PAPER 1

Water Security and Climate Change Risks for Municipalities and Critical Infrastructure Across South Africa

AUTHORS:

Dr James D.S. Cullis

Zutari (Pty) Ltd

ABSTRACT

South Africa is a water scarce country with many towns and cities already experiencing sever water security challenges. Recent events, including the Cape Town water crisis, the current water supply crisis for Gqeberha, continuing drought conditions in large parts of South Africa and an increase in recent flooding events, particularly in urban areas, have highlighted the increasing water security risks for towns and cities in South Africa. Climate change is considered to be a significant factor in this increasing risk that needs to be urgently taken into account in terms of both water resource planning and infrastructure planning and design. Population growth and economic development, however, are also contributing to the increasing water security challenge.

In this paper we present the results of a study that looked at current and future water security risks for all municipalities as a result of both expected climate change impacts as well as future population growth scenarios up to 2050. The study was done in support of the development for the CSIR Greenbook for assisting municipalities with evaluating their climate change risks and giving consideration to appropriate adaptation and mitigation options. The study, however, also builds on work done for previous projects including contributing to the Long-Term Adaptation Scenarios (LTAS) research program, DWS climate change strategy and a study of the economic impacts of climate change for South Africa for National Treasury. These studies, as well as recent work done in support of update estimates of climate change risk for water supply to the city of Cape Town will be presented and recommendations made for appropriate adaptation and response options.

We also consider the impact of climate change on increasing flood risks across South Africa, particularly for critical infrastructure such as dams, bridges and power lines, and describe how supporting a transition to becoming a Water Sensitive City (WSC) in particular is crucial in managing both increasing water security and urban flood risks, as well as additional co-benefits necessary to create resilient, sustainable and liveable infrastructure and urban areas in South Africa, but also relevant for the rest of the SADC region and for other cities across Africa. In particular, we advocate for a better understanding of the specific risks associated with climate change and developing bottom-up solutions that address the underlying risks and vulnerabilities and allow for an adaptive pathways solution to increasing resilience. Investing in Ecological Infrastructure (EI) such as rehabilitation of catchments and promoting the transition to a Water Sensitive City (WSC) are critical.

INTRODUCTION

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 1 900 mm in the east of the country and in the mountainous areas, to almost zero in the west and northwest 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). Despite the low levels of water availability, South Africa has however been able to provide the bulk of its population with a secure water supply and to support the largest economy in Africa.

This would not have been possible without the development of a highly integrated and well-developed bulk water supply systems that has been continually adapting to the changing needs of the country. Many towns and cities within South Africa however are already starting to experience increasing water security risks and without further development of the bulk water supply system it is likely that many parts of South Africa will start to experience sever water shortages which will impact both on people's livelihoods, but also economic development. South Africa already has the greatest number of large dams in Africa, and the sixth greatest number of large dams globally (ICOLD) and there is limited potential for new dams or additional surface water supply, hence it will be necessary to consider alternative supply options as well as improved water use efficiency. The likely impacts of climate change must also be taken into consideration for future planning.

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).

Water supply is considered to be one of the principal mechanisms for the realization of climate change impacts on society (UN Water, 2010). 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 southwest 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).

A study of the potential economic impacts of climate change in South Africa, (Cullis et al, 2015) showed that the existing integrated bulk water supply system, however, provides some resilience to the potential impacts of climate change by being able to manage water supply from different parts of the country, and the efficient utilisation of dam storage. The benefits of this, however, will vary significantly between different towns dependent on their current and future water supply sources. For example, several towns are already highly dependent on groundwater, while other towns, particularly in the coastal region, are already starting to implement desalination and re-use. The town of Beaufort West for example has already implemented a direct potable re-use (DPR) plant. The integration of alternative supply sources is a key part of transition to becoming a Water Sensitive City (Brown et al, 2016).

