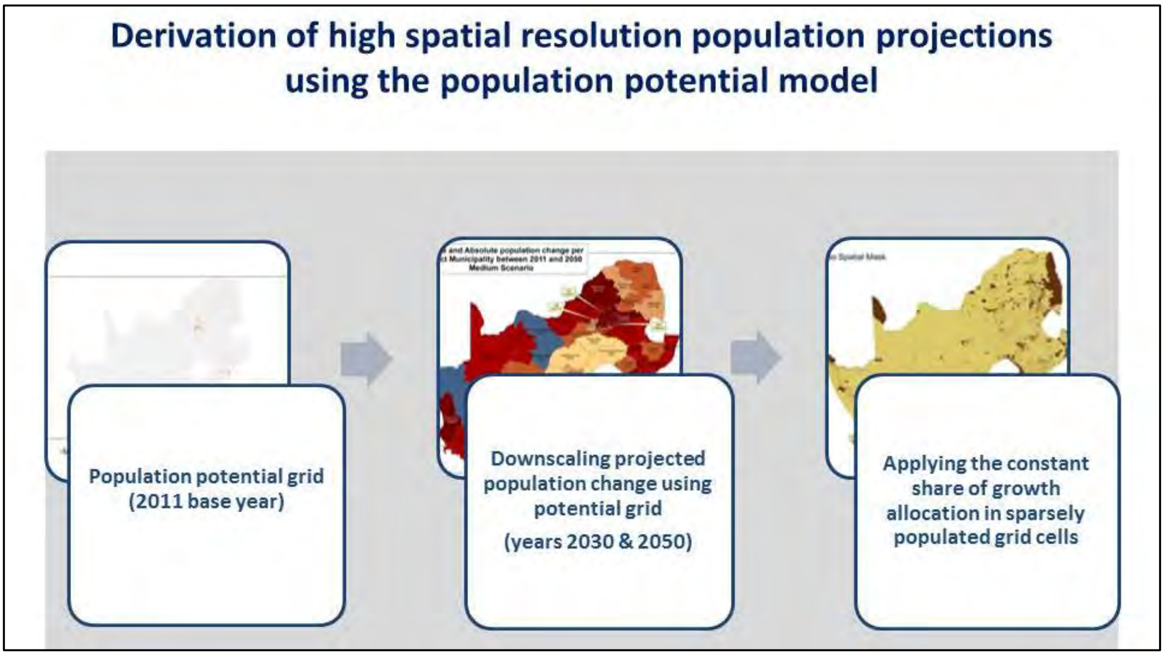


Figure 16: The process of downscaling aggregate-level population projections to 1 km grid resolution

In Sections 5.1 and 5.2, the steps taken to build the potential model are explained. The model building phase used the 2001 population data as a base and using national and municipal population totals, the gridded 2011 population data were derived. This downscaled 2011 dataset could then be compared to the actual 2011 gridded data to assess the validity of the downscaling method (Section 5.3). Section 5.4 consists of the population maps for the years 2030 and 2050, for both the medium and high growth scenarios, for 2011 as the base year.

Table 12: National demographic population projections

POPULATION PROJECTION	MED (nr. of inhabitants)	HIGH (nr. of inhabitants)
2011	*51460000*	*51640000*
2016	*55620000*	*55860000*
2030	*64890000*	*66900000*
2050	*74760000*	*79740000*

5.1 Moving windows

The first aspect considered for the potential model was bandwidth which is called window size in this report. The potential function is a distance-weighted summation of population counts. Figure 17 shows the weight matrix for the 5^2 km^2 window. We refer to window size according to the number of rows or columns, since the cells are all 1 km^2. This means that a 5 km by 5 km window is referred to as a 5 km window. When the window size is an even number, one extra row and column are added to create one single centre cell. The weight of each cell in a window is given by $\frac{1}{d_{ij}^2}$, where distance (d_{ij}^2) is the Euclidean distance from cell i to cell j. Half of the cell size, namely 0.5 km, is used for distance for the centre cell to avoid self-potential discontinuity which occurs as a result of zero distance for the centre cell. The window is moved across the study area such that every grid cell has a population potential value.

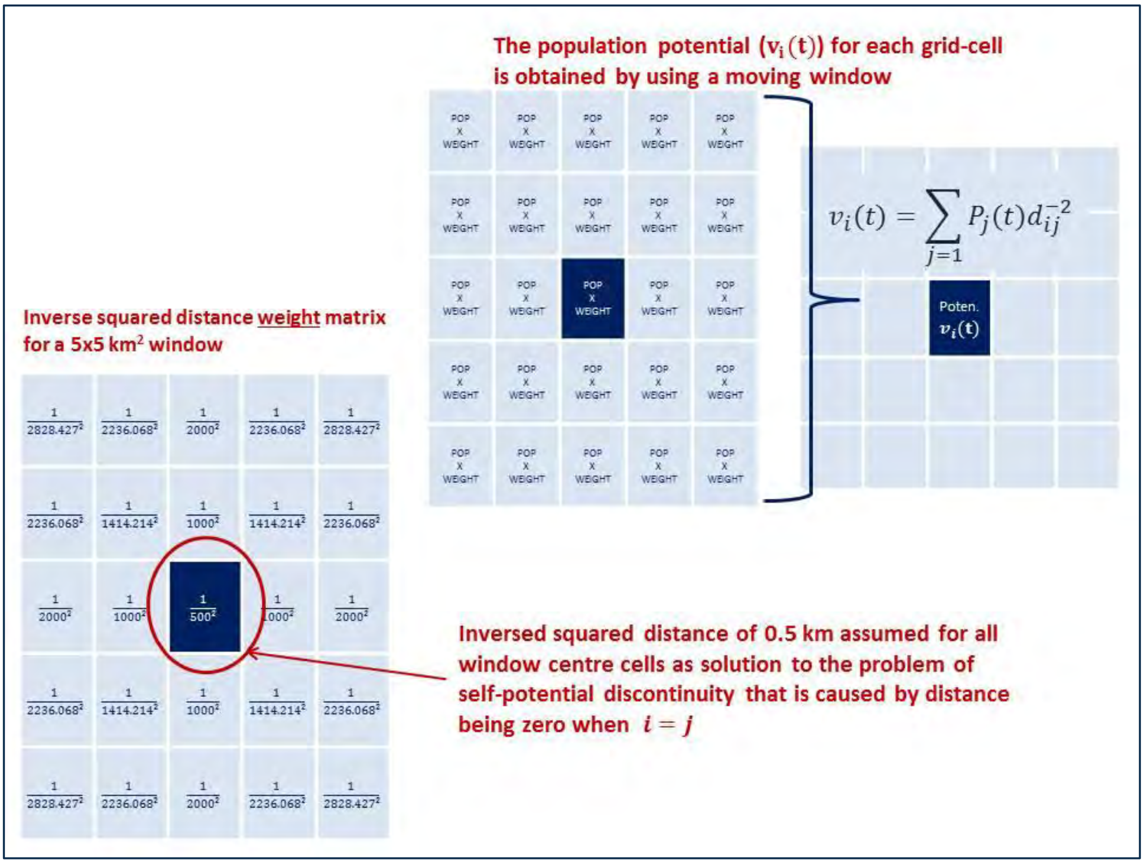


Figure 17: Calculating population potential for centre cell

For this study four bandwidths (window sizes) were considered and this resulted in four population potential grids as illustrated in Figure 17. Based on the settlement type (Figure 18) of each grid cell, the final potential grid was derived from the four settlement-specific grids, by choosing the potential value from a corresponding cell in the grid whose type corresponds to that of the cells.

