National Water Reuse Programme:
Programme Design and Preparation of a Full Funding Proposal to the Green Climate Fund (GCF)

Climate Change Risk & Vulnerability Analysis – Water Sector and Select Municipalities (WRP Indicative Locations)

Annexure 28 to GCF Full Funding Proposal

09 June 2023

DEVELOPMENT BANK OF SOUTHERN AFRICA
Building Africa's Prosperity

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TABLE OF CONTENTS

LIST OF FIGURES

Figure 62: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019) ... 45
Figure 63: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019) ... 45
Figure 64: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019) ... 46
Figure 65: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019) ... 46
Figure 66: Extremely high projected water stress in Nelson Mandela Bay in the year 2040 (Source: WRI) .. 47
Figure 67: Historic average maximum temperature (available only from January 1979 to July 2000) for City of Ekurhuleni ... 48
Figure 68: Historic average minimum temperature (available only from January 1979 to July 2000) for City of Ekurhuleni ... 48
Figure 69: Historic total monthly rainfall (available only from January 1979 to July 2000 for City of Ekurhuleni ... 48
Figure 70: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for City of Ekurhuleni ... 49
Figure 71: Ekurhuleni's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019) ... 49
Figure 72: Present-day water availability in Ehurhuleni municipality (Source: CSIR, Greenbook, 2019) ... 50
Figure 73: Groundwater recharge potential (left) and groundwater dependency (right) in Ekurhuleni municipality at present (Source: CSIR, Greenbook, 2019) ... 50
Figure 74: Surface water indices in Ekurhuleni under the current climate (Source: CSIR, Greenbook, 2019) 51
Figure 75: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019) ... 51
Figure 76: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019) ... 52
Figure 77: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni ... 53
Figure 78: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni ... 53
Figure 79: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019) ... 54
Figure 80: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni ... 54
Figure 81: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019) ... 55
Figure 82: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019) ... 55
Figure 83: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni ... 56

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

AADD	Annual Average Daily Demand
CMIP	Coupled Model Intercomparison Project
COGTA	Department of Cooperative Governance and Traditional Affairs
CSAG	Climate System Analysis Group
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of Southern Africa
DWS	Department of Water and Sanitation
GCF	Green Climate Fund
GCM	Global Climate Model
IPCC	Intergovernmental Panel on Climate Change
LTAS	Long Term Adaptation Scenario
MAR	Mean Annual Runoff
MISA	Municipal Infrastructure Support Agent
NCCAS	National Climate Change Adaptation Strategy
ND-GAIN	Notre Dame Global Adaptation Initiative
NDC	Nationally Determined Contribution
NMB	Nelson Mandela Bay
NWRS	National Water Resource Strategy
NWSM	National Water and Sanitation Masterplan
RCP	Representative Concentration Pathway
RWS	Regional Water Supply
SSP	Shared Socioeconomic Pathway
SPI	Standardised Precipitation Index
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WCWDM	Water Conservation and Water Demand Management
WRI	World Resources Institute
WRP	Water Reuse Programme
WRYM	Water Resources Yield Model
WWTW	Wastewater Treatment Work

1. Overview

1.1 Purpose of this report

The purpose of this report is to support the climate basis of the Water Reuse Programme (WRP), as articulated in the Green Climate Fund (GCF) funding proposal. This report synthesizes and presents the climate-related evidence base on which the Water Reuse Programme is predicated, focusing on the risk and vulnerability of South Africa's water resources in the face of climate change and how this is expected to manifest in eight priority municipalities.

1.2 Report methodology

This report relies on published studies and pre-existing sources of data and analyses. It thus represents secondary research, drawing on a range of both primary and secondary research publications. Sources (referenced throughout) include scholarly articles published in peer-reviewed journals; reports commissioned, endorsed, and published by the Government of South Africa (including submissions to the United Nations Framework Convention on Climate Change (UNFCCC)); comprehensive studies published by highly regarded international organisations of good standing (including the World Bank and UN agencies) and by reputable national research institutions (including the Centre for Scientific and Industrial Research or CSIR, and the Climate Systems Analysis Group or CSAG at the University of Cape Town).

Three principal sources of information reflected in this report:

- Site-specific future climate projections from the GCF's https://climateinformation.org/create-report/
- The World Resources Institute's (WRI's) Aqueduct's Water Risk Atlas https://www.wri.org/aqueduct
- CSIR's Greenbook – both the Municipal Risk Profiles https://riskprofiles.greenbook.co.za/ and the Story Maps for surface water https://pta-gis-2-web1.csir.co.za/portal/apps/GBCascade/index.html?appid=74fc5a7337f34460b7a09242d0770229 and drought https://pta-gis-2-web1.csir.co.za/portal/apps/GBCascade/index.html?appid=a4f13438a8c04f45a5408ef646792a8b

To ensure that the content of this report is up-to-date and reflective of recent scholarship and advances in climate change science, the authors have relied only on sources published within the last decade (2011 – 2021). In this regard, the Greenbook vulnerability assessment which was undertaken from 2016 to2019, and is updated regularly, is the most up-to-date assessment of climate vulnerability at national through to local scales.

1.3 Context

South Africa is a water-stressed nation, and its national water resource system is continually being subjected to pressures, with a potential 17% water deficit forecast by 2030. A number of interventions have been initiated by national government already to avoid this projected water deficit with a key element of these interventions being to develop an enhanced level of diversification in relation to the “mix” of water supply sources. The South African National Water and Sanitation Master Plan (2018) makes a specific note of the need to reduce water demand and increase water supply through, amongst others, the “*re-use of effluent from wastewater treatment plants, water reclamation, as well as desalination and treated acid mine drainage*”.

At present, most effluent discharge and urban run-off are not reused. The South African National Water and Sanitation Master Plan recognizes this and notes that the opportunity to initiate a framework for the scaled development of water reuse infrastructure is evident. To this end, the Development Bank of Southern Africa (the ‘DBSA) has partnered with various government departments (including the Department of Water and Sanitation (the ‘DWS’), the Department of Cooperative Governance and Traditional Affairs (‘COGTA’) through its agency the Municipal Infrastructure Support Agency (‘MISA’), and the National Treasury for the development of a National Water Reuse Programme (‘WRP’). In addition, as an Accredited Entity of the GCF, the DBSA also submitted a proposal to the GCF to support the design and implementation of the WRP in South Africa. Noting the importance of water reuse to diversifying the ‘water mix’ in South Africa, and the challenges and barriers to entry that exist in the development of these water reuse projects at scale, the development of a focussed programme to address these challenges and ultimately implement pathfinder projects is critical to contributing towards building a more resilient water future.

Pegasys (Pty) Ltd, (the ‘Consultant’) was appointed in January 2021 by the DBSA for the provision of specialist consultancy services in respect of this programme design for the implementation of the WRP in addition to the preparation of a full-funding proposal to the GCF (the ‘Assignment’).

2. South Africa’s Climate Risk & Vulnerability in the Water Sector

South Africa is a water-scarce country, with low levels of rainfall and relatively high per-capita water consumption. Existing water stress is projected to increase significantly under climate change, with a decline in annual average rainfall volume, and an increase in temperatures (and evaporative losses). Impacts on runoff vary by catchment, with large parts of the country’s western and interior regions expected to see a decline in water availability, with the eastern parts of the country potentially expected to experience a slight increase due to higher rainfall.

2.1 South Africa’s Water Resource Status Quo

Context

South Africa is a water-scarce country, and the sustainable provision of water is amongst its most significant challenges. Basic water-related services including the provision of potable water and access to sanitation and stormwater drainage are not readily available to a significant proportion of the population. According to WRI’s water risk index, at the country level South Africa as a whole faces “extremely high” baseline physical water risk (World Resources Institute n.d.).

Furthermore, challenges facing water supply are exacerbated by the increased frequency and severity of droughts in recent years – such as Cape Town’s ‘Drought of the Century’ between 2016 and 2018 – and other similar extreme weather events such as the Cape storms and occasional flooding in Gauteng and Kwa-Zulu Natal.

The second edition of the National Water Resource Strategy (NWRS2) (issued in 2013) states that South Africa is currently over-exploiting its renewable water resources on a national level and requires both demand-side and supply-side interventions.

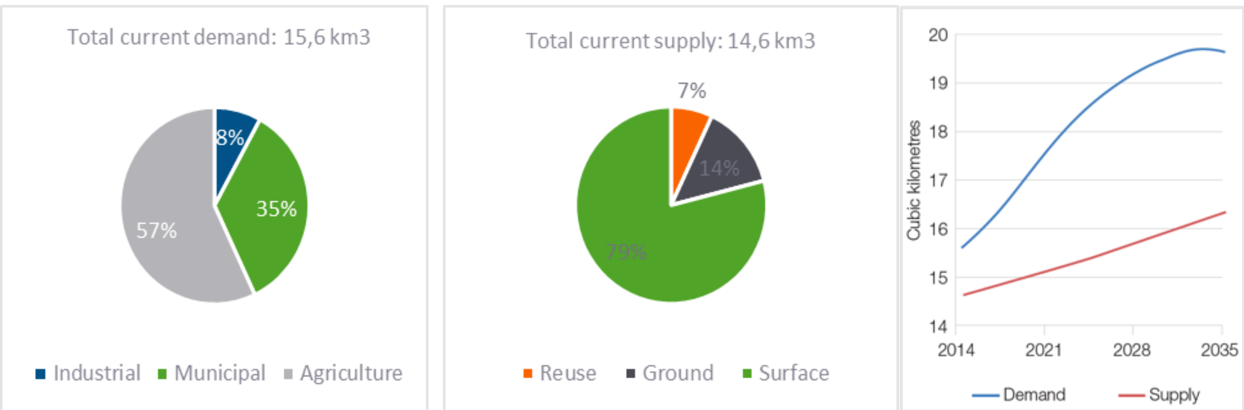


Figure 1: (left): South African water demand by sector; (middle): supply mix; and (right) supply vs demand
Source: (Hedden and Cilliers 2014) adapted from (DWS, National Water Reuse Strategy (NWRS), First Edition 2004)

National water demands in South Africa have increased steadily since 2004 and is likely to continue growing at about 1.2% per annum over the next ten years (DWS, National Water Reuse Strategy (NWRS), Second Edition 2013). National water demand was estimated at 15,6 km^3 per annum in 2014, with the largest use arising from the agricultural sector at 57% (8,9 km^3), followed by municipal demand at 35% (5,5 km^3) and lastly, the industrial sector accounting for the remaining 8% (1,2 km^3), as seen in Figure 1.

South Africa's current water supply mix is strongly dominated by surface water (79%), relying heavily on related surface water infrastructure (over 4,395 registered dams) to meet national water demands. National water supply was estimated at 14.6 km^3 per annum in 2014 with the largest use arising from surface water, followed by groundwater (14%) and then reuse/return flows (13%). The water balance included National Water Resource Strategy indicated over exploitation as early as 2014 with demand outstripping supply into the future with the 'business as usual' scenarios (see Figure 1, right). As a result, by 2030, South Africa is projected to face major water resource shortages (17% supply shortfall).

More recently in 2018, the National Water and Sanitation Masterplan (NWSM) provided updated water demand figures per sector as indicated in Figure 2**Error! Reference source not found.** (DWS, National Water and Sanitation Master Plan 2018).

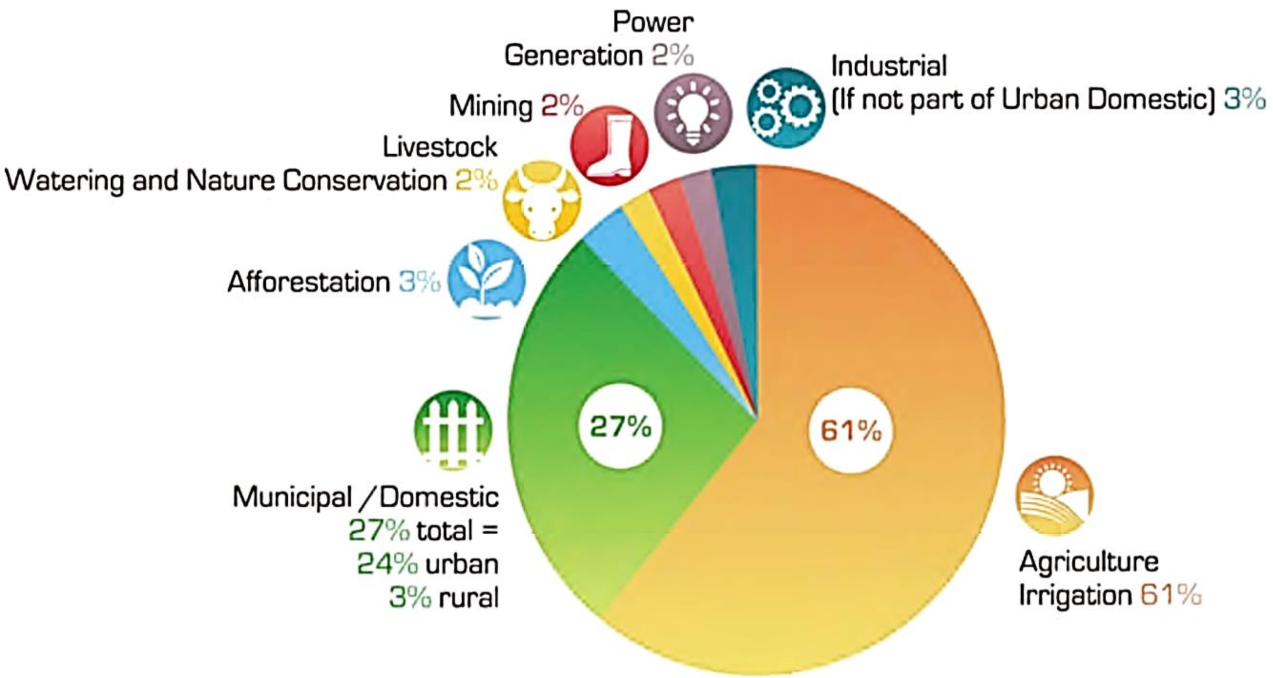


Figure 2: Water use by sector
Source: (DWS, National Water and Sanitation Master Plan 2018)

Challenges

While South Africa has a heavy reliance on surface water, it has low levels of rainfall relative to the world average, receiving an average of 495 mm/year compared with the world average of 1,033 mm/year (Hedden and Cilliers 2014), thus ranking as the 30th driest country in the world (DWS, National Water Reuse Strategy (NWRS), Second Edition 2013). High rainfall variability and evaporation is also experienced, as well as increasing challenges relating to water pollution (DWS, National Water and Sanitation Master Plan 2018).

Many parts of South Africa have reached, or are fast approaching the point at which all viable freshwater resources are fully utilised. According to the NWRS, 98% of all surface water resources have been utilised, allowing only 2% for future growth (NWRS1, 2004). There are also a number of additional challenges contributing towards increased pressures on water nationwide, including:

- Backlogs in the maintenance and rehabilitation of national water infrastructure and many dams, resulting in reduced storage capacity; and
- Higher than normal levels of water wastage with the average municipal non-revenue water (NRW) estimated to be around 37%, while losses of as high as 60% were estimated in many supply schemes (McKenzie, Siqalaba and Wegelin 2012).

The National Water Resource Strategy in the Water Reuse Context

Water reuse is considered as one of several options of augmenting water supply in South Africa and diversifying its water mix. The National Strategy for Water Reuse is a sub-component of and is consistent with the NWRS2 (DWS, 2013). The first (2004) and second (2013) editions of the NWRS, along with the most recent NWSMP (2018) all identify the need to optimise both demand-side and supply side water management.

The NWRS2 acknowledged that "*the time has now come where a mix of water resources is required to reconcile supply and demand*" and therefore, "*there is a need to find new ways of reducing water demand and increasing availability – which move beyond 'traditional solutions' of infrastructure development*" (DWS, National Water Reuse Strategy (NWRS), Second Edition 2013). An innovative approach is required that involves planning, design and implementation of systems that improve water use. Thus, the Department of Water and Sanitation (DWS) has committed to the development of a number of water reconciliation strategies, which includes the reuse of wastewater.

2.2 Current and Future Climate Change: Implications for South Africa's Water Resources

Current climate

South Africa is located within southern Africa's 'drought belt' and, according to the World Bank, is the fifth most water-scarce country in sub-Saharan Africa (The World Bank 2021). An estimated 50% of the country's water supplies are used by the industrial agriculture sector (The World Bank 2021). The country's topography varies from desert to semi-desert in the drier north-western region to sub-humid and wet along the country's eastern coast. At least half the country is classified as arid or semi-arid (The World Bank 2021).South Africa is recognised as vulnerable to climate variability and change, in part due to the country's high dependence on rain-fed agriculture and natural resources, high levels of poverty and income inequality, particularly in rural areas, and a low adaptive capacity. In 2019 the country ranked in the bottom 100 of the 182 countries assessed for climate vulnerability by the Notre Dame Global Adaptation Initiative (ND-GAIN) index (University of Notre Dame 2021).

Since the 1960s, South Africa has already experienced a rise in average annual temperatures country-wide, by 1.5°C. Temperature has increased more markedly across arid, inland areas of the country, with records showing that both maximum and minimum daily temperatures have risen, in all seasons (The World Bank 2021).

Rainfall trends display less clarity than temperature, with significant inter-annual variability. This is true not only for South Africa but all of southern Africa. There are also considerable geographic variances in historic rainfall patterns. Since the 1960s, a marginal reduction in rainfall was experienced during the early rainfall season. Observations also point to potentially significant decreases in the number of rain days across almost all hydrological zones, which indicates a tendency towards an increase in the intensity of rainfall events (i.e. more rain falling in heavy downpours), coupled with prolonged dry spells (The World Bank 2021).

Future climate

Whilst acknowledging that there will be considerable spatial and temporal variability of water availability in South Africa (or indeed, anywhere), all the available climate science information creates a consistent narrative that water scarcity for South Africa will increase due to climate. Demographic changes and increases in the use of water for agriculture will compound the problem, but there can be little doubt that climate change is likely to be a significant driver.

Looking at the synthesis of global climate models (GCMs), the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 Working Group 1 Summary for Policy Makers shows that at any amount of future warming South Africa will receive reduced rainfall (Figure 3).

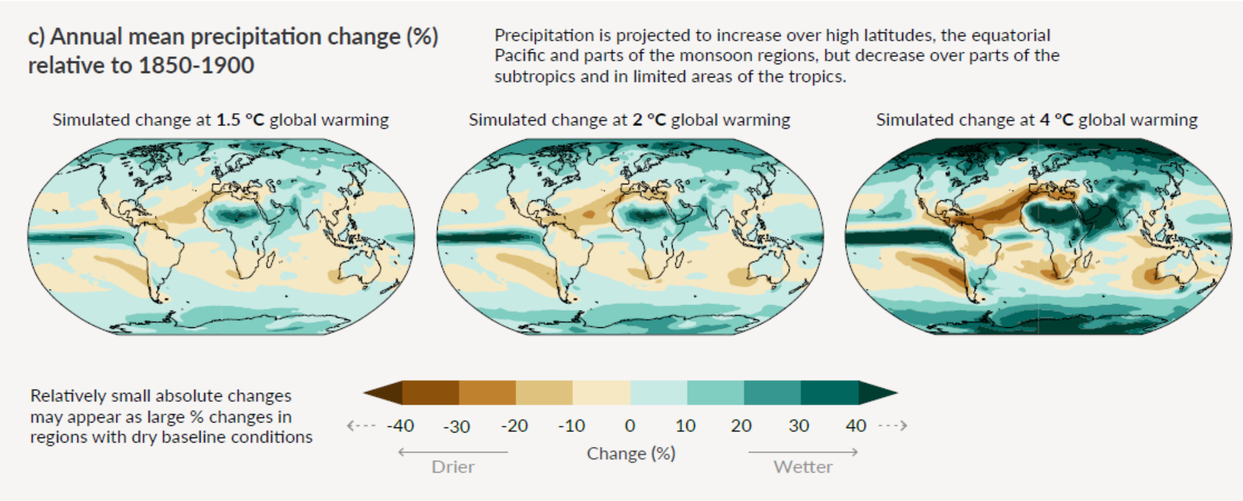


Figure 3: Annual mean precipitation changes, relative to 1850-1900, for various future degrees of warming from the CMIP6 ensemble.

As the figure notes, even small percentage changes from this model synthesis are likely to result in larger percentage changes for areas with dry baseline conditions (at a spatial resolution smaller than the GCMs). This figure is derived from the multi-model mean of the Coupled Model Intercomparison Project Phase 6 (CMIP6). All models in the CMIP6 project are subjected to routine evaluation using tools made available by the CMIP coordination group (https://wcrp-cmip.org/cmip-phase-6-cmip6/#evaluation). Additionally, scientific studies have evaluated the performance of the CMIP6 ensemble for many regions of the world. Nooni et al. (2023) showed that the model ensemble outperformed individual models and captured spatial trends across climatic zones, for Africa and the Arabian Peninsula (Nooni, et al., 2023). In a study aimed specifically at understanding future rainfall patterns in southern Africa, Sian et al. (2021) compared the historical data of 23 CMIP6 GCMs against rain gauge-based data to assess the individual models' performance in simulating annual precipitation variation, seasonal inter-annual variability and trends (Sian, et al., 2021). On the basis of the best performing models, their results confirm an overall drying pattern over all sub-regions of southern Africa under Shared Socioeconomic Pathways (SSP)2-4.5 (and they note that it is imperative to properly manage water resources through sound planning).

The IPCC report concludes with high confidence (Assessment Report 6 WG1 Technical Summary TS.4.3.2) that with 2°C of global warming southern Africa will experience increases in drought and aridity as early as the mid-21st century. The report also places high confidence in a projected decrease in total precipitation for southernmost Africa regions (TS.4.3.2.1). The impacts of these physical changes are summarised in the Working Group II report, "Climate Change 2022: Impacts, adaptation and vulnerability":

Country-level projections are now available from the sixth Coupled Model Intercomparison Project (CMIP-6), with the SSP scenarios consistent with the Intergovernmental Panel on Climate Change's (IPCC's) sixth assessment report (AR6).

In all future time periods, under all scenarios except the single most optimistic (and at this time unrealistic), South Africa will experience temperature rise due to climate change (Figure 4).

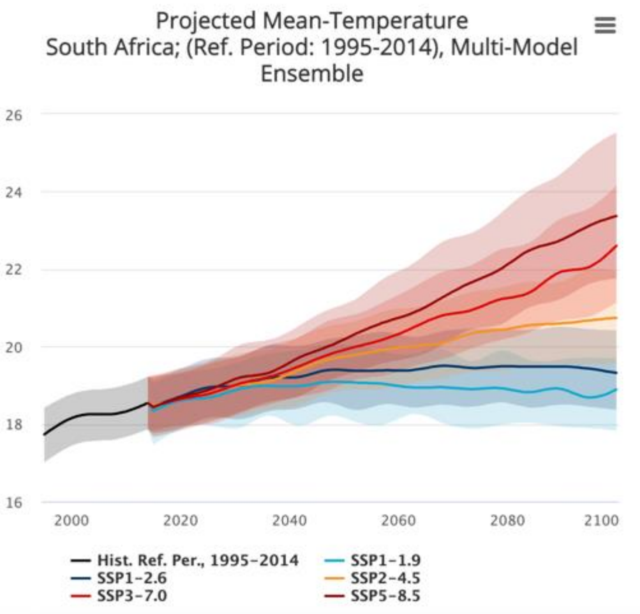


Figure 4: Comparison of historic reference mean annual temperature and future temperature under different SSPs, through 2100 (Source: World Bank CCKP)

It is expected that under a Business-as-Usual future, by mid-century the South African coast will warm by 1-2°C, and the interior as much as 3°C.

Future projections of precipitation are more complex. Overall, for the period 2020-2039, under all SSPs (barring the most optimistic and unrealistic), there is a very slight signal of decrease in total annual average rainfall volume. Sub-nationally, projections indicate that the western part of the country and the interiors will get dryer, while the south-eastern and eastern areas – particularly the coastal regions in these areas – will get wetter (World Bank Climate Change Knowledge Portal n.d.).

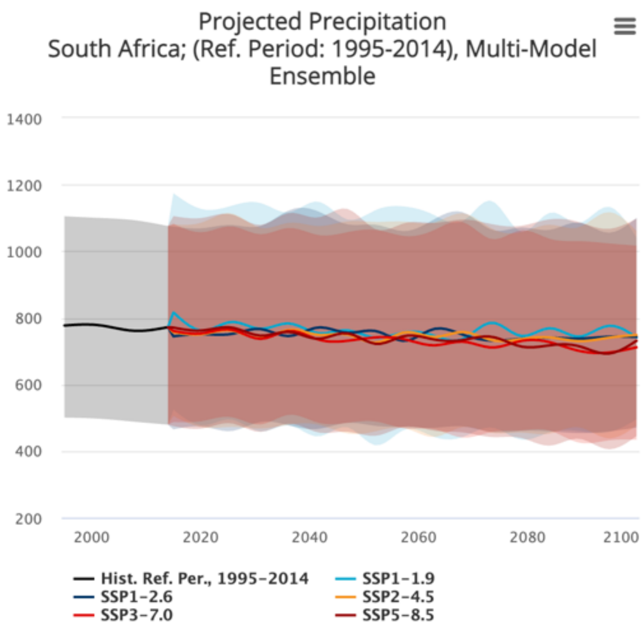


Figure 5: Comparison of historic reference mean annual rainfall and future rainfall under different SSPs, through 2100 (Source: World Bank CCKP)

Climate change impacts on runoff

Preliminary results for national runoff using the Pitman modelling approach suggest a change that lies between a 20% reduction to a 60% increase under an unconstrained greenhouse gas emissions scenario (unconstrained emissions scenario) (SANBI and DEA 2013). If global emissions are constrained to stabilise at 450 ppm CO_2 equivalent, (L1S emissions scenario) the risk of extreme increases and reductions in runoff are sharply reduced, and the impacts lie between a 5% decrease and a 20% increase in annual runoff (Figure 6). Using a different suite of modelling approaches would change these results slightly but the range is so wide that it would be unlikely to result in a material change in the overall message (SANBI and DEA 2013).

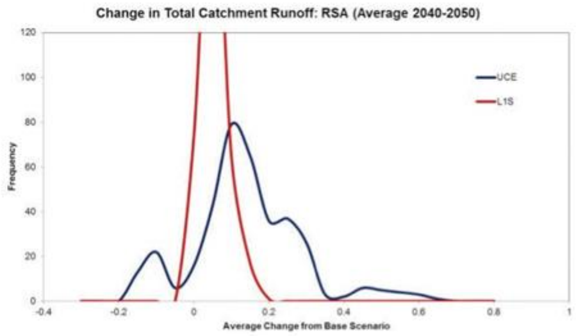


Figure 11. Preliminary projected changes in annual runoff for South Africa under an unconstrained greenhouse gas emissions scenario (blue line unconstrained CO_2 emissions (UCE)), and an emissions scenario constrained to stabilise at 450 ppm CO_2 equivalent (red line level 1 stabilisation (L1S))

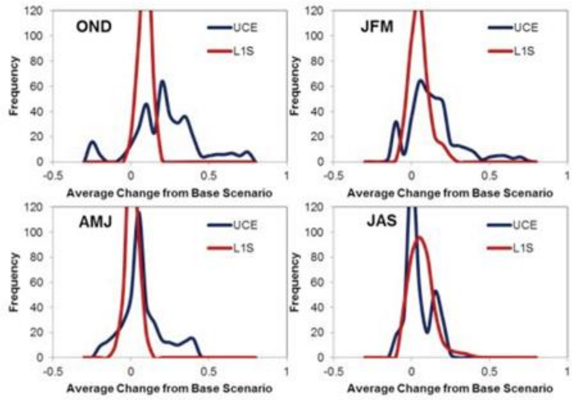


Figure 12. Preliminary projected changes in seasonal runoff for South Africa under an unconstrained greenhouse gas emissions scenario (blue line, unconstrained CO2 emissions (UCE)), and an emissions scenario constrained to stabilise at 450 ppm CO2 equivalent (red line, level 1 stabilisation(L1S)). The graphs represent the months of the four seasons spring (OND), summer (JFM), autumn (AMJ) and winter (JAS)

Figure 6: Preliminary projected changes for annual runoff and (b) seasonal runoff (Source: SANBI and DEA, 2013)

Results for national runoff expressed seasonally echo the annual results, with only minor exceptions that indicate a small risk of increased runoff in summer and winter months under both emissions scenarios, and an increased risk of reduced runoff in autumn months under the L1S emissions scenario. If global emissions are constrained to stabilise at 450 ppm CO_2 equivalent, the risk of extreme increases and reductions in runoff are strongly reduced, and the impacts lie between a 10% decrease and a 30% increase in seasonal runoff (Figure 6) (SANBI and DEA 2013).

Spatially, the impacts on annual runoff vary strongly, with median impacts very positive along the eastern seaboard and in the central interior, and negative in parts of the Western Cape. Areas showing the highest risks of extreme runoff related events include Kwazulu-Natal, parts of southern Mpumalanga and the Eastern Cape (SANBI and DEA 2013). Other areas show neutral to reduced risk in runoff, with the exception of the central and lower Orange River region (Figure 7). Specific areas of high risk where cumulative negative climate change impacts are likely to occur (including increased evaporation, decreased rainfall and decreased runoff) include the southwest of the country, the central-western parts and to some extent the extreme north (SANBI and DEA 2013).

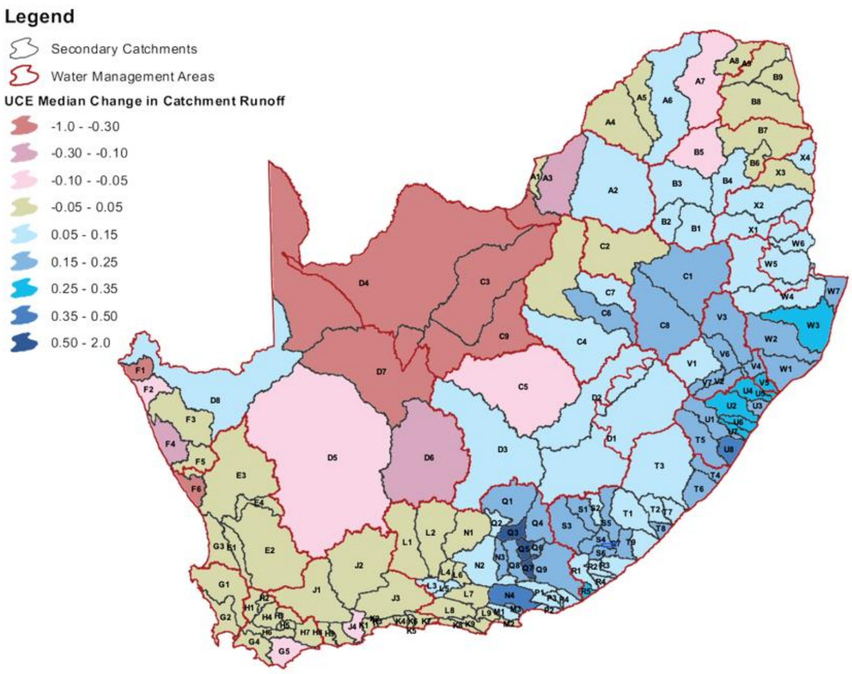


Figure 7: Median impact of climate change on the average annual catchment runoff for the period 2040-2050 (Source: SANBI and DEA, 2013)

Hydrological models using downscaled climate projections have been the primary means of assessing sectoral impacts. The hydrological system is dynamic, and changes in climate may result in unanticipated hydrological responses, possibly beyond the ranges for which the models' ability to represent processes has been tested (Ziervogel, et al., 2014). Preliminary projections under the wide range of scenarios generated by the MIT hybrid approach for runoff range from a 20% decrease to a 60% increase by as early as 2050 under an unmitigated emissions pathway, while under a constrained emissions scenario projections of runoff range from a 5% decrease to a 20% increase. It is worth noting that a 60% increase in rainfall is a low probability outcome from the modelling framework and is also physically very implausible. Spatially, the eastern seaboard and central interior of the country are likely to experience increases while much of the Northern and Western Cape are likely to experience decreases in runoff (Ziervogel, et al., 2014).

Impact studies for the water resources sector have begun to look beyond changes in streamflow to changes in the timing of flows and the partitioning of streamflow into baseflows and stormflows, reservoir yields, and extreme hydrological events. Under all future climate scenarios considered by the Long Term Adaptation Scenarios (LTAS), higher frequencies of flooding and drought events are projected. Complexities of the hydrological cycle, influences of land use and management and the link- ages to society, health, and the economy indicate far higher levels of complexity in the water resources sector than in other sectors. What has emerged is that land uses that currently have significant impacts on catchment water resources will place proportionally greater demands on the catchment's water resources if the climate were to become drier. The influence of climate change on water quality is an emerging research field in South Africa, with assessments limited to water temperature and non-point source nitro- gen and phosphorus movement. A critical interaction that has not been explored is between changes in water quality and quantity and the combined impacts, such changes might have impact on various types of water use, e.g., irrigation, domestic consumption, or aquatic ecosystems support (Ziervogel, et al., 2014).

Climate change impacts on water quality

The impacts of climate change on water quality are generally not well studied either globally or in southern Africa. In general the impacts are descriptive in nature and based on knowledge of how water quality responds to predicted changes in climatic drivers, namely temperature, evaporation, rainfall and hydrology (SANBI and DEA 2013).

An increase in air temperature will lead to an increase in water temperature. Increased water temperatures could affect, inter alia, the quality of water for irrigation, dissolved oxygen content of water, the rates of chemical and biological reactions in water, and could have wide- ranging repercussions in the health sector through the creation of favourable conditions for the incubation and transmission of water-borne diseases (SANBI and DEA 2013).

Heat waves can lead to short-term water quality impacts and increased fish mortality due to low oxygen concentrations brought about by a rapid increase in decomposition processes, and stress on temperature-sensitive fish species (SANBI and DEA 2013).

Enhanced evaporation is additional evaporation, over and above that which takes place under present climatic conditions, from open water bodies such as dams and wetlands and from the soil and plant systems. Evaporation has the effect of concentrating salts and other constituents in open water bodies when their water volume is reduced. It can also concentrate salts and other constituents in the soil when soil moisture is reduced as a result of evaporation at the soil surface and water losses through evapotranspiration from plants (SANBI and DEA 2013).

Rainfall intensity affects catchment wash-off processes as it increases the erosion of soil and other pollutants that accumulate on the surface of the catchment. It can also lead to surcharging sewers when sewage pipes become blocked with washed-off debris, or the discharge of partially treated wastewater from over-loaded wastewater treatment works (WWTW). This in turn poses a health risk to humans and can impact on aquatic ecosystems when the increased organic loads decompose and consume oxygen in the process (SANBI and DEA 2013).

One of the strategies for dealing with droughts is to store more water for use during periods of water shortages. During droughts less water is available to dilute wastewater discharges and irrigation return flows resulting in aggravated impacts on downstream users and aquatic ecosystems (SANBI and DEA 2013).

Climate change impact on water services

Urban and rural water supply currently accounts for 23% and 4% of the national water resource allocation respectively. The Water for Growth and Development Framework (DWAF, 2009b) estimates that due to the projected growth in population, domestic water use will increase from 27% of total national water use to between 30% and 35%. DWAF (2009b) also states that urban municipal areas account for 23% of the national water use, while rural settlements use only 4%. This is partly because service levels in urban areas are much higher, but also because 20% to 30% of water use in urban areas is industrial (SANBI and DEA 2013).

2.3 South Africa's Water Supply Vulnerability

The Greenbook Risk Tool (CSIR and Aurecon, 2019) undertook comprehensive integrated modelling to assess the impact of future climate change on surface water and water supply for municipalities in South Africa, and found that climate change exacerbates water risks at the municipal level. 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 Water Resources Yield Model (Cullis & al, 2015; Schulze, 2011) 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.

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 8.

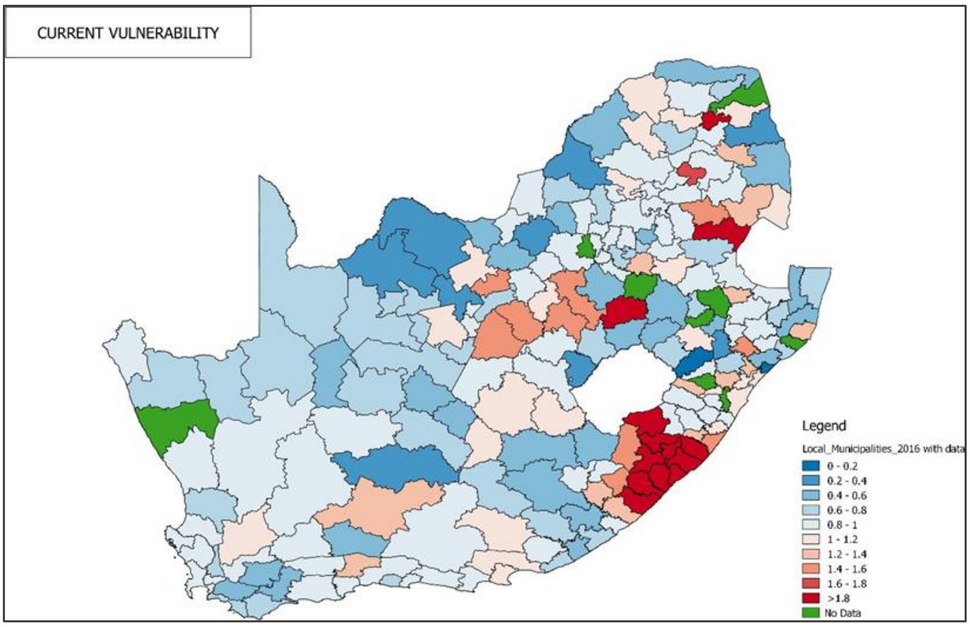


Figure 8: Current water supply vulnerability (estimated demand/supply) (Source: CSIR, Greenbook, 2019)

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 estimated future water supply vulnerability (excluding climate change impacts and water supply augmentation options) is shown for the medium population growth scenario and the high population growth scenario (Figure 9). 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.

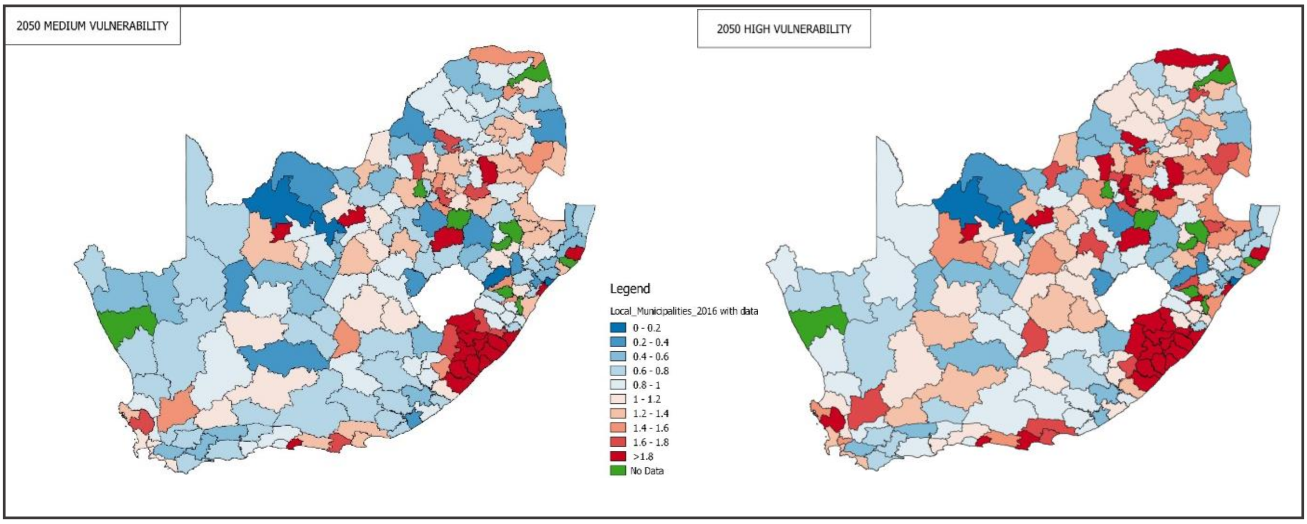


Figure 9: Water supply vulnerability (estimated demand/supply) 2050 medium growth (left) and high growth(right) (Source: CSIR, Greenbook, 2019)

Exposure to Climate Change

The estimated impacts of climate change on the mean annual runoff (MAR) for the 10th (wet), 50th (median) and 90th (dry) percentile climate change scenario are shown in Figure 10. 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.

The impacts of climate change on water supply at a national level, using a national configuration of the Water Resources Yield Model (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. Due to bulk water transfers and the use of major dams, the impact of climate change on 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.

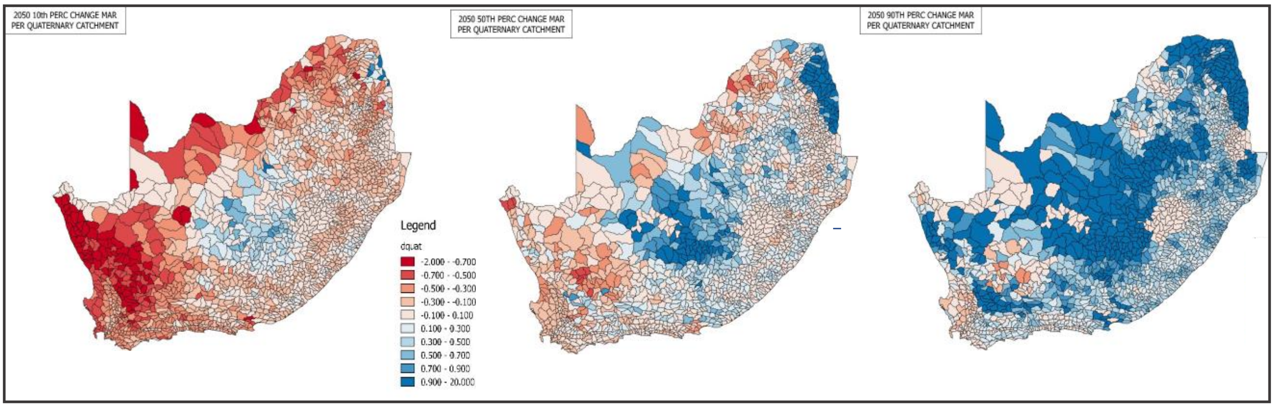


Figure 10: Climate change impacts by 2050 on MAR under the 10% (dry), 50% (median) and 90%v(wet) climate scenarios, from left to right (Source: CSIR, Greenbook, 2019)

The study did 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.

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 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 11, Figure 12, and Figure 13 show the exposure of each local municipality to climate change for evaporation, precipitation and local runoff (i.e. based on E1). Figure 14, Figure 15 and Figure 16 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.

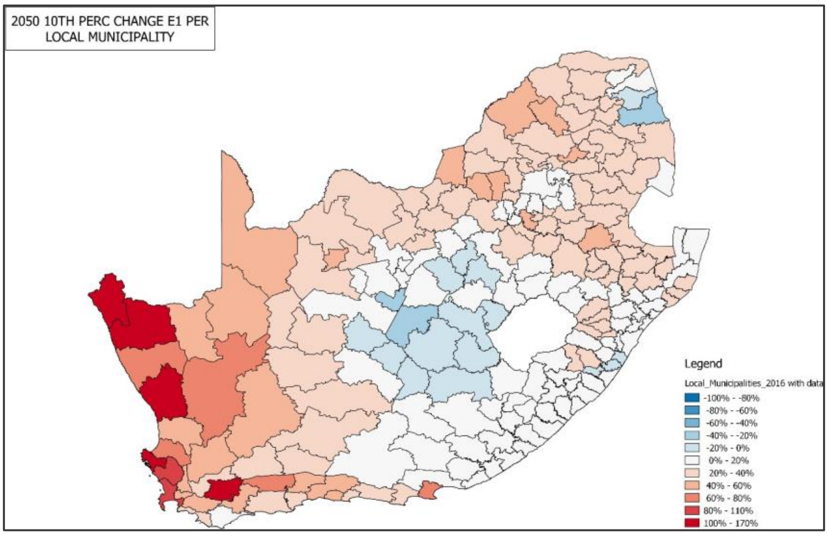


Figure 11: Climate change exposure (E1) by 2050 10% (dry) climate scenario considering local runoff changes (Source: CSIR, Greenbook, 2019)

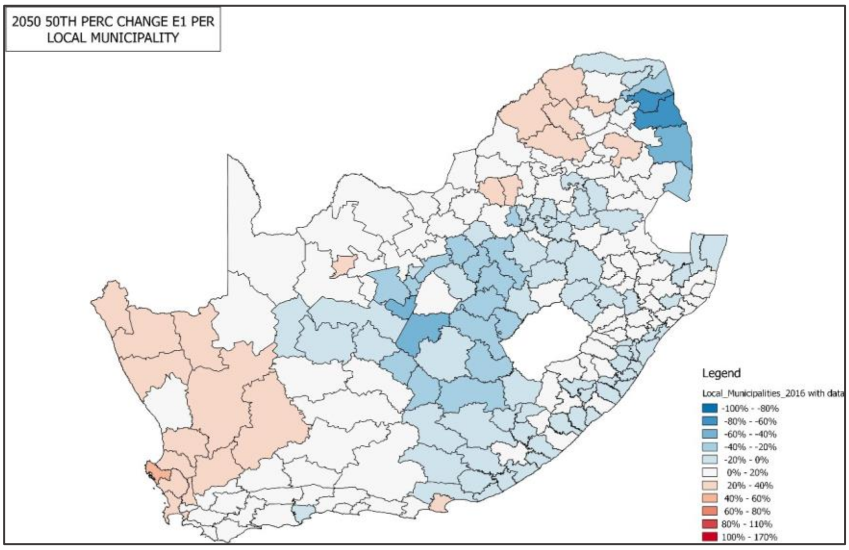


Figure 12: Climate change exposure (E1) by 2050 50% (median) climate scenario considering local runoff changes (Source: CSIR, Greenbook, 2019)

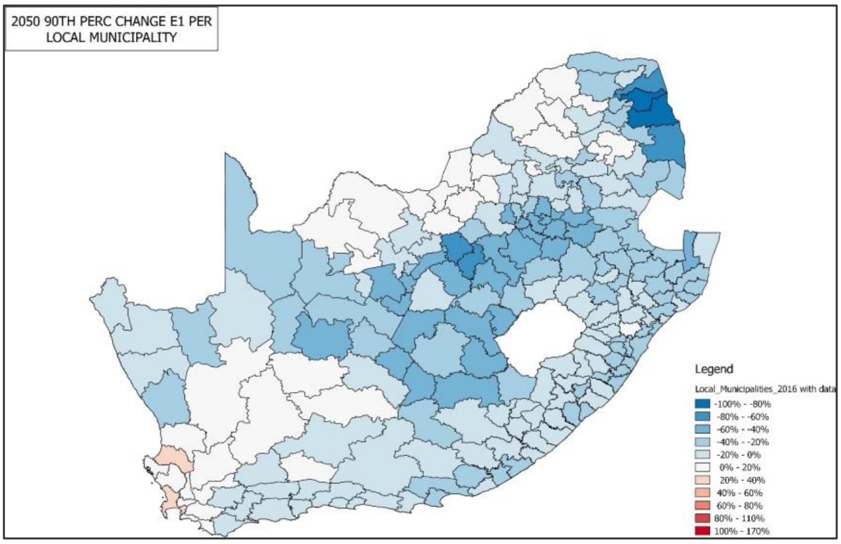


Figure 13: Climate change exposure (E1) by 2050 90% (wet) climate scenario considering local runoff changes (Source: CSIR, Greenbook, 2019)

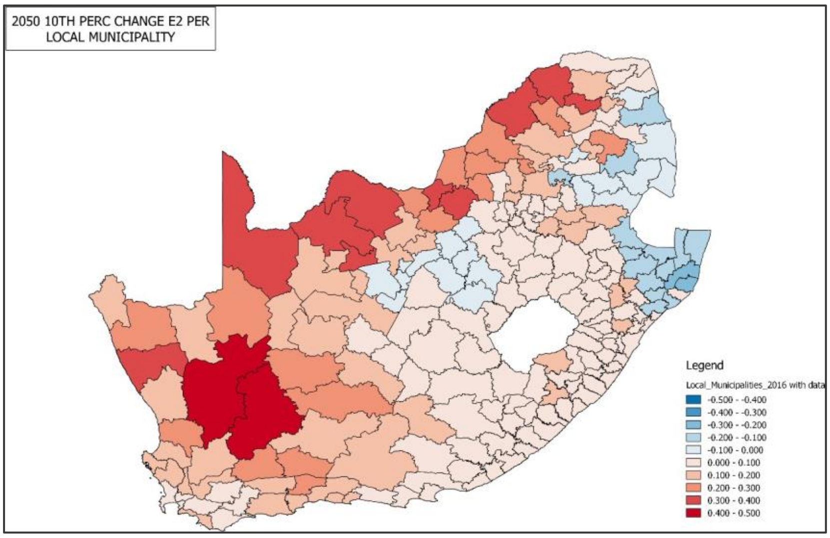


Figure 14: Climate change exposure (E2) by 2050 10% (dry) climate scenario considering regional urban water supply changes (Source: CSIR, Greenbook, 2019)

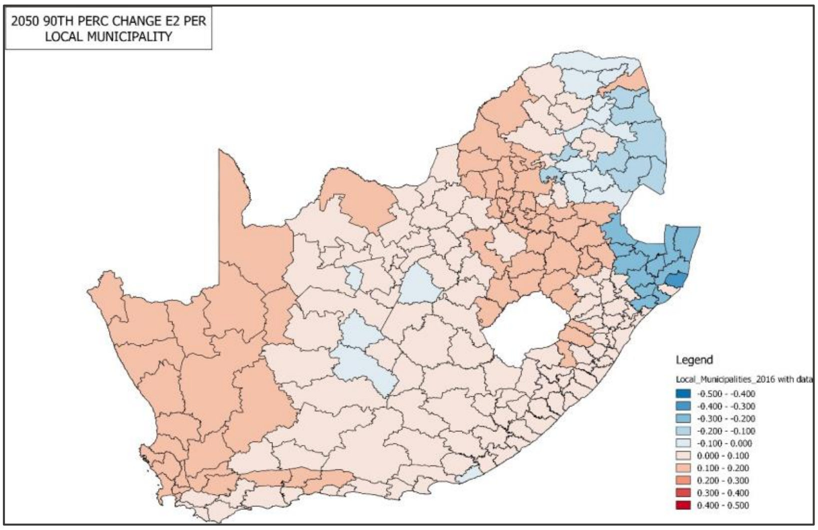


Figure 15: Climate change exposure (E2) by 2050 50% (median) climate scenario considering regional urban water supply changes (Source: CSIR, Greenbook, 2019)

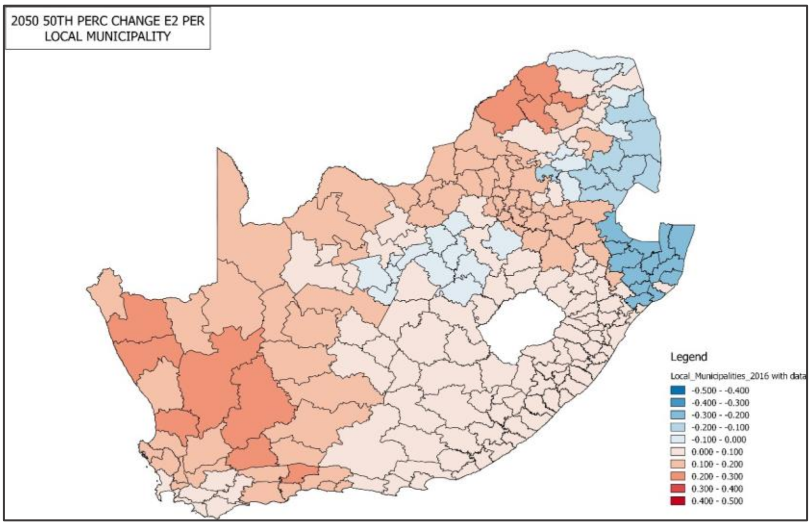


Figure 16: Climate change exposure (E2) by 2050 90% (wet) climate scenario considering regional urban water supply changes (Source: CSIR, Greenbook, 2019)

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 for water.

The percentage reliance on surface water and groundwater for water supply is included as part of 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 and evaporation.

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 18, Figure 19 and Figure 20. 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 (Figure 17).

The future water supply vulnerability for municipalities assuming no population growth is shown in Figure 18, the future water supply vulnerability for municipalities assuming medium population growth is shown in Figure 19 and the future water supply vulnerability for local municipalities assuming high population growth for the E1 and E2 scenarios is shown in Figure 20.

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. 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 20).

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) and (E2) scenarios and for the high population growth scenario with climate change exposure (E2) scenarios in Figure 21.

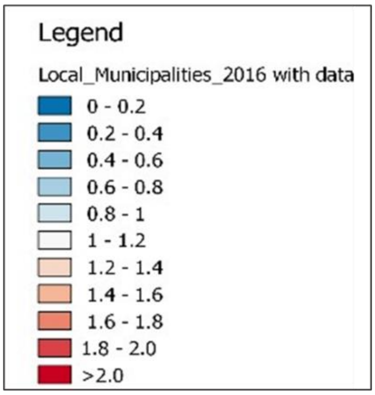


Figure 17: Vulnerability map legend

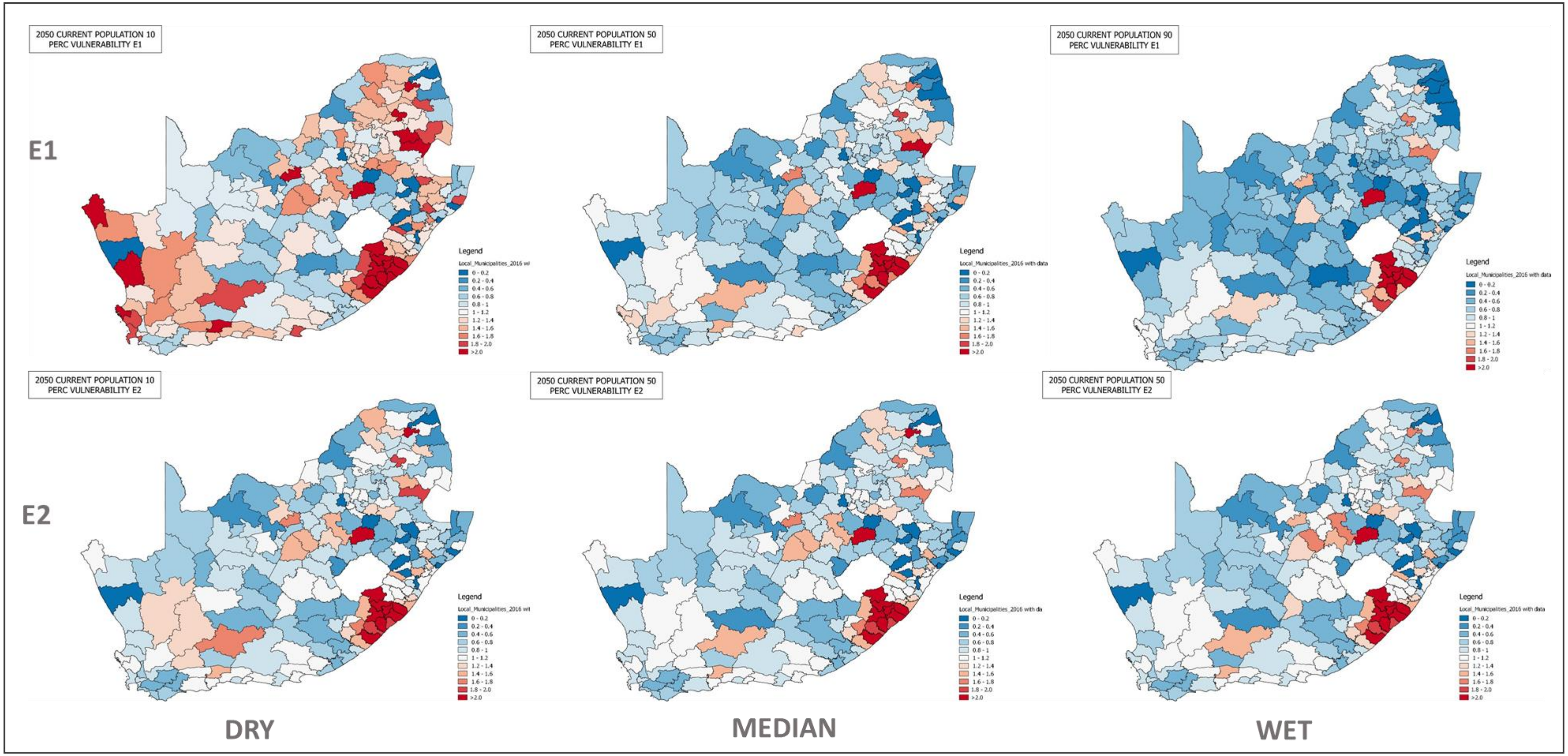


Figure 18: 2050 water supply vulnerability (estimated demand/supply) with dry, median and wet scenarios under climate change exposure E1 and E2 scenarios, and current population (Source: CSIR, Greenbook, 2019)

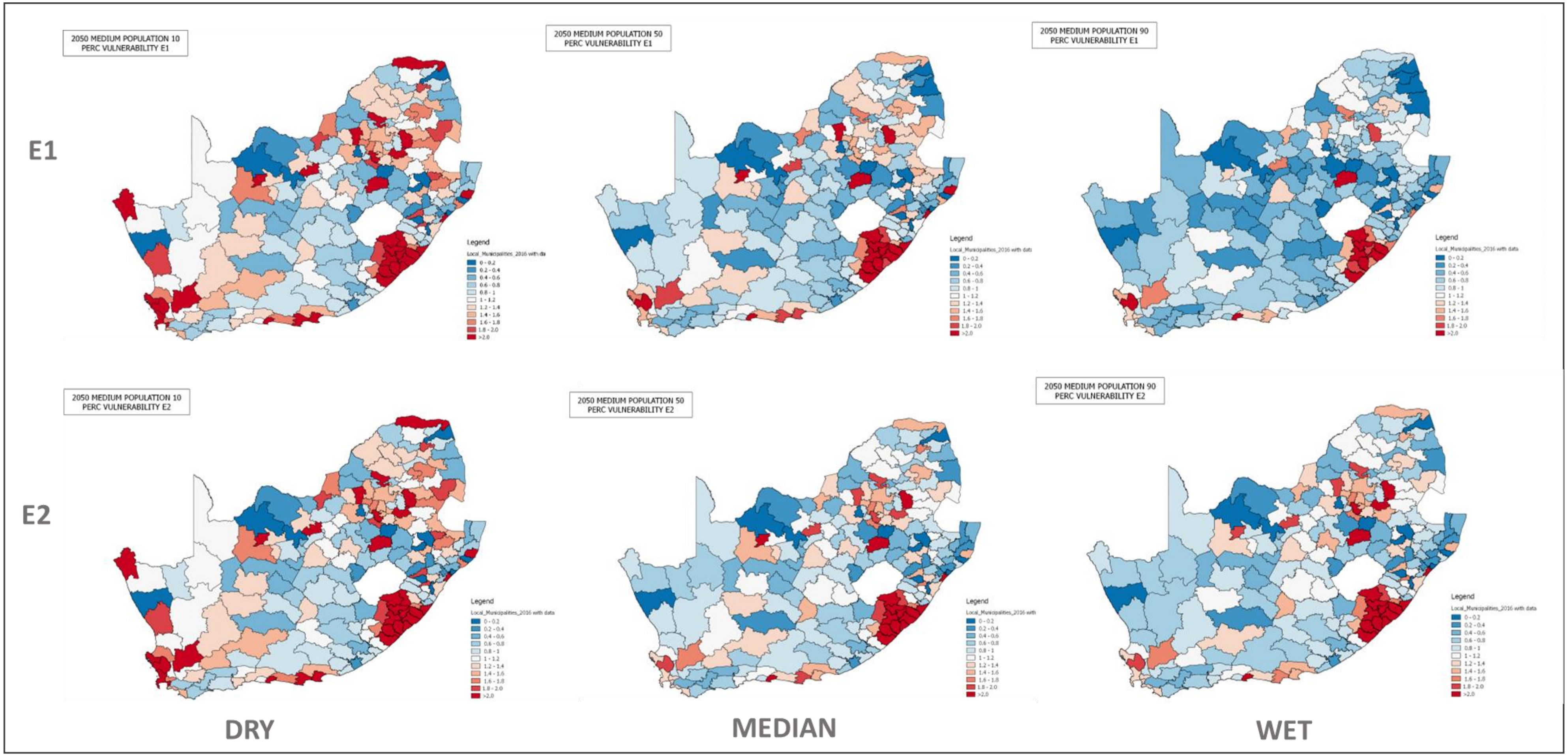


Figure 19: 2050 water supply vulnerability (estimated demand/supply) with dry, median and wet scenarios under climate change exposure E1 and E2 scenarios, and medium population growth (Source: CSIR, Greenbook, 2019)

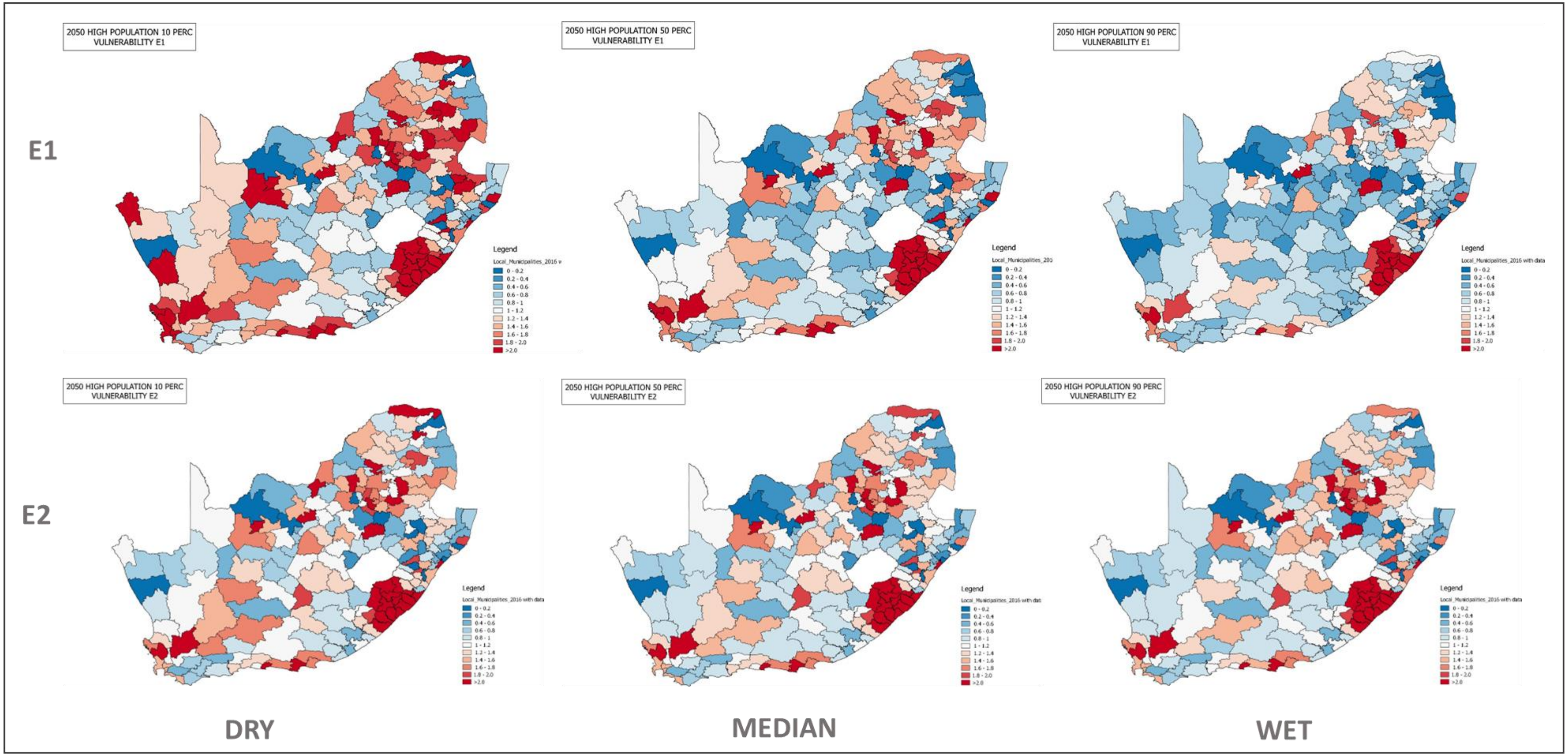


Figure 20: 2050 water supply vulnerability (estimated demand/supply) with dry, median and wet scenarios under climate change exposure E1 and E2 scenarios, and high population growth (Source: CSIR, Greenbook, 2019)

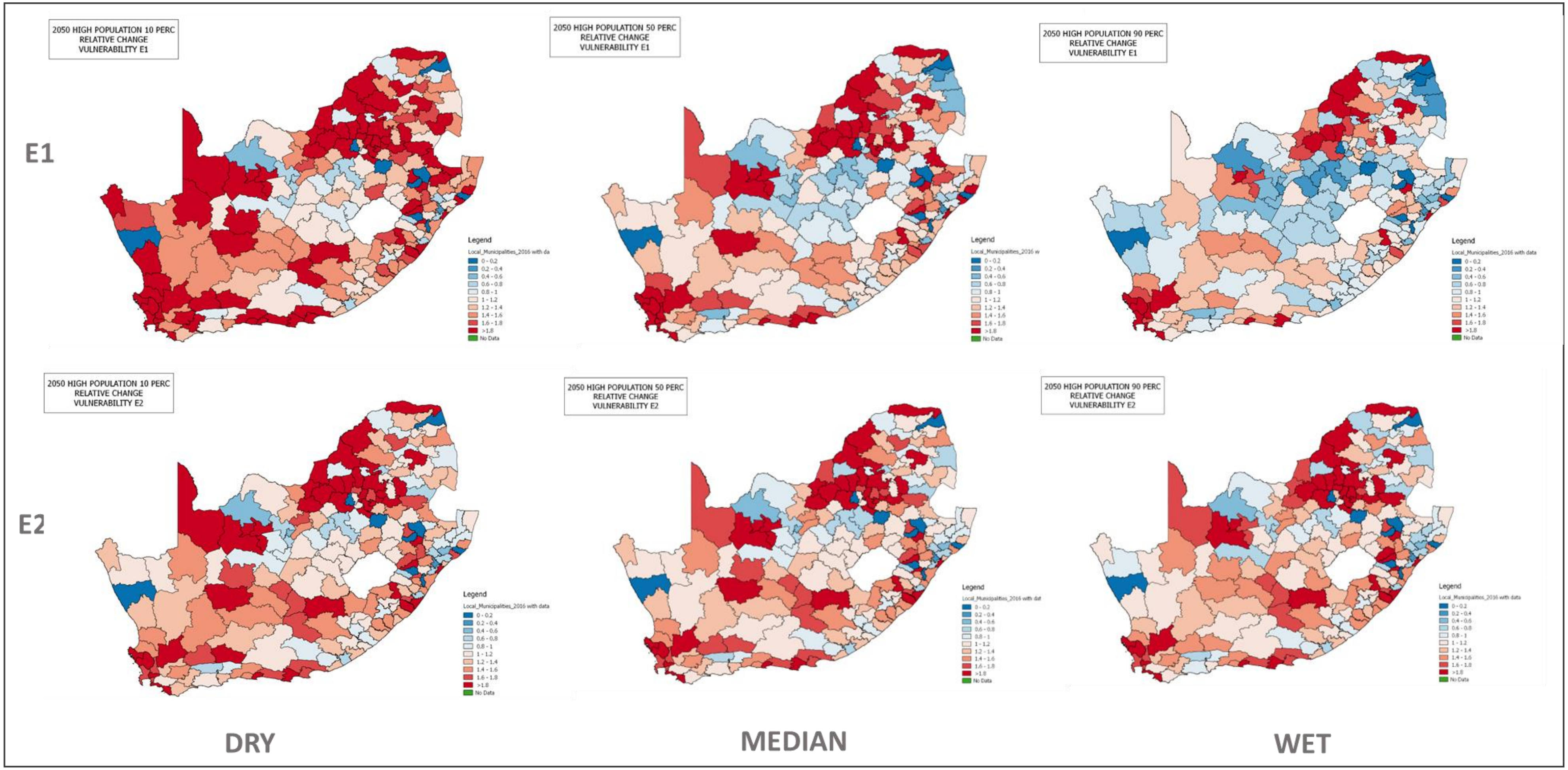


Figure 21: Relative change in water supply vulnerability with dry, median and wet scenarios under climate change exposure E1 and E2 scenarios, and high population growth (Source: CSIR, Greenbook, 2019)

3. Municipal Climate Risk & Vulnerability

The section provides a summary snapshot of localised climate change risk and vulnerability for water resources in ten priority municipalities targeted by the WRP in its first phase

3.1 Introduction

This section presents an overview of climate change impacts in eight municipalities in South Africa. These municipalities have been selected as sites for the first phase of the WRP due to their need for adaptive capacity in the water sector. They are all experiencing varying degrees of water stress and scarcity, with such impacts expected to be exacerbated by climate change in coming decades. The eight municipalities are:

- City of Cape Town;
- Nelson Mandela Metropolitan Municipality;
- City of Ekurhuleni;
- City of Johannesburg Metropolitan Municipality;
- City of Tshwane Metropolitan Municipality;
- eThekwini Metropolitan Municipality;
- Drakenstein Local Municipality; and
- Mangaung Metropolitan Municipality.