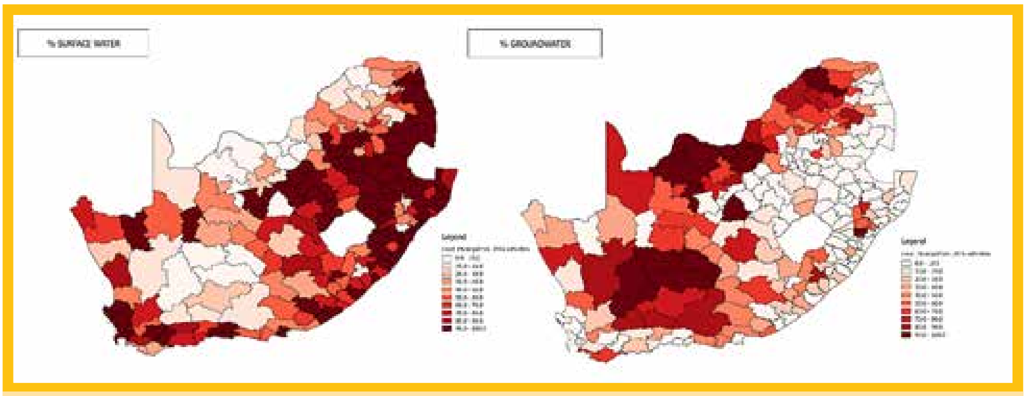

FIGURE 1: Percentage of municipal water supply provided from surface water (left) and groundwater (right)

Climate change is also likely to impact on the frequency and intensity of flood events across South Africa (Engelbrecht, et al, 2019). This presents a significant increasing risk to both towns and cities, particularly in areas where informal development has taken place within existing flood plains (Le Roux, et al, 2019), but also in terms of critical infrastructure such as bridges, roads, dams, and power line crossings (DEA, 2013). Adapting to these increasing risks, particularly in urban areas and for critical infrastructure, will be critical in terms of supporting social and economic development in South Africa, and the post COVID economic recovery plan.

APROACH AND METHODOLOGY

Water Security Risks for South Africa Municipalities

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). 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.

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

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

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

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

$$Exposure\ (E_1) = \frac{\Delta MAE}{(\Delta MAR \times \%SW) + (\Delta MAP \times \%GW)}$$

$$Exposure\ (E_2) = \frac{\Delta MAE}{(\Delta RWS \times \%SW) + (\Delta MAP \times \%GW)}$$

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

ΔRWS = the change in Regional Water Supply derived from the study used to calculate the impact of climate change on average water supply at a WMA scale (from Cullis et al, 2015).

ΔMAP = change in the mean annual precipitation

ΔMAE = change in the mean annual evaporation

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

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 Cole et al, (2017). Future projects of population growth for local municipalities across South Africa were provided by the CSIR. These were used to estimate future water demands for all local municipalities assuming that increasing water demand was proportional to the increase in population.[1]

Climate Change Impacts on Future Water Supply and Demand

Settlements in South Africa get water primarily from either surface water sources, or groundwater sources, or some combination of both (Figure 1). Climate change will impact on these two water sources differently. In order to determine the overall exposure to climate change risks for water supply we have determined 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.

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 average temperature.

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 consider 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 and the nature of the demand. Requirements for environmental flow releases and the impacts of upstream demands, future developments and augmentation options are also critical. The ability to manage the system and 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), and any water quality constraints, also need to be taken into consideration.

In order to highlight the importance of having access to a regional integrated bulk water supply option, we have adopted two separate approaches to estimating the impact of climate change on the availability of surface water supply. The first (E1) assumes that changes in water supply are directly proportional to changes in the Mean Annual Runoff (MAR) of the catchment in which the settlement or municipality is located. This would be the case for example of 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). This study 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. Each of these approaches to determine the provisional impact on surface water are described below.

The likely impact of climate change on the proportion of water supply 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. Recharge potential does vary across the country, however for this initial assessment we have assumed the climate change impact is directly proportional to likely changes in MAP. Further work should consider these regional differences. As with the comment above in terms of the specific impacts on surface water yield, further research should also consider the potential for increased resilience through conjunctive use of both surface and groundwater sources.