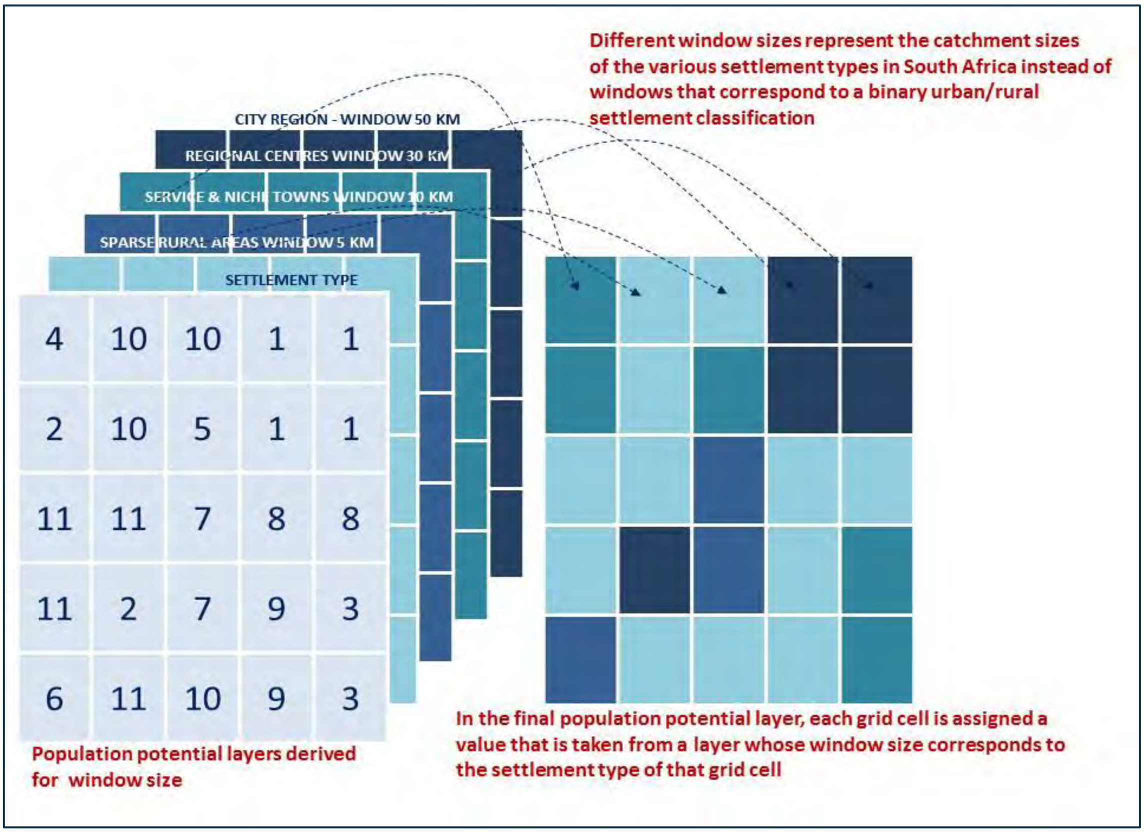


Figure 18: Assigning the right population potential according to settlement types

The computation of the population potential raster is done in R Studio and this script can be found in Appendix A. In the next section details of an experiment where different window sizes and distance-decay functions were tested are given.

5.2 Calibration experiments for the population potential Model

During the model building phase an experiment was set up using the 2001 population to calculate the grid-level potential for disaggregating the 2011-2001 population change. Questions that were addressed were:

- Which distance decay function yields better prediction accuracy?
- Is there a difference in results when using different sets of moving windows?

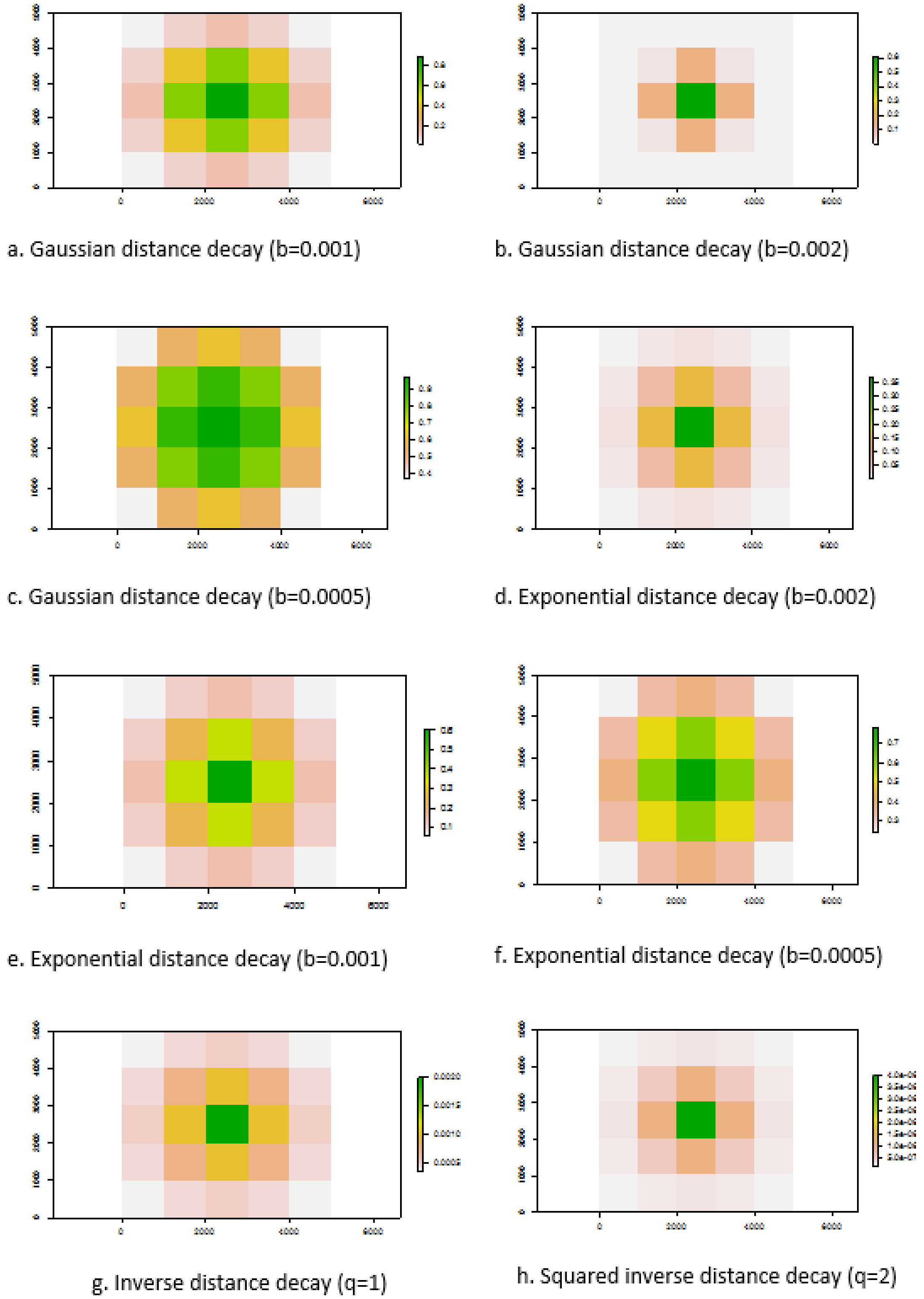
Three different distance decay functions (Eq. 1-3) were implemented and Figure 19 (a-h) shows the differences between them for a 5 km window. For the Gaussian and exponential decay functions the bandwidth must be on a similar distance scale to the data. In this case the grid cell resolution is 1 000 m, prompting our choices for the inverse bandwidth to be

1/2000 (0.0005), 1/1000 (0.001) and 1/50 (0.02). For the powered inverse distance function, powers 1 and 2 were implemented.