3.2 City of Cape Town

The City of Cape Town is located within the Western Cape province, on the coast of southwestern South Africa. Historically, its climate has been classified as warm temperate climate (with dry and cool summers) under the Köppen-Geiger climate classification system (CSIR 2015).

Historic climate

The historic average maximum and minimum temperatures (Figure 22 and Figure 23) show minimal variation between 1979 and 2000 with the average maximum temperature sitting below 23°C and the average minimum temperature being above 10°C.

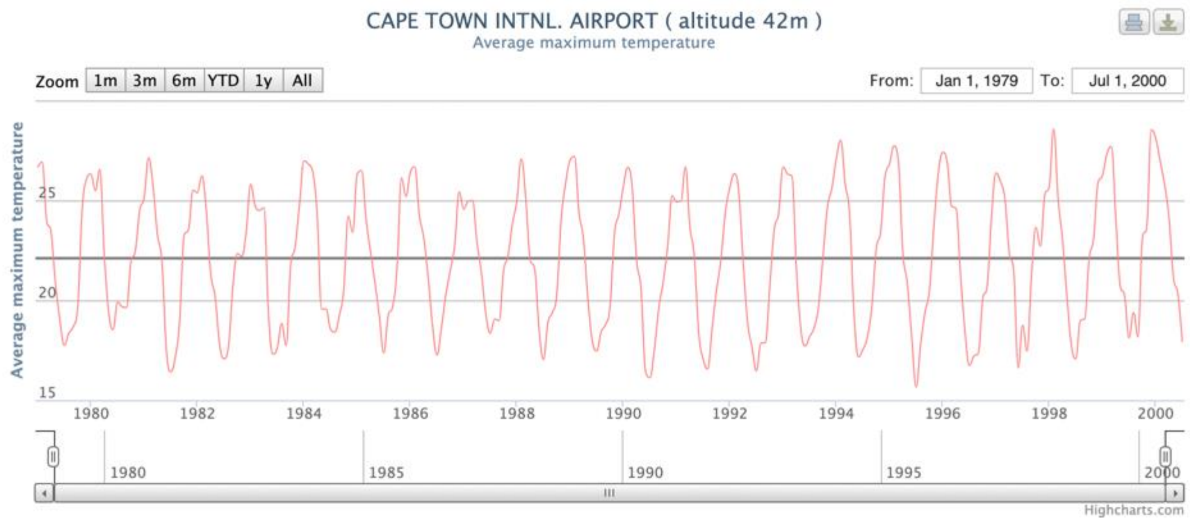


Figure 22: Historic average maximum temperature (available only from January 1979 to July 2000) for City of Cape Town[1]

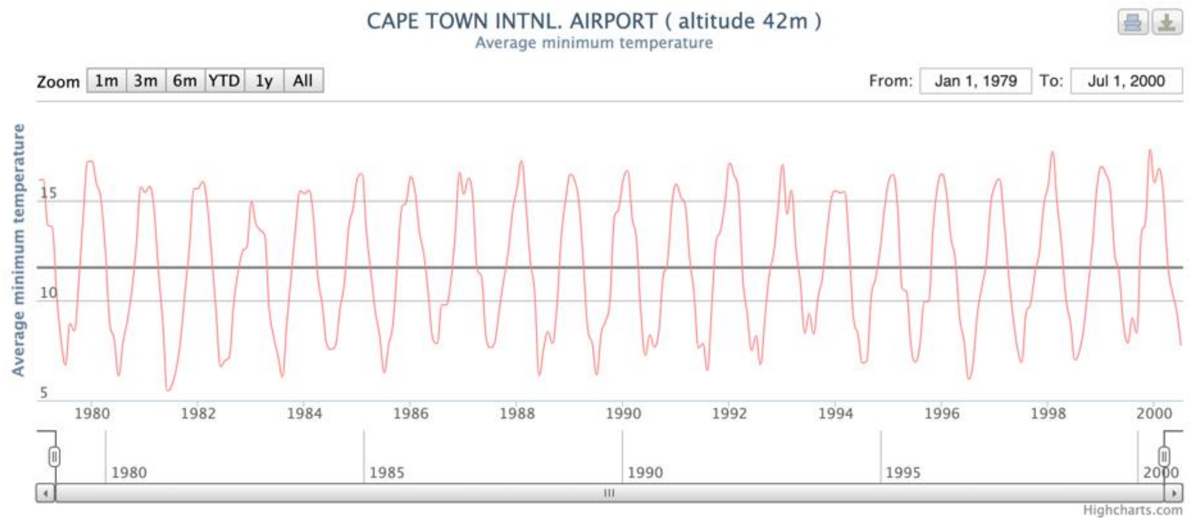


Figure 23: Historic average minimum temperature (available only from January 1979 to July 2000) for City of Cape Town[2]

The historic total monthly rainfall had a few peaks (greater than 150mm) between 1991 and 1995 but the average total monthly rainfall is 50 mm (Figure 24).

[1] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[2] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

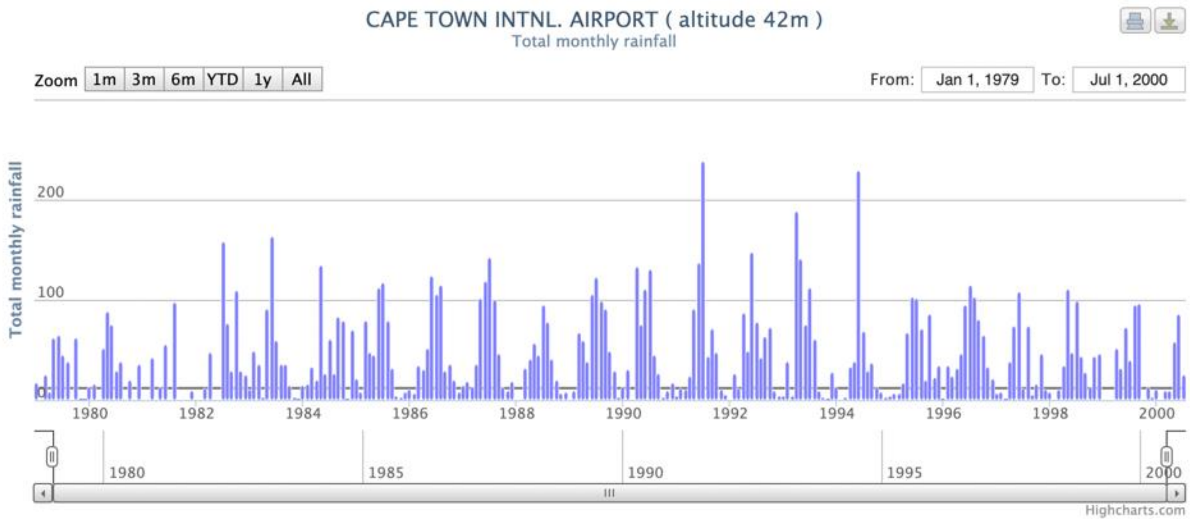


Figure 24: Historic total monthly rainfall (available only from January 1979 to July 2000) for City of Cape Town[3]

Dry spell durations in the past showed the highest duration between 1998 and 2000 with the average dry spell duration between 1979 and 2000 being less than 10 days (Figure 25).

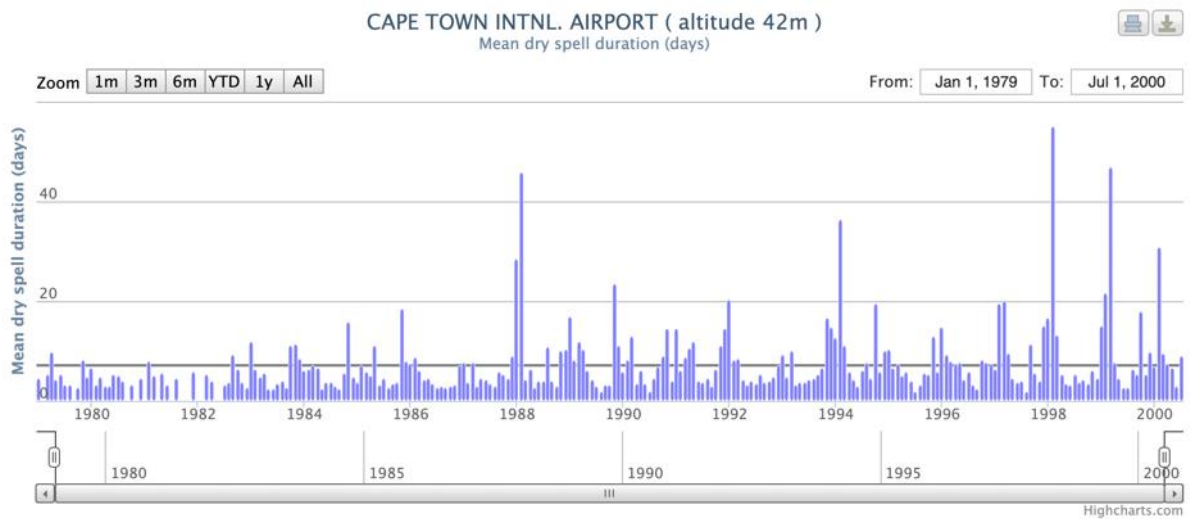


Figure 25: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for City of Cape Town[4]

Current climate and water resources

As depicted in Figure 26, the municipality's current average annual temperature is approximately 18°C and current annual average rainfall is 800 mm (CSIR and Aurecon 2019).

[3] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

[4] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

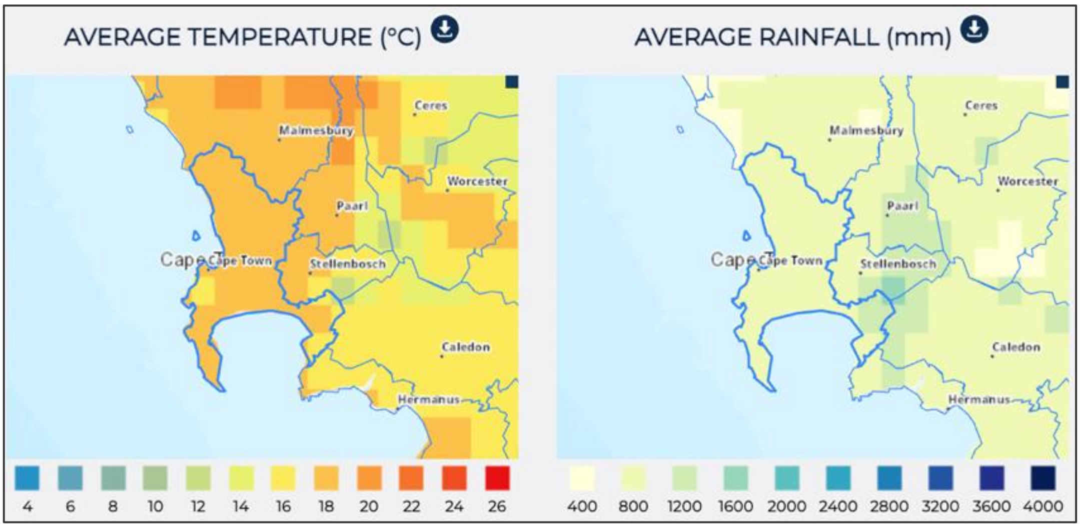


Figure 26: City of Cape Town's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality is not classified as vulnerable, but is positioned at the very edge of its available supply (CSIR and Aurecon 2019), as reflected in Figure 27.

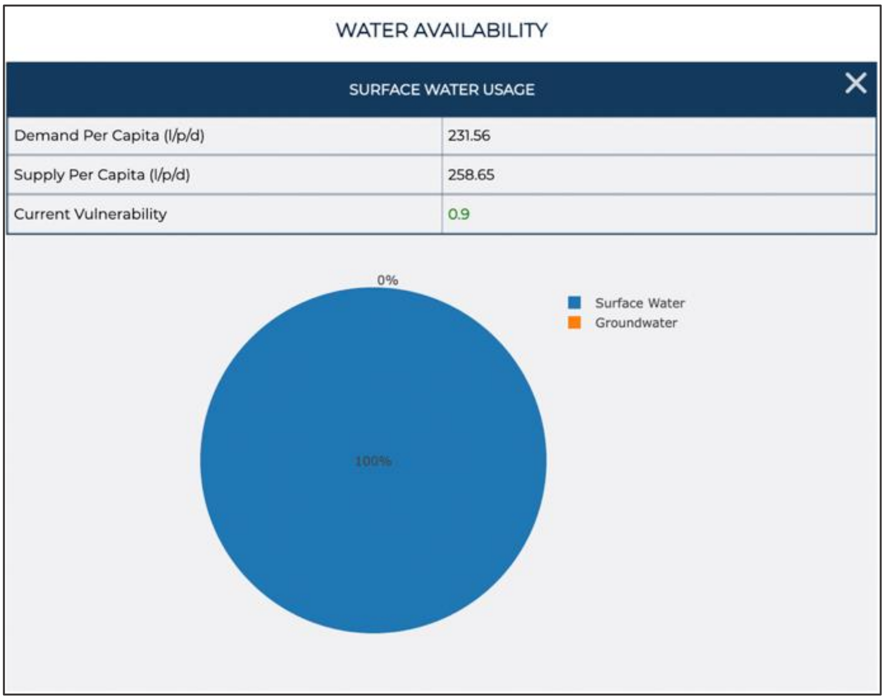


Figure 27: Present-day water availability in Cape Town municipality (Source: CSIR, Greenbook, 2019)

Figure 28 indicates that most of Cape Town has low-to-moderate groundwater recharge potential. Yet, there is already a combination of dependency on surface water and groundwater.

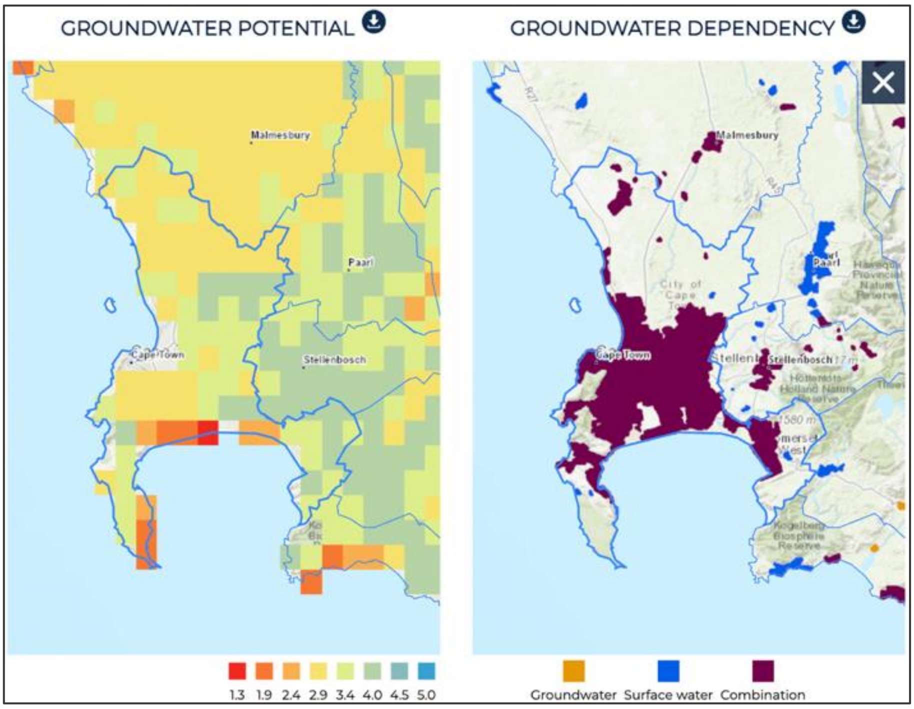


Figure 28: Groundwater recharge potential (left) and groundwater dependency (right) in Cape Town municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources (Figure 29) are just able to meet the municipality's needs at the moment (CSIR and Aurecon 2019).

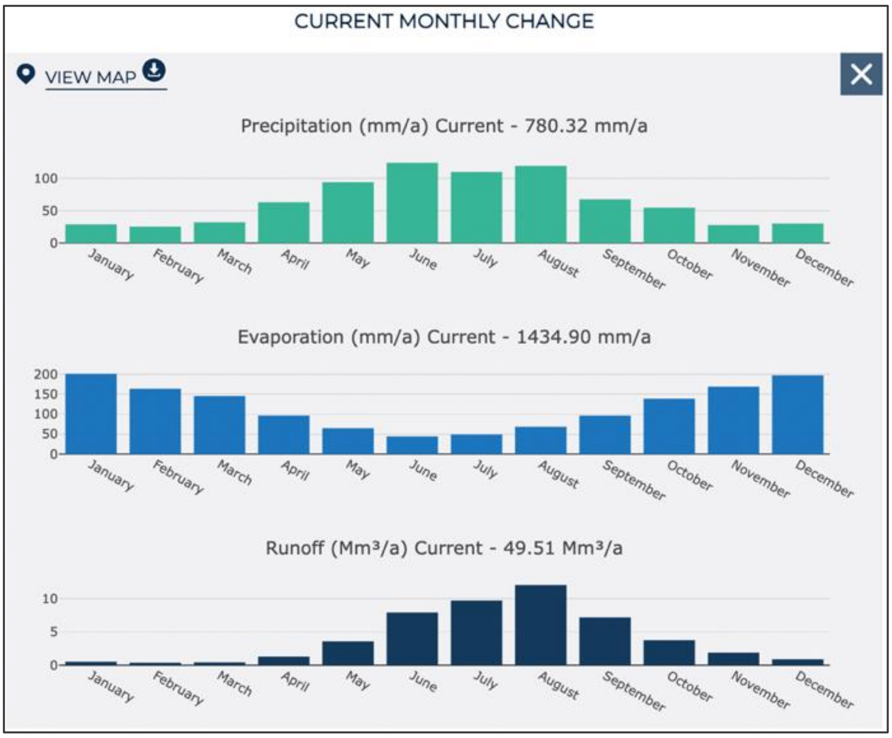


Figure 29: Surface water indices in the City of Cape Town under the current climate (Source: CSIR, Greenbook, 2019)

However, given the climatic conditions in southwestern South Africa, the city faces significant drought risk under the current climate (Figure 30)[5] relative to most of the country as well as to southern Africa as a whole.

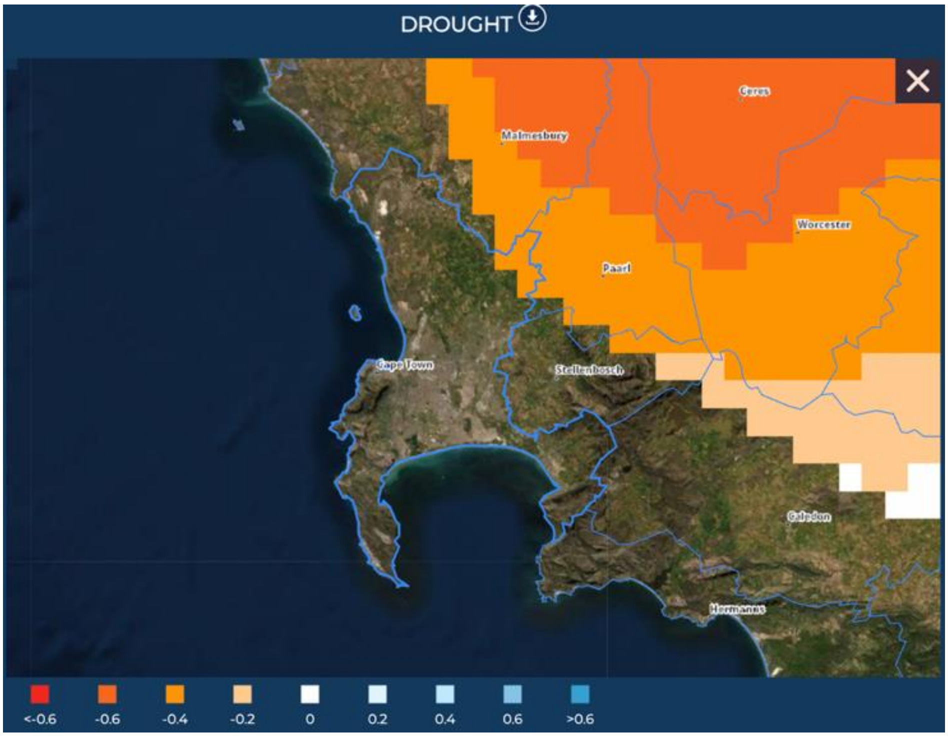


Figure 30: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Cape Town is already feeling the impact of climate change, and is one of the cities in South Africa that is at the very frontline of climate-driven shocks. A high-profile recent illustration of this is the extreme multiyear drought that occurred between 2015 and 2019, which led to the risk that Cape Town could effectively run out of water – an event that made headlines globally as an impending “Day Zero” (City of Cape Town 2021).

Studies examining the likelihood of this type of multi-year drought event have established attribution to anthropogenic climate change, finding that while the return period of such an extreme drought is extremely rare – once in a hundred years – climate change increased the likelihood of the drought by a factor of three (Otto et al. 2018). Another peer-reviewed attribution study suggested that climate change may have made the Cape Town drought of 2018 as much 4.3 times more likely (Nangombe et al. 2020). Scholarly research has also determined that the rainfall deficit that led to the drought was made up to six times more likely by climate change. (Pascale et al. 2020)

Future Climate

Validated models from the fifth phase of the Coupled Model Intercomparison Project (CMIP-5) indicate that under a moderate or intermediate emissions scenario (Representative Concentration Pathway or RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP’s first

[5] Note that due to technical challenges with map layer overlays, the color-coded drought risk layer is not perfectly superimposed on the corresponding land area, leaving some coastal areas without the color applicable to them (i.e., the colors visible closest to the location on the map). In the case of Cape Town, the relevant values are -0.4 and -.0.6.

phase) from 2011 – 2040, the City of Cape Town is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- -3% decrease in mean annual precipitation (many models agree on the decrease, with some models agreeing about the projected increase in length of dry spells. A few models also suggest an increase in the number of dry spells).
- 2% increase in aridity
- -5% decrease in annual mean soil moisture
- -3% decrease in annual mean water discharge (with a few models agreeing on an decrease in the 2-year, 5-year, 10-year, and 50-year return periods for annual maximum water discharge)
- -3% decrease in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that even under RCP 4.5, in 2050, Cape Town will experience temperature rise of up to 1.9°C (CSIR and Aurecon 2019).

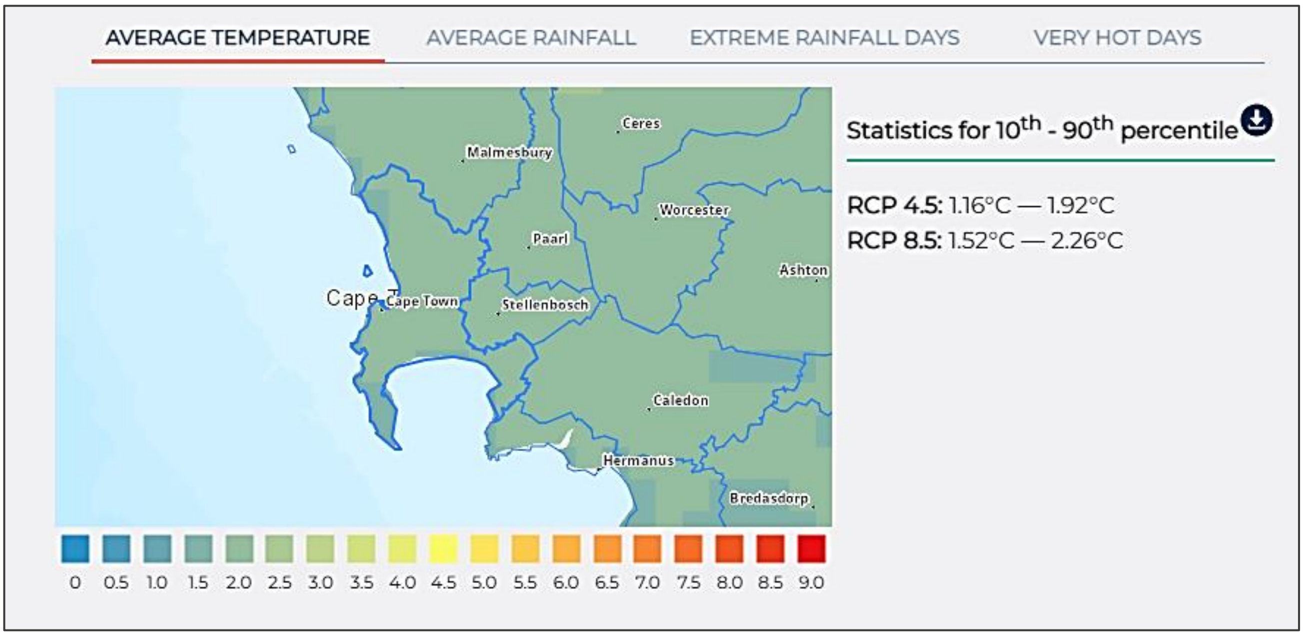


Figure 31: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Future average maximum and minimum temperature projections for RCP4.5 between 2030 and 2050 also show an overall increase, but this varies between 2.5°C and 0.5°C (Figure 32 and Figure 33).

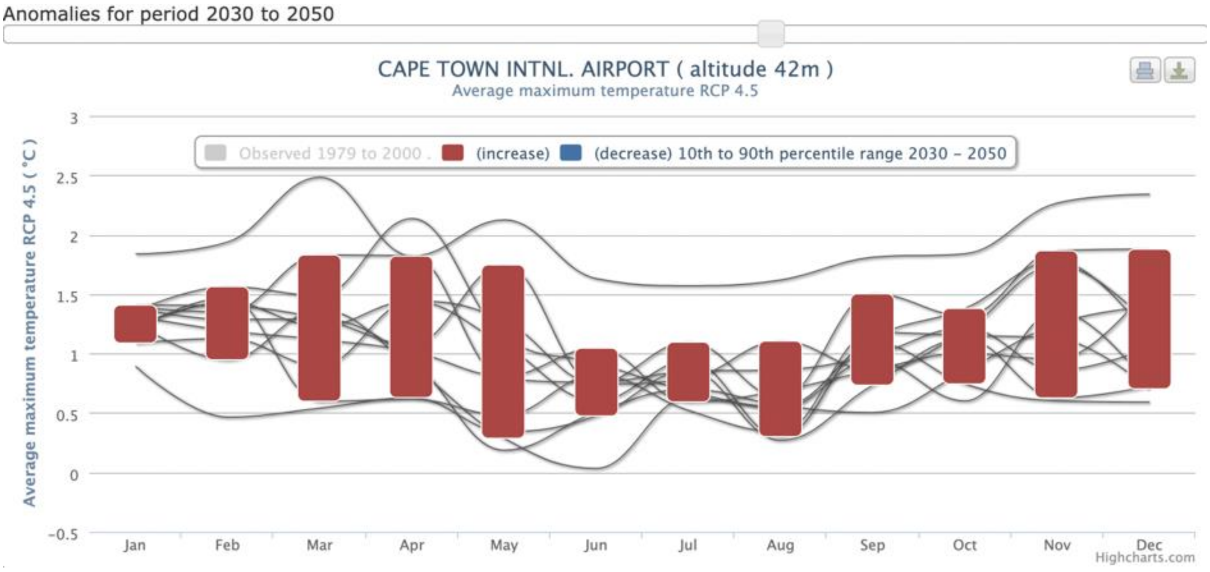


Figure 32: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for City of Cape Town [6]

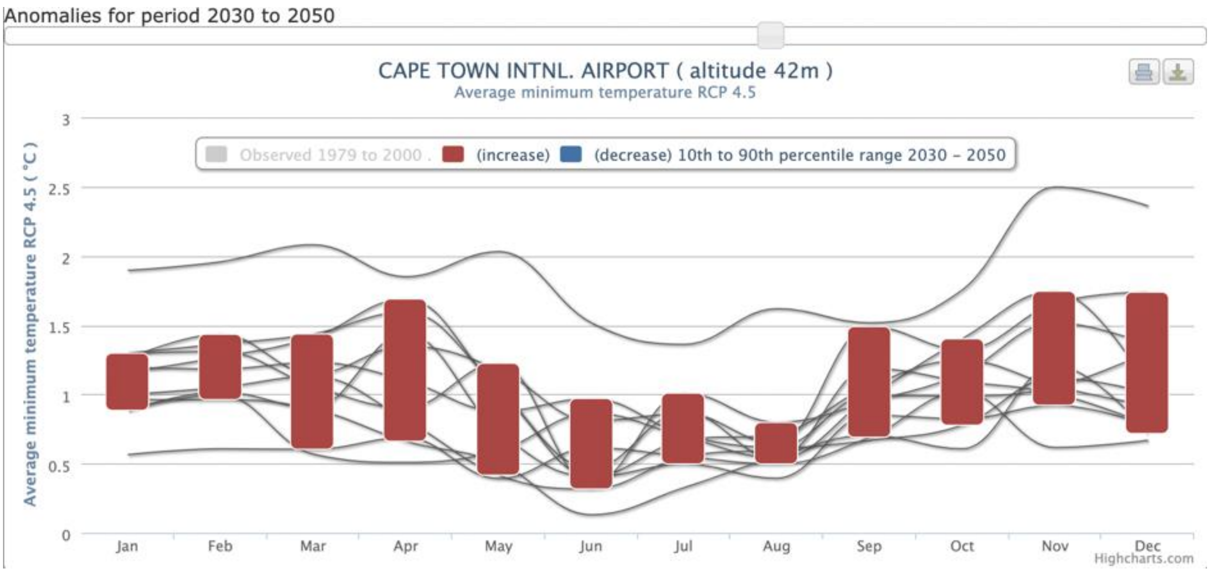


Figure 33: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for City of Cape Town [7]

Average rainfall in 2050, under RCP 4.5, is likely to decrease substantially (CSIR and Aurecon 2019).

[6] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

[7] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

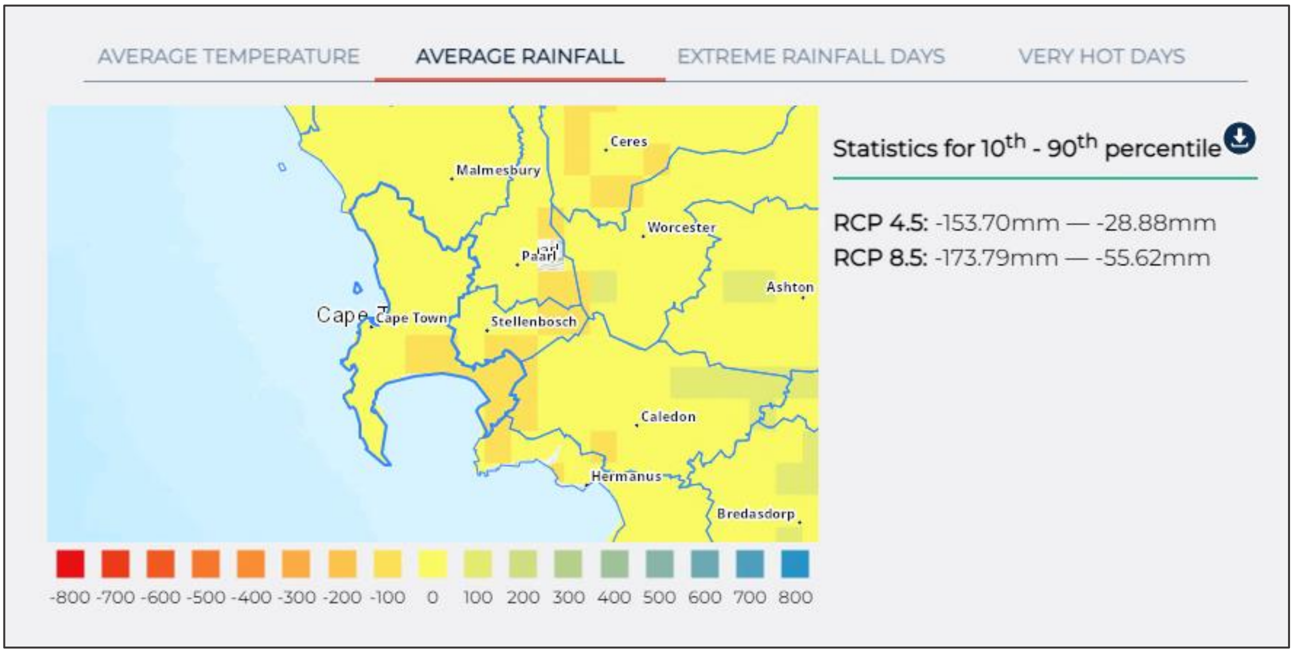


Figure 34: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Figure 35 shows a relative decrease in projected rainfall for RCP4.5 between 2030 and 2050.

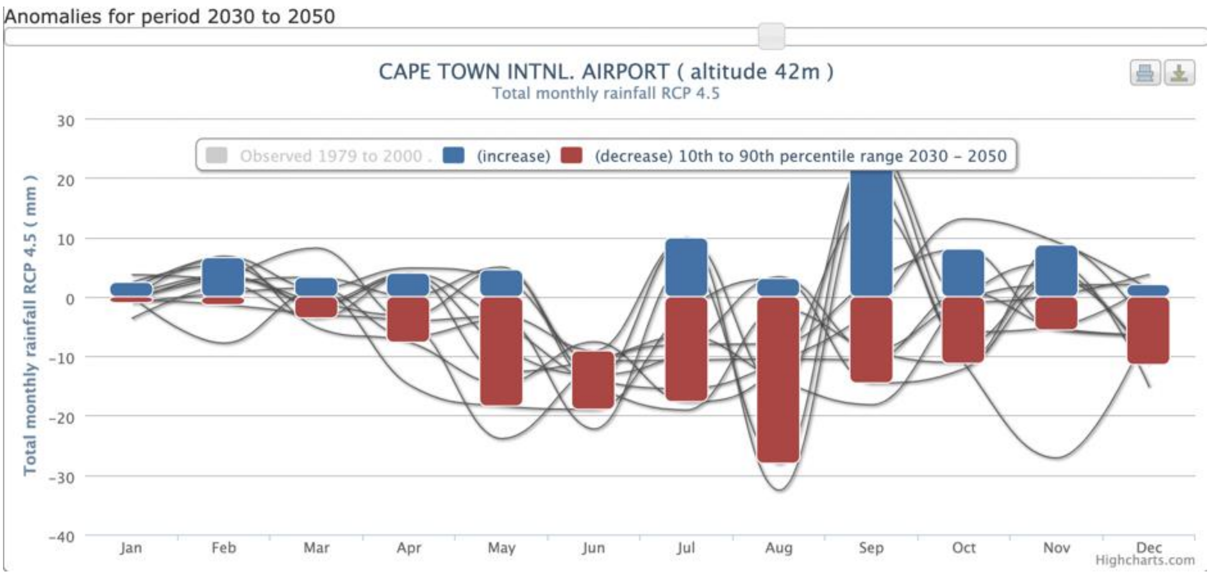


Figure 35: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for City of Cape Town [8]

Cape Town is expected to experience a slight decrease in extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019).

[8] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

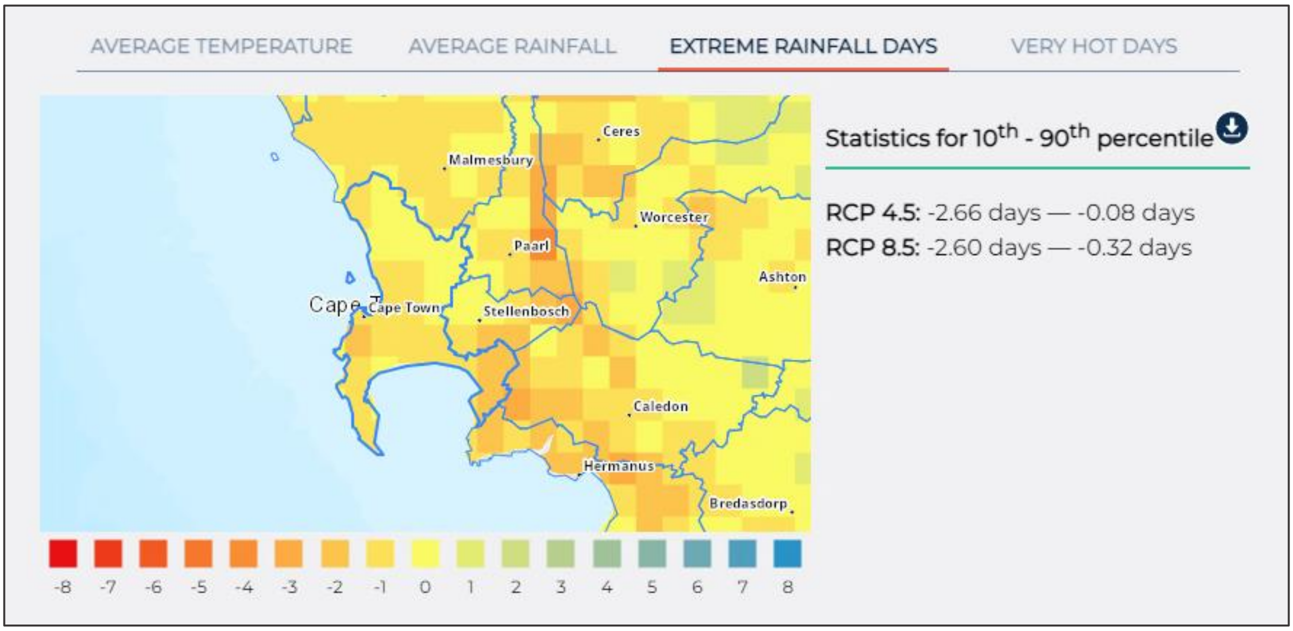


Figure 36: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality will also experience an increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

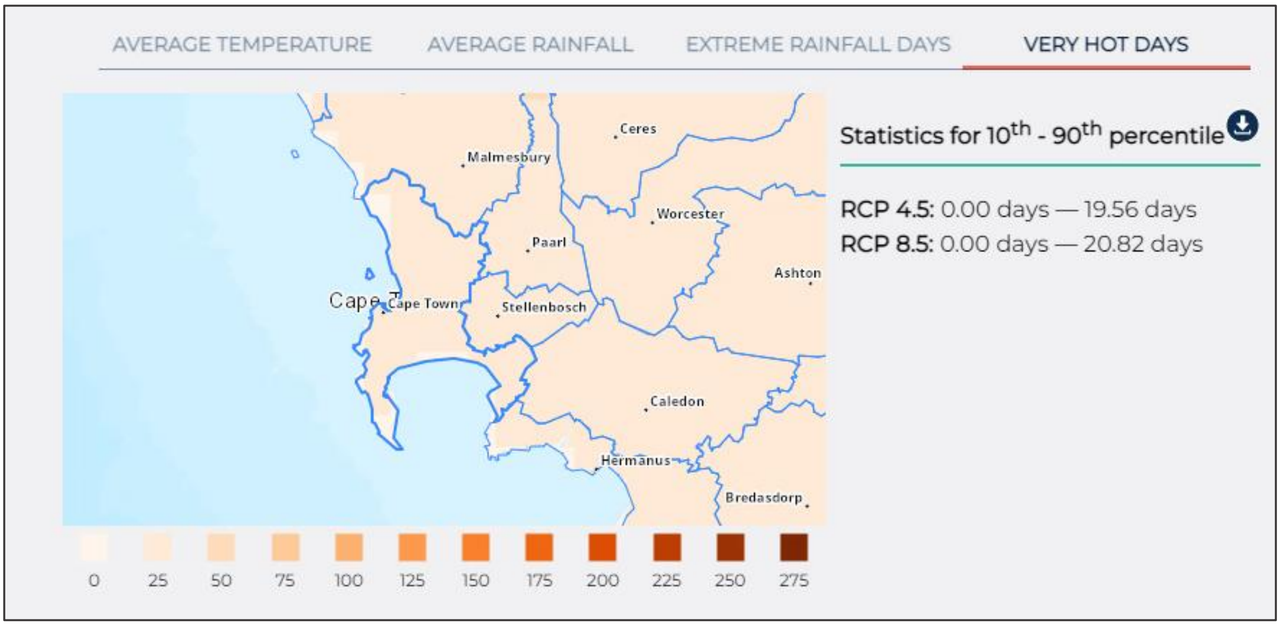


Figure 37: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Slightly longer dry spells are observed in the summer months for the City of Cape Town (Figure 38).

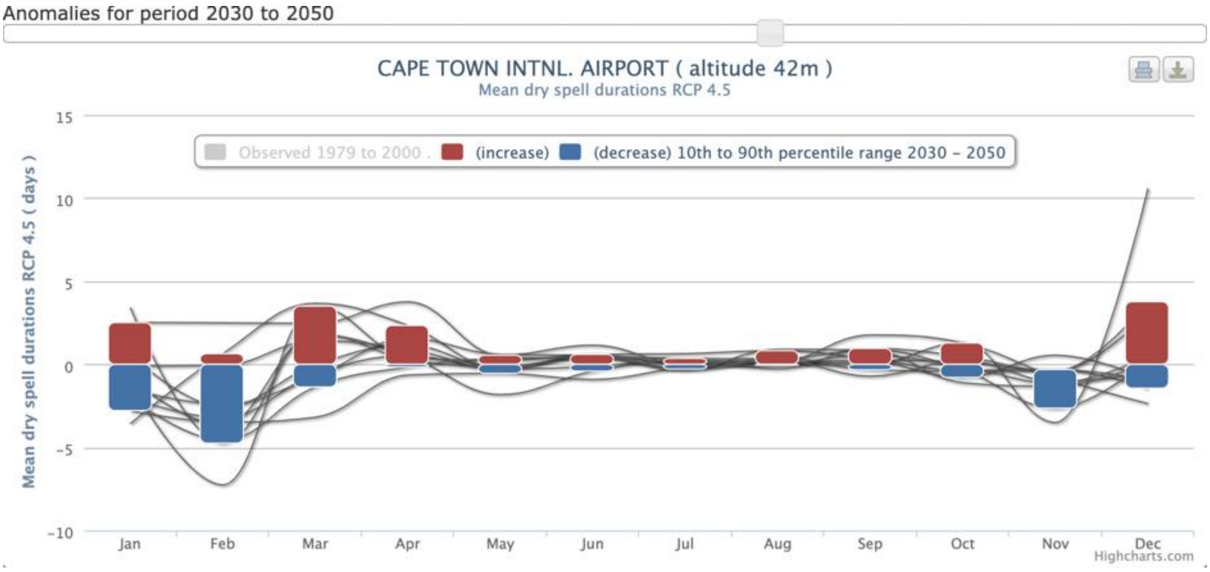


Figure 38: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for City of Cape Town[9]

Future drought risk in Cape Town in 2050 is projected to be very high, in terms of the standardised precipitation index (SPI) drought index, coupled with *extremely high* risk of increased drought tendency across the municipality (CSIR and Aurecon 2019).

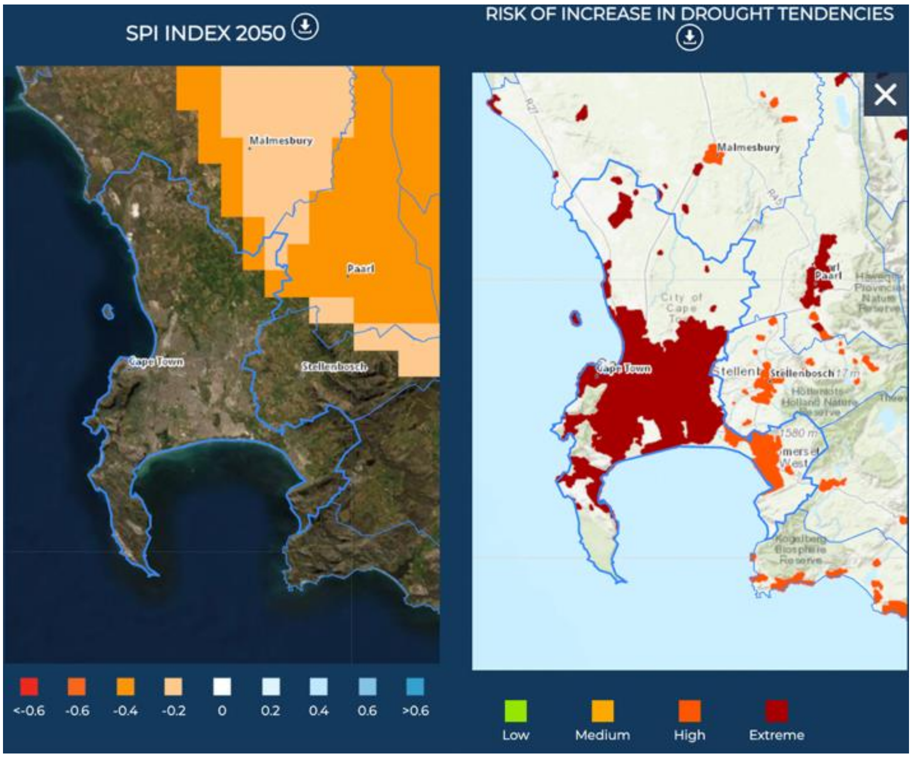


Figure 39: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential is modest in 2050. However, Cape Town faces *extremely high* risk of groundwater depletion.

[9] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

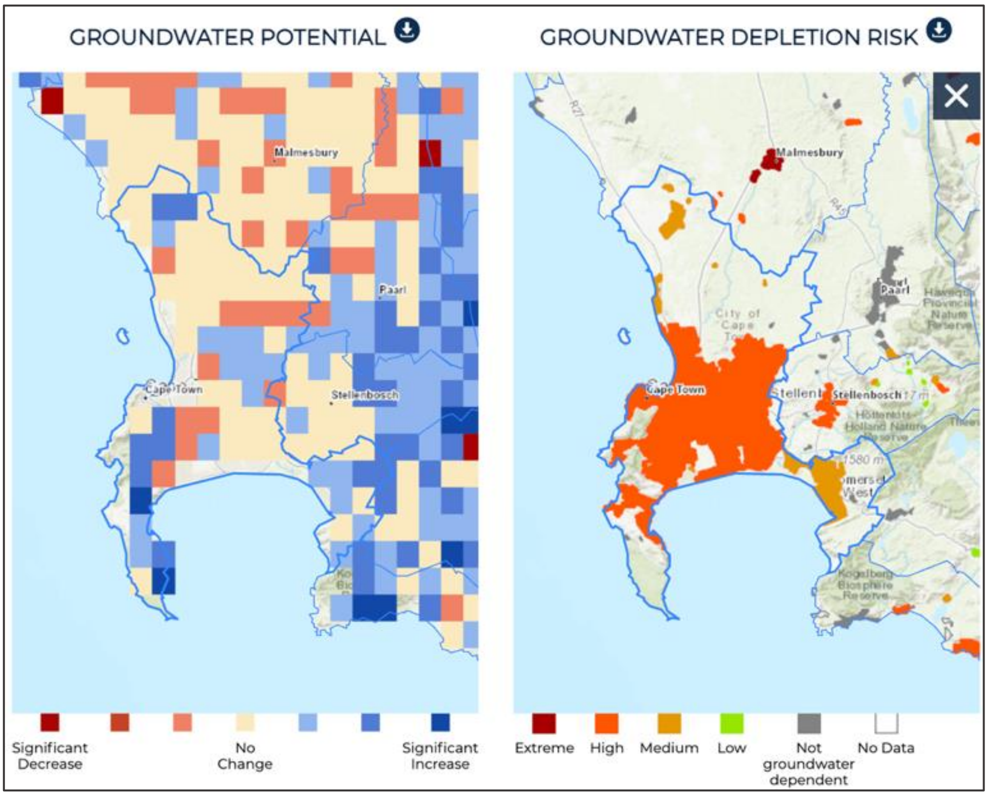


Figure 40: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show that, on average, there will be a decrease in precipitation, and increase in evaporation, and a decrease in runoff.

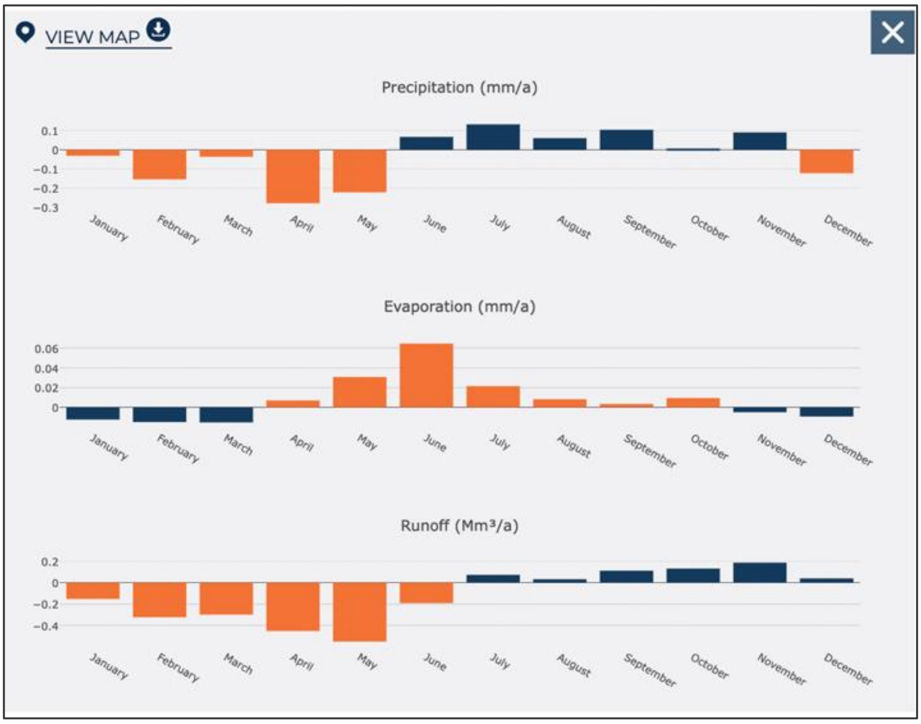
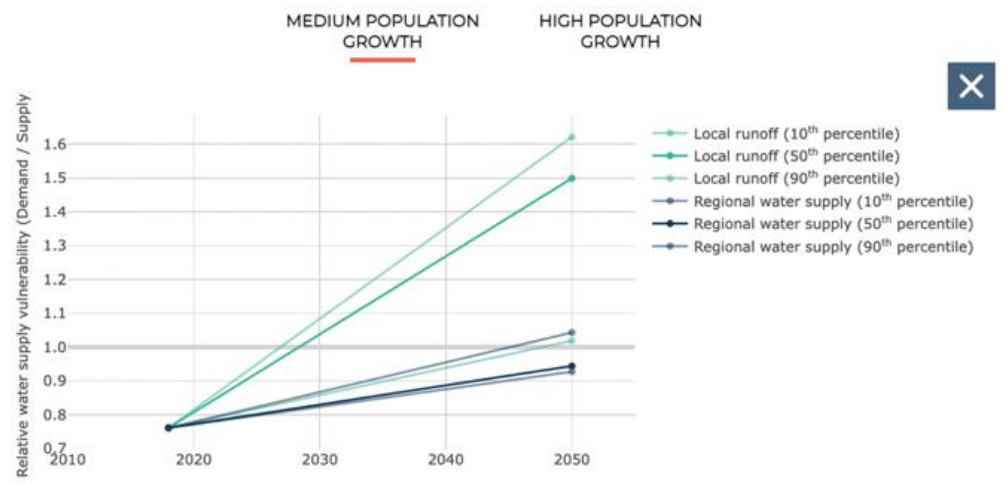


Figure 41: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, by 2050, Cape Town's regional water supply is not likely to keep pace with population growth and – in the face of decreased precipitation, increased evaporation, decreased runoff linked to climate change – the city will be highly vulnerable to climate change (CSIR and Aurecon 2019).



VULNERABILITY CONTRIBUTION FACTORS		PERCENTAGE CHANGE
Mean annual precipitation	⌄	-2.55%
Mean annual evaporation	⌃	4.18%
Mean annual runoff	⌄	-13.53%
Regional urban water supply	⌃	48.22%
Population growth	⌃	66.82%

Figure 42: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019)

A wealth of studies indicate that the type of multi-year extreme drought that affected Cape Town between 2015 and 2018 is more likely to recur frequently in the future due to climate change (Ziervogel 2019), and that there is strong confidence in climate models' projections of increased drying in southwestern South Africa (Pascale et al. 2020).

Model projections for future rainfall in southwestern South Africa (in the Western Cape region around Cape Town), for instance, paint a grim picture of several multi-year droughts (yellow dots in the figure below) occurring between the present day and 2100 (Wolski 2017).

Overall, there is robust evidence that slow-onset climate hazards like drought, in particular, are expected to become far more frequent, with 'once in a 100-year drought events' likely to occur multiple times in a century (Wolski 2017).

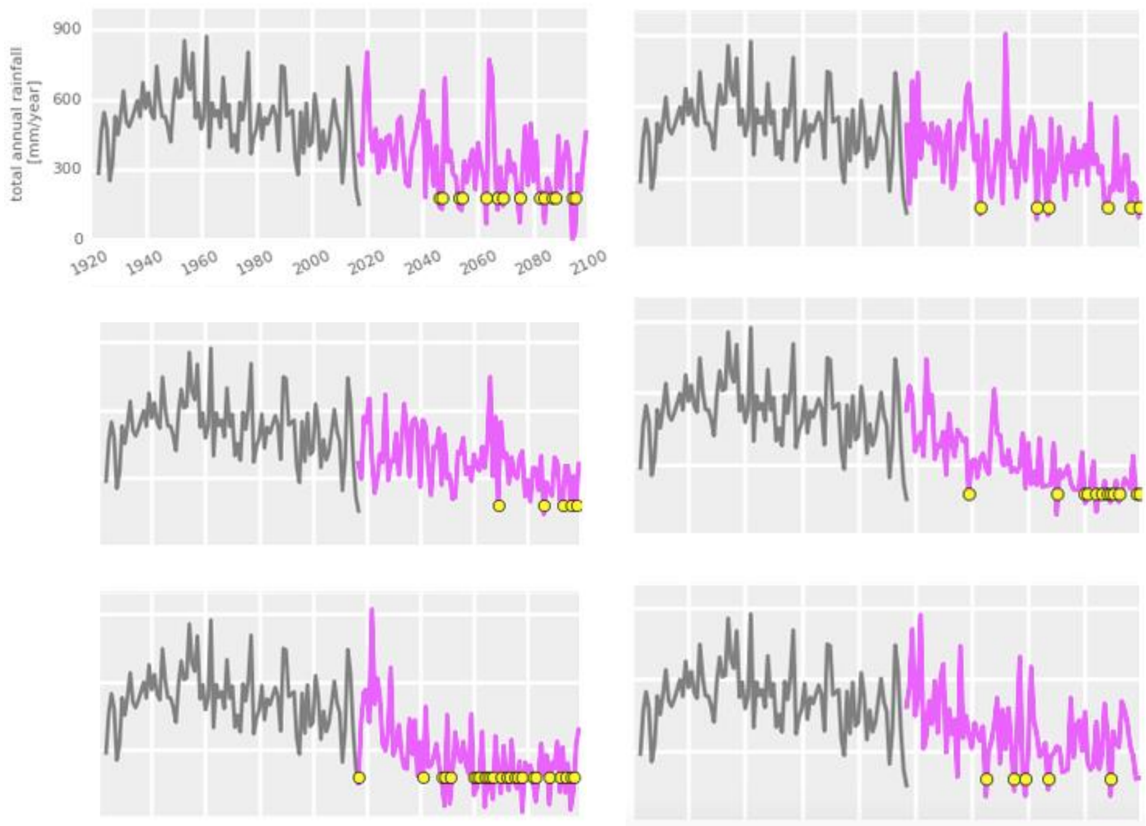


Figure 43: Six (illustrative of 16) global general circulation models (GCMs) depicting past trends in mean annual rainfall (grey) and future projected mean annual rainfall (pink) in southwestern South Africa (around Cape Town). Despite inter-annual climate variability (peaks and valleys indicating extremely high rainfall years and extremely low rainfall years), the overall trend for rainfall is a decreasing one. Yellow dots mark years that have rainfall magnitude corresponding to 2017, i.e. the year that precipitated Cape Town's 'Day Zero' drought.

