



GREENBOOK
adapting settlements for the future

SURFACE WATER & WATER SUPPLY RISK FOR SETTLEMENTS

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supply risk, while the unshaded area shows a potential overall reduction in water supply risk.
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1 INTRODUCTION

Water supply is considered to be one of the principal mechanisms for the realization of climate change impacts on society (UN Water, 2010). This is due to the fact that water availability is directly related to changes in precipitation, temperature and evaporation. In addition, water is a fundamental requirement for life and critical to most, if not all, requirements for livelihood support, economic growth and development. Most studies of the potential impacts of climate change on future water resources focus on the impacts on precipitation and streamflow only. The results of these studies are often inconclusive due to the high levels of uncertainty not only in the climate models, but also in the models used to interpret the potential impacts on streamflow and water supply (Garcia et al., 2014).

Very few of these studies recognize the fact that water resources engineers have been dealing with uncertainty as a critical component of infrastructure planning since the Egyptians started planning for the seasonal flooding of the River Nile. In an era when the importance of considering anthropogenic impacts on climate change is widely accepted, it is equally important to consider the role of humans in addressing issues of uncertainty and variability in water supply through water resources planning and infrastructure design that may already provide some resilience to future climate change impacts.

Climate change is also critical in terms of water supply in South Africa (DWA, 2013). The objective of this study was to determine a first order estimate of the future urban water supply risk for settlements across South Africa, taking in to account both population growth and exposure to climate change by 2050. The results of this study will enable the public and private sector to understand the potential risks that each town faces in the future as well as what general adaptation and mitigation measures can be implemented to reduce each town's risk.

For this study we adopted a bottom up, risk-based approach to determining the relative risks faced by different towns due to the combined impacts of climate change and population growth. This was limited to surface water supply and did not consider associated risks to groundwater supply, although these could be easily integrated into the proposed risk framework. The study also does not take into account the highly complex and interconnected nature of both the natural and man-made water distribution system. This required more detailed assessment of individual towns, catchments and/or bulk water distribution systems. It is highly recommended that this, more detailed climate change risk assessment be done,

particularly for the towns identified as being of high risk, as these more detailed studies may reveal additional resilience, or even elevated risks to these specific towns.

The study also looked only at changes in the mean annual runoff and the associated impact on the average annual water supply to each town. It did not address the more complex issue of potential changing seasonality or the changes in the occurrence of extreme events like floods and droughts. The study also focused only on urban water supply and not other users.

2 BACKGROUND

2.1 South Africa is a water-scarce country

With an average rainfall of only 450 mm/year and significant annual and seasonal variability, South Africa is a water-scarce country. Rainfall also varies from over 1900 mm in the east of the country and in the mountainous areas, to almost zero in the west and north west of the country. Conversion of rainfall to runoff is also low with an average mean annual runoff (MAR) of only 40 mm, one seventh of the global average of 260 mm per year (DWA, 2013).

Like precipitation, runoff is highly variable both in space and time (DWA, 2013).



Figure 1: Johannesburg is the only major global city to be located on a continental divide as a result it is dependent on a highly integrated bulk water supply system (Photo credit: Chris Kirchhoff – www.brandsouthafrica.com)

Demand for water is not evenly distributed, with most of the major water demand centres located far from the available water resources. The city of Johannesburg for example, which is the major economic hub of the country, is the only large city in the world to be located on a continental divide. This has resulted in a need to store water and to move water around the country to meet current and future demands. As a result, the International Commission of Large Dams (ICOLD) ranks South Africa sixth in the world in terms of the number of large dams and we have a highly developed and complex bulk water supply infrastructure system that is capable of moving water from one part of the country to another.

Only a relatively small part of the country is critical in terms of water security. These areas, identified as the Strategic Water Source Areas tend to be in the high rainfall areas and mountains of South Africa and Lesotho. Representing less than 8% of the total surface area of the country, they provide over 50% of the mean annual runoff of the country and are critical to the water supply to the major urban areas including Johannesburg, Cape Town and Port Elizabeth. Protecting these areas is critical to the future water security of South Africa.

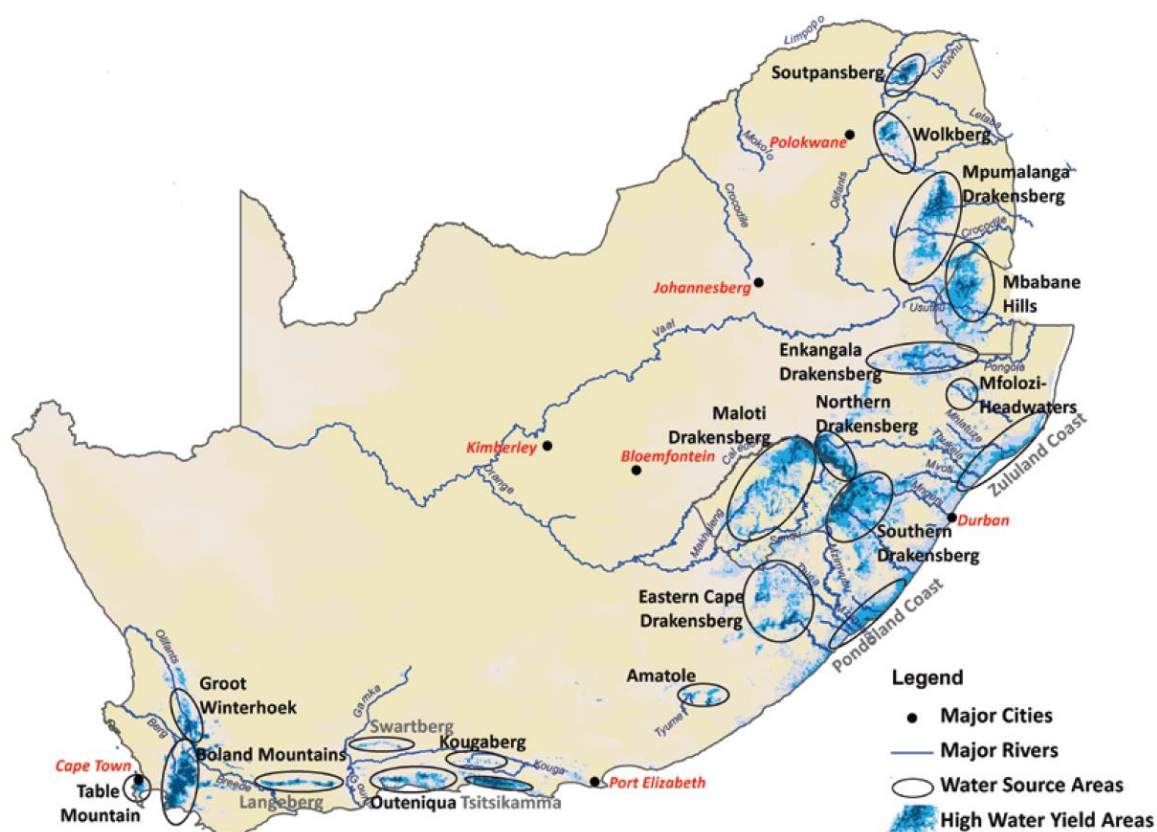


Figure 2: The Strategic Water Source Areas of South Africa (WWF, 2013)



2.2 Climate change risks for water supply

While there is a general consistency among climate models on increasing temperatures due to climate change, particularly for inland locations, there is still much uncertainty about the potential impacts on precipitation. These are much more varied with some areas likely to experience dryer conditions, while other areas might experience increased precipitation. Even areas likely to experience no impact or even a drying climate, may see an increase in rainfall intensity which could increase the risk of flooding. Impacts on the seasonality of runoff are also important in terms of water supply impacts, particularly for areas with limited storage.

A review of the impacts of climate change on the water sector in South Africa (Schulze, 2011) concluded that it was not all “doom and gloom”. Due to variability in the impacts of climate change some areas of South Africa would most likely be “winners” while other areas and other sectors would be “losers”. Particular “hotspots” of concern, primarily due to decreasing rainfall, are the south west of the country, the West Coast and to a lesser extent the extreme north of the country. Even in areas considered to be “winners” due to increasing precipitation, there are potential increases in risks due to increased intensity of rainfall events and associated water logging and flooding (Schulze, 2011).

Water availability is not only impacted by changes in precipitation. Increasing temperatures will lead to increased evaporation which could further reduce runoff and increase water losses from dams. Increasing temperatures will also impact on demand, particularly for irrigation, but also from urban and industrial users. This could also contribute to reduced water security if existing systems are not able to meet these increasing demands.

Increasing temperatures will also increase pollution and water quality risks.



Figure 3: The Katse Dam – critical to future water security and climate resilience for water supply to Gauteng (Photo credit: Christian Wörtz – Wikimedia Commons)

2.3 The benefits of an integrated bulk water supply system

As a result of South Africa's highly complex and integrated bulk water supply system consisting of a number of large dams and inter-basin transfers the country has developed a high level of skills in water resources planning. For example, stochastic time-series simulations are used to design the bulk water system to a high level of assurance of supply which is then managed through the analysis of complex water resources system models for balancing demand and supply. This proactive approach to water resources planning, as well as the investment in critical infrastructure provides some reliability in the system despite highly variable precipitation and streamflow. This is critical to the economic development of South Africa and has been shown to also provide significant resilience to climate change impacts on future water supply, provided it continues to be managed effectively (DEA, 2015a; Cullis et al., 2015).

Individual towns and cities have made significant improvements in their water use efficiency. Figure 4 shows an example of how the City of Cape Town has managed to continue to support population growth without significantly increasing its net water requirements. The recent

drought conditions and subsequent risk for “day zero” in Cape Town, combined with similar drought scares in Durban, Port Elizabeth and Gauteng have, however, highlighted the significant challenges with managing water supply risks for all settlements in South Africa.

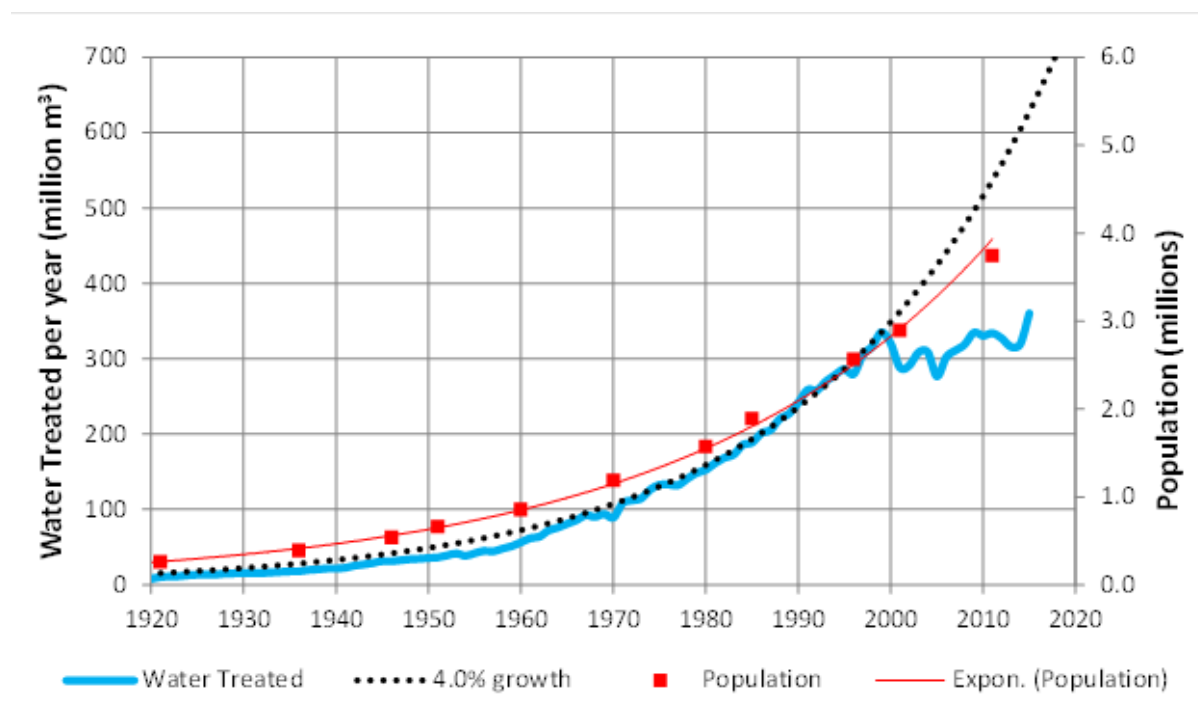


Figure 4: Cape Town water supply and population (City of Cape Town)

As part of the Long-Term Adaptation Scenarios (LTAS) and in collaboration with the National Treasury and the National Planning Commission, the United Nations University World Institute for Development Economic Research (UNU-WIDER) undertook a study of the economic impacts of climate change for South Africa (DEA, 2015a Cullis et al., 2015) which included the water sector as a critical channel through which the economic impacts of climate change would be realized. This study adopted a hybrid frequency distribution (HFD) to determining the climate change risks for a wider range of possible future climate scenarios than would be achieved through the typical top-down approach based on individual climate change models or a selection of models (Schlosser et al., 2012). The advantage of the HFD approach is that it looks at a much wider range of potential impacts and provides the basis for risk-based decision making. A comparison of the HFD model results with individual regional climate model results for six different hydro-zones across South Africa is shown in Figure 5.

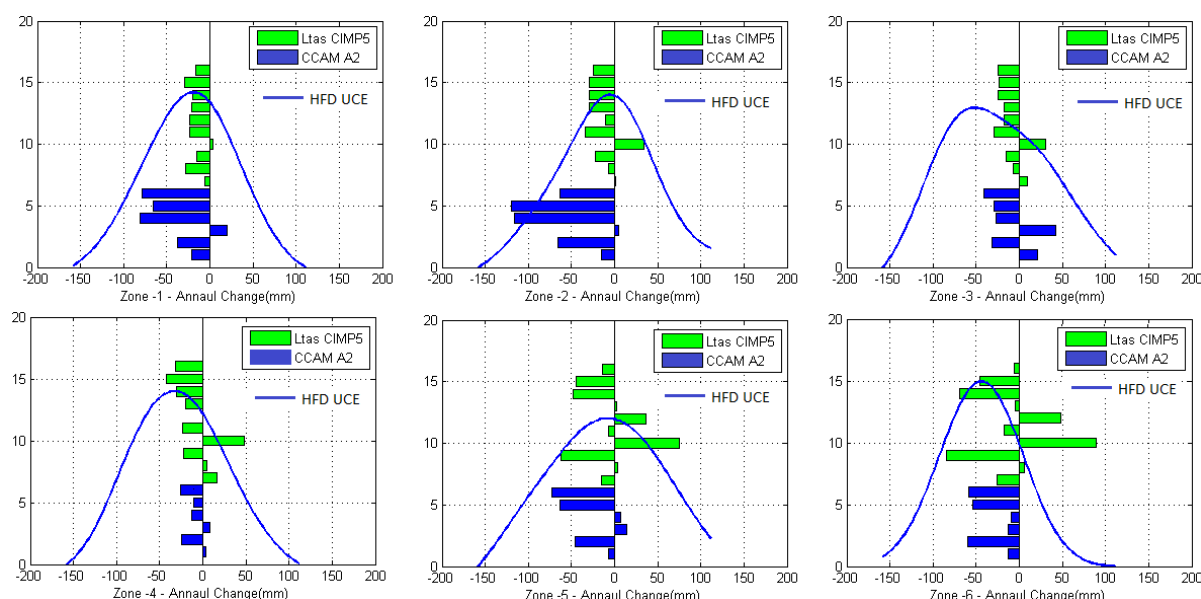


Figure 5: Median changes in average annual precipitation in mm/year for the period 2040-2050 as compared to the period 1990 to 2000 for the six hydroregions (Source: Cullis et al., 2015).

Note: The results compare the outputs of statistically downscaled and regional climate model results (shaded bars) with that of the HFD of an unconstrained emissions (UCE) scenario (blue curve) from the IGSM=for mean annual precipitation by 2050.

The results of this study showed that despite a significant impact of climate change on surface water runoff that varies significantly across the country (Figure 6), these impacts were mitigated in terms of total water supply (Figure 7). This is likely because South Africa already has a well-developed and highly integrated bulk water distribution system that has been designed to address the existing high spatial and temporal variability in water supply and existing water scarcity and that water can be effectively moved around the country.

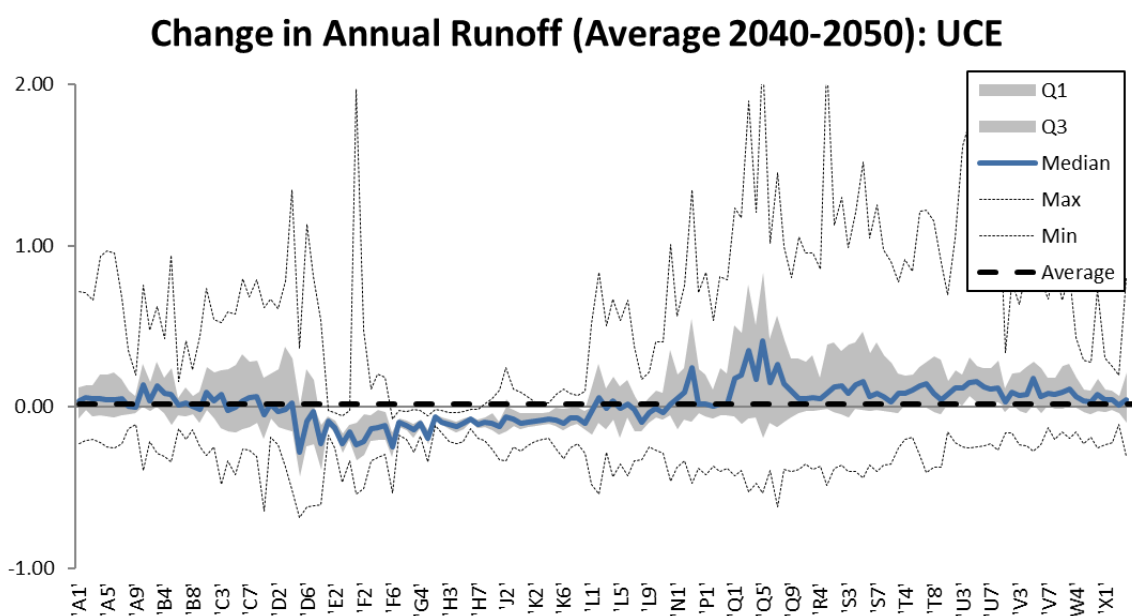


Figure 6: The range of possible climate change impacts on mean annual runoff (MAR) for secondary catchments across South Africa under the Unconstrained Emissions Scenario by 2050 relative to current day average (After Cullis et al., 2015)

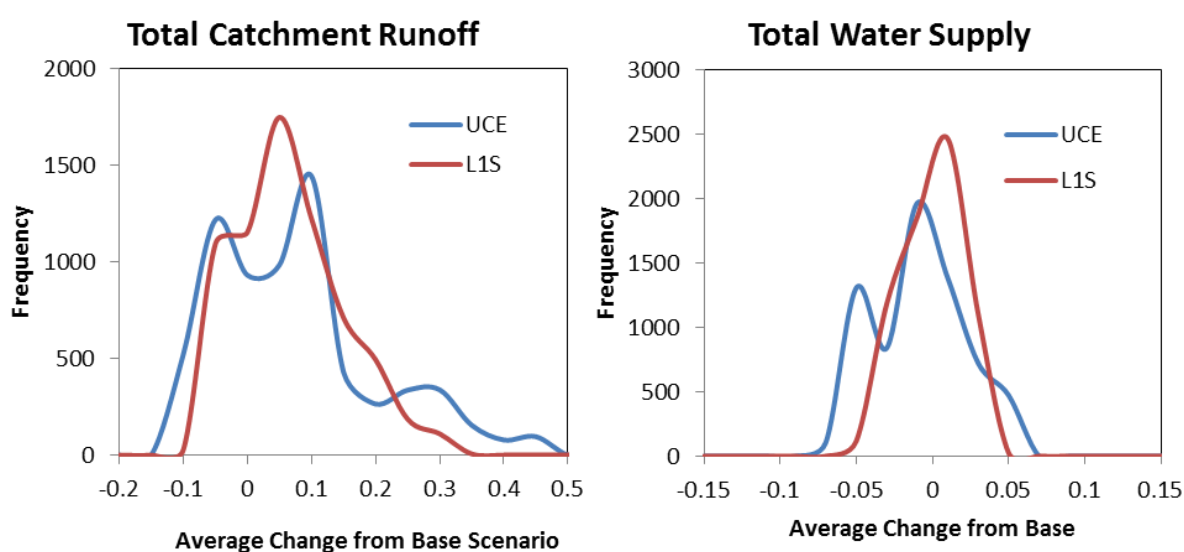


Figure 7: Comparison of the potential impacts of climate change in terms of total catchment runoff for the country and the change in the ability to meet the total national water supply demands for the period 2040 to 2050 under an Unconstrained Emission (UCE) scenario and Level 1 Stabilisation (L1S). (Cullis et al., 2015)

In the metropolitan areas, the existing water supply infrastructure is considered to provide a reasonably high level of resilience in terms of future water supply if it continues to be planned in advance and managed correctly (Cullis et al., 2015). Of greater concern are the smaller cities and towns that are dependent on only a single source or do not have the capacity to

efficiently manage and maintain existing and future water supply infrastructure. This is illustrated in the high degree of variability in terms of potential climate change impacts on water supply to different Water Management Areas (WMAs) shown in Figure 8 based on the results of the LTAS (DEA, 2015a) study and UN-WIDER report (Cullis et al., 2015a).

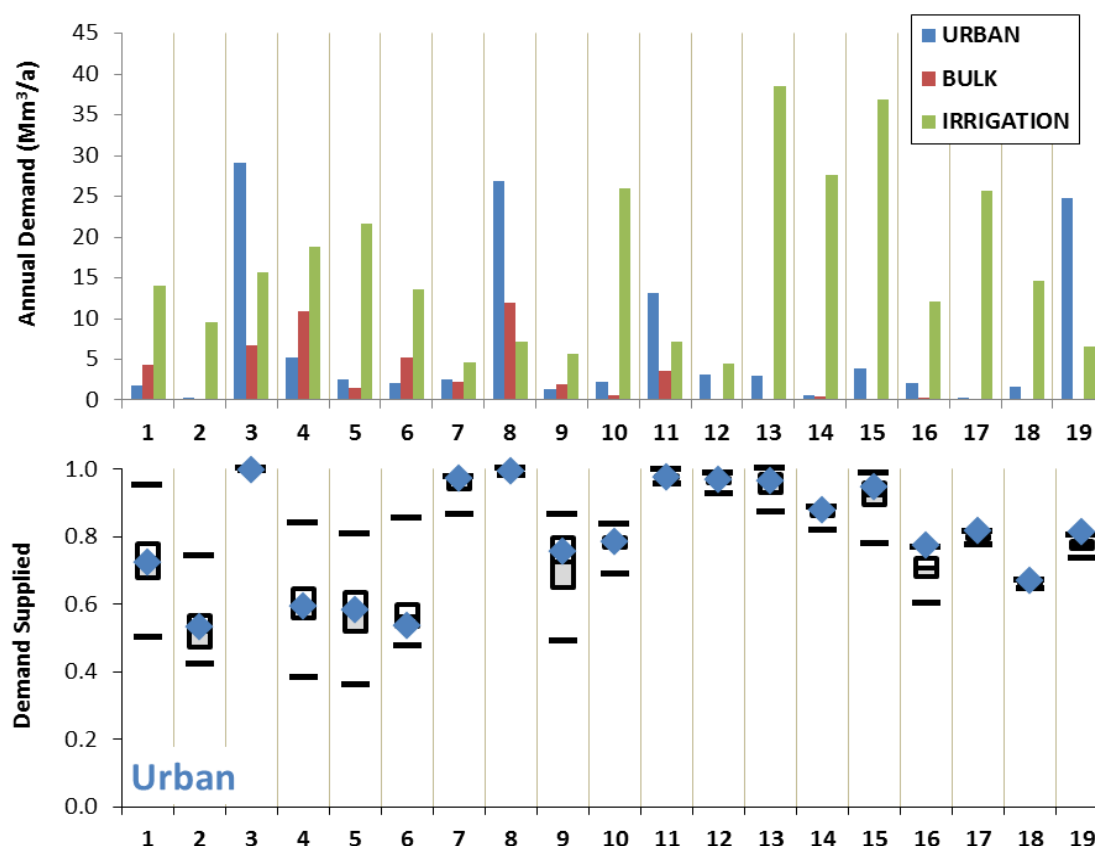


Figure 8: Range of possible impacts of climate change on average annual water supply to 19 WMAs by 2050 relative to the base climate scenario (DEA, 2015a and Cullis et al., 2015)

It is important to note that the above results are based on a national scale analysis. The analysis required substantial simplification of the existing water supply infrastructure as well as other local impacts on precipitation, catchment runoff and water supply. The analysis was also based on time series simulation and determined in terms of the potential impact on the average annual supply and did not consider specific impacts during critical periods or the potential for increased frequency of droughts and extreme events that would impact on the yield from the system. More specific results in selected WMAs or for individual catchments or towns requires more detailed water supply models as well as stochastic analysis of alternative baseline and future scenarios to determine the potential impact on the total system yield and not just in terms of potential impacts on average annual supply.



2.4 Decision making under climate change uncertainty

According to Poff et al. (2015) “securing the supply and equitable allocation of fresh water to support human well-being while sustaining healthy, functioning ecosystems is one of the grand environmental challenges of the twenty-first century, particularly in light of accelerating stressors from climate change, population growth and economic development”. Increasingly climate change is being incorporated into water resources and infrastructure planning across Africa. See for example the World Bank’s initiatives on Enhancing the Climate Resilience of Africa’s Infrastructure (ECRAI) including the water and energy sectors (Cervigni et al., 2015).

There still remains a high degree of uncertainty in the results from individual climate models which continues to be a challenge for decision makers. A recent review of decision making processes undertaken as part of the Future Resilient African Cities and Lands (FRACTAL¹) research project identified at least three drivers of increasing complexity that provide a challenge for decision makers (Taylor et al., 2017):

- the increasing complexity of problems – the rise of “wicked problems”
- the necessary shift away from linear models of decision making
- the rise of “risk” as a central concept for dealing with uncertainty

In response to these drivers of increasing complexity, a range of different decision-making processes and methods have been developed that include both normative or prescriptive concepts (support methods) as well as descriptive approaches (process methods) (Taylor et al., 2017). For climate change impact assessments, in particular, these can be further characterised as top-down or bottom-up approaches, the two methods being characterised as climate model analysis-based and vulnerability analysis-based respectively (Brown, 2011). Limitations exist in the traditional top-down approaches, according to Brown (2011): “A central issue in top-down approaches to planning under climate change uncertainty is the use of GCM projections. They provide forecasts of the future that are potentially informative but also have significant uncertainties and unknown reliability.” Assessing the projection reliabilities poses difficulties because the actual climate outcomes are uncertain. The uncertainty predominantly lies in that the projections are based on current understandings of climate responses to increasing greenhouse gas emissions (Brown, 2011). Bottom-up approaches, on the other

¹ <http://www.fractal.org.za>

hand, first assess the climate-related risk and vulnerabilities for a particular system, or systems, according to some desirable outcome or performance requirement (Poff et al., 2015).