Future Population and Climate Change Scenarios

A set of climate change scenarios for South Africa was provided by the CSIR. These included a 10th, 50th and 90th percentile scenario for the two of the IPCC global climate scenarios representing Relative Concentration Pathway (RCP) 4.5 and RCP 8.5. For this study only the RCP 8.5 results were used. The precipitation and temperature impacts for the different scenarios by 2050 where 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. These were then used to estimate average monthly evaporation based on the Hargreaves equation (Hargreaves, 1994). Similar scenarios were also used in a national climate change study (Cullis et al, 2017) and were used to determine the impact on the average annual water supply to different water management areas incorporating the regional bulk water supply systems.

Population growth scenarios were provided by the CSIR (Le Roux et al, 2019b) including a medium and high growth scenario. These scenarios were produced at the level of individual settlements and taking into account migration impacts but were then aggregated up to municipality scale for estimating future water demands which were assumed to be directly proportional to the change in population numbers at municipal level.

Impact of Climate Change on Surface Water Runoff

The impact of the different climate change scenarios on surface water runoff, used in the E1 definition of exposure as described above, 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, 2012) and has become one of the most widely used monthly time step rainfall-runoff models within southern Africa (Hughes et al, 2006). As a first order assumption we have consider the climate change impact on local water supply sources as directly proportional to the change in mean annual runoff (MAR). This will, however very significantly, particularly in terms of the amount of storage available, and also as a result of any impact on both seasonal and inter-annual variability which could result in the impact on "yield" being very different from the impact on average surface water availability.

Impact of Climate Change on Regional Bulk Water Supply Systems

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 us 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 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.

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 Water Management Area (WMA). 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.

RESULTS AND DISCUSSION

Current and Futrure Water Supply Vulnerability due to Population Growth

The current water supply vulnerability of a municipality has been calculated as being the ratio of the total demand to the total supply and is shown in Figure 24. These results are based on estimate by the Department of Water and Sanitation (DWS) and aggregated by Cole et al (2017). A value of 1 implies that the demand and supply of the 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 region with the highest vulnerability is the eastern portion of the Eastern Cape which has a vulnerability of more than 2. This is largely due to historic under-investment in bulk water supply systems for the province and reflects the fact that many towns and municipalities are highly dependent on local and often unprotected surface water sources.

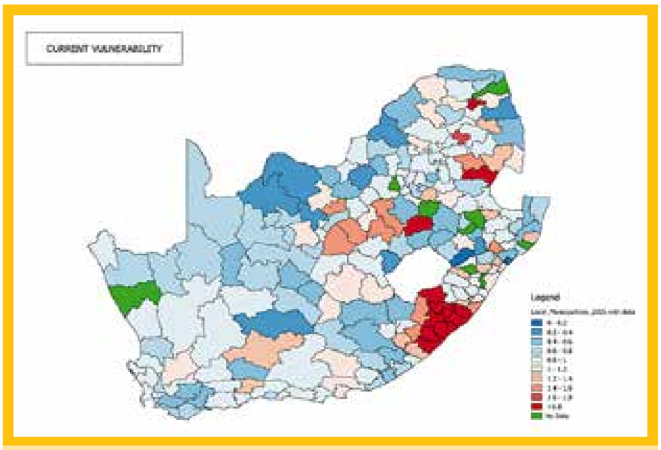

FIGURE 2: Current water supply vulnerability (estimated demand/ supply) for municipalities in South Africa

The estimated future water supply vulnerability (excluding climate change) is shown in Figure 3.These results show an increasing number of municipalities where water demand will increase current supply. In general, the water supply vulnerability in the Eastern Cape remains high, but there are increasing number of local municipalities across the country, particularly in the western and southern cape, Gauteng, Limpopo and Mpumulanga. The municipalities on the border are expected to see significant population growth as a result of migration from other countries, while there might even be a reduction in water supply vulnerability for some more rural municipalities as these experience population declines due to internal rural- urban migration.

Overall Exposure to Future Climate Change Impacts on Municipal Water Supply

The 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. 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.