WRI's Aqueduct Water Risk Index's localized projection of future climate change related water risk for the City of Cape Town (Figure 44) notes that the projected change in water stress between the present and 2040 is "extremely high," with a change (increase in stress) of more than 80% relative to the current baseline under a Business-As-Usual scenario. WRI's Aqueduct classifies this as "*near normal*" change in water stress for the region.

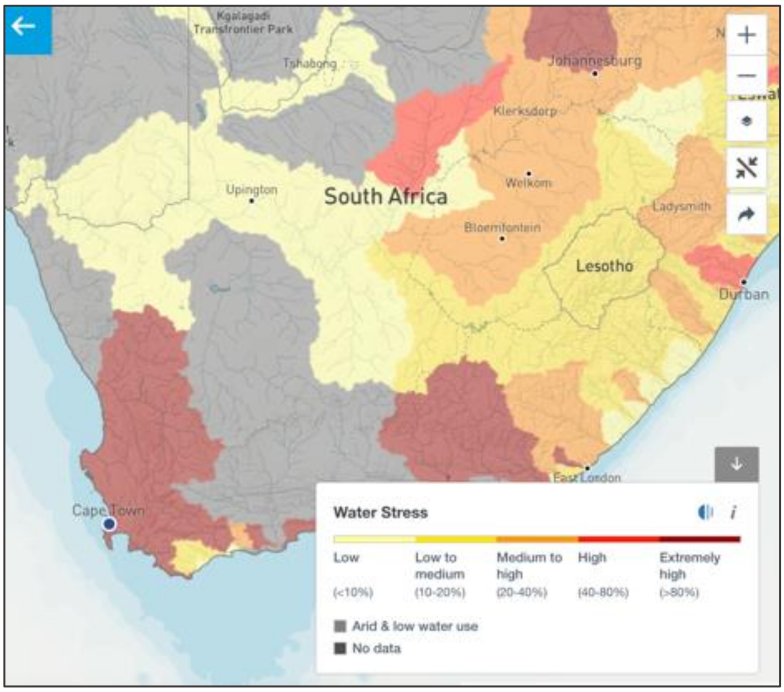


Figure 44: Extremely high projected water stress in Cape Town, in the year 2040 (Source: WRI)

3.3 Nelson Mandela Metropolitan Municipality

Nelson Mandela Bay (NMB) Metropolitan Municipality is located on the coast, surrounded on the land side by Sarah Baartman District Municipality, in the Eastern Cape province.

Historically, its climate has been classified as hot and arid steppe climate under the Köppen-Geiger climate classification system (CSIR 2015), with pockets of warm, humid climatic conditions.

Historic climate

From a historical perspective, the NMB average maximum temperatures have shown minimal deviation from 1979 to 2000 with the average temperature sitting at 22.5°C (Figure 45).

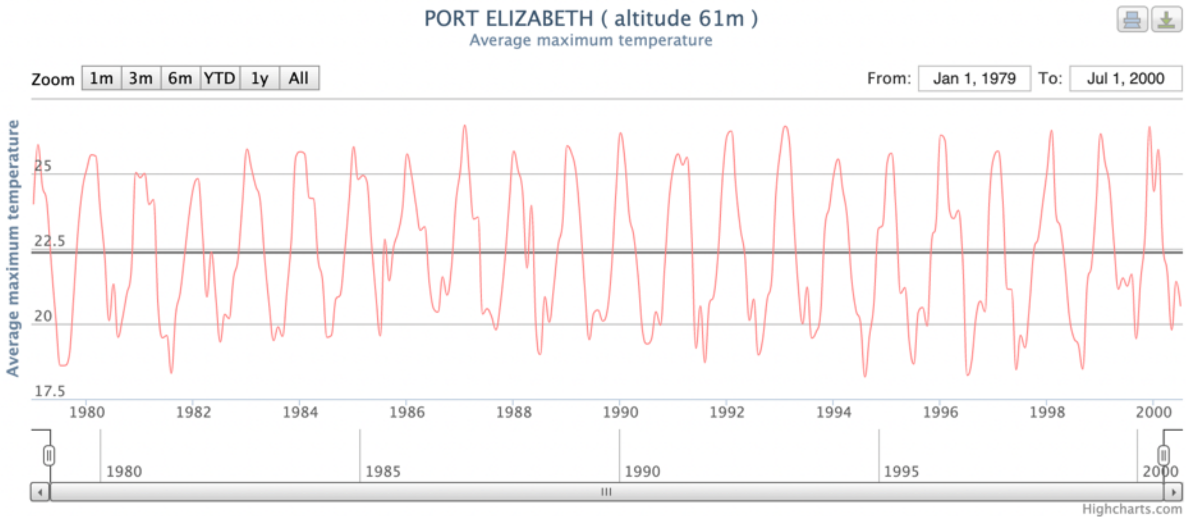


Figure 45: Historic average maximum temperature (available only from January 1979 to July 2000) for NMB[10]

Similar observations can be seen in NMB's historic average minimum temperatures which averaged just below 15°C between 1979 and 2000 (Figure 46).

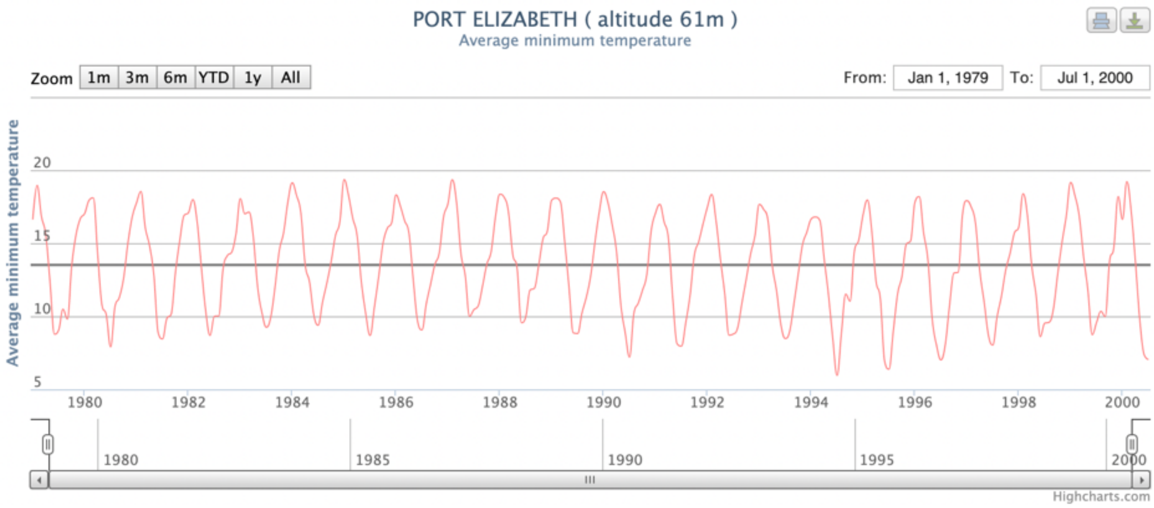


Figure 46: Historic average minimum temperature (available only from January 1979 to July 2000) for NMB[11]

[10] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[11] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

The historic total monthly rainfall for NMB between 1979 and 2000 also show minimal change as can be seen in the figure below.

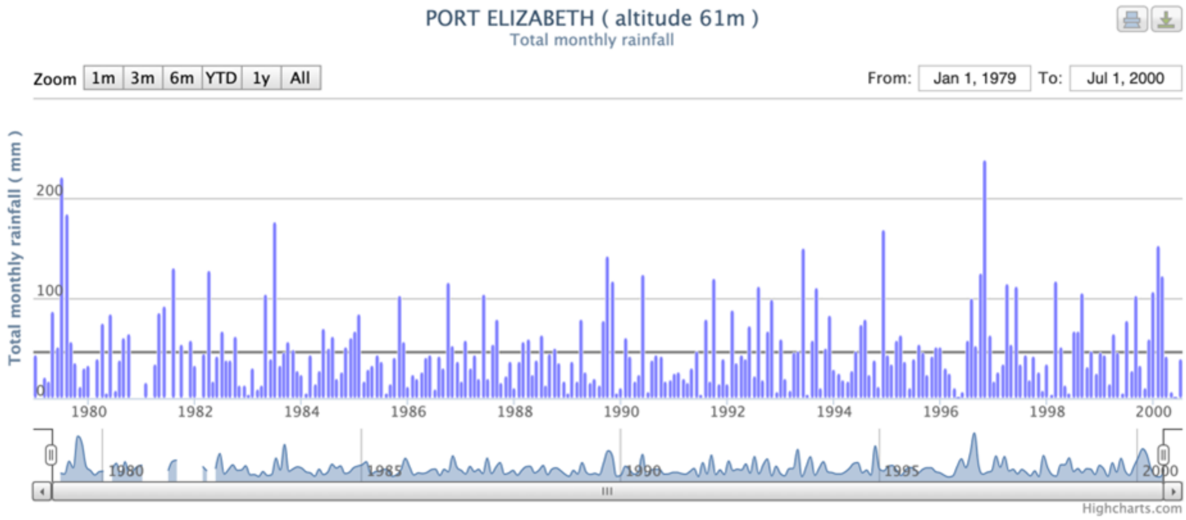


Figure 47: Historic total monthly rainfall (available only from January 1979 to July 2000) for NMB[12]

NMB's historic mean dry spell durations (in days) shows little variation between 1979 and 2000 (Figure 48) with the average duration being approximately 5 days.

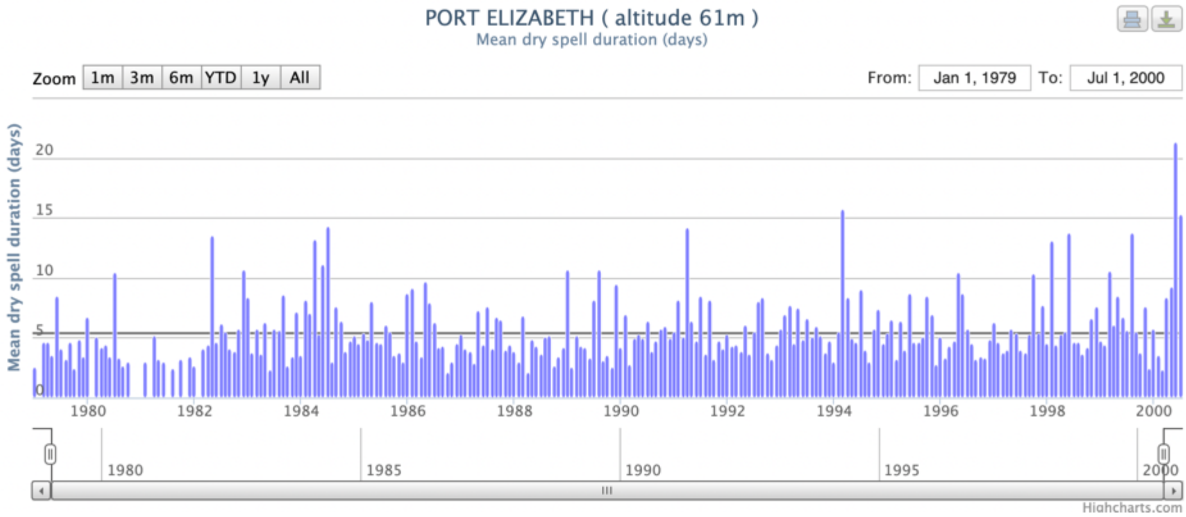


Figure 48: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for NMB[13]

Current climate and water resources

As depicted in Figure 49, the NMB municipality's current average annual temperature is approximately 18-20°C and current annual average rainfall is 1200 mm (CSIR and Aurecon 2019).

[12] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[13] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

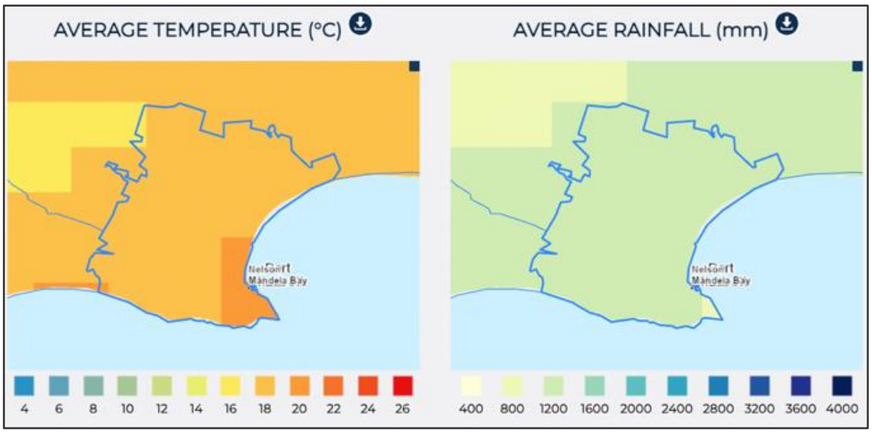


Figure 49: Nelson Mandela Bay's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality has moderate water supply vulnerability (CSIR and Aurecon 2019), as reflected in Figure 50.

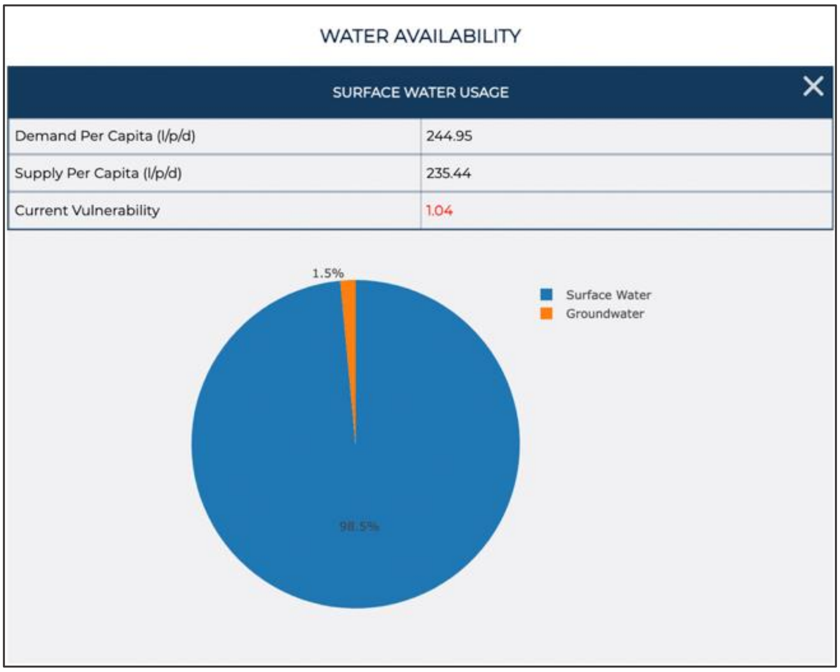


Figure 50: Present-day water availability in NMB municipality (Source: CSIR, Greenbook, 2019)

Figure 51 indicates that the municipality is dependent on a combination of surface water and groundwater at the moment, and that it has groundwater recharge potential in some areas (CSIR and Aurecon 2019).

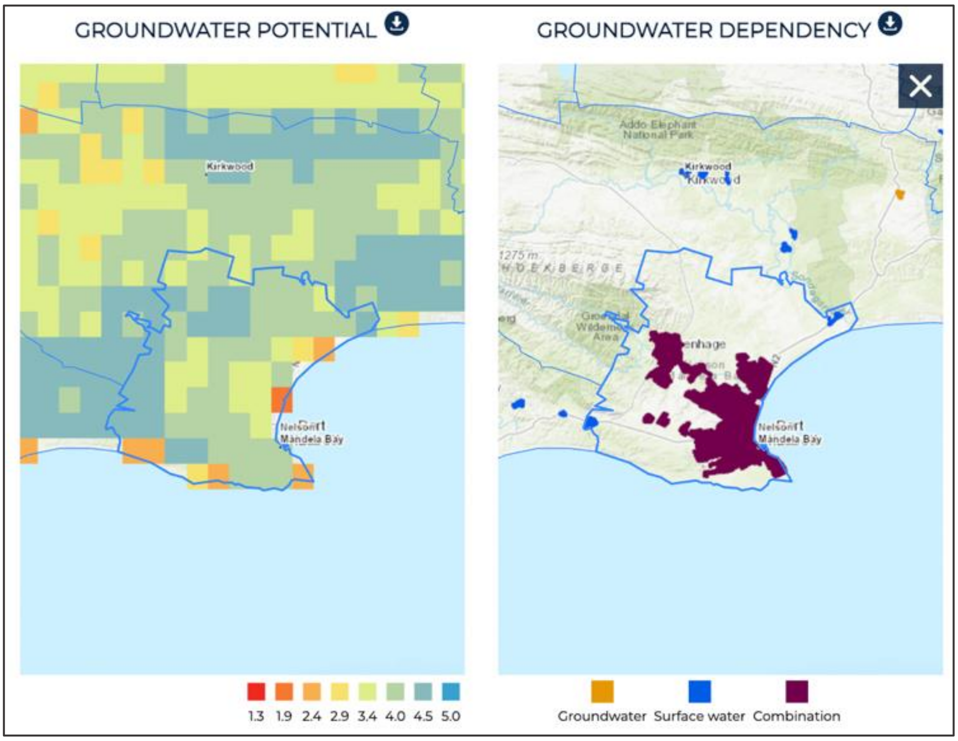


Figure 51: Groundwater recharge potential (left) and groundwater dependency (right) in NMB municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are not exclusively able to meet the municipality's needs at the moment (CSIR and Aurecon 2019).

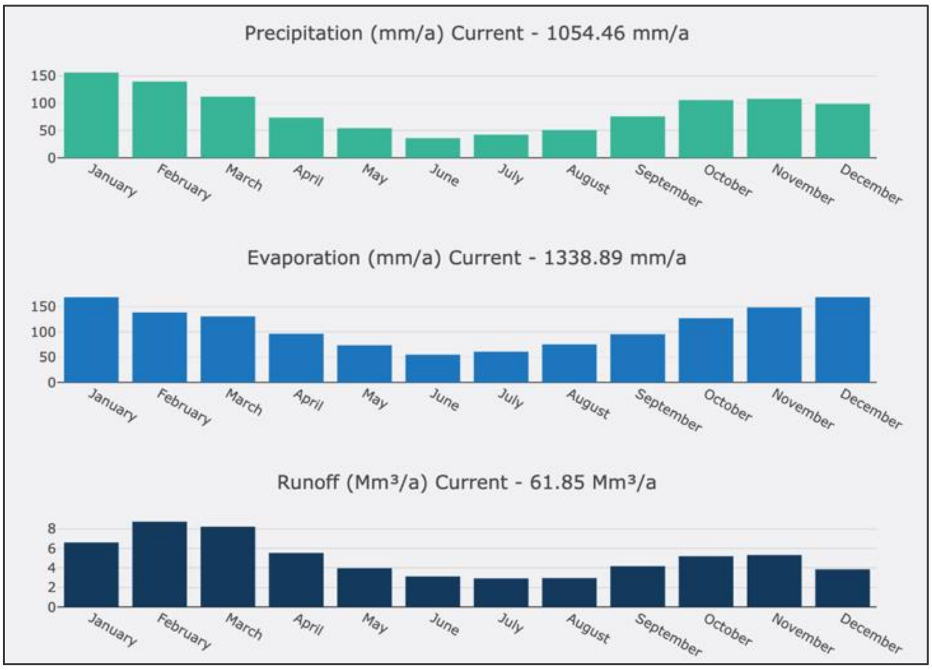


Figure 52: Surface water indices in NMB under the current climate (Source: CSIR, Greenbook, 2019)

As a result, NMB's already faces drought risk under the current climate (Figure 53) (relative to some other regions of the country).

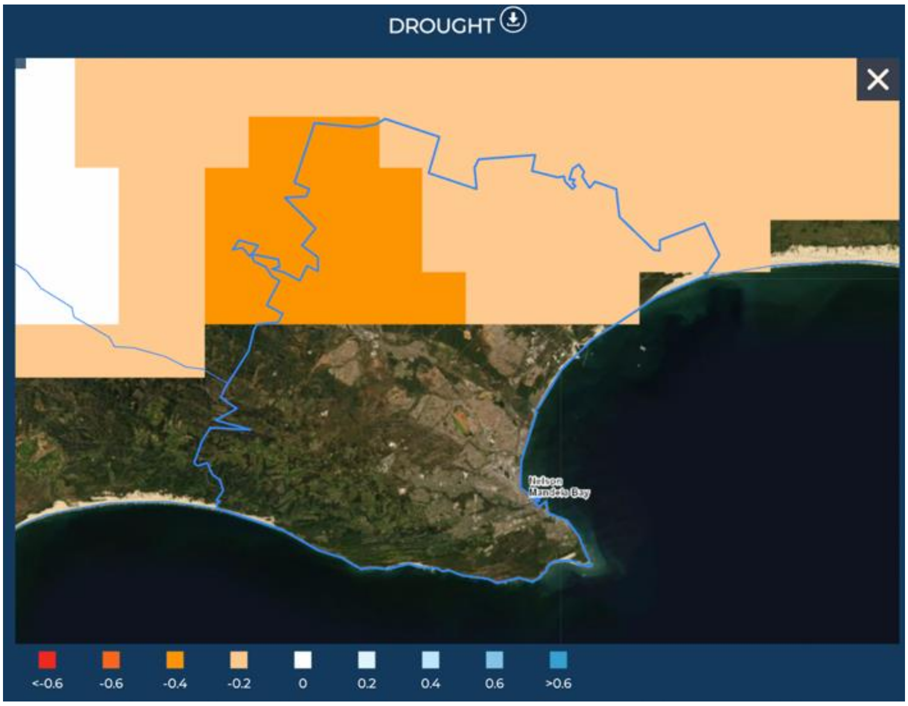


Figure 53: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP's first phase) from 2011 – 2040, Nelson Mandela Bay municipality is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- -1% decrease in mean annual precipitation (some models agree on the decrease, with a few models agreeing about the projected increase in both the number and length of dry spells).
- 0% change in aridity
- -3% decrease in annual mean soil moisture
- -4% decrease in annual mean water discharge (with a few models agreeing on a decrease in the 2-year, 5-year, 10-year, and 50-year return periods for annual maximum water discharge. Some models also agree on a decrease in minimum annual water discharge)
- -4% decrease in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, NMB will experience a modest temperature rise of up to 1.46°C (CSIR and Aurecon 2019).

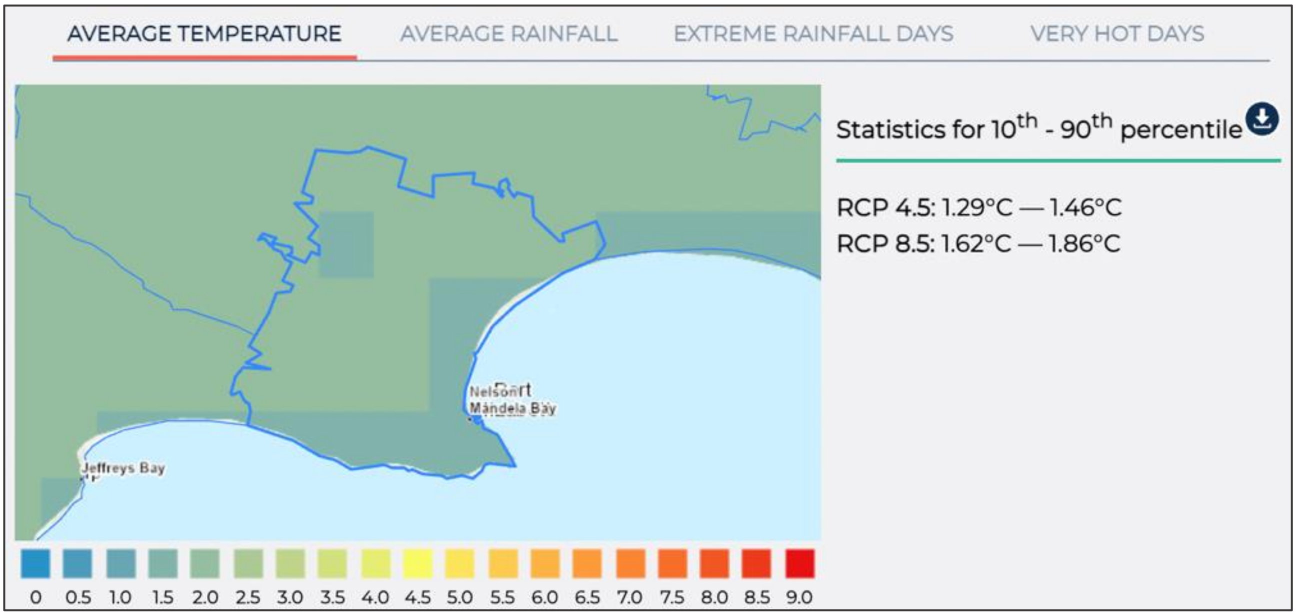


Figure 54: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Similar observations regarding future average maximum and minimum temperature can be seen in Figure 55 and Figure 56 which shows an increase between 2030 and 2050 for RCP 4.5.

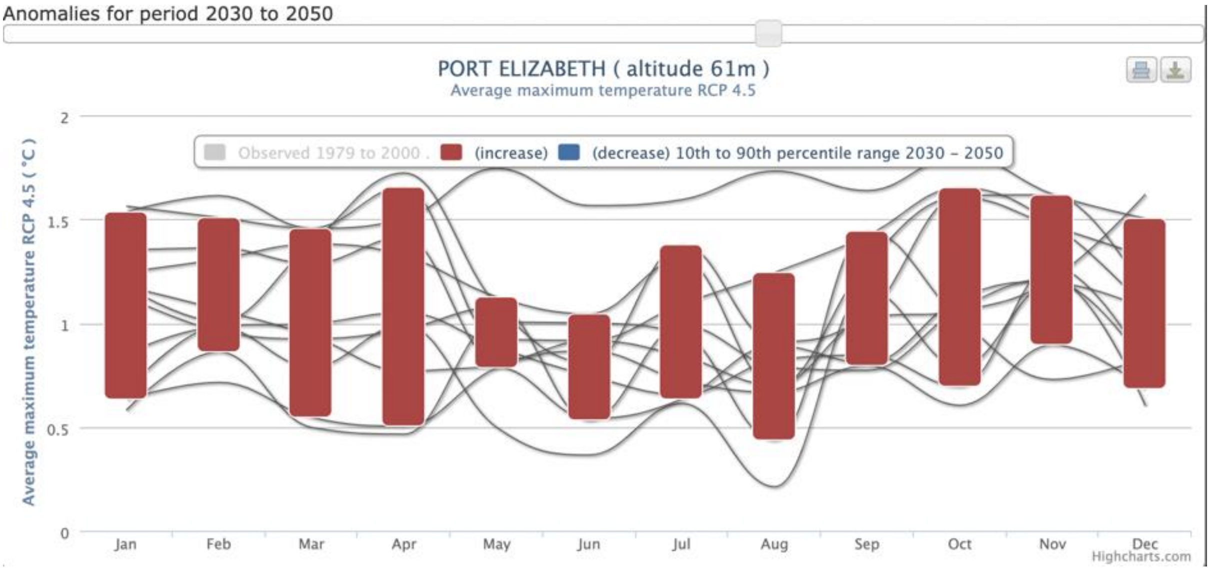


Figure 55: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for NMB [14]

[14] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

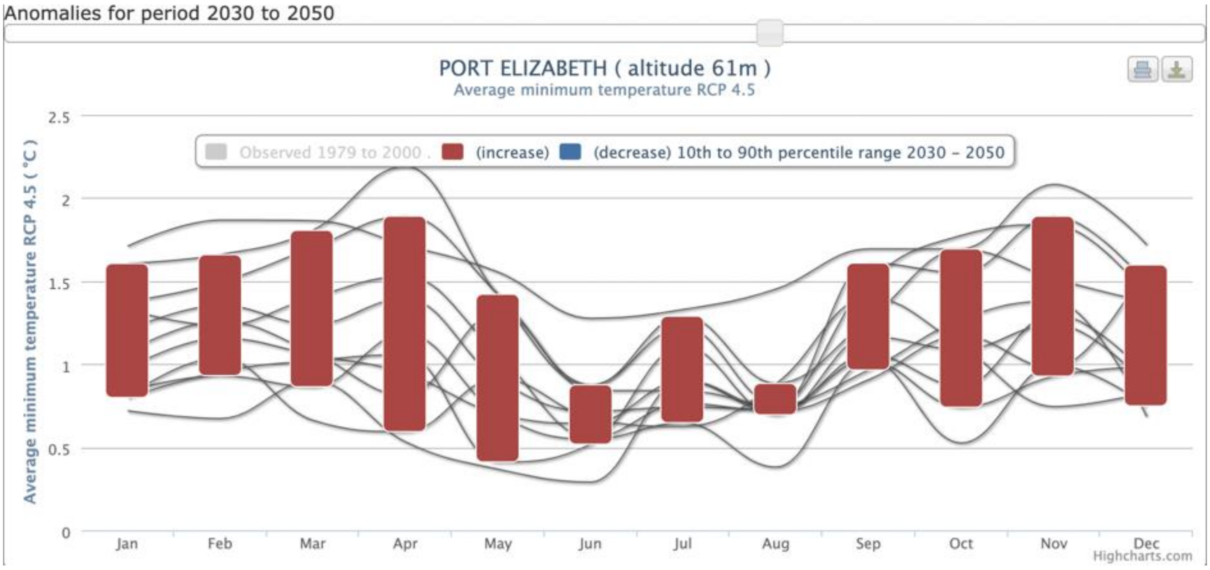


Figure 56: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for NMB [15]

Average rainfall in 2050, under RCP 4.5, will be more variable. Average rainfall totals may decrease very slightly, but modelling results also have an outer range where a marginal increase is also plausible (CSIR and Aurecon 2019).This is also observed in 58 where future total monthly rainfall projections are varied between 2030 and 2050, but a relative decrease can be observed.

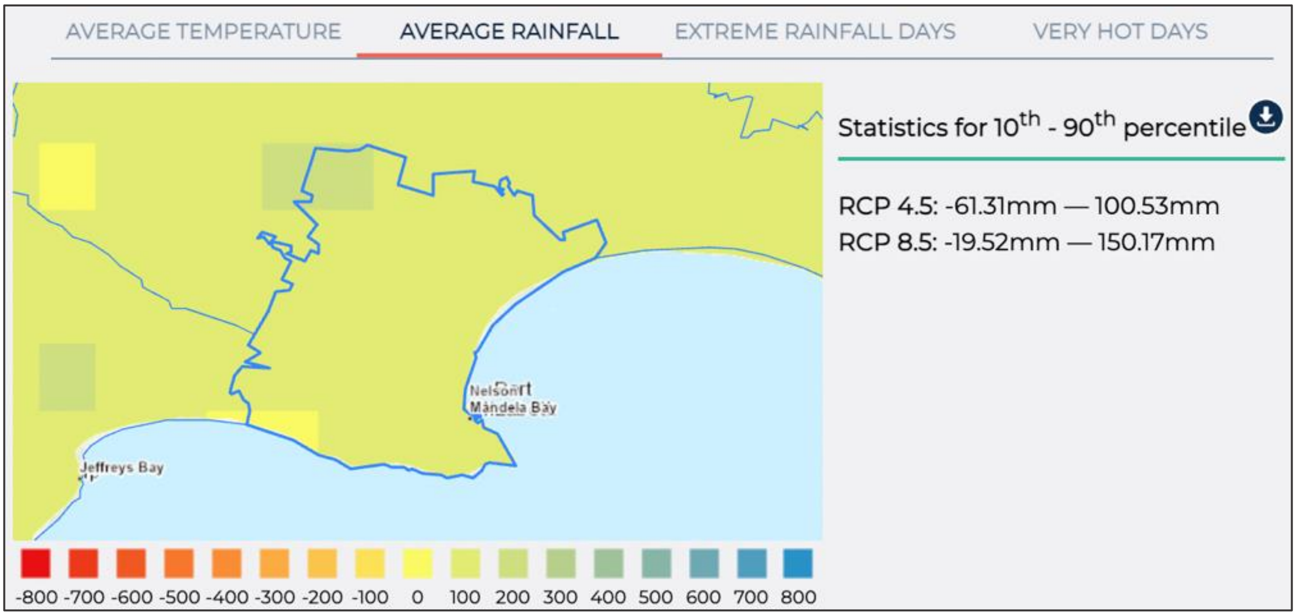


Figure 57: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

[15] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

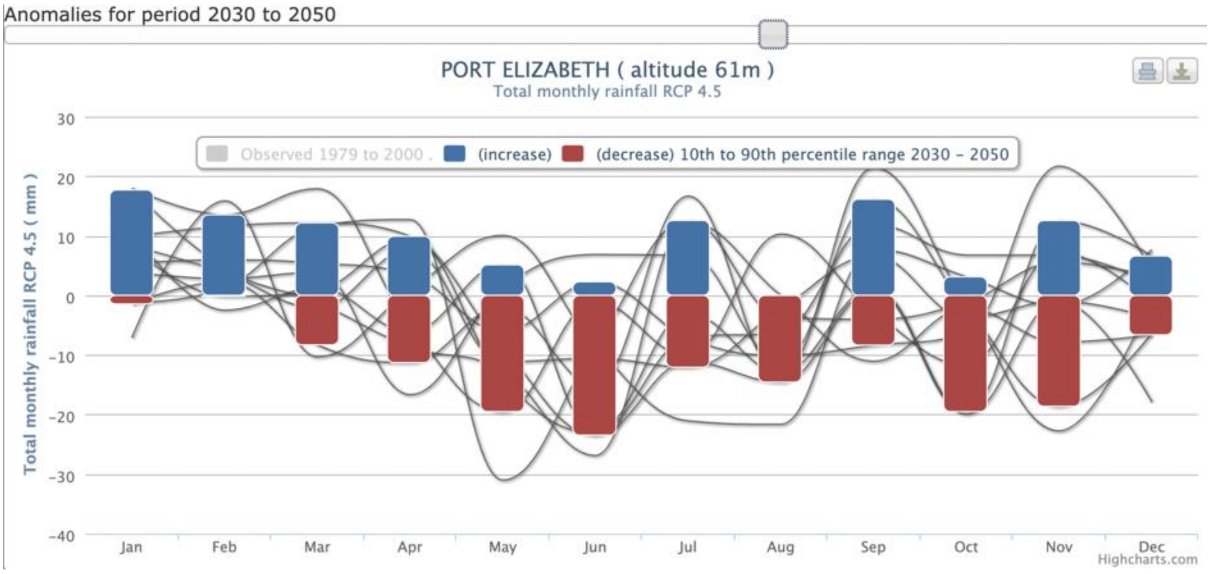


Figure 58: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period)for NMB [16]

The same variability and range is true of projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019).

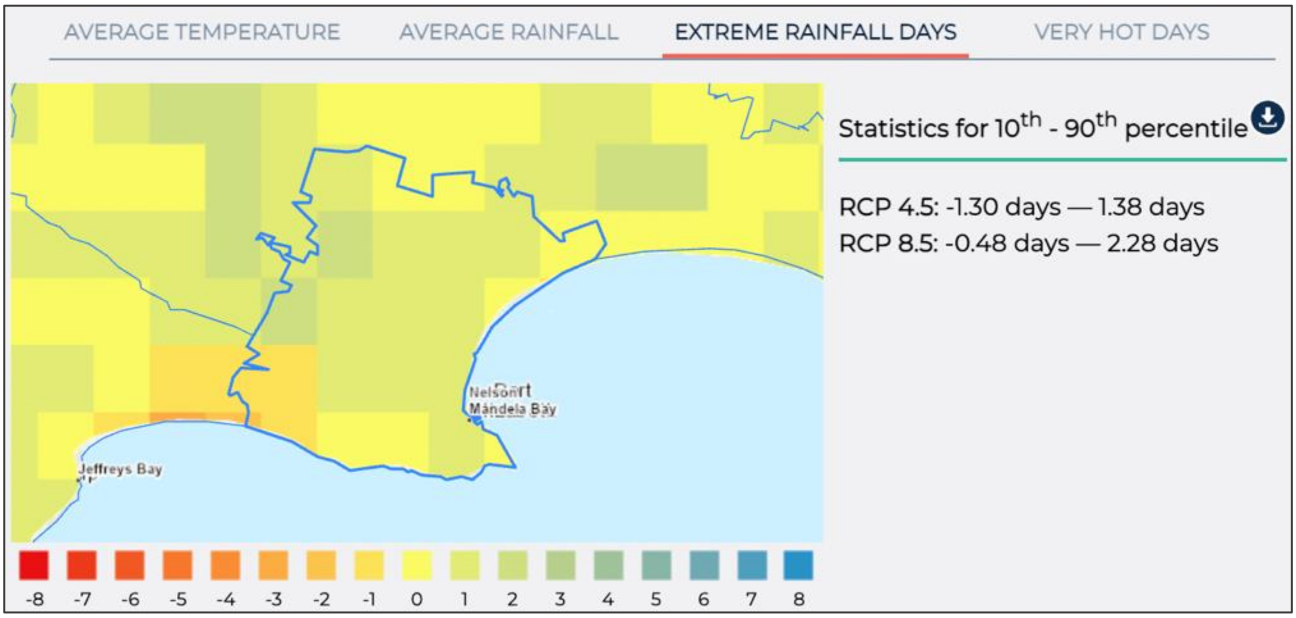


Figure 59: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality will experience a marked increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

[16] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

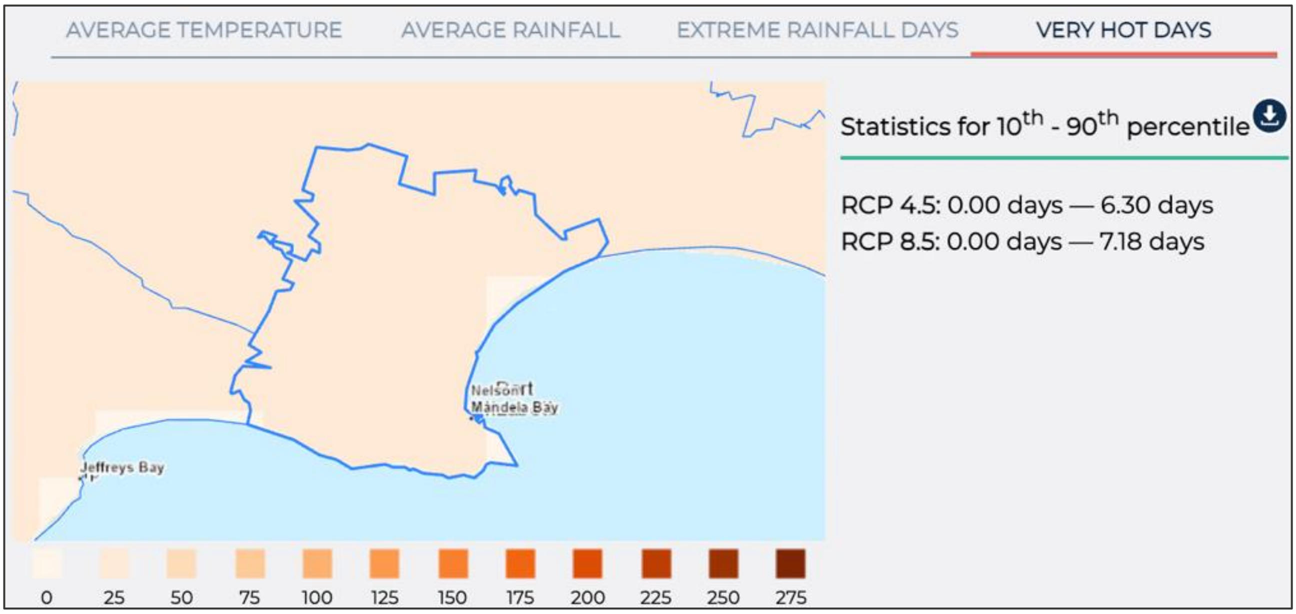


Figure 60: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Future mean dry spell durations between 2030 and 2050 for NMB (Figure 61) shows a potential increase towards the middle of the year, particularly in June, July and August.

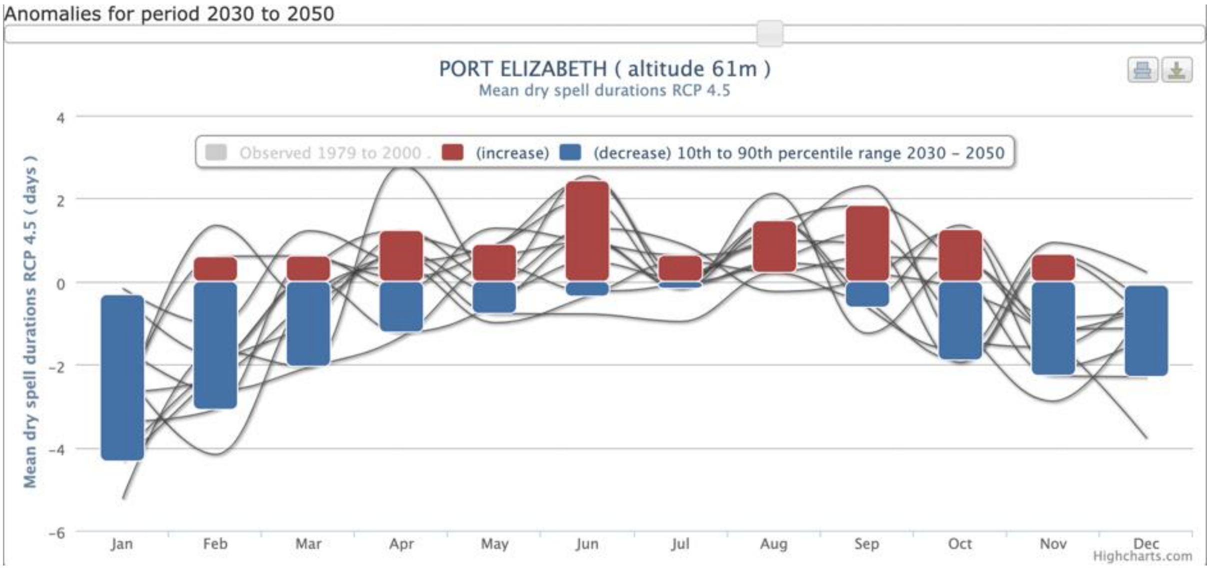


Figure 61: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for NMB[17]

Future drought risk in Nelson Mandela Bay in 2050 is projected to be high, in terms of the SPI drought index, in addition to several areas subject to extreme increases in drought tendency across the municipality (CSIR and Aurecon 2019).

[17] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

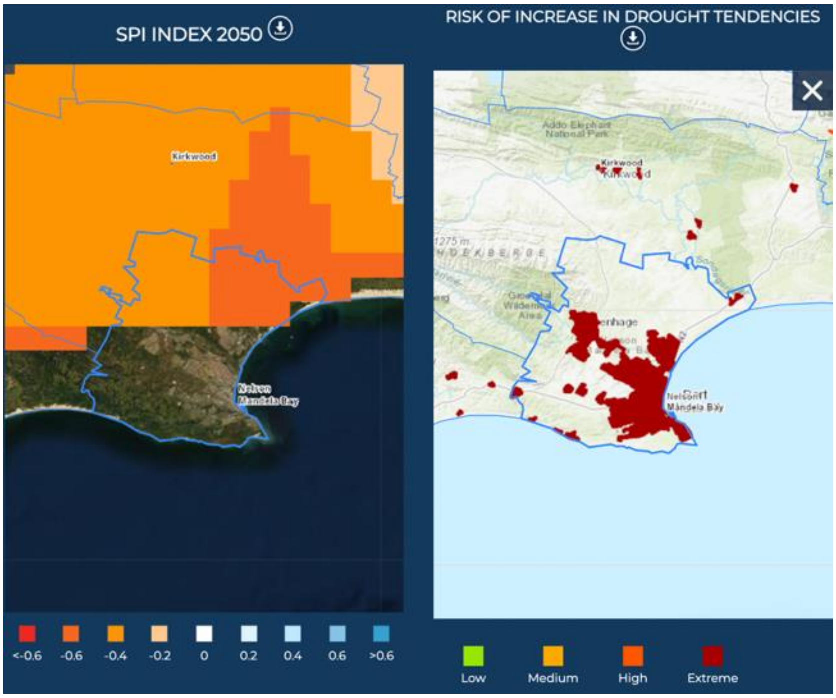


Figure 62: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential is largely unchanged in 2050. Certain areas of the municipality are expected to face high risk of groundwater depletion under future climate conditions in 2050.

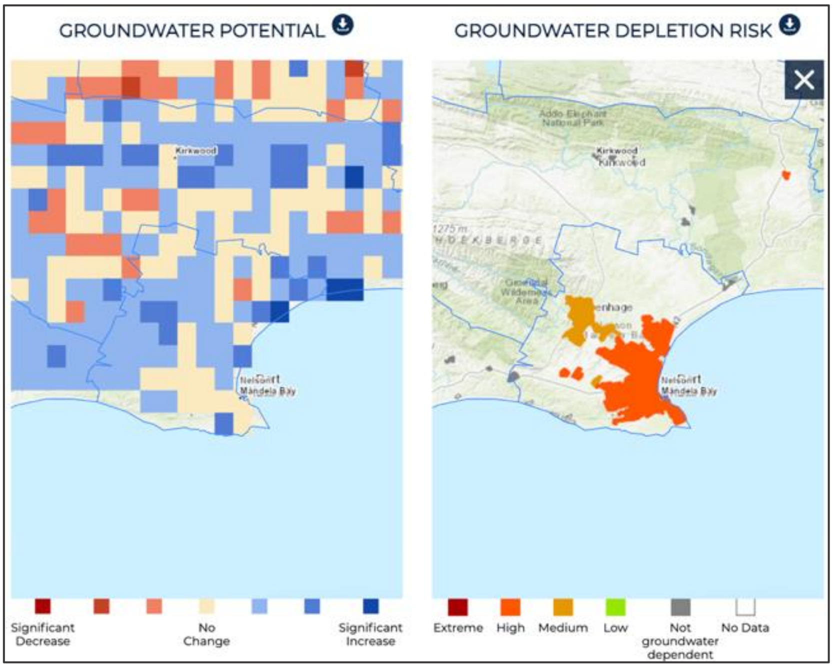


Figure 63: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show small changes in precipitation, evaporation, and runoff, but in terms of annual averages the change is not extremely large.

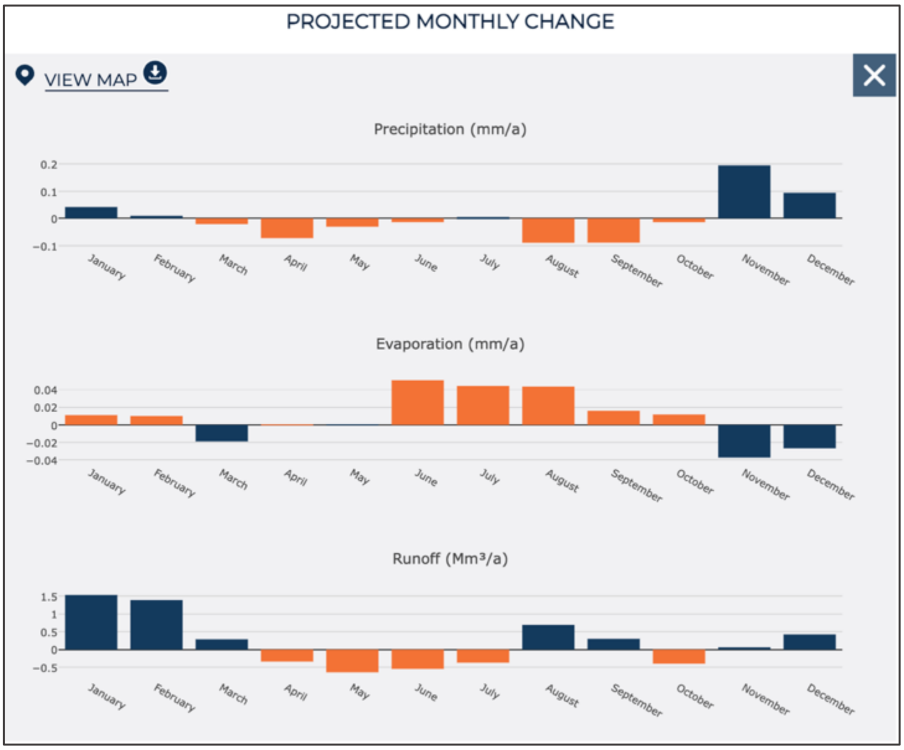
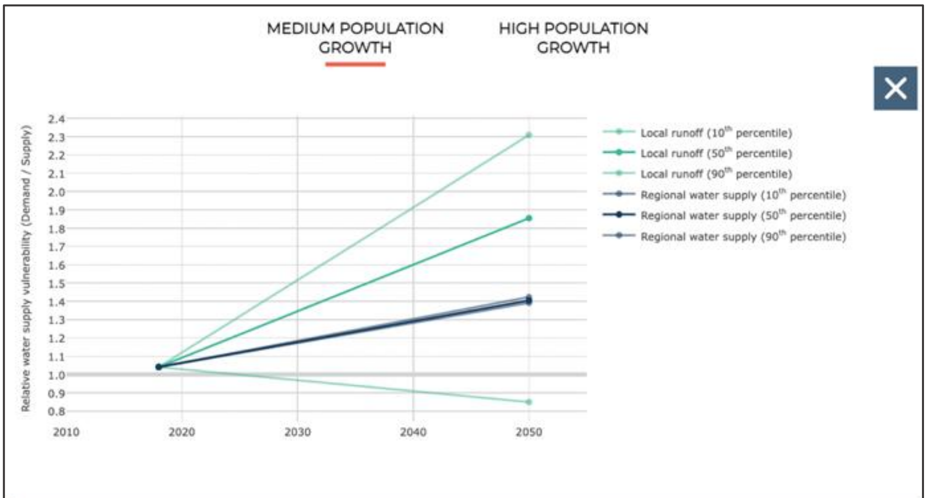


Figure 64: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, due to only a very small anticipated increase in regional urban water supply by 2050, NMB's future relative water supply vulnerability (as a ratio of demand and supply) is expected to rise measurably, even under a medium population growth future (CSIR and Aurecon 2019).



VULNERABILITY CONTRIBUTION FACTORS	PERCENTAGE CHANGE
Mean annual precipitation	-1.88%
Mean annual evaporation	2.75%
Mean annual runoff	-23.54%
Regional urban water supply	1.43%
Population growth	33.19%

Figure 65: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019)

WRI's Aqueduct Water Risk Index's localized projection of future climate change related water risk for Nelson Mandela Bay municipality notes that the projected change in water stress between the present and 2040 is "extremely high," with a change (increase in stress) of more than 80% relative to the current baseline under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*2x (two-fold)*" change in water stress.

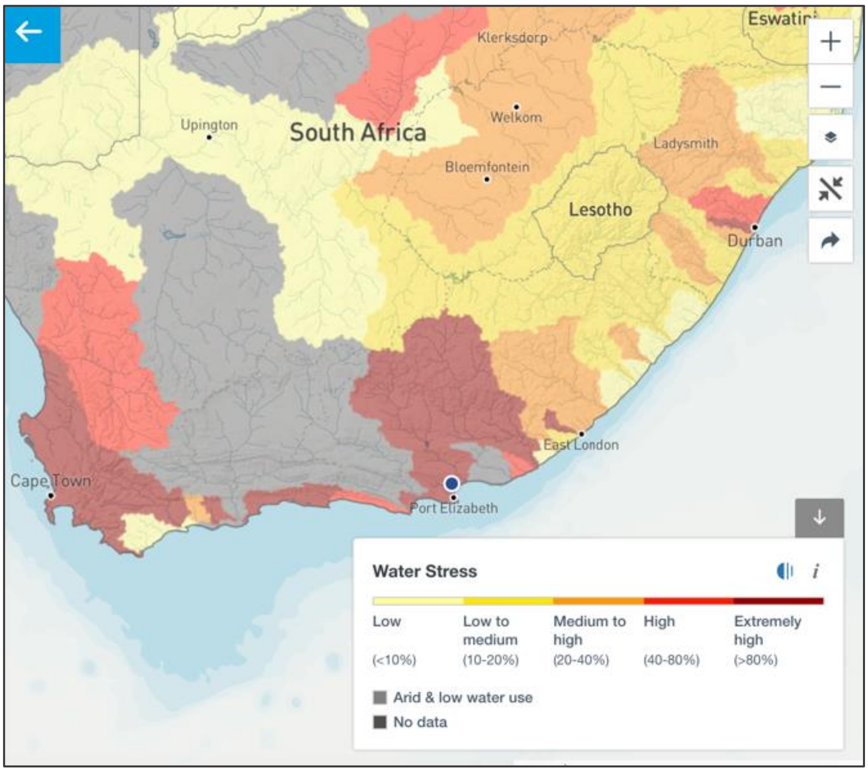


Figure 66: Extremely high projected water stress in Nelson Mandela Bay in the year 2040 (Source: WRI)

3.4 City of Ekurhuleni

Ekurhuleni Municipality is located inland in Gauteng province, adjacent to the City of Johannesburg and the City of Tshwane. Historically, its climate has been classified as having warm and temperate climate under the Köppen-Geiger climate classification system (CSIR 2015), with warm summers and dry winters.

Historic climate

Historic average maximum and minimum temperatures for the City of Ekurhuleni showed little variation between 1979 and 2000 (Figure 67 and Figure 68).

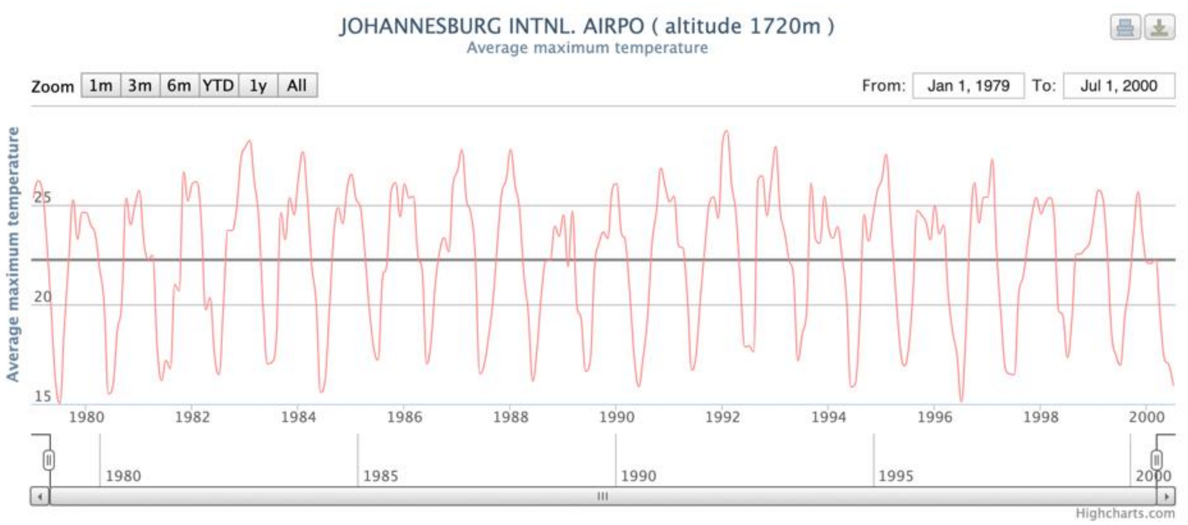


Figure 67: Historic average maximum temperature (available only from January 1979 to July 2000) for City of Ekurhuleni[18]

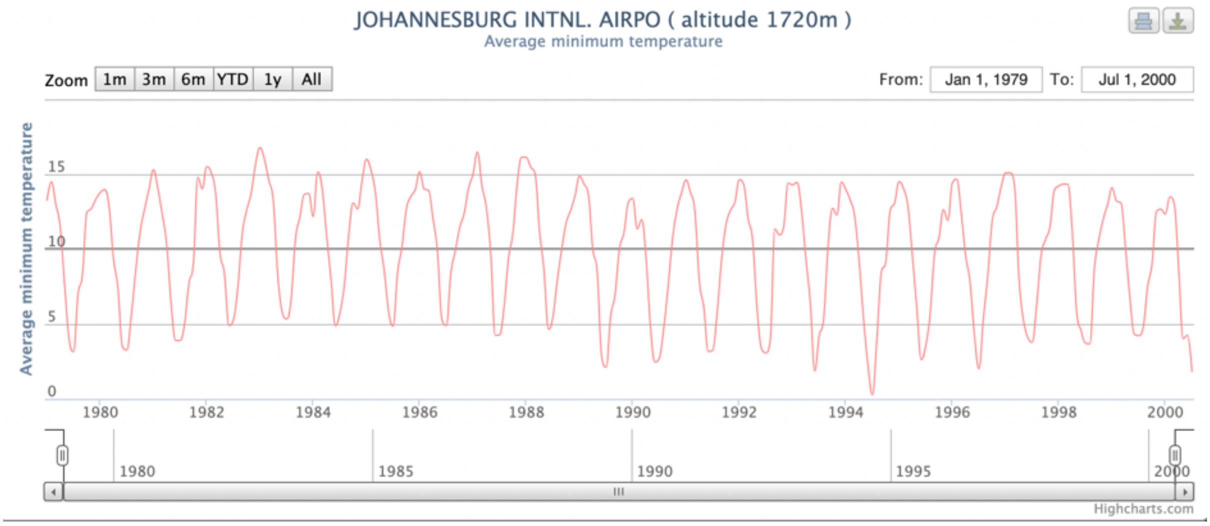


Figure 68: Historic average minimum temperature (available only from January 1979 to July 2000) for City of Ekurhuleni[19]

Some of the highest total monthly rainfall events (greater than 200mm) occurred in 1996 and 1997, with total monthly rainfall showing a slight increase between 1979 and 2000 (Figure 69).

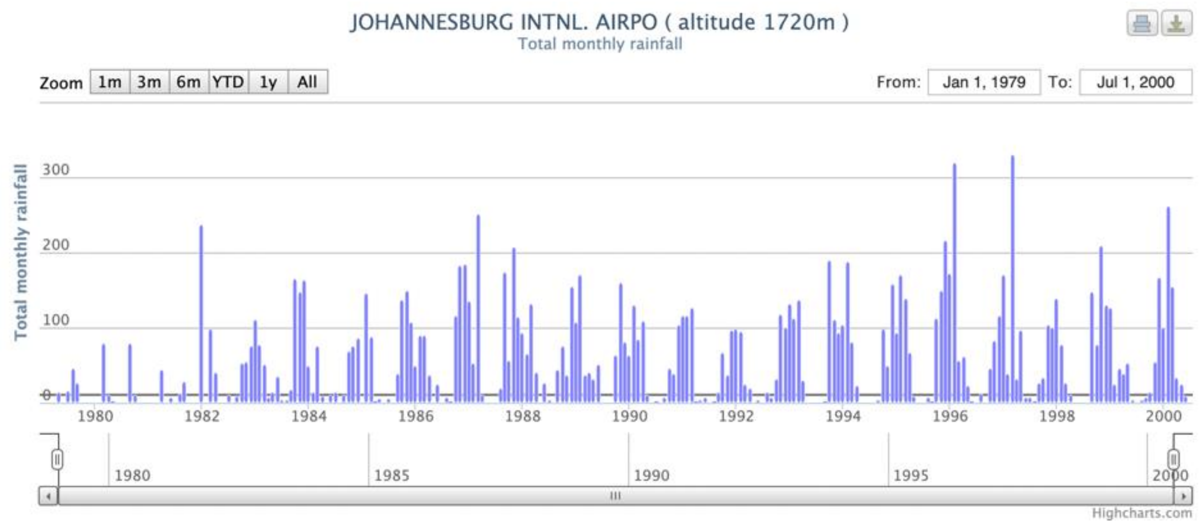


Figure 69: Historic total monthly rainfall (available only from January 1979 to July 2000 for City of Ekurhuleni [20]

Particularly long dry spells were observed between 1986 and 1989 as well as between 1993 and 1995 and in 1999 (greater than 75 days) (Figure 70). In general, dry spell duration for the City of Ekurhuleni tended to be below 50 days.