A number of bottom-up approaches exist, but in general all the approaches begin with a stakeholder engagement and assessment of socio-economic systems (see Figure 9 for a comparison of traditional top-down with the proposed bottom up risk and vulnerability approach to understanding climate change risks). A system is characterized and its response to climate variation identified, based on a climate sensitivity analysis (Brown, 2011). In the final stages the most relevant vulnerabilities of the systems are identified and management prospects are identified to mitigate as much as possible for these vulnerabilities.

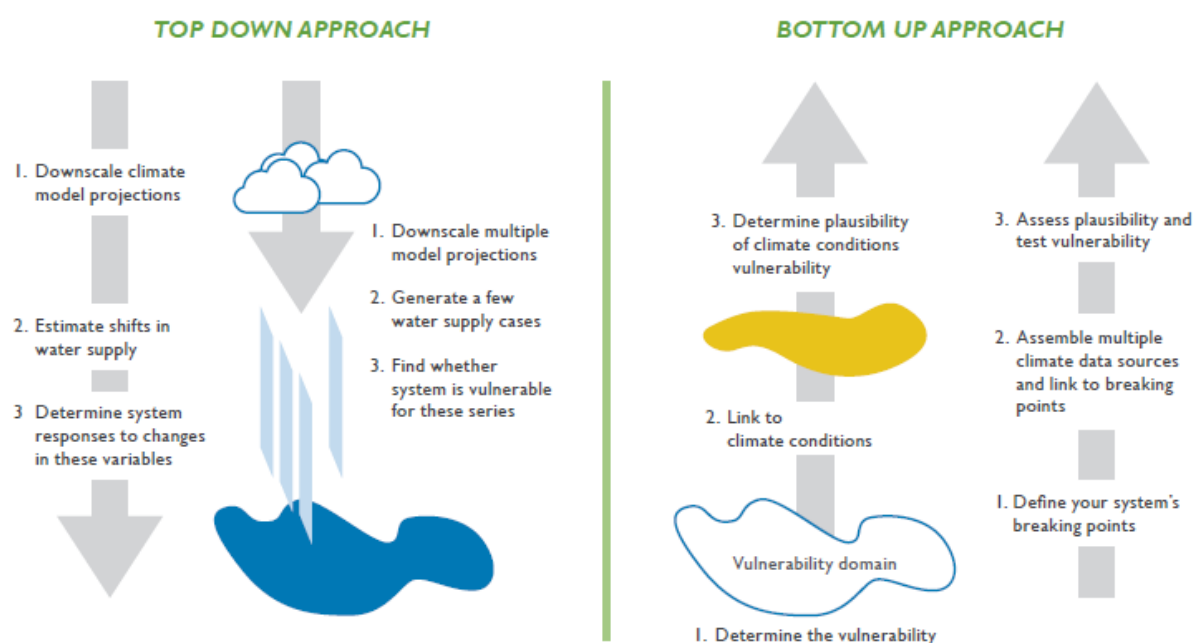


Figure 9: A comparison of top-down vs bottom-up methods for the assessment of climate change risks (DEA, 2013b).

The use of a bottom-up approach as opposed to a traditional top-down approach for decision making is particularly appropriate for application in developing countries such as those located in Sub-Sahara Africa where it is recommended that alternative and more collaborative approaches to knowledge production and decision-making be adopted (Polk, 2015). A bottom-up approach also allows for the efficient allocation of scarce resources to focus on the most critical aspects of uncertainty relevant to decision making for the specific system. This can be done as part of a decision tree framework as proposed by the World Bank (Ray and Brown, 2015). This approach has been applied, for example, in assessing the climate change risk for water supply to Lusaka in Zambia, using a city centric approach (Ilunga et al., 2018).

3 METHODOLOGY

3.1 Overview

Due to the complex nature of water supply and the limitations of this study it is not possible to do a detailed assessment of the specific climate change risks for each individual settlement across South Africa. The results of this study therefore presents only a high level, first order estimate of the relative potential impacts of climate change for water supply to municipalities by 2050 also taking into account the potential impacts of population growth.

In order to get a high-level first order assessment of the relative climate change risks for water supply to municipalities across South Africa, a general risk equation was developed to determine the current and future surface water supply vulnerability that combines both climate change and development risks (i.e. due to an increase in population and associated increase in water demand).

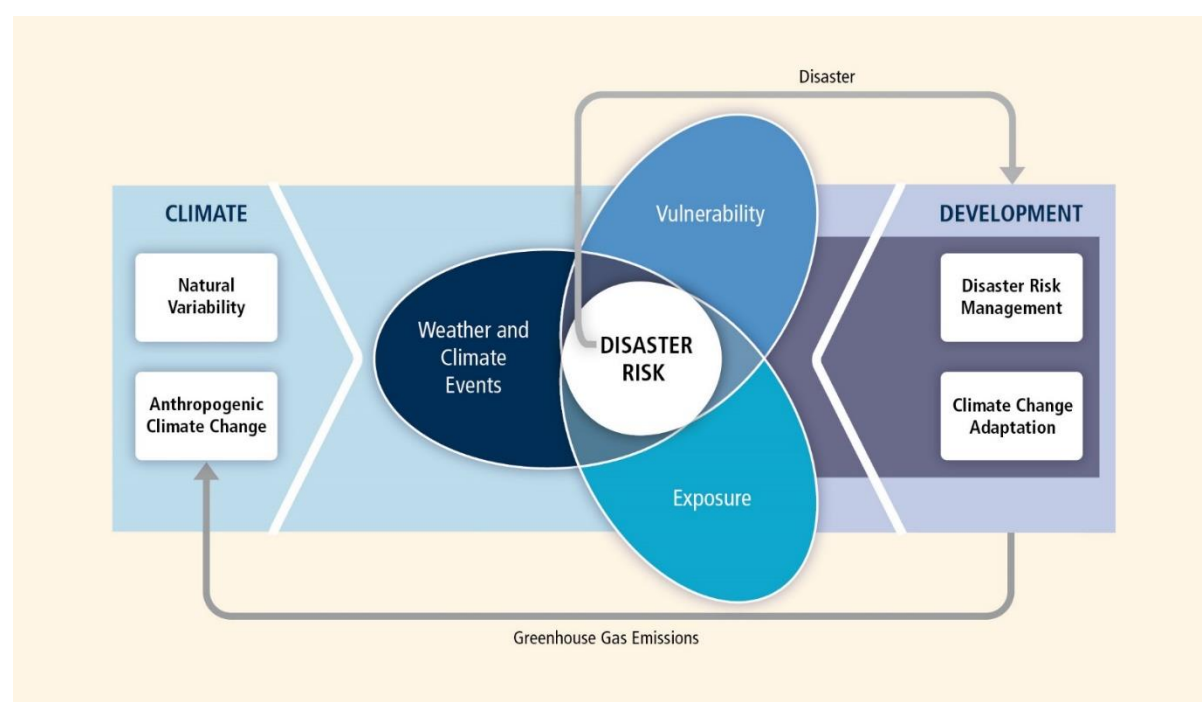


Figure 10: Adopting a risk-based approach to identifying climate change risks and vulnerabilities (IPCC, 2012)

The general risk equation recognizes that risk is not just based on the direct exposure to a climate change (e.g. the change in precipitation or temperature) but is also dependent on the vulnerability of each town in terms of its current and future water demand and water



availability. Future water supply risk could therefore be affected either by reduced availability of surface water or by an increase in demand and it is important to consider that these factors will be different for different towns. The basic risk equation used in this study is given and is consistent with the general approach recommended by the IPCC for understanding climate change risks. It is also consistent with the development of bottom-up solutions to climate change impacts through a better understanding of the drivers of risk.

$$\text{Risk} = \frac{\text{Vulnerability} \times \text{Exposure}}{\text{Adaptive Capacity}}$$

Where

$$\text{Vulnerability} = \frac{\text{Demand}}{\text{Supply}}$$

$$\text{Exposure (E1)} = \frac{\Delta MAE}{(\Delta MAR \times \%SW) + (\Delta MAP \times \%GW)}$$

$$\text{Or Exposure (E2)} = \frac{\Delta MAE}{(\Delta RWS \times \%SW) + (\Delta MAP \times \%GW)}$$

Adaptive Capacity²

= Known augmentation options

+ savings from Water Conservation Demand Management

Where:

- MAP = change in the mean annual precipitation
- MAE = change in the mean annual evaporation
- MAR = change in the mean annual runoff
- RWS = change in regional water supply availability
- %SW = percentage of total supply that is from surface water
- %GW = percentage of total supply that is from groundwater

² Note that while it was the intention of the study to include adaptive capacity by way of including the know augmentation options, data on these were only readily available for settlements in the Western and Eastern Cape. Hence it was only calculated for a small number of municipalities as an example of potential impacts.



3.2 Current and future vulnerability

Vulnerability is determined as the ratio of available water supply and estimated demand.

The current water demands, current water supply, percentage of supply from surface water and from groundwater and the future augmentation options were taken from a synthesis of the DWS All Towns study of 2011 and supplemented from various DWS reconciliation studies for the major metropolitan areas that was compiled by Megan Cole (Cole et al., 2017).

Future projects of population growth for local municipalities across South Africa were provided by the CSIR and these were used to estimate future water demands for all local municipalities.

For this study we have made the simple assumption that water demand will increase proportional to the increase in population. In reality, it is important to note that there are many other factors that impact on urban water requirements including economic development which tends to result in an increase in per capita urban water demand, as well as other urban demands associated with the growth of industries within the urban area. Similarly, efforts to improve water use efficiency, conservation and demand management will result in an increase in water demand that is lower than the estimated population growth.

3.3 Exposure to climate change

Settlements in South Africa get water primarily from either surface water sources, or groundwater sources, or some combination of both. Climate change will impact on these two types of water source differently. In order to determine the overall exposure to climate change risks for water supply we have determine the overall exposure based on an estimated change in surface water availability multiplied by the percentage of the town's water supply that is provided from surface water plus an estimated change in groundwater availability multiplied by the percentage of the town's water supply that is provided from groundwater. This provides a combine impact on water supply.

Climate change is also anticipated to impact on demand with higher temperatures leading to increasing demands for water unless specific mitigation actions are taken to manage demand and improve water use efficiency. While there has been some research to indicate how climate change will impact on increased irrigation water requirements (see for example Cullis et al.,



2015 and Schultze, 2010) as well as evaporation losses from dams and reservoirs there has been only limited research into the impact that this will have on urban water demand. As a first order estimate we have assumed that the increase in urban water demand is proportional to the increase in potential evaporation demand as a result of increasing temperatures. Hopefully further research will enable us to make a much better estimate of the impact on demand.

Determining the impact of climate change on water supply is almost impossible without a detailed analysis of the specific water supply system of each individual town and settlement. This needs to take into account the source of the water, the unique spatial and temporal variability in runoff, the specific characteristics of the catchment (which could be far from the actual location of the settlement), the volume of storage available, the requirements for environmental flow releases, the nature of the demand, the impacts of upstream demands, future developments and augmentation options, the ability to manage the system, the ability to utilize a diversity of water supply options (including inter-basin transfers), the potential for conjunctive use from groundwater, access to desalination or re-use of treated effluent, the acceptable levels of risk (i.e. the degree to which demand can be managed through periods of drought), and any water quality constraints, etc.

As none of this detailed modelling is possible for this study, we have adopted two separate approaches to estimating the impact of climate change on the availability of surface water supply. The reality for most settlements will likely fall somewhere in between these two.

The first (E1) assumes that changes in water supply are proportional to changes in the Mean Annual Runoff (MAR) of the catchment in which the settlement is located. This would be the case for a town with access to run-of-river supply only from local sources, with limited or no storage. The second (E2) is based on the results of a study that modelled the overall impacts of climate change on water supply to each of the original 19 Water Management Areas (WMA) of South Africa that made use of a national configuration of the Water Resources Yield Model (WRYM) that accounts for the interconnectedness of systems through inter-basin transfers and the main national and local water supply systems. It is important to note that even this study did not model these individual systems in any detail, but was rather a high level, first order estimate at a national scale. This second approach is more appropriate for the metropolitan areas and municipalities that are integrated into some of the large bulk water supply systems such as the Vaal System or the Western Cape Water Supply System (WCWSS). These two approaches essentially represent the extreme options for the potential



impact of climate change on water supply to individual towns. The truth lies somewhere in between but would require a more detailed analysis of each individual system.

A further caveat is that both approaches are based on the change in the average annual runoff or regional water supply and are not based on the overall system yield impacts. Hence, they may not truly reflect the potential impacts of climate change during periods of drought that occur as a result of significant changes in the seasonal or inter-annual variability of precipitation and runoff. Again, this would require a more detailed analysis of each individual town and its local and regional water supply system.

For this analysis the impact on the proportion of water supply to a town that comes from groundwater is assumed to be directly proportional to the impact on Mean Annual Precipitation (MAP). This is assumed because groundwater yield is a function of precipitation and recharge. Further analysis could link this more directly to the results of the analysis of potential groundwater impacts undertaken for this study, but again it would ultimately require a more detailed analysis of the individual water supply systems taking into account both surface and groundwater impacts.

3.3.1 Impact on surface water runoff

The impact of the different climate change scenarios on surface water runoff was determined using the Pitman model (Pitman, 1973) at quaternary catchment scale across South Africa using existing calibrated Pitman parameters contained in Water Resources 2012 (WR2012). The Pitman model is a monthly rainfall-runoff model that is the standard for water resources planning in South Africa (Pitman, 2006; DWA, 2013) and has become one of the most widely used monthly time step rainfall-runoff models within southern Africa (Hughes et al., 2006).

3.3.2 Impact on regional urban water supply

For this study it was not possible to model the water supply system to each individual town or local municipality. As a first order estimate of the impact of climate change on water supply (and not just on surface water runoff) for urban areas across South Africa, we made use of a national configuration of the Water Resources Yield Model (WRYM) that had been developed for the Long-Term Adaptation Scenarios (LTAS) flagship research programme (DEA, 2015a) and UNU-WIDER report (Cullis et al., 2017). The national WRYM was based on secondary

catchment scale modelling units (Figure 11) and aggregated results at the level of Water Management Area (WMA). The WRYM was selected as it is still the primary water resources modelling tool used by the DWS for bulk water resources systems analysis in South Africa.

Although the national model was a simplification of much more detailed WRYM models configured for individual water supply systems in South Africa, it was still adequately detailed for the purposes of this study (Figure 12). The outputs from the model include the impact of climate change scenarios on the water supplied to agriculture, urban and bulk industry and these were aggregated to WMAs. Without modelling the individual towns or bulk water supply systems it was not possible to determine the specific impacts for individual towns or cities, but the results of the study for the WMA in which the town or city was located were used to adjust the current water supply volumes to get a first order estimate of the impacts of climate change.

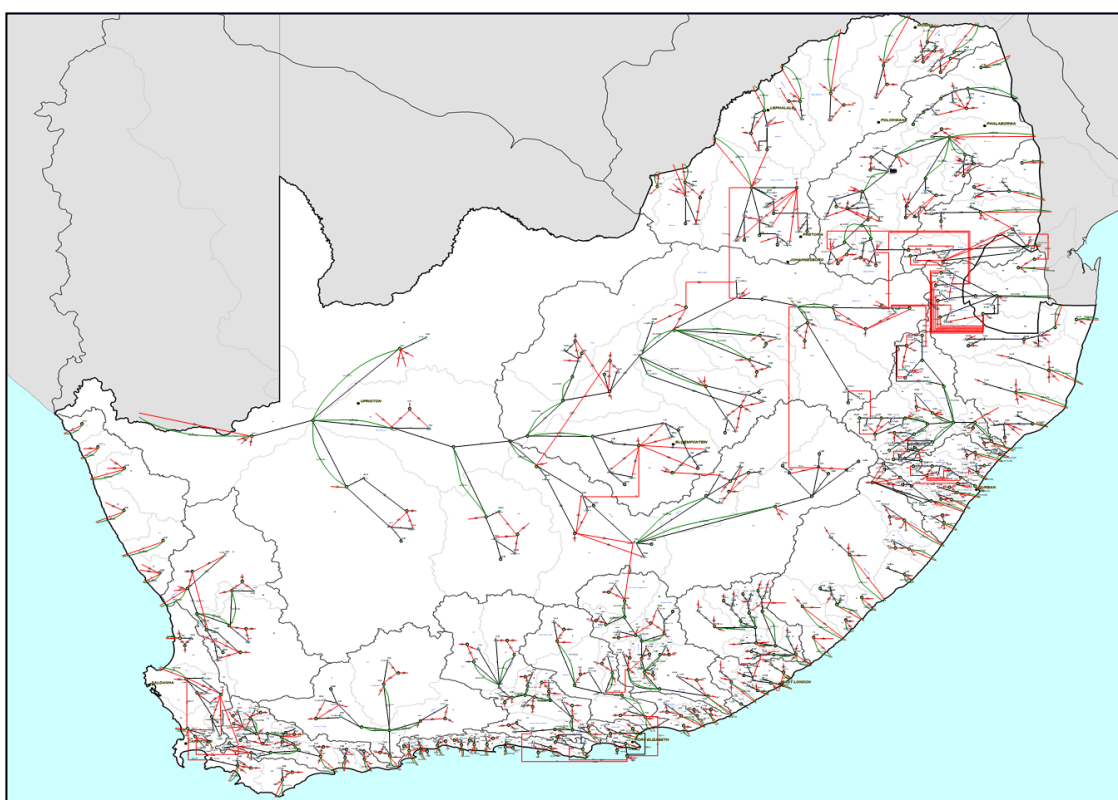


Figure 11: Schematic diagram of the national WRYM system model developed for South Africa showing the main nodes and links which represent both natural stream channels and inter-basin transfers (DEA, 2015a)

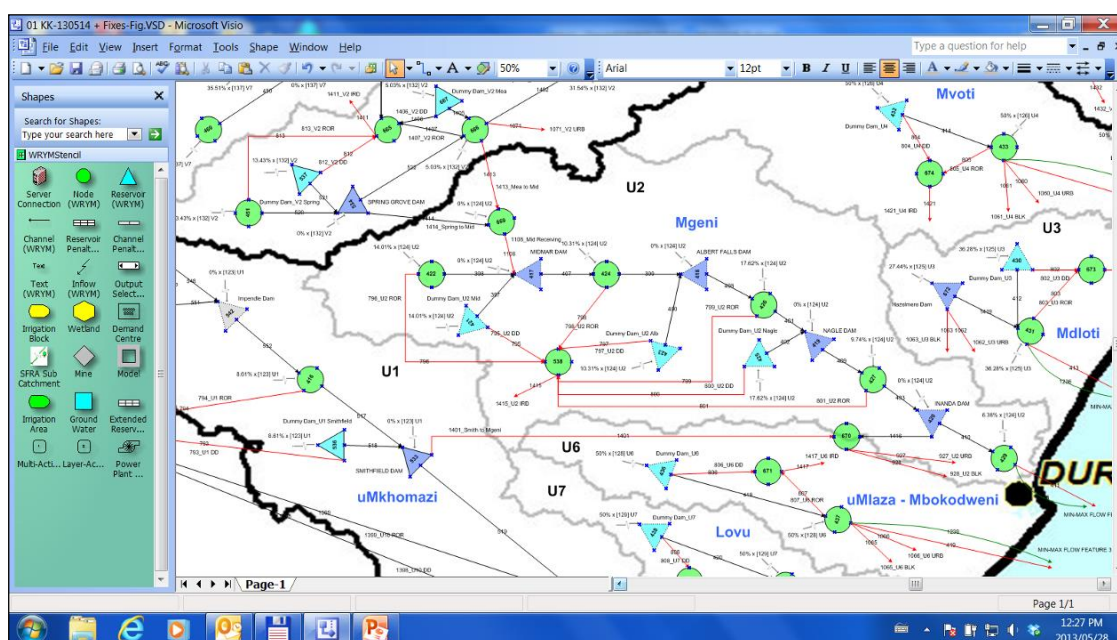


Figure 12: Detail of part of the national WRYM system model (Mooi-Mgeni River System) (DEA, 2015a)

3.4 Climate change scenarios

A set of climate change scenarios for South Africa was provided by the CSIR. These were then aggregated at quaternary catchment scale and presented as a time series of average monthly precipitation values as well as maximum and minimum daily temperatures which were then used to estimate average monthly evaporation based on the Hargreaves equation (Hargreaves, 1994). Similar climate change scenarios were used in the UNU-WIDER study (Cullis et al., 2017) and used to determine the impact on regional urban water supply.

4 RESULTS

4.1 Vulnerability

4.1.1 Precipitation, Evaporation and Runoff

The Mean Annual Precipitation (MAP) for each quaternary catchment is shown in Figure 13. The average MAP for South Africa is 450 mm/a, but as can be seen this varies significantly across the country, with the wettest areas in the east of the country and in the high mountains and the driest areas in the north western parts. The high MAP areas are around the mountains of Lesotho and the Drakensberg, the Western Cape fold mountains and areas in the provinces of Mpumalanga, KZN and Limpopo.

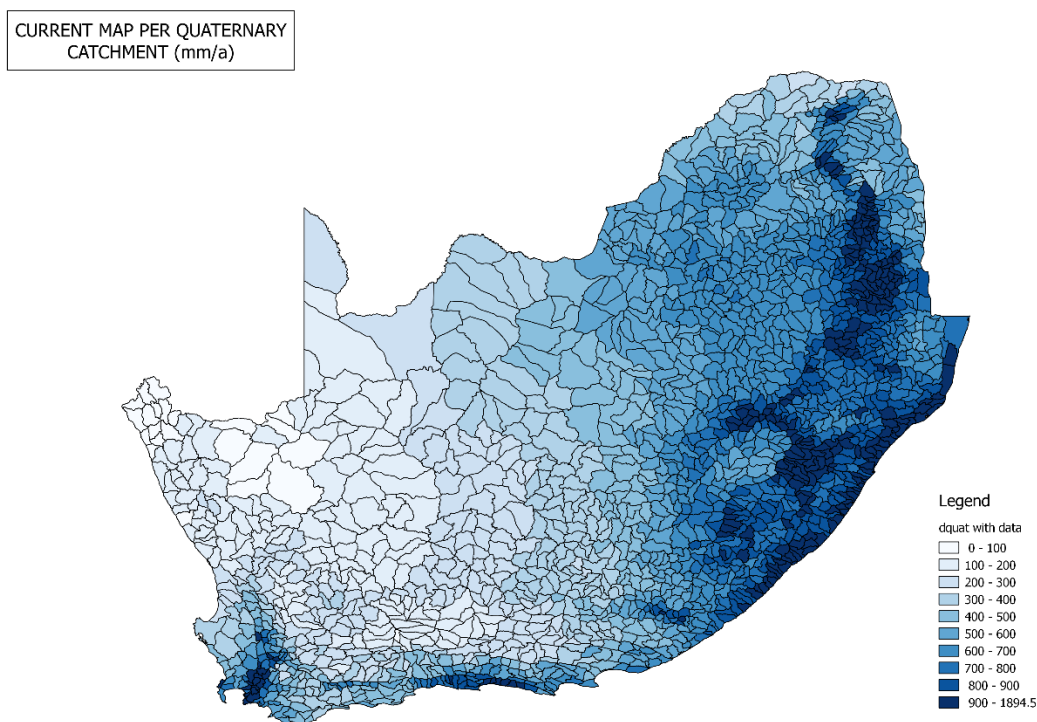


Figure 13: Current Mean Annual Precipitation (MAP) (mm/a)

The Mean Annual Evaporation (MAE) for all quaternary catchments has been calculated by making use of the original Hargreaves (1994) equation which is a function of maximum and minimum temperature. The MAE of South Africa is shown in Figure 14 and ranges from 1 300 mm/a in the Eastern Cape to over 3 700 mm/a in the Northern Cape.

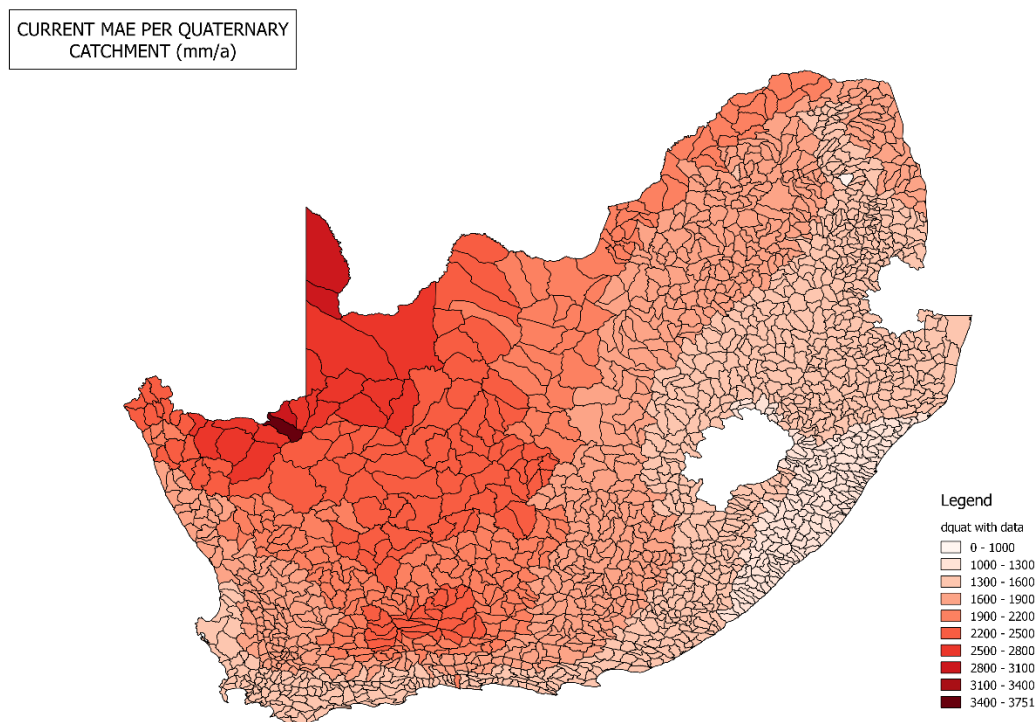


Figure 14: Current Mean Annual Evaporation (MAE) (mm/a)

The Mean Annual Runoff (MAR) for each of the catchments is shown in Figure 15. The highest MAR values are for the catchments in Lesotho as well as the mountains of the Western Cape. These catchments form the Strategic Water Source Areas (SWSAs) of South Africa. The total MAR for the country is around 50 000 Mm³/a.