Combined Water Security Risks of Population and Climate Change

The overall water supply vulnerability (demand/supply) by 2050 under the 10% percentile (dry) and 90th percentile (wet) future climate change scenario and medium and high population growth scenario are shown in Figure 5. These results indicate the Eastern Cape remains the greatest area of concern, but that this is largely as a result of the current lack of basic water supply infrastructure. In terms of future impacts, there are an increasing number of municipalities are risk, but these vary depending on the specific climate change scenario and also the impacts of population growth.

Even under the "wet' scenario, there are a number of municipalities, particularly in the Western Cape that will experience increasing water security risks, while in some cases any increase in water security risk due to climate change is matched by a reduction in demand.

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 population growth (high scenario) are plotted in Figure 5. This plot 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. Overall, the impacts of population growth appear to be greater than due to climate change.

For future water resource planning, however, is critical to take both factors into account, and to undertake a more detailed analysis of the impacts on individual water supply systems and also in terms of estimating the level of risk by determining the impacts on system yield, rather than just average supply.

CONCLUSIONS

This is a first order estimate of the relative future water security risks for all local municipalities across South Africa due to future climate change impacts and population growth. Given the high-level nature several assumptions have been made that would differ from more focused analysis of individual water supply systems. As a result, it should not be taken as the final climate change risk profile for any specific individual local municipality, but rather as an indication of overall trends and highlighting key issues to be investigated further. Additional analysis is required specifically with regards the unique nature of the water supply system to each individual municipality, particularly when integrated with a regional or bulk water supply system.

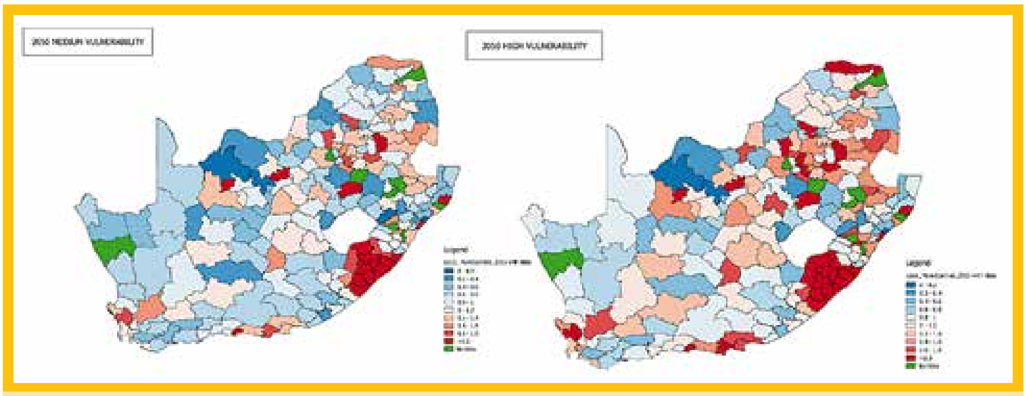

FIGURE 3: Water supply vulnerability (i.e. demand/supply) for local municipalities by 2050 as a result of the medium (left) and high (right) population growth scenarios, excluding the impacts of climate change