[18] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[19] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[20] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

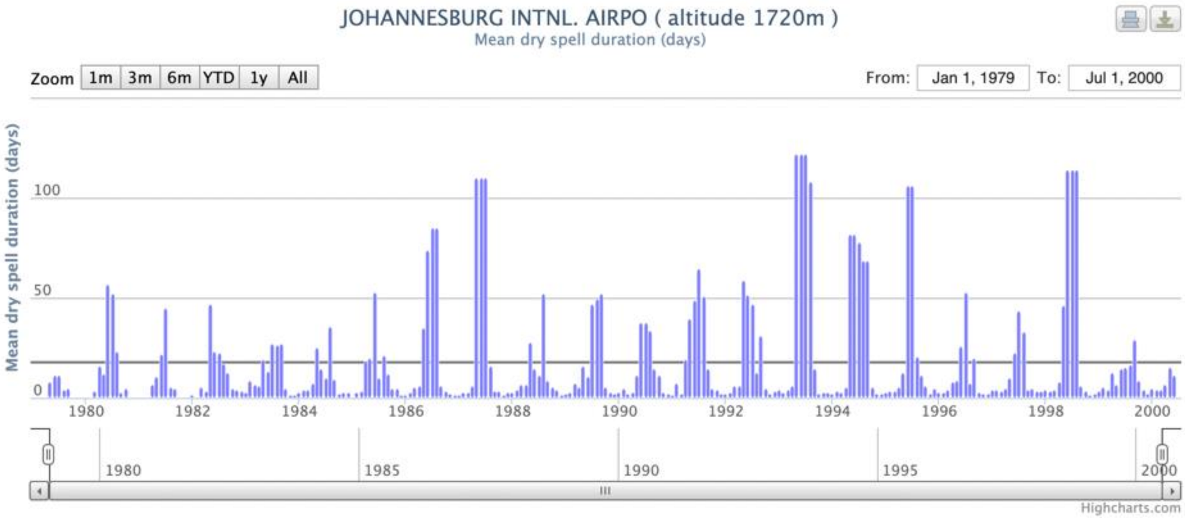


Figure 70: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for City of Ekurhuleni[21]

Current climate and water resources

As depicted in Figure 71, Ekurhuleni's current average annual temperature is approximately 16-18°C and current annual average rainfall is 1200 mm (CSIR and Aurecon 2019).

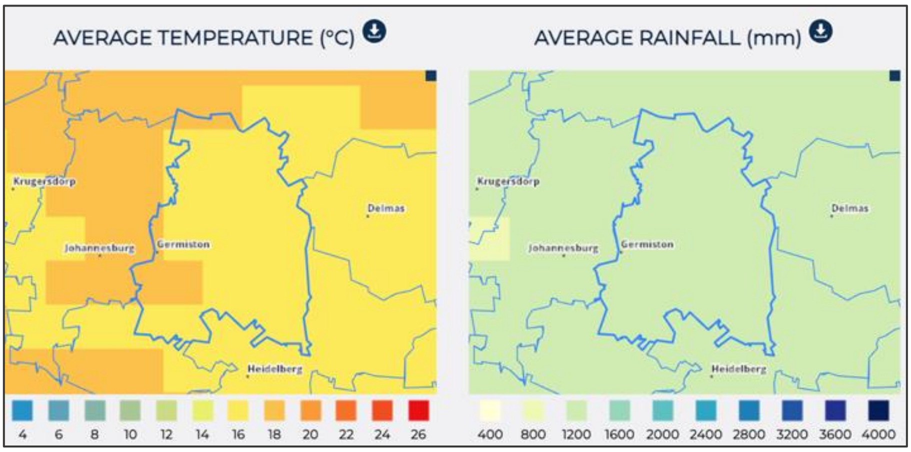


Figure 71: Ekurhuleni's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality does not currently have water supply vulnerability and is meeting its needs (CSIR and Aurecon 2019), as reflected in Figure 72.

21 Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

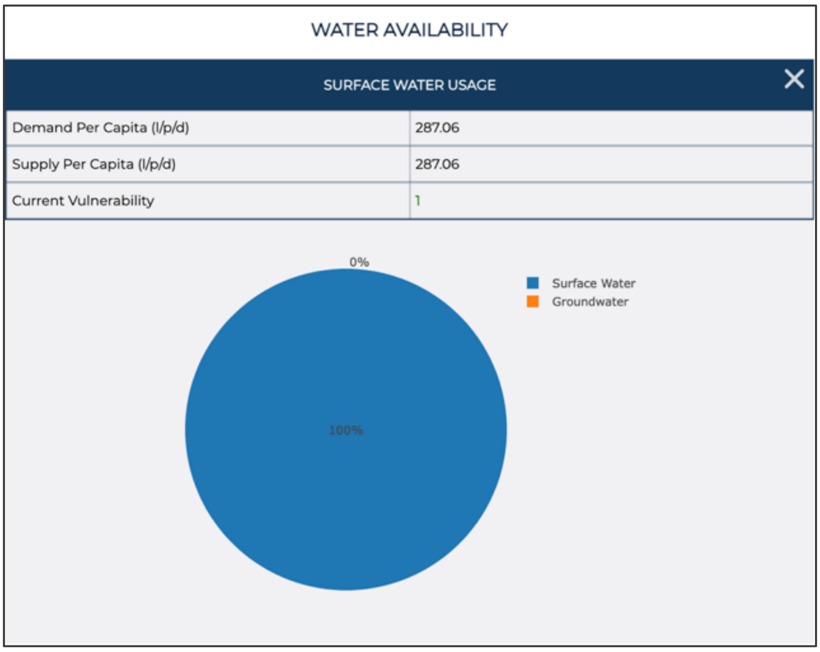


Figure 72: Present-day water availability in Ehurhuleni municipality (Source: CSIR, Greenbook, 2019)

Figure 73 indicates that the municipality is dependent on a combination of surface water and groundwater at the moment, and it has moderate groundwater recharge potential in some areas (CSIR and Aurecon 2019).

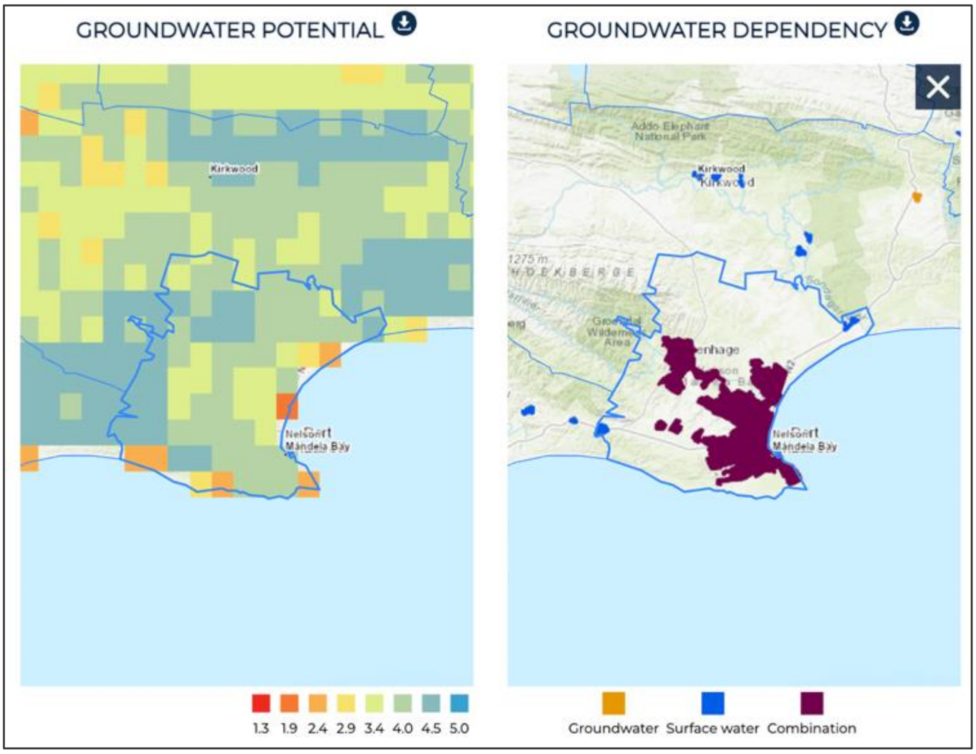


Figure 73: Groundwater recharge potential (left) and groundwater dependency (right) in Ekurhuleni municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are not exclusively able to meet the municipality's needs at the moment (CSIR and Aurecon 2019).

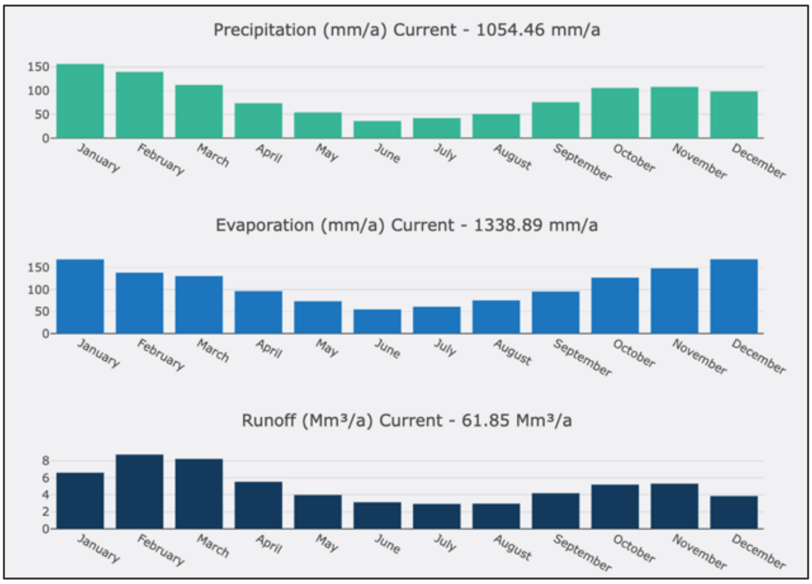


Figure 74: Surface water indices in Ekurhuleni under the current climate (Source: CSIR, Greenbook, 2019)

Even in the current climate, Ekurhuleni already faces slight drought risk (Figure 75) (relative to some other regions of the country), and has experienced multiple instances of drought, an increase from the historic baseline.

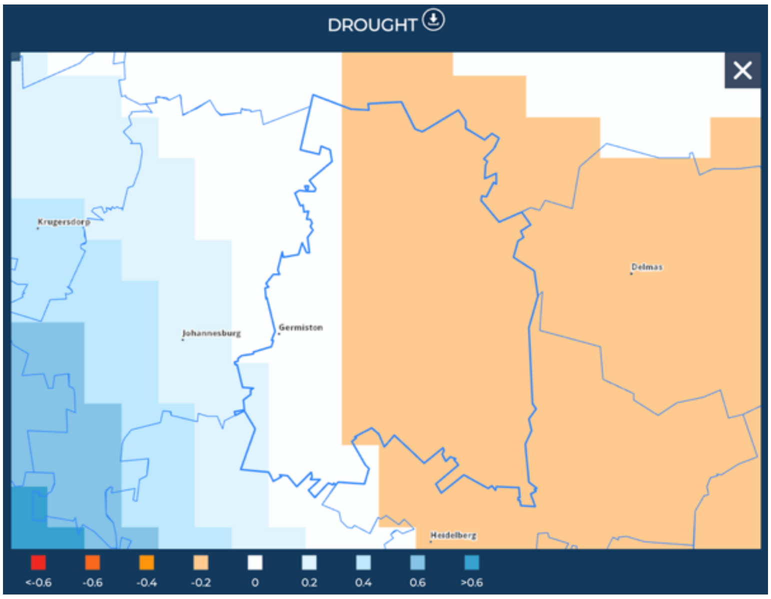


Figure 75: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario (RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP's first phase) from 2011 – 2040, Ekurhuleni municipality is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)

- 1% increase in mean annual precipitation (some models agree on the increase, with a few models agreeing about the projected decrease in the number of dry spells, but with an indication that the length of the longest dry spell may increase).
- 2% increase in aridity (the area is expected to become more dry)
- -2% decrease in annual mean soil moisture
- 0% change in annual mean water discharge (with a few models agreeing on an increase in maximum annual discharge, and an increase in the 2-year, 5-year, 10-year, and 50-year return periods for annual maximum water discharge. Some models also agree on a decrease in minimum annual water discharge)
- 1% increase in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, Ekurhuleni will experience a significant temperature rise of up to 2.82°C (CSIR and Aurecon 2019).

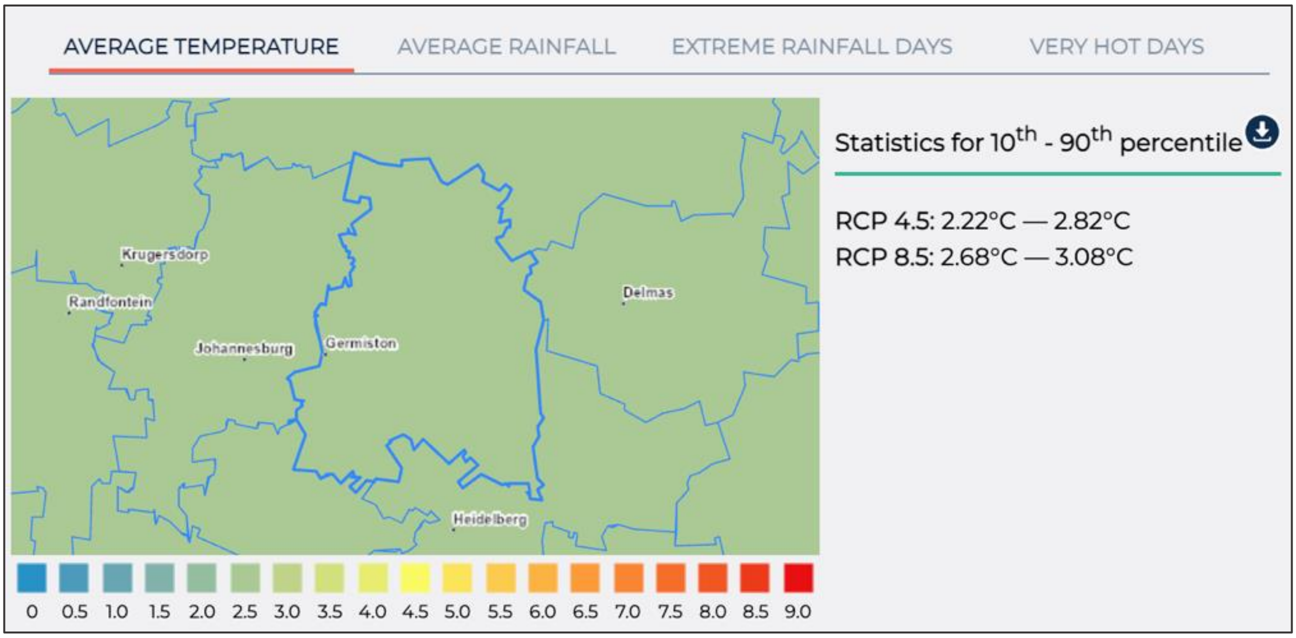


Figure 76: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

A clear rise in temperature can be observed in Figure 77 and Figure 78 for the City of Ekurhuleni between 2030 and 2050 for RCP4.5.

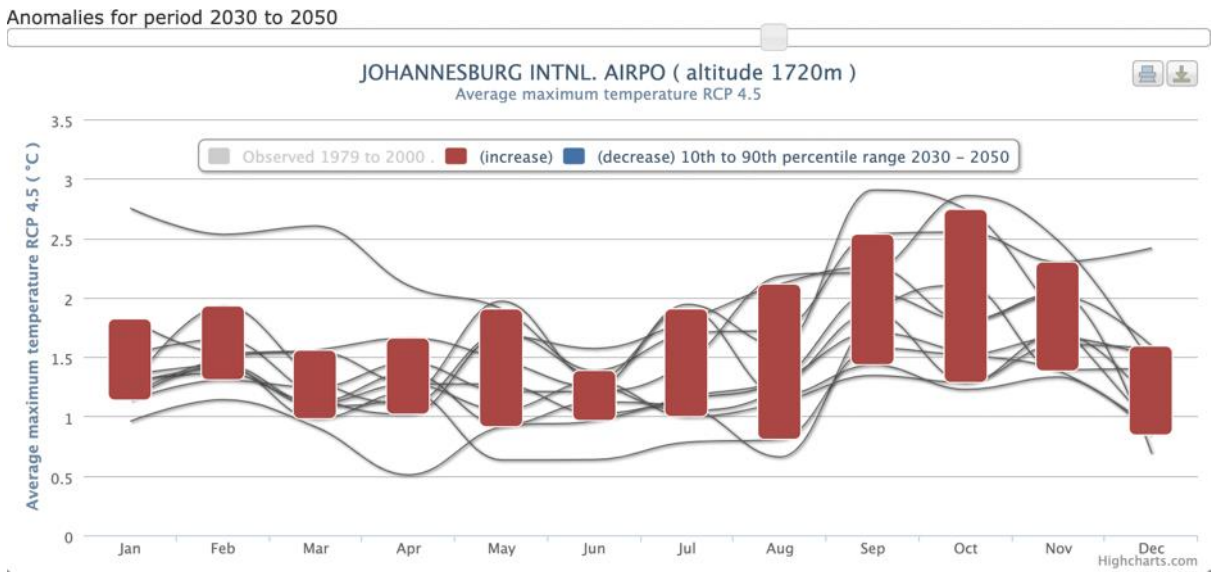


Figure 77: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni[22]

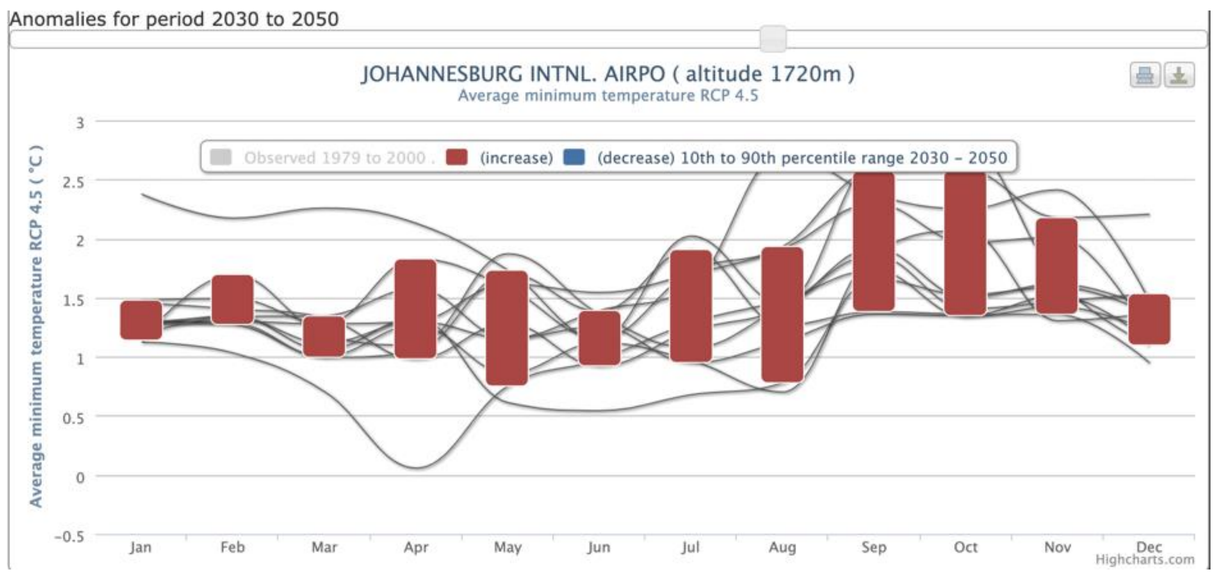


Figure 78: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni[23]

Average rainfall in 2050, under RCP 4.5, will be more variable. Average rainfall totals may decrease very slightly, but broadly the trend indicated is an increase in average rainfall (CSIR and Aurecon 2019).

[22] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

[23] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

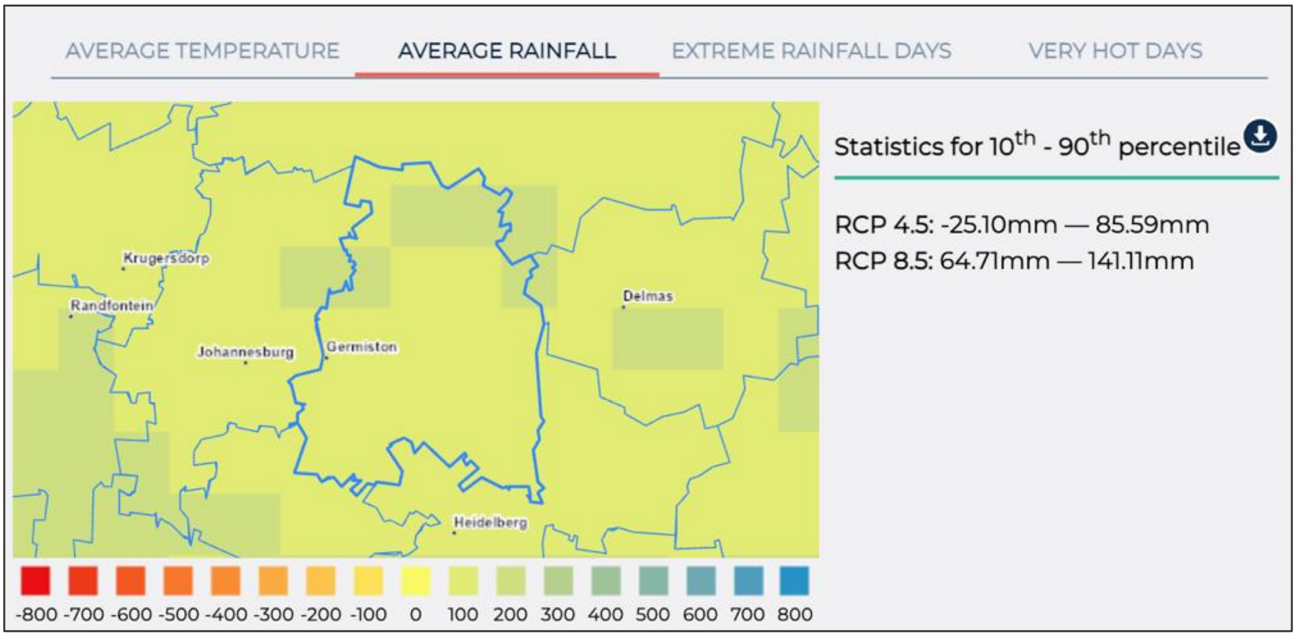


Figure 79: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Similarly, the future total monthly rainfall projections show a relative increase in rainfall for the City of Ekurhuleni (Figure 80).

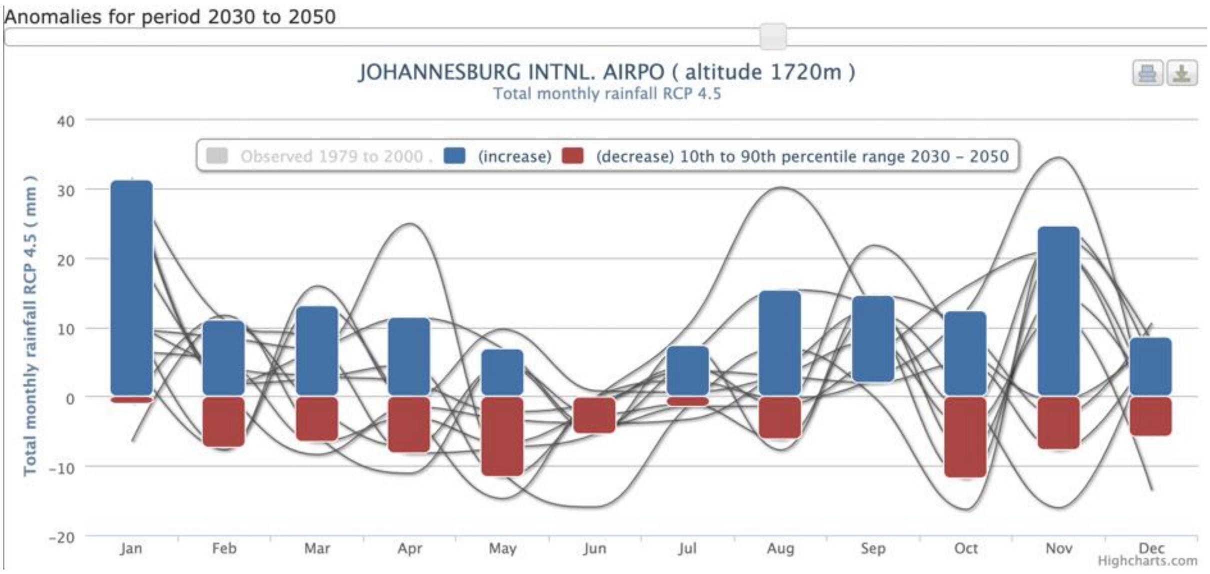


Figure 80: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni [24]

The same variability and range is true of projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019). They could decrease or increase slightly.

[24] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

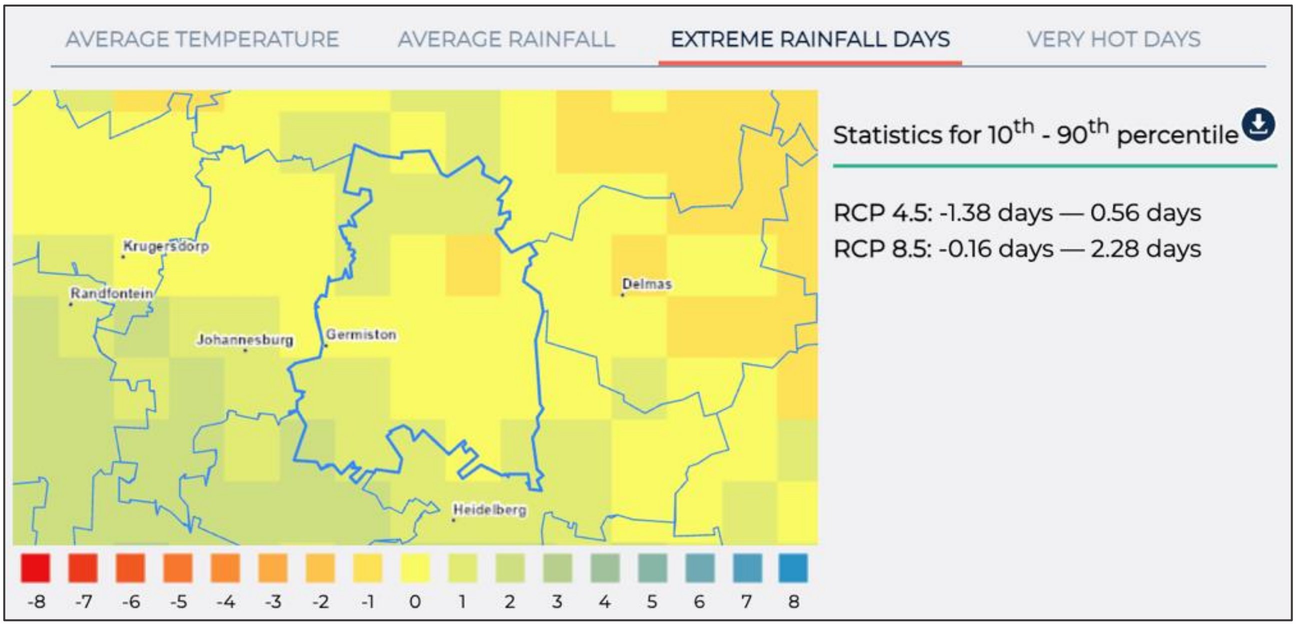


Figure 81: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality will experience a notable increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

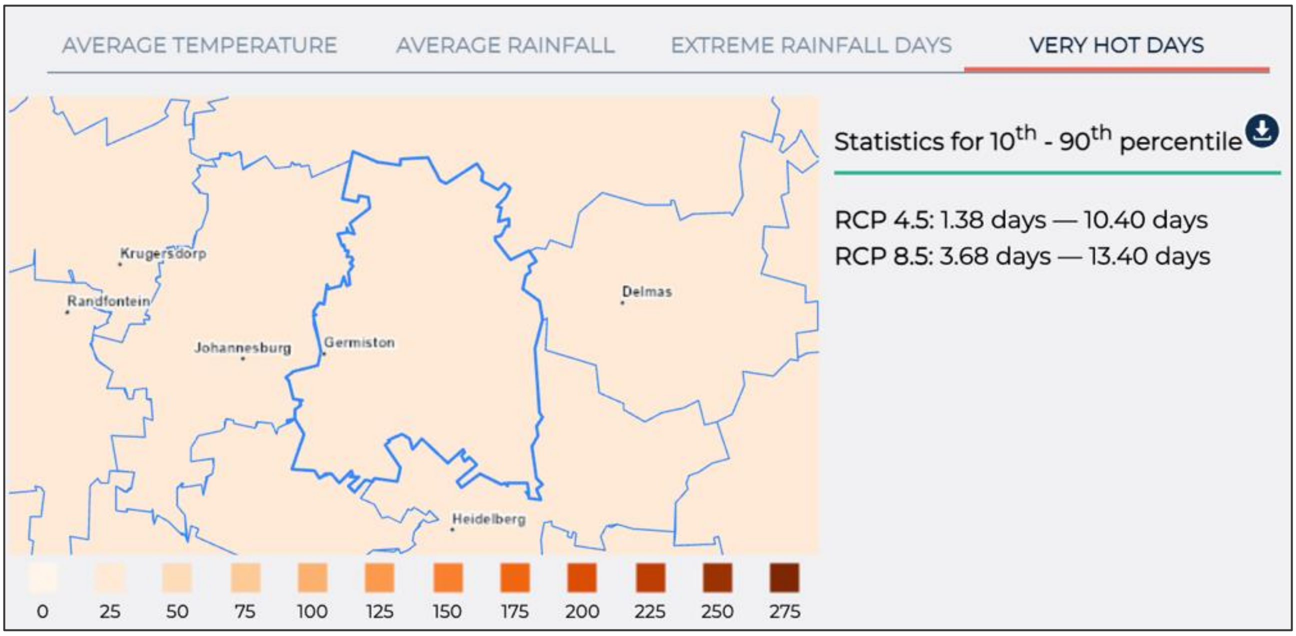


Figure 82: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Figure 83 shows future mean dry spell duration projections for the City of Ekurhuleni for 2030-2050 (RCP4.5). A slight increase in dry spell duration can be observed in the months of May, June and July.

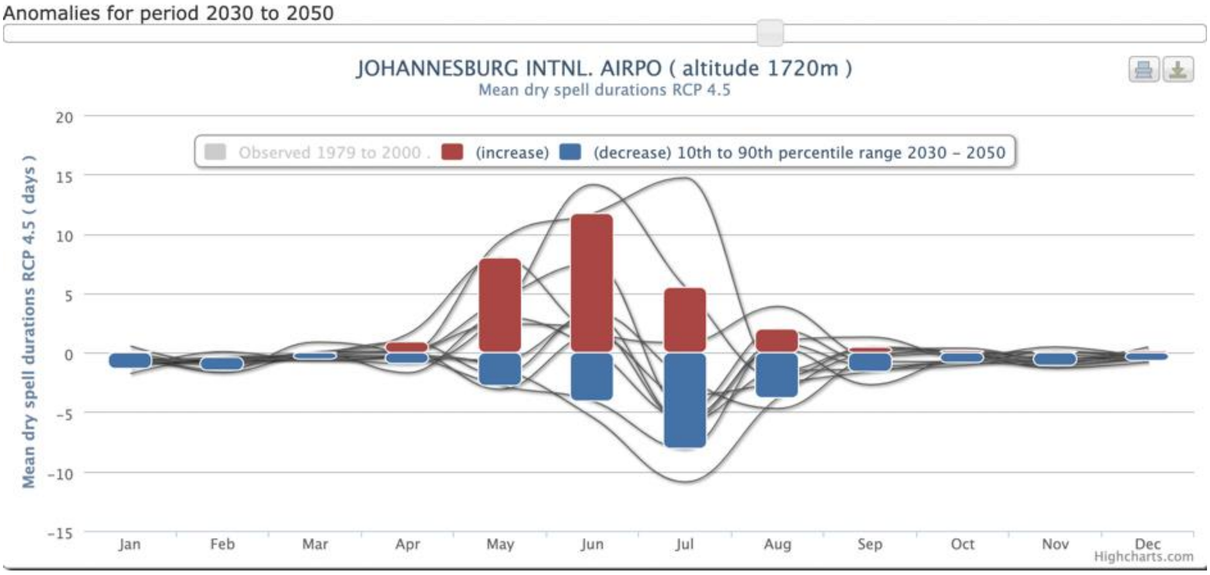


Figure 83: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the City of Ekurhuleni [25]

Future drought risk in Ekurhuleni in 2050 is projected to low, in terms of the SPI drought index, as well as an estimated low increase in drought tendency across the municipality (CSIR and Aurecon 2019).

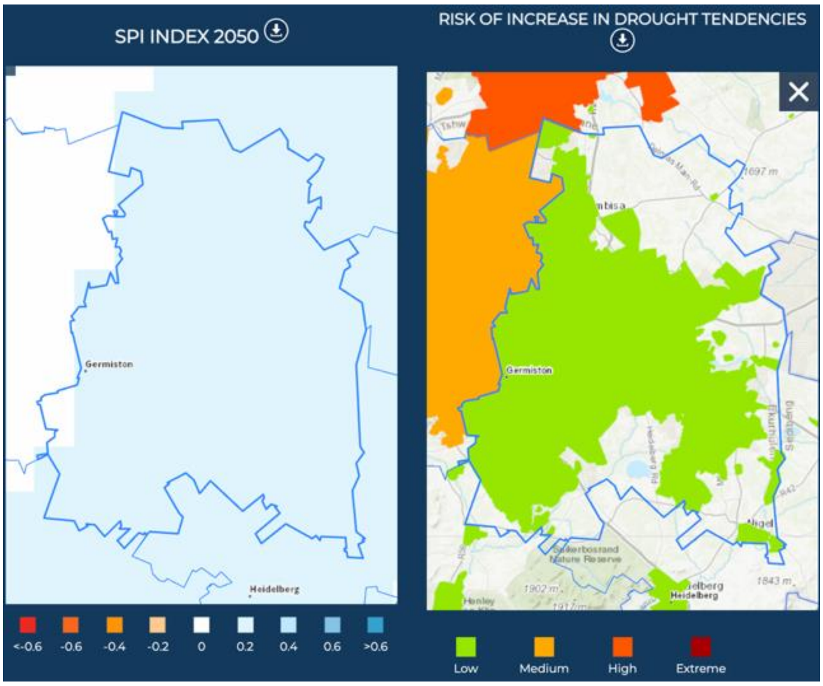


Figure 84: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential may increase marginally by 2050. However, given that the municipality is not groundwater-dependent, future groundwater risk is not material to future water risk and vulnerability.

[25] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

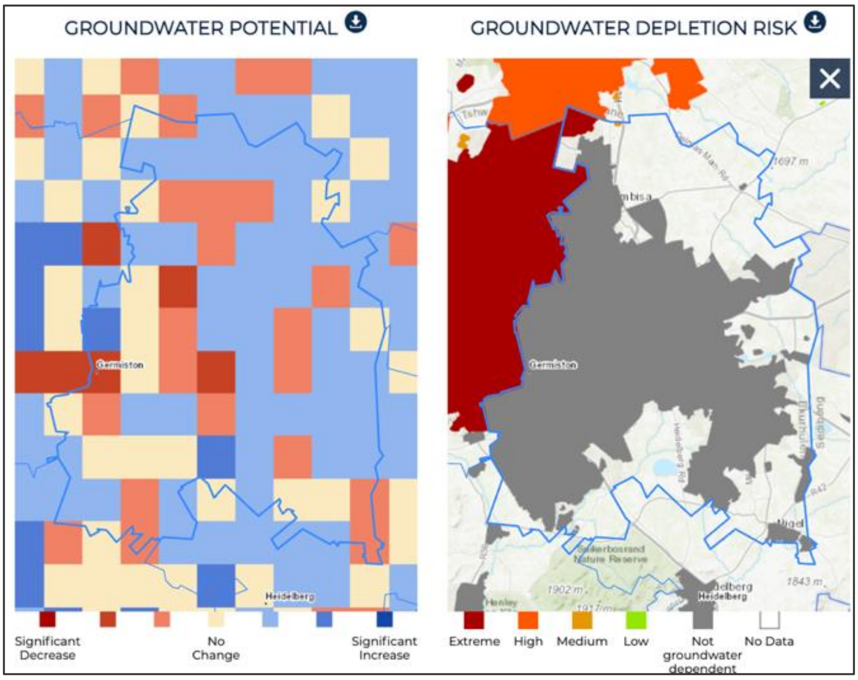


Figure 85: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show small changes in precipitation, evaporation, and runoff, but in terms of annual averages the change is not extremely large.

Figure 86: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, due to changes in multiple factors that give rise to water supply vulnerability by 2050, Ekurhuleni's future relative water supply vulnerability (as a ratio of demand and supply) is expected to rise somewhat compared to the present day, under a medium population growth future (CSIR and Aurecon 2019).

Figure 87: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019

WRI's Aqueduct Water Risk Index's localized projection of future climate change related water risk for Ekurhuleni municipality notes that the projected change in water stress between the present and 2040 is "medium-to-high," with a change (increase in stress) of between 20-40% relative to the current baseline, under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*1.4 times*" change in water stress.

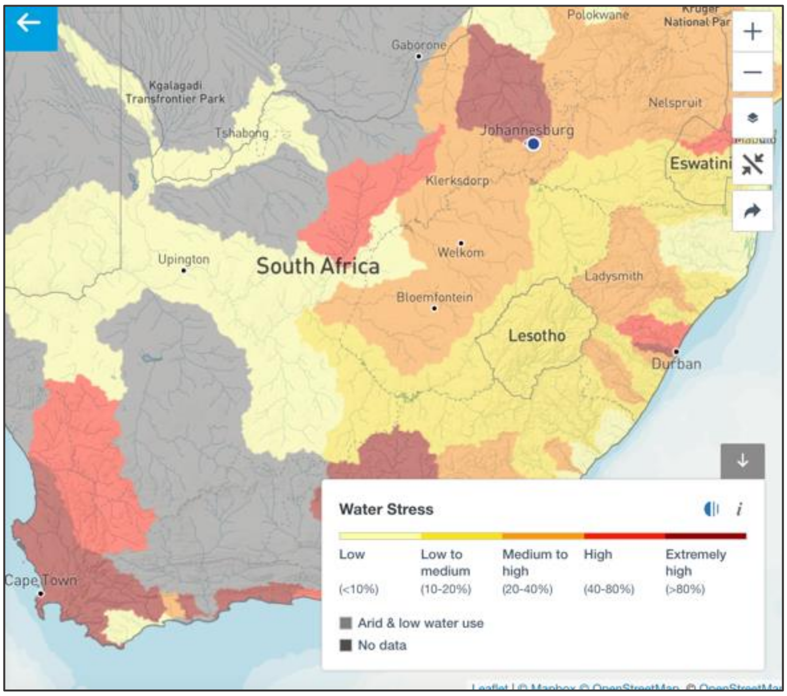


Figure 88: Medium-to-high projected water stress in Ekurhuleni in the year 2040 (Source: WRI)

3.5 City of Johannesburg

The City of Johannesburg is located inland in Gauteng province, adjacent to the City of Tshwane and Ekurhuleni municipality. Historically, its climate has been classified as having warm and temperate climate under the Köppen-Geiger climate classification system (CSIR 2015), with warm summers and dry winters.

Historic climate

The City of Johannesburg's historic average maximum temperatures ranged from 15°C to >25°C between 1979 and 2000 (Figure 89). Average minimum temperatures ranged between 0°C and 17°C for the same time period (Figure 90).

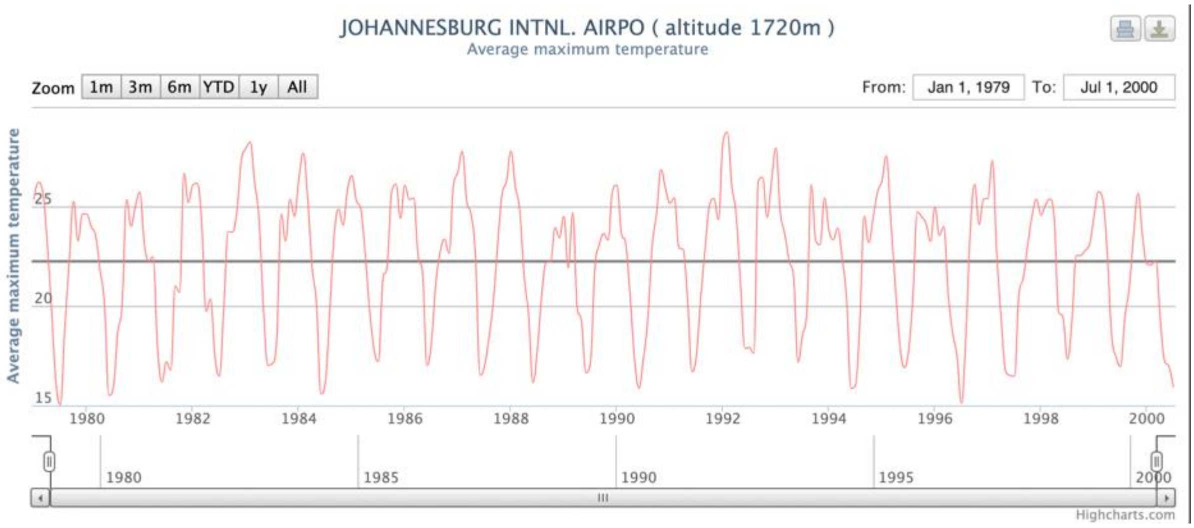


Figure 89: Historic average maximum temperature (available only from January 1979 to July 2000) for the City of Johannesburg[26]

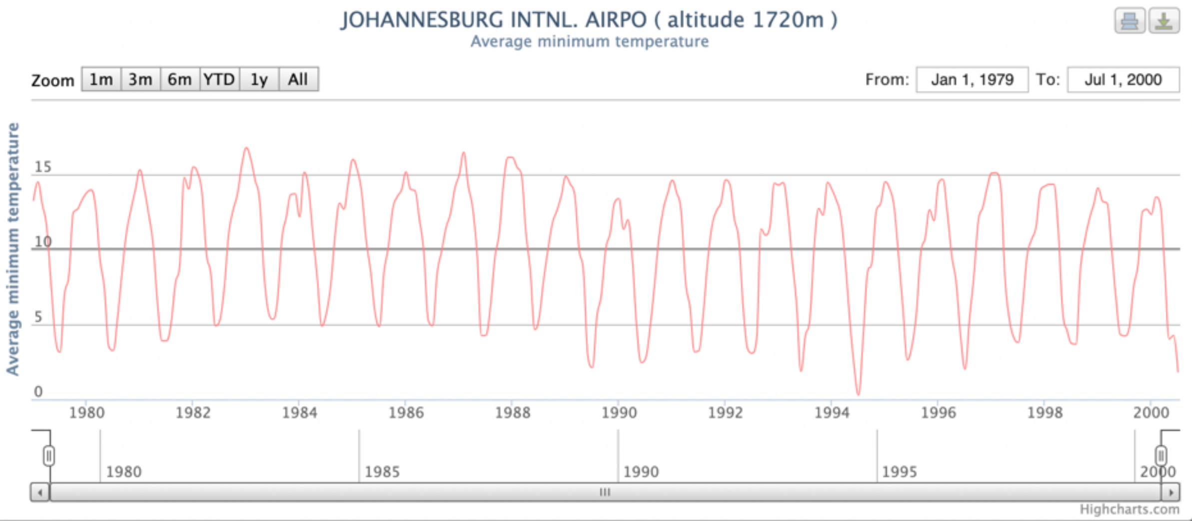


Figure 90: Historic average minimum temperature (available only from January 1979 to July 2000) for the City of Johannesburg[27]

A slight increase in total monthly rainfall can be observed for the City of Johannesburg between 1979 and 2000 (Figure 91).

[26] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[27] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

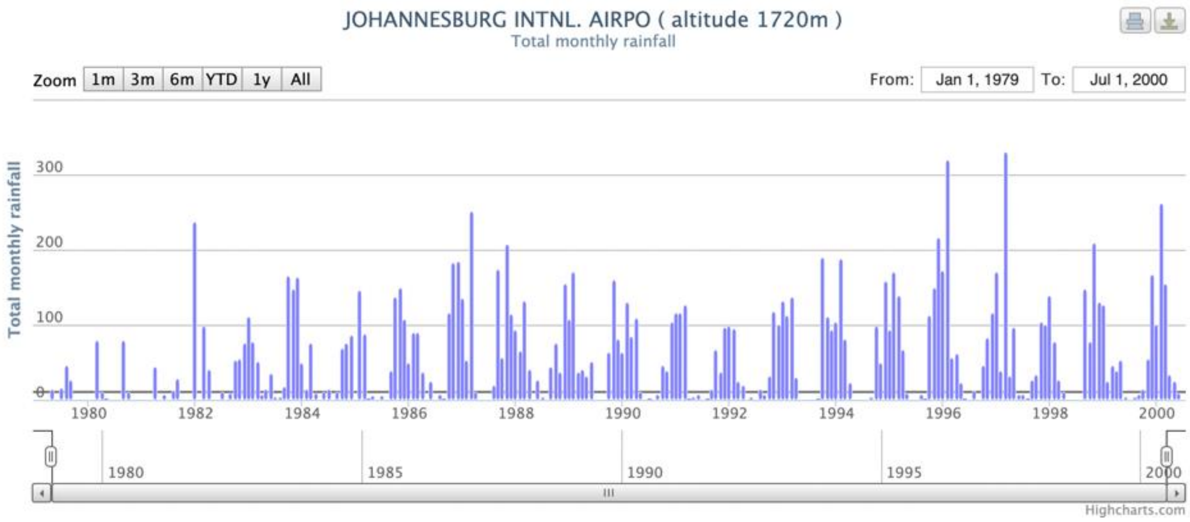


Figure 91: Historic total monthly rainfall (available only from January 1979 to July 2000) for the City of Johannesburg[28]

High mean dry spell durations occurred in 1986, 1987, 1993-1995 and in 1999 with the duration being over 50 days (Figure 92). Apart from this, the City of Johannesburg's mean dry spells tended to last below 50 days between 1979 and 2000.

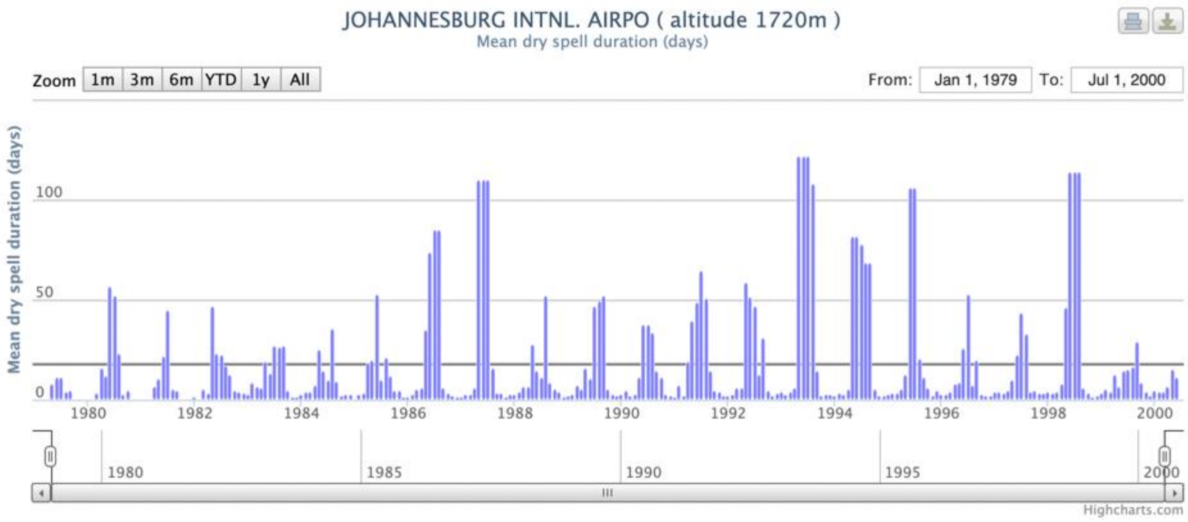


Figure 92: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for the City of Johannesburg[29]

Current climate and water resources

As depicted in Figure 93, Johannesburg's current average annual temperature is approximately 16-18°C and current annual average rainfall is 1200 mm (CSIR and Aurecon 2019).

[28] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

[29] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

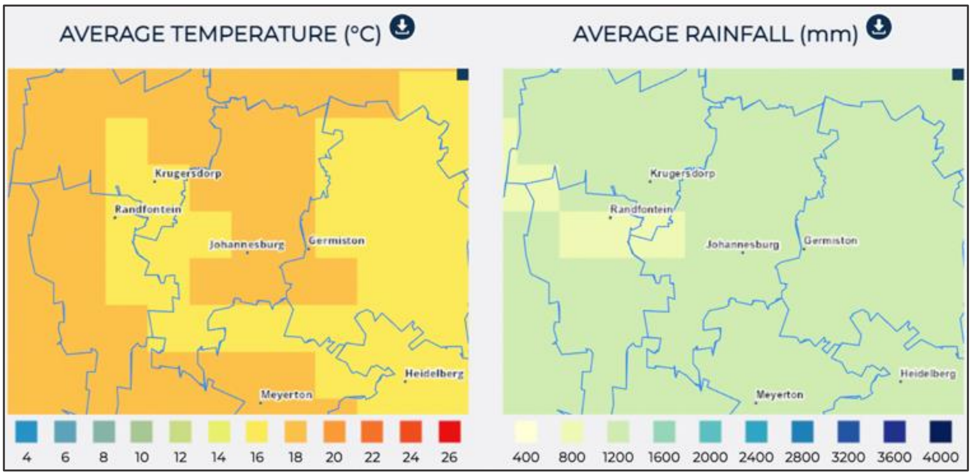


Figure 93 : Johannesburg's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality does not currently have water supply vulnerability and is meeting its needs (CSIR and Aurecon 2019), as reflected in Figure 94.

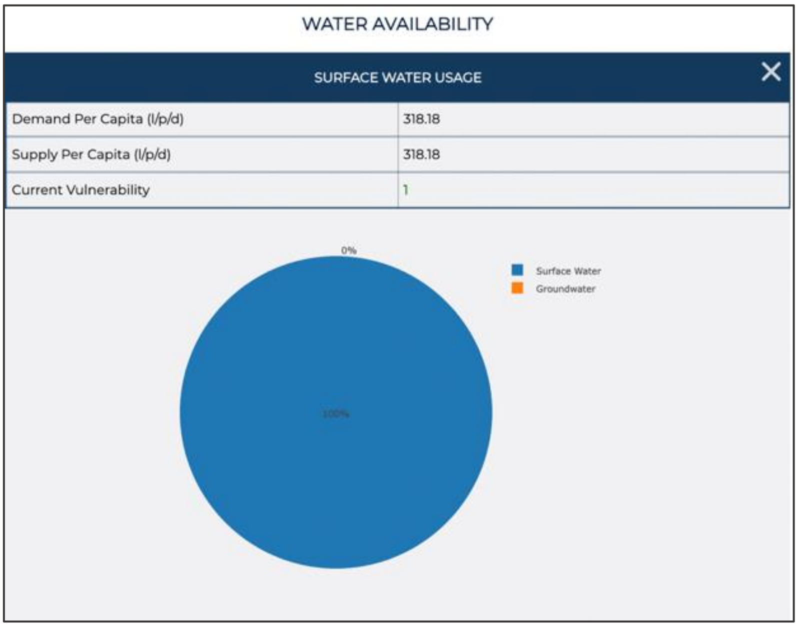


Figure 94: Present-day water availability in Johannesburg municipality (Source: CSIR, Greenbook, 2019)

Figure 95 indicates that the municipality is dependent on a combination of surface water and groundwater at the moment, and it has moderate-to-high groundwater recharge potential in some areas (CSIR and Aurecon 2019).

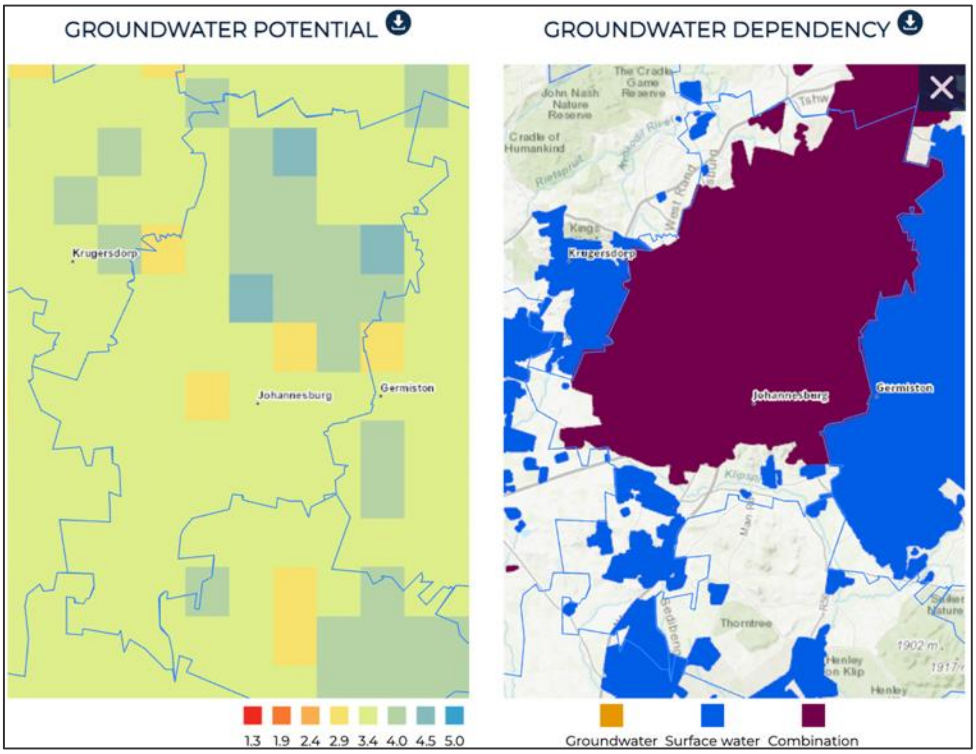


Figure 95: Groundwater recharge potential (left) and groundwater dependency (right) in Johannesburg municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are not exclusively able to meet the municipality's needs at the moment (CSIR and Aurecon 2019).

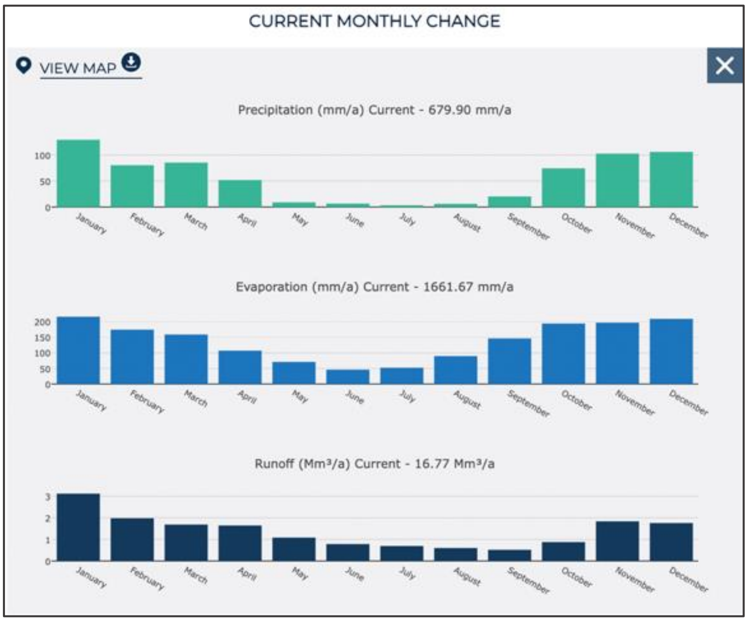


Figure 96: Surface water indices in Johannesburg under the current climate (Source: CSIR, Greenbook, 2019)

Under the current climate, Johannesburg does not face high levels of drought risk (Figure 97) relative to some other regions of the country, although the area has experienced instances of drought in recent decades.

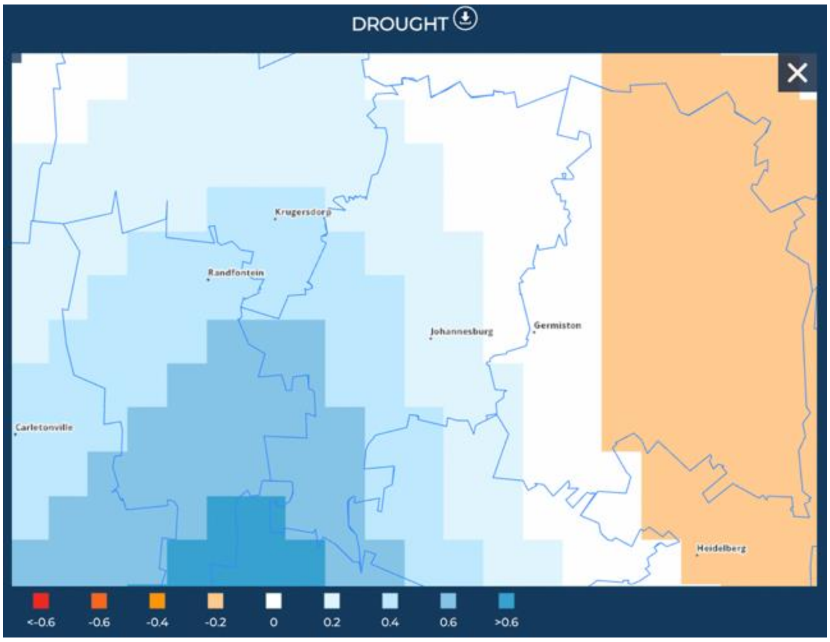


Figure 97: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario (RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP's first phase) from 2011 – 2040, Johannesburg municipality is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- 1% increase in mean annual precipitation (some models agree on the increase, with a few models agreeing about the projected decrease in the number of dry spells, but with an indication that the length of the longest dry spell may increase).
- -3% decrease in aridity (the area is expected to become less dry)
- -4% decrease in annual mean soil moisture
- 1% change in annual mean water discharge (with inconsistency on return periods of maximum annual discharge: for instance, some models suggest an increase in the 2-year and 5-year return periods, but some indicate a decrease in the 10-year, and 50-year return periods for annual maximum water discharge. A few models also agree on a decrease in minimum annual water discharge)
- 1% increase in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, Johannesburg will experience a significant temperature rise of up to 2.79°C (CSIR and Aurecon 2019).

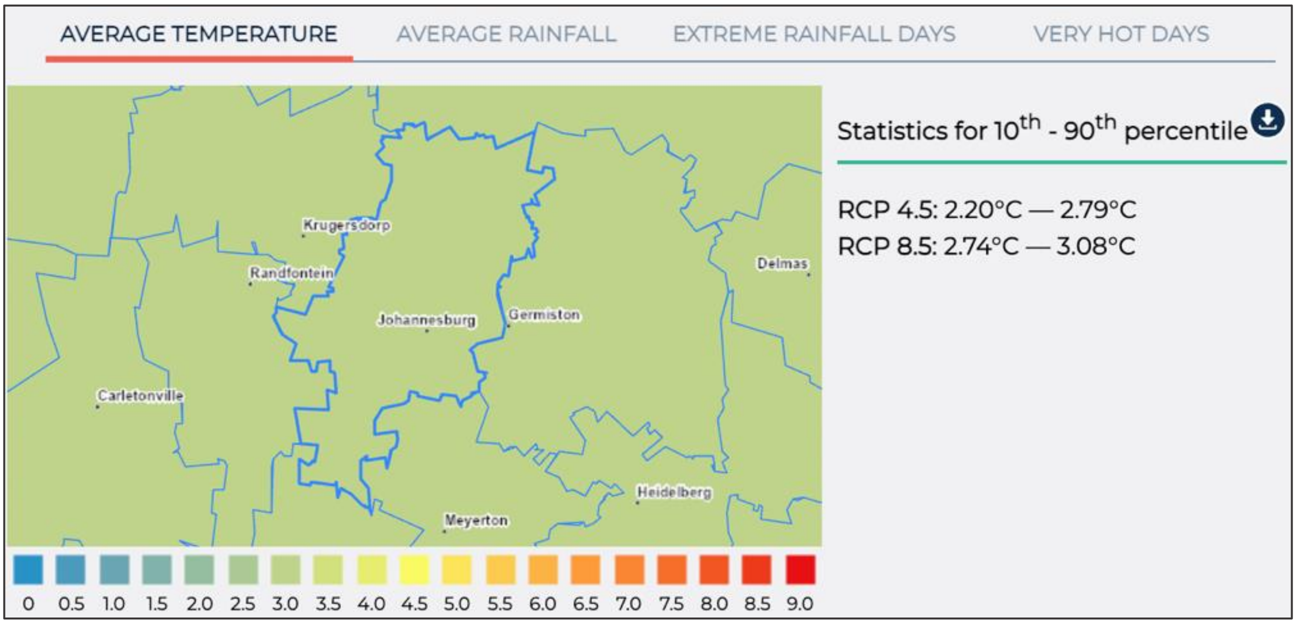


Figure 98: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

A clear rise in temperature can be observed in Figure 99 and Figure 100 which shows the average maximum and minimum temperature projections for the City of Johannesburg between 2030 and 2050 (RCP4.5).