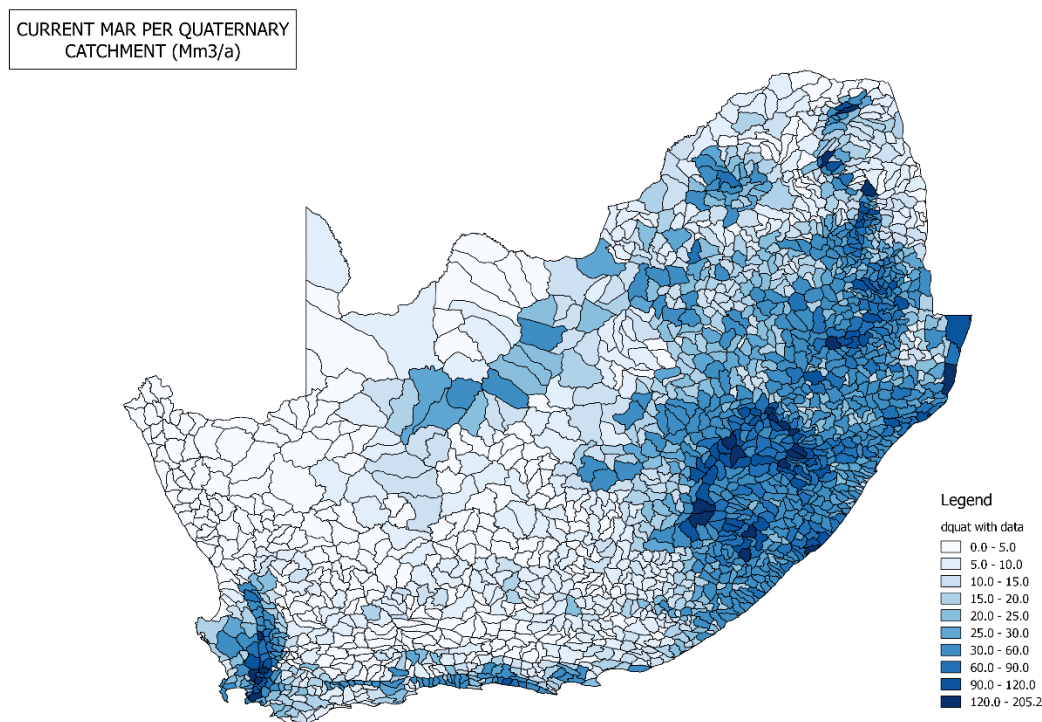


Figure 15: Current Mean Annual Runoff (MAR) for all quaternary catchments across South Africa, Lesotho and Swaziland

4.1.2 Per capita water use

The average per capita daily water use, as recorded in the DWS All Towns study (Cole et al., 2017), is around 250 l/p/d. This varies significantly across the country from around 8 l/p/d for Umzimkhulu Local Municipality in KwaZulu-Natal to 925 l/p/d in Khai-Ma Local Municipality in the Northern Cape..

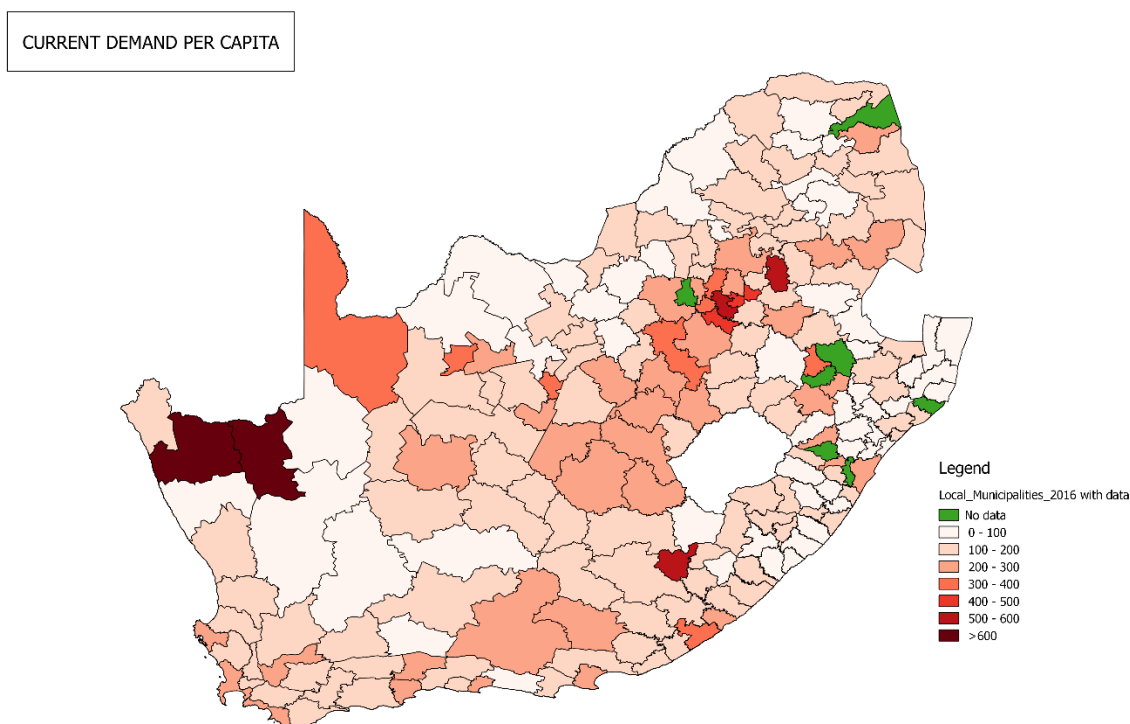


Figure 16: Current per capita daily use (l/p/d)

4.1.3 Dependency on surface and groundwater supply

The dependency on surface water supply (Figure 17) and groundwater supply (Figure 18) varies significantly across the country and as a result so will the exposure to climate change impacts on surface water availability. The majority of the southern and eastern coastal municipalities are predominantly reliant on surface water, while the municipalities in the Northern Cape and North West are predominantly reliant on groundwater. Ratlou and Tswaing local municipalities in the North West province and Karoo Hoogland Local Municipality in the Northern Cape, for example, are 100% reliant on groundwater for their water supply. Having access to both surface and groundwater supply could provide more flexibility and therefore resilience to the potential impacts of climate change.

% SURFACE WATER

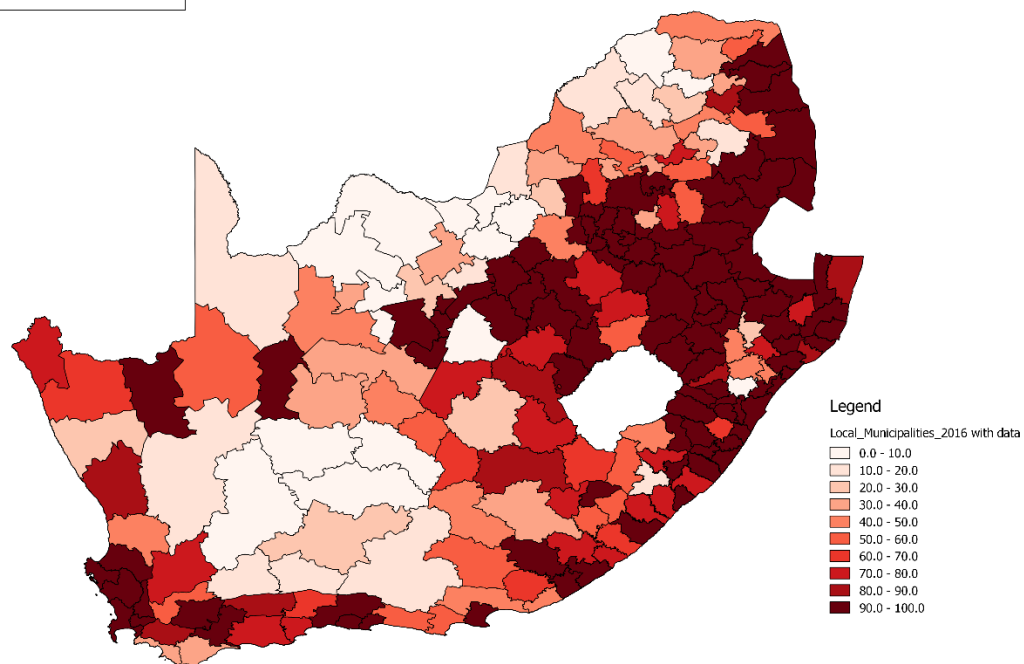


Figure 17: Percentage of supply from surface water

% GROUNDWATER

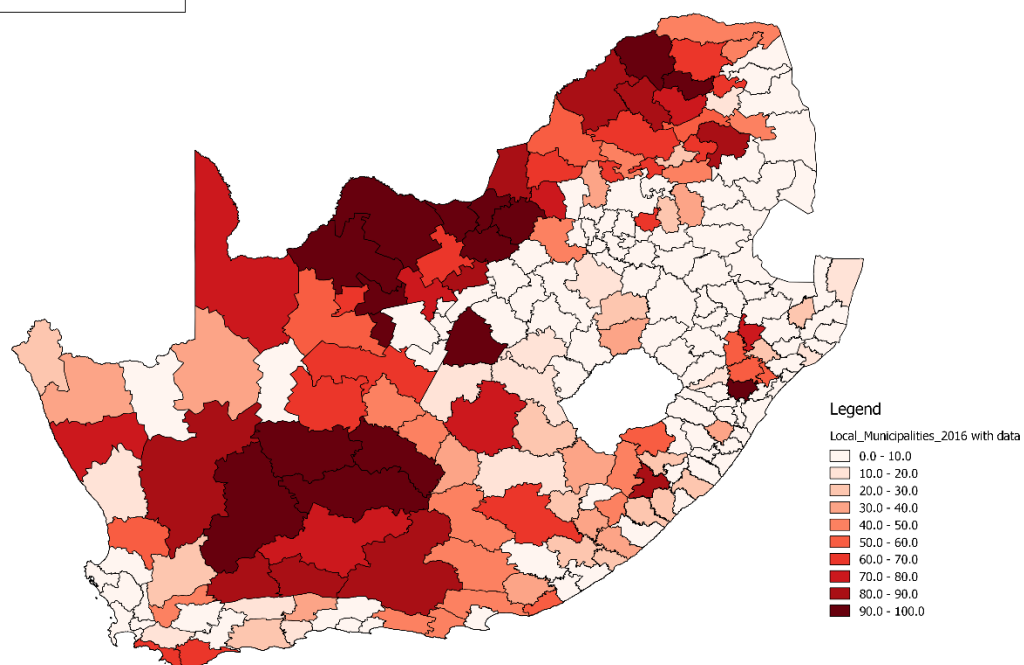


Figure 18: Percentage of supply from groundwater

4.1.4 Future population growth

Population growth is one of the main drivers of increasing urban water requirements, but not the only one. The percentage change in population for the medium (Figure 19) and high (Figure 20) growth scenarios for 2050 are shown. Despite a likely significant increase in the total population for South Africa, not all municipalities will necessarily see growth. Some municipalities, such as Joe Morolong in the Northern Cape could experience a decrease in population of up to 70% whereas others show an increase of up to 200% such as Gamagara and Musina. This is most likely as a result of migration both internal, and also from other African countries. This variability in population growth will have a significant impact on the future urban water requirements and will also contribute to variability in the overall vulnerability to climate change where the risk due to population increases could be significantly greater than the risk associated with the climate change impacts on precipitation and runoff.

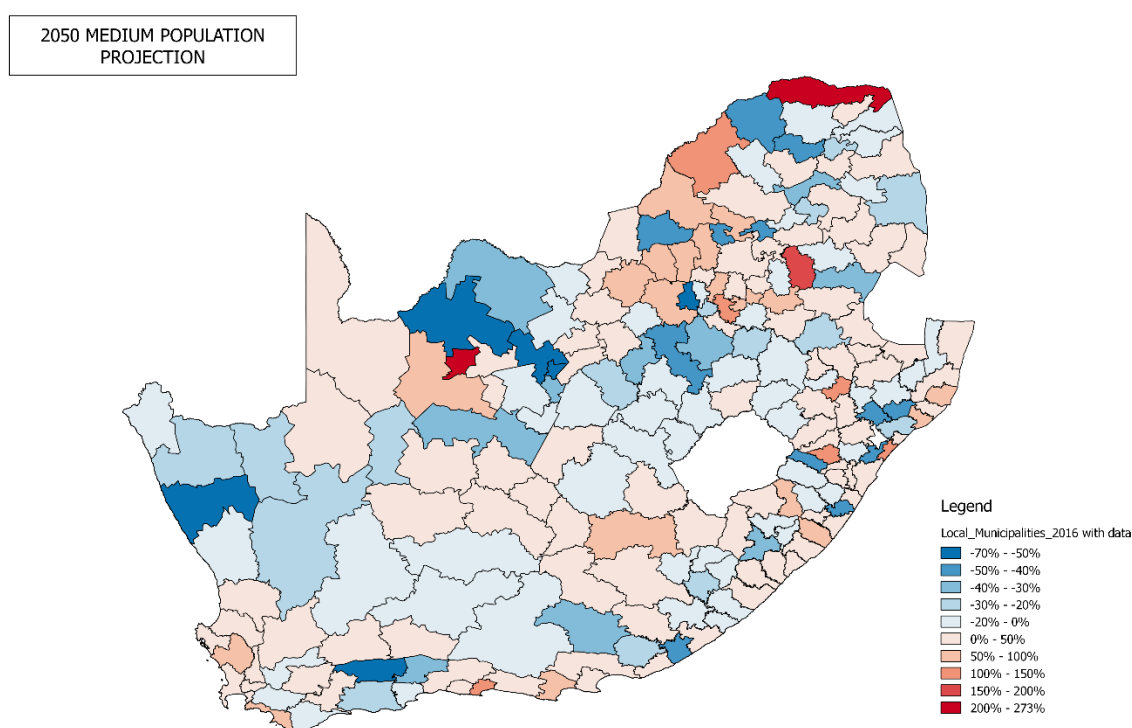


Figure 19: 2050 medium population growth

2050 HIGH POPULATION
PROJECTION

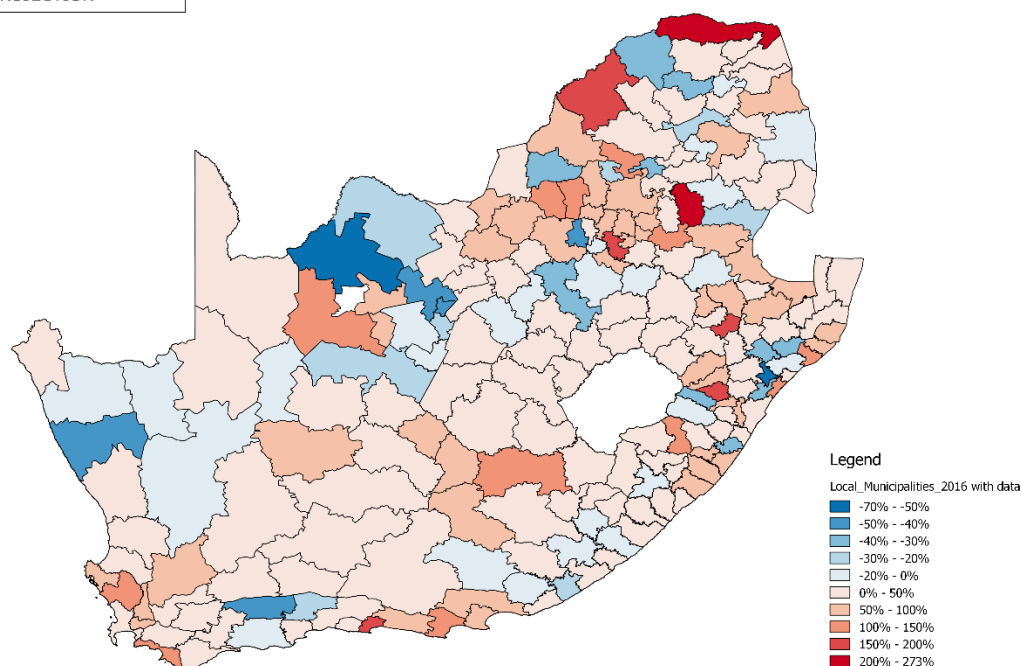


Figure 20: 2050 high population growth

4.1.5 Current water supply per capita

The water supply to each town in South Africa is unique and requires individual attention. Water supply to the metropolitan areas is assessed as part of the reconciliation studies for each of the major bulk water supply systems. The water supply risks for smaller towns and local municipalities are documented as part of the DWS All Towns study. This information has been collated into a national database by Cole et al. (2017) and is used here to estimate current and future water supply vulnerabilities for all local municipalities across South Africa.

The average daily water supply per capita for all local municipalities is shown in Figure 21.

CURRENT SUPPLY PER CAPITA

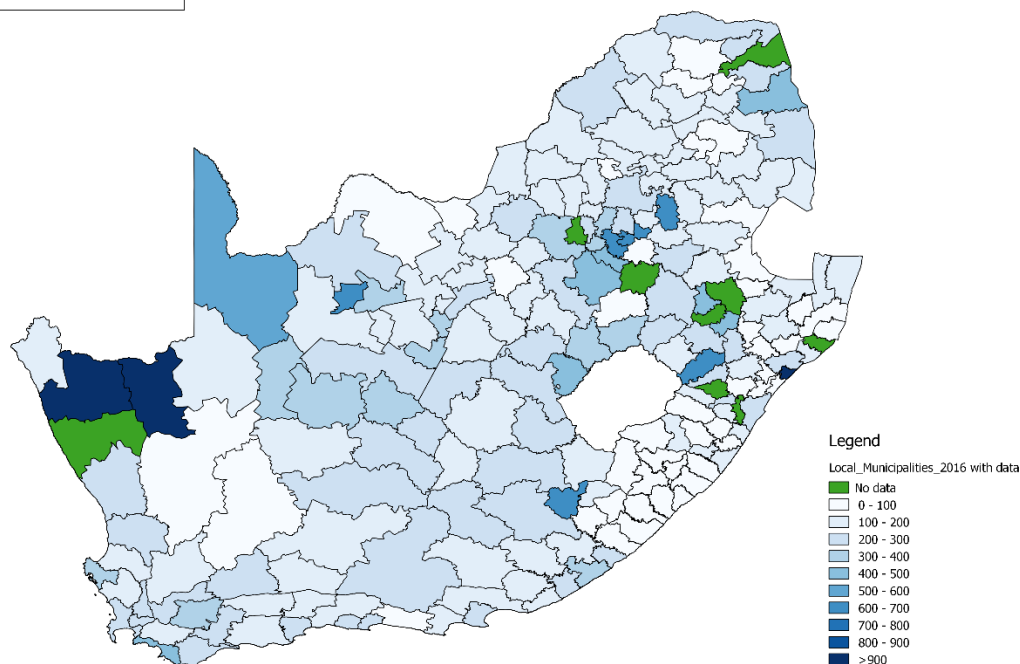


Figure 21: Current estimated daily water supply availability per capita (l/p/d) (Source; Cole et al., 2017)

4.1.6 Current and future water supply vulnerability

The current water supply vulnerability of a municipality has been calculated as being the ratio of the total demand to the total supply. A value of 1 implies that the demand and supply of the local municipality are equal while a value of less than 1 means that there is surplus of supply. A value of more than 1 means that either the demand is too high, or the supply is too low or both. The vulnerability (i.e. demand/supply) of local municipalities is shown in Figure 22.

The region with the highest vulnerability is the eastern portion of the Eastern Cape which has a vulnerability of more than 2. The municipality with the highest vulnerability is Mhlontlo with a vulnerability of 20. Other municipalities in the area are Matatiele (5.3), Umzimvubu (4.0) and Ngquza Hill (3.9). The average usage per capita is relatively low for these four municipalities and ranges from 89 to 148 l/p/d. It can therefore be deducted that the challenges that these four local municipalities face are not related to demand, but rather to supply. The fact that these municipalities appear to have very low levels of supply does not necessarily mean that households are without water as many households would make of alternative water supply options such as rainwater tanks or water supply trucks.

The threemunicipalities with the lowest vulnerability are Inkosi Langalibalele (0.14), Mandeni (0.15) and Msinga (0.2) which are all in KwaZulu-Natal. These low vulnerability values can possibly be ascribed to the large volume of water supply that they can receive. Their demand per capita is also relatively low with values of 88, 176 and 57 l/p/d respectively.

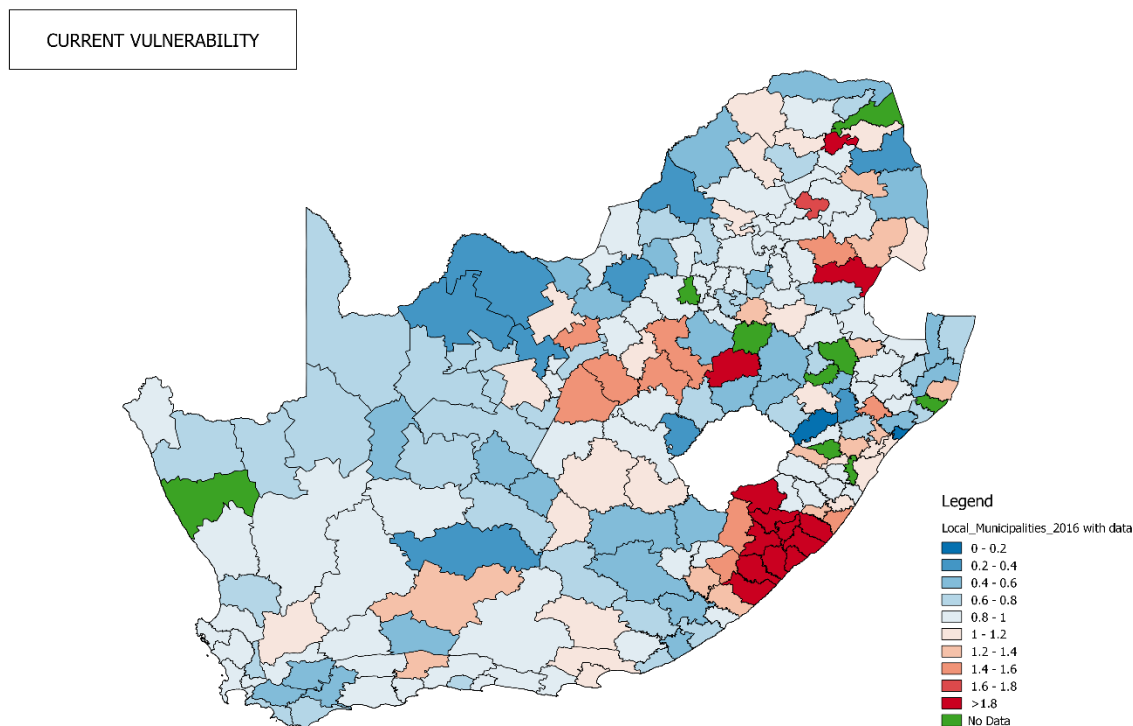


Figure 22: Current water supply vulnerability (estimated demand/supply)

The estimated future water supply vulnerability (excluding climate change impacts and water supply augmentation options) is shown for the medium population growth scenario (Figure 23) and the high population growth scenario (Figure 24). These results show that the local municipalities near Port Elizabeth and East London will increase in vulnerability. The Bela-Bela Local Municipality is showing an increase in vulnerability from a current value of just over 1, to a vulnerability of 2 for the 2050 high population growth scenario. This means that Bela-Bela's vulnerability has doubled as a result of the likely increase in population for this growth scenario. The vulnerability of the local municipalities within Gauteng has also increased from between 0.8 and 1 to between 1.2 and 1.7. This is however without the additional supply from the Polihali Dam which is currently under development in Lesotho and will provide water security for Gauteng for the foreseeable future.

2050 MEDIUM VULNERABILITY

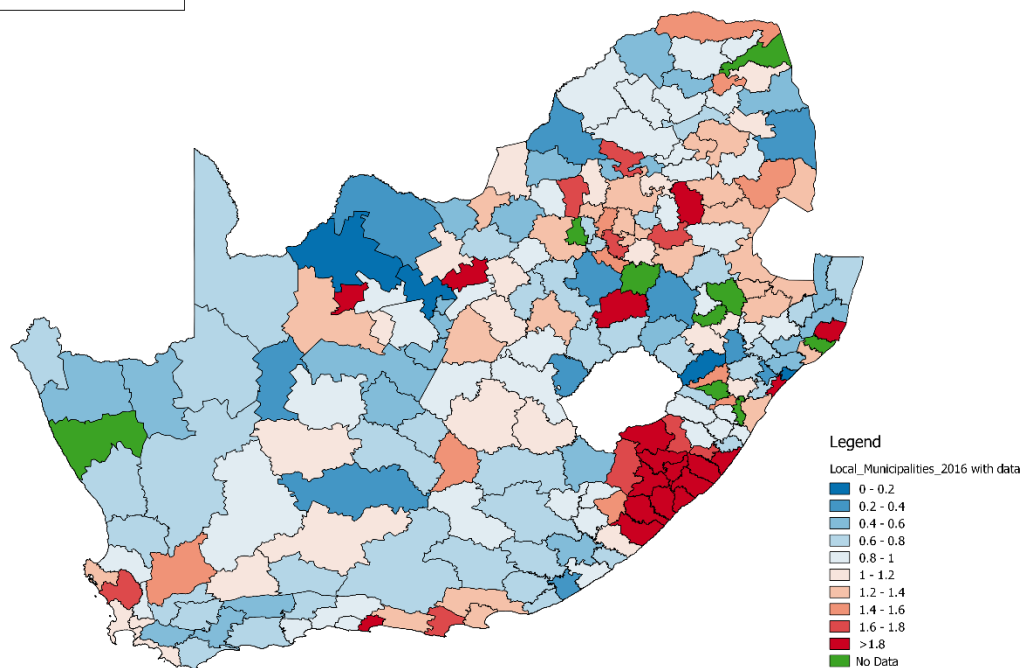


Figure 23: 2050 medium growth water supply vulnerability (estimated demand/supply)

2050 HIGH VULNERABILITY

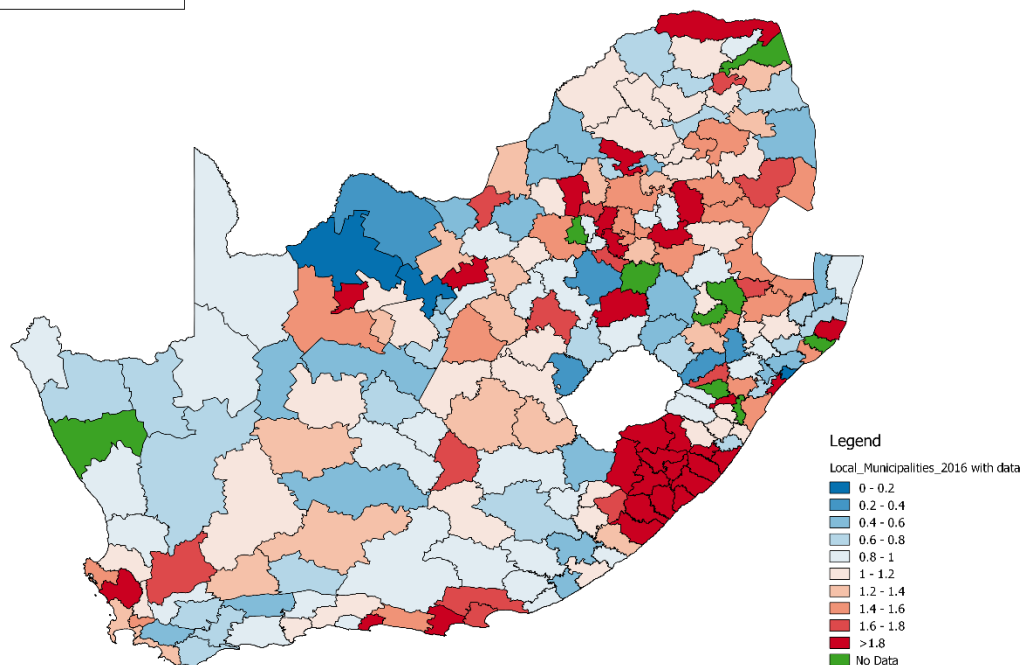


Figure 24: 2050 high growth water supply vulnerability (estimated demand/supply)

4.2 Exposure to climate change

4.2.1 Precipitation

The 10th, 50th and 90th percentile change in MAP for each quaternary catchment is shown in Figure 25, Figure 26 and Figure 27. The 10th percentile figure shows there is a significant decrease in precipitation of around 30-50% whereas the 90th percentile shows an increase in rainfall of 10-20%. The West Coast of South Africa is likely to experience drying across most scenarios with decreases in MAP of 50% for the 10th percentile and 10% for the 90th percentile. Parts of the Free State and Lesotho however show an increase in MAP for the 10th, 50th and 90th percentile. These are anywhere from 5 to 15% increase. This result is positive for all the users of the Orange River and including the potential to transfer water to Gauteng through the Lesotho Highlands Water Project and to Nelson Mandela Bay through the Orange-Fish tunnel.