For bandwidths that are no bigger than grid cell size, the Gaussian decay is more rapid than the Exponential. For bigger bandwidths, the Gaussian decay is slower. Slower distance decay results in a smoother surface. Ideally the degree of smoothing needs to be limited to avoid allocation of population growth in unlikely areas. In both the Exponential and Gaussian functions, the centre cell weight approaches one as the bandwidth increases. Squared inverse decay weights are smaller (approaching zero) than the inverse decay weights.

In cases where the urban/rural segmentation is used separate urban and rural population potential surfaces would be generated with the final potential surface being a combined product. In this case settlement type based potential surfaces were defined by specifying different moving window sizes within which potential would be calculated. Details on window sizes used are contained in Figure 18. The window size seems to affect the degree of smoothing and distortions on the region's edge or boundary as illustrated in Figure 20 (a) – (b). Therefore, two moving window size sets were tested, where details of Set 2 are in Figure 18 and Set 1 consisted of 100^2 km^2, 50^2 km^2, 30^2 km^2 and 10^2 km^2 windows.

In summary, we found that the Gaussian distance decay function yielded marginally better results than the inverse distance weighting, but the challenge with this function is finding the optimal bandwidth. Further, given that the improvements are marginal, ease of use motivated our final choice of using the square-inverse distance decay function for our population potential model. A different set of moving windows was implemented and we found that there were marginal improvements for the inverse distance decay function but no difference for the Gaussian function. However, when assessing the effects on the boundaries, the boundary of the country is blurry in Figure 20 (b), which indicates that it is better to use the smaller sized window set.



a. Gaussian distance decay (b=0.001)

b. Gaussian distance decay (b=0.002)

c. Gaussian distance decay (b=0.0005)

d. Exponential distance decay (b=0.002)

e. Exponential distance decay (b=0.001)

f. Exponential distance decay (b=0.0005)

g. Inverse distance decay (q=1)

h. Squared inverse distance decay (q=2)

Figure 19: Implementing different distance decay functions for calculating population potential using a 52 km^2 window as an example

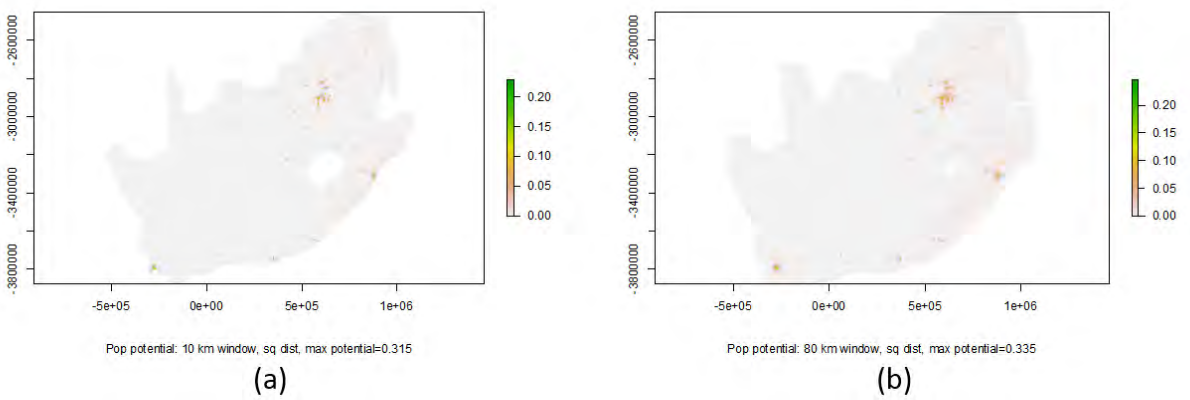


Figure 20: Edge or boundary effects and increased smoothing emerge as a result of increasing window size for calculating population potential. These effects are observed as boundary distortion and reduced granularity in (b) compared to (a).

5.3 Validating the population downscaling method

The downscaling method was validated by using gridded population data from 2001 to derive the potential grid and subsequently use the potential grid to disaggregate national and municipal level population counts from the 2011 census. The 2011 population grid derived using SPOT building data is considered the observed data. Both the 2001 and 2011 population grids were derived using a dasymetric mapping technique, transforming the spatial support from points to blocks. As a result of the change of spatial support processing, discrepancies from actual counts per block are expected. Therefore, accuracy metrics that were selected include *Mean Error (ME)* which is also known as *bias* and the *Unbiased Root Mean Square Error (URMSE)* which is a bias-adjusted measure of precision or deviation of the estimated gridded population ($\widehat{P_i}$) to the observed gridded population (P_i).

The error (E) and the relative error (RE) were also calculated for each grid cell to enable visual assessment mapping (Figures 21 and 22 show Absolute and Relative Error mapped) of the differences between the modelled and observed population. The error shows the over- or under-estimation of the population count for each cell, whereas RE provides an indication of how far, in percentages, the estimated population counts are to the observed counts. The closer the error measures (Equations 7-10) are to zero, the better the model predicts the population distribution.

$$E = \widehat{P_i} - P_i \quad (7)$$

$$RE = \frac{\widehat{P_i} - P_i}{P_i} \times 100 \quad (8)$$

$$ME = \frac{\sum_{i=1}^{N}(\widehat{P_i} - P_i)}{N} \quad (9)$$

$$URMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - \widehat{P_i})^2}{N} - \left(\frac{\sum_{i=1}^{N}(\widehat{P_i} - P_i)}{N}\right)^2} \quad (10)$$

Another metric that was used to evaluate the correlation between the estimated and observed population at the grid-cell level was the Spearman correlation coefficient (R). Table 13 shows that the downscaling of municipal level projections resulted in 85 % reduction in bias from 0.26 to 0.04 which is close to zero when compared to downscaling national projections. Looking at the pairwise correlation coefficient which increased from a high value of 0.92 to 0.95, one can conclude that the method achieves the objective of downscaling population projections with a high degree of accuracy.

Table 13: Results of the population potential disaggregation model for 2011 using the inverse square distance kernel and national population projections and local municipal projections as inputs

Description	2011 Pop	Abs Error (%)	Bias	URMSE	Corr. coeff. (R)	Summary statistics of empirical population distribution				
						1st Quart	Median	Mean	3rd Quart	Max
Actual pop	51754497	-	-	-	-	0	0	42.2	0	51140
Potential model (given national pop proj)	52025089	0.5	0.26	127.5	0.92	0	0	42.5	0	56520
Potential model (given LM pop proj)	51754497	0	0.04	126.8	0.95	0	0	42.2	0	58570