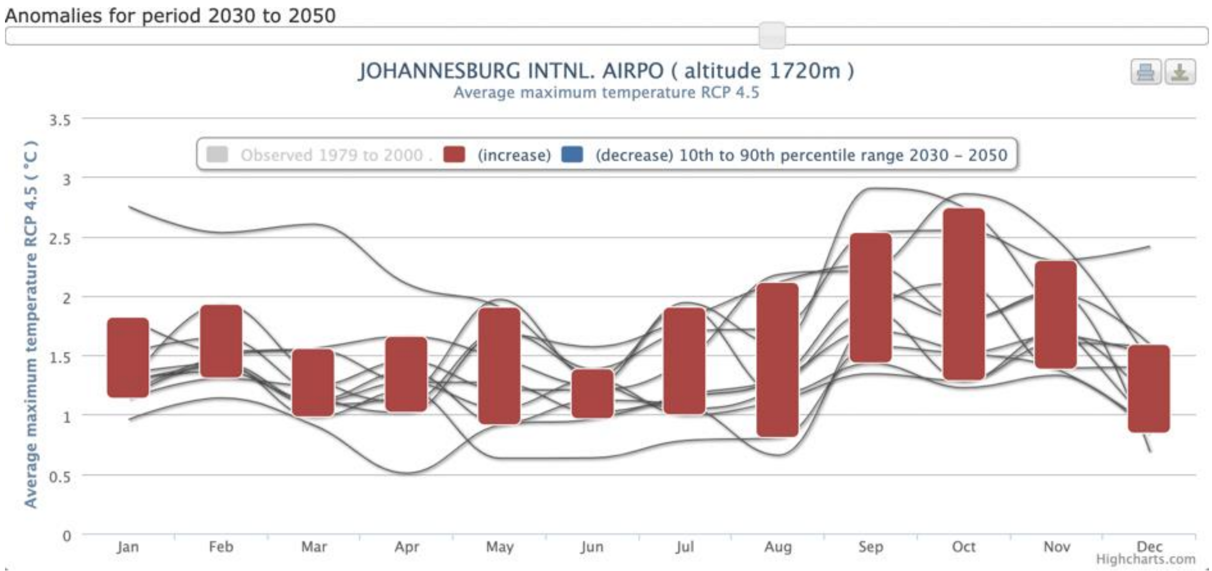


Figure 99: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Johannesburg[30]

[30] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

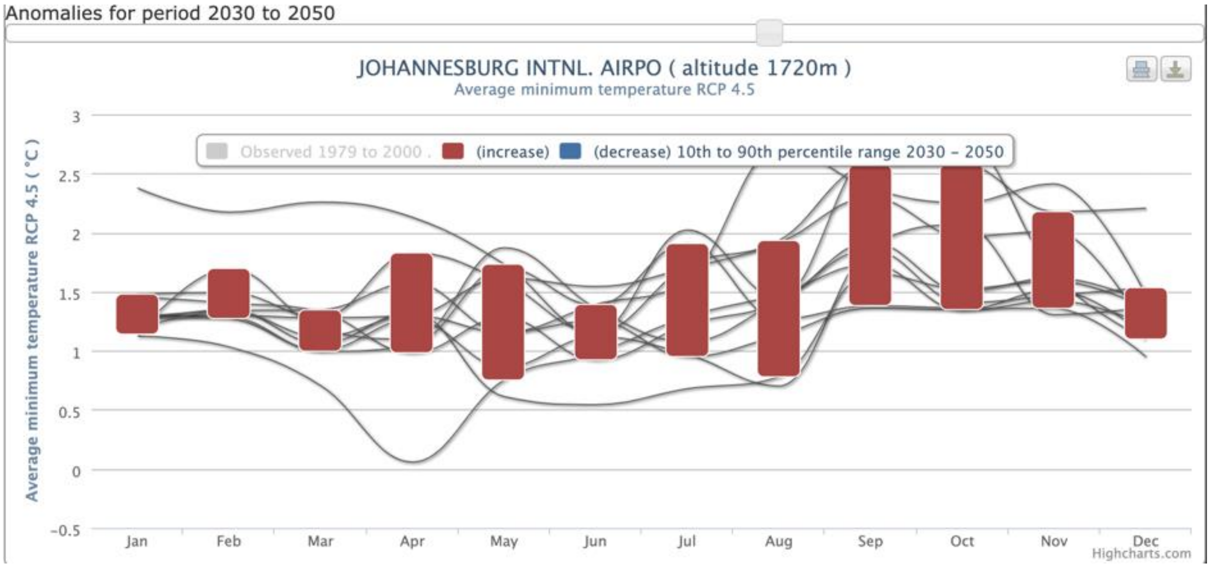


Figure 100: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Johannesburg[31]

Average rainfall in 2050, under RCP 4.5, will be more variable but likely to rise. Broadly the trend indicated is an increase in average rainfall (CSIR and Aurecon 2019).

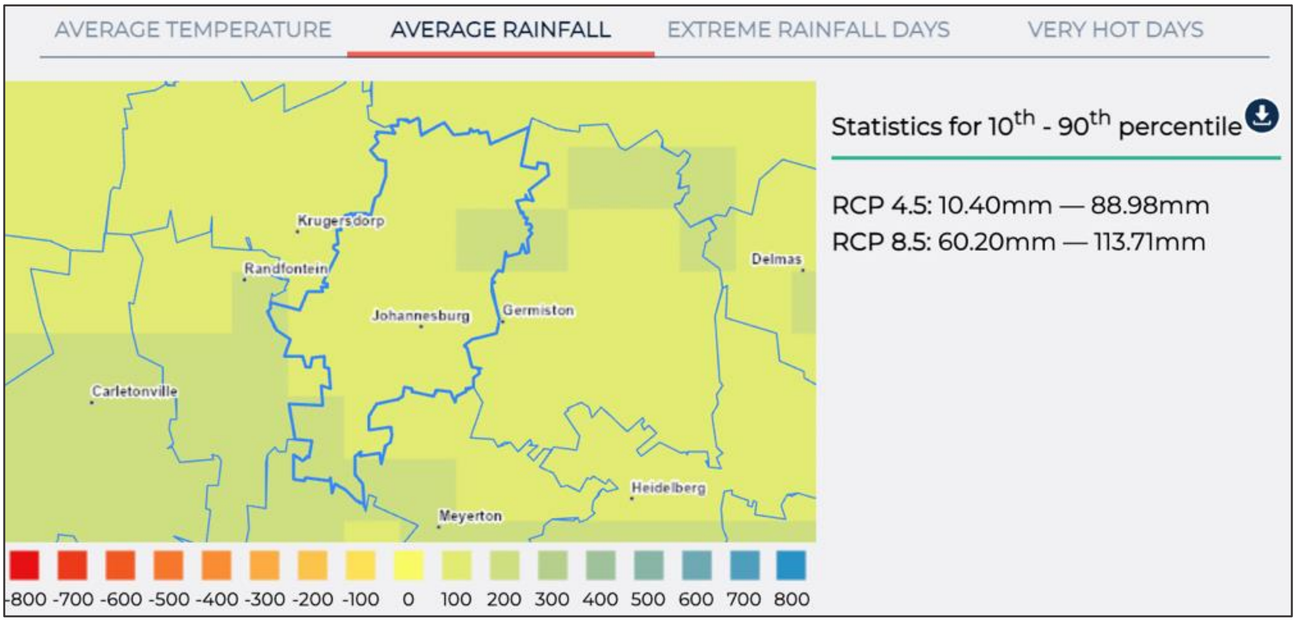


Figure 101: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

A relative increase in total monthly rainfall projections is evident in Figure 102 for the City of Johannesburg between 2030 and 2050.

[31] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

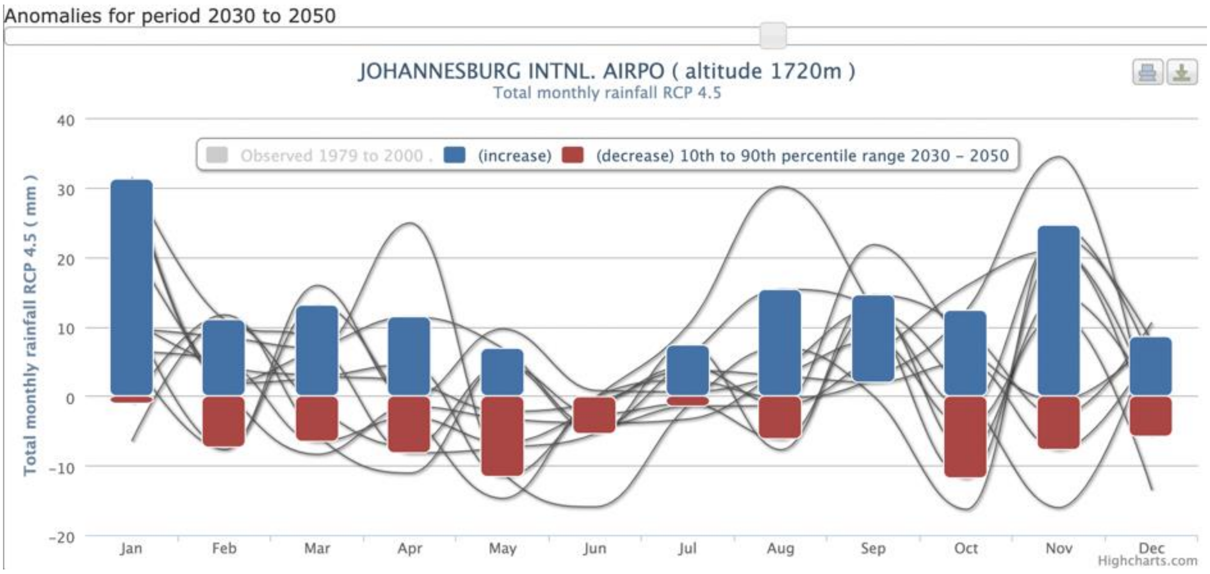


Figure 102: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the City of Johannesburg[32]

There is also some variability and range in projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019). The trend points to a slight potential increase.

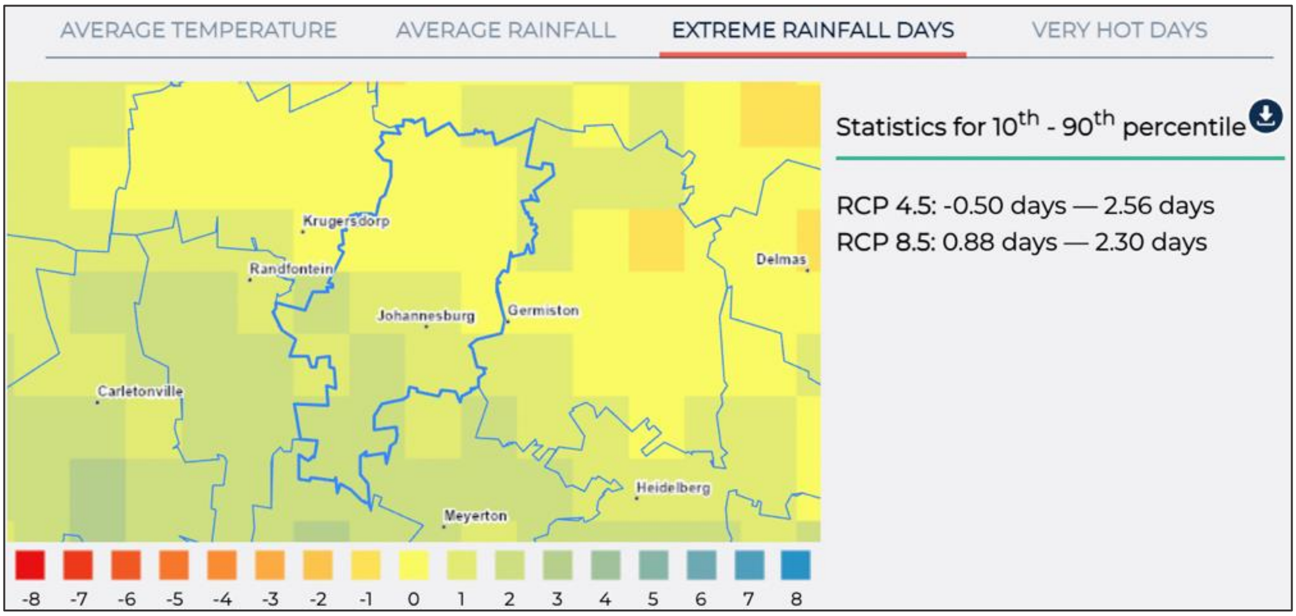


Figure 103: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality will experience a notable increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

[32] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

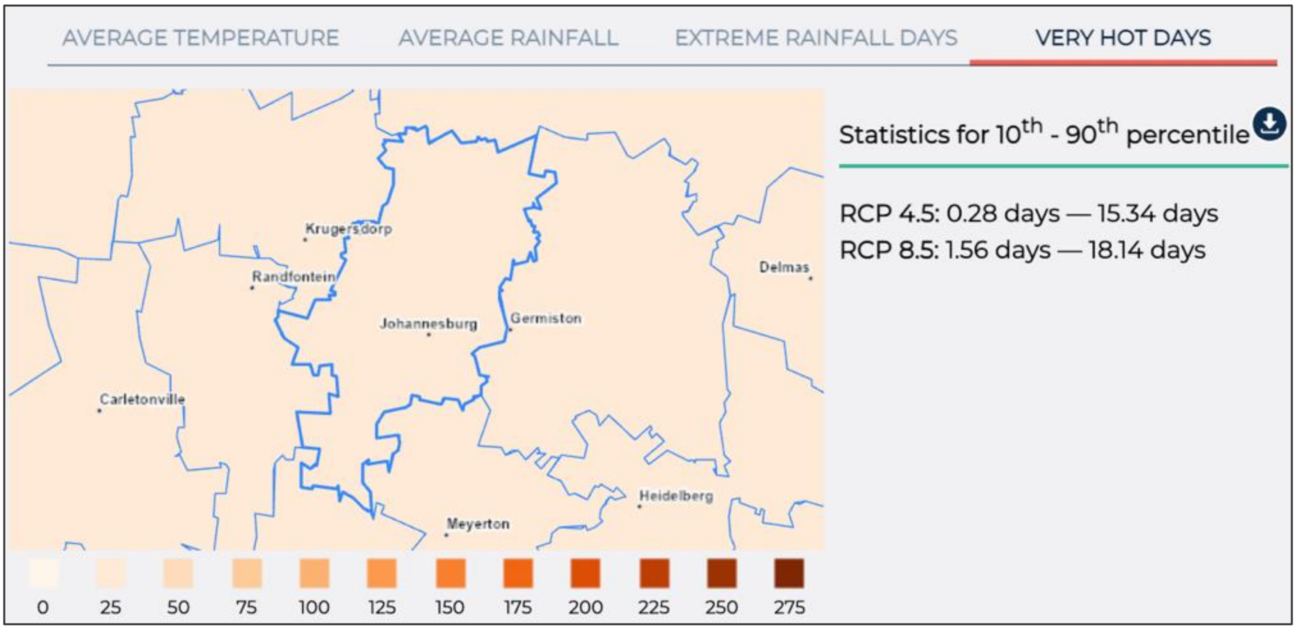


Figure 104: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Figure 105 shows longer dry spell durations for the City of Johannesburg between 2030 and 2050 (RCP4.5) in the months of May, June and July.

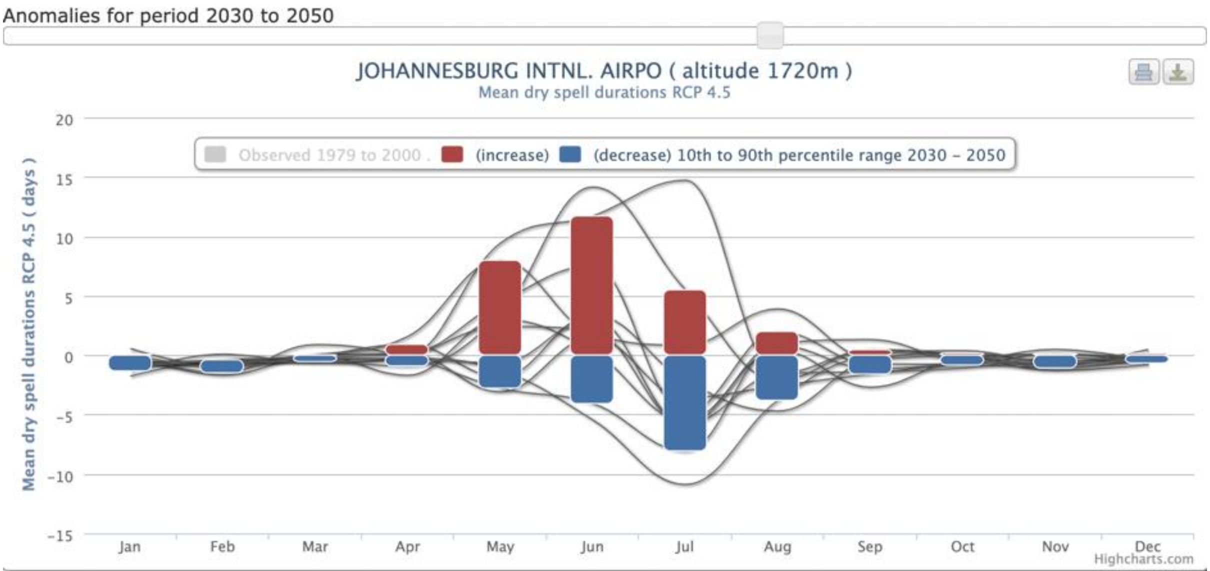


Figure 105: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the City of Johannesburg[33]

Future drought risk in Johannesburg in 2050 is somewhat greater in western regions of the municipality, in terms of the SPI drought index, but with estimated medium increase in drought tendency across the whole municipality (CSIR and Aurecon 2019).

[33] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

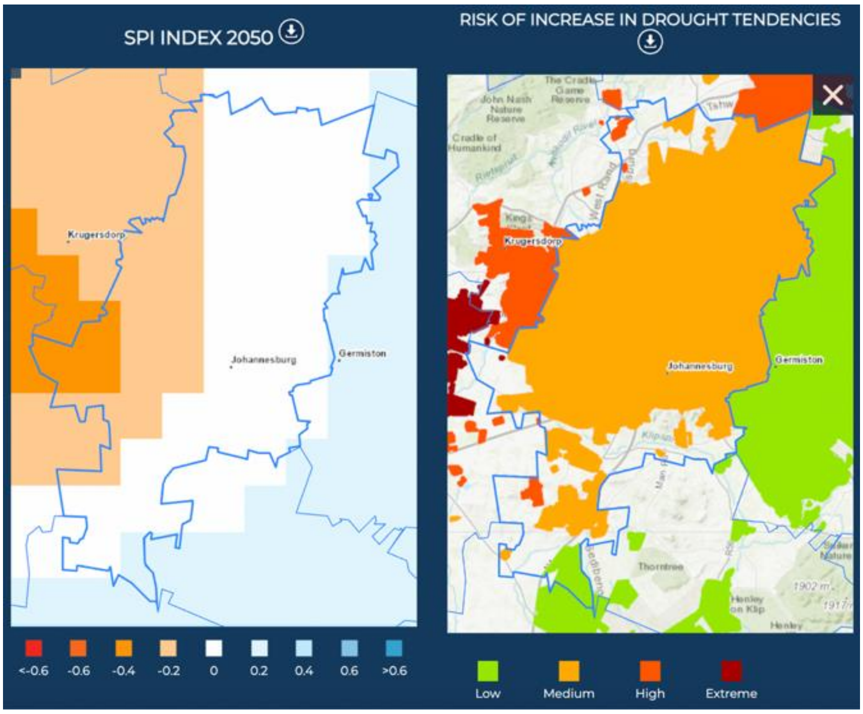


Figure 106: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential may increase or decrease marginally in different parts of Johannesburg by 2050. However, given that the municipality does depend on groundwater, an extremely high level of groundwater depletion risk is anticipated.

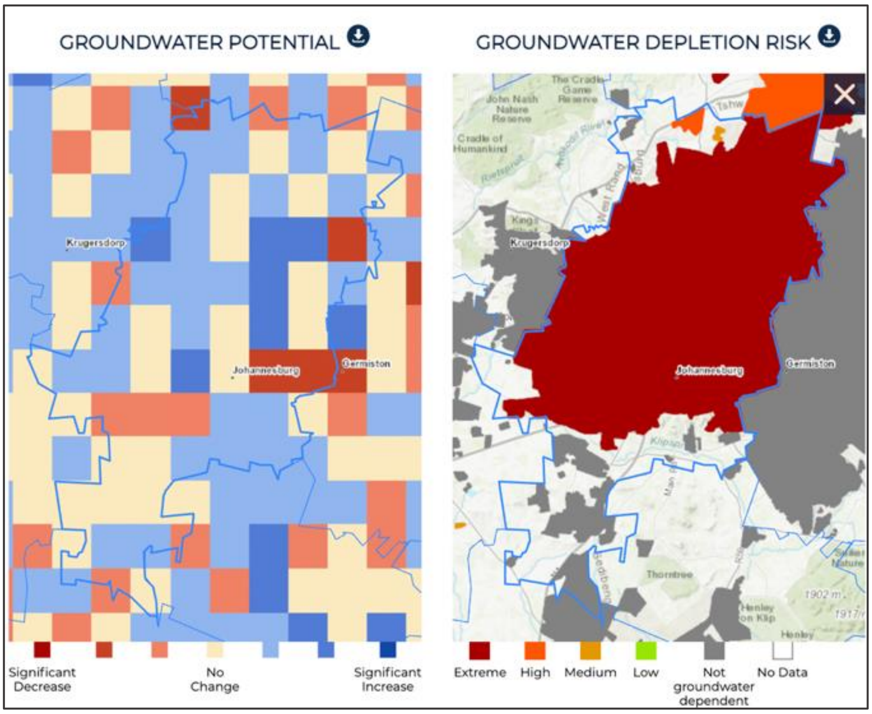


Figure 107: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show decreases in precipitation, increases evaporation, and decreases runoff.

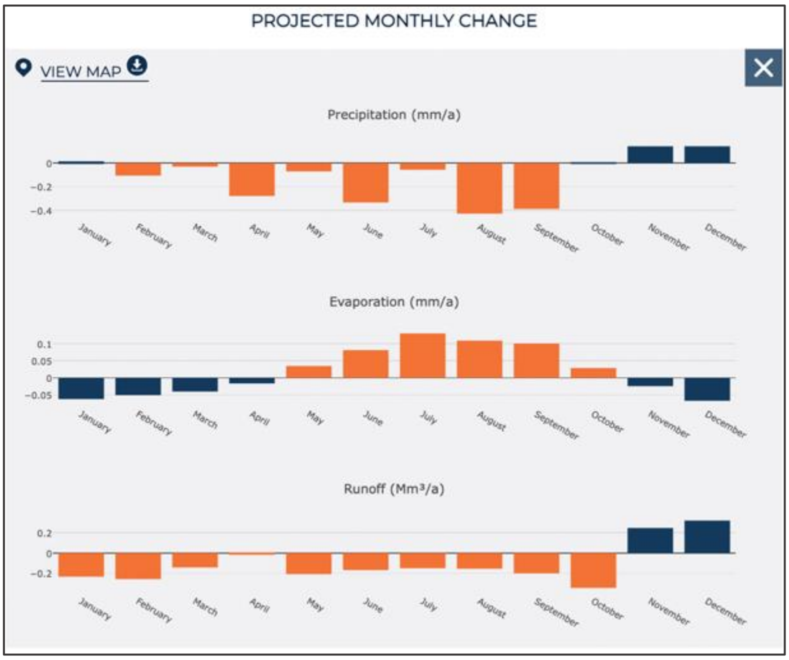


Figure 108: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, due to changes in multiple factors that give rise to water supply vulnerability by 2050, Johannesburg's future relative water supply vulnerability (as a ratio of demand and supply) is likely to rise under a medium population growth future (CSIR and Aurecon 2019).

Figure 109: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019

WRI's Aqueduct Water Risk Index's localized projection of future climate change related water risk for the City of Johannesburg municipality notes that the projected change in water stress between the present and 2040 is "medium-to-high," with a change (increase in stress) of between 20-40% relative to the current baseline, under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*1.4 times*" change in water stress.

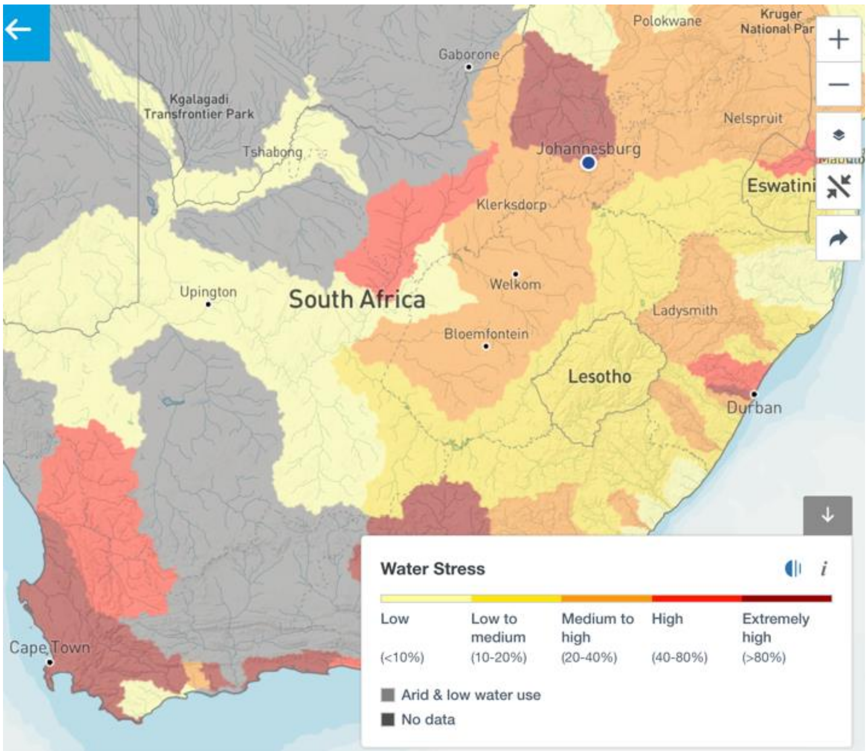


Figure 110: Medium-to-high projected water stress in the City of Johannesburg in the year 2040 (Source: WRI)

3.6 City of Tshwane

The City of Tshwane is located inland in Gauteng province, North of the City of Johannesburg. Historically, its climate has been classified as being a warm and temperate climate under the Köppen-Geiger climate classification system (CSIR 2015), with warm summers and dry winters.

Historic climate

Historic maximum and minimum temperatures showed little variability between 1979 and 2000 for the City of Tshwane (Figure 111 and Figure 112).

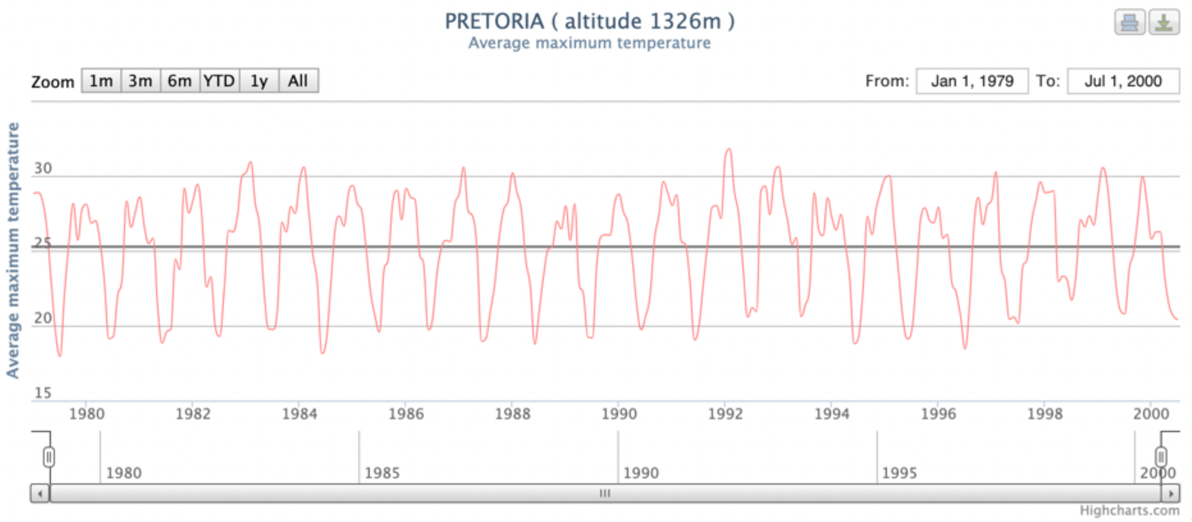


Figure 111: Historic average maximum temperature (available only from January 1979 to July 2000) for the City of Tshwane[34]

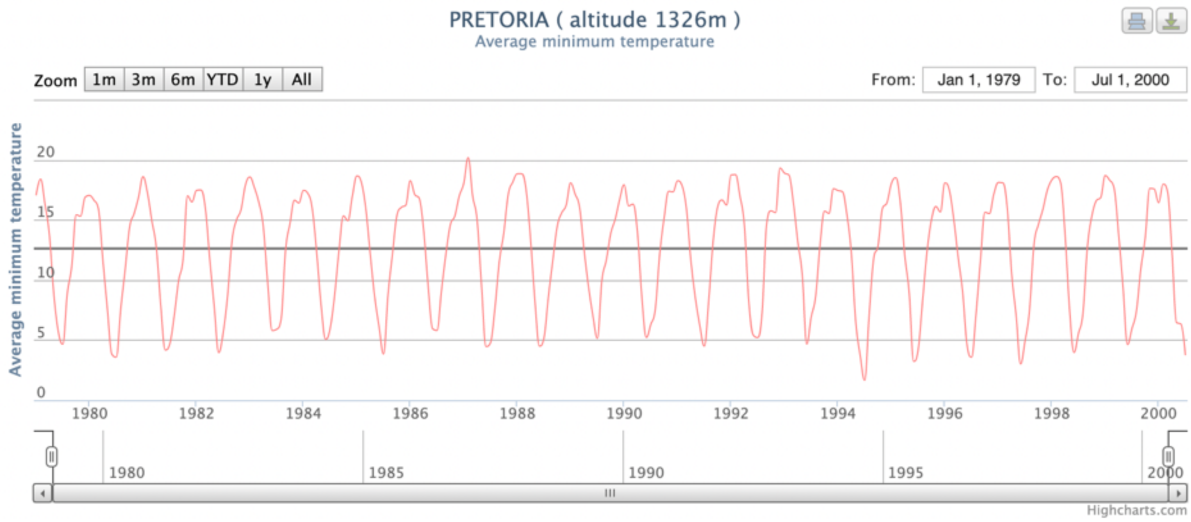


Figure 112: Historic average minimum temperature (available only from January 1979 to July 2000) for the City of Tshwane[35]

A slight increase in historic total monthly rainfall can be seen in Figure 113 for the City of Tshwane between 1979 and 2000.

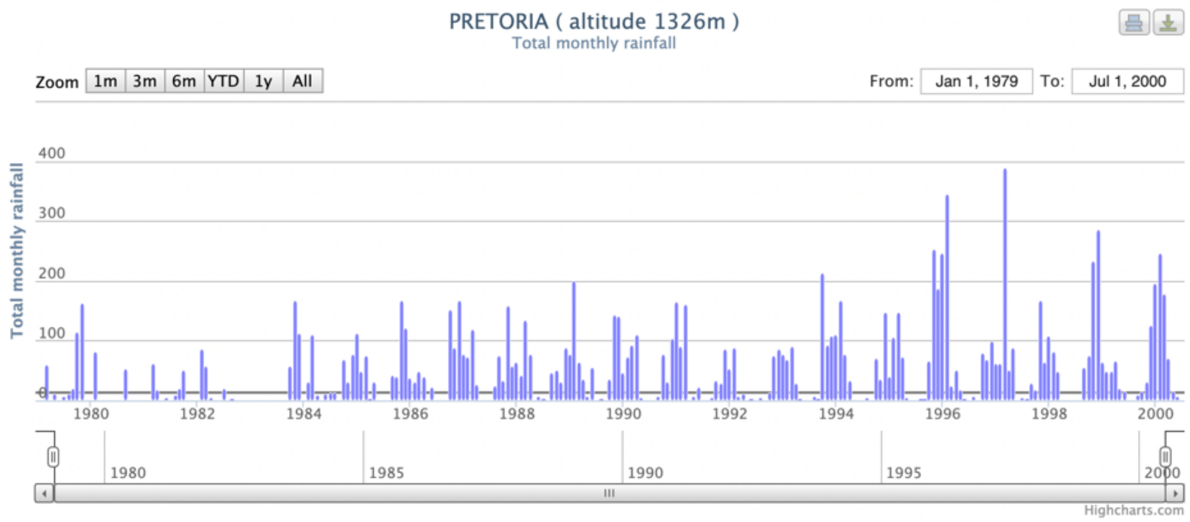


Figure 113: Historic total monthly rainfall (available only from January 1979 to July 2000) for the City of Tshwane[36]

Historic mean dry spell durations for the City of Tshwane between 1979 and 2000 show a slight increase with the longest dry spell duration being observed in 1999 (Figure 114).

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[34] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

[35] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

[36] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

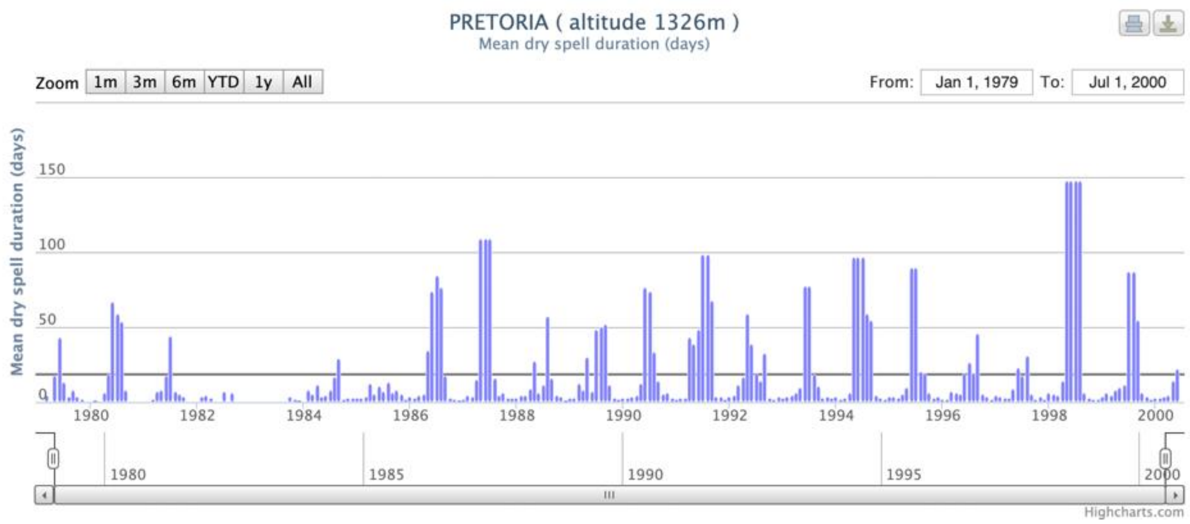


Figure 114: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for the City of Tshwane[37]

Current climate and water resources

As depicted in Figure 115, Tshwane's current average annual temperature is approximately 18-20°C and current annual average rainfall is 1200 mm (CSIR and Aurecon 2019).

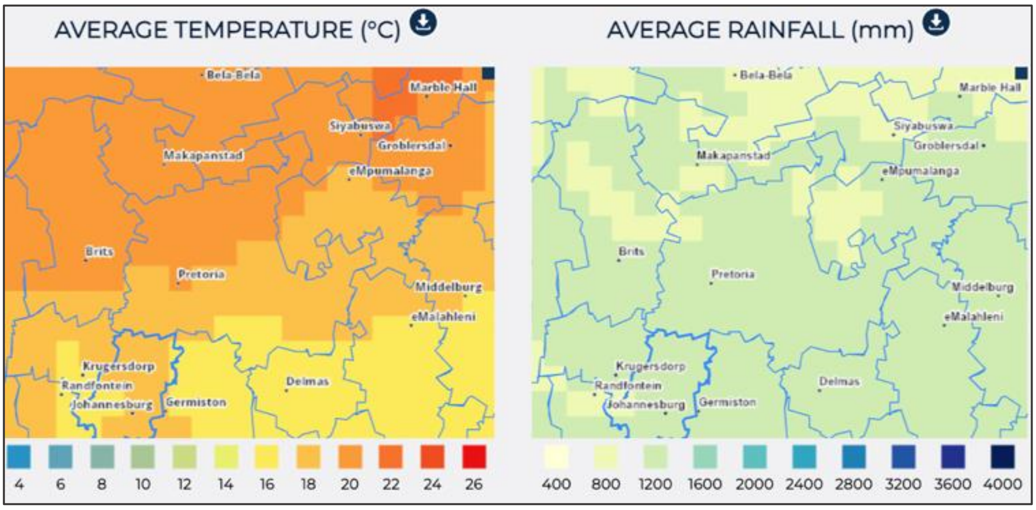


Figure 115: Tshwane's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality already faces a small surplus and thus is not currently vulnerable (CSIR and Aurecon 2019), as reflected in Figure 116.

[37] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

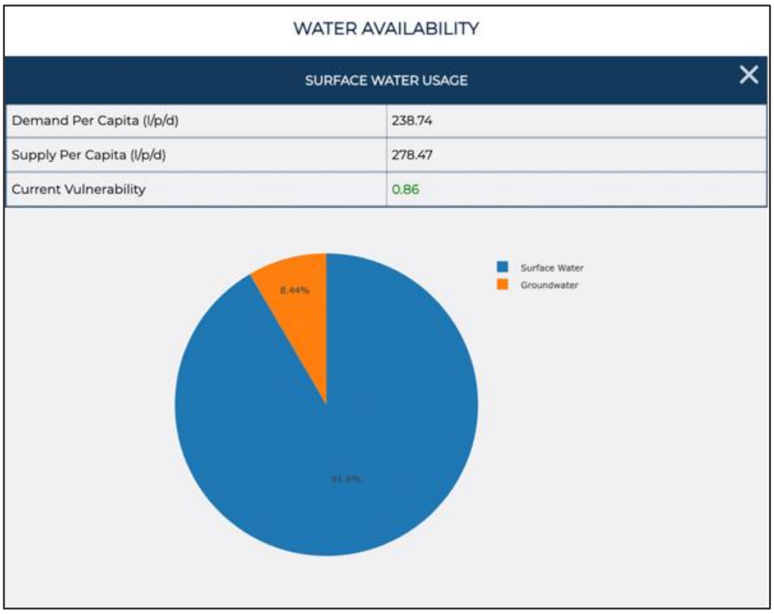


Figure 116: Present-day water availability in Tshwane municipality (Source: CSIR, Greenbook, 2019)

Figure 117 indicates that the municipality is dependent on a combination of surface water and groundwater at the moment, and it has moderate-to-high groundwater recharge potential in some areas (CSIR and Aurecon 2019).

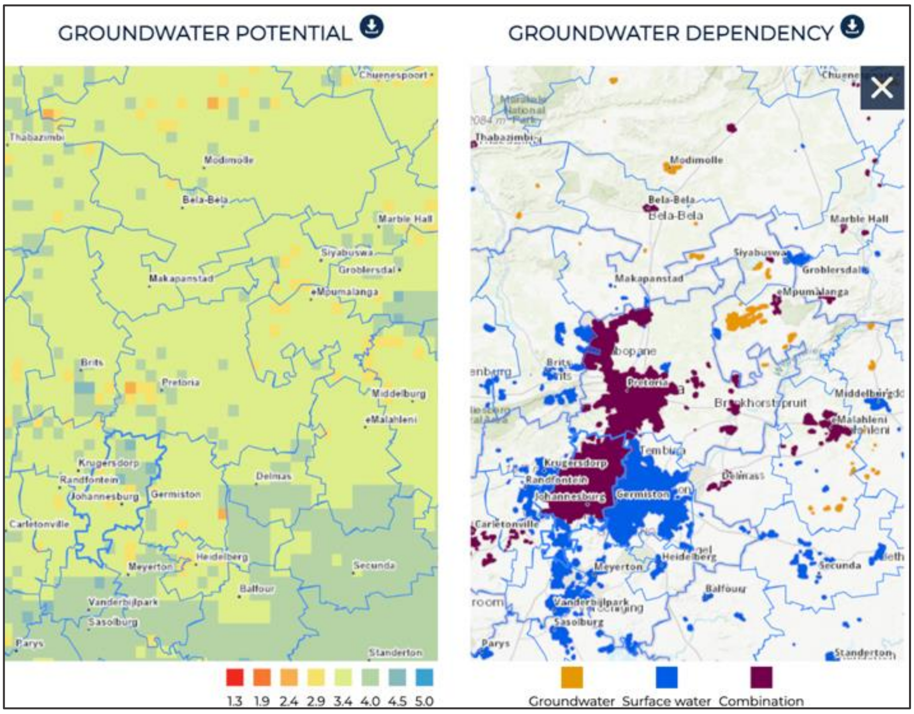


Figure 117: Groundwater recharge potential (left) and groundwater dependency (right) in Tshwane municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are not exclusively able to meet the municipality's needs at the moment (CSIR and Aurecon 2019).

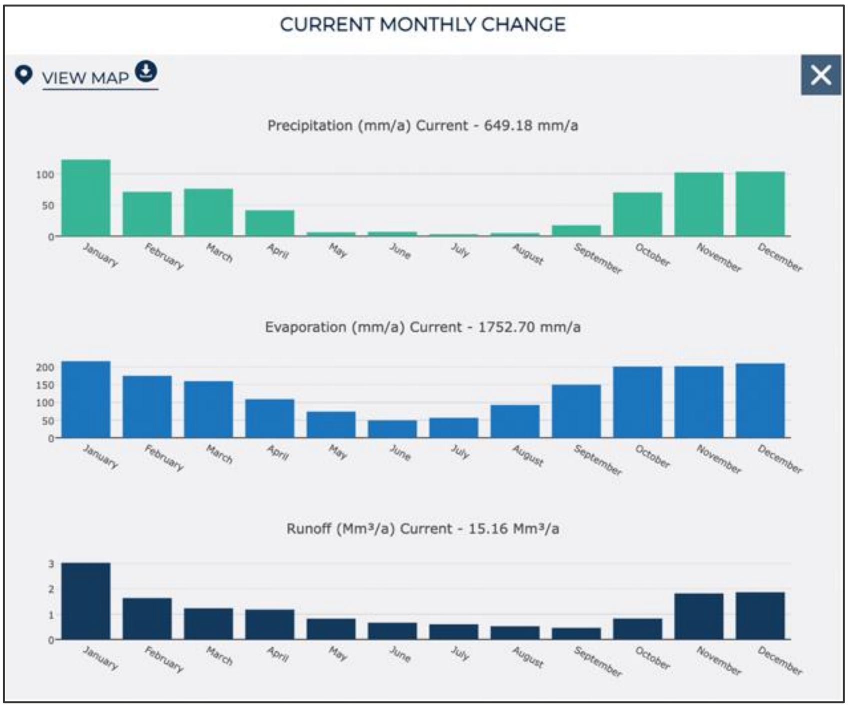


Figure 118: Surface water indices in Tshwane under the current climate (Source: CSIR, Greenbook, 2019)

Under the current climate, the City of Tshwane does not face high levels of drought risk (Figure 119) relative to some other regions of the country, although the area has experienced instances of drought in recent decades.

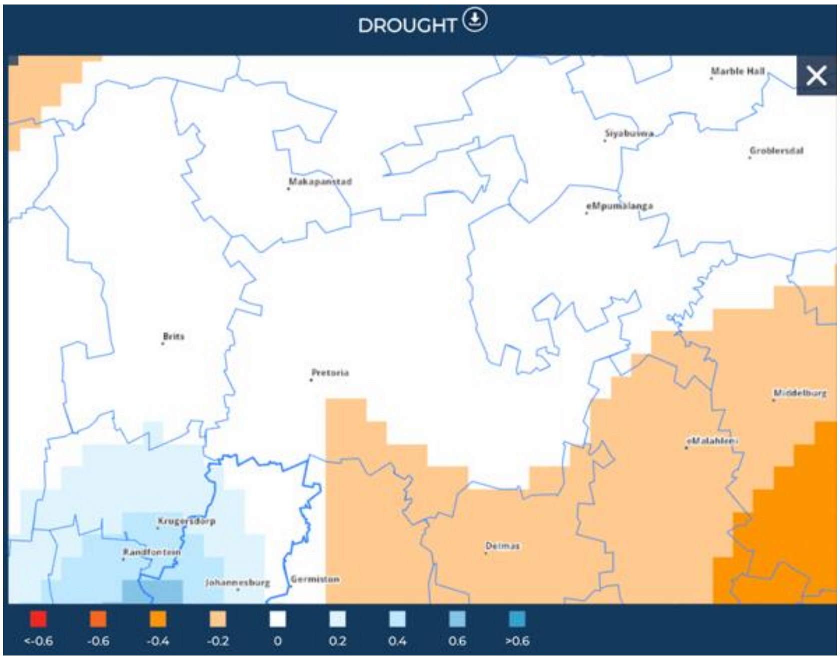


Figure 119: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario (RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the

WRP's first phase) from 2011 – 2040, the City of Tshwane is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- 1% increase in mean annual precipitation (a few models agree on the increase, with some models agreeing about the projected decrease in the number of dry spells, and with a few indicating that the length of the longest dry spell may increase).
- 8% increase in aridity (the area is expected to become more dry)
- 1% increase in annual mean soil moisture
- 3% change in annual mean water discharge (including an increase of maximum annual discharge in the 2-year, 5-year, 10-year, and 50-year return periods)
- 2% increase in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, Tshwane will experience a significant temperature rise of up to 2.81°C (CSIR and Aurecon 2019).

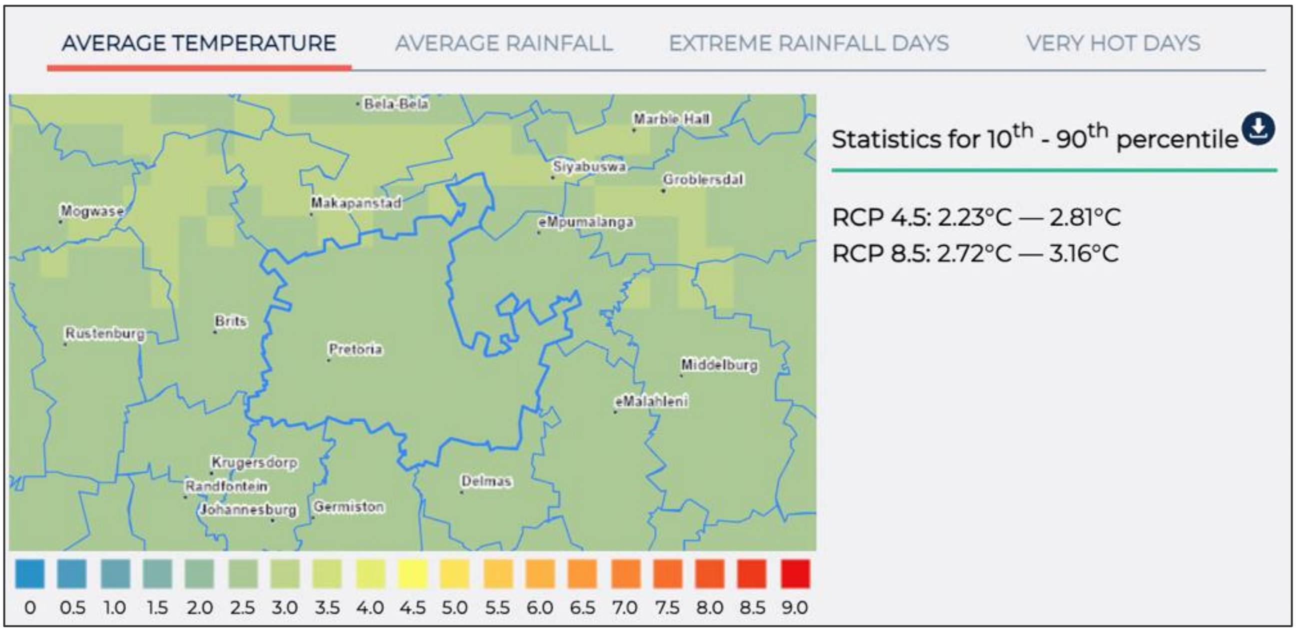


Figure 120: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Figure 121 and Figure 122 show City of Tshwane's future average maximum and minimum temperature projections between 2030 and 2050 (RCP4.5) and a clear rise in temperatures is evident.

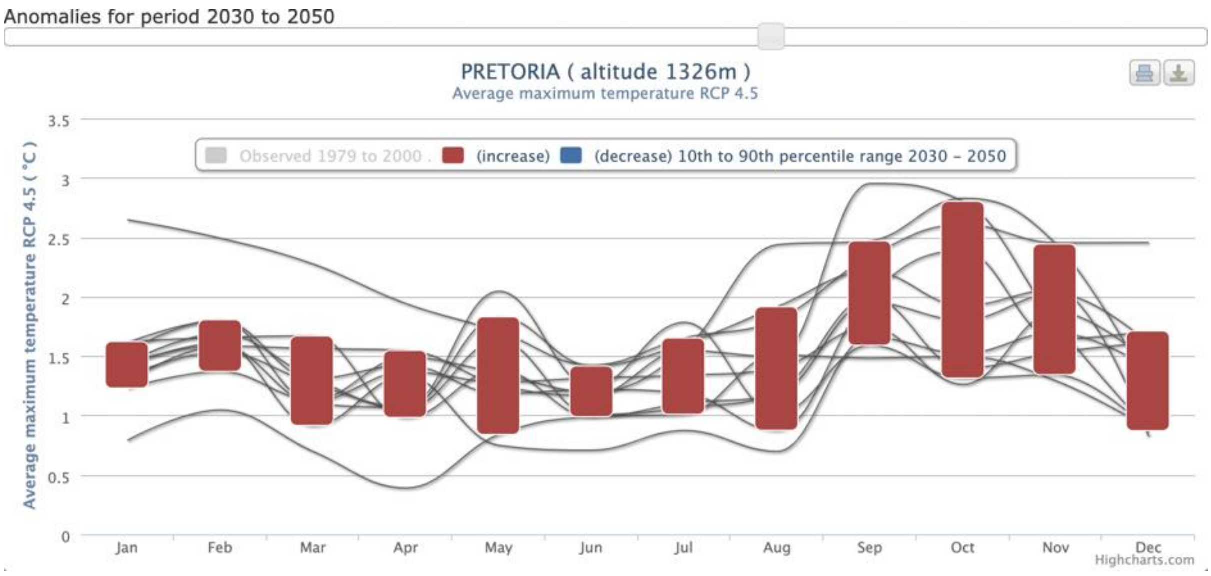


Figure 121: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Tshwane[38]

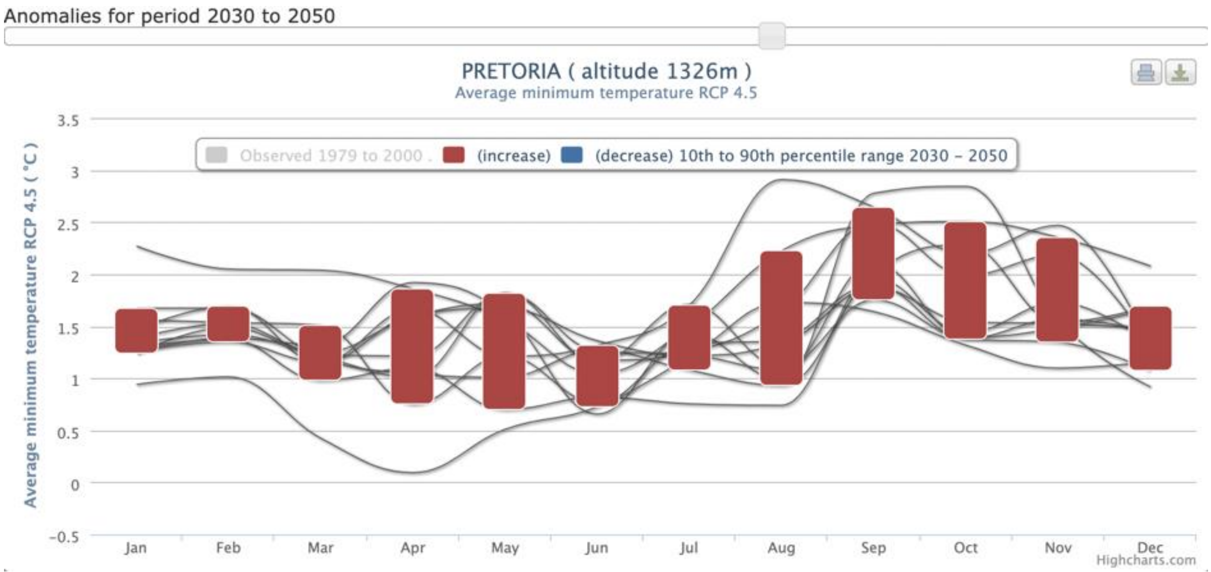


Figure 122: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the City of Tshwane[39]

Average rainfall in 2050, under RCP 4.5, is variable, with the range covering both a potential decrease and an increase. Thus, there is uncertainty in the direction of future rainfall change (CSIR and Aurecon 2019).

[38] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

[39] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

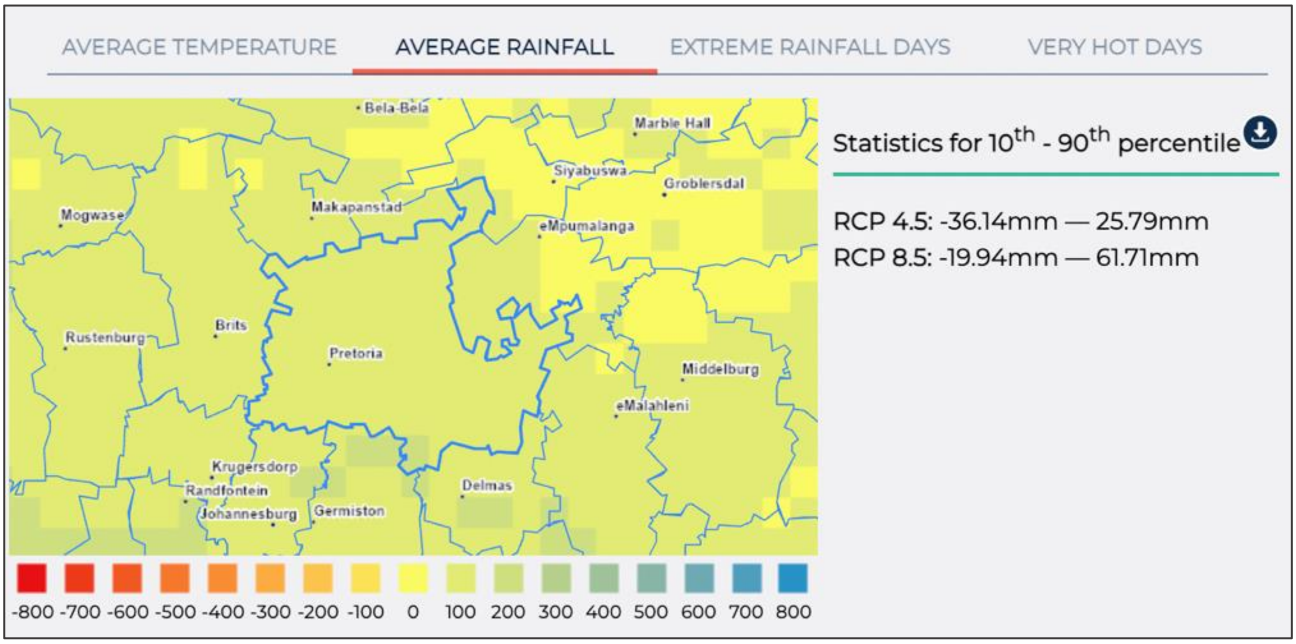


Figure 123: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

A relative increase in rainfall is observed in Figure 124 which shows the total month rainfall projections for City of Tshwane between 2030 and 2050 (RCP4.5).

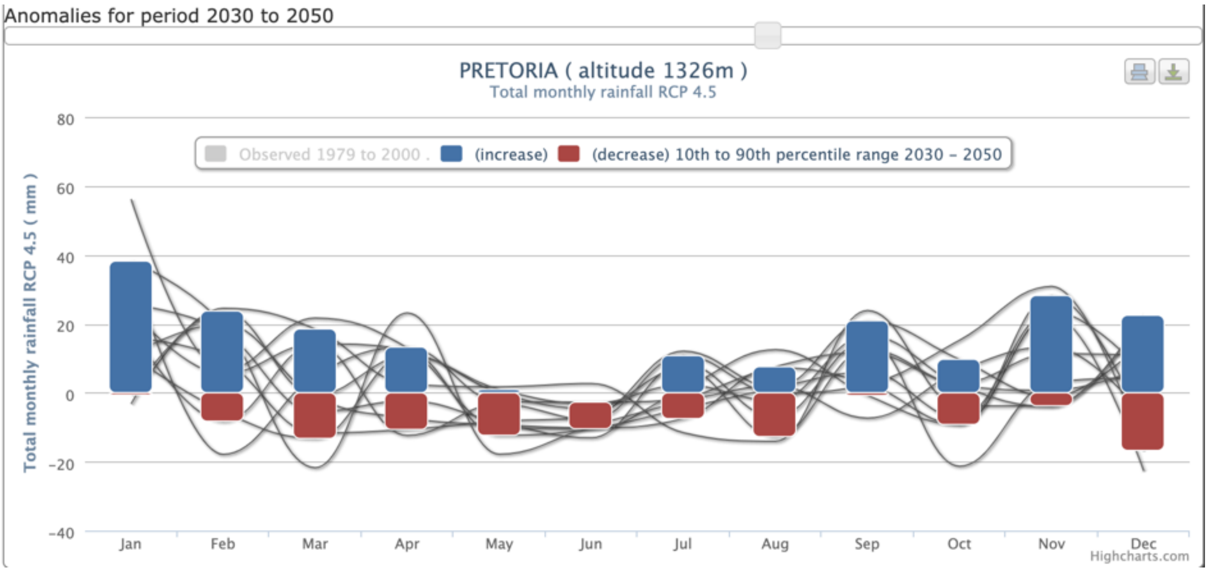


Figure 124: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the City of Tshwane[40]

There is also some variability and range in projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019). The change, either way, is insubstantial.

[40] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

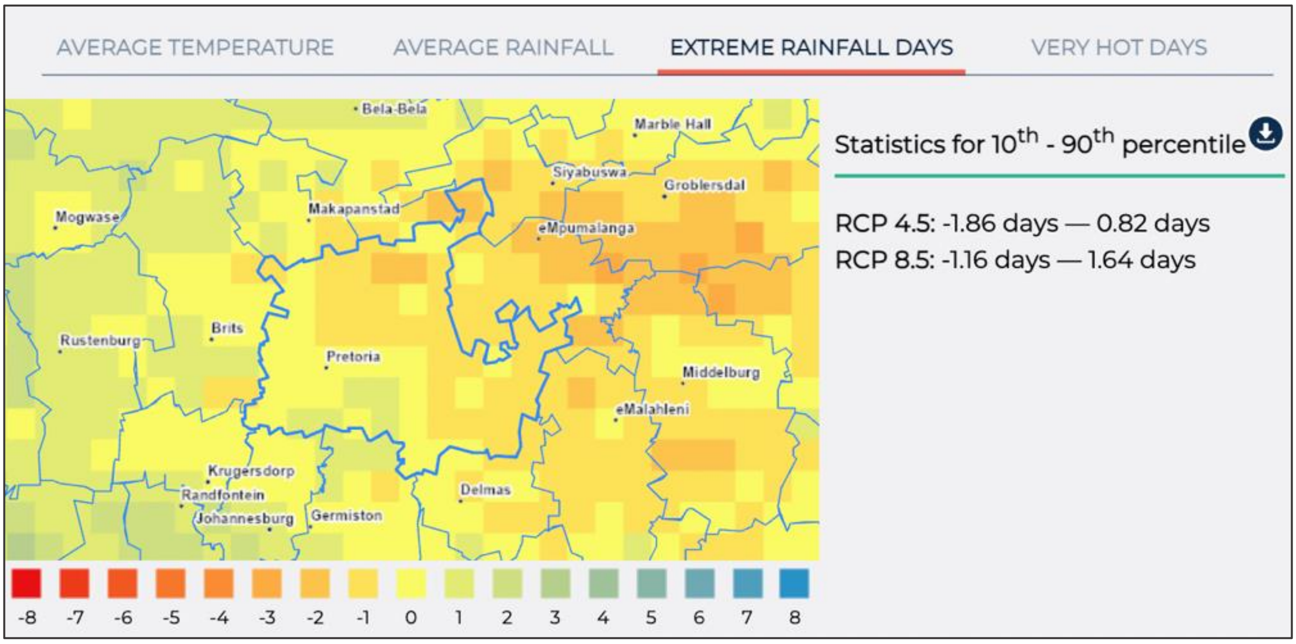


Figure 125: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality is likely to experience a marked increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

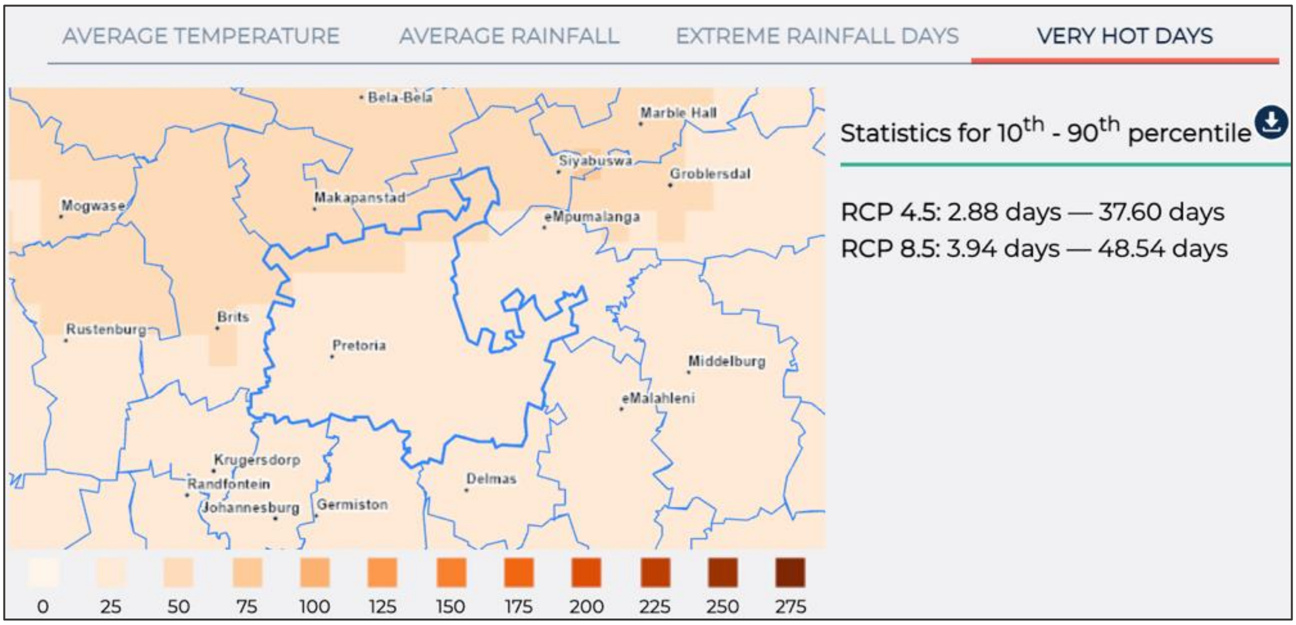


Figure 126: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

As can be seen in Figure 127, slightly longer dry spells are observed in the months towards the middle of the year for the City of Tshwane between 2030 and 2050 (RCP4.5).