2050 10th PERC CHANGE MAP PER
QUATERNARY CATCHMENT

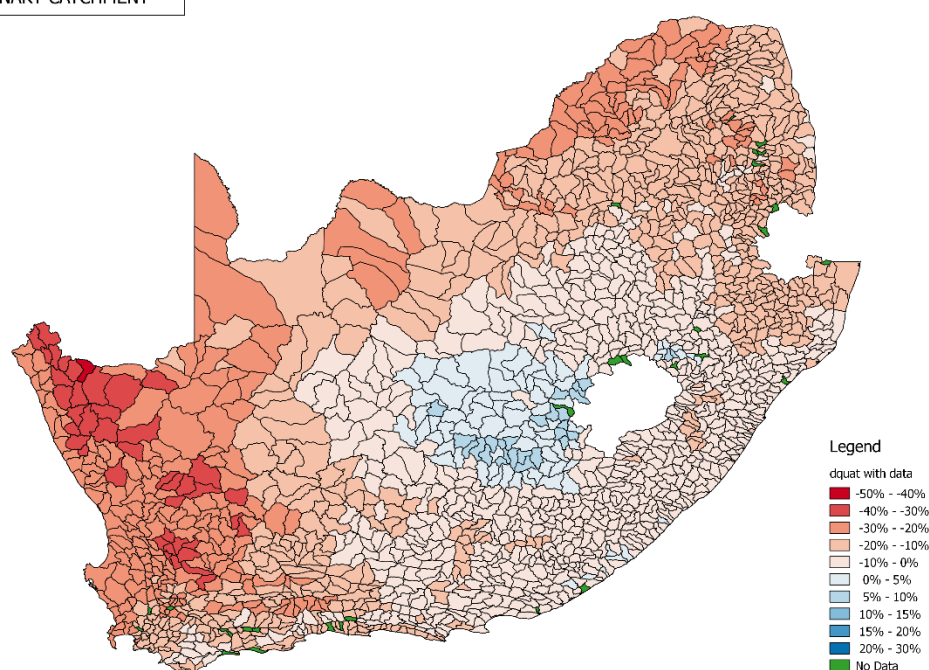


Figure 25: 2050 10th percentile change in MAP

2050 50th PERC CHANGE MAP PER
QUATERNARY CATCHMENT

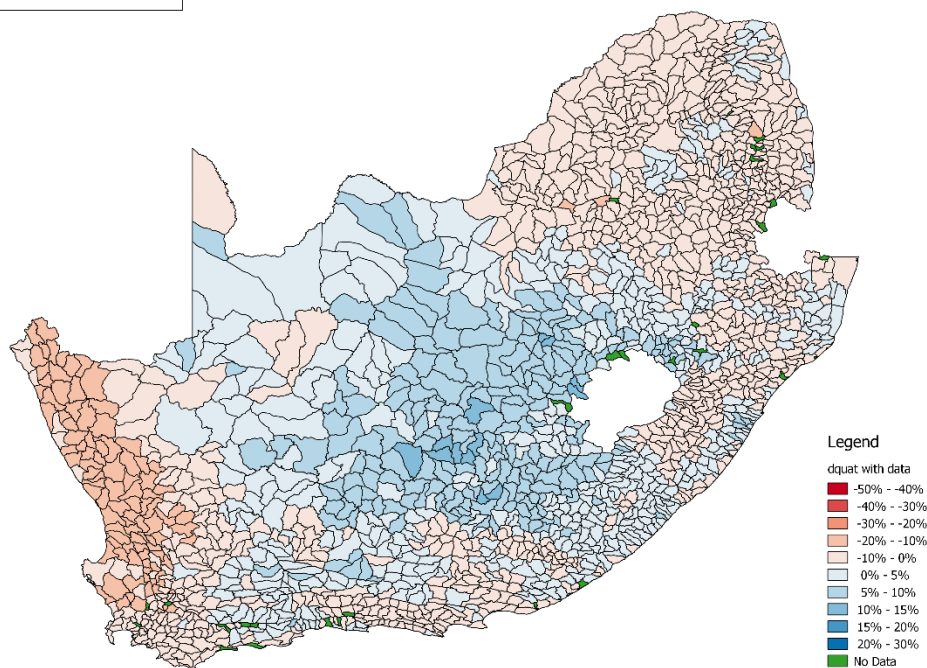


Figure 26: 2050 50th percentile change in MAP

2050 90th PERC CHANGE MAP PER
QUATERNARY CATCHMENT

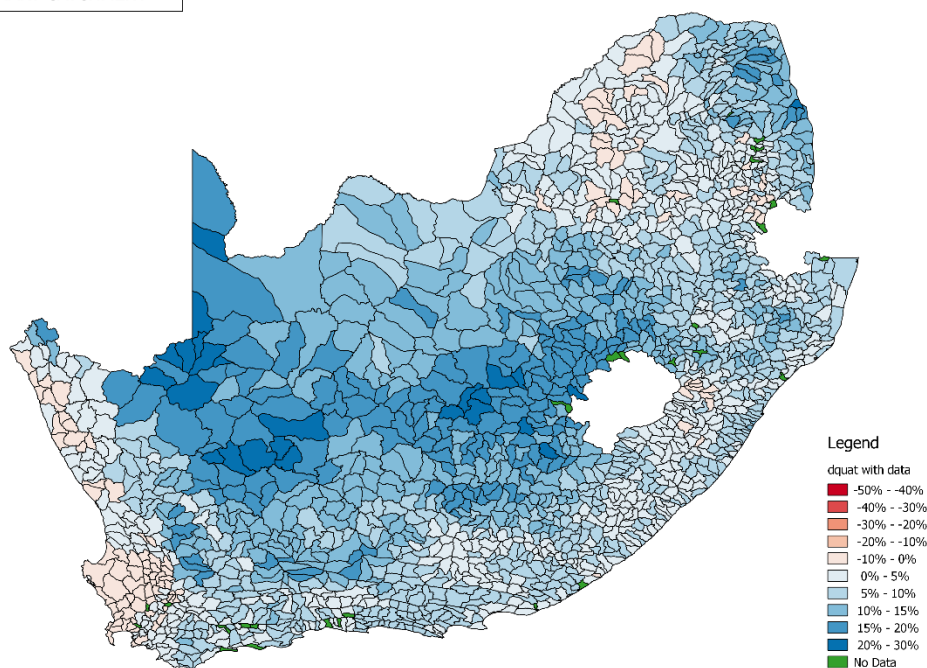


Figure 27: 2050 90th percentile change in MAP

4.2.2 Evaporation

The 10th, 50th and 90th percentile change in MAE for each quaternary catchment is shown in Figure 28, Figure 29 and Figure 30. These figures show that the coastal areas of South Africa will see much less impact on MAE in 2050 when compared to the rest of South Africa. Some areas in the southern Cape could even potentially see a decrease of up to 5% in the estimated MAE. The rest of South Africa will most likely experience an increase in MAE in 2050. The areas that will experience the greatest increase will be the inland areas in the north and north west of the country, The 90th percentile figure indicates that these areas could experience significant increases in evaporation of up to 25% by 2050. This will impact on surface water availability, but also demand for water, particularly for irrigation.

2050 10th PERC CHANGE MAE PER
QUATERNARY CATCHMENT

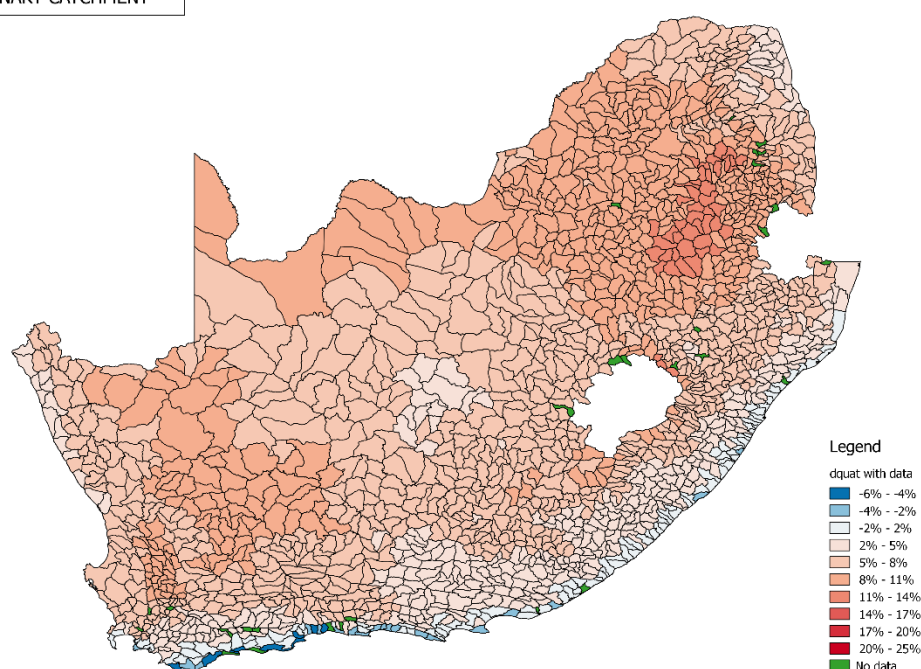


Figure 28: 2050 10th percentile change in MAE

2050 50th PERC CHANGE MAE PER
QUATERNARY CATCHMENT

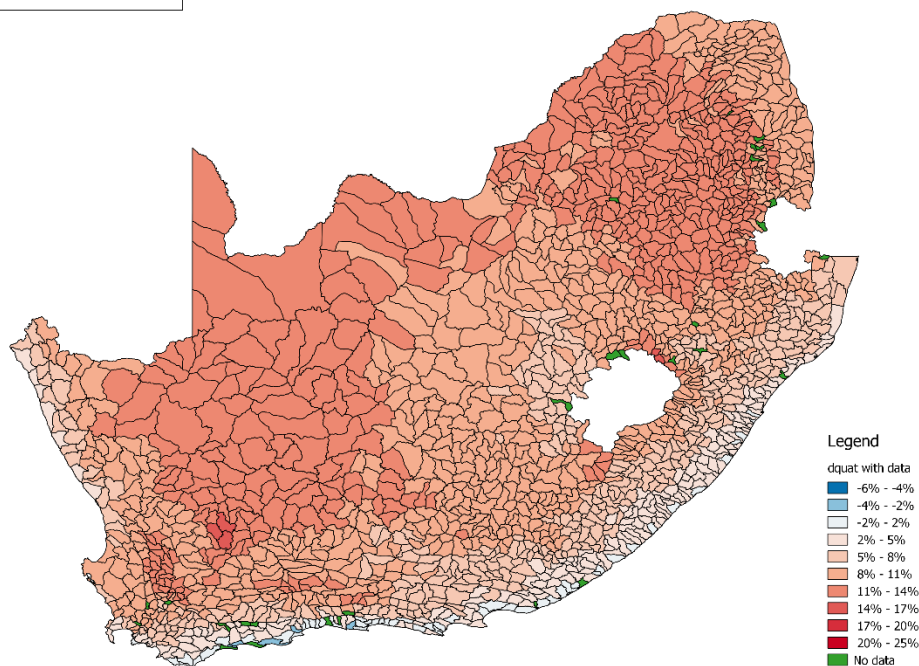


Figure 29: 2050 50th percentile change in MAE

2050 90th PERC CHANGE MAE PER
QUATERNARY CATCHMENT

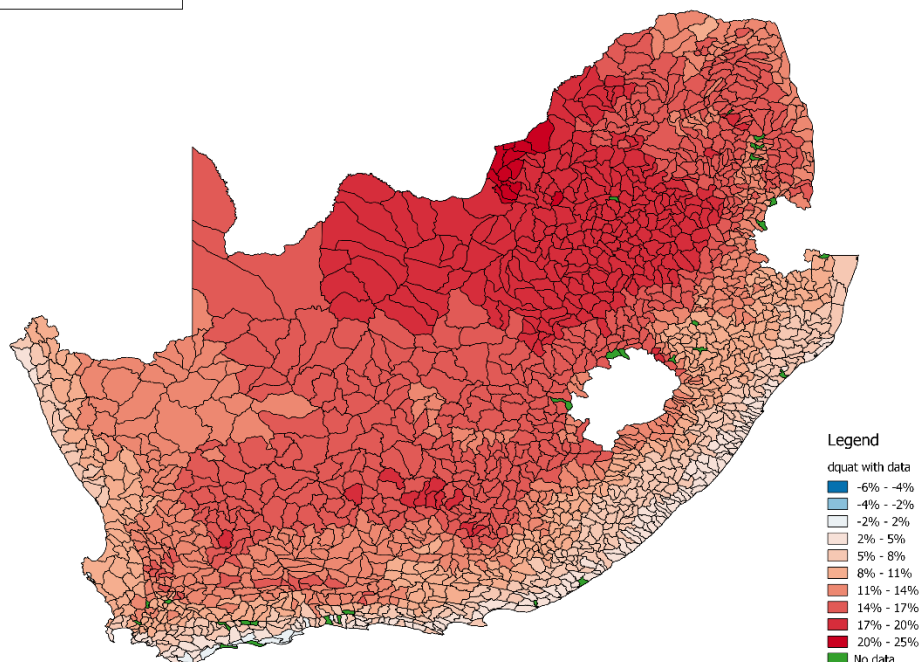


Figure 30: 2050 90th percentile change in MAE

4.2.3 Runoff

The estimated impacts of climate change on the MAR for the 10th (i.e. wet), 50th (median) and 90th (i.e. dry) percentile climate change scenario are shown in Figure 31, Figure 32 and Figure 33. These results show a general increase in runoff in the east and general reduction in runoff in the west under the median climate change scenario which is consistent with the anticipated changes in precipitation and also with previous studies. Even under the maximum (wet) scenario there is a reduction in the MAR for the Western Cape catchments. Under the minimum (dry) most catchments show reduced MAR, but there are a few in the Free State and Lesotho with potential for an increase in runoff. It is also important to note that these results are for catchment level runoff only and do not take into account the cumulative effects of water moving downstream from one catchment to the next. They also do not take into account the impacts of upstream demands or infrastructure such as dams, canals, pipelines or the contribution of return flows from wastewater treatment works.

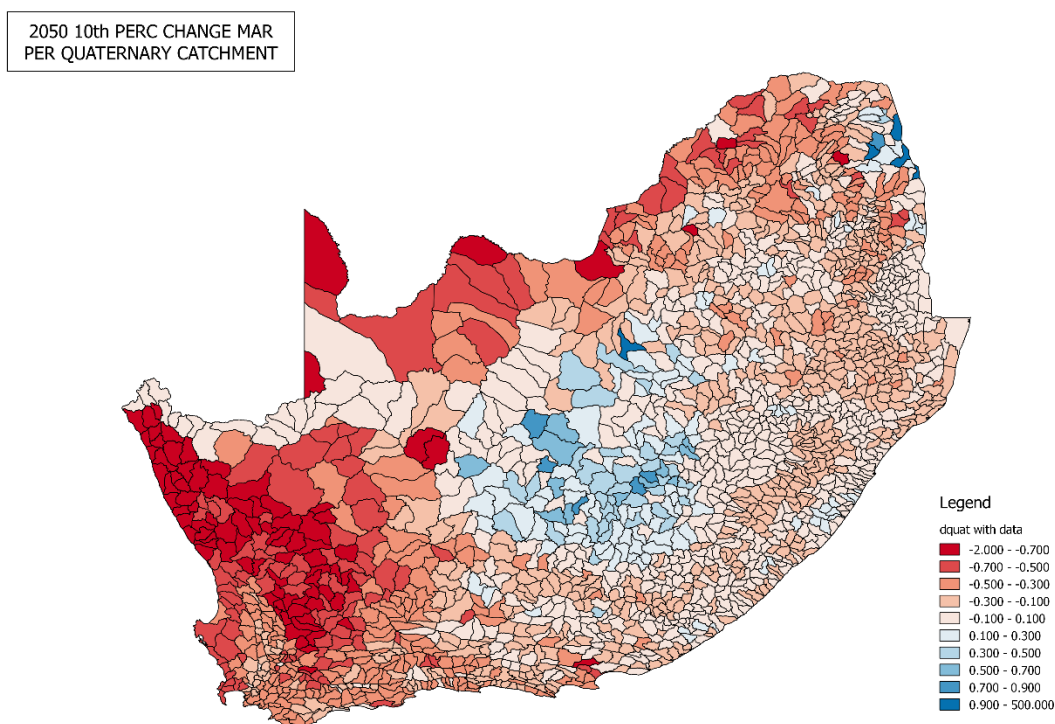


Figure 31: Climate change impacts by 2050 on MAR under the 10% (dry) climate scenario

2050 50TH PERC CHANGE MAR
PER QUATERNARY CATCHMENT

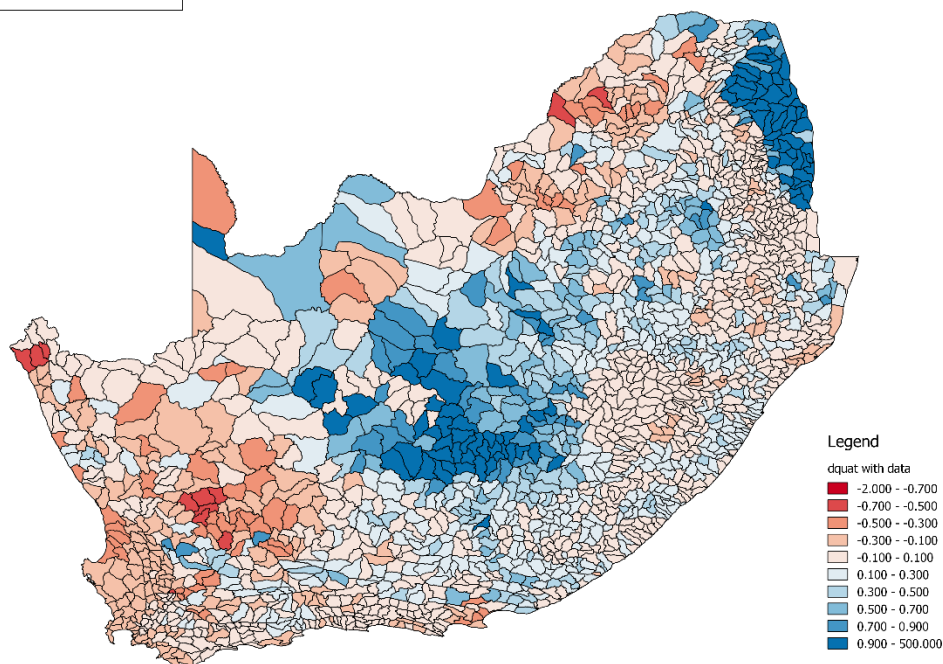


Figure 32: Climate change impacts by 2050 on MAR under the 50% (median) climate scenario

2050 90TH PERC CHANGE MAR
PER QUATERNARY CATCHMENT

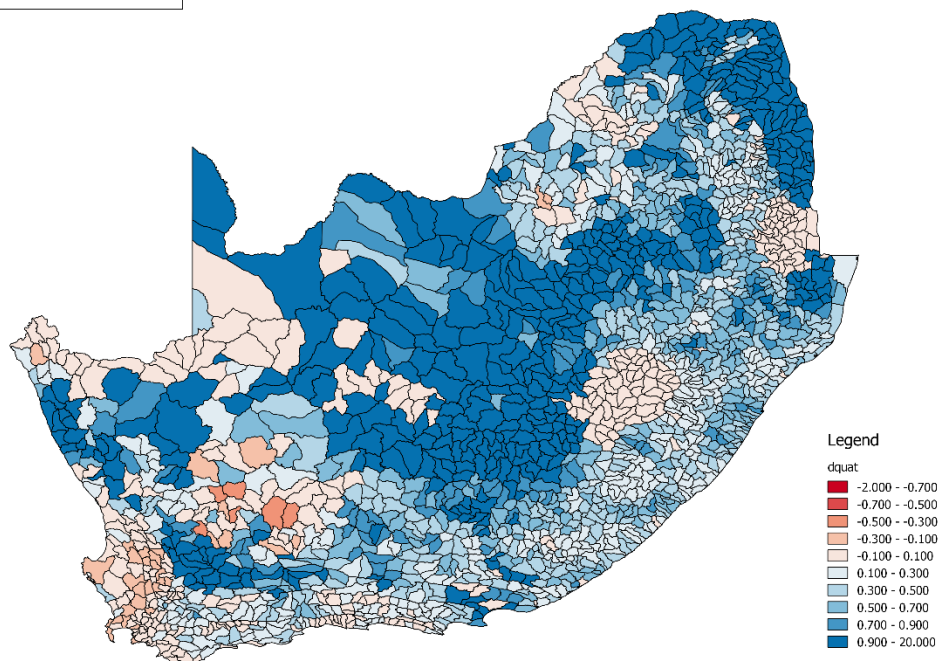


Figure 33: Climate change impacts by 2050 on MAR under the 90% (wet) climate scenario



4.2.4 Water supply impacts

The results of a study to investigate the impacts of climate change on water supply at a national level using a national configuration of the WRYM (DEA, 2015a and Cullis et al., 2017) are used to estimate the impact of climate change on water supply to urban areas taking into account the potential benefits from the integrated nature of the national bulk water distribution and water infrastructure system. Three of the CSIR CMIP5 scenarios were used to estimate the change in the ability to supply water for urban, bulk and agriculture requirements in each of the 19 original WMAs in this study. Because of the ability to move water around the country and to make use of our major dams, the impact of climate change on bulk water supply to local municipalities that are connected to this integrated bulk water supply system is significantly lower than the impact on local surface water runoff. This study, does however also take into account the potential impact from upstream demands, and so in some cases taking into account the integrated bulk water system could reduce water availability, even in some cases where there might be a slight increase in local surface water.

Figure 34 shows the total demand from each sector in each of the original 19 WMAs as well as the percentage of the average annual demand from urban water users that can be met over a ten-year period up to 2050 based on the current climate and the full range of future climate scenarios considered. The results indicate that many of the WMAs will not be able to provide for future water demands without significant water supply augmentation, but that climate change will have an added impact on this. In some cases, climate change may assist in meeting these future demands, and in other cases it will reduce the water availability. The challenge is the range of uncertainty. The major demand centres such as Gauteng (WMA 3 and 8) appear to be able to meet future demands, despite climate change. This is largely because of the inclusion of Polihali Dam. Water supply to Cape Town (WMA 19) will most likely reduce, but only by a few percent. Some of the smaller urban areas appear to have greater risk, partly because they are not part of a large bulk water supply system. The greatest risk across all scenarios appears to be in WMA 16 which is the Gouritz WMA

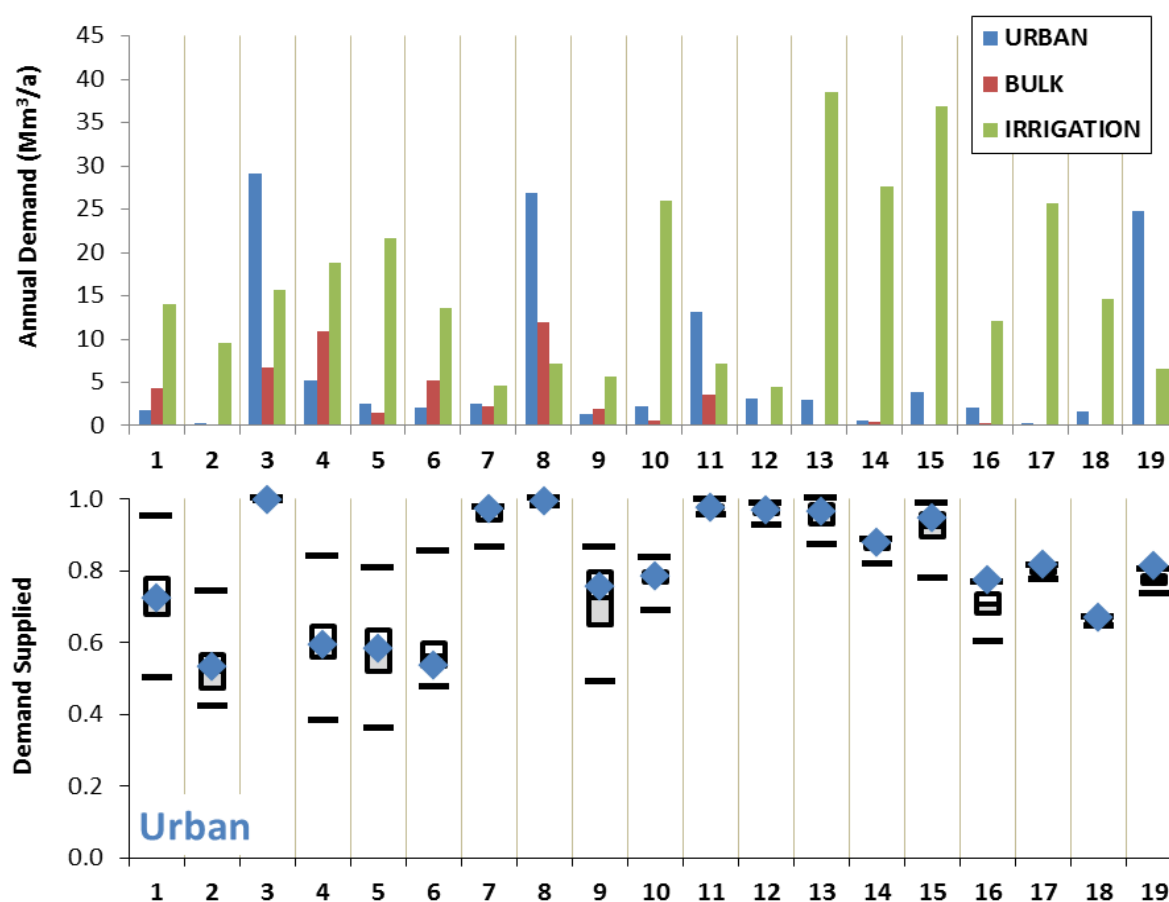


Figure 34: Range of possible impacts of climate change on average annual water supply to 19 WMAs by 2050 relative to the base climate scenario (DEA, 2015 and Cullis et al., 2015)

The relative change in the ability to supply the average annual urban water demand from each WMA by 2050 is shown in Figure 35 for the 10th, 50th and 90th percentile for each WMA. Again, this shows how climate change could even potentially result in an increase in water availability, as a result of the potential for increasing precipitation, particularly in the strategic water source areas including in Lesotho. Unfortunately this study (DEA, 2015a) did not go down to the level of individual municipalities and as a result we have had to apply the overall impact on urban water supply for the WMA in which the municipality is located as a first order estimate of the potential impact on water supply to that municipality taking into account the potential benefits from being part of an integrated regional (and in some cases national) water supply system.