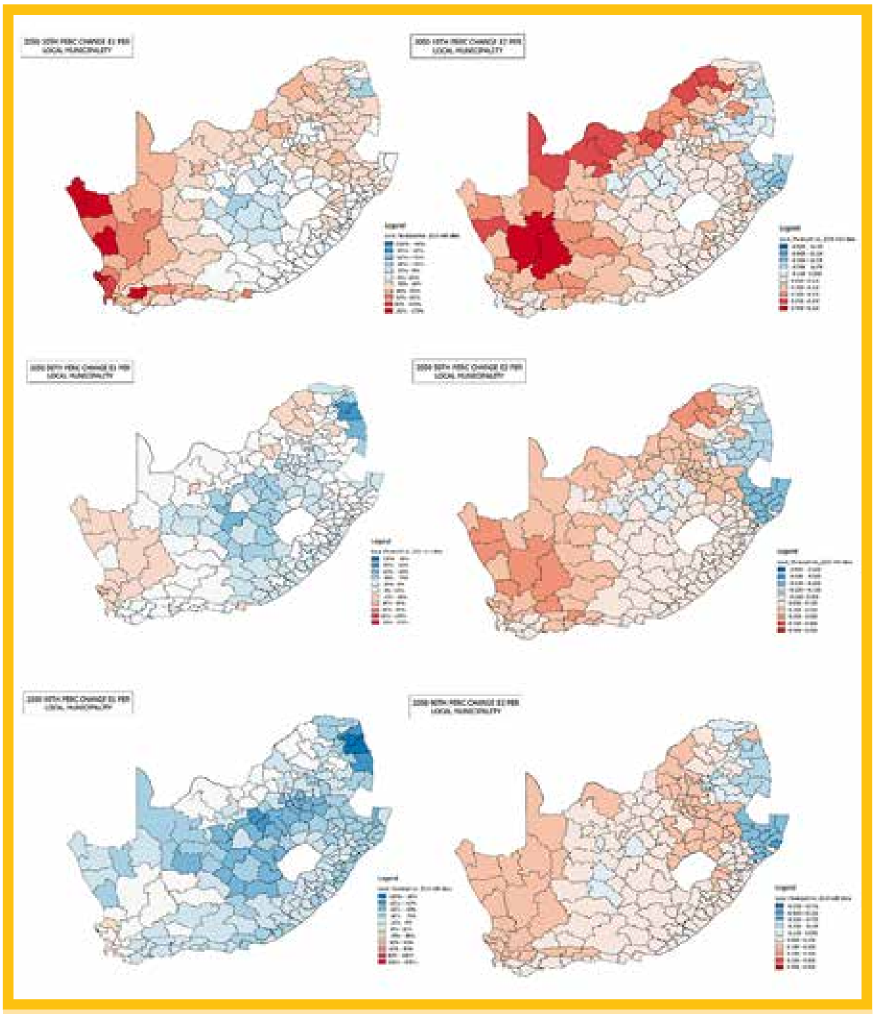

FIGURE 4: Overall exposure of municipal water supply to climate change impacts for the 10th (top), 50th (middle) and 90th (bottom) climate change scenarios for 2050 and also in terms of exposure (E1) based on local surface water impacts only (left) and exposure (E2) based on regional water supply impacts (right)

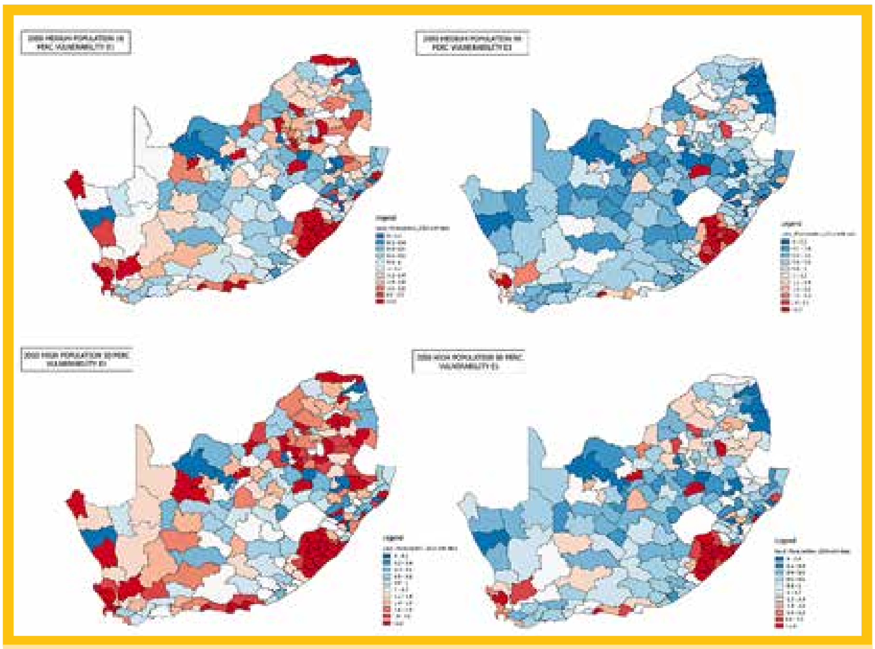

FIGURE 5: Water supply vulnerability (estimated demand/supply) by 2050 with 10% (left) and 90% (right) climate change exposure (E1) scenario and medium (top) and high (bottom) population growth scenarios

The climate change risk for water supply to municipalities 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. 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), or both. There are, however, one or two municipalities that could experience a reduction in water supply risk, either a result of a declining population, or due to the positive impacts of increasing precipitation and surface water availability 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.