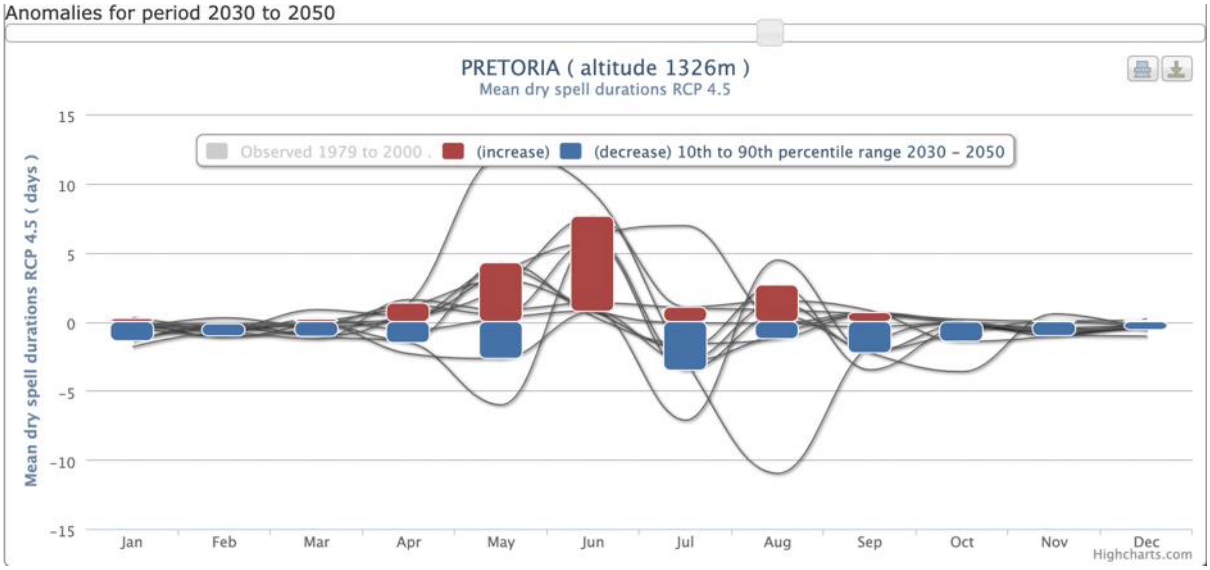


Figure 127: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the City of Tshwane[41]

Future drought risk in Tshwane in 2050 is not significant in terms of the SPI drought index, but there may be a high level of increase in drought tendency, especially in the west of the municipality (CSIR and Aurecon 2019).

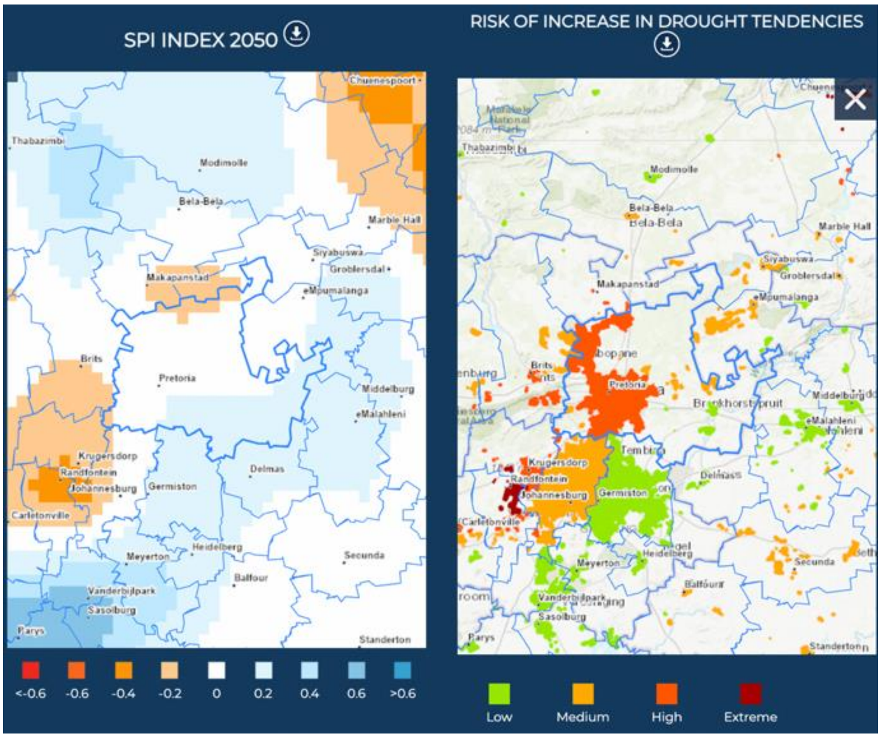


Figure 128: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential may increase or decrease marginally in different parts of Tshwane by 2050. However, given that the municipality does depend on groundwater, it is expected to experience high levels of groundwater depletion risk in the western and central parts of the city.

[41] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

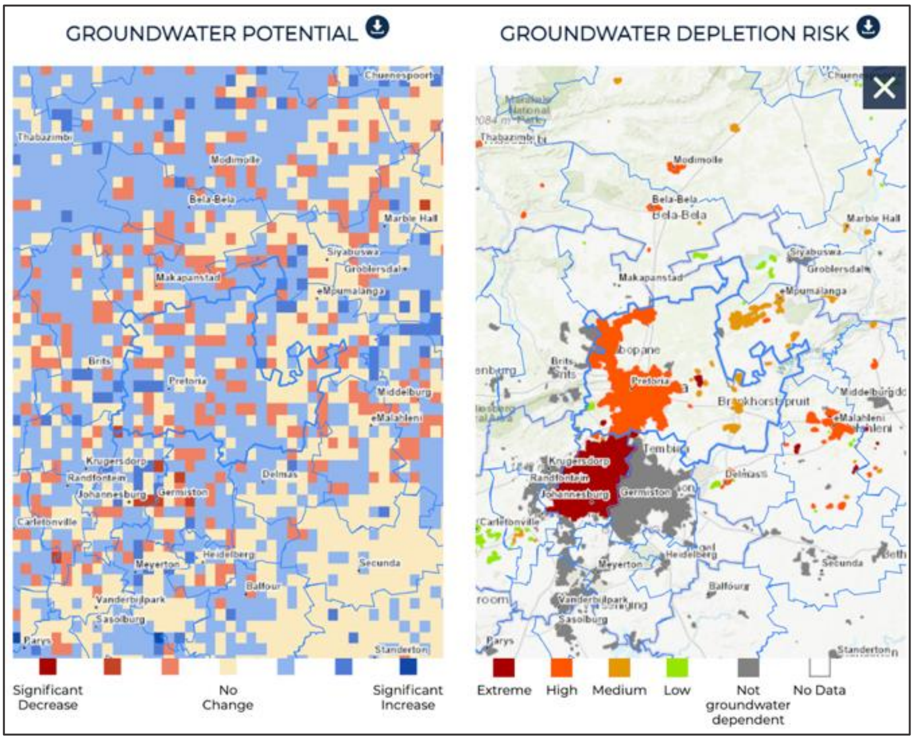


Figure 129: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show decreases in precipitation, increases evaporation, and changes in runoff that result in increased runoff over the year.

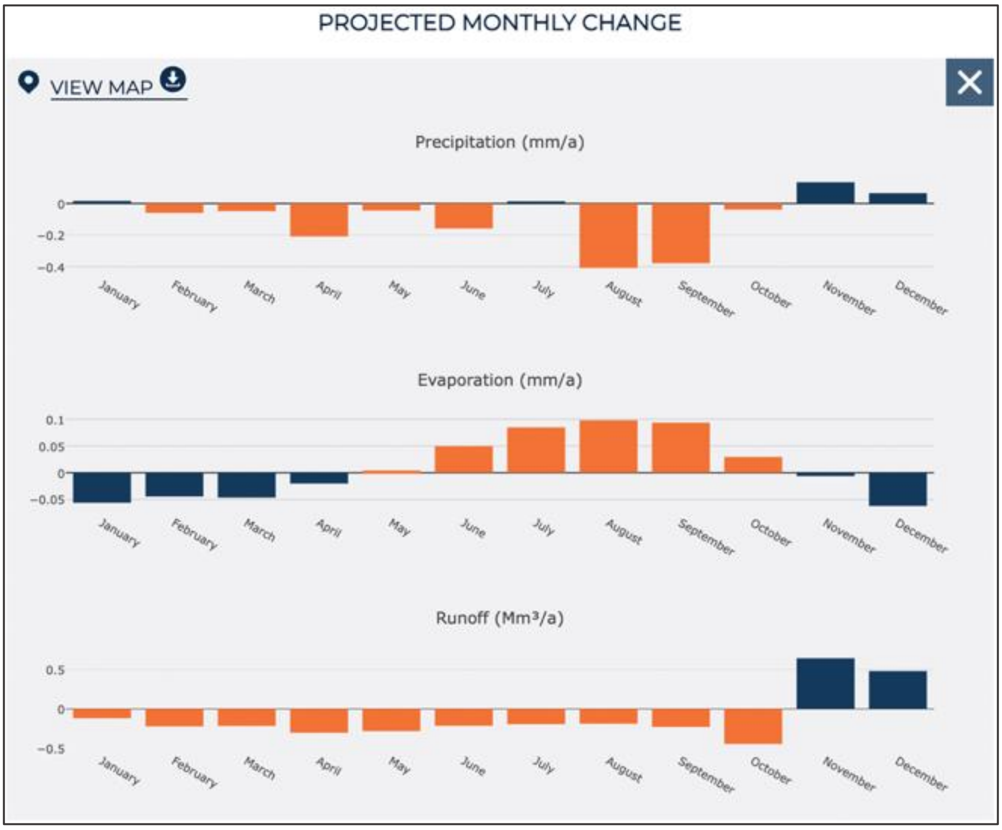


Figure 130: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, due to changes in multiple factors that give rise to water supply vulnerability by 2050, the City of Tshwane's future relative water supply vulnerability (as a ratio of demand and supply) is likely to rise under a medium population growth future (CSIR and Aurecon 2019).

Figure 131: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019

WRI's Aqueduct Water Risk Index's localized projection of future climate change related water risk for the City of Tshwane municipality notes that the projected change in water stress between the present and 2040 is "extremely high," with a change (increase in stress) of between >80% relative to the current baseline, under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*1.8 times*" change in water stress.

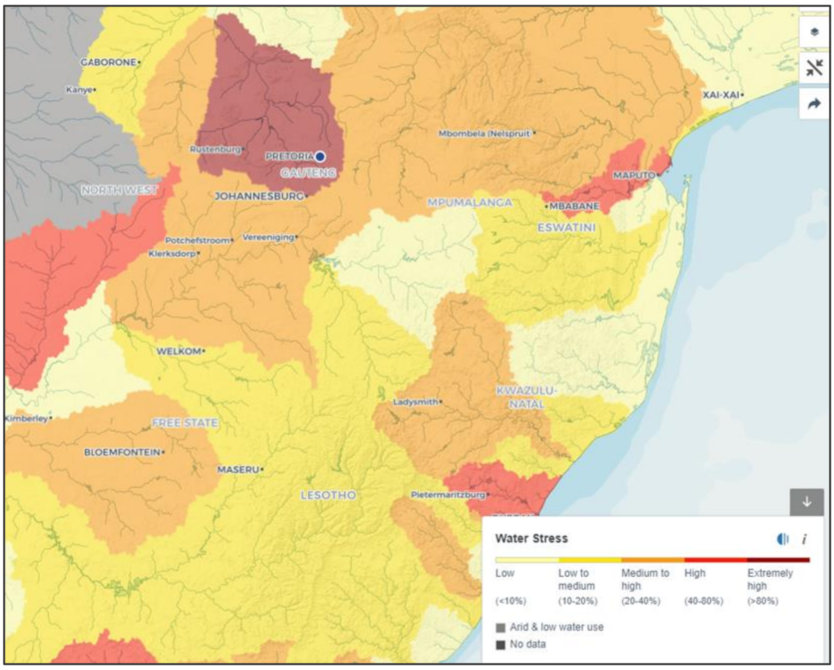


Figure 132: Extremely high projected water stress in the City of Tshwane in the year 2040 (Source: WRI)

3.7 eThekwini Metropolitan Municipality

eThekwini municipality is located inland in Kwa-Zulu Natal province and includes the city of Durban. Historically, its climate has been classified as being warm and temperate under the Köppen-Geiger climate classification system (CSIR 2015), with warm and humid summers.

Historic climate

The historic average maximum and minimum temperatures for eThekwini show little variation between 1979 and 2000 (Figure 133 and Figure 134).

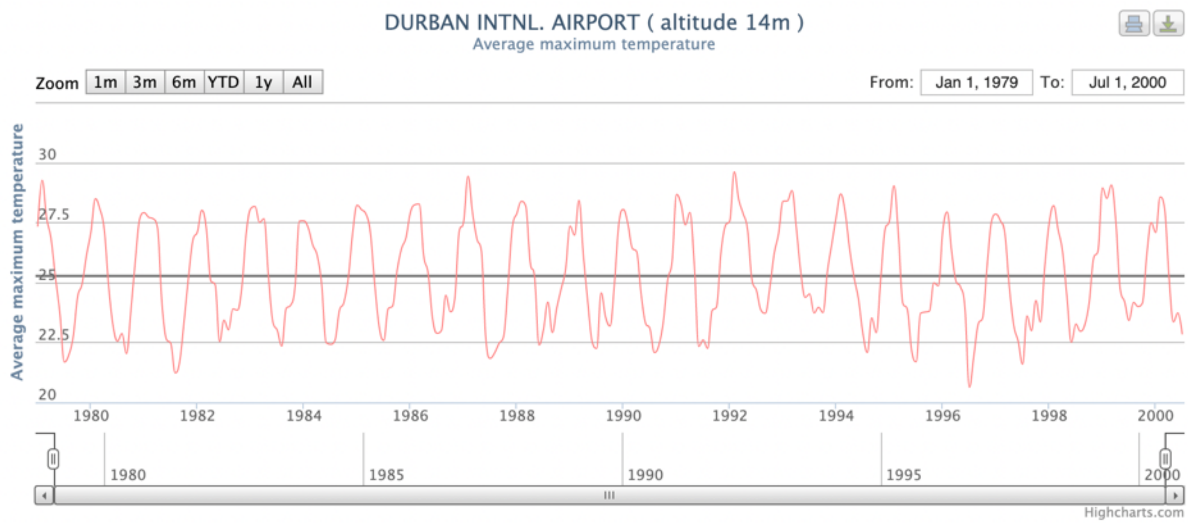


Figure 133: Historic average maximum temperature (available only from January 1979 to July 2000) for the eThekwini Metropolitan Municipality[42]

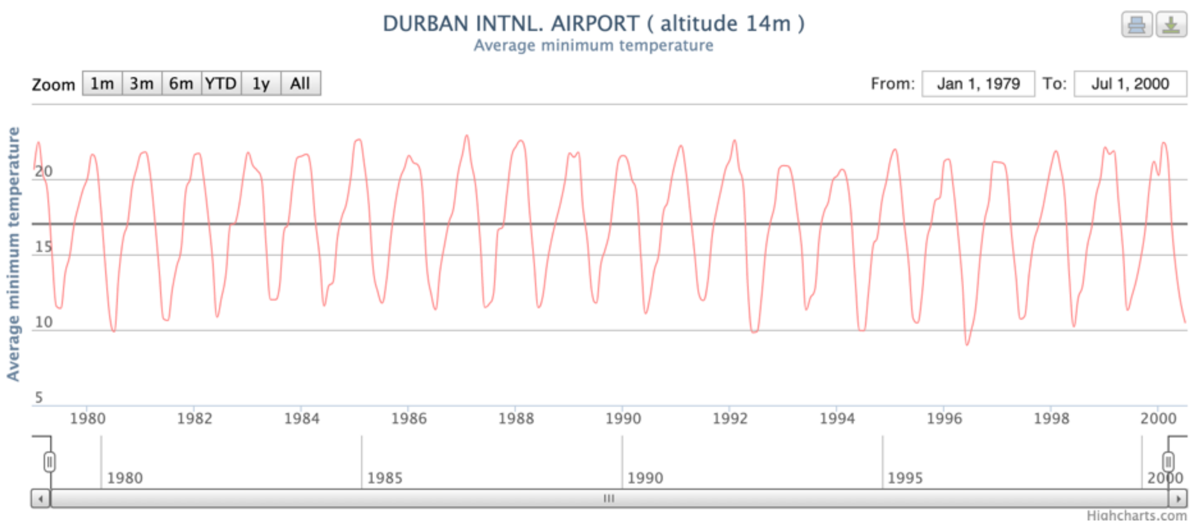


Figure 134: Historic average minimum temperature (available only from January 1979 to July 2000) for the eThekwini Metropolitan Municipality[43]

[42] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[43] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

Historic total monthly rainfall between 1979 and 2000 for the city is varied with the highest occurring in 1996 (Figure 135).

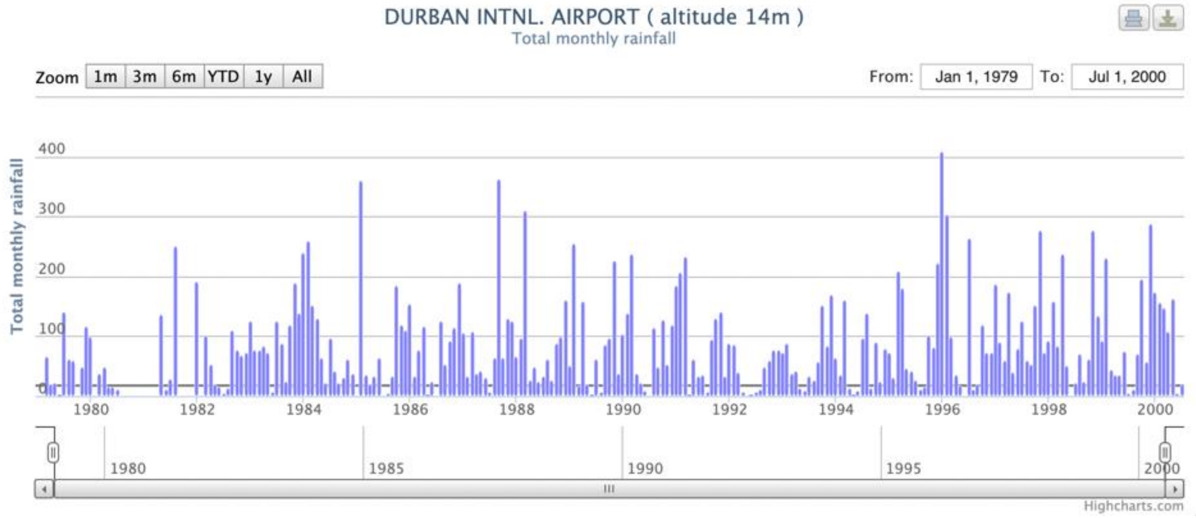


Figure 135: Historic total monthly rainfall (available only from January 1979 to July 2000) for the eThekwini Metropolitan Municipality[44]

The longest mean dry spell durations (greater than 30 days) for the eThekwini Metropolitan Municipality occurred in 1993 and 1999 (Figure 136).

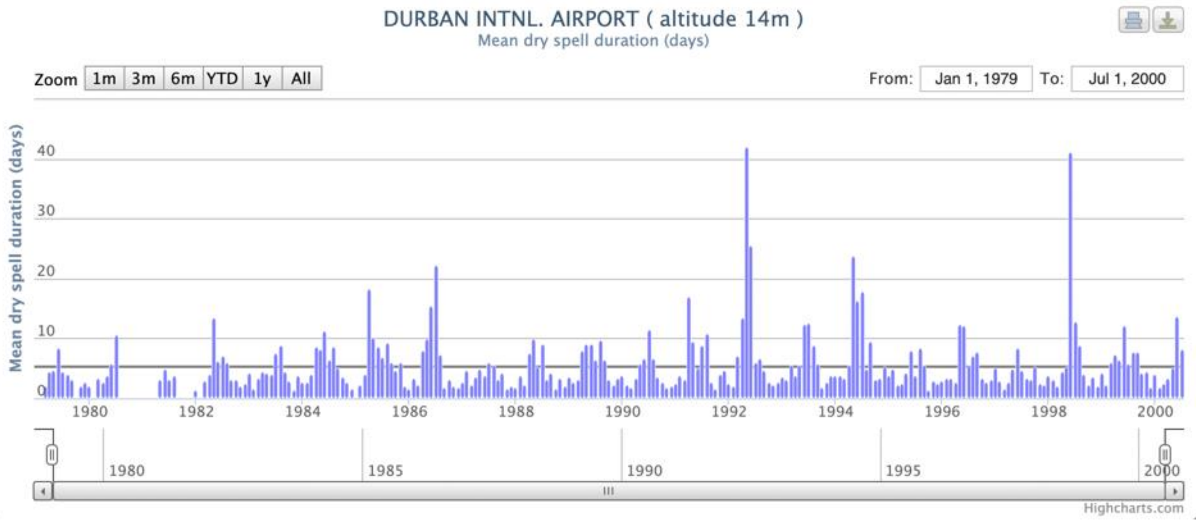


Figure 136: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for the eThekwini Metropolitan Municipality[45]

Current climate and water resources

As depicted in Figure 137, eThekwini's current average annual temperature is approximately 20-22°C and current annual average rainfall is 2000-2400 mm (CSIR and Aurecon 2019).

[44] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

[45] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

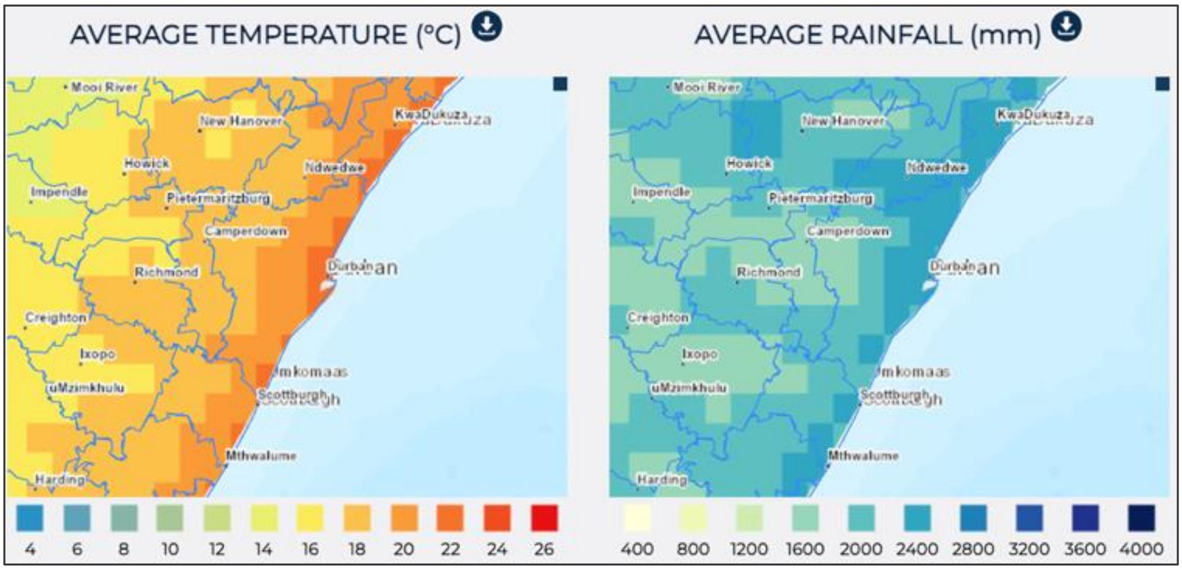


Figure 137: eThekwini's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality already faces a deficit and thus is experiencing vulnerability (CSIR and Aurecon 2019), as reflected in Figure 138.

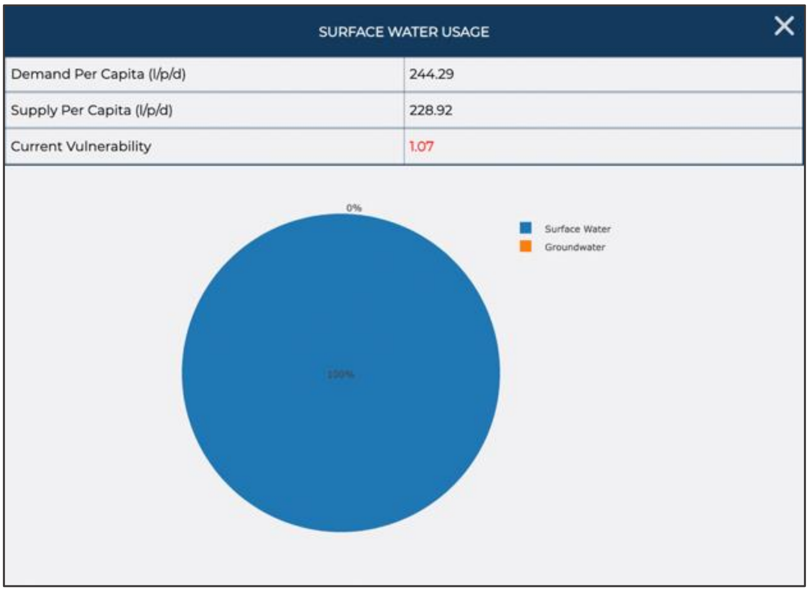


Figure 138: Present-day water availability in eThekwini municipality (Source: CSIR, Greenbook, 2019)

Figure 139 indicates that the municipality is not dependent on groundwater (except for a small pocket towards its northern edge) at the moment, and it has extremely high groundwater recharge potential in most areas (CSIR and Aurecon 2019).

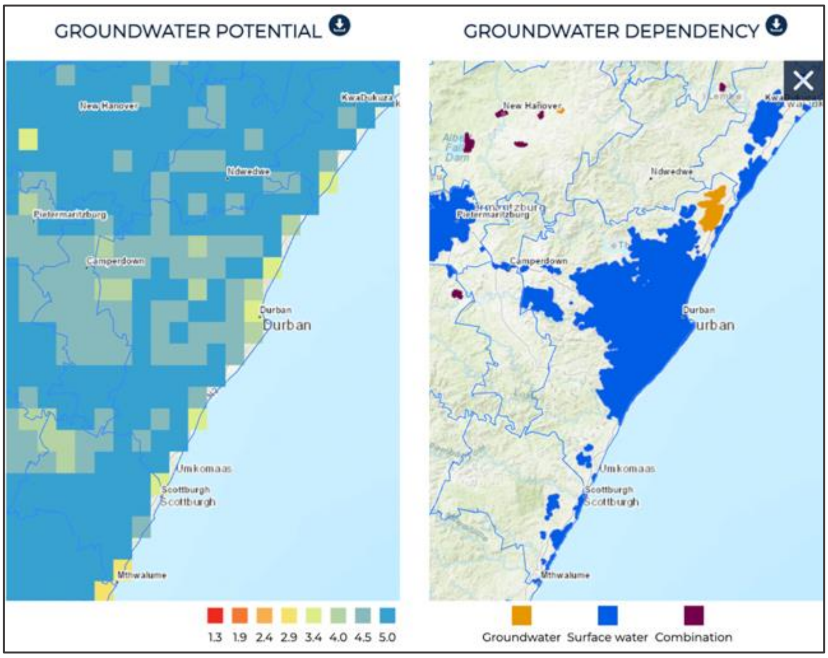


Figure 139: Groundwater recharge potential (left) and groundwater dependency (right) in eThekwini municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are meeting most of the municipality's needs at the moment (CSIR and Aurecon 2019).

Figure 140: Surface water indices in eThekwini under the current climate (Source: CSIR, Greenbook, 2019)

Under the current climate, eThekwini does not face drought risk (Figure 141) relative to some other regions of the country.

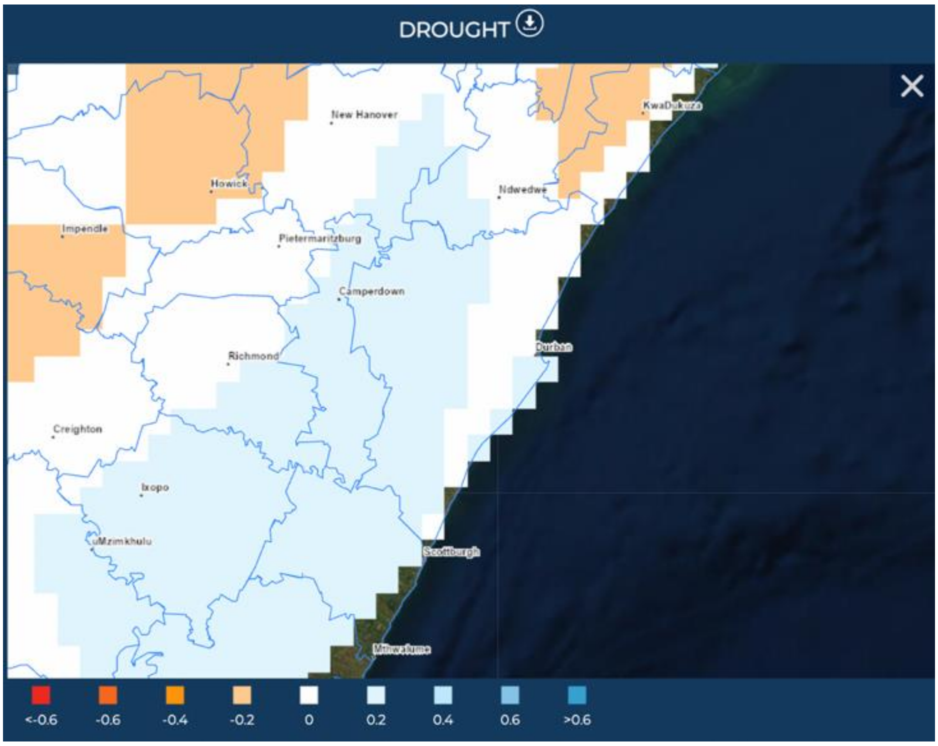


Figure 141: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario (RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP's first phase) from 2011 – 2040, eThekwini is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- 3% increase in mean annual precipitation (many models agree on the increase, with a few models also agreeing about a decrease both in the number of dry spells and the length of the longest dry spells).
- 0% change in aridity
- 0% change in annual mean soil moisture
- 4% increase in annual mean water discharge (including an increase of maximum annual discharge in the 2-year, 5-year, 10-year, and 50-year return periods, with a few models agreeing on a decrease in minimum annual discharge)
- 4% increase in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, eThekwini will experience a temperature rise of up to 1.92°C (CSIR and Aurecon 2019).

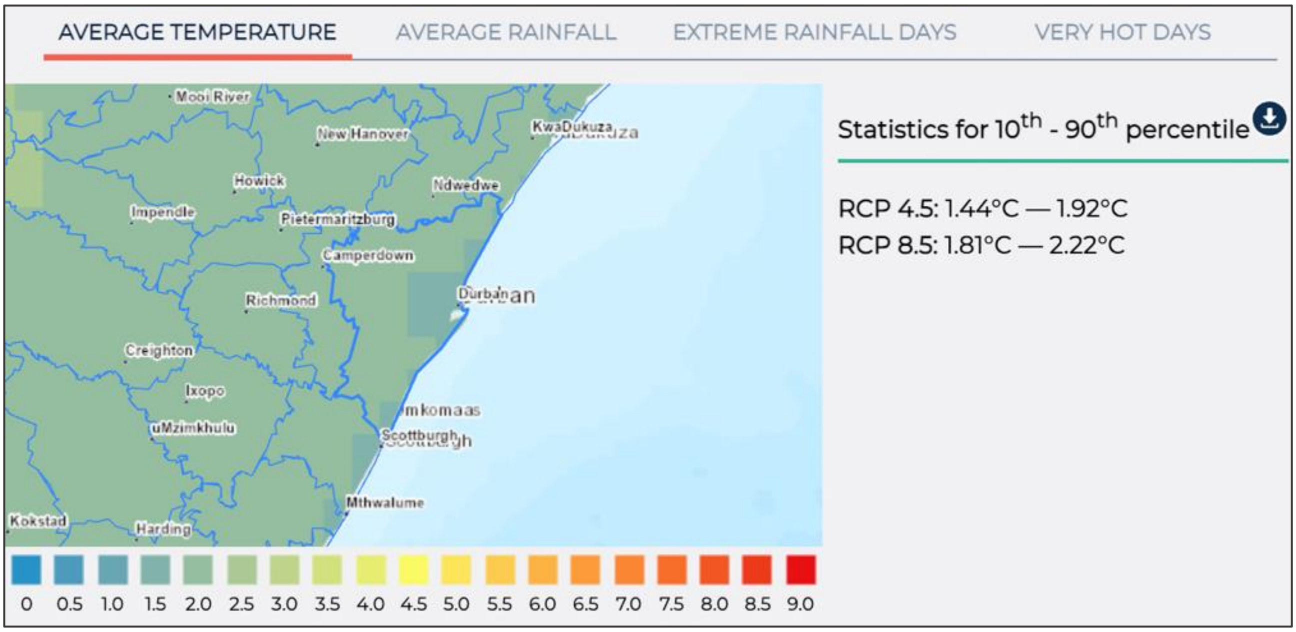


Figure 142: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Figure 143 and Figure 144 show a clear increase in future average maximum and minimum temperature projections for 2030 to 2050 (RCP4.5).

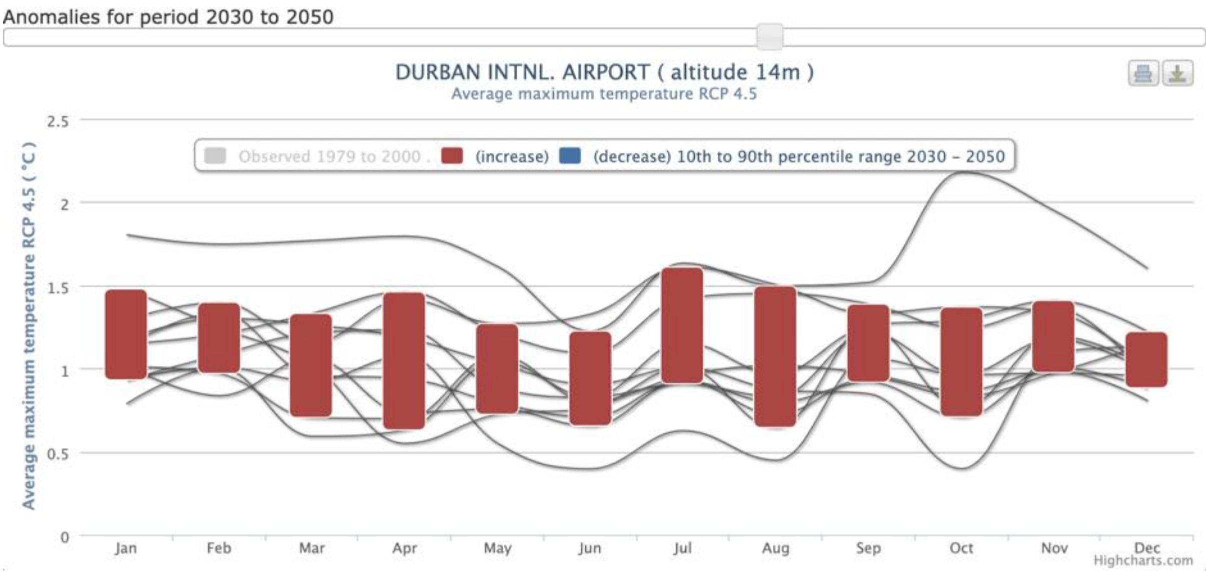


Figure 143: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the eThekwini Metropolitan Municipality[46]

[46] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

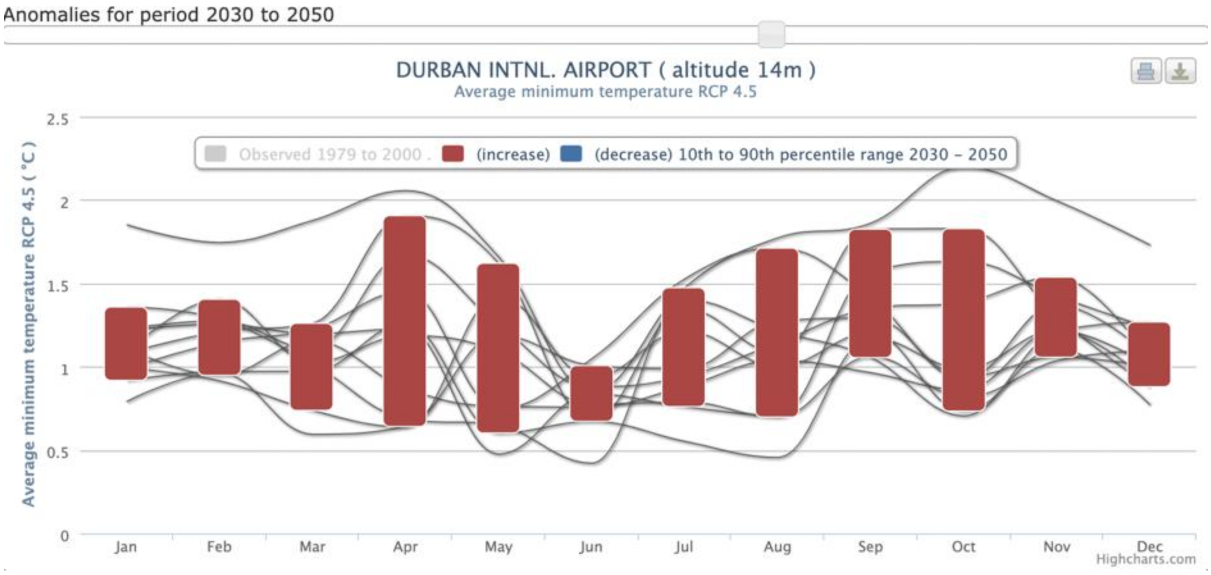


Figure 144: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the eThekwini Metropolitan Municipality[47]

Average rainfall in 2050, under RCP 4.5, is expected to increase substantially, implicating a wetter future (CSIR and Aurecon 2019).

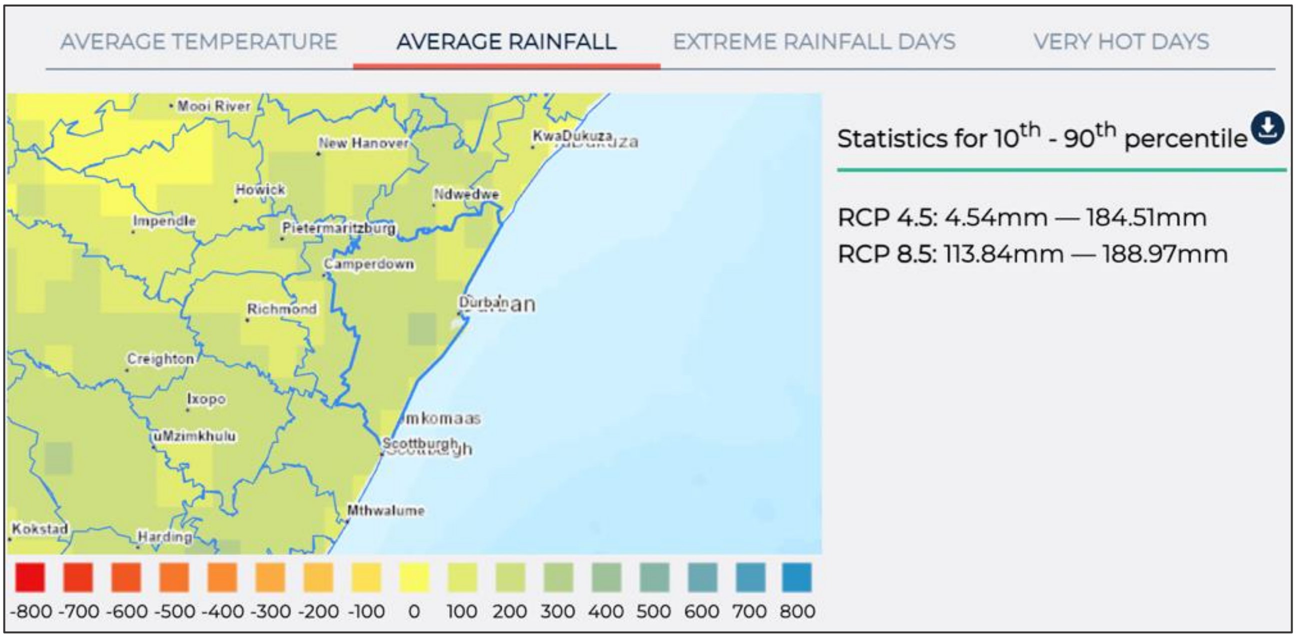


Figure 145: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The future monthly rainfall projections in Figure 146 is more variable but a slight decrease in rainfall is observed between 2030 and 2050 (RCP4.5).

[47] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

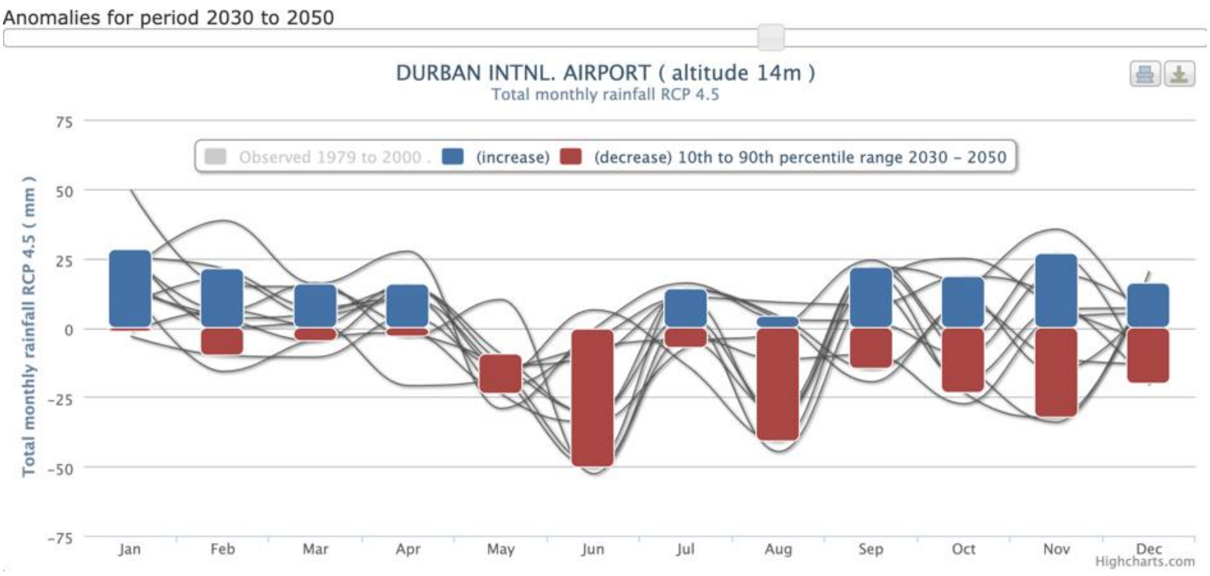


Figure 146: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the eThekwini Metropolitan Municipality[48]

There is some variability and range in projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019), with the possibility of decrease or increase of a few days.

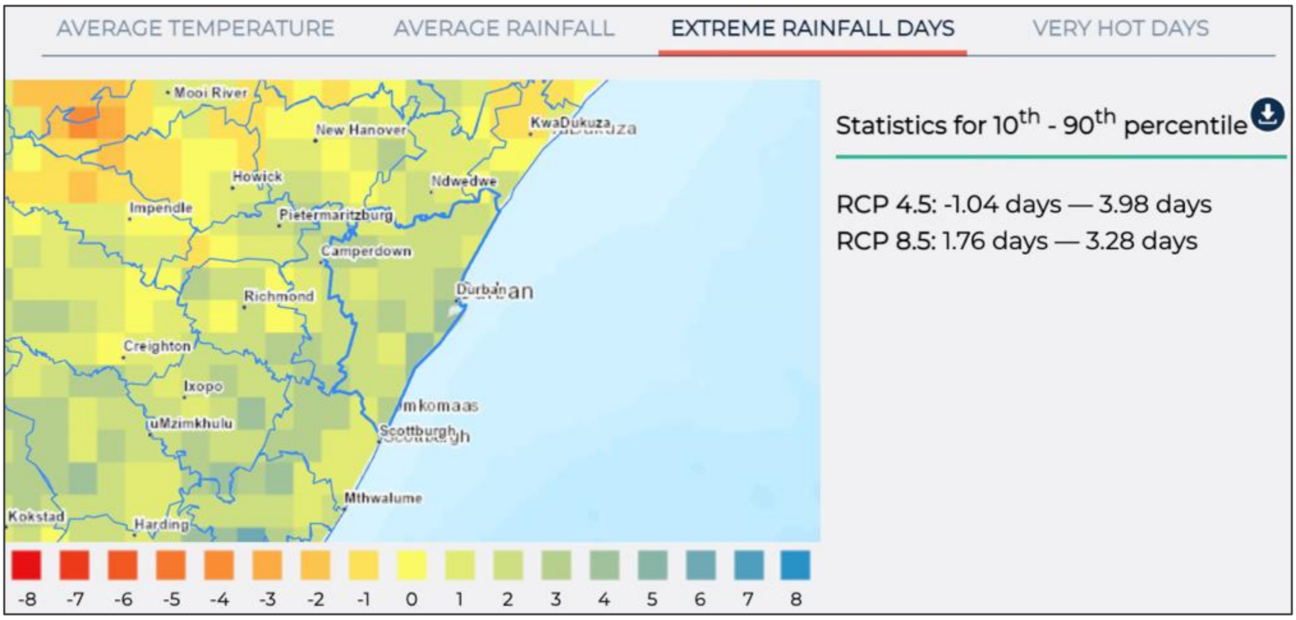


Figure 147: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality is likely to experience a small increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

[48] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

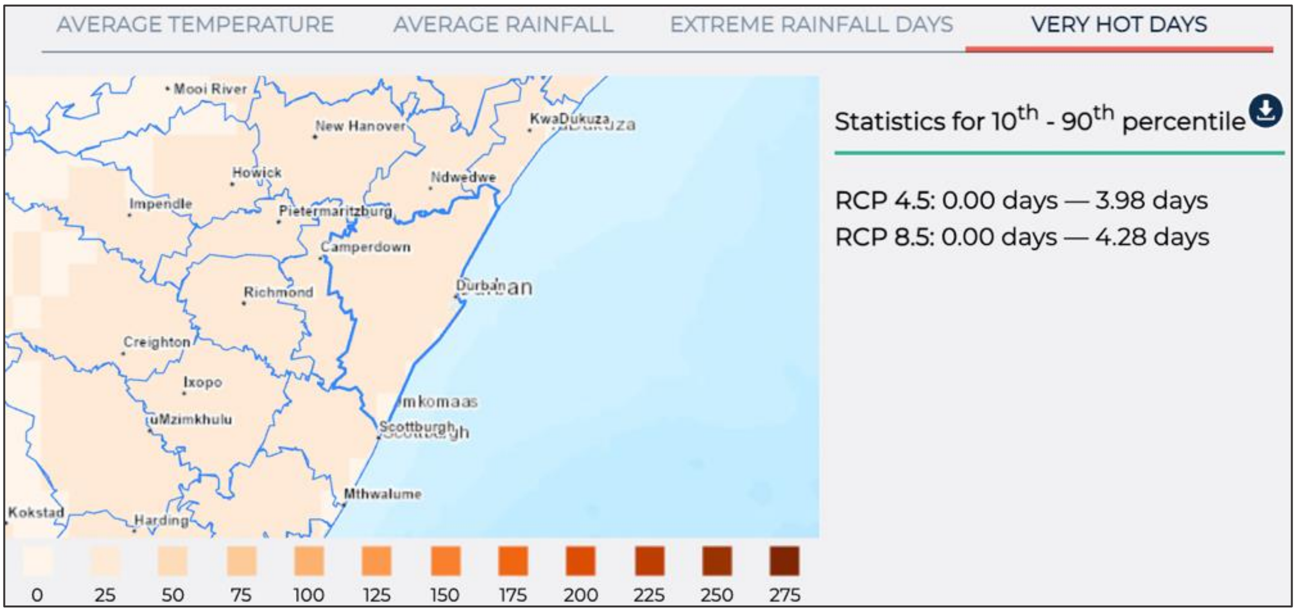


Figure 148: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Figure 149 shows slightly longer dry spells in the winter months and shorter dry spells in the summer months for the eThekwini Metropolitan Municipality between 2030 and 2050 (RCP4.5).

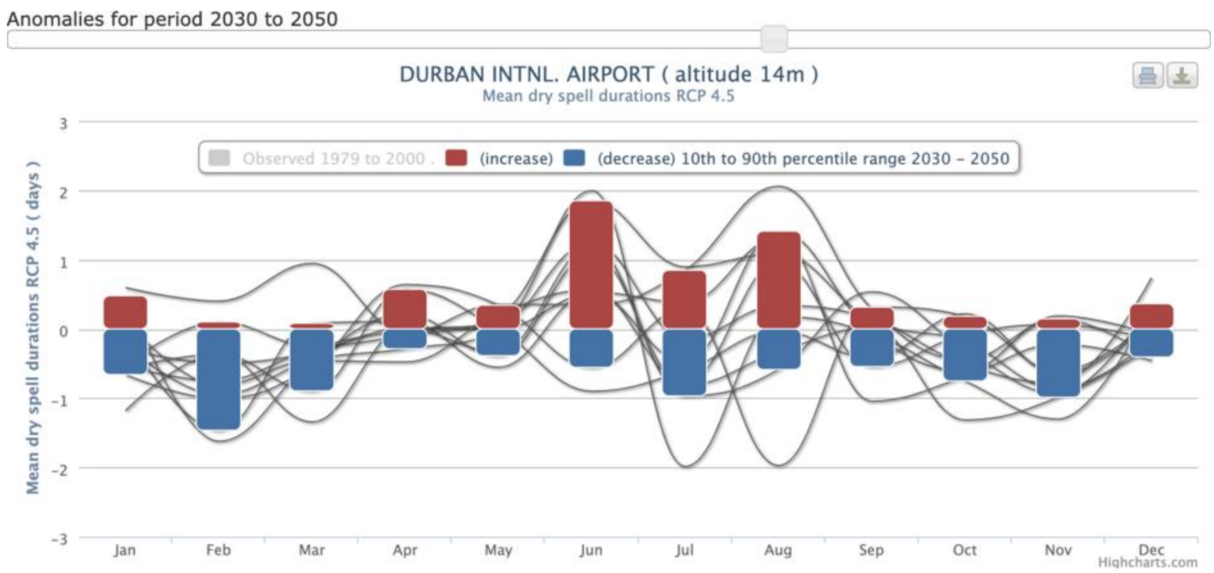


Figure 149: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the eThekwini Metropolitan Municipality[49]

Future drought risk in eThekwini in 2050 is not significant in terms of the SPI drought index, but there may be a medium level of increase in drought tendency across much of the municipality (CSIR and Aurecon 2019).

[49] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

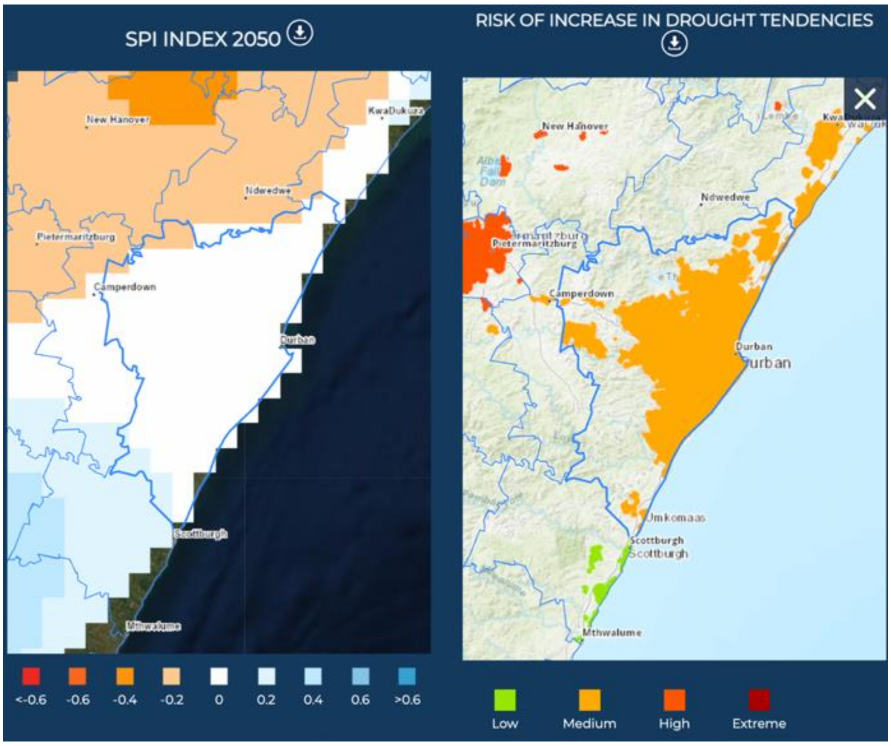


Figure 150: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential may remain stable or increase marginally in different parts of eThekwini by 2050. However, given that the municipality does not depend on groundwater, its groundwater depletion risk is not material (except for the small pocket in the north that faces medium levels of depletion risk).

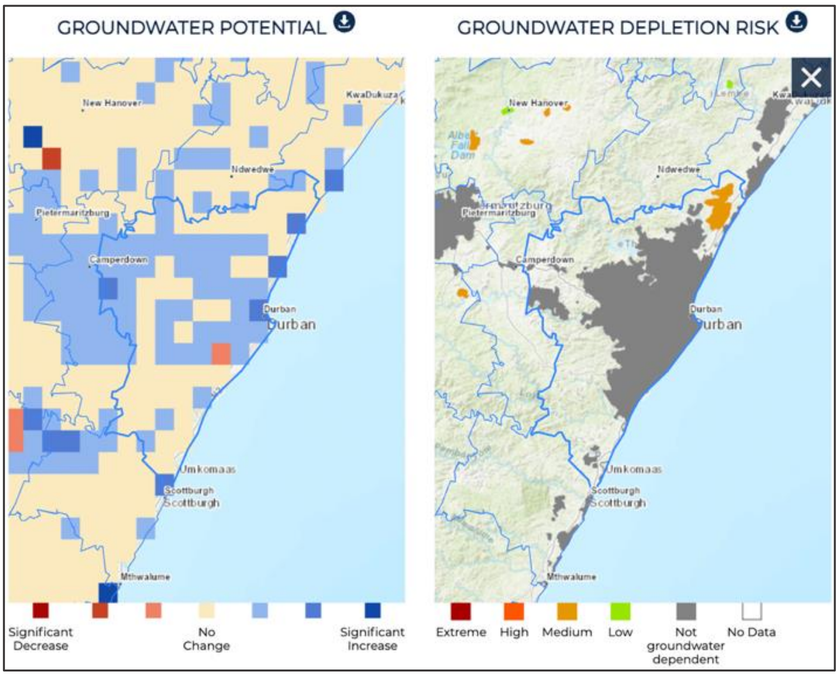


Figure 151: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show a mixed picture in terms of changes in precipitation, evaporation, and runoff.

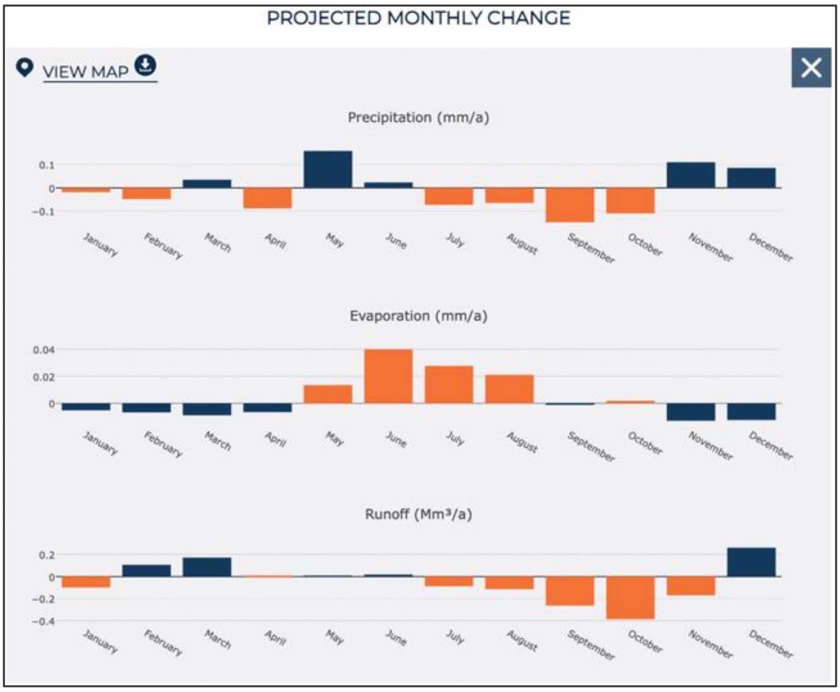
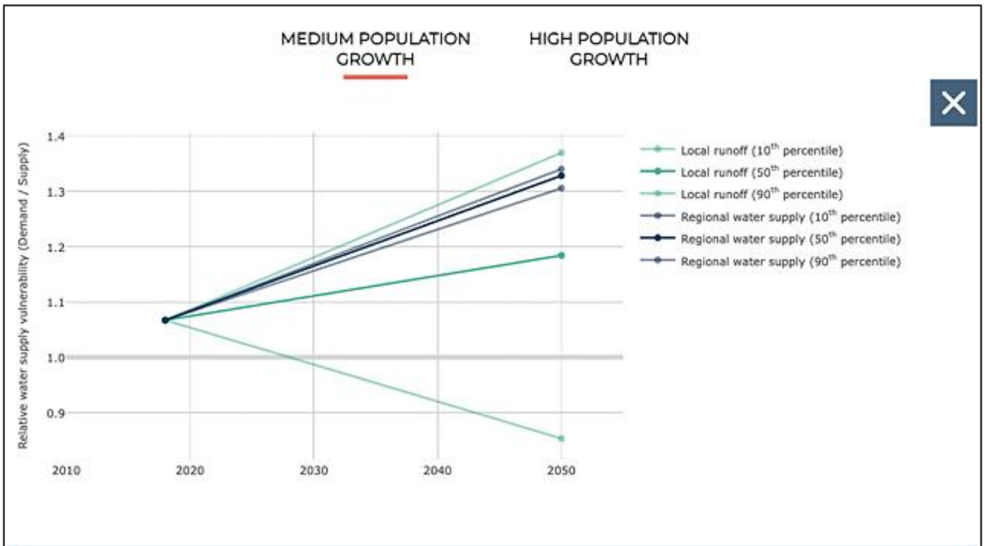


Figure 152: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, factoring in changes in multiple indicators that give rise to water supply vulnerability by 2050, eThekwini municipality's future relative water supply vulnerability (as a ratio of demand and supply) is likely to rise under a medium population growth future (CSIR and Aurecon 2019).



VULNERABILITY CONTRIBUTION FACTORS	PERCENTAGE CHANGE
Mean annual precipitation	3.12%
Mean annual evaporation	3.36%
Mean annual runoff	12.77%
Regional urban water supply	0.53%
Population growth	21.08%

Figure 153: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019

WRI's Aqueduct Water Risk Index's localized projection of future climate change related water risk for eThekwini municipality notes that the projected change in water stress between the present and 2040 is "extremely high," with a change (increase in stress) of more than 80% relative to the current baseline, under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*1.4 times*" change in water stress in the region.

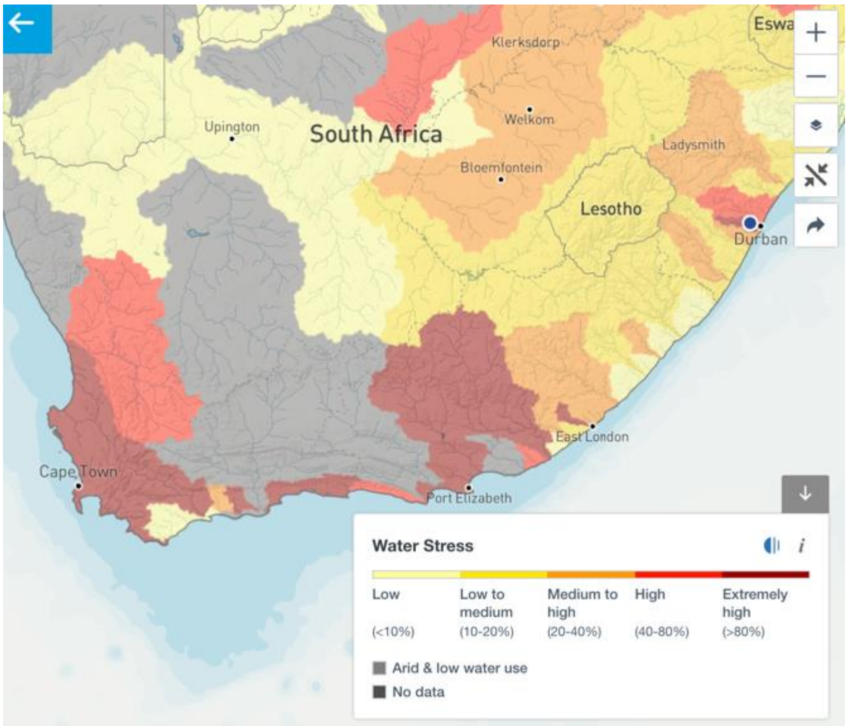


Figure 154: Extremely high projected water stress in eThekwini municipality in the year 2040 (Source: WRI)

3.8 Drakenstein Local Municipality

Drakenstein local municipality is located inland in the Western Cape province, in the winelands region of the country, including Paarl. Historically, its climate has been classified as being warm temperate climate under the Köppen-Geiger climate classification system (CSIR 2015), with warm and dry summers.