2050 10TH PERC URBAN WATER
SUPPLY CHANGE PER WMA

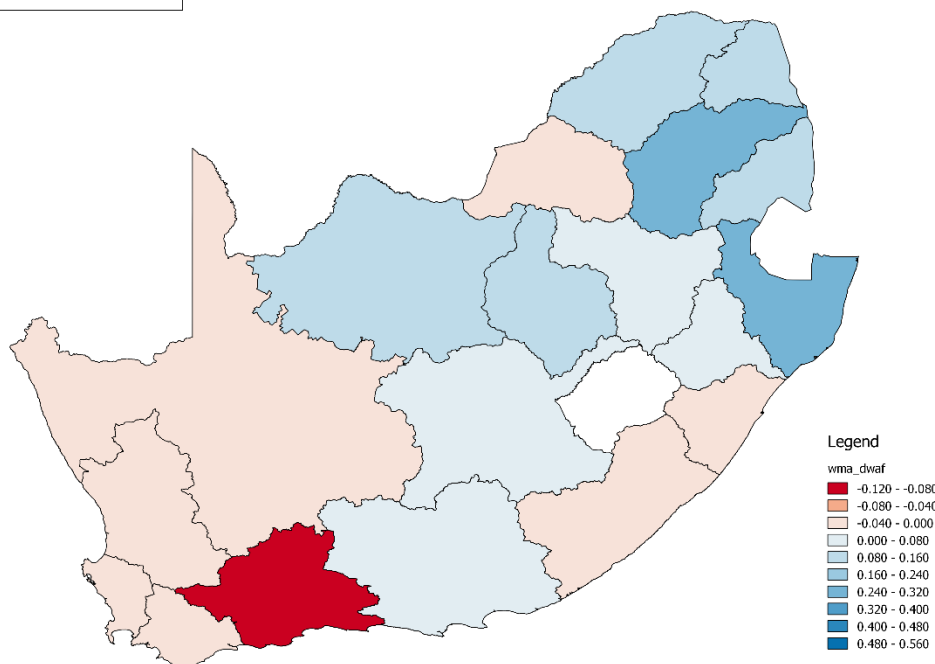


Figure 35: Climate change impacts by 2050 on urban water supply under the 10% (dry) climate scenario

2050 50TH PERC URBAN WATER
SUPPLY CHANGE PER WMA

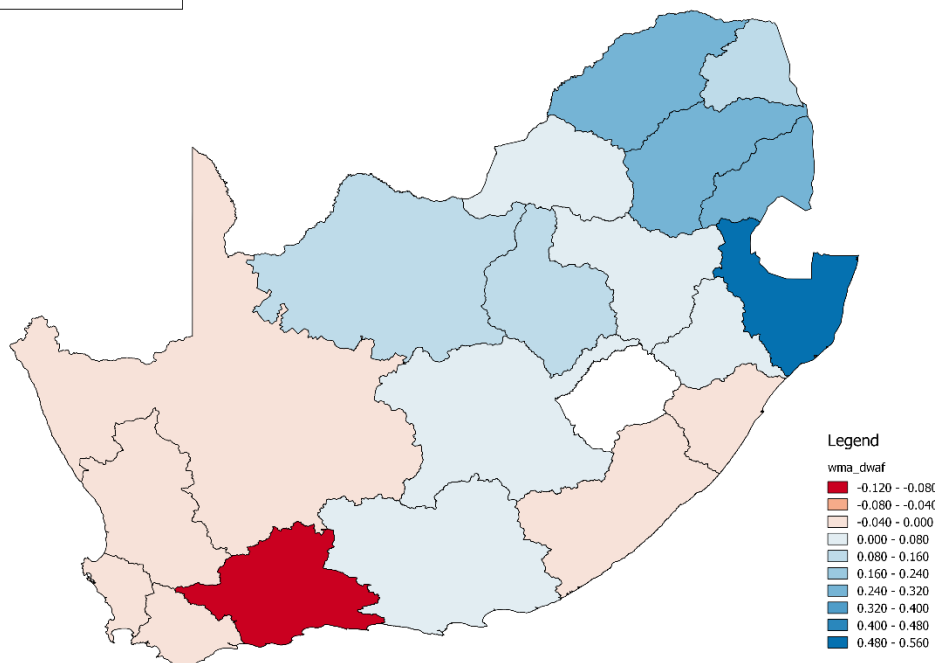


Figure 36: Climate change impacts by 2050 on urban water supply under the 50% (median) climate scenario

2050 90TH PERC URBAN WATER
SUPPLY CHANGE PER WMA

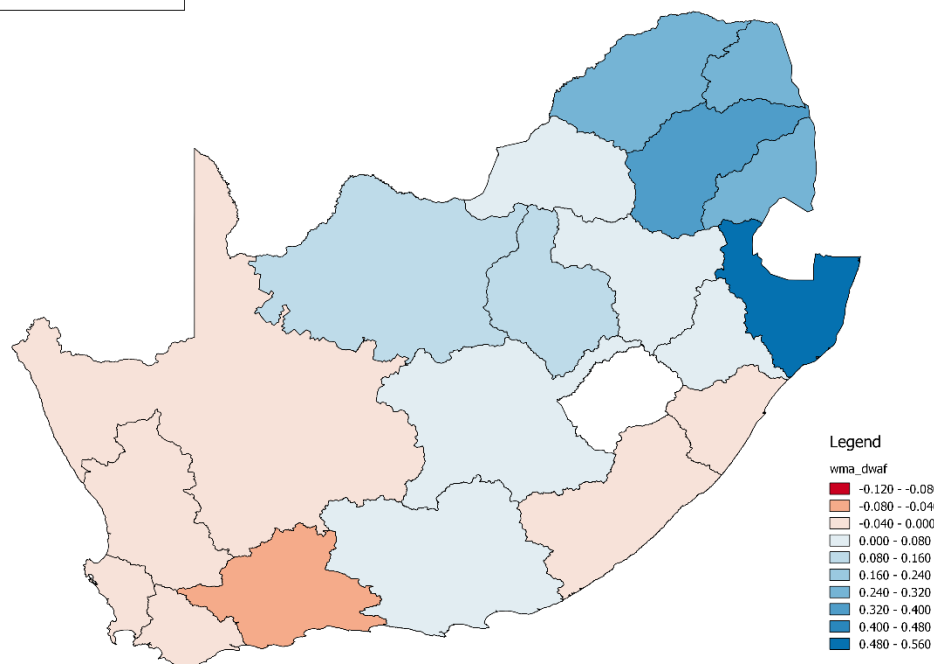


Figure 37: Climate change impacts by 2050 on urban water supply under the 90% (wet) climate scenario

It is important to note that the above results are based on a national scale analysis only. The analysis required substantial simplification of the existing water supply infrastructure as well as other local impacts on precipitation, catchment runoff and water supply. The analysis was also based on time series simulation and determined in terms of the potential impact on the average annual supply and did not consider specific impacts during critical periods or the potential for increased frequency of droughts and extreme events that would impact on the yield from the system. More specific results in selected WMAs or for individual catchments or towns require more detailed water supply models as well as stochastic analysis of alternative baseline and future scenarios to determine the potential impact on the total system yield and not just in terms of potential impacts on average annual supply. It is recommended that more focused studies of each of the major bulk water supply systems as well as the stand alone schemes operated by DWS and individual schemes for towns be done, particularly for the municipalities identified as potentially being at high risk due to future climate change impacts.



4.2.5 Overall exposure

The overall exposure to future climate change risks for water supply is calculated in two ways:

$$\text{Exposure (E}_1\text{)} = \frac{\Delta MAE}{(\Delta MAR \times \%SW) + (\Delta MAP \times \%GW)}$$

$$\text{Exposure (E}_2\text{)} = \frac{\Delta MAE}{(\Delta RWS \times \%SW) + (\Delta MAP \times \%GW)}$$

Where: ΔMAR = the change in the Mean Annual Runoff for the catchment in which the town is located (i.e. indicating a dependence on local surface water impacts)

ΔRWS = the change in Regional Water Supply derived from the study used to calculate the impact of climate change on water supply at a WMA scale as a result of the analysis of the national configuration of the WRYM (i.e. indicating a dependence on a national integrated water supply options)

The calculated level of exposure to the 10th (dry), 50th (median), and 90th (wet) climate scenario for local municipalities based on the two different approaches are given in the figures below.

Figure 38, Figure 39 and Figure 40 show the exposure of each local municipality to climate change for evaporation, precipitation and local runoff (i.e. based on E1). Figure 41, Figure 42 and Figure 43 show the exposure of each local municipality to climate change for evaporation, precipitation and regional water supply (i.e. based on E2). These figures all consider the local municipality's relative reliance on groundwater and surface water for their water supply.

When looking at the climate change exposure for both the impacts on surface water runoff (scenario E1) and the impacts on the regional water supply system (scenario E2) for the 10th, 50th and 90th percentiles, the West Coast of South Africa seems to be more exposed than the eastern portions of South Africa. This is because there is a decrease in runoff and regional water supply and precipitation in the west when compared to the increases that are to be experienced in the east. While there may be only a limited difference in the impact on the median scenario, the benefits of being connected to a regional bulk water supply system are shown by the smaller impacts under the E2 scenario particularly for the dry (10th percentile) scenario. The fact that the impact/benefit is also less in the wet (90th percentile) scenarios indicates the importance of taking into consideration up-stream demands, particularly when these are competing demands, or have first access to water.

2050 10TH PERC CHANGE E1 PER
LOCAL MUNICIPALITY

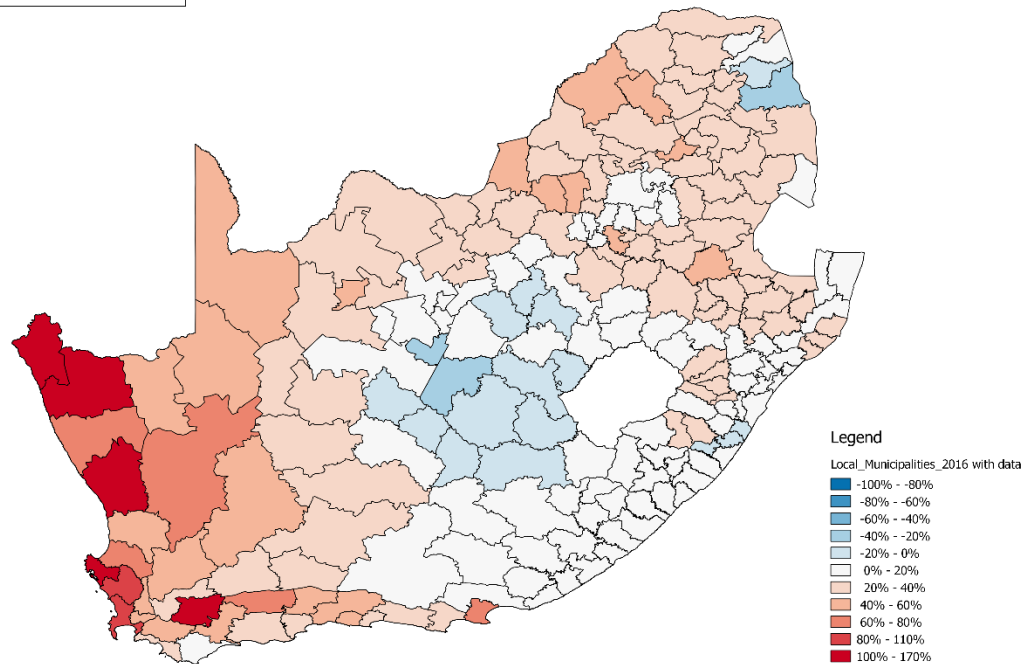


Figure 38: Climate change exposure (E1) by 2050 10% (dry) climate scenario considering local runoff changes

2050 50TH PERC CHANGE E1 PER
LOCAL MUNICIPALITY

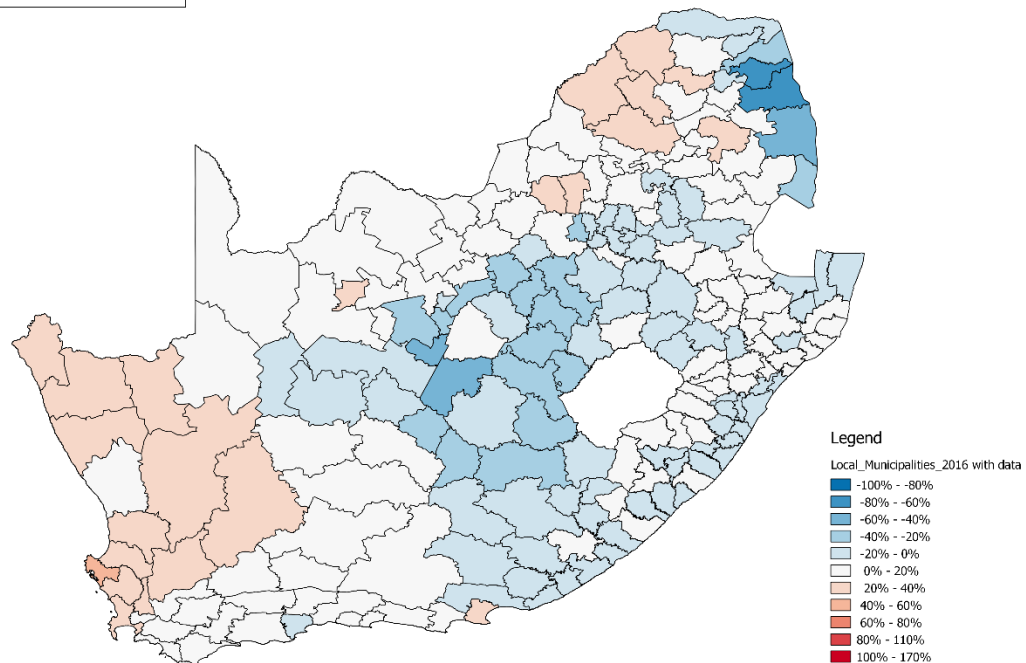


Figure 39: Climate change exposure (E1) by 2050 50% (median) climate scenario considering local runoff changes

2050 90TH PERC CHANGE E1 PER
LOCAL MUNICIPALITY

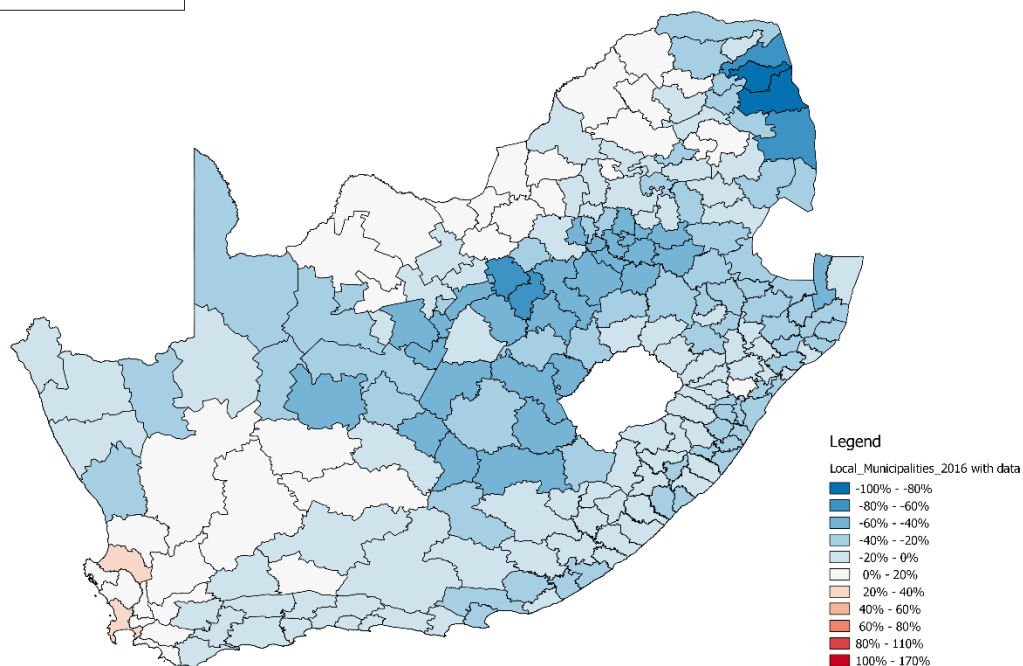


Figure 40: Climate change exposure (E1) by 2050 90% (wet) climate scenario considering local runoff changes

2050 10TH PERC CHANGE E2 PER
LOCAL MUNICIPALITY

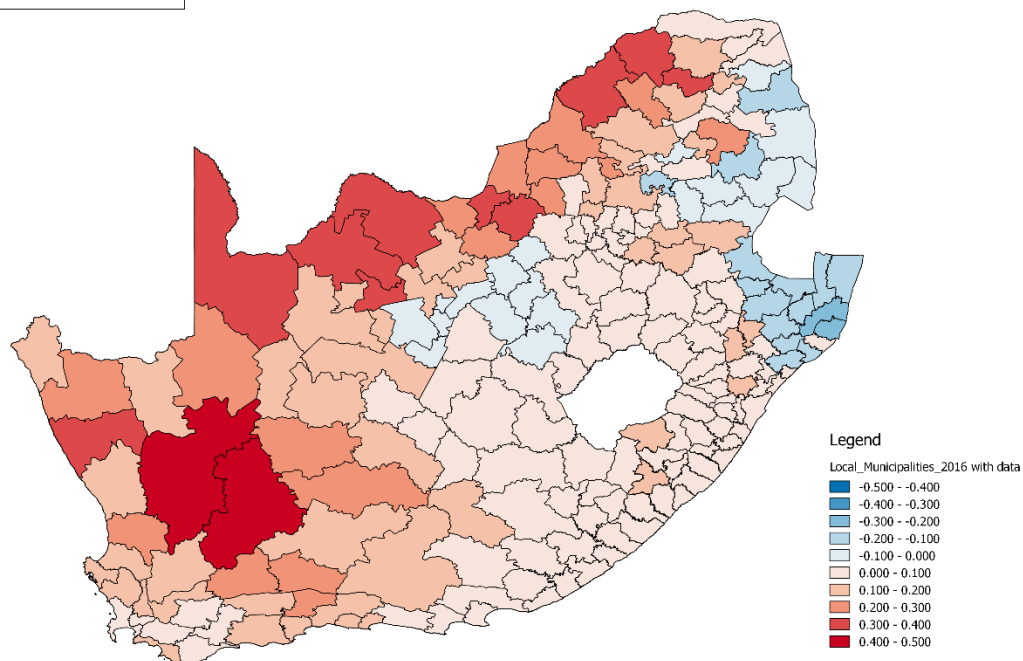


Figure 41: Climate change exposure (E2) by 2050 10% (dry) climate scenario considering regional urban water supply changes

2050 50TH PERC CHANGE E2 PER
LOCAL MUNICIPALITY

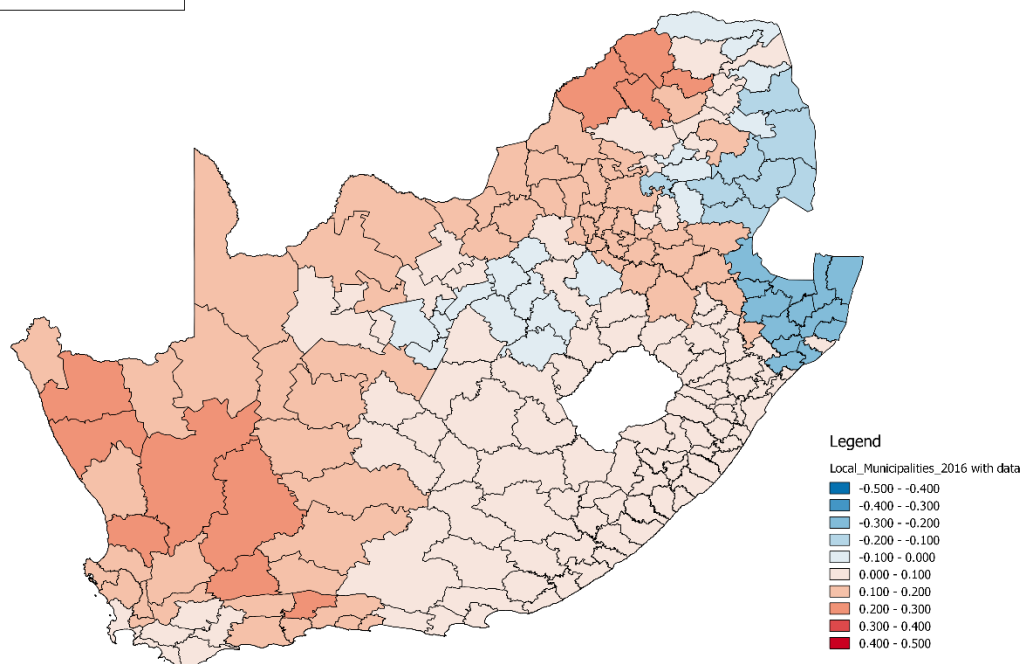


Figure 42: Climate change exposure (E2) by 2050 50% (median) climate scenario considering regional urban water supply changes

2050 90TH PERC CHANGE E2 PER
LOCAL MUNICIPALITY

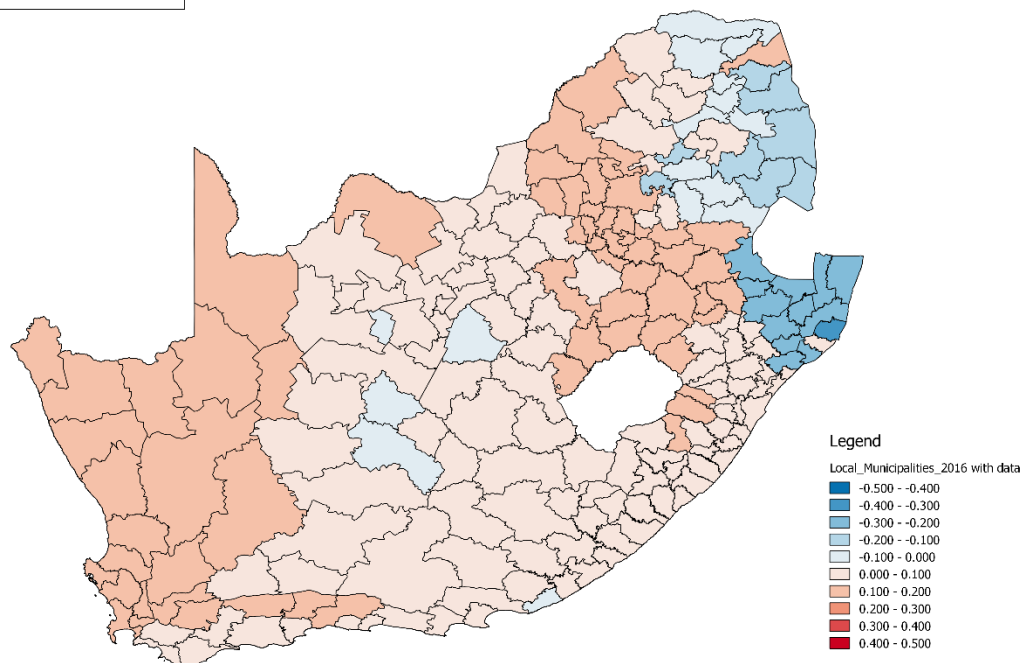


Figure 43: Climate change exposure (E2) by 2050 90% (wet) climate scenario considering regional urban water supply changes



The reason for including the percentage reliance on surface water and groundwater for water supply is because the study's focus is on water supply therefore the percentage reliance of a local municipality on surface water and groundwater for water supply would affect the overall exposure that the local municipality has to water supply. For instance, a decrease in MAR of 10% for a town which is 100% reliant on surface water would have the same effect as a town which experiences a 20% decrease in MAR but is 50% reliant on surface water for water supply. The same is true for the change in MAP and the local municipality's reliance on groundwater as the change in MAP affects the groundwater supply. There are several other factors which would need to be considered to ensure that this is true, such as the seasonal change of rainfall. Examples of this are the following two local municipalities:

- Nkomazi Local Municipality located in the Ehlanzeni District Municipality of Mpumalanga could experience on average a 38% increase in MAR, 10% increase in MAE, 2% increase in MAP and is 100% reliant on surface water for water supply. Therefore its exposure to changes in MAR, MAP and MAE is 79%. This implies a reduction in overall vulnerability of 21%.
- Renosterberg Local Municipality located in the Pixley Ka Seme District Municipality of the Northern Cape could experience on average a 87% increase in MAR, 10% increase in MAE, 8% increase in MAP and is 60% reliant on surface water for water supply. Therefore its exposure to changes in MAR, MAP and MAE is 71%. This implies a reduction in overall vulnerability of 29%.

These local municipalities experience different changes in MAR and MAE but due to their different percentage reliance on surface water, their exposure to the change in MAR is similar for the climate change impacts on surface water supply. This is shown in Figure 44. The images on the left show the exposure of the two local municipalities, the central images show the change in MAR, MAP and MAE and the images on the right show the percentage reliance on surface water for water supply.

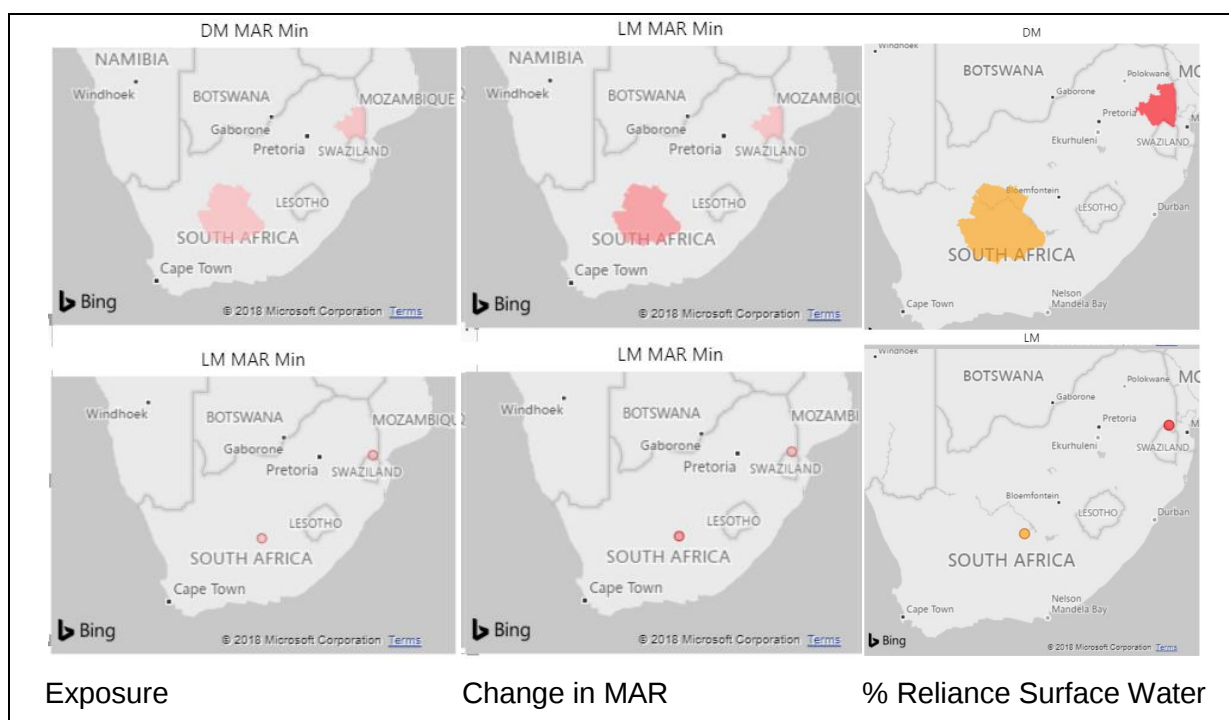


Figure 44: Comparison of Nkomazi Local Municipality and Renosterberg Local Municipality in terms of exposure, MAR and reliance on surface water

4.3 Climate change risk and future vulnerability

The future vulnerability of water supply to all local municipalities, taking into account both climate change impacts and population growth impacts, is shown in Figure 45 to Figure 62. A value of more than one implies that the local municipality's demand is more than its supply and a value of less than one implies that the local municipality's demand is less than its supply.