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. Further work is required, particular for high-risk municipalities.

RECOMMENDATIONS

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

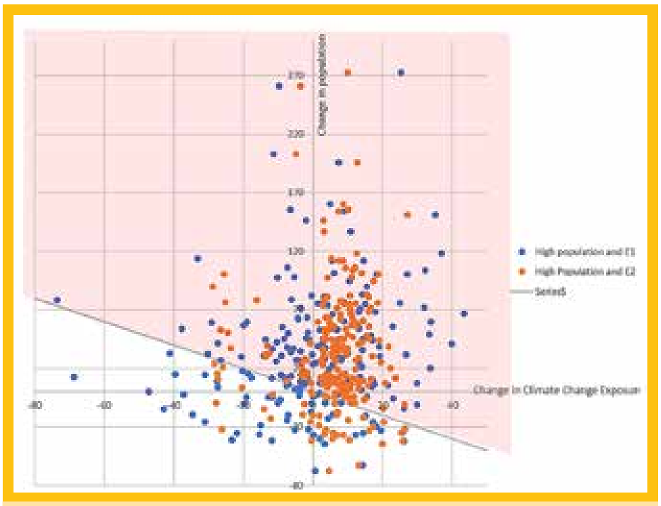

FIGURE 6: Estimated percentage change in water supply risk for municipalities by 2050 as a result of population growth (High Scenario) and exposure to climate change estimated based on impacts on local surface water runoff (E1) and taking into account the potential impacts due to regional water supply 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. Each point represents an individual municipality

well as other factors that impact on water security such as continued catchment degradation and water quality risks.

Some recommendations for climate change adaptation for improved water security include the following:

- Improved operation, maintenance and management of existing water supply infrastructure is critical in terms of managing future water supply requirements and improving current water use efficiency.
- Investments must be made 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 supply options and long term investments in ecological infrastructure (EI).
- Better catchment protection and investing in ecological infrastructure (EI) is required such as 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 from population growth 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, vulnerabilities, and adaptation potential.
- Increased investments in monitoring particularly of surface and groundwater resources is required.
- Improved co-operative governance between local, national, and provincial departments, and different water users, is critical for the efficient operation of complex and integrated bulk water supply systems.
- Continuous monitoring and communication with stakeholders are important, particularly during periods of drought where users are critical in terms managing demands, and also in investing in future schemes.
- Improved water use efficiency and reduced unaccounted for water is important, but it must be noted that the more efficient users become, the harder it is to manage demand during periods of drought.

With the urban areas being the focus for most of the future population growth, particularly in developing countries, it is critical that urban water security is a priority focus area for all national and local governments.

As these results have shown, the specific impact of climate change and population growth will vary significantly between different municipalities based on their location and economic growth trajectories. Each municipality also has a unique water supply system and unique challenges for managing demand.

While a national study like this one can provide general insights and highlight key priorities, it is critical that each municipality be considered from a bottom-up perspective. Increasingly it is important to adopt a bottom-up approach founded on the principles of co-exploration and co-discovery of solutions to challenges such as climate change and future water security (Ilunga, 2017). Such an approach also requires supporting the transition to becoming a Water Sensitive City. The principles of a Water Sensitive City include embracing a diversity of water supply options, introducing ecological infrastructure and catchment interventions to both manage the increasing urban flood risk as well as improved water security and providing recreation and cultural spaces that also help in cooling cities. Better incorporating indigenous knowledge into the water planning process is also becoming more critical and increasingly important for improved water security.

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[1] For this study we have made the simple assumption that water demand will increase proportional to the increase in population. There are however many 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.