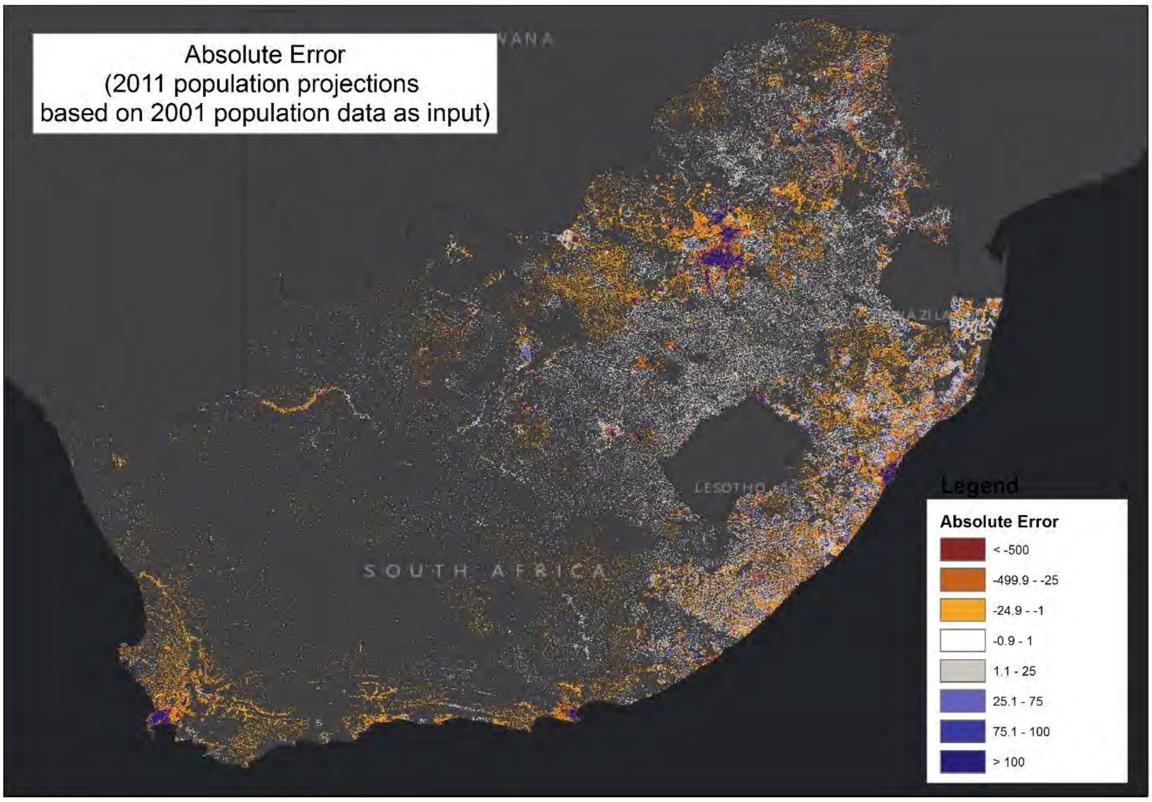


Figure 21: Absolute Error of 2011 population projections based on 2001 population data as base year input

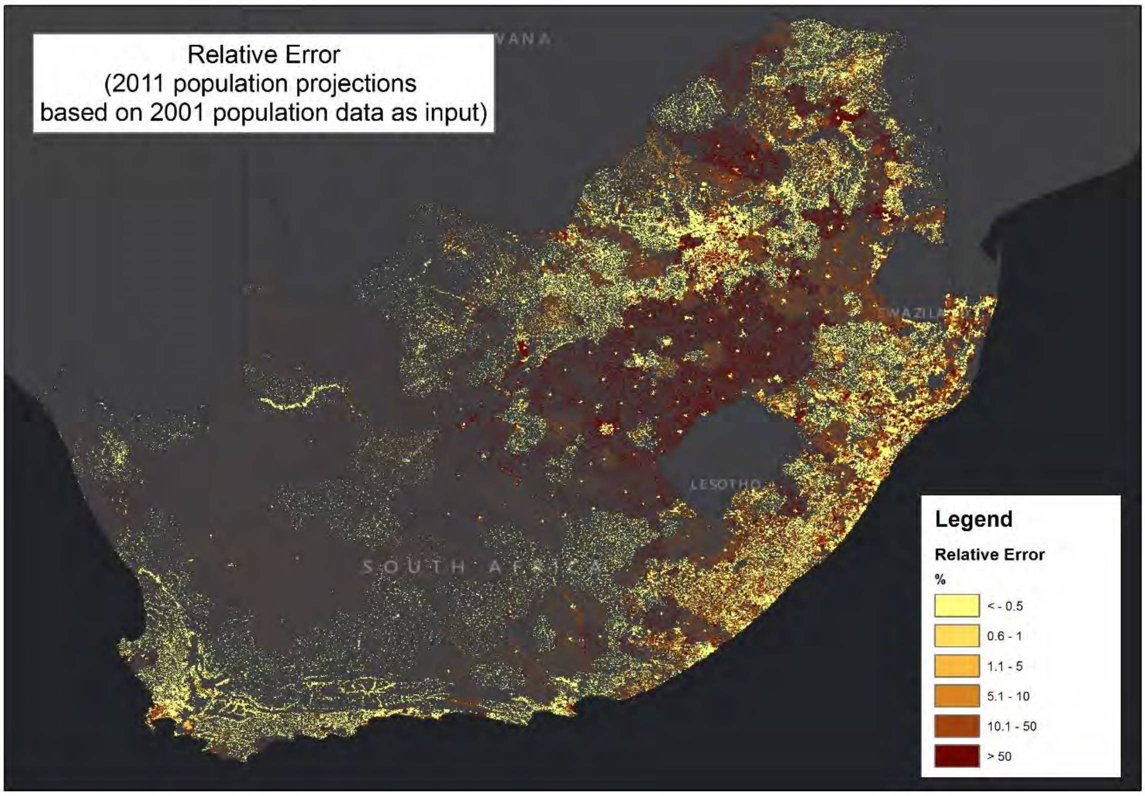


Figure 22: Relative Error of 2011 population projections based on 2001 population data as base year input

5.4 Downscaled population projections for 2030 and 2050

The final population potential grid is combined from the different grids created based on the settlement type and corresponding window sizes as discussed in Section 5.1. It is shown in Figure 23 and the four city regions are very clearly distinguished by their high population potential values. The Gauteng region attracts by far the most people and it is expected to grow even further in the future. There are smaller cities that show high population potential values, such as Upington in the Northern Cape and the cities along the east coast include Port Elizabeth, Durban and Richards Bay.