The future water supply vulnerability for municipalities assuming no population growth is shown in Figure 45 to Figure 50, the future water supply vulnerability for municipalities assuming medium population growth is shown in Figure 51 to Figure 56 and the future water supply vulnerability for local municipalities assuming high population growth for the E1 and E2 scenarios is shown in Figure 57 to Figure 62.

These results show that the Eastern Cape still has the highest level of water supply vulnerability under the future population and climate change scenarios. With no population growth a number of other local municipalities, in the Western Cape and North-West under the dry (10th percentile) scenario are also included (Figure 45). Once population growth is added, many more local municipalities become vulnerable with demand outstripping supply. Under

the worst-case scenario, high population growth and the 10th percentile (dry) scenario nearly half of the local municipalities show severe water supply deficiencies by 2050 (Figure 57).

The relative change in water supply risk for all local municipalities as a result of both the changes in population and potential climate change impacts on water supply are given for the high population growth scenario with respectively 10th, 50th and 90th percentile climate change exposure (E1) scenarios in Figure 63 to Figure 65 and for the high population growth scenario with climate change exposure (E2) scenarios in Figure 66 to Figure 68.

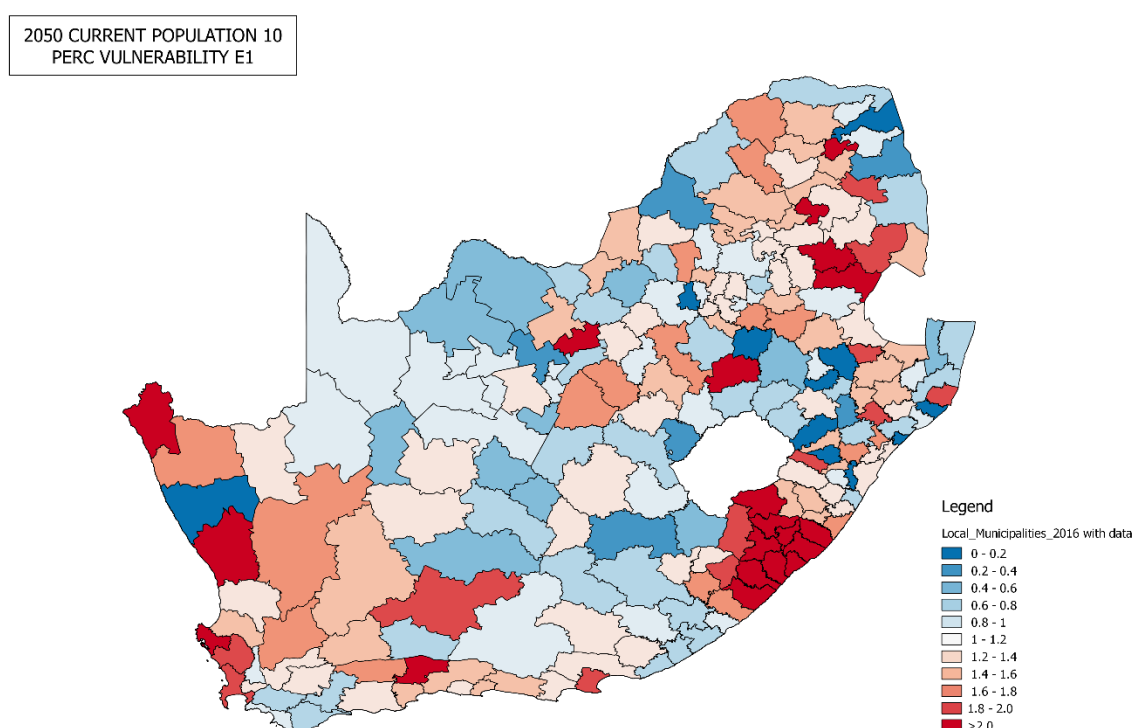


Figure 45: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E1) scenario and 0% population growth

2050 CURRENT POPULATION 50
PERC VULNERABILITY E1

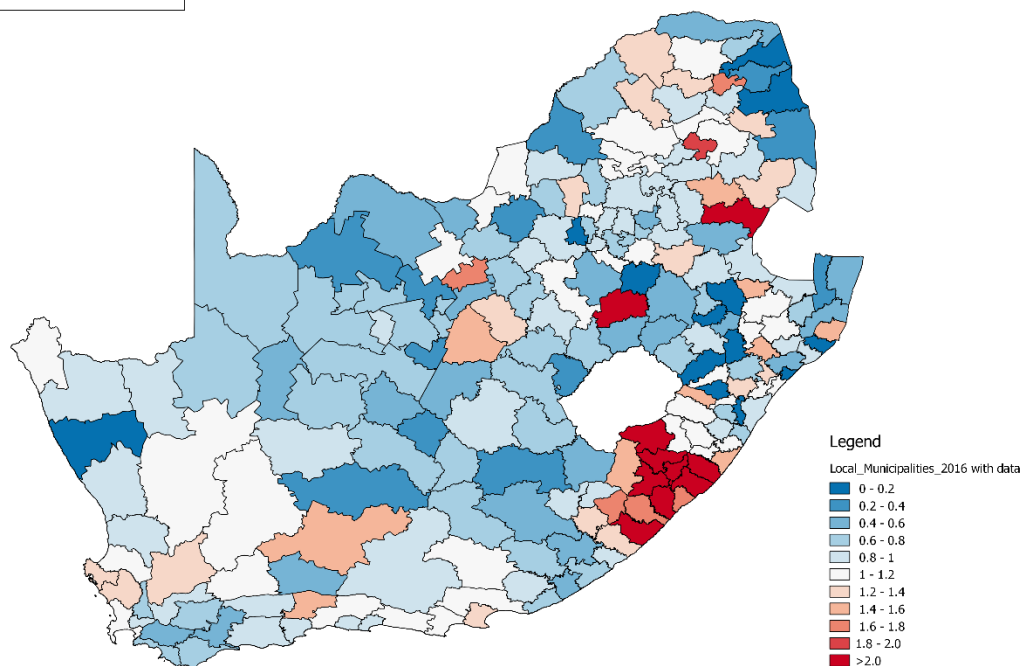


Figure 46: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E1) scenario and 0% population growth

2050 CURRENT POPULATION 90
PERC VULNERABILITY E1

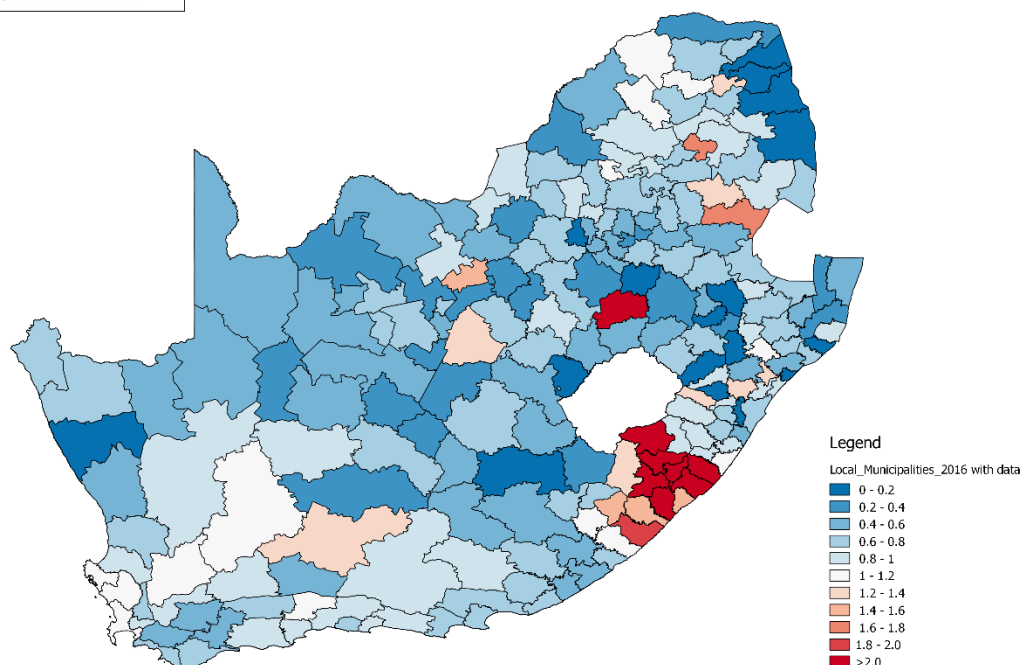


Figure 47: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E1) scenario and 0% population growth

2050 CURRENT POPULATION 10
PERC VULNERABILITY E2

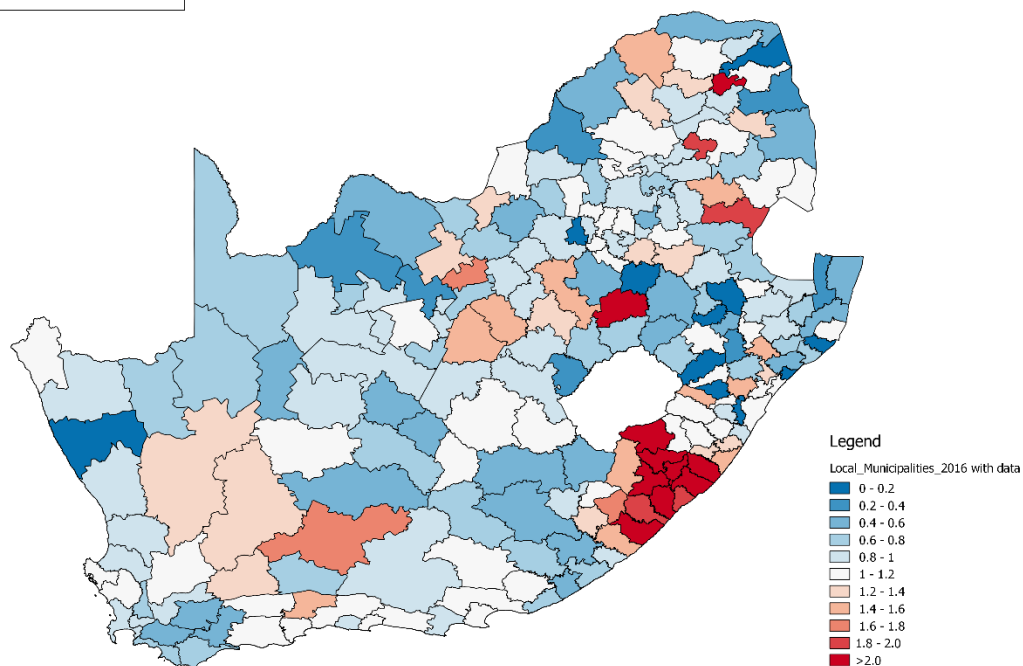


Figure 48: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E2) scenario and 0% population growth

2050 CURRENT POPULATION 50
PERC VULNERABILITY E2

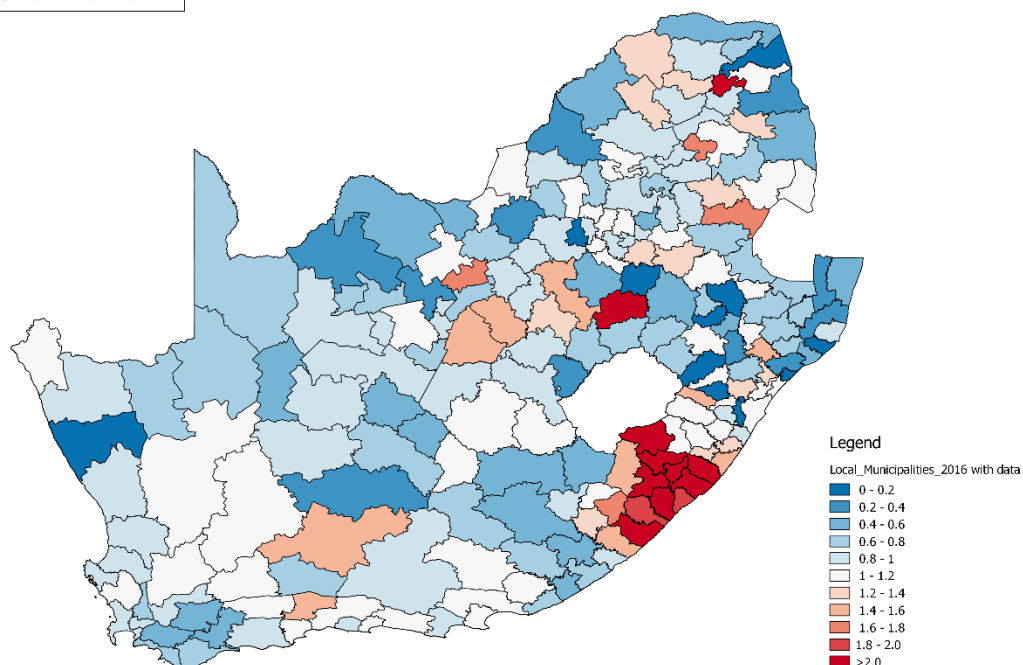


Figure 49: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E2) scenario and 0% population growth

2050 CURRENT POPULATION 50
PERC VULNERABILITY E2

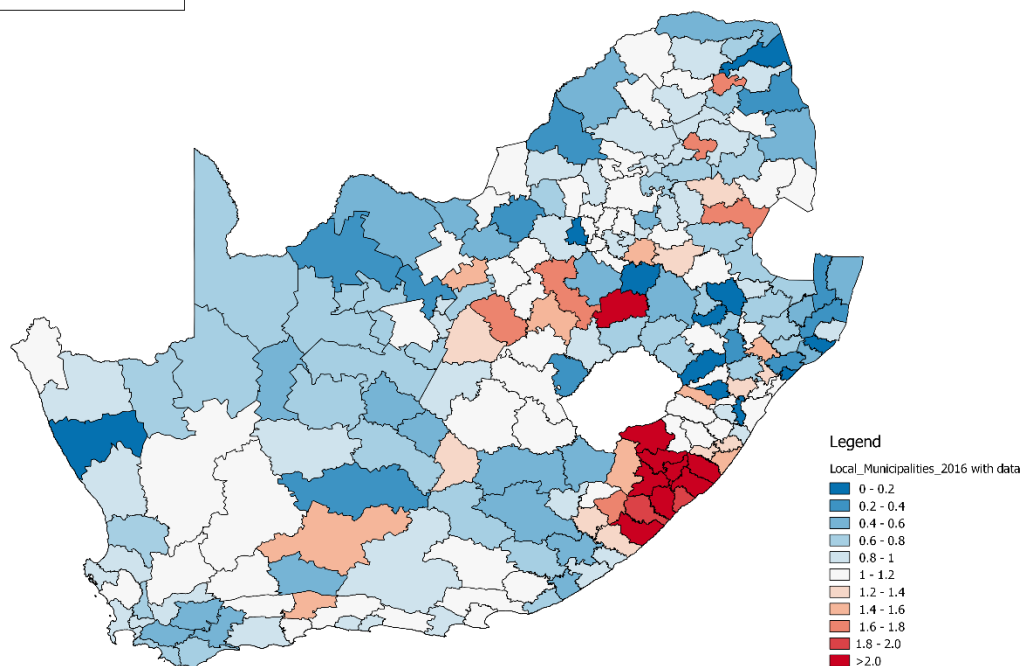


Figure 50: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E2) scenario and 0% population growth

2050 MEDIUM POPULATION 10
PERC VULNERABILITY E1

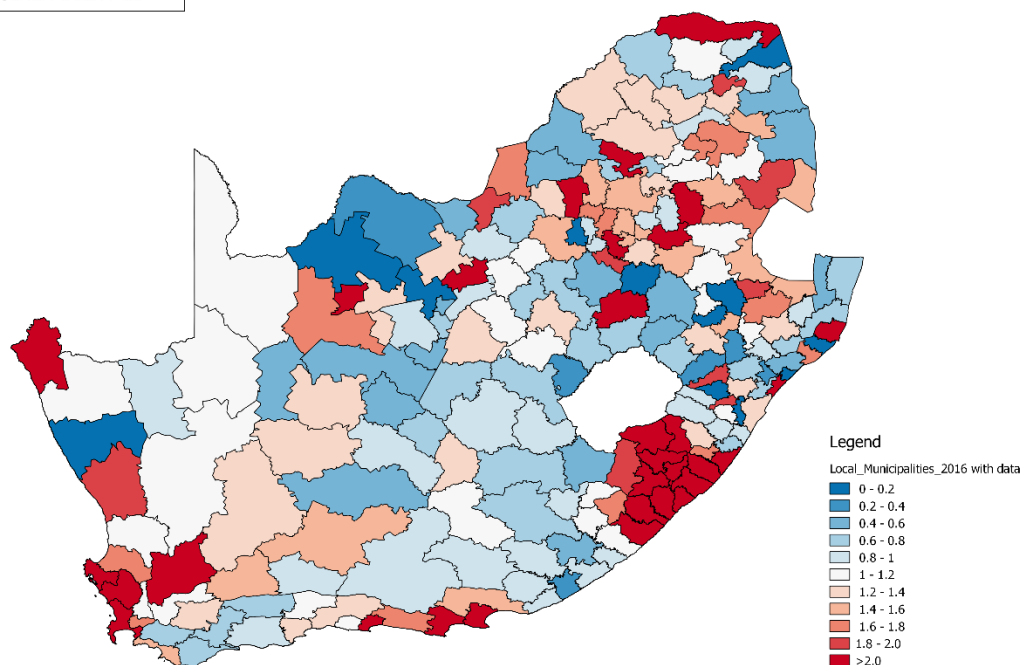


Figure 51: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E1) scenario and medium population growth

2050 MEDIUM POPULATION 50
PERC VULNERABILITY E1

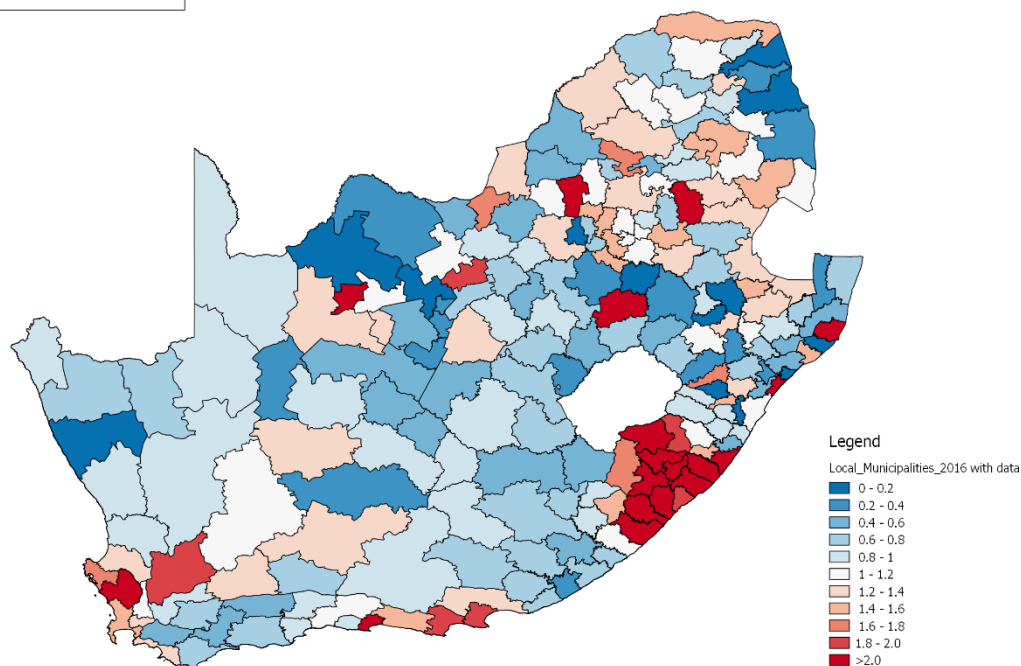


Figure 52: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E1) scenario and medium population growth

2050 MEDIUM POPULATION 90
PERC VULNERABILITY E1

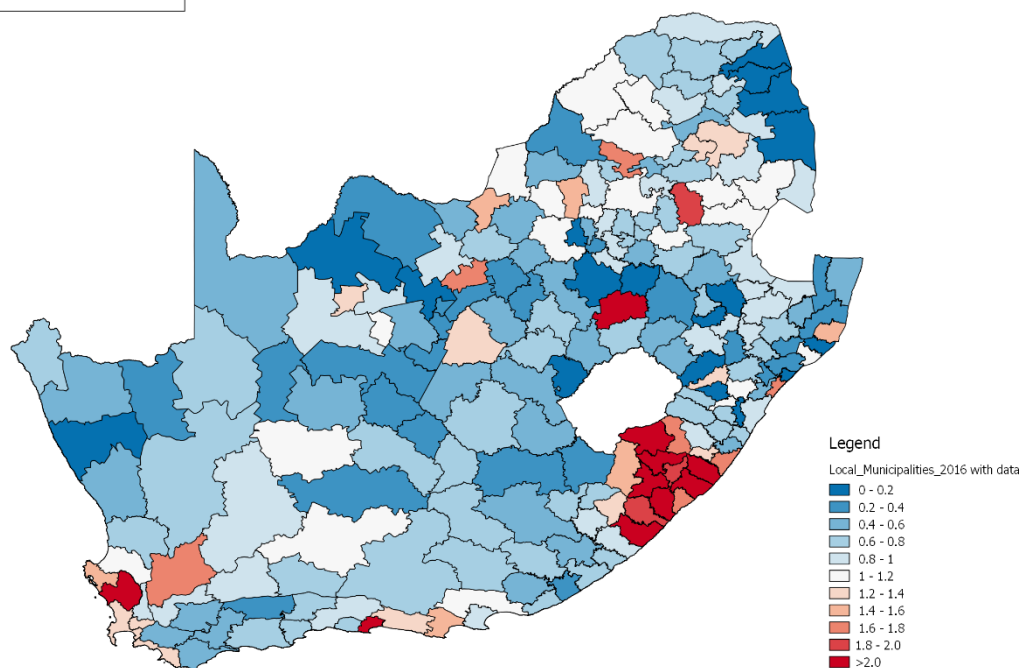


Figure 53: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E1) scenario and medium population growth

2050 MEDIUM POPULATION 10
PERC VULNERABILITY E2

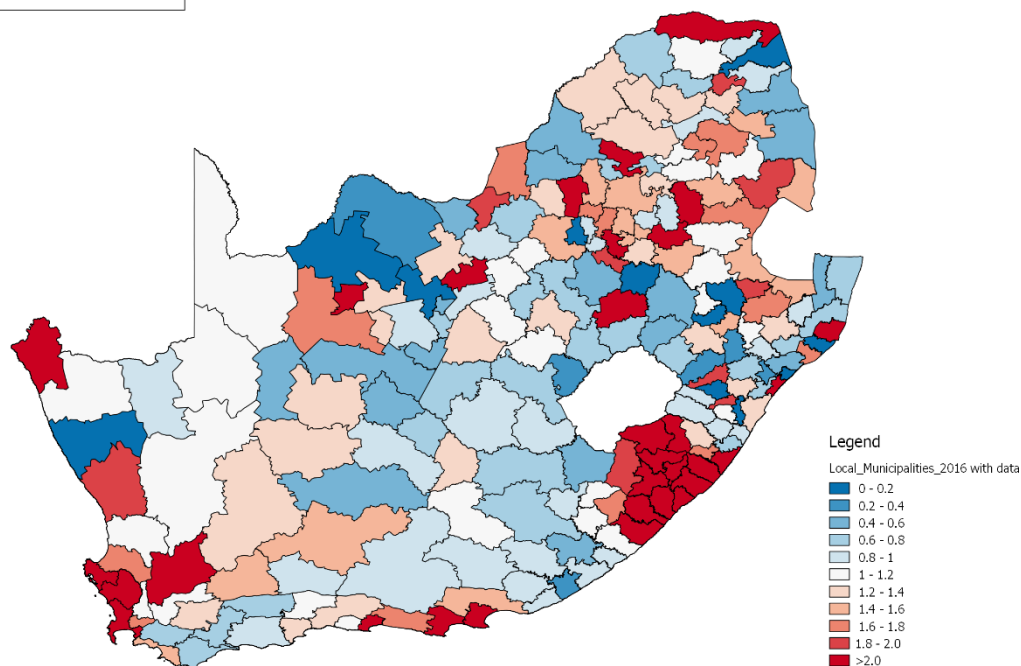


Figure 54: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E2) scenario and medium population growth

2050 MEDIUM POPULATION 50
PERC VULNERABILITY E2

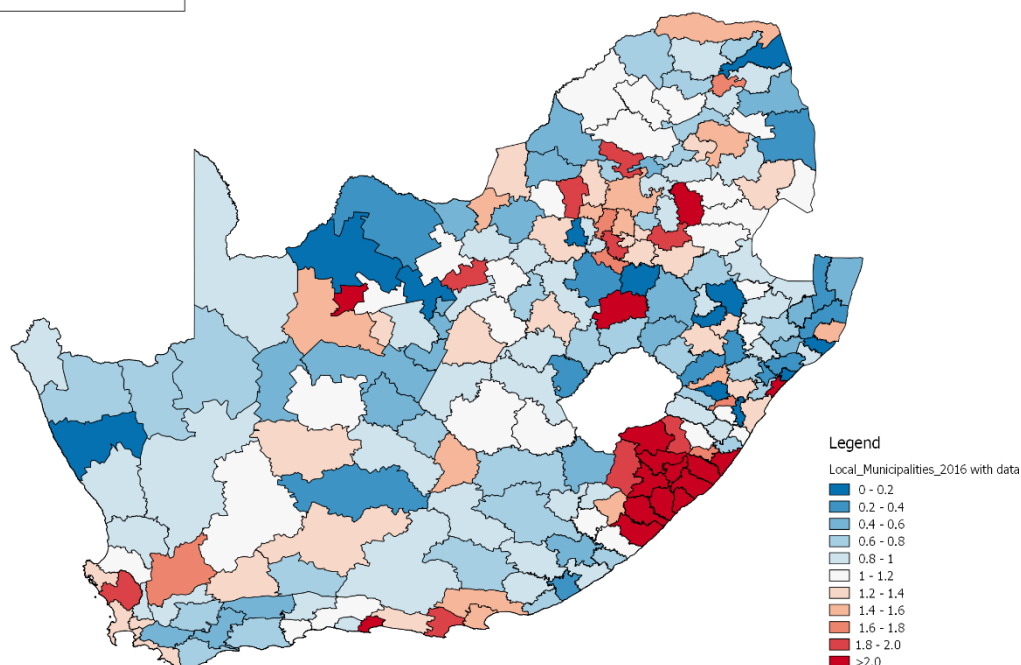


Figure 55: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E2) scenario and medium population growth