Historic climate

Figure 155 and Figure 156 show limited variation in average maximum and minimum temperatures for the municipality between 1979 and 2000.

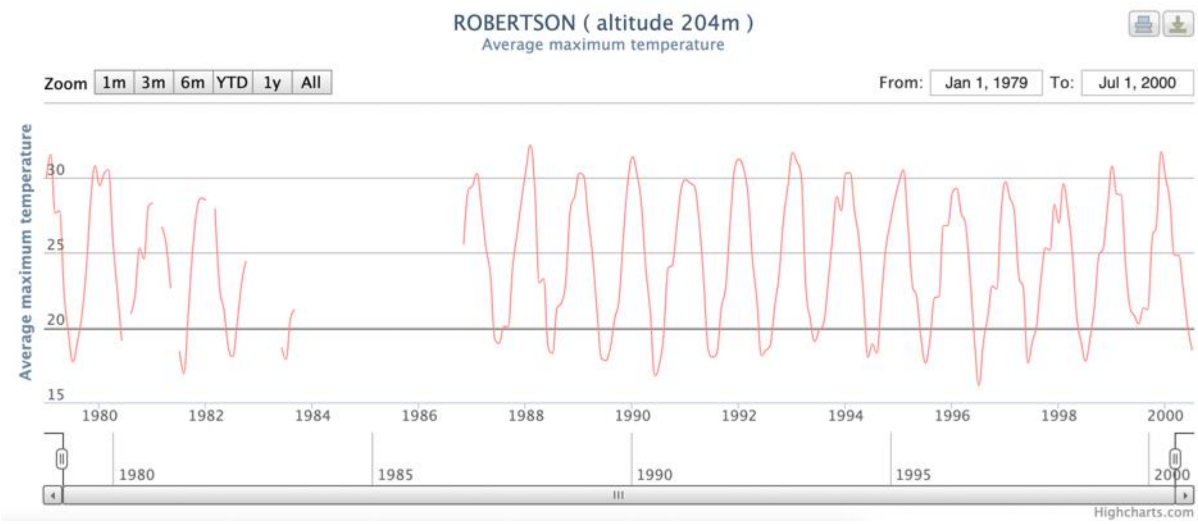


Figure 155: Historic average maximum temperature (available only from January 1979 to July 2000) for the Drakenstein Local Municipality[50]

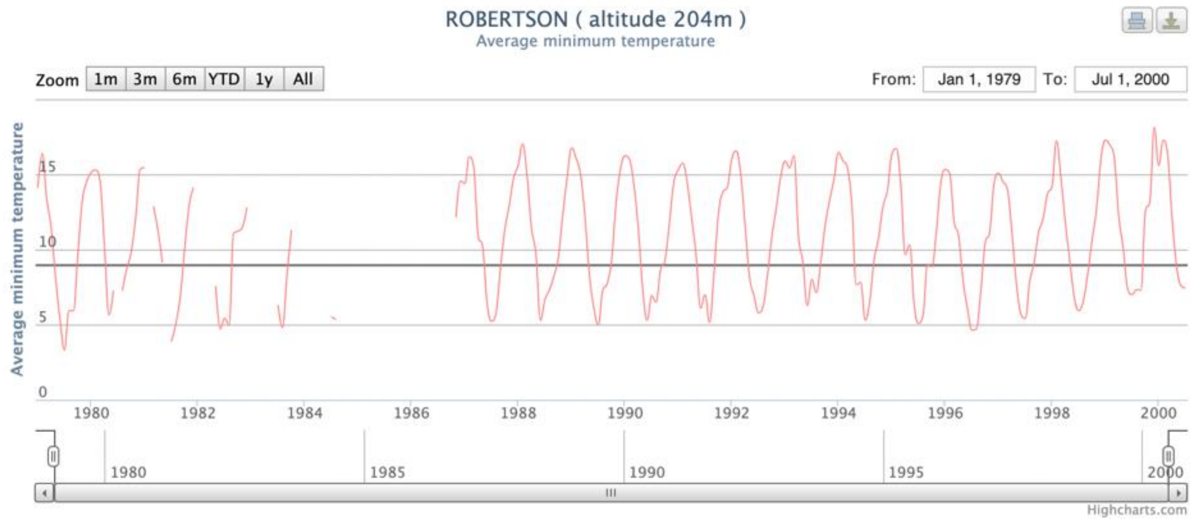


Figure 156: Historic average minimum temperature (available only from January 1979 to July 2000) for the Drakenstein Local Municipality[51]

Total monthly rainfall has tended to be below 100mm between 1979 and 2000 in Drakenstein with the highest occurring in 1999 (greater than 200mm) (Figure 157).

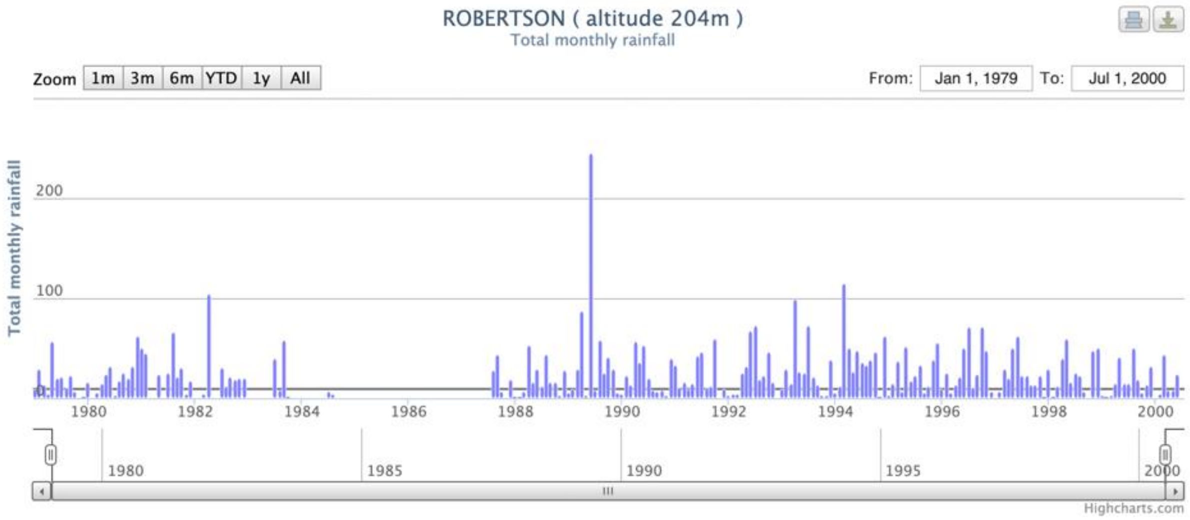


Figure 157: Historic total monthly rainfall (available only from January 1979 to July 2000) for the Drakenstein Local Municipality[52]

The longest historic mean dry spell duration for the Drakenstein Local Municipality occurred in 1981 (30 days) with most dry spells being below 15 days in duration between 1979 and 2000 (Figure 158).

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50 Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

51 Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

52 Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

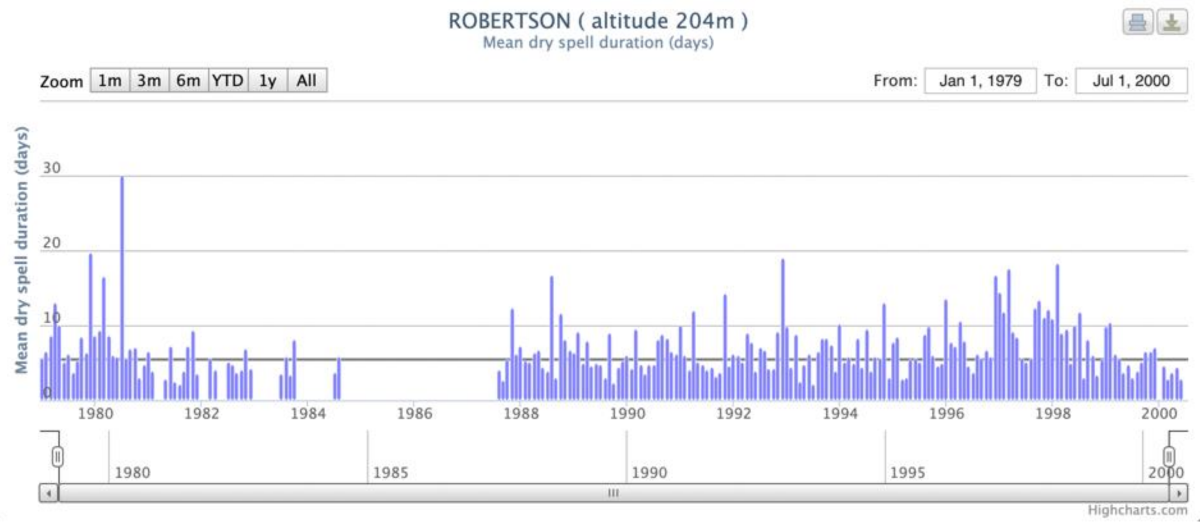


Figure 158: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for the Drakenstein Local Municipality[53]

Current climate and water resources

As depicted in Figure 159, Drakenstein Municipality's current average annual temperature is approximately 16-18°C (closer to 20°C in the north) and current annual average rainfall is 800-1200 mm (CSIR and Aurecon 2019).

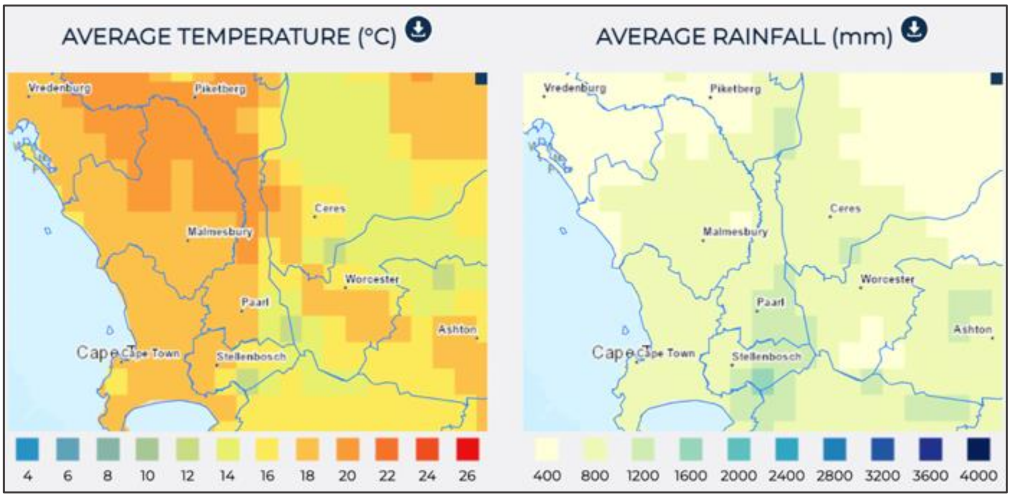


Figure 159: Drakenstein Municipality's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality is not vulnerable and has a substantial surplus of water supply (CSIR and Aurecon 2019), as reflected in Figure 160.

[53] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

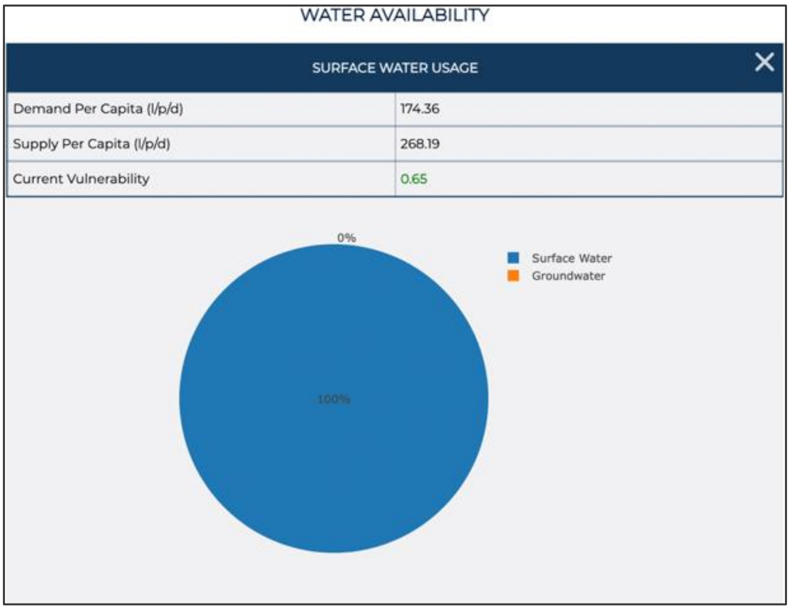


Figure 160: Present-day water availability in Drakenstein municipality (Source: CSIR, Greenbook, 2019)

Figure 161 indicates that the municipality is not dependent on groundwater at the moment, and it has moderate groundwater recharge potential in most areas (CSIR and Aurecon 2019).

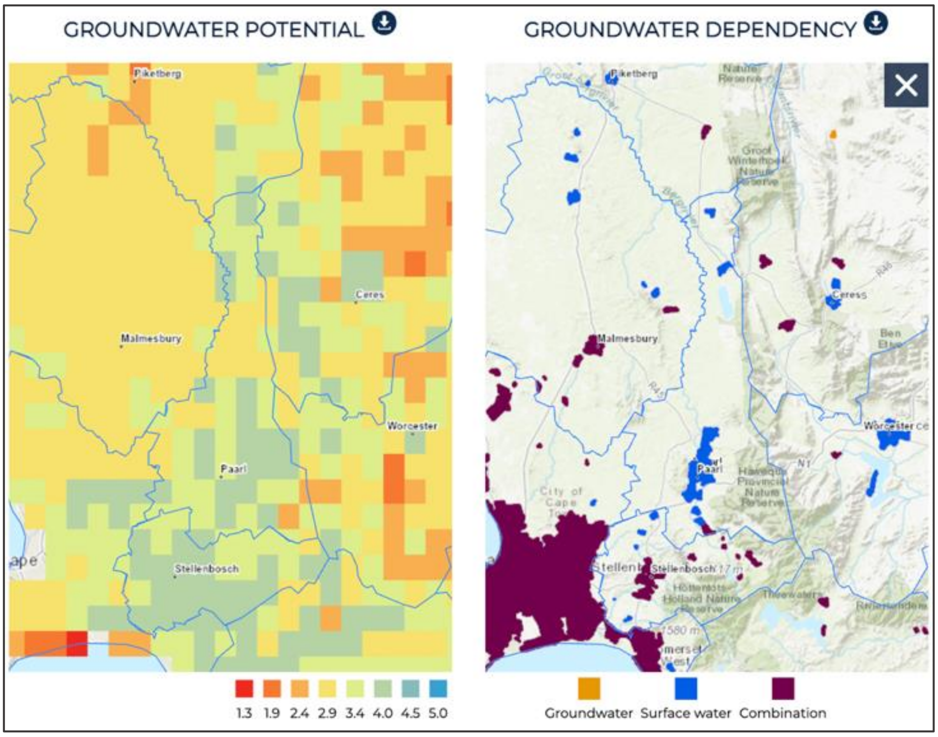


Figure 161: Groundwater recharge potential (left) and groundwater dependency (right) in Drakenstein municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are meeting all of the municipality's needs at the moment (CSIR and Aurecon 2019).

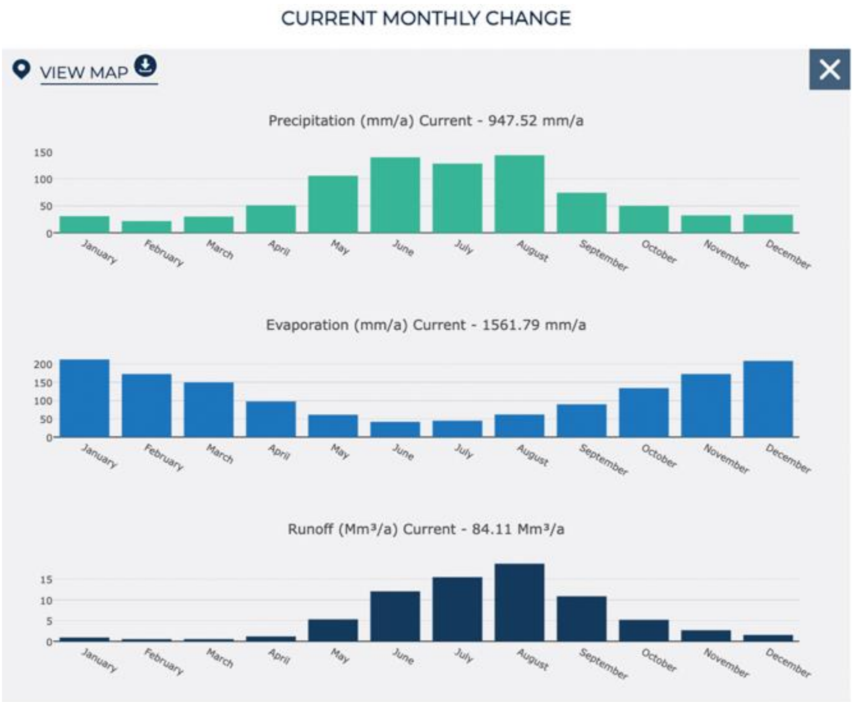


Figure 162: Surface water indices in Drakenstein Municipality under the current climate (Source: CSIR, Greenbook, 2019)

Despite this current abundance of water, under the current climate, Drakenstein municipality faces significant drought risk (Figure 163) relative to some other regions of the country, and has experienced drought in recent years.

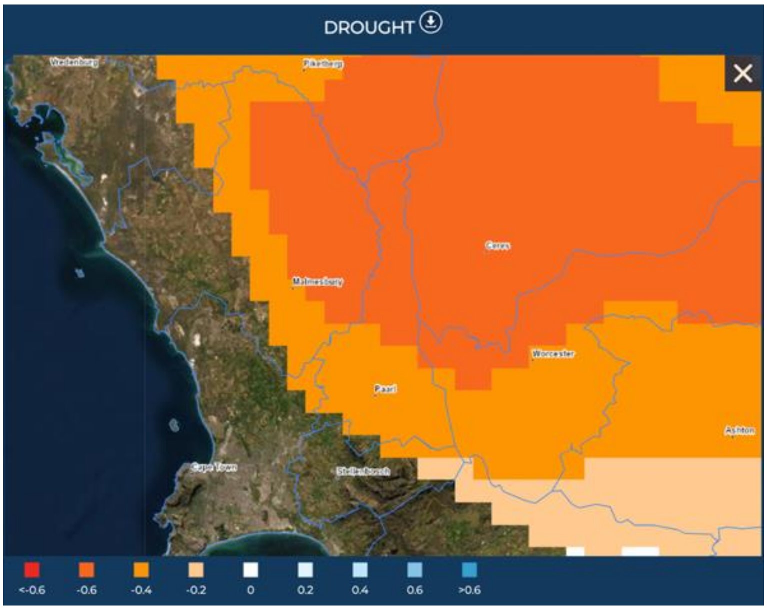


Figure 163: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario (RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP's first phase) from 2011 – 2040, Drakenstein municipality is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- -5% decrease in mean annual precipitation (many models agree on the decrease, with a few models also agreeing about both a decrease in the number of dry spells and a decrease in the length of the longest dry spell).
- 5% increase in aridity
- -11% decrease in annual mean soil moisture
- -6% decrease in annual mean water discharge (with a few models in agreement about the decrease in the 2-year, 5-year, 10-year, and 50-year return periods for annual maximum water discharge, as well as a decrease in maximum water discharge)
- -4% decrease in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, Drakenstein Municipality will experience a temperature rise of up to 2.12°C (CSIR and Aurecon 2019).

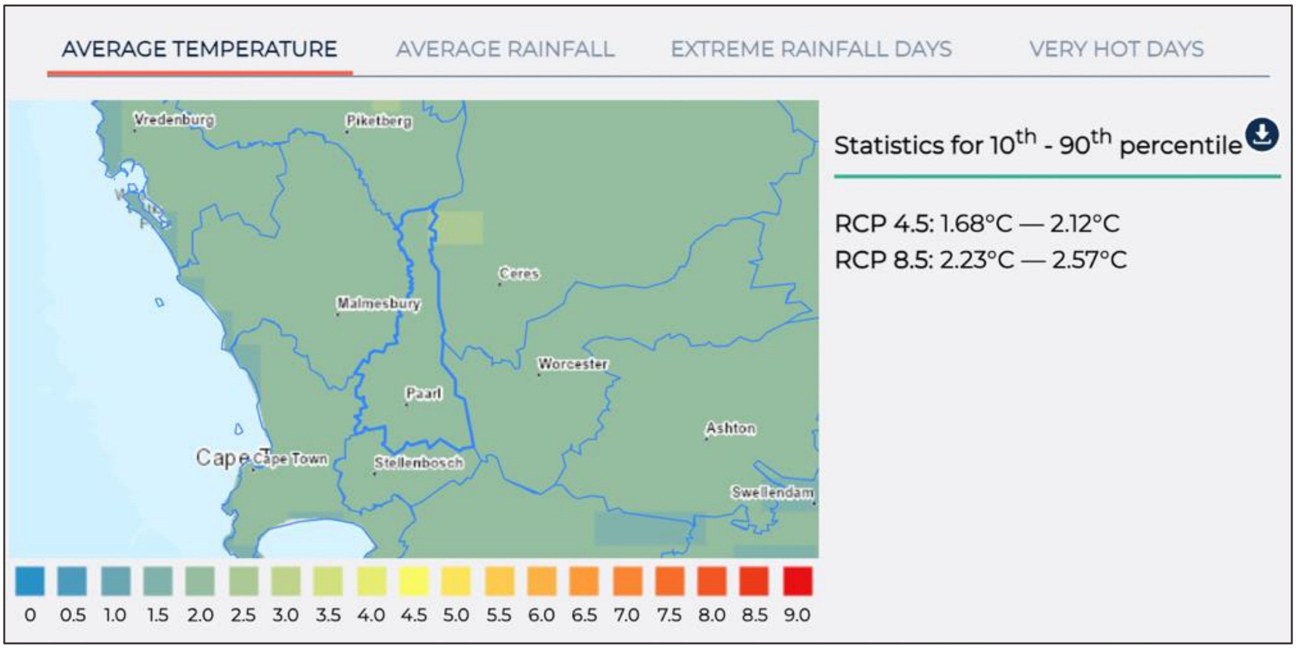


Figure 164: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

An observable rise in temperature can be seen in Figure 165 and Figure 166 which shows the municipality's future average maximum and minimum temperature projections for 2030 to 2050 (RCP4.5).

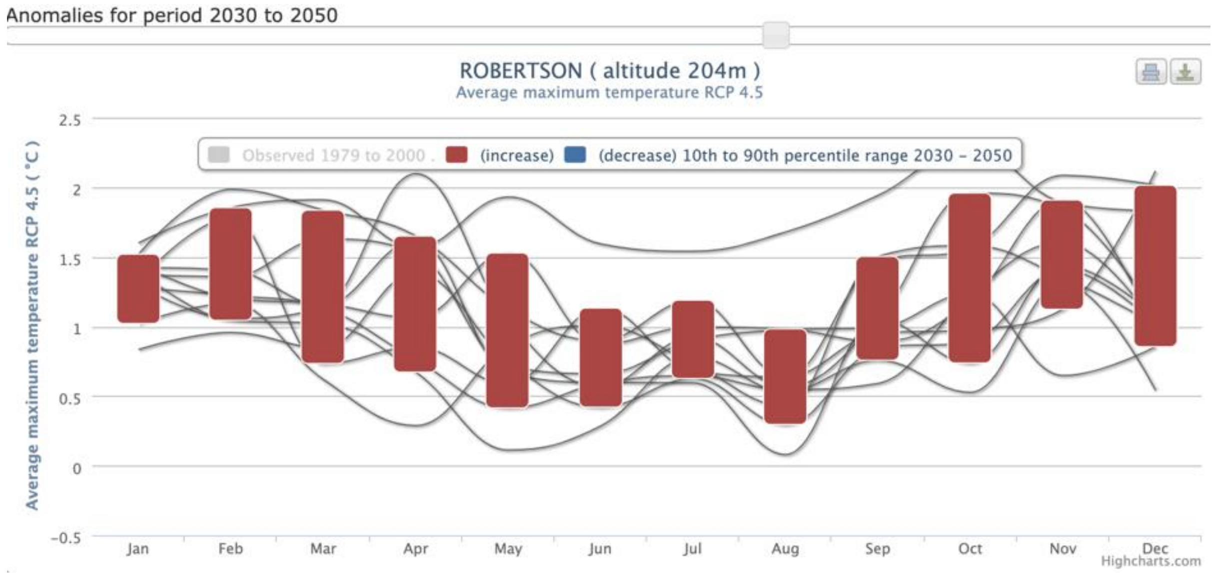


Figure 165: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the Drakenstein Local Municipality[54]

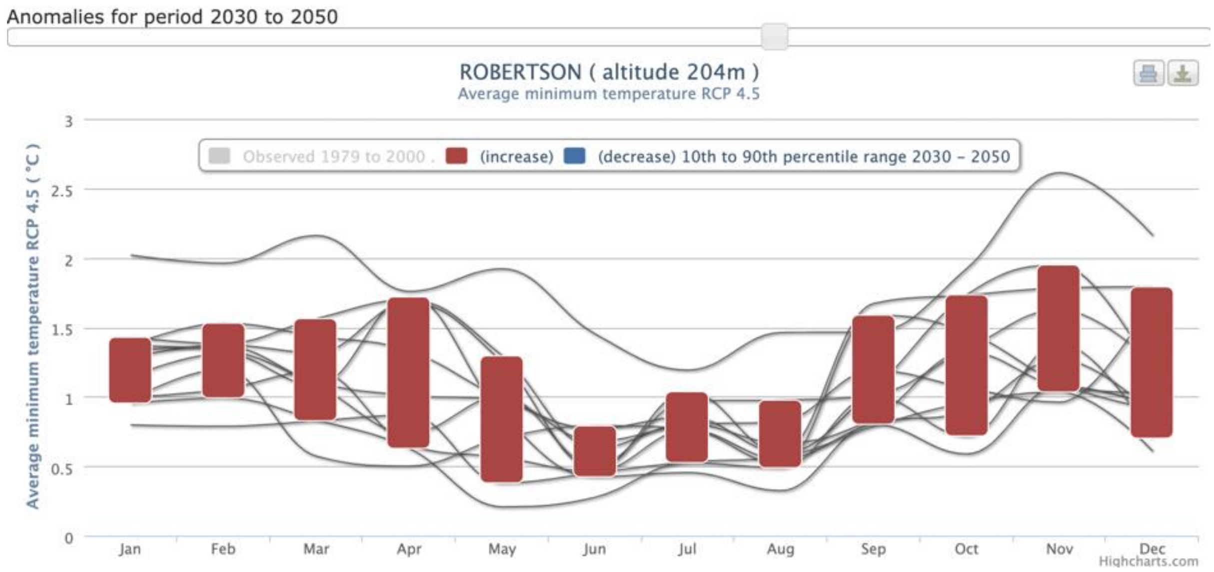


Figure 166: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the Drakenstein Local Municipality[55]

Average rainfall in 2050, under RCP 4.5, is expected to decrease significantly, implicating a drier future (CSIR and Aurecon 2019).

[54] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

[55] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

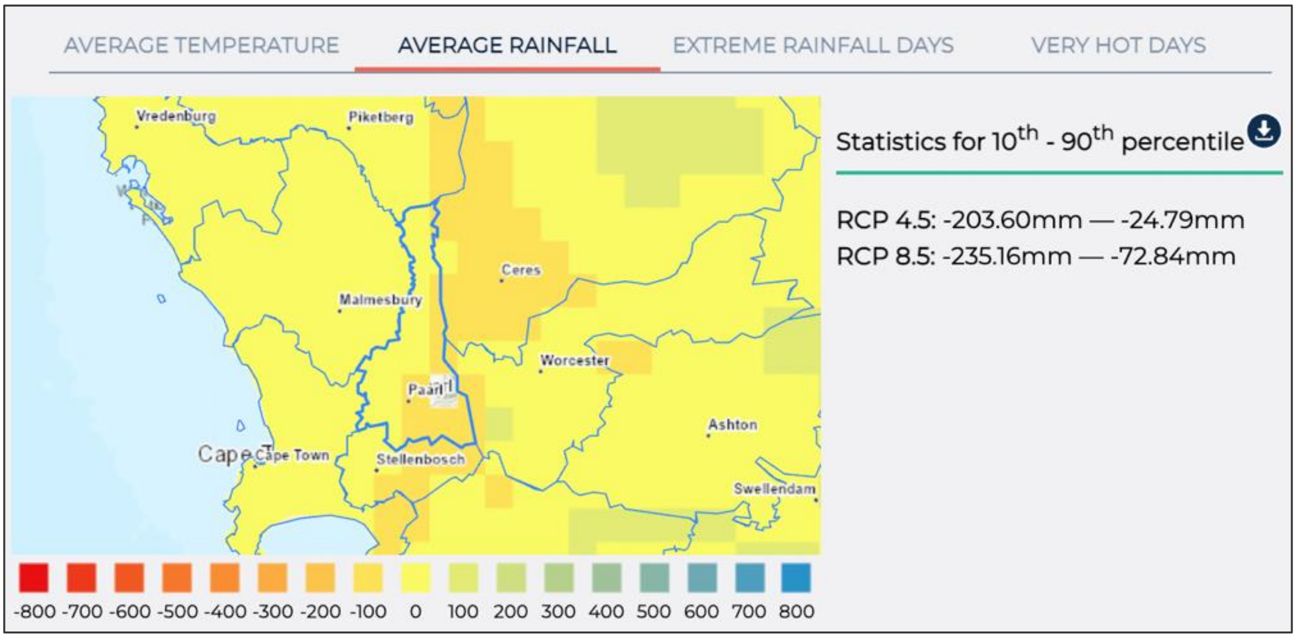


Figure 167: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

As can be seen in Figure 168, a relative decrease in rainfall is projected for the Drakenstein Local Municipality between 2030 and 2050 (RCP4.5).

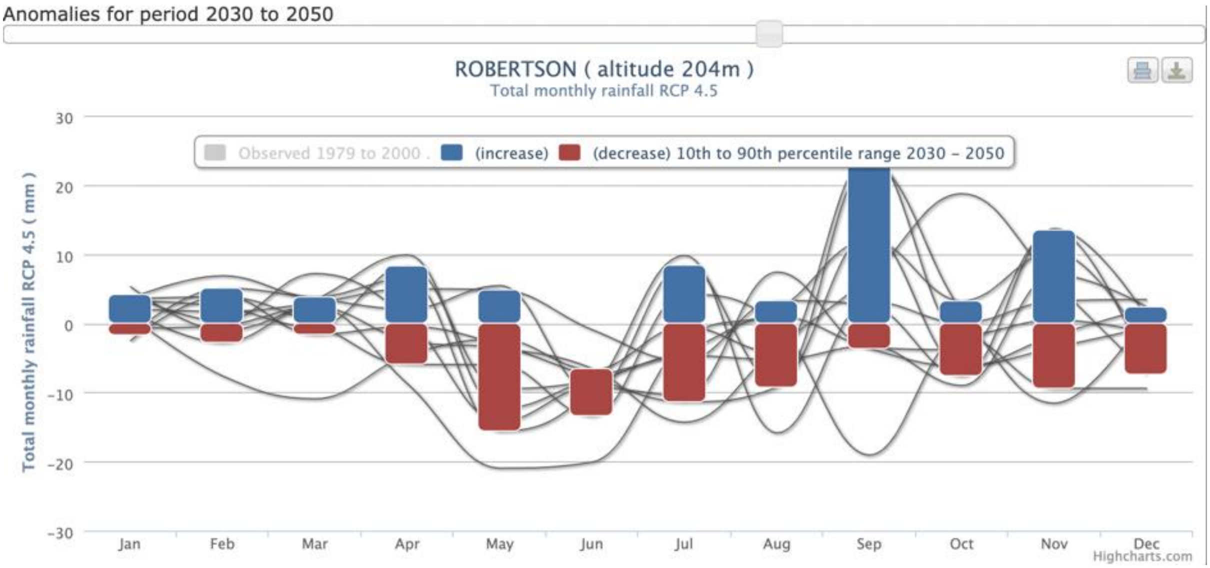


Figure 168: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the Drakenstein Local Municipality[56]

There is some variability and range in projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019), but the signal is predominantly a decreasing one.

[56] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

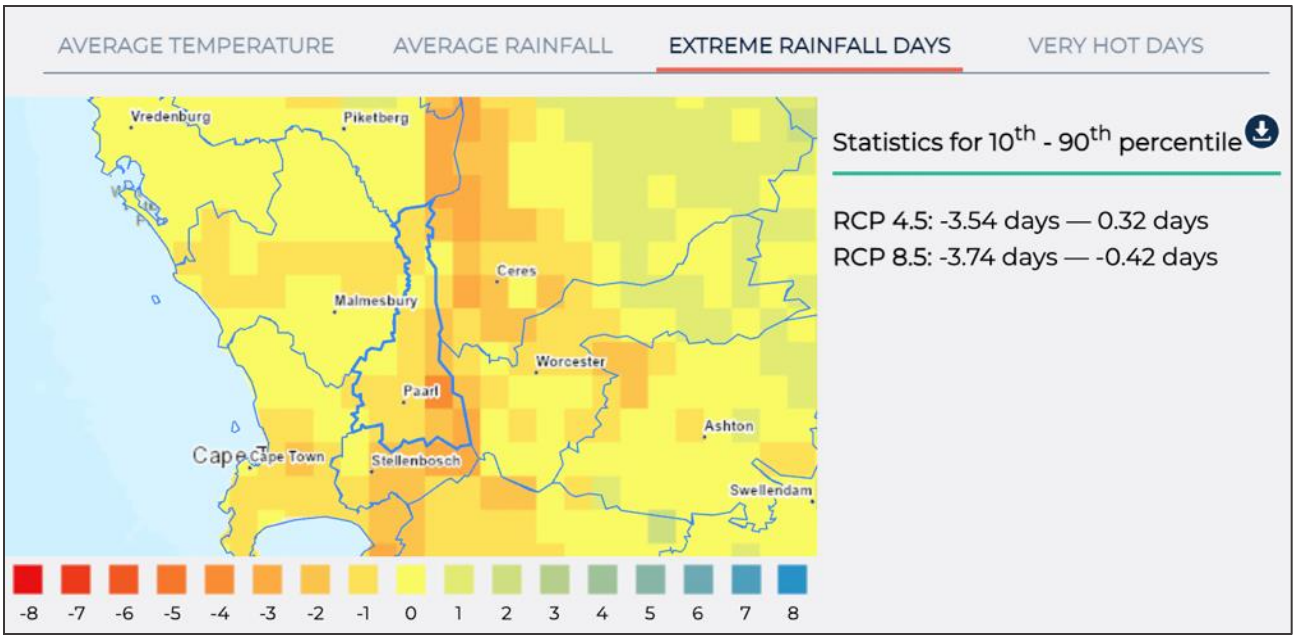


Figure 169: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality is likely to experience a significant increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

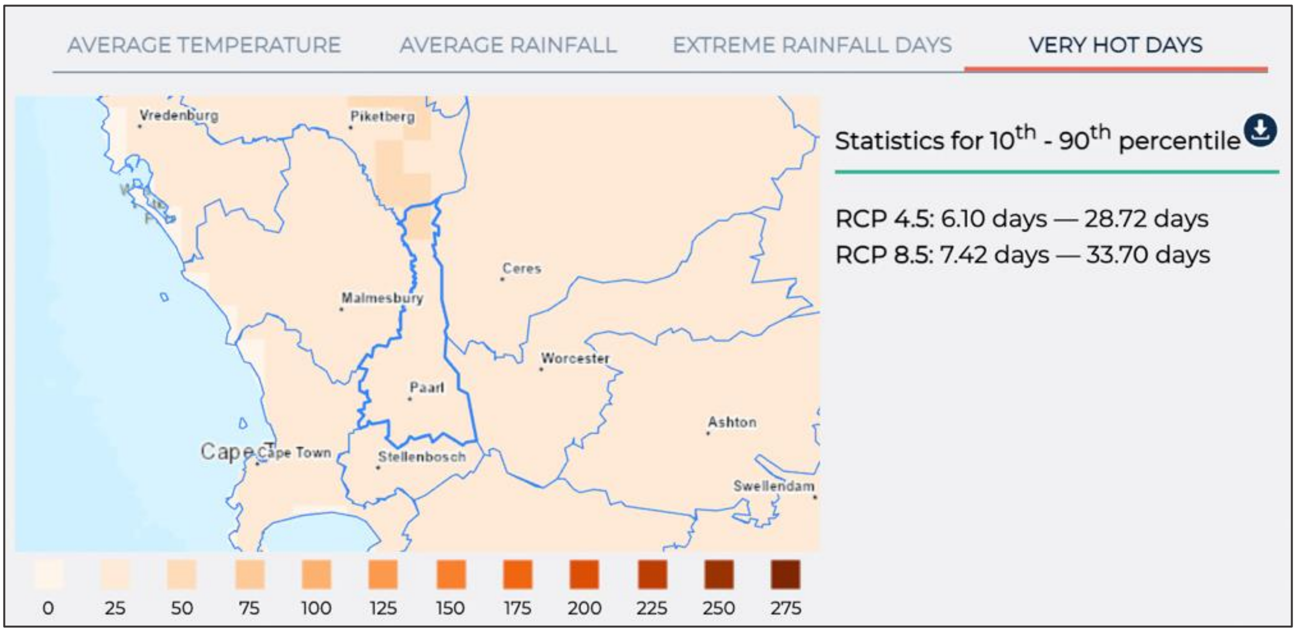


Figure 170: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

No discernible trend on length of dry spells could be observed for the municipality between 2030 and 2050 (Figure 171).

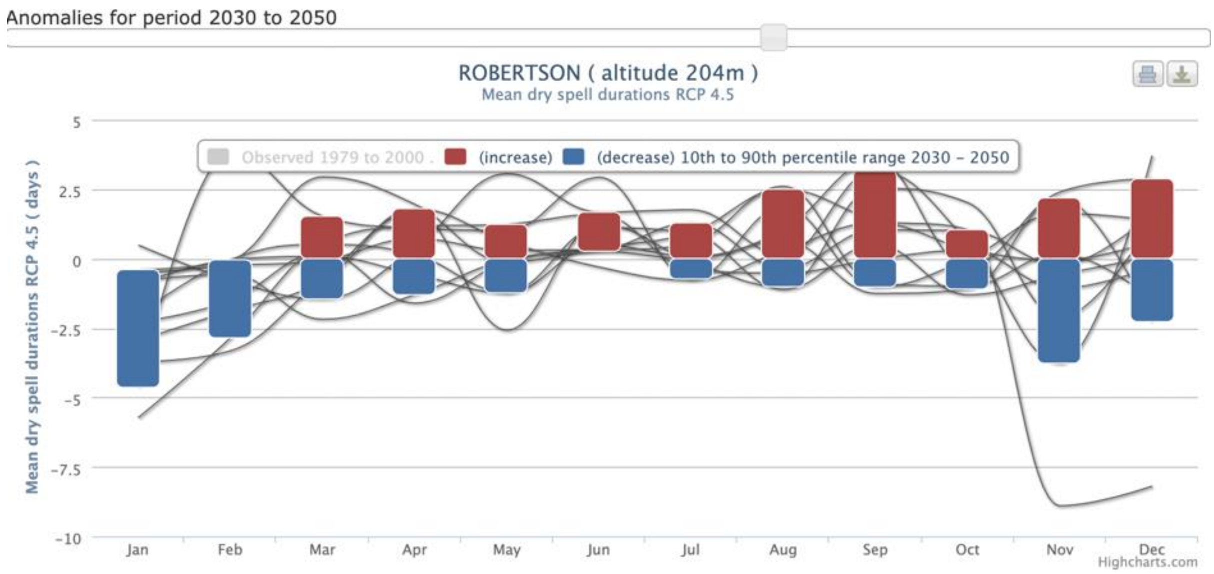


Figure 171: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the Drakenstein Local Municipality[57]

Future drought risk in Drakenstein municipality in 2050 is extremely high in terms of the SPI drought index. It is also likely to experience an extremely high rise in drought tendency in certain areas within the municipality (CSIR and Aurecon 2019).

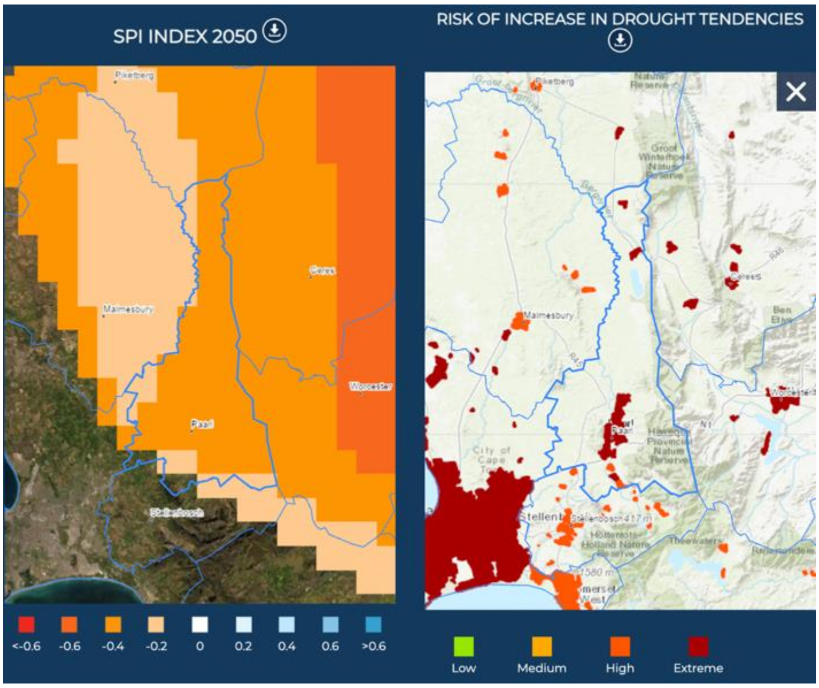


Figure 172: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential may remain the same or even grow in different parts of Drakenstein municipality by 2050. However, given that the municipality does not depend on groundwater, its groundwater depletion risk is not material for water supply vulnerability.

[57] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

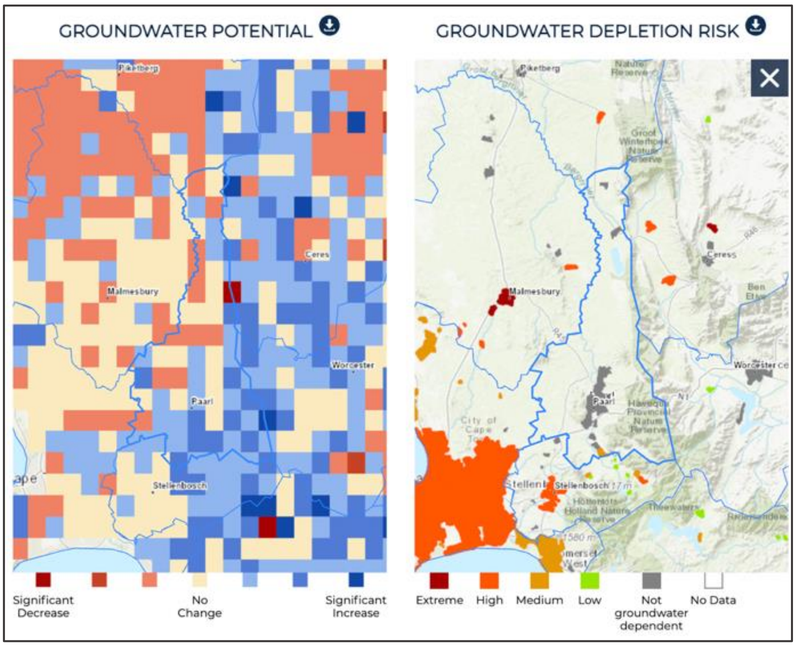


Figure 173: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show a mixed picture in terms of changes in precipitation, evaporation, and runoff, but the combination of decrease in precipitation, increase in evaporation, and decrease in runoff is a matter of concern.

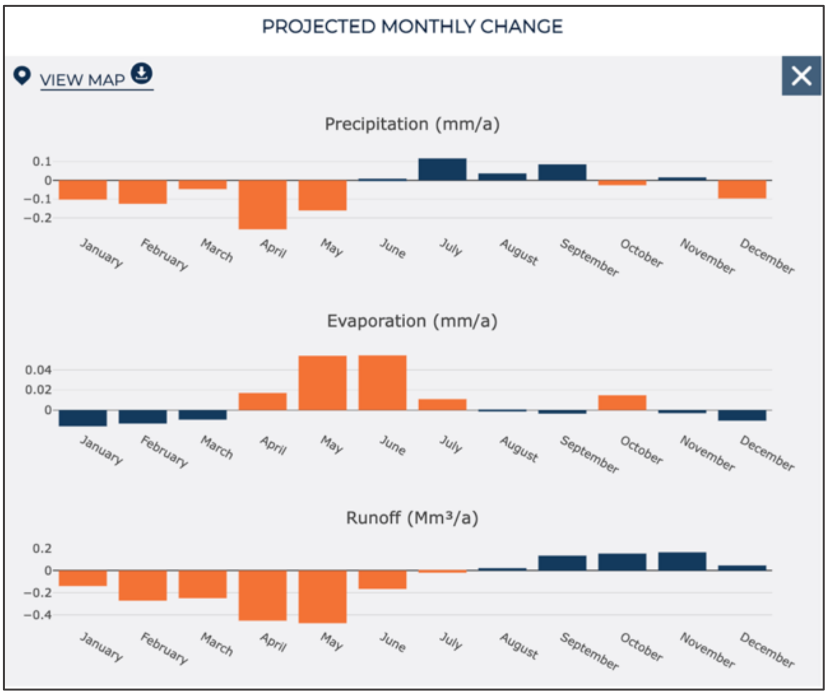
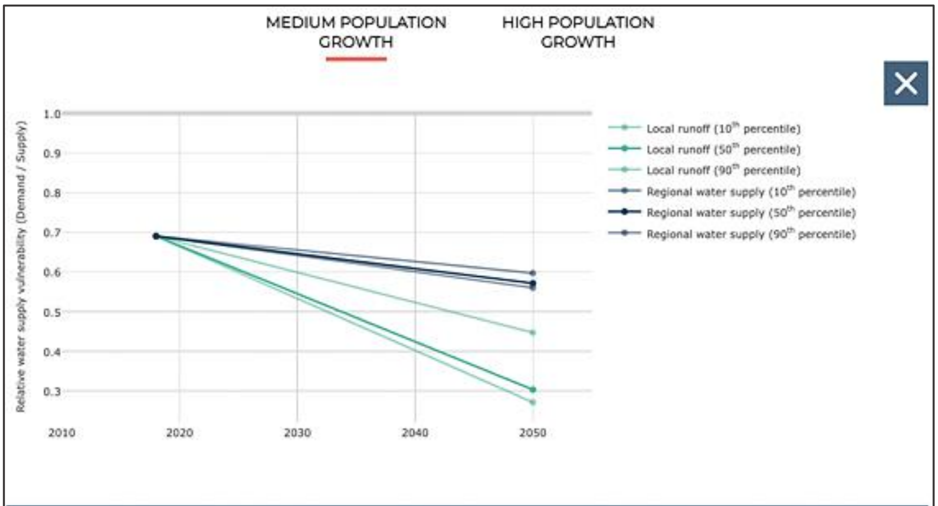


Figure 174: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, factoring in changes in multiple indicators that give rise to water supply vulnerability by 2050, Drakenstein municipality's future water supply vulnerability (as a ratio of demand and supply) is negligible, since supply will continue to exceed demand under a medium population growth scenario (CSIR and Aurecon 2019).



VULNERABILITY CONTRIBUTION FACTORS	PERCENTAGE CHANGE
Mean annual precipitation	7.52%
Mean annual evaporation	10.33%
Mean annual runoff	109.2%
Regional urban water supply	11%
Population growth	-16.71%

Figure 175: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019

WRI's Aqueduct Water Risk Index's localized projection of future water risk for Drakenstein municipality notes that the projected change in water stress between the present and 2040 is "extremely high," with a change (increase in stress) of more than 80% relative to the current baseline, under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*1.4 times*" change in water stress in the region.

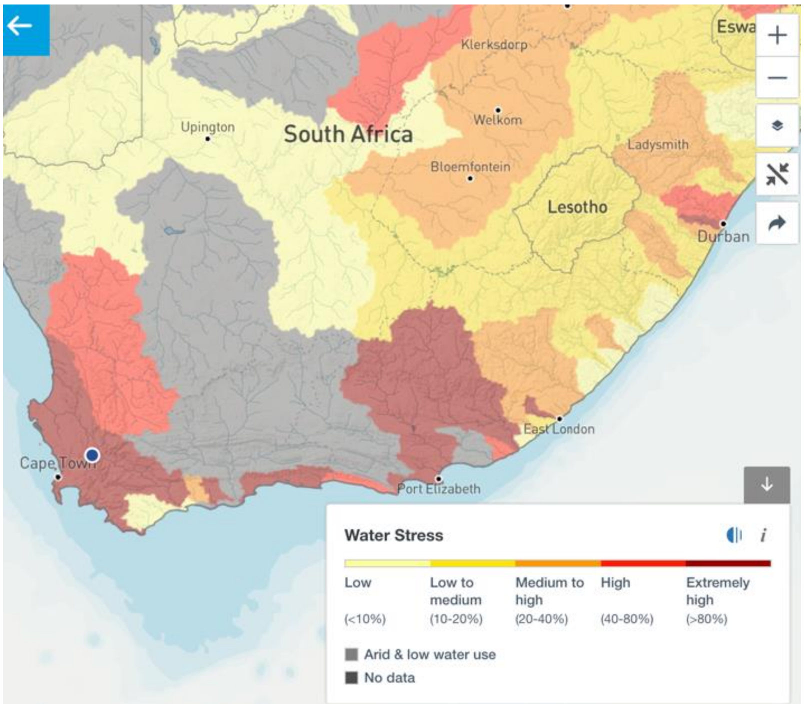


Figure 176: Extremely high projected water stress in Drakenstein municipality in the year 2040 (Source: WRI)

3.9 Mangaung Metropolitan Municipality

Mangaung metropolitan municipality is located inland in the Free State province, around Bloemfontein. Historically, its climate has been classified as being arid steppe climate under the Köppen-Geiger climate classification system (CSIR 2015), characterised by cold and aridity.

Historic climate

Minimal variation is observed in Figure 177 and Figure 178 with regards to historic average maximum and minimum temperatures for the municipality.

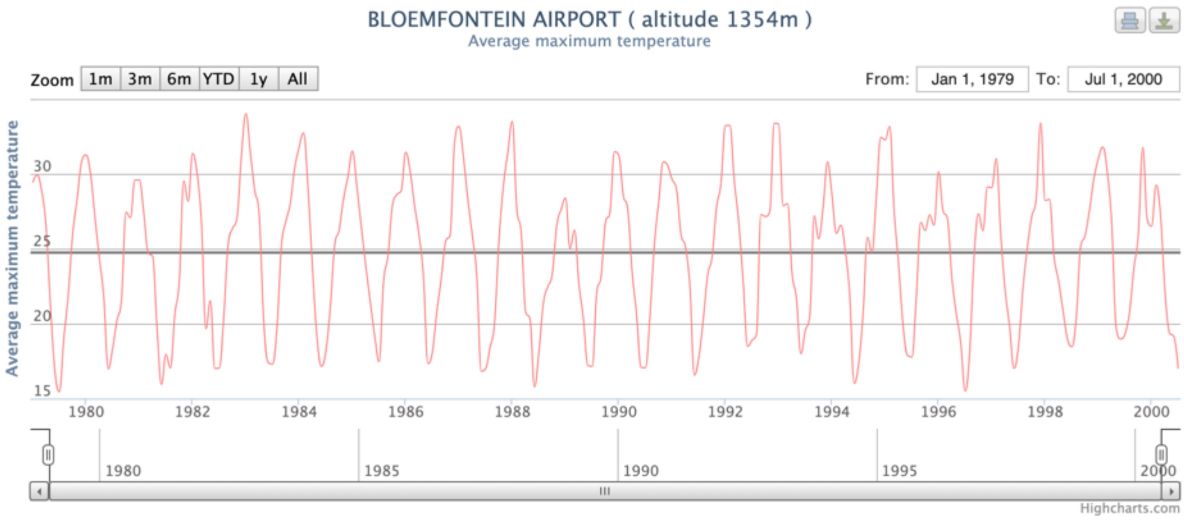


Figure 177: Historic average maximum temperature (available only from January 1979 to July 2000) for the Mangaung Metropolitan Municipality[58]

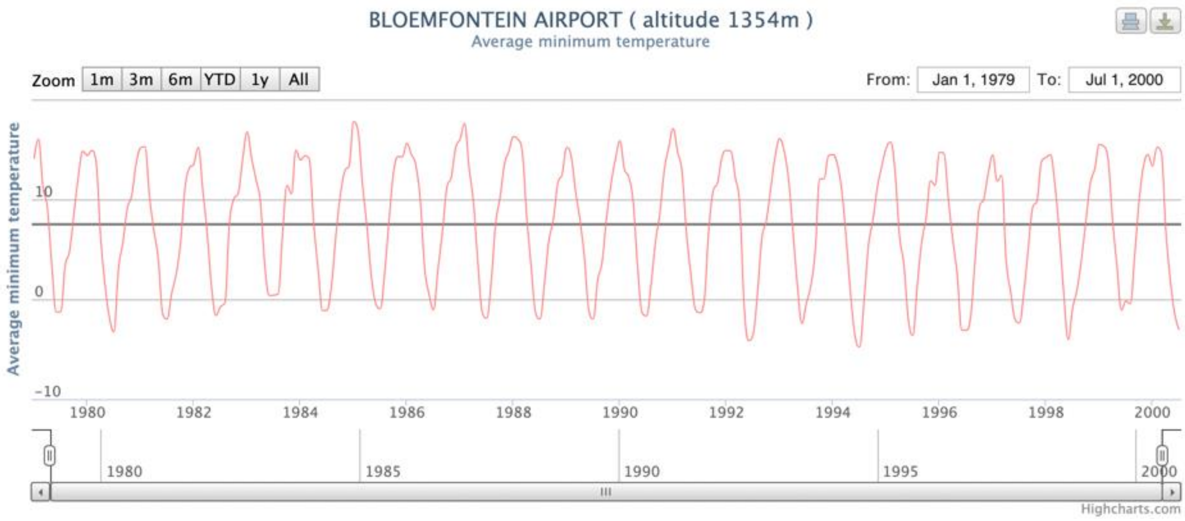


Figure 178: Historic average minimum temperature (available only from January 1979 to July 2000) for the Mangaung Metropolitan Municipality[59]

[58] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[59] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

Historical total monthly rainfall for the Mangaung Metropolitan Municipality tended to be below 150mm between 1979 and 2000 with one event in 1988 exceeding 400mm (Figure 179).

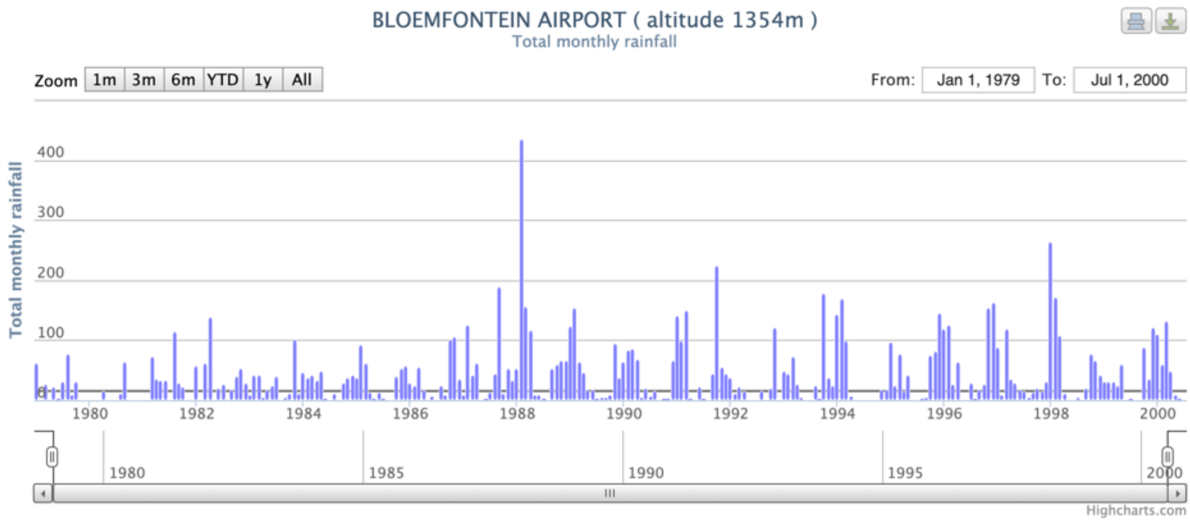


Figure 179: Historic total monthly rainfall (available only from January 1979 to July 2000) for the Mangaung Metropolitan Municipality[60]

Relatively long dry spells (25->75 days) are observed throughout the history of the municipality between 1970 and 2000 (Figure 180).

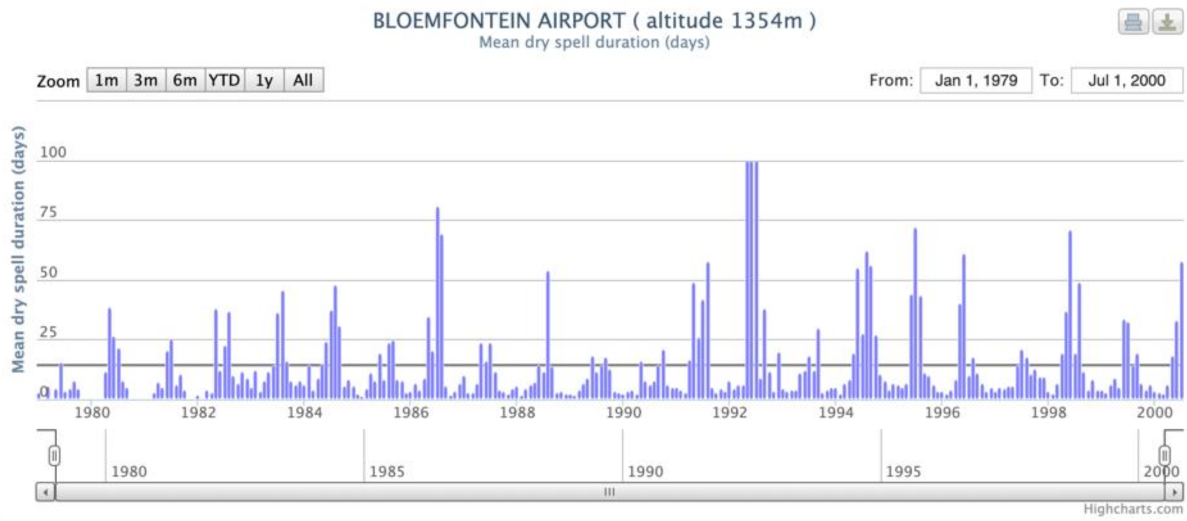


Figure 180: Historic mean dry spell durations in days (available only from January 1979 to July 2000) for the Mangaung Metropolitan Municipality[61]

Current climate and water resources

As depicted in Figure 181, Mangaung's current average annual temperature is approximately 16°C (closer to 18°C in the northwest) and current annual average rainfall is 1200-1600 mm (CSIR and Aurecon 2019).

[60] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.
[61] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/.

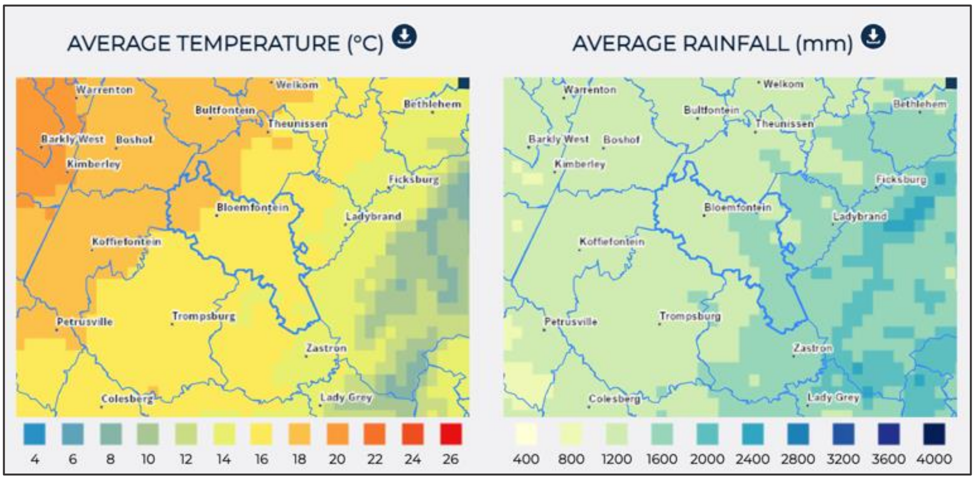


Figure 181: Mangaung Municipality's current temperature (left) and rainfall (right) annual averages (Source: CSIR, Greenbook, 2019)

At present, based on the demand / supply ratio of surface water, the municipality is not vulnerable and has a slight surplus of water supply (CSIR and Aurecon 2019), as reflected in Figure 182.