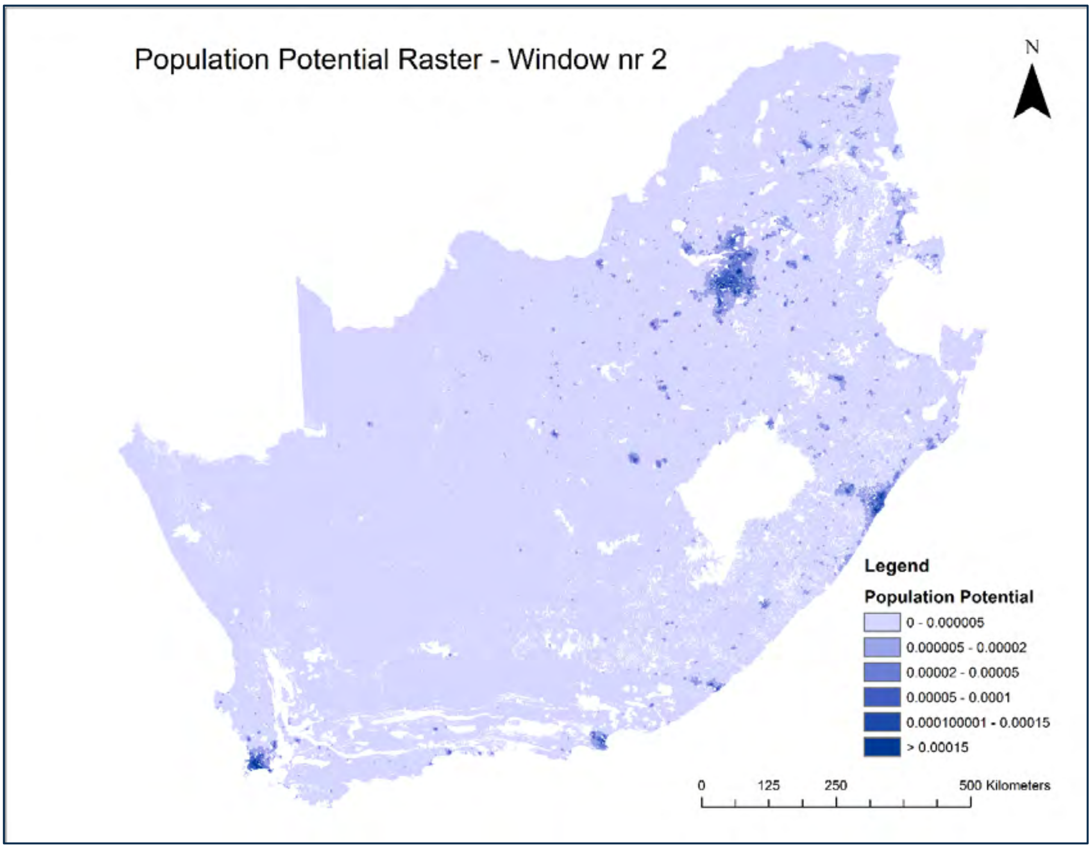


Figure 23: Population Potential Raster

5.5 Linking downscaled population projections to settlements

The 1x1 km population growth grids produced (Figure 24) were relocated back to the built-up settlement layer (see report on Objective 1 of this workstream) through

a) Converting the raster 1x1 km grids to a point layer
b) Selecting all points within 1 km from the built-up settlement layer

c) Joining (Spatial Join) the selected points to the closets built-up settlement (using the ‘closest function’ in the spatial join). The outputs are then a point layer indicating its closest linked built-up settlement
d) Creating a table using summary statistics through summing the population per built-up settlement
e) Joining the table with the built-up settlement layer through a unique ID. This was done for 2001, 2011, 2030 and 2050 for both the medium and high population scenarios including absolute growth, relative growth and general growth patterns. The outputs are shown in Figure 25
f) Linking this built-up settlement layer to the CSIR town typology (see report on Objective 1 of this workstream) for analyses/discussion purposes.

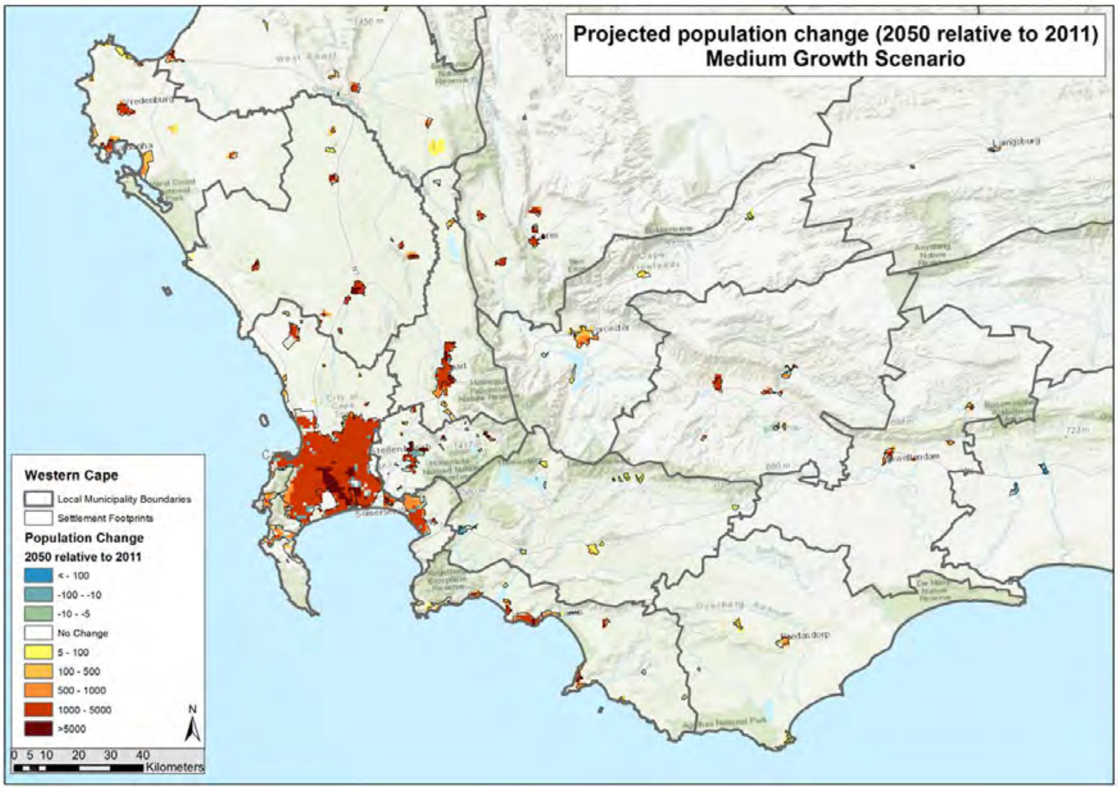


Figure 24: Population change

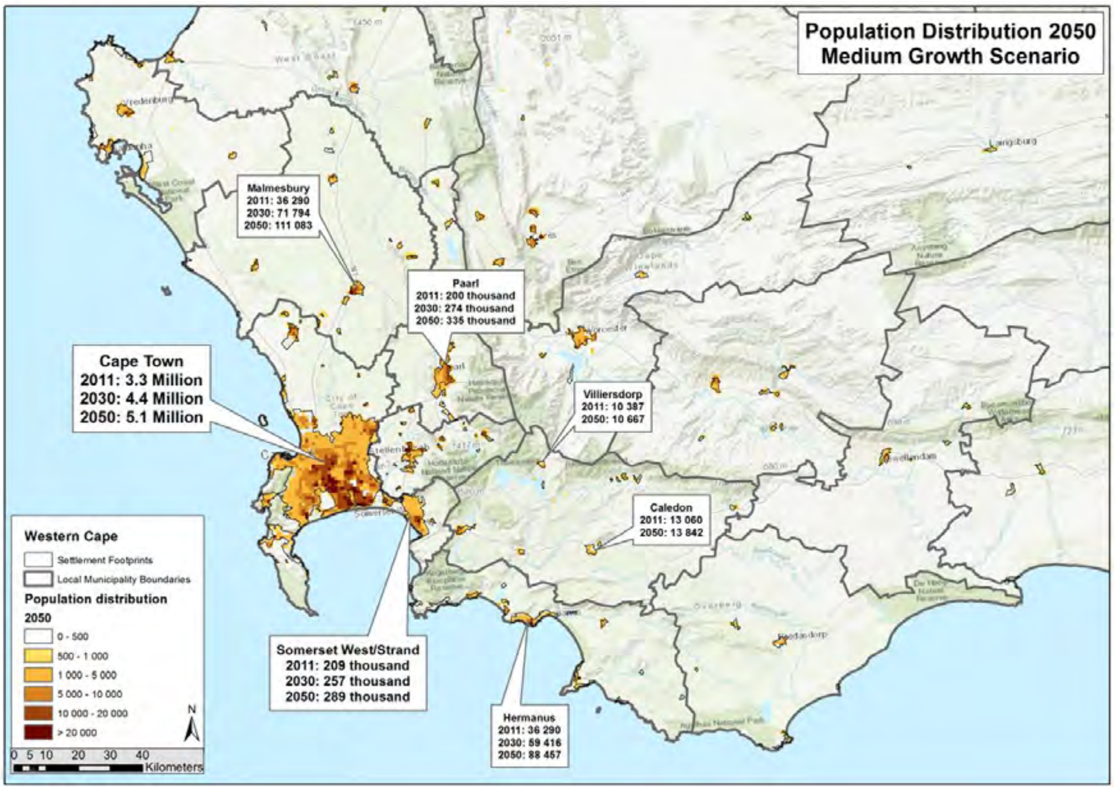


Figure 25: Linked population growth (1x1 km) to settlement built-up layer

6 PROJECTING THE FUTURE VULNERABILITY OF SOUTH AFRICAN SETTLEMENTS RESULTS

Population change (growth or decline) is an inevitable phenomenon. The world's urban population is growing and Africa specifically is urbanising at a rapid rate. South Africa is expected to follow this worldwide trend and experience high population growth and urbanisation, with current projections indicating an additional 19-24 million people to be added to the country by 2050, the vast majority of this growth to be added to cities and towns.