2050 MEDIUM POPULATION 90
PERC VULNERABILITY E2

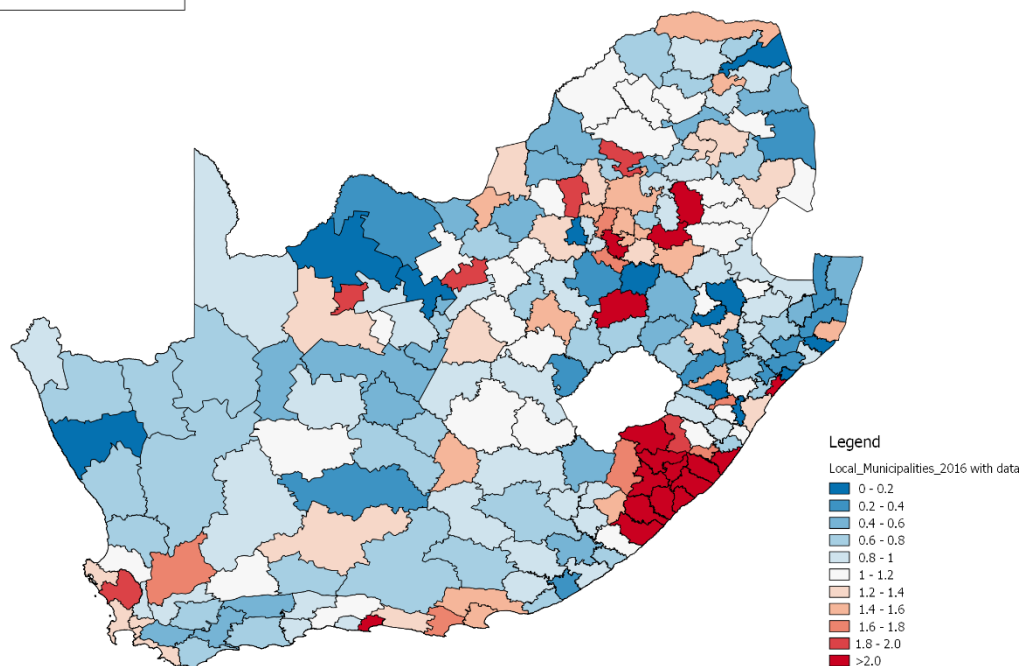


Figure 56: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E2) scenario and medium population growth

2050 HIGH POPULATION 10 PERC
VULNERABILITY E1

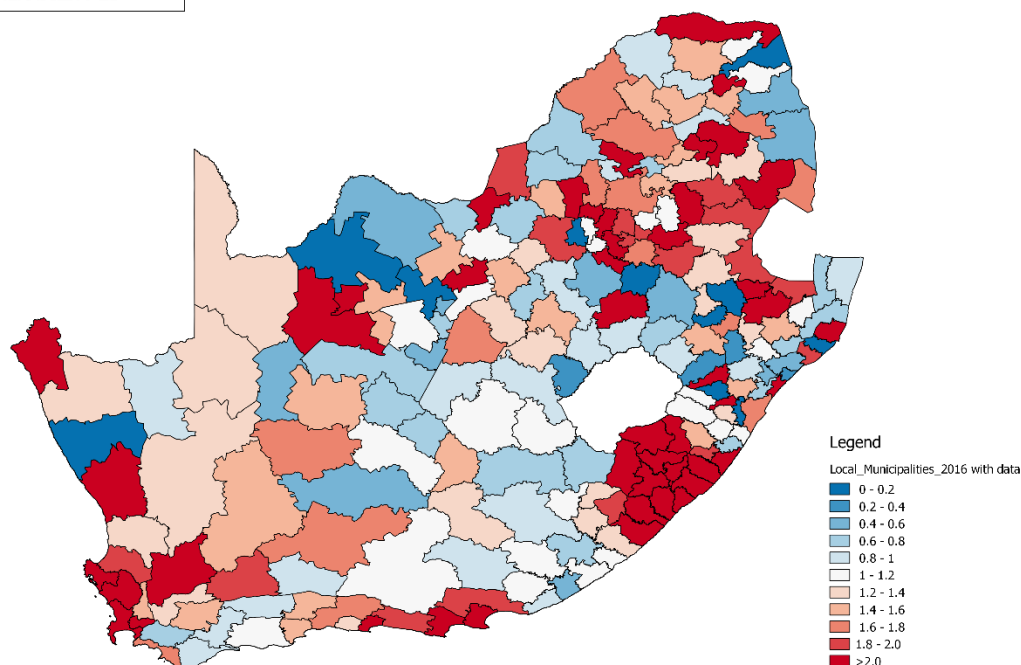


Figure 57: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E1) scenario and high population growth

2050 HIGH POPULATION 50 PERC
VULNERABILITY E1

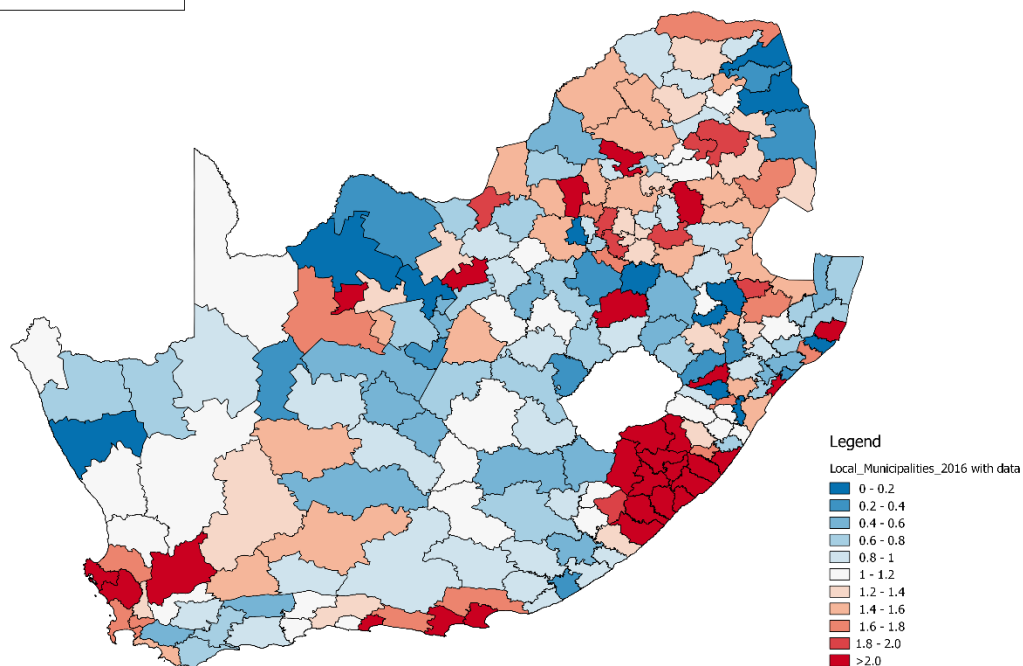


Figure 58: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E1) scenario and high population growth

2050 HIGH POPULATION 90 PERC
VULNERABILITY E1

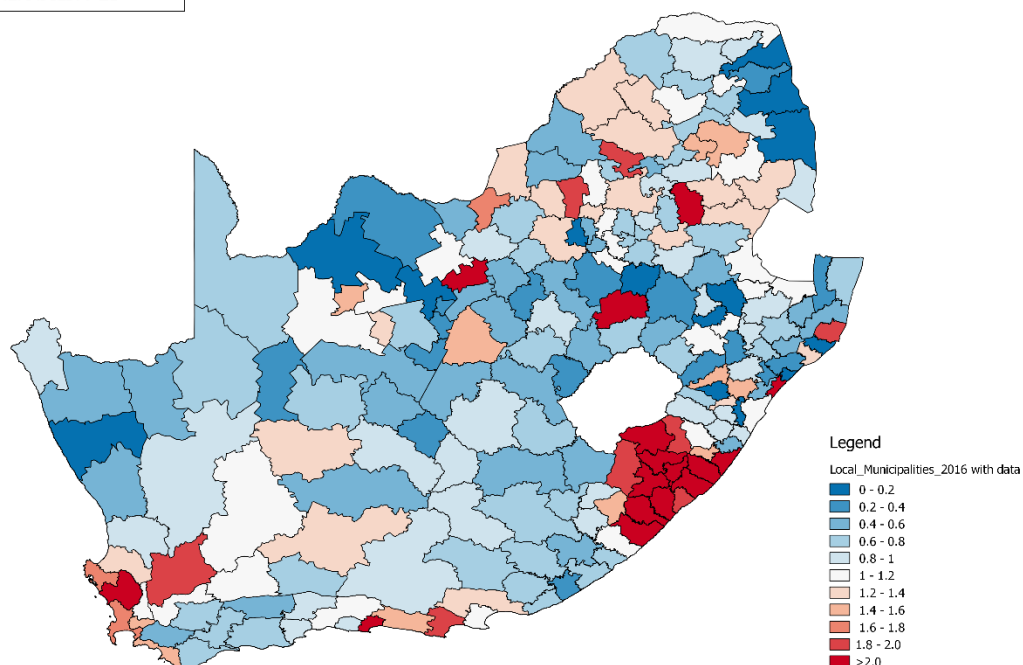


Figure 59: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E1) scenario and high population growth

2050 HIGH POPULATION 10 PERC
VULNERABILITY E2

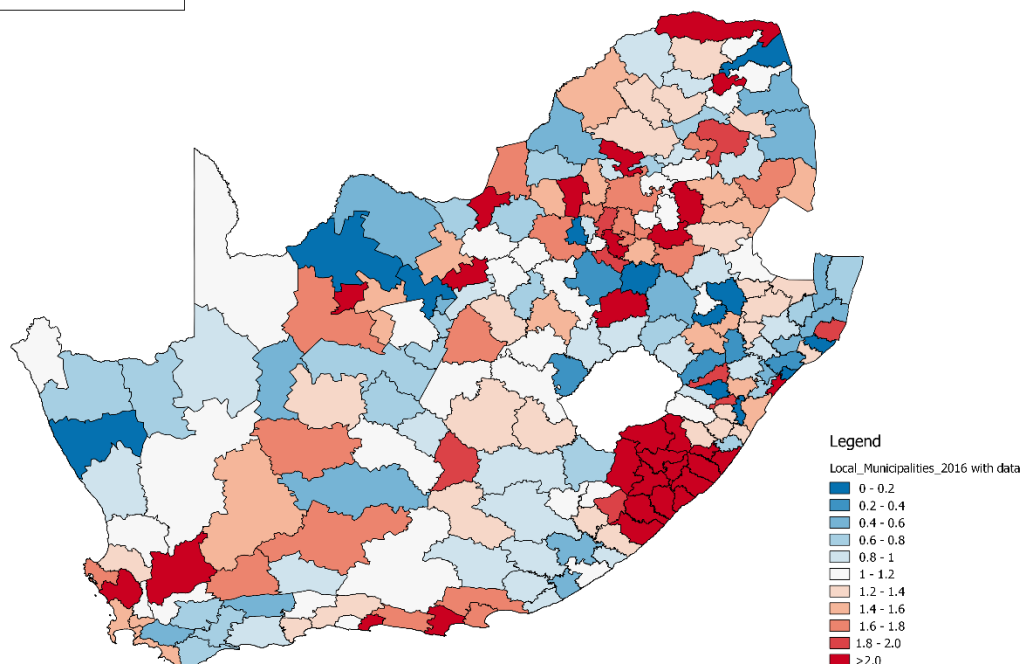


Figure 60: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E2) scenario and high population growth

2050 HIGH POPULATION 50 PERC
VULNERABILITY E2

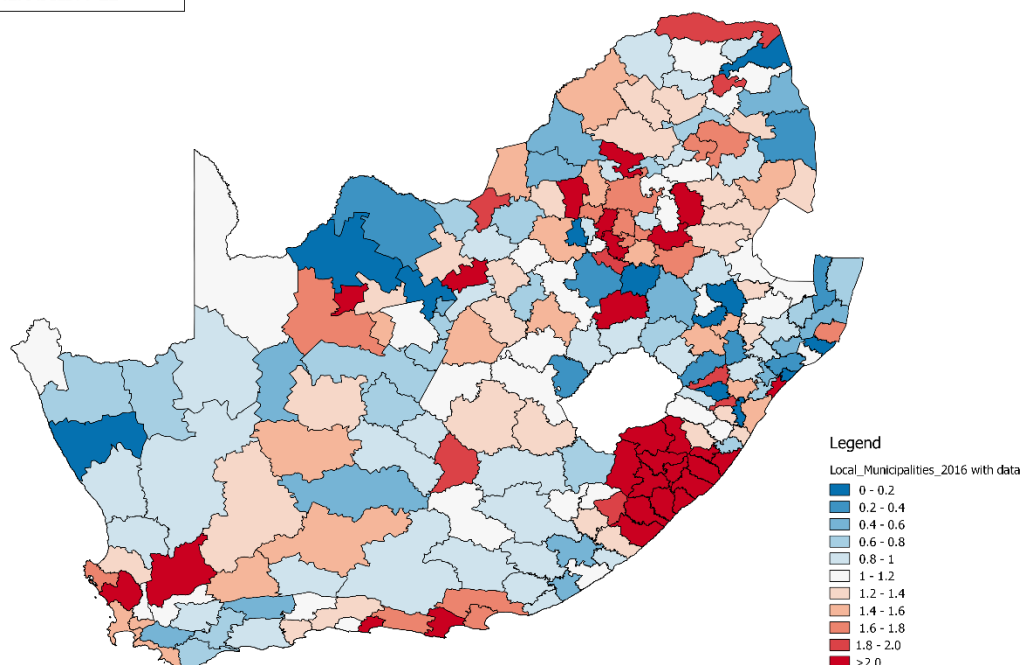


Figure 61: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E2) scenario and high population growth

2050 HIGH POPULATION 90 PERC
VULNERABILITY E2

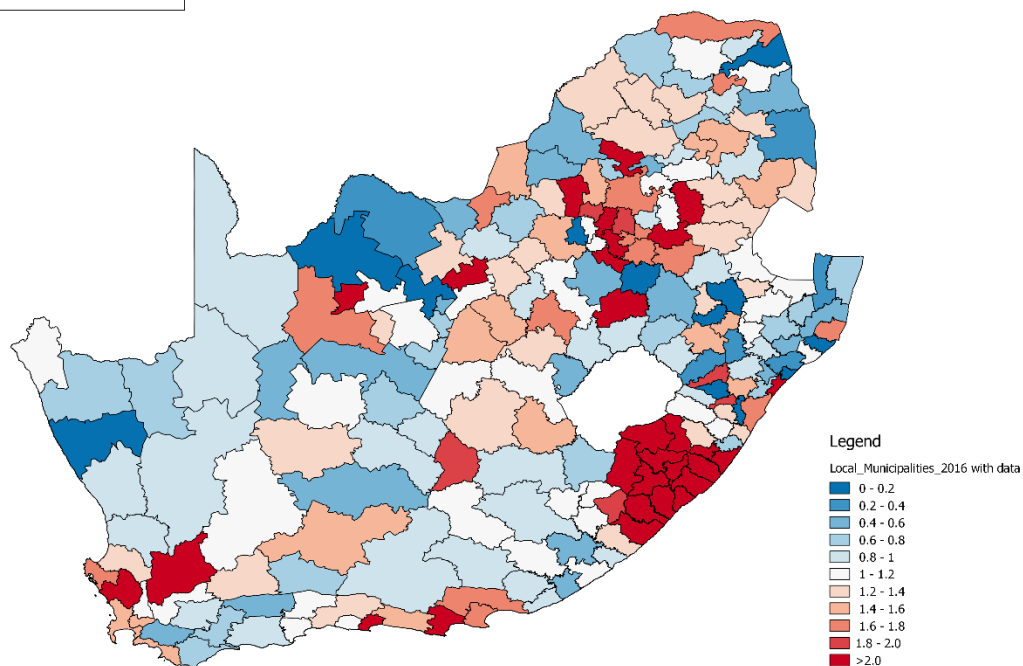


Figure 62: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E2) scenario and high population growth

2050 HIGH POPULATION 10 PERC
RELATIVE CHANGE
VULNERABILITY E1

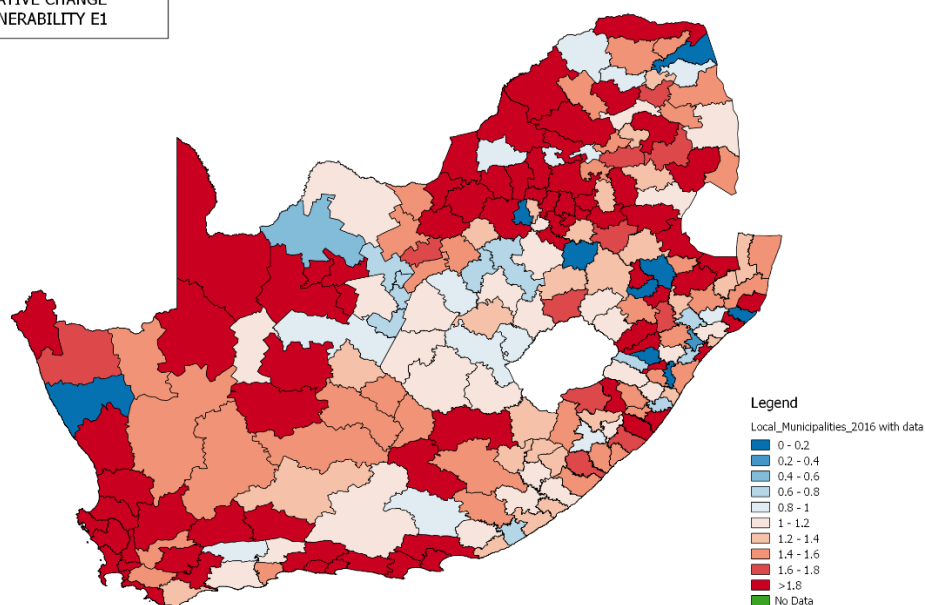


Figure 63: Relative change in water supply vulnerability with 10th percentile (dry) climate change exposure (E1) scenario and high population growth.

2050 HIGH POPULATION 50 PERC
RELATIVE CHANGE
VULNERABILITY E1

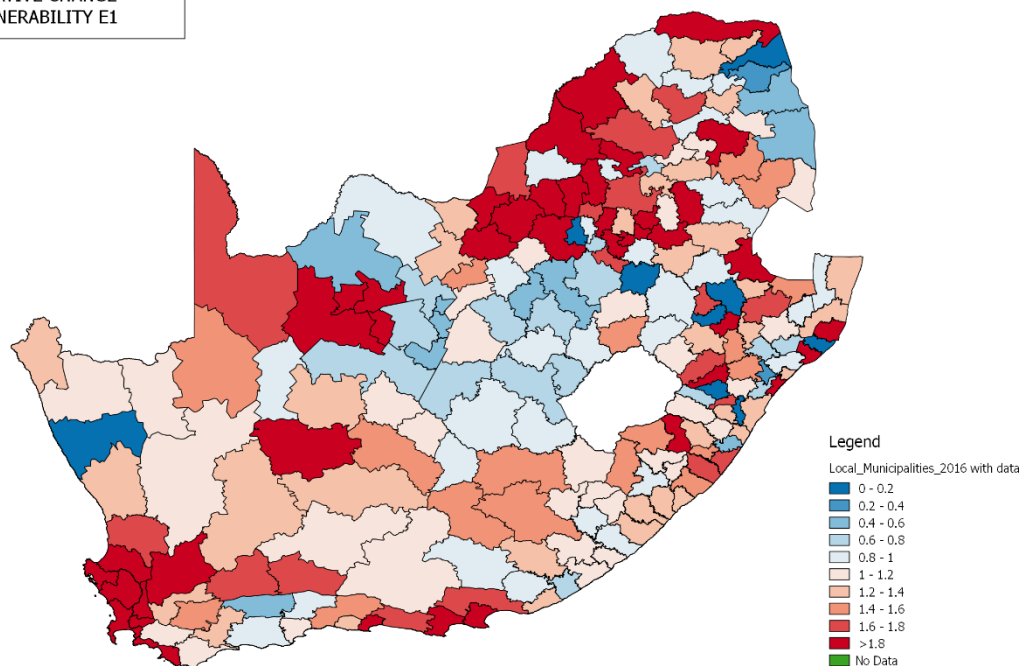


Figure 64: Relative change in water supply vulnerability with 50th percentile (mean) climate change exposure (E1) scenario and high population growth

2050 HIGH POPULATION 90 PERC
RELATIVE CHANGE
VULNERABILITY E1

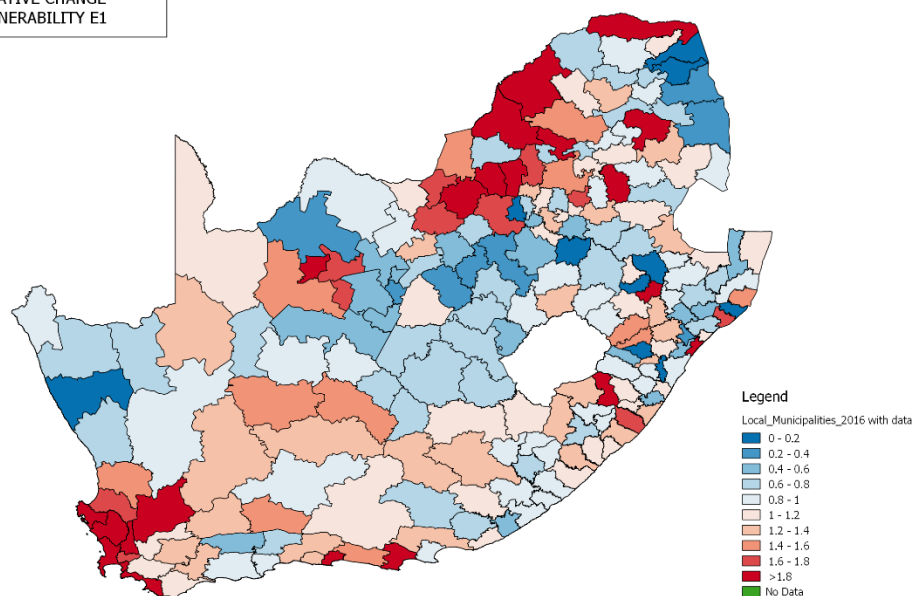


Figure 65: Relative change in water supply vulnerability with 90th percentile (wet) climate change exposure (E1) scenario and high population growth

2050 HIGH POPULATION 10 PERC
RELATIVE CHANGE
VULNERABILITY E2

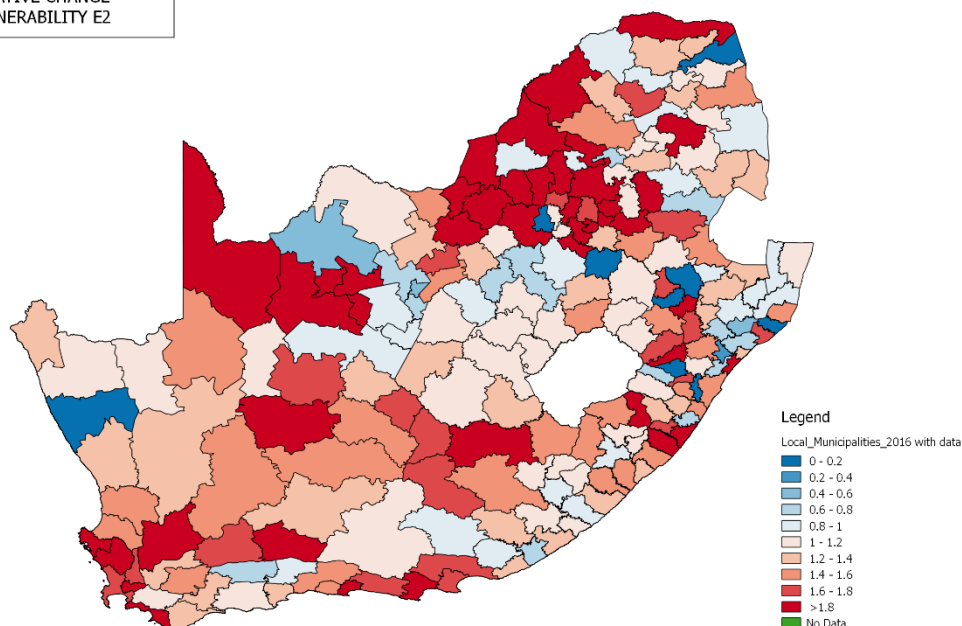


Figure 66: Relative change in water supply vulnerability with 10th percentile (dry) climate change exposure (E2) scenario and high population growth

2050 HIGH POPULATION 50 PERC
RELATIVE CHANGE
VULNERABILITY E2

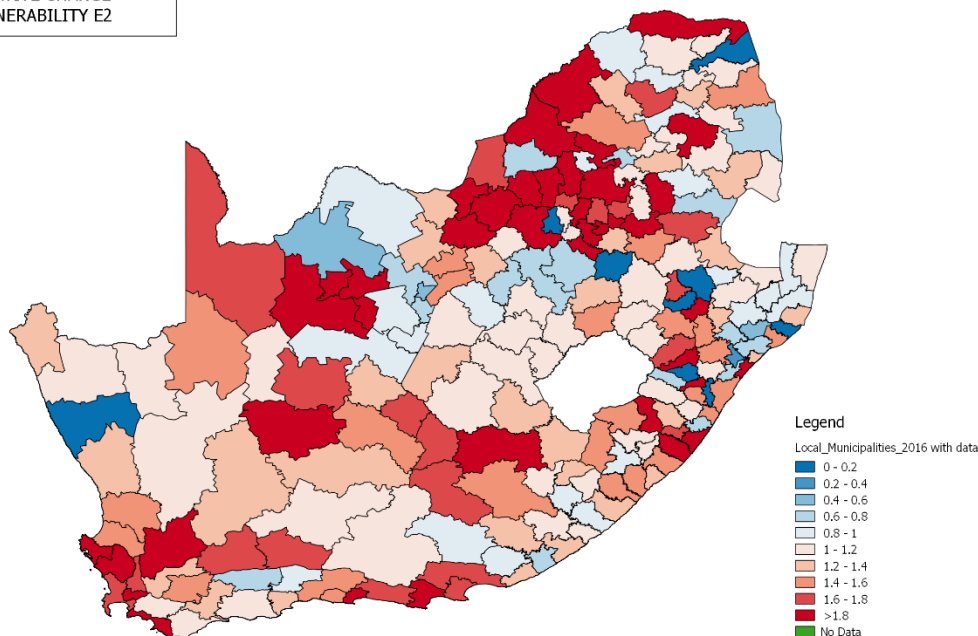


Figure 67: Relative change in water supply vulnerability with 50th percentile (mean) climate change exposure (E2) scenario and high population growth

2050 HIGH POPULATION 90 PERC
RELATIVE CHANGE
VULNERABILITY E2

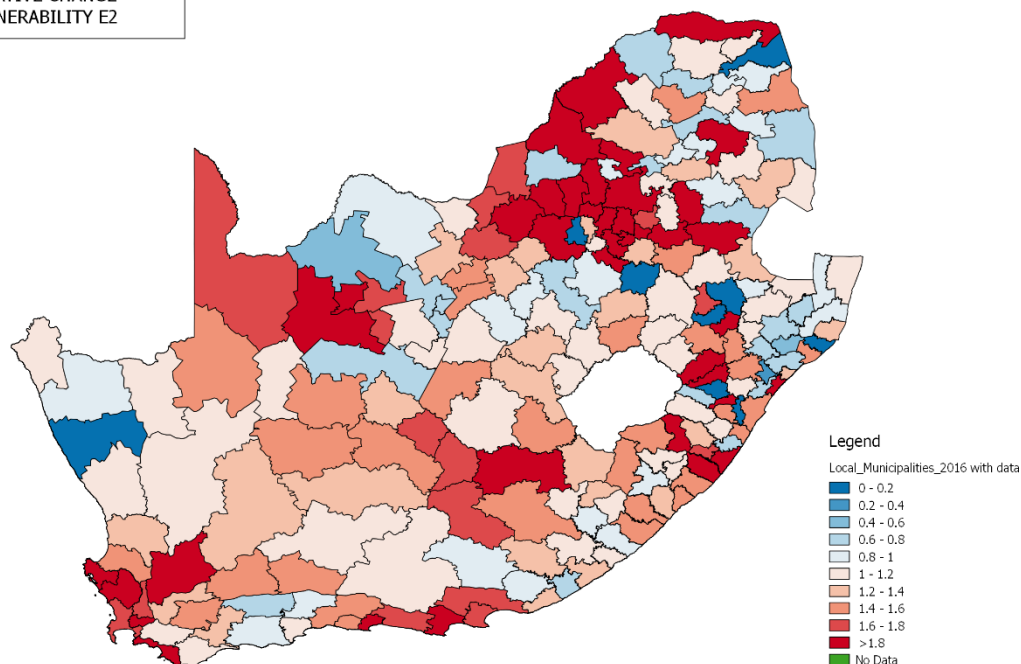


Figure 68: Relative change in water supply vulnerability with 90th percentile (wet) climate change exposure (E2) scenario and high population growth

4.4 Potential for augmentation and reduced water losses

As an initial estimate of the potential for adaptive capacity we have increased the future water availability for each municipality by the total volume of water supply augmentation options identified in the All Towns study and reduced the overall water demand by the potential savings from reduction of unaccounted for water (UAW). The implementation of water conservation and demand management (WCDM) measures is assumed. The impact of this is shown in Figure 69 to Figure 74 for the Eastern Cape and Western Cape provinces, for which this information was readily available. The results are based on the high population growth scenario and indicate that current augmentation options can address the climate change risk in most parts of the Eastern Cape and the Western Cape, even under a maximum drying scenario if combined with efforts to reduce UAW. The exceptions are a handful of local municipalities that require consideration for additional augmentation options.