If this growth is not managed and planned for effectively, it will place an enormous amount of pressure on bulk infrastructure delivery, as well as having critical implications for national and regional policies and inter-governmental prioritisation efforts. This growth however also opens up the possibilities of designing our cities to be resilient. Adhering to design principles that would support resilience in our cities can open up pathways to change.

Figures 26 – 29 show that the vast majority of population growth will be centred in already urbanised areas, and specifically the eight metropolitan municipalities, which show the projected change in population from 2011-2030/50 for both the medium and high population growth scenarios. The metropolitan growth is expected to increase from 20.45 million (2011) people to approximately 32.5 million people (2050) increasing the percentage of South Africans occupying these spaces from 39.8% (2011) to 43.3% (2050). This means that 63% of all expected growth in South Africa will be located in the 8 metropolitan areas and Gauteng alone will account for 42% of all expected growth.

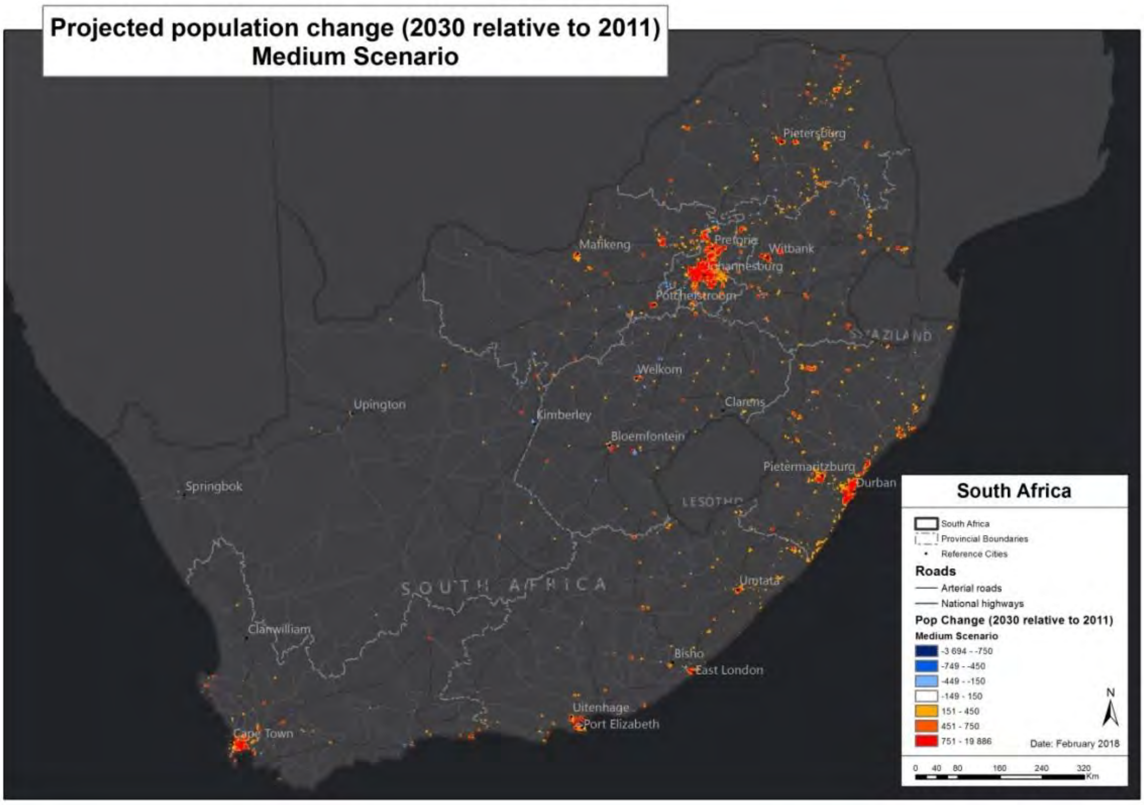


Figure 26: Population projection of 2030 on a 1 km² scale for the medium scenario

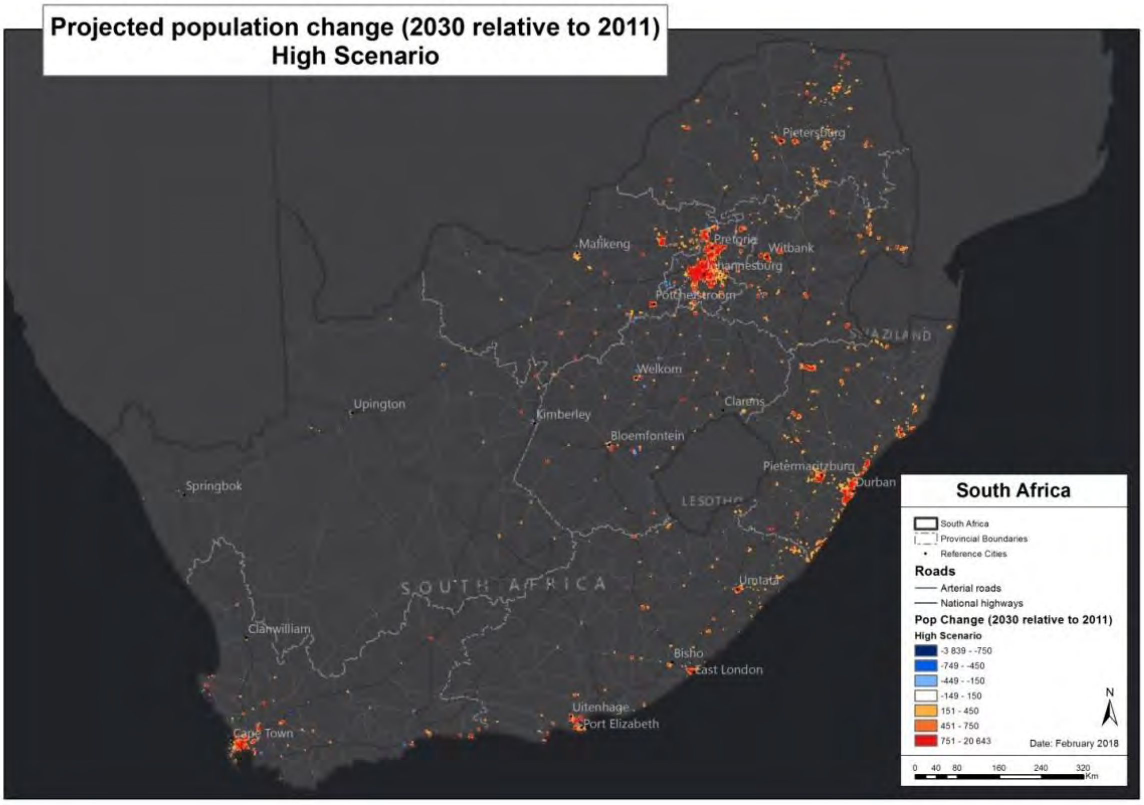


Figure 27: Population projection of 2030 on a 1 km² scale for the high scenario

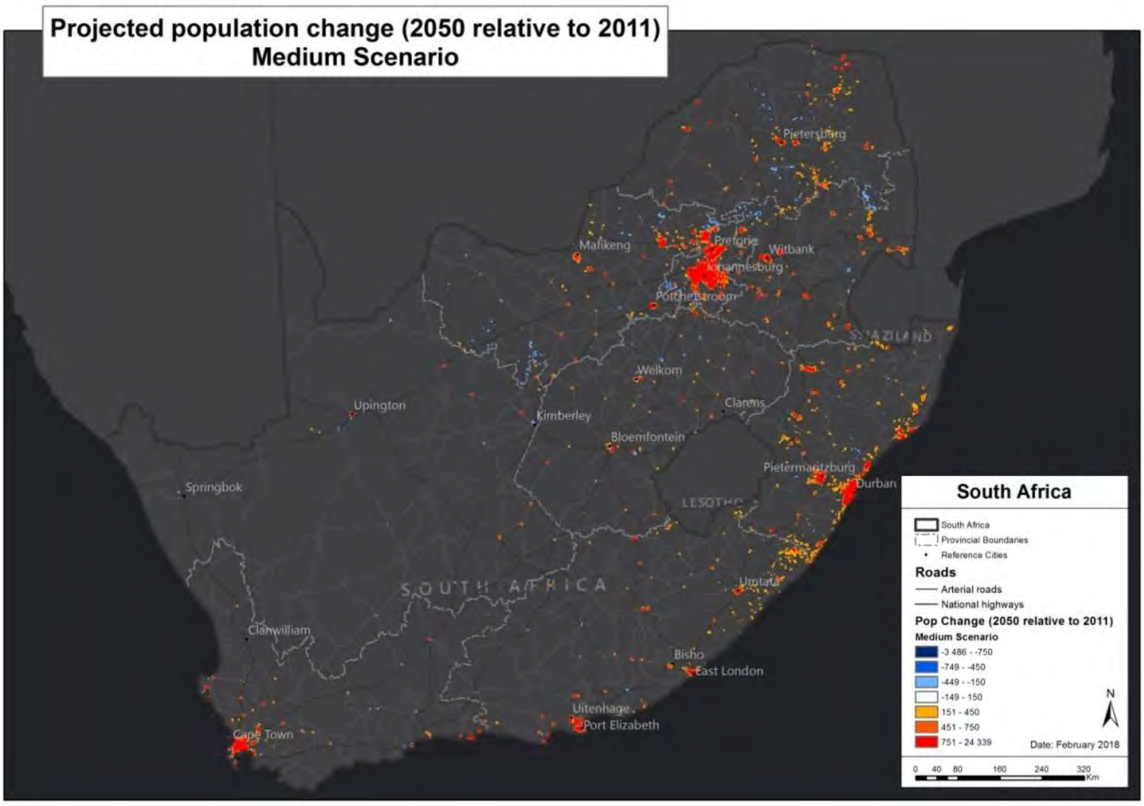


Figure 28: Population projection of 2050 on a 1 km² scale for the medium scenario

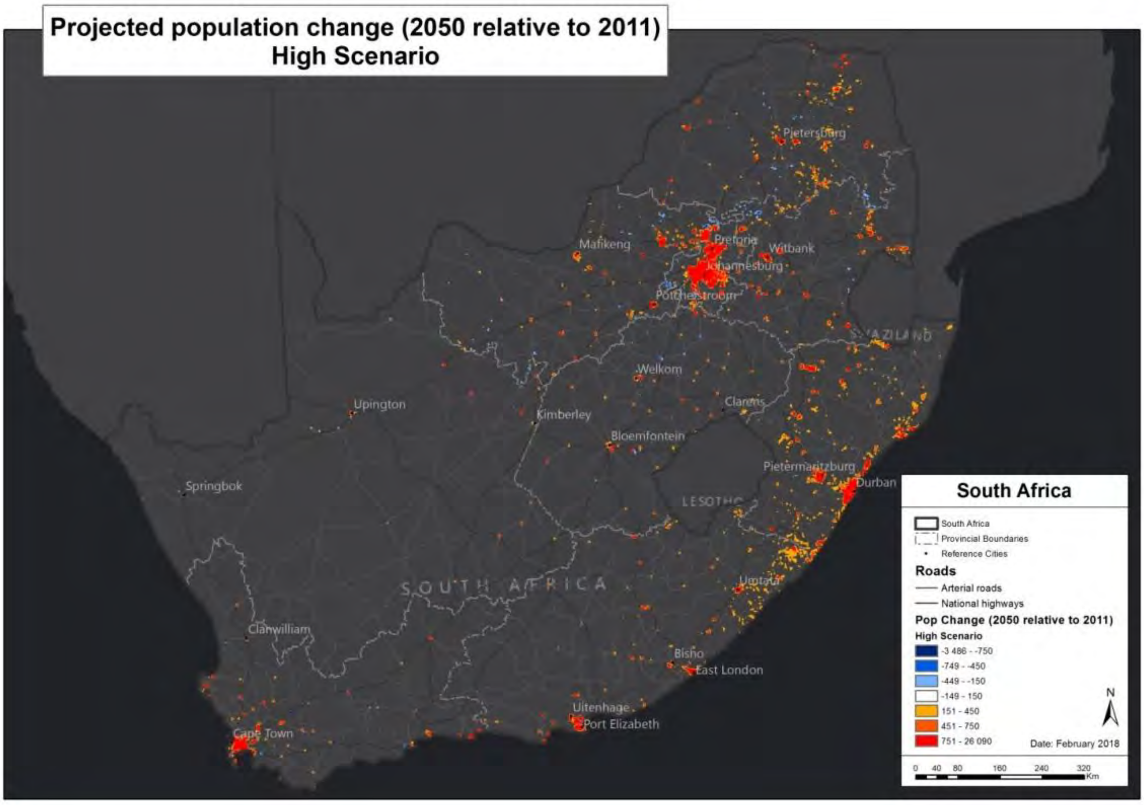


Figure 29: Population projection of 2050 on a 1 km² scale for the high scenario

Population growth and decline was further analysed for each of the 9 provinces according to the CSIR town typology.

Western Cape's population change narrative is given as an example:

- The population in the Western Cape is projected to increase by 2.7 million by 2050.
- 96% of this growth will be in City Regions (72%), Regional Service Centres (10%) and Service Towns (14%).
- The City of Cape Town is expected to grow by 1.8 million people, an increase of 50.7% from 2011, and accounting for 96% of the growth in Western Cape City Region.
- Of the 14% growth in Service Towns, 66% will occur in only 5 towns, namely Plettenberg Bay, Malmesbury, Hermanus, Ceres and Robertson. Service towns will see the fastest rate of increase (97% growth in the Western Cape). Plettenberg Bay, Malmesbury and Hermanus will become more influential, each expected to grow to more than 100 000 people, on par with Regional Service Centres such as Worcester and Vredenburg.
- Of the 10% growth in Regional Service Centres, 79% will occur in Paarl/Wellington, Vredenburg, George and Worcester. Knysna and Mossel Bay will see steady year on

year increases to 2050, while Oudtshoorn will continue to decline by as much as 30% in 2050 based on 2011 figures.

The full narrative for the whole country and all the provinces can be viewed as a story map on the Green Book website.