2050 HIGH POPULATION 10 PERC
VULNERABILITY E1 WCDM & AUG

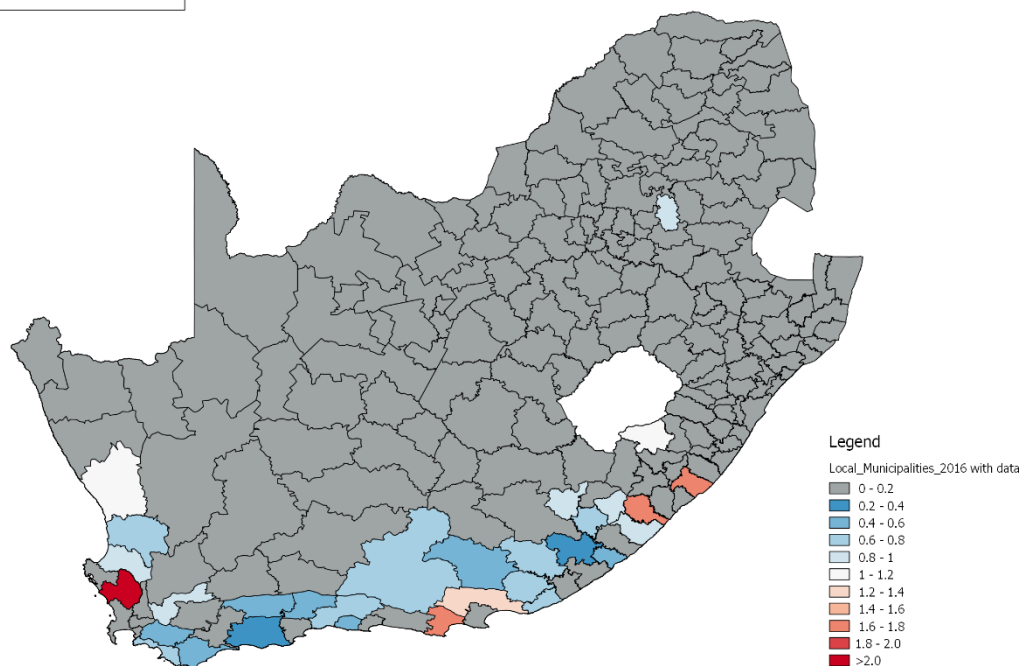


Figure 69: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E1) scenario, high population growth and WCDM and Augmentation

2050 HIGH POPULATION 50 PERC
VULNERABILITY E1 WCDM & AUG

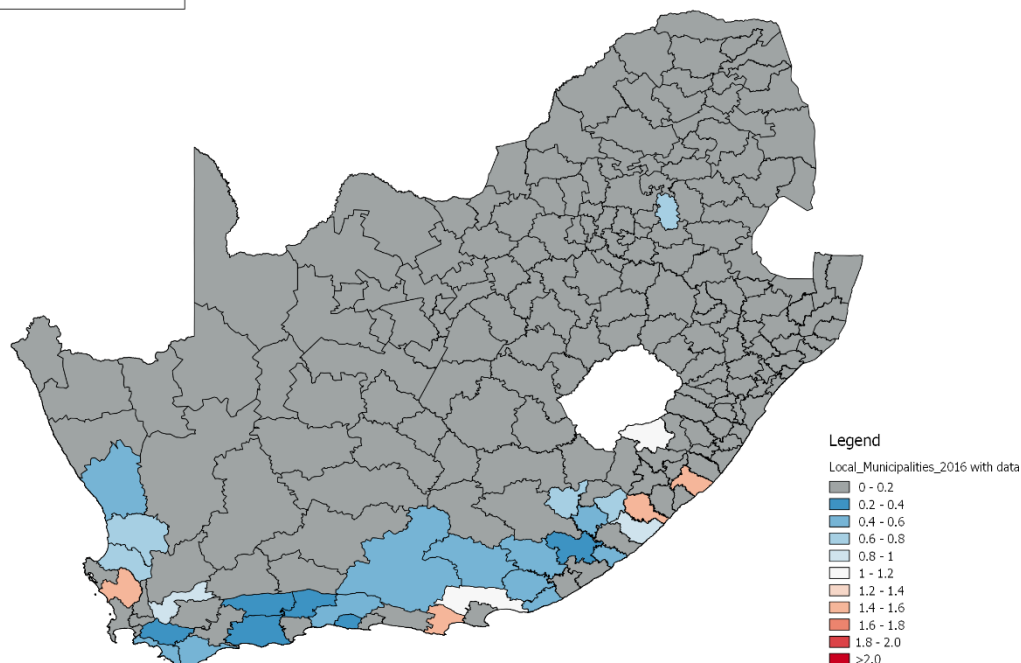


Figure 70: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E1) scenario, high population growth and WCDM and Augmentation

2050 HIGH POPULATION 90 PERC
VULNERABILITY E1 WCDM & AUG

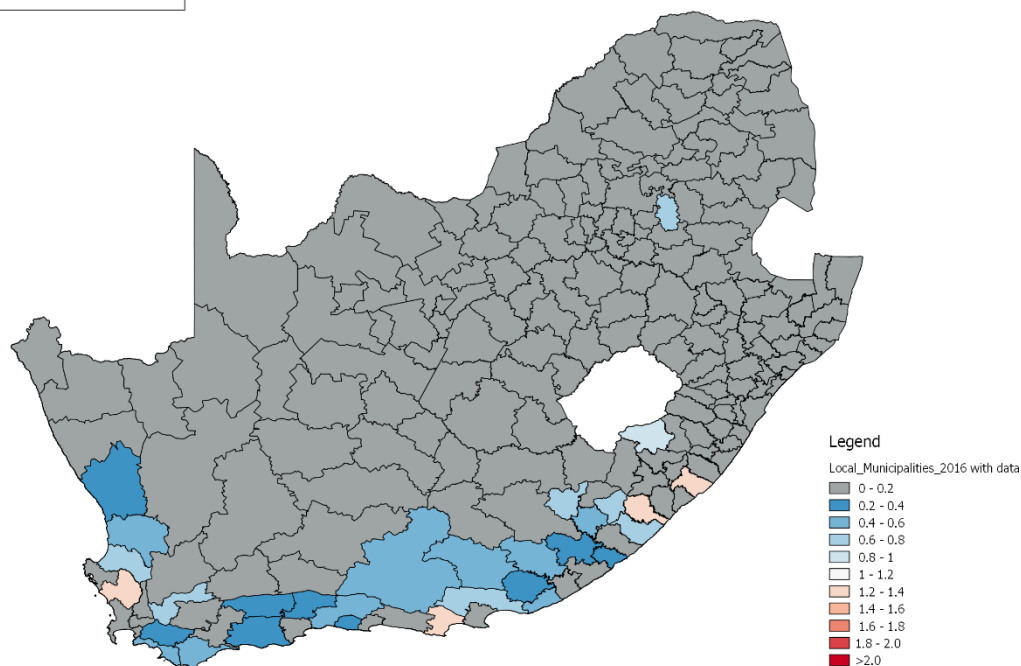


Figure 71: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E1) scenario, high population growth and WCDM and Augmentation

2050 HIGH POPULATION 10 PERC
VULNERABILITY E2 WCDM & AUG

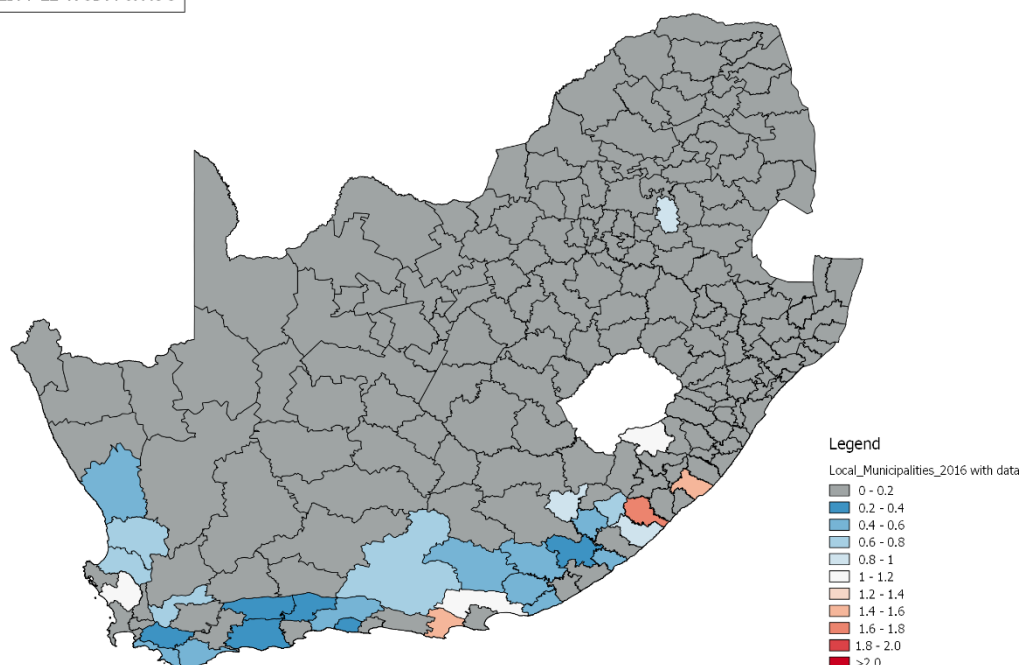


Figure 72: 2050 water supply vulnerability (estimated demand/supply) with 10% (dry) climate change exposure (E2) scenario, high population growth and WCDM and Augmentation

2050 HIGH POPULATION 50 PERC
VULNERABILITY E2 WCDM & AUG

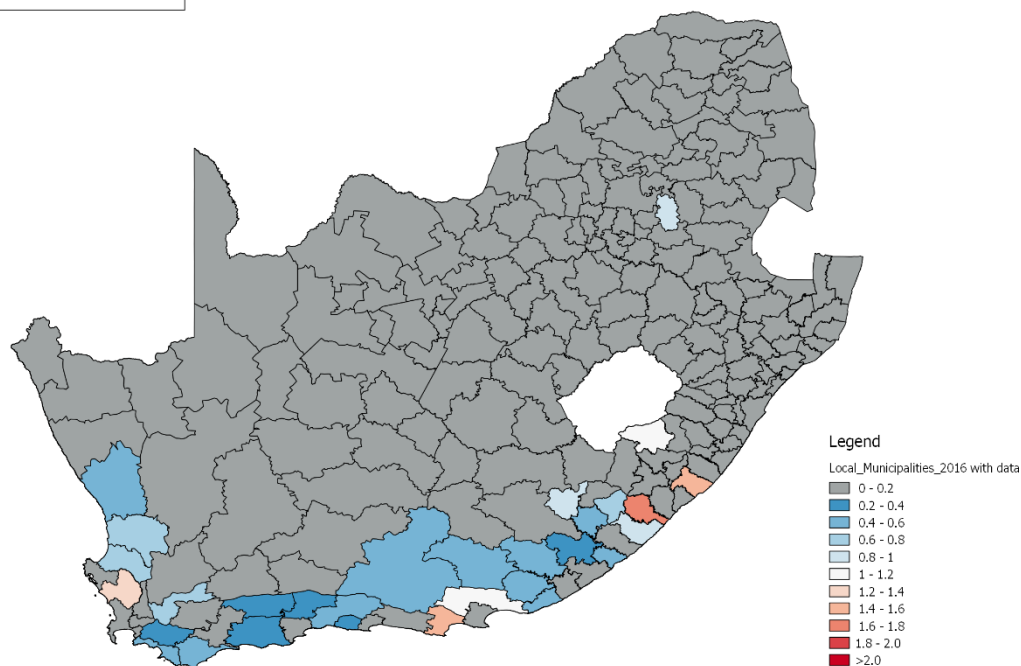


Figure 73: 2050 water supply vulnerability (estimated demand/supply) with 50% (median) climate change exposure (E2) scenario, high population growth and WCDM and Augmentation

2050 HIGH POPULATION 50 PERC
VULNERABILITY E2 WCDM & AUG

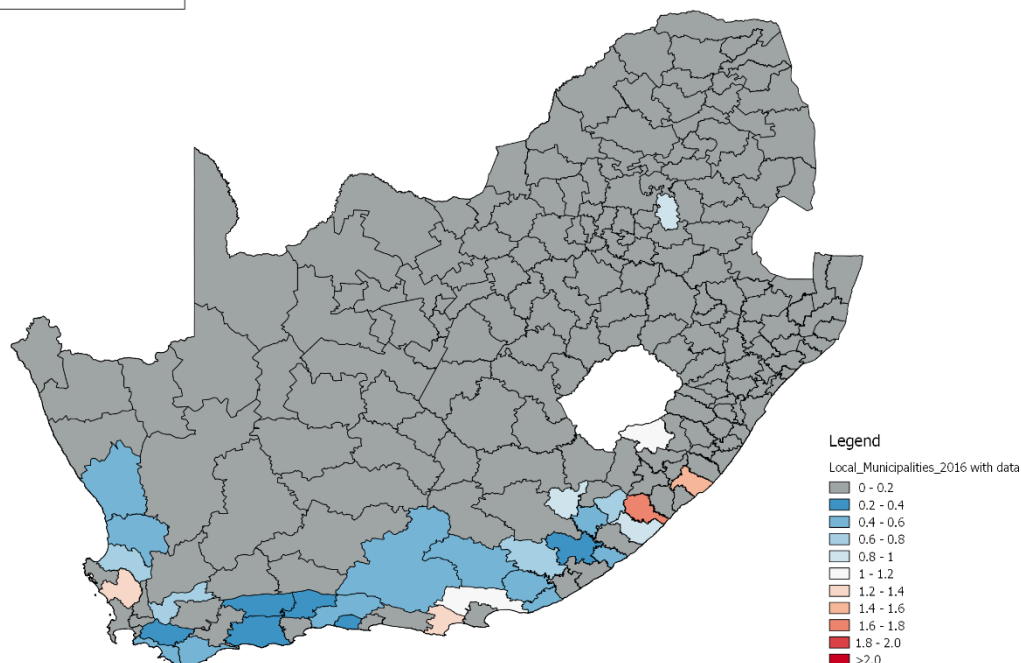


Figure 74: 2050 water supply vulnerability (estimated demand/supply) with 90% (wet) climate change exposure (E2) scenario, high population growth and WCDM and Augmentation



5 CONCLUSION

As described earlier, this is a first order estimate of the relative climate change risks for all local municipalities across South Africa. As a result, it should not be taken as the final climate change risk for specific individual local municipalities. Additional analysis is required, taking into account the unique nature of the water supply system to each individual local municipality, particularly when integrated with a regional or bulk water supply system.

The climate change risk for water supply is calculated based on the water supply vulnerability (i.e. demand/supply) multiplied by the exposure either as a function of the change in the local MAR or as a function of the likely change in the percentage of water supply that can be met at a regional or WMA scale combined with the exposure to impacts on groundwater and the possible impact of increasing evaporation on urban water demands.

The results show the importance of taking into account both the impacts of climate change as well as population growth on future water demands and the associated changes in vulnerability (i.e. demand/supply). Overall the results of this study indicate that the local municipalities with the highest water supply vulnerability, both current and future, are located in the Eastern Cape. This can be ascribed primarily to the fact that these places have limited existing supply capacity while there will be likely increases in future population with associated increases in water supply demand. In future, most municipalities will see an increase in water supply risk either as a function of increasing population growth or exposure to potential climate change impacts for both supply and demand (evaporation). There are, however, one or two that could experience a reduction in water supply risk, either a result of a declining population, or due to the positive impacts of increased runoff due to climate change. These areas might, however, also experience an increase in flood risk.

The results of the study highlight the importance and potential benefits of being connected to a diverse and more integrated bulk water supply system. In this scenario the major economic hubs of Johannesburg, Durban and Cape Town, which are also the major centres for urban water demand are the most likely to benefit from the mitigating impacts of being connected to a highly integrated bulk water supply system.



However, despite this, the municipalities in the Western Cape and the Northern Cape still show a likely increase in climate change risk for water supply even under the wettest (10th%) scenario, although this is much less than if based on local changes in MAR only.

Based on this analysis, the top ten most-at-risk municipalities for climate change impacts on water supply vulnerability are listed below (Table 1). It is important to note that this is based on several critical assumptions and while useful in terms of giving an indication of the most vulnerable areas of the country to future climate change risks, additional analyses should be undertaken for each of the individual municipalities to investigate their unique water supply risks and to identify suitable adaptation and climate change mitigation measures.

Table 1: Top ten most-at-risk municipalities for climate change impacts on water supply

Ranking	Current vulnerability	Vulnerability based on high population growth	Median Exposure to climate change (E1) with local runoff	Median Exposure to climate change (E2) with regional water supply	Overall climate change risk with local runoff	Overall climate change risk with regional water supply
1	Mhlontlo	Mhlontlo	Saldanha Bay	Lephalale	Mhlontlo	Mhlontlo
2	Matatiele	Matatiele	Bergrivier	Molemole	Matatiele	Matatiele
3	Umzimvubu	Ngquza Hill	Swartland	Hantam	Ngquza Hill	Ngquza Hill
4	Ngquza Hill	Mbizana	Lephalale	Kamiesberg	Mbizana	Mbizana
5	Nyandeni	Nyandeni	Nelson Mandela Bay	Blouberg	Umzimvubu	Umzimvubu
6	Nketoana	Umzimvubu	Cederberg	Karoo Hoogland	Nyandeni	Nyandeni
7	Ntabankulu	Nketoana	City of Cape Town	Cederberg	Mbhashe	Nketoana
8	Mbizana	Mbhashe	Rustenburg	Laingsburg	Nketoana	Mbhashe
9	Mbhashe	Ntabankulu	Witzenberg	Mogalakwena	Swartland	Ntabankulu
10	Chief Albert Luthuli	King Sabata Dalindyebo	Mogalakwena	Oudtshoorn	Bitou	Bitou

In order to compare the relative impacts of climate change versus population growth on the overall water supply vulnerability, the results of the study for both exposure to climate change and also the anticipated future population growth (high scenario) are plotted in Figure 75.

This plot not only shows the relative importance of the two drivers of increasing water supply risk, but also the benefits of considering the impacts of a regional, integrated bulk water supply system that mitigates the potential future risks due to climate change and population growth.

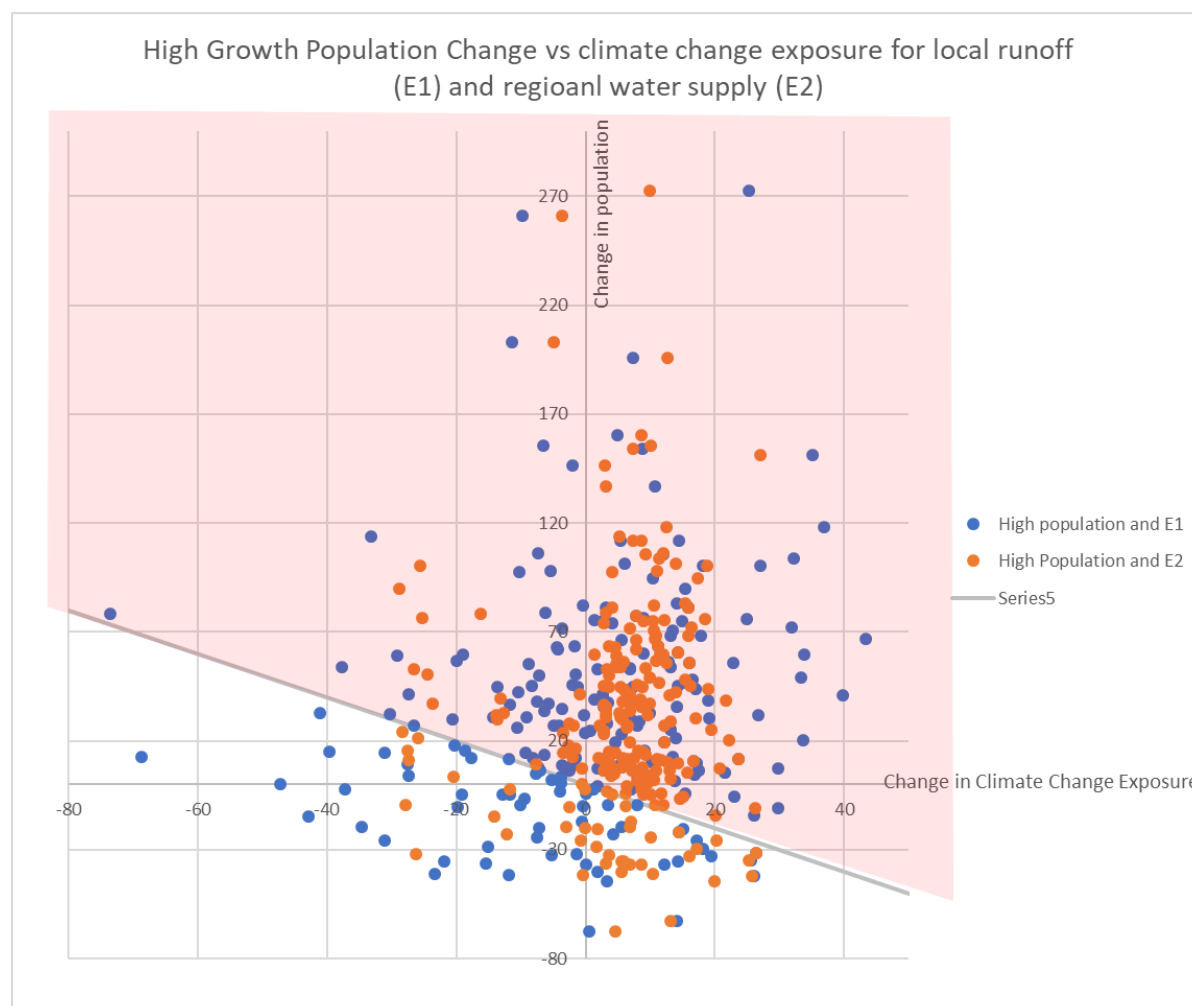


Figure 75: Estimated percentage change in water supply risk for municipalities by 2050 as a result of population growth (High Scenario) and exposure to climate change estimated based on impacts on local surface water runoff (E1) and taking into account the potential impacts due to regional water supply systems (E2). The shaded areas show overall increase in water supply risk, while the unshaded area shows a potential overall reduction in water supply risk.

It is, however, important to note that this is a first order estimate only and that a number of critical assumptions have been made. In order to understand the true climate change risks for water supply to settlements, it will be necessary to consider each individual settlement in more detail taking into account the unique nature of its current and future water supply infrastructure.



6 ADAPTATION RESPONSES

Adapting South African settlements to increasing water supply risks includes not only adapting to climate change impacts, but also to future growth and development requirements as well as other factors that impact on water security such as continued catchment degradation and water quality risks. Some recommendations for adaptation include:

- Investments in more diverse water supply options including conjunctive use (e.g. surface and groundwater), alternative supply options such as desalination and re-use, increased integration between sources and investments in ecological infrastructure.
- Better catchment protection and investing in ecological infrastructure including the removal of invasive alien plants and the rehabilitation and protection of wetlands. Compliance with ecological water requirements, as required by the National Water Act, will become even more critical in the face of increasing demands and climate change.
- More detailed assessment of climate change risk for individual towns and water supply systems including bottom-up assessment of climate change risk and vulnerabilities.
- Increased investments in monitoring, maintenance and management (i.e. streamflow and groundwater monitoring) as well as managing bulk water supply infrastructure.
- Improved co-operative governance between local, national and provincial departments is critical for the efficient operation of complex and integrated water supply systems.
- Continuous monitoring and communication with stakeholders is important, particularly during periods of drought where users are critical in terms managing demands.
- Improved water use efficiency and reduced unaccounted for water is important, but it must be noted that the more efficient users become with water, the harder it is to manage demand during periods of drought. A balance must be found.

7 THE WAY FORWARD

It is important to be reminded that this is a first order estimate of the relative climate change risks for all local municipalities across South Africa and as such a number of assumptions and simplifications have been made in order to undertake the analysis for all municipalities in a relatively short period of time and with limited resources. As a result, it should not be taken as a definitive assessment of climate change risk for water supply to specific individual local municipalities. Additional analysis is required for each individual municipality considering the



unique nature of the water supply system to each individual local municipality, particularly when integrated with a regional or bulk water supply system.

It is also recommended that a bottom up approach be taken that tries to understand the unique nature of each municipality and adopts a co-exploration approach to identifying climate risks and finding ways to better incorporate climate information into decision making for towns and cities. Such an approach has been demonstrated as part of the Future Resilient African Cities and Lands (FRACTAL) research project being undertaken by the University of Cape Town and a number of partners as part of the Future Climates for African (FCFA) Program.

While it is important to understand the future climate change risks for settlements it is also imperative that investments are made to follow best practice for water resources planning. This includes increased investments in the three M's: Monitoring, Maintenance and Management. This will best enable an adaptive management approach to climate change.

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