7 CONCLUDING REMARKS

Urban models are mainly computer-based simulations that are used to evaluate, explain, explore and predict spatial events and theories regarding spatial location and interaction between land uses, population, employment, transportation and other related activities (Batty, 2009). Given the complex nature of spatial systems and processes, modelling inherently presents fundamental challenges, whether in extrapolating current socio-economic trends or projecting changed conditions into the future. Socio-economic scenarios are, of necessity, based on assumptions, and in the context of spatial and temporal population distribution, a model will result in more or less accurate results based on the type of model used and the underlying assumptions that inform it (Gaffin, Rosenzweig, Xing & Yetman, 2004). The application and performance of growth models is dependent on both the quality and scope of the available data, as well as the overall understanding of underlying processes represented in the model (Batty & Howes, 2001).

In this study a geospatial methodology was developed for downscaling aggregate level population projections into a high spatial resolution gridded dataset using a combination of a potential gravity model and a constant share of growth model for grid-cell allocation of population counts. As part of the process, new input datasets were created, namely the settlement typology and the geospatial mask to account for the variety of settlement types in the country and to constrain growth to areas which are plausible for settlements. Recently gridded population datasets for the world with similar grid resolution as that chosen for this study were produced. One of the ways in which this work will be furthered will be through a comparison study between the 2011 population grid produced in this study and the one from the global dataset. Another topic being considered for inclusion is the incorporation of economic spatial trends in the downscaling method. A first exploration of economic trends was performed and the outcome of that exercise is included as Appendix B.

8 NEXT STEPS AND FUTURE RESEARCH INTERESTS

Further refinement of the model is currently being explored. It is envisioned that through this further research, the model will be expanded to explicitly take into consideration the economy as a major population pull/push factor. This work is being undertaken by Kathryn Arnold for her MSc Geomatics thesis, in which she will investigate and quantify the correlation between population growth and economic development. The basis for this research is highlighted in Appendix B.

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11 APPENDIX B: THE POSSIBILITY OF INCLUDING ECONOMIC SCENARIOS TO REFINE THE SETTLEMENT-SCALE POPULATION GROWTH MODEL

Population growth has multiple drivers. Since the gravity model is based on the current population and its distribution, adding other drivers would improve the modelling output. Before implementing other drivers for population growth, their exact influence needs to be tested.

In this research, a relation between economic growth and population growth on settlement level was explored. *The question being addressed is how big is the influence of the economic growth on the population growth?* The settlement types of city region, city, regional centre, service town and local niche town were used for the analysis. From the meso-zone data set, the polygons with these settlement types were selected. Next, population data from 1996, 2001 and 2011 are added as an attribute to these polygons. The sum of all SPOT building point inside each meso-zone were added as an attribute for each year by using the tool Spatial Join in ArcMap.

For the economic data the gross value added (GVA) data were used in 9 different subclasses. The subclasses were defined by the Standard Industrial Classification of all Economic Activities (SIC). A detailed point dataset of the SIC-codes 1-4 and SIC-code 6-10 was available for South Africa. SIC 9 and SIC 10 were aggregated as SIC 9. Table 14 shows description of each SIC-code.

Table 14: Standard Industrial Classification of all Economic Activities

SIC-CODE	DESCRIPTION
SIC 1	*Agriculture, forestry and fishing*
SIC 2	*Mining and quarrying*
SIC 3	*Manufacturing*
SIC 4	*Electricity, Gas and Water supply*
SIC 6	*Wholesale and retail trade*
SIC 7	*Transport, Storage and Communication*
SIC 8	*Financial Intermediation, Insurance, Real Estate, and Business Services*
SIC 9&10	*Community Social and Personal Services, Government Services*

These point data sets contained the fraction of the total GVA of the country per SIC-codes per point. For the corresponding years, the data were added for each SIC code using the Spatial Join tool. Next, from these absolute numbers both the population growth and the economic growth for were calculated in percentages. The growth was calculated for three periods, for 1996 to 2001, for 2001 to 2011 and for 1996 to 2011.

The relation between these variables was assessed through a correlation metric. To avoid making assumptions about the distribution of the data, a non-parametric metric was chosen, namely the Spearman correlation coefficient for the relation at the meso-zone level between the growth in each SIC-code and the population growth. Meso-zones are administrative boundaries, only used to map geo-information on a more detailed level. Since the meso-zone level might be too small to detect any relations, the same relations are being tested on a local municipality level (Table 16).

Table 15: Spearman's ρ and R^2 on meso-zone level, but summarized for each settlement type

PER MESO ZONE	City Region		City		Regional Service Centre		Service Town		Local Niche Town	
	ρ	R^2	ρ	R^2	ρ	R^2	ρ	R^2	ρ	R^2
SIC1	0.0602	0.0036	-0.079	0.0063	0.0252	0.0006	0.0656	0.0043	-0.0632	0.0040
SIC2	0.06	0.0036	-0.194	0.0380	0.1766	0.0311	0.2295	0.0526	-0.0461	0.0021
SIC3	0.1634	0.0267	-0.114	0.0132	0.0672	0.0045	0.1579	0.0249	-0.0221	0.0004
SIC4	0.0048	0.00002	0.068	0.0047	0.0574	0.0033	0.0179	0.0003	0.0108	0.0001
SIC6	0.0955	0.0091	-0.1255	0.0157	0.109	0.0118	0.1919	0.0368	0.0485	0.0023
SIC7	0.2911	0.0847	0.0245	0.0006	0.156	0.0243	0.3101	0.0962	0.0185	0.0003
SIC8	0.1939	0.0376	0.2608	0.0680	-0.0057	0.00003	0.0332	0.0011	0.1678	0.0281
SIC9	0.0093	0.00008	0.1612	0.0260	0.1077	0.0116	0.1271	0.0161	0.0749	0.0056

The Spearman's correlation coefficient ρ in Table 15 shows without any exceptions very weak relations between each of the settlement and the different economic categories. This implies that economic growth has very little influence on population growth. None of the R^2 metrics were higher than 0.1, which implies that the economic growth explains less than 10% of population growth. That means that over 90% of the population growth can be explained by other factors. The relationship was tested again on larger scale areas, namely local municipalities. These results are shown in Table 16.

Table 16: Spearman's ρ and R^2 on local municipality level, but summarized for each settlement type

PER LOCAL MUNICIPALITY	City Region		City		Regional Service Centre		Service Town		Local Niche Town	
	ρ	R^2	ρ	R^2	ρ	R^2	ρ	R^2	ρ	R^2
SIC1	0.0459	0.0021	0.0493	0.0024	-0.016	0.0002	0.0982	0.0096	-0.0558	0.0031
SIC2	0.0785	0.0061	-0.0897	0.0080	0.2322	0.0539	0.3223	<u>0.1039</u>	-0.0266	0.0007
SIC3	0.0503	0.0025	-0.1288	0.0165	-0.036	0.0013	0.1317	0.0170	-0.0264	0.0006
SIC4	-0.0875	0.0076	0.1457	0.0212	0.0402	0.0016	0.0065	0.00004	0.0230	0.0005
SIC6	0.1520	0.0231	0.0287	0.0008	0.0871	0.0075	0.3357	<u>0.1127</u>	0.0410	0.0017
SIC7	0.3166	<u>0.1002</u>	0.0303	0.0009	0.1666	0.0277	0.3707	<u>0.1374</u>	0.0354	0.0012
SIC8	-0.0514	0.0026	0.2453	0.0601	0.0622	0.0038	0.1809	0.0327	0.1818	0.0330

The result of this second correlation test shows a slightly stronger relation between the different economic sectors and the population growth, but still all relations are very weak. Only the four underlined R^2-values explain a little more than the set threshold of 10%. And the corresponding Spearman's ρ show again a very weak relation between the economic growth and the population growth for each SIC-codes and each settlement type on local municipality level.

Due to the weak association between GVA growth as an indicator for the influence of the economy on population growth, the possibility of including a parameter for economic trends in the population potential model was not explored further.