WATER AVAILABILITY

SURFACE WATER USAGE	
Demand Per Capita (l/p/d)	281.09
Supply Per Capita (l/p/d)	296.93
Current Vulnerability	0.95

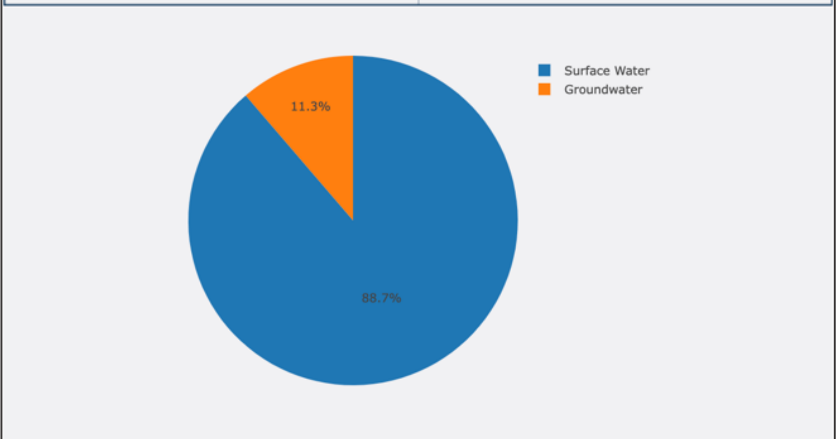


Figure 182: Present-day water availability in Mangaung municipality (Source: CSIR, Greenbook, 2019)

Figure 183 indicates that the municipality is not highly dependent on groundwater at the moment except in a few small pockets, and it has moderate groundwater recharge potential in most areas (CSIR and Aurecon 2019).

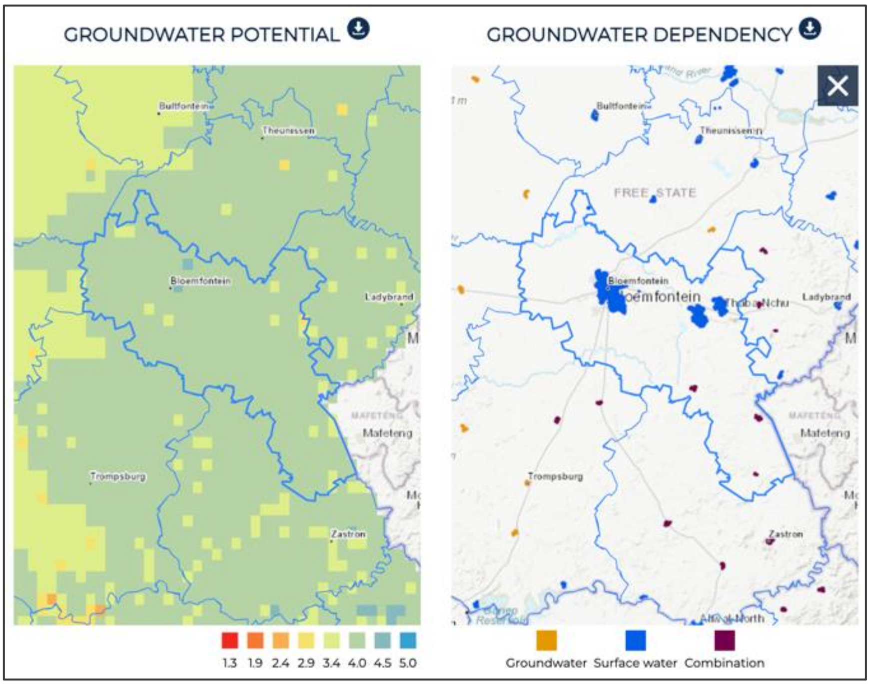


Figure 183: Groundwater recharge potential (left) and groundwater dependency (right) in Mangaung municipality at present (Source: CSIR, Greenbook, 2019)

Surface water resources are meeting all of the municipality's needs at the moment (CSIR and Aurecon 2019).

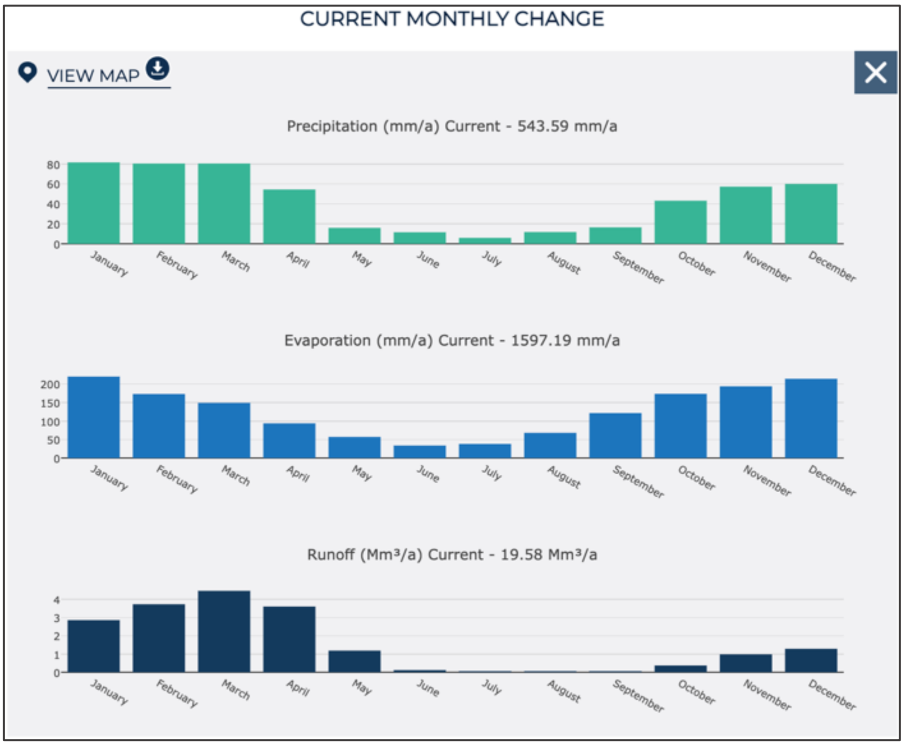


Figure 184: Surface water indices in Mangaung Municipality under the current climate (Source: CSIR, Greenbook, 2019)

Under the current climate, Mangaung municipality faces a moderate drought risk in some areas (Figure 185) relative to some other regions of the country.

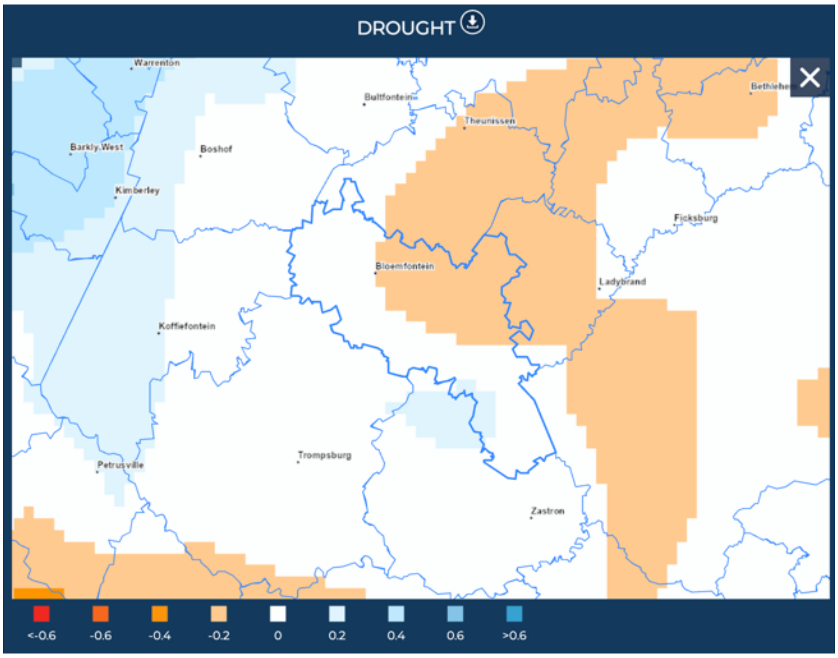


Figure 185: Projected change in drought tendencies (i.e. the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP 8.5) (Source: CSIR, Greenbook, 2019)

Future Climate

Validated models from the fifth phase of CMIP-5 indicate that in a moderate or intermediate emissions scenario (RCP 4.5), in the short-to-medium-term future (i.e., a timeframe relevant to water reuse investments under the WRP's first phase) from 2011 – 2040, Mangaung municipality is likely to experience climate change in a number of ways, per www.climateinformation.org (GCF, WMO, WCRP, SMHI n.d.):

- 1°C rise in mean annual temperature (many models agree on a rise in temperature, particularly about a rise in mean annual maximum temperature and mean annual minimum temperature)
- 5% increase in mean annual precipitation (many models agree on the increase, with a few models also agreeing about both a decrease in the number of dry spells and a decrease in the length of the longest dry spell).
- -3% decrease in aridity
- 7% increase in annual mean soil moisture
- 9% increase in annual mean water discharge (with a few models in agreement about the increase in the 2-year, 5-year, 10-year, and 50-year return periods for annual maximum water discharge, as well some models agreeing about the increase in maximum water discharge)
- 9% increase in annual mean runoff
- Many models agree on the increase in warm, tropical, humid nights

Models suggest that under RCP 4.5, in 2050, Mangaung Municipality will experience a temperature rise of up to 2.94°C (CSIR and Aurecon 2019).

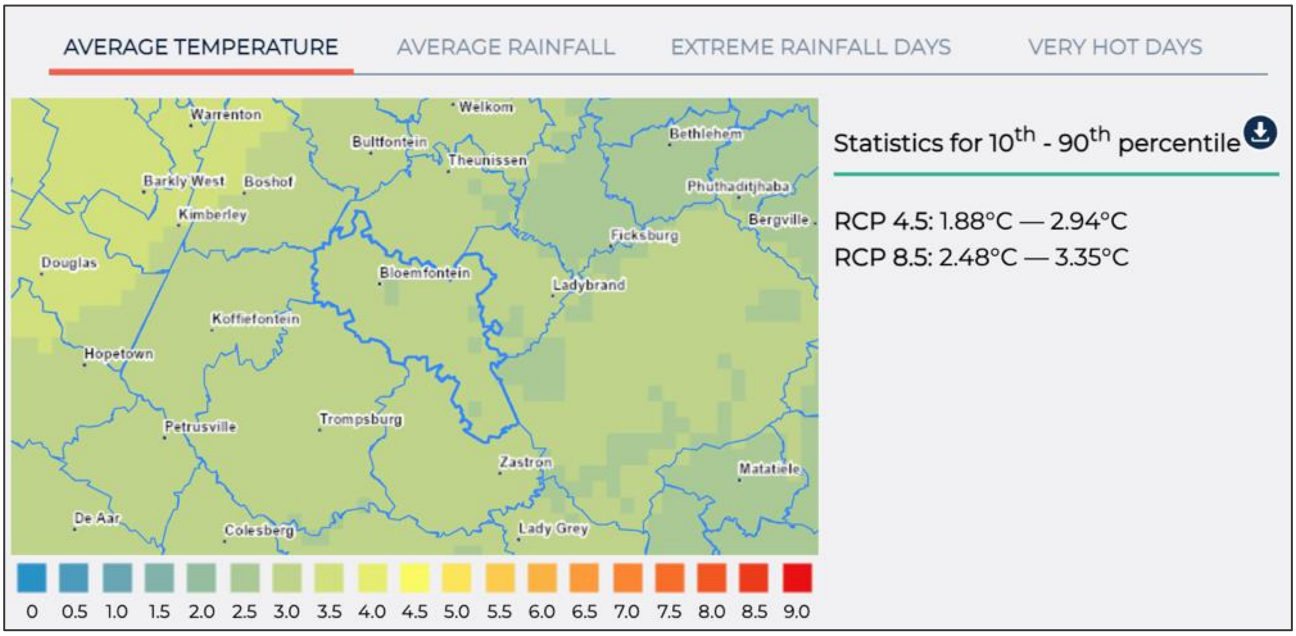


Figure 186: Change in average temperature (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

A clear increase in temperature can be observed in the municipality's future average maximum and minimum temperature projections for 2030 to 2050 (RCP4.5) (Figure 187 and Figure 188).

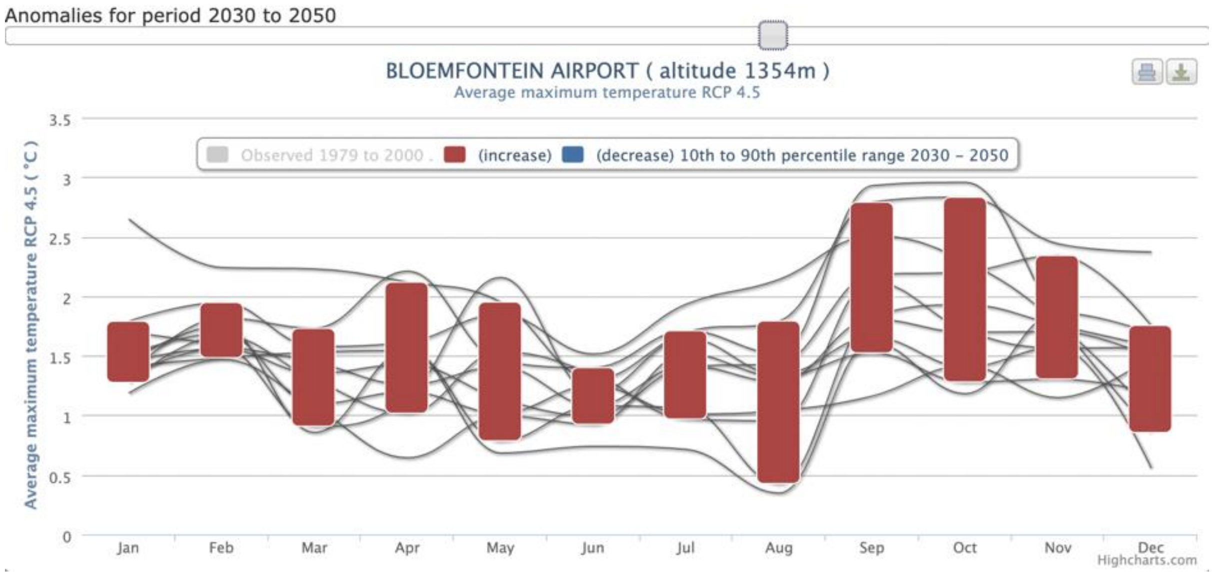


Figure 187: Future average maximum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the Mangaung Metropolitan Municipality[62]

[62] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

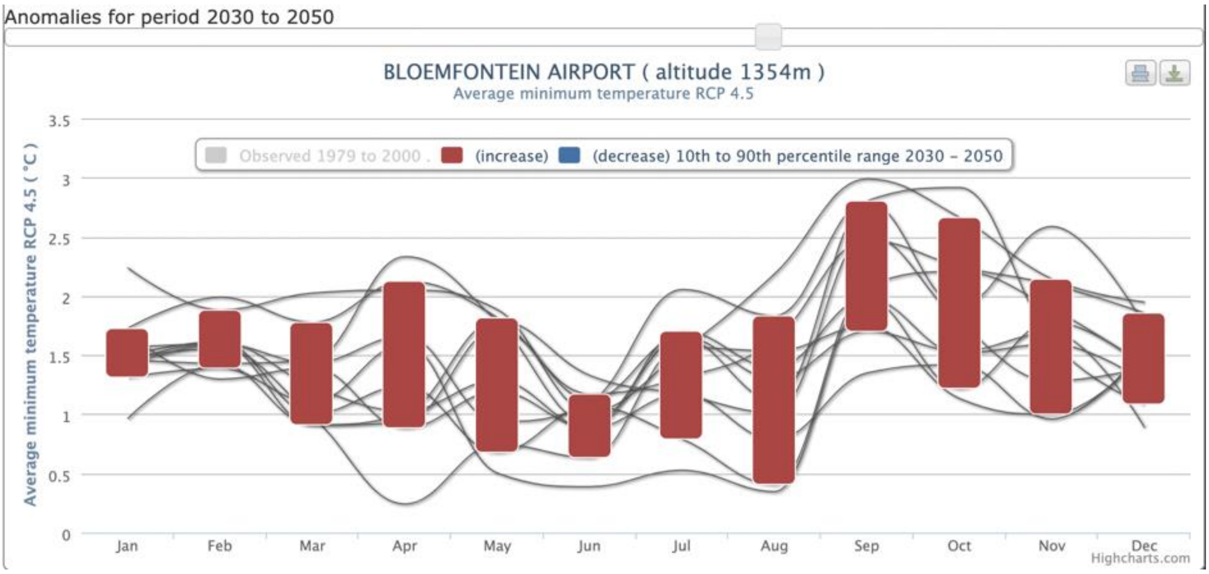


Figure 188: Future average minimum temperature projections (RCP 4.5, for the 2030 – 2050 period) for the Mangaung Metropolitan Municipality[63]

Average rainfall in 2050, under RCP 4.5, is expected to increase significantly, implicating a wetter future (CSIR and Aurecon 2019).

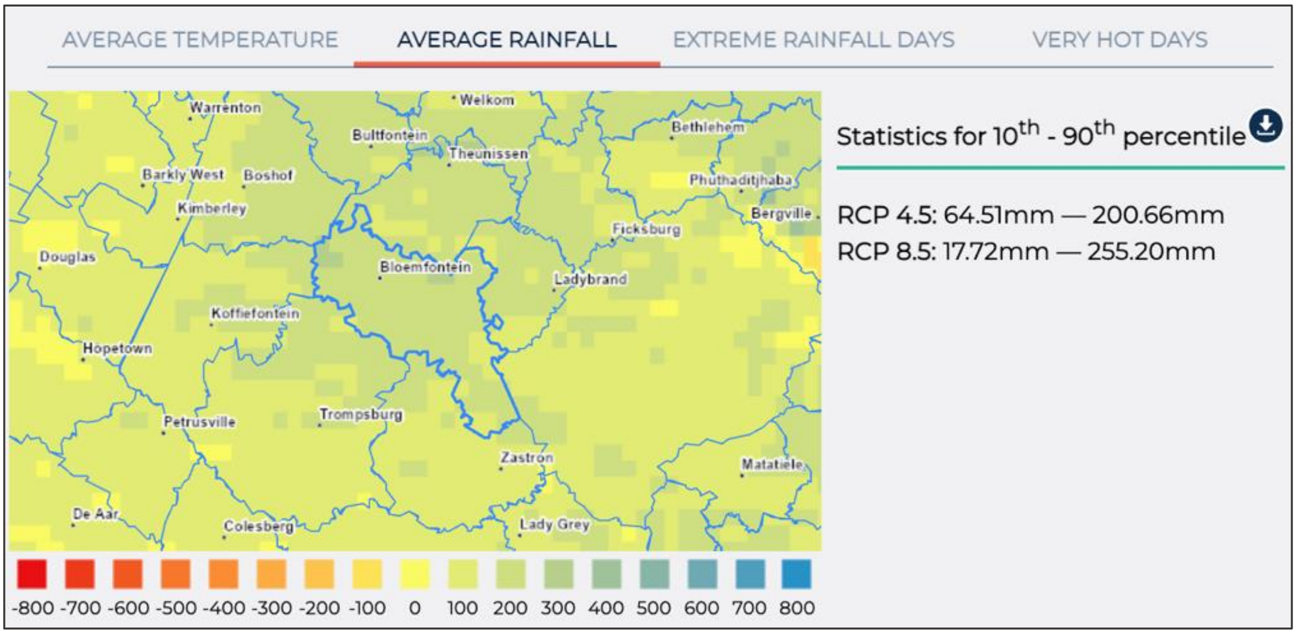


Figure 189: Change in average rainfall (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Projected rainfall for the municipality shows little change between 2030 and 2050 (RCP4.5) (Figure 190).

[63] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

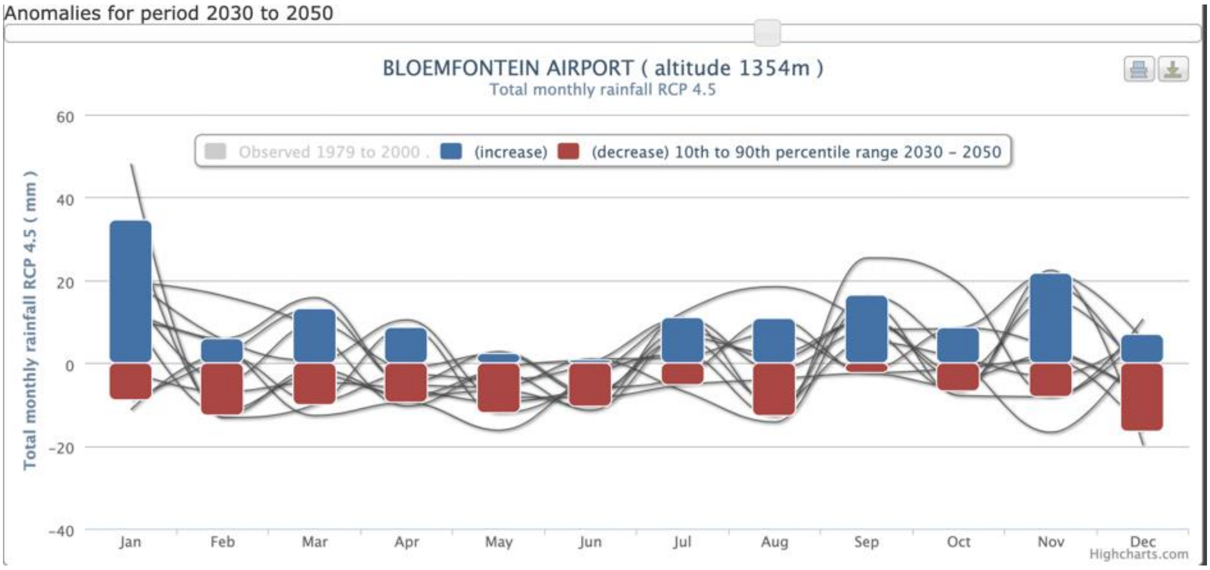


Figure 190: Future total monthly rainfall projections (RCP 4.5, for the 2030 – 2050 period) for the Mangaung Metropolitan Municipality[64]

There is some variability and range in projections for extreme rainfall days (i.e., days with heavy precipitation), under RCP 4.5 in 2050 (CSIR and Aurecon 2019), with either a marginal decrease or slight increase.

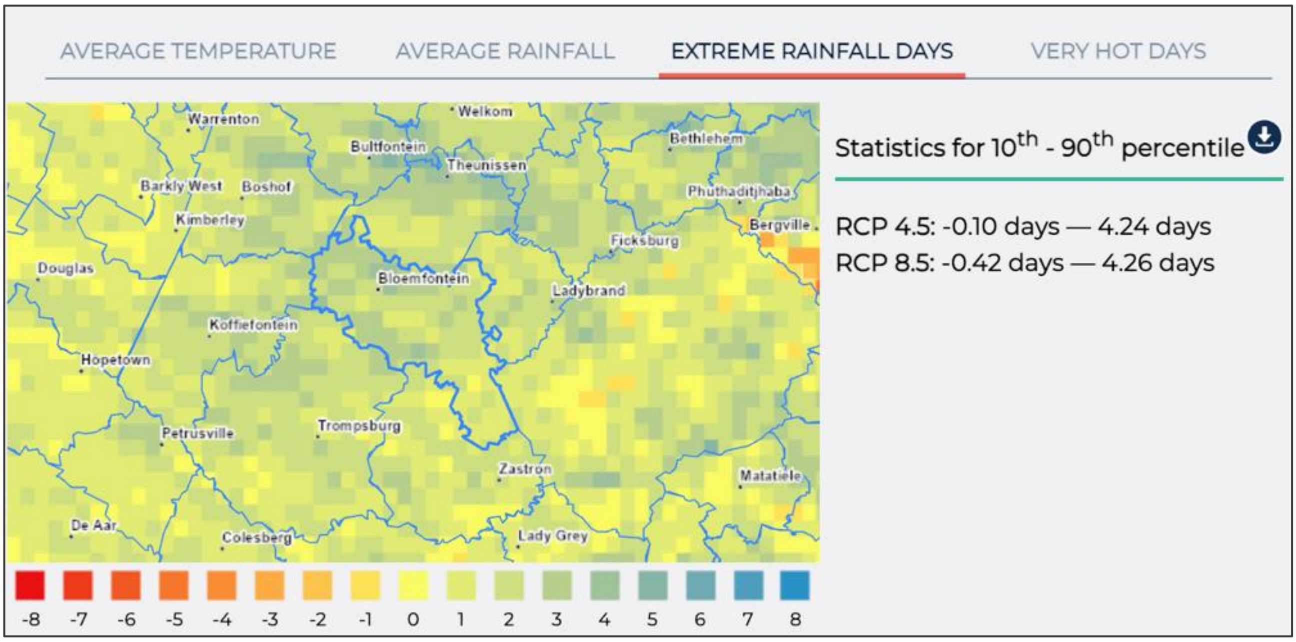


Figure 191: Change in extreme rainfall days (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

The municipality is likely to experience an increase in the number of very hot days annually, under an RCP 4.5 future scenario in 2050 (CSIR and Aurecon 2019).

[64] Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

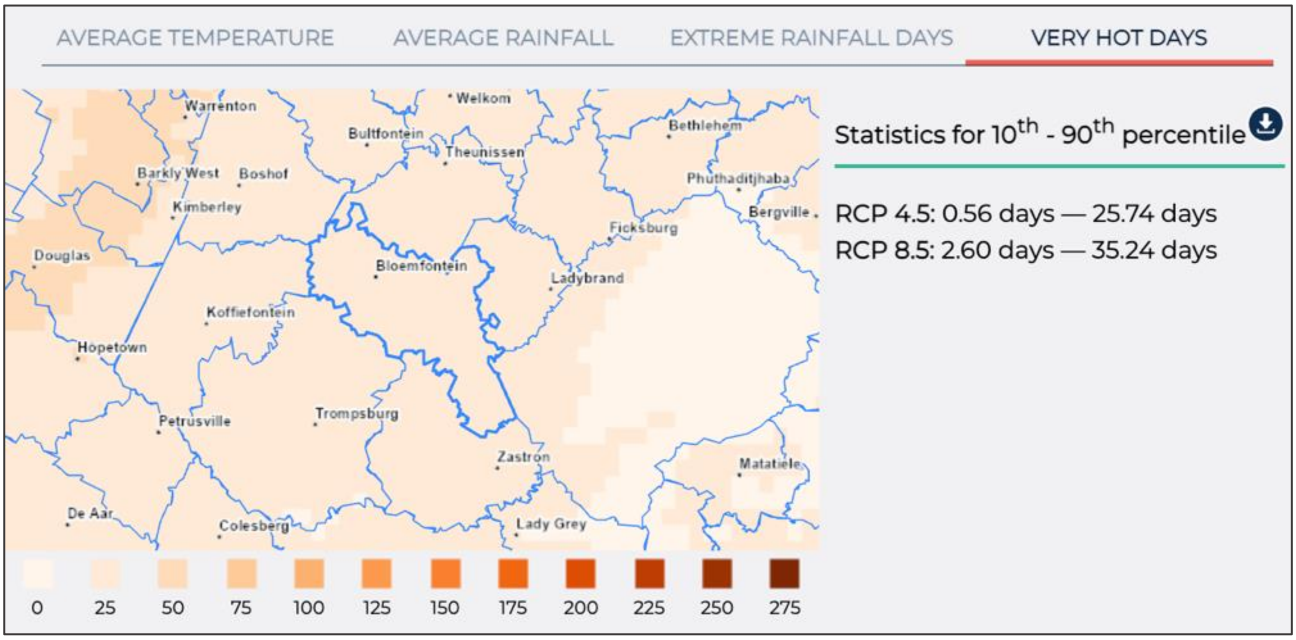


Figure 192: Change in number of very hot days per year (2021 - 2050) over the historic baseline (1961-1990) (Source: CSIR and Aurecon, Greenbook, 2019)

Slightly longer dry spells can be observed in Figure 193 which shows the municipality's future mean dry spell duration projections between 2030 and 2050 (RCP4.5).

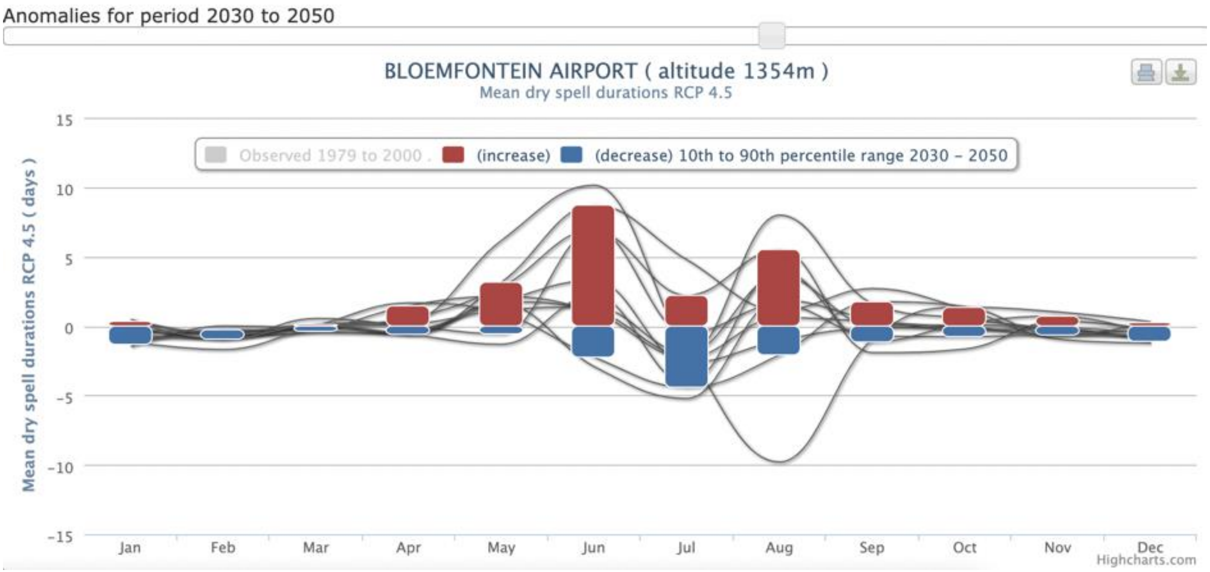


Figure 193: Future mean dry spell durations projections by month (RCP 4.5, for the 2030 – 2050 period) for the Mangaung Metropolitan Municipality[65]

Future drought risk in Mangaung municipality in 2050 is very low in terms of the SPI drought index. It is also highly unlikely to experience any rise in drought tendency (CSIR and Aurecon 2019).

65 Graph sourced from the University of Cape Town's Climate Information Platform, operated by the Climate Systems Analysis Group (CSAG). https://cip.csag.uct.ac.za/webclient2/datasets/africa-merged-cmip5/. Future climate projections presented as anomalies relative to the historical 1980 – 2000 baseline.

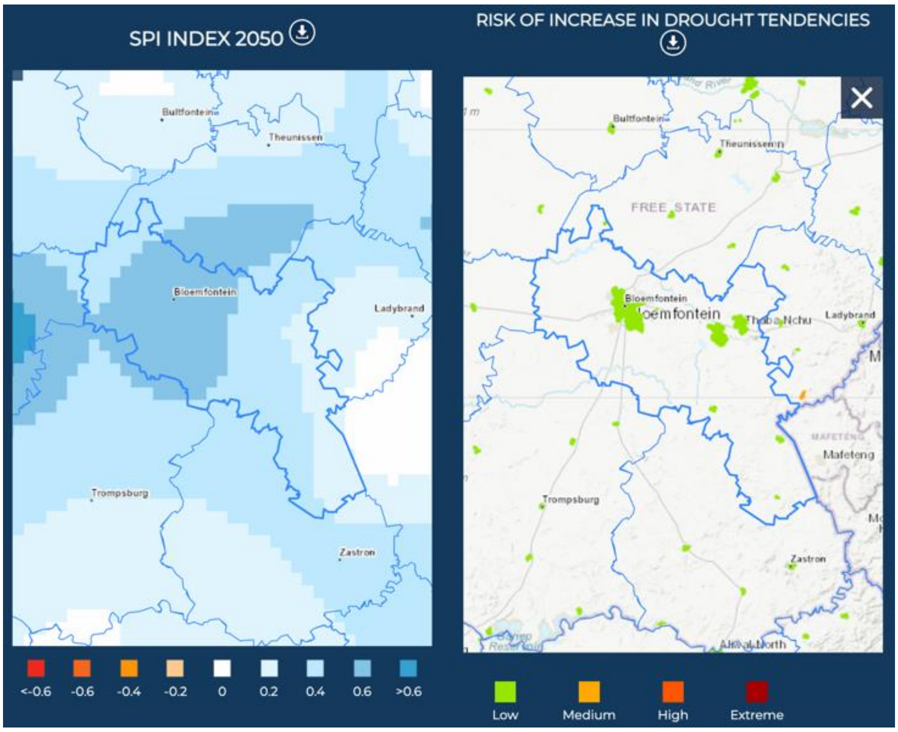


Figure 194: Change in drought risk in 2050 based on the SP Index and estimation of drought incidence tendencies (Source: CSIR and Aurecon, Greenbook, 2019)

Groundwater potential may grow to some degree in much of Mangaung municipality by 2050. However, given that the municipality does not depend to a large extent on groundwater, barring in a few pockets deemed at low risk of depletion, its overall groundwater depletion risk is not material for water supply vulnerability.

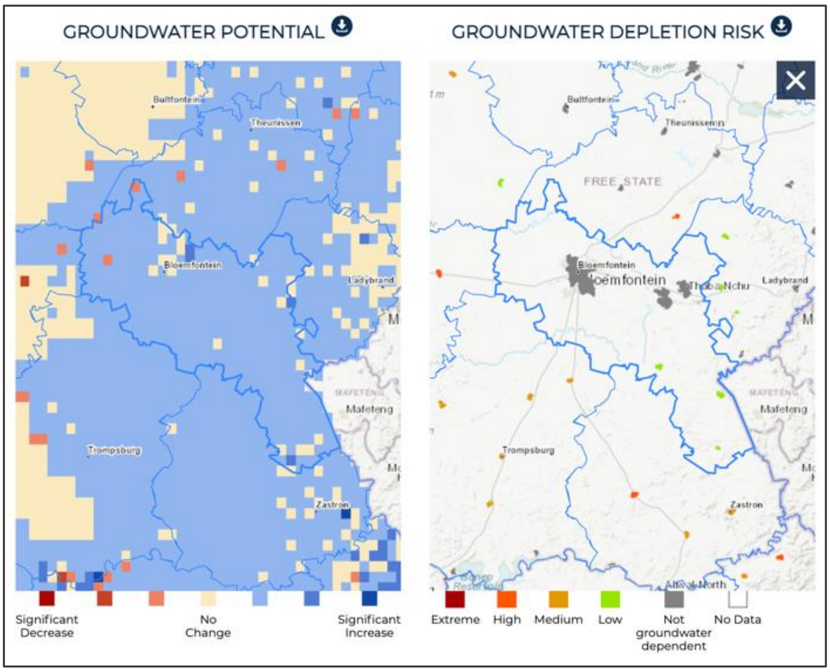


Figure 195: Future groundwater potential and dependency (Source: CSIR, Greenbook, 2019)

Future (2050) trends in surface water show a mixed picture in terms of changes in precipitation, evaporation, and runoff, but the municipality will experience a combination of decrease in precipitation, increase in evaporation, and a slight increase in runoff.

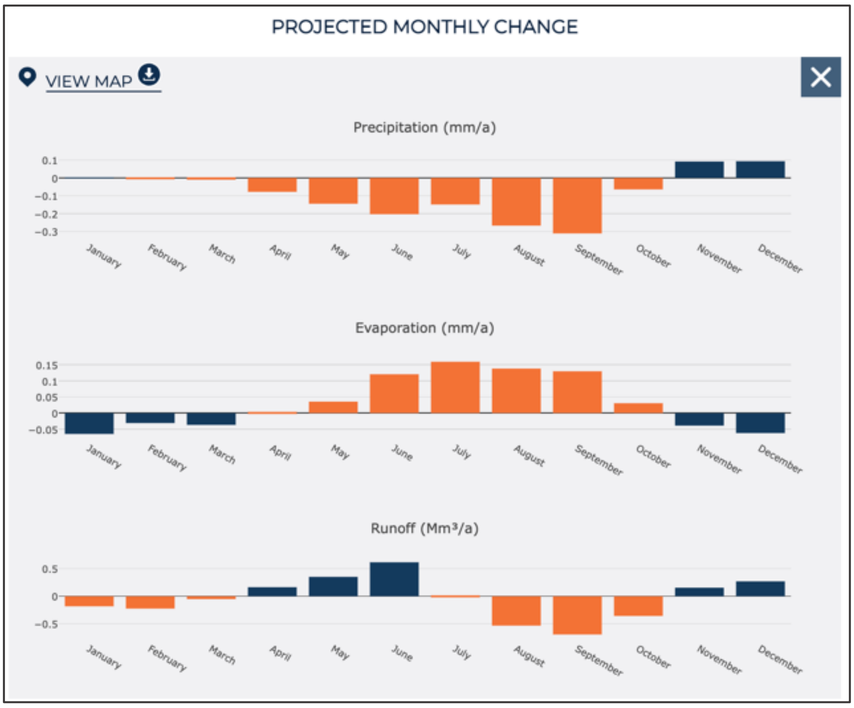


Figure 196: Future trends in surface water for 2050 (Source: CSIR, Greenbook, 2019)

Overall, factoring in changes in multiple indicators that give rise to water supply vulnerability by 2050, Mangaung municipality's future water supply vulnerability (as a ratio of demand and supply) is low since supply will continue to exceed demand under a medium population growth scenario (CSIR and Aurecon 2019).

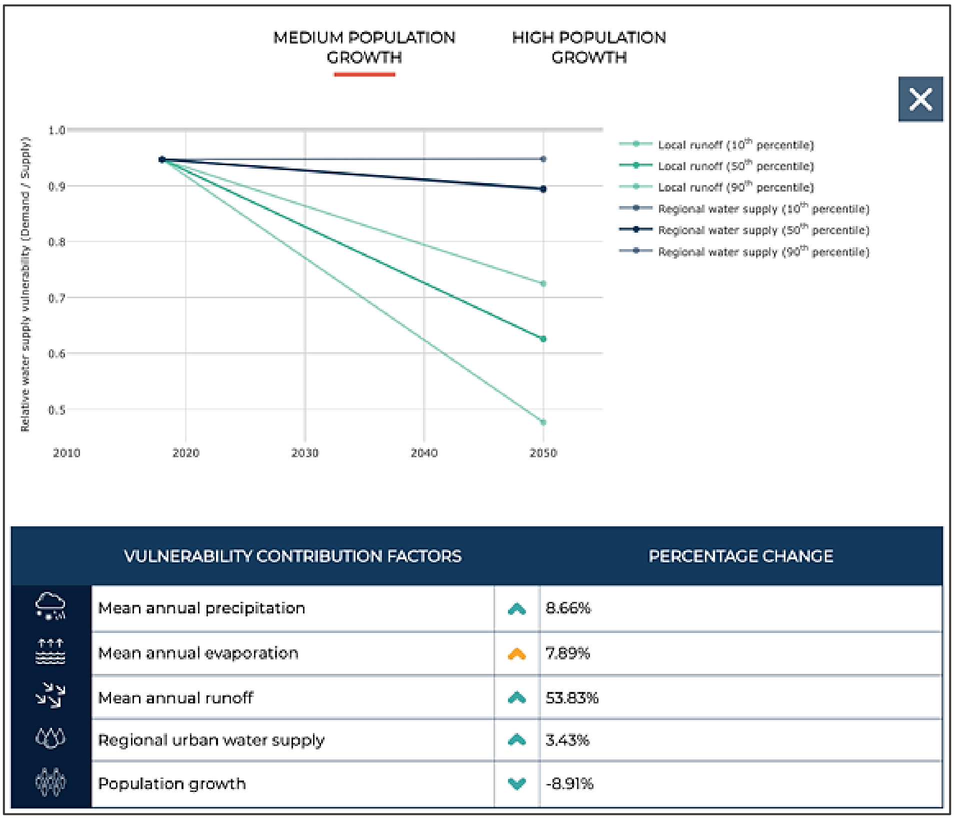


Figure 197: Percentage change in vulnerability contributors by 2050 (Source: CSIR and Aurecon, Greenbook, 2019

WRI's Aqueduct Water Risk Index's localized projection of future water risk for Mangaung municipality notes that the projected change in water stress between the present and 2040 is "medium-to-high," with a change (increase in stress) of between 20-40% relative to the current baseline, under a Business-As-Usual scenario. WRI's Aqueduct classifies this as a "*1.4 times*" change in water stress in the region.

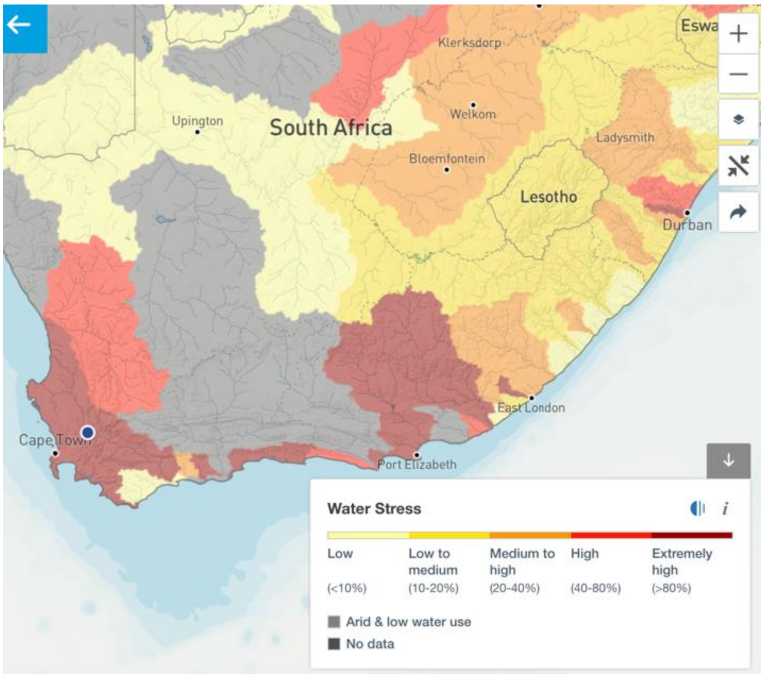


Figure 198: Medium-to-high projected water stress in Mangaung municipality in the year 2040 (Source: WRI)

4. Role of Water Reuse in Climate Adaptation

Water reuse has received recognition globally as a viable climate change adaptation measure. It has the potential to be an important constituent of South Africa's multifaceted climate change adaptation response in the water sector. The Water Reuse Programme is well positioned to drive investments in key municipalities, thereby demonstrating effectiveness and developing replicable models for widespread adoption countrywide.

4.1 General

The implementation of a national WRP through the scale-up of water reuse approaches and water reuse infrastructure in municipalities would significantly enhance water security in South Africa and combat the impact that climate change has on water security in the country.

A successful WRP should be able to demonstrably indicate that climate change resilience objectives will be achieved (by strengthening the country's adaptive capacity against water stress and scarcity), and should be able to measurably maximize climate change adaptation in a manner that meets the criteria and requirements of the GCF.

Possible role of the WRP

The number of planned reuse projects represent an opportunity for the WRP as most of these projects are likely to require further project preparation, funding as well as procurement support. Analysis done to design the WRP does indicate that since the technology is becoming more accepted and Municipalities are starting to see the need to improve water resilience by means of water reuse, this would be the right time to initiate the WRP.

4.2 The Market for Water Reuse in South Africa

The need for water reuse as a means of augmenting and diversifying the water mix in South Africa is widely acknowledged in national policies and guidelines (see NWRS1 & NWRS2, NWSM 2018, Water Sensitive Urban Design framework and guidelines and others).

Acceptance for water reuse from municipal WWTW as an alternative water supply has largely been seen in the industrial sector. However, the industrial use of water in South Africa is estimated to be only 8% (1.248 km^3) of the total annual water demand and there is a gap in the expansion of the use of reused water to other sectors, particularly for the domestic and agricultural sectors.

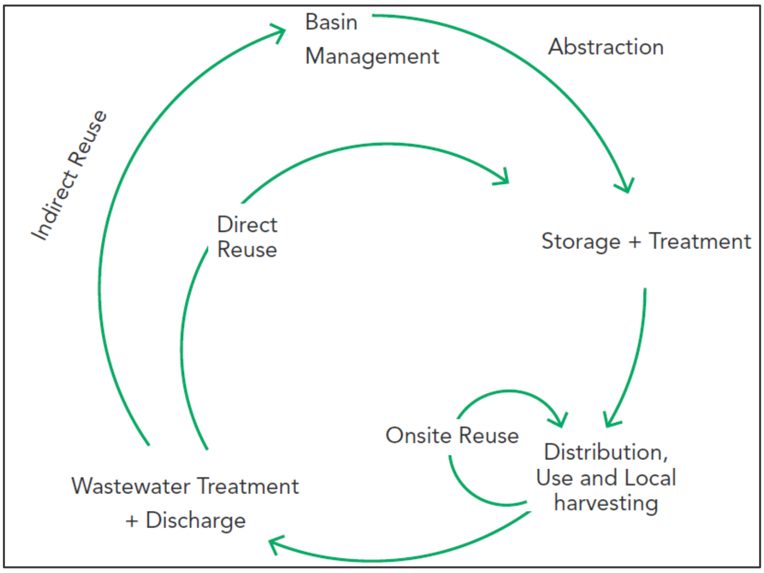


Figure 199: Water reuse opportunities across the water value chain (GreenCape 2018)

South Africa has in excess of 1,000 municipal WWTW that produce and discharge approximately 2.1 km^3/year of treated effluent to receiving waters (DWS, National Water Reuse Strategy (NWRS), Second Edition 2013, 3, Appendix D). There is a strong correlation between potable use and effluent discharge in cities, where approximately 60% of the annual average daily demand (AADD) is returned to WWTWs for processing and subsequent discharge as treated effluent. This creates an opportunity for reuse in growing cities, as effluent quantities generally increase in proportion to increased AADD. However, in instances where the AADD is reduced either due to a) water restrictions or b) Water Conservation and Water Demand Management (WCWDM) campaigns, the potable use of water may decrease, but the nutrient loading of effluent generated is likely to remain largely constant.

The industrial, mining and power generation (IMP) sectors reconciliation strategy indicated wastewater reuse can contribute up to 14.3% of the water demand for the sector as part of its water mix (Reddy and Siqalaba 2018). There is sufficient treated effluent supply to meet these demands, although there are many other factors to be considered before water reuse projects can be implemented, and therefore, a considerable market for water reuse for these applications.

The need for large scale treatment plants in close proximity of significant industrial demand means that water reuse systems are likely to be limited to the largest 8 metros and some secondary cities with large industrial bases (such as Drakenstein, Rustenburg and Emfuleni). Graham (2019) noted that a valuable contribution in the water reuse space would be to map locations of suitable municipal wastewater treatment works in relation to suitably large industrial water users to identify the most promising geographic areas for projects. This has been done in Sections 7 and 8. Coastal regions could be the most accessible market for municipal-scale direct potable reuse and indirect potable reuse due to the possibility of brine discharge into the ocean, as well as relatively few downstream users being reliant on return flows, thereby reducing potential regulatory barriers. However, the larger industrial customers are located inland, thus inland opportunities are also available. Also, inland areas don't have the option of seawater desalination which puts more emphasis on the need for water reuse schemes from WWTW. A GreenCape (2018) analysis estimated typical costs for DPR and IPR being

30-50% cheaper than seawater desalination systems, indicating reuse as a stronger market option than desalination for coastal cities.

Treated effluent from WWTW is already being distributed for non-potable applications in several municipalities, typically focussing on irrigation and selected industrial uses (mostly cooling), albeit at a relatively small scale. Yet, the scale of reuse is usually limited to the contribution that the consumer or municipality is willing to make to the supply network. Also, municipalities are not always able to guarantee consistent quality or quantity of treated effluent supply, resulting in a lack of uptake. For example, Saldanha Bay municipality, that has many heavy industrial consumers, sells only 6% of WWTW effluent, despite the demand exceeding this quantity by a considerable amount. As another example, the City of Cape Town invested in WWTW reuse during the Western Cape drought (2016-2018) and currently sells approximately 75 Mℓ/day (from various WWTWs) of a total production of 450 Mℓ/day (i.e. 16%), indicating additional expansion is possible. These factors all contribute to significant market opportunities for water reuse in South Africa.

4.3 Water Reuse as a Climate Change Adaptation Intervention

Water reuse has gained traction internationally as a climate change adaptation measure (Salequzzaman 2015). As pressure on freshwater resources has mounted across the globe, governments have adopted a broader spectrum of approaches to enhance water sector resilience, including water reuse (sometimes referred to as water reclamation and recycling).

Examples include Windhoek, Namibia, where direct wastewater reuse for human consumption has been in operation for over four decades, and both developed countries such as Japan, Germany, Spain, and Israel, and developing countries such as Pakistan, Brazil, Nepal, and Vietnam (Jiménez and Asano 2008).

In its most recently published Working Group report on climate change impacts, adaptation, and vulnerability (Assessment Report 5; WGII's report under Assessment Report 6 is awaited in January 2022), the IPCC explicitly identified water reuse as a "design and operations" based adaptive strategy against climate change (Intergovernmental Panel on Climate Change 2014). It took note of successful application of water reuse as a climate change adaptation response in Asia, Australia, and active exploration of water reuse by Cape Town (Intergovernmental Panel on Climate Change 2014).

Water reuse (under the umbrella term water recycling) is also recognized as a viable climate change adaptation measure by the European Union, which classifies it under structural and physical adaptation (with both technological and service delivery elements) (Climate Adapt EU n.d.).

Several state and local jurisdictions in the United States have implemented water reuse too. These include Virginia, Tampa Bay in Florida, El Paso in Texas, Reno-Sparks in Nevada, the Chino basin in southern California, and New York City (Water Reuse Association 2021).

Depending on the type of water reuse technology and process applied, and the type of beneficial use the reclaimed, treated, and recycled water is offered for, there are a range of benefits from water reuse as a measure for climate change adaptation. According to the United States Water Reuse Association, water reuse investments often:

- "Compare favourably to other options for providing new water supplies by using less energy, imposing a smaller carbon footprint, and generating fewer air pollution emissions;
- Ensure reliable and resilient community water supplies in the face of increasingly frequent, severe, and prolonged droughts, wildfire, and other climate-related risks by drawing on a stable, locally generated, and controlled water source;
- Support sustainable economic prosperity, advanced clean manufacturing, and well-paying high-skill employment opportunities by providing business and industry with a reliable, long-term supply of water; and
- Protect rivers, lakes, and streams—as well as aquifers and wetlands—by reducing extractive water demands, reducing nutrient and other pollutant loads, and providing high-quality water for replenishing groundwater and riparian base flows" (Water Reuse Association 2021).

In South Africa, water reuse is a critical element in the country's multifaceted approach to water sector climate change adaptation. The level of current and future – climate change induced – water stress in South Africa is such that municipalities and communities cannot depend on one type of water resources management and water adaptation approach alone; an "all of the above" approach is warranted to ensure water efficiency is maximized and water resources are used to their full potential.

However, water reuse is a relatively novel approach in South Africa, and for it to become established as a viable intervention and achieve widespread replication the country first needs a number of strategic pilot projects that pave the way forward. The proposed national Water Reuse Programme is the appropriate vehicle to drive such nation-wide incorporation of water reuse as a local climate change adaptation measure, and to ensure that water reuse becomes embedded within municipal water resources management.

5. Conclusions

Strategy and Plans

The DWS has over the years developed a series of strategic instruments outlining the need to strengthen and improve the management of water, whether this be the management of water resources or the management of water supply and services. The NWSM (DWS, National Water and Sanitation Master Plan, 2018) outlines the need to introduces alternative approaches to improve the water mix noting projected deficit of 17% by 2030 and noting that there are only limited alternatives in terms of major resource development including large scale impoundments.

South Africa has submitted its first adaptation communication as a component of its Nationally Determined Contribution (NDC) in line with the Paris Agreement in Article 7, paragraph 11. The adaptation communication provides detailed information on South Africa's planned contribution to the global adaptation goal during the NDC period, anticipated climate impacts, a description of the National Climate Change Adaptation Strategy, and details of planned adaptation actions over the next decades and their associated costs for key areas of the economy that are likely to be most impacted by climate change (health, agriculture and forestry, human settlements, biodiversity, and water) (Republic of South Africa, 2021).

The National Climate Change Adaptation Strategy (NCCAS) (DEFF, 2020) responds to this challenge, to inform climate change adaptation planning in the country. The NCCAS will serve as South Africa's National Adaptation Plan and fulfils South Africa's commitment to its obligations in terms of Article 7.9 of the Paris Agreement under the UNFCCC. It will further provide a policy instrument in which national climate change adaptation objectives for the country can be articulated to provide overarching guidance to all sectors of the economy in implementing adaptation (Republic of South Africa, 2021).

The NCCAS is aligned with the country's policy and legislation, building on principles contained therein, including international agreements South Africa is party to. Relevant domestic legislation and policy include the National Climate Change Response Policy (DEA, 2011a), National Development Plan (NPC, 2011), National Strategy for Sustainable Development (DEA, 2011b), sector adaptation strategies/plans, as well as provincial and municipal adaptation strategies/plans ((Republic of South Africa, 2021).

Within the first adaptation communication under Goal 3 (Implementation of NCCAS adaptation interventions for the period 2021 to 2030) it is noted that:

> "…*local government plays a key role in climate change response, and therefore building the capacity of the local sphere of government will be significant in achieving adaptation goals. This capacity support should be inclusive of human resources; institutionalisation of climate change response; financial resources and technological and/or technical support. The cities will play a pivotal role in leading climate change response in the country by virtue of urbanisation trends and services offered to the community.*" (Republic of South Africa, 2021).

Water, amongst others, has been identified as a priority with a focus on enhancing water security through the development and deployment of climate-resilient infrastructure as well as ensuring the integration of climate information into infrastructure development planning.

This is underpinned by Goal 4 (Access to funding for adaptation implementation through multilateral funding mechanisms) noting that the domestic financial sector should play a pivotal role in terms of helping investors in adaptation space to satisfy funding requirements to meet the NDC goals. Direct unilateral access to advance adaptation finance by the private sector is outlined as being still a significant issue (Republic of South Africa, 2021). Towards this the plan outlines the importance of developing a climate change adaptation investment pipeline for projects indicating that the adaptation needs and costs for the period 2021 – 2030 is USD 16 – 267 billion (Republic of South Africa, 2021).

Climate Vulnerabilities

The development of a National WRP is understood as a key intervention to improve water security at the local, municipal scale and is, therefore, important in supporting the plans outlined in the first adaptation communication, as a component of its NDC.

South Africa will experience temperature rise due to climate change (Figure 4). It is expected that under a Business-as-Usual future, by mid-century the South African coast will warm by 1-2^{o}C, and the interior as much as 3^{o}C. Future projections of precipitation are more complex. Overall, for the period 2020-2039, under all SSPs (barring the most optimistic and unrealistic), there is a very slight signal of decrease in total annual average rainfall volume (Figure 5).

Based on climate model projections, the Standardised Precipitation-Evapotranspiration Index drought index suggests a marked increase in the risk of droughts in 2020-2039 period and even in the 2040-2059 period, under a moderate emissions scenario. Thus, the country's already-stressed water resources will be put under greater pressure by climate change, with South Africa expected to become drier as the southern African region warms at nearly twice the rate of the rest of the world, becoming a climate change hotspot in terms of both hot extremes and drying (Intergovernmental Panel on Climate Change, 2014).

It is important to consider the impacts of climate change in the context of current vulnerability as well as future resilience to climate shocks and the potential for adaptation. The Green Book risk assessment (CSIR and Aurecon, 2019) has provided the most thorough assessment of national and municipal vulnerability to date, being completed in 2019 and being updated regularly. This assessment has shown by looking at climate change impact in conjunction with water supply contexts (local supply E1 and regional supply E2), against differing population growth scenarios that there is significant vulnerability across many municipalities. By taking a median climate scenario and looking at the adjustments in vulnerability from the current context to futures with medium and high population growth, these vulnerabilities often increase between 20—40% (Figure 200). This particularly in key country economic nodes of Gauteng, Kwa-Zulu Natal, Eastern Cape and Western Cape, where rapid urbanisation around the cities of Johannesburg/ Tshwane, eThekwini, Nelson Mandela Bay and Cape Town are taking place.

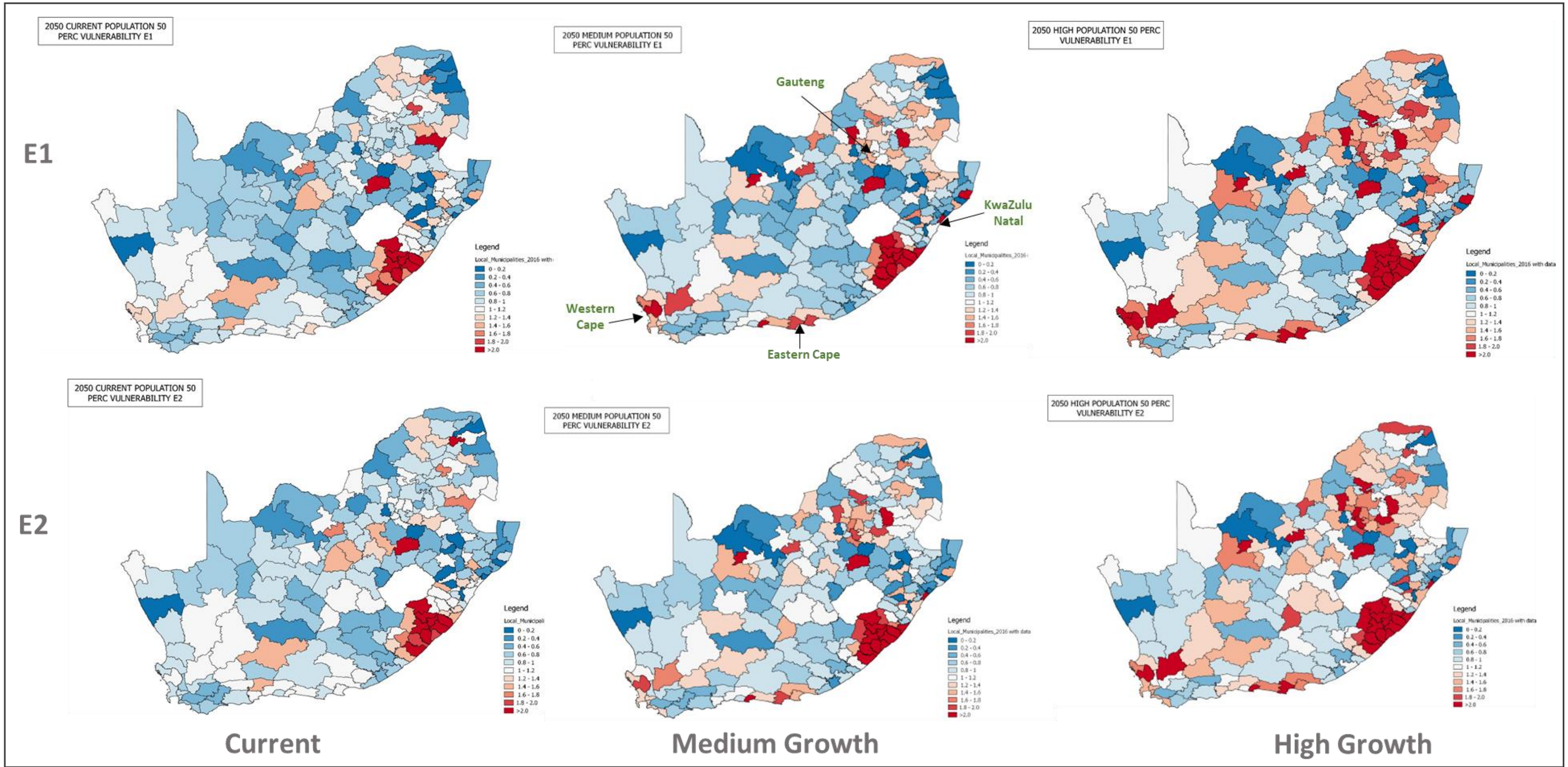


Figure 200: 2050 water supply vulnerability (estimated demand/supply) with median scenarios under climate change and exposure E1 and E2 scenarios, with current through to high population growth (Source: CSIR, Greenbook, 2019)

The National WRP will develop a project pipeline and the market study has outlined a number of project options that could be considered to be part of the pipe. Ten indicative projects were identified as possible pathfinder projects and these municipalities were reviewed using the municipal risk tool developed by the Green Book study (CSIR and Aurecon, 2019) and are compared to WRI Aqueduct Risk Tool for water stress by the year 2040 (Table 1). While all show increased risk and vulnerability due to the impacts of climate change, more detailed vulnerability assessments would be imperative to strengthen the climate basis and to determine the final list of projects for implementation.

Table 1: Summary of municipal vulnerabilities for potential indicative projects

PILOT MUNICIPALITIES (Showing Treated Water Output from WRP Ml/d)	Green Book Projected Vulnerability 2050 Median Climate Scenario Exposure E2		WRI Aquaduct Risk Tool
	Medium Population Growth	High Population Growth	Water Stress 2040
Eastern Cape			
Nelson Mandela Metropolitan Municipality (40 Ml)	40-60% deficit	60-80% deficit	>80% Extremely High
Free State			
Mangaung Metropolitan Municipality (25 Ml)	0-20% surplus	0 -20% deficit	20-40% Medium High
Gauteng			
City of Ekurhuleni (60 Ml)	40-60% deficit	60-80% deficit	20-40% Medium High
City of Johannesburg Metropolitan Municipality (50 Ml)	60-80% deficit	100% deficit	20-40% Medium High
City of Tshwane Metropolitan Municipality (30 Ml) Project 2	40-60% deficit	60-80% deficit	>80% Extremely High
Kwa Zulu Natal			
eThekwini Metropolitan Municipality (100 Ml)	20-40% deficit	40-60% deficit	20-40% Medium High
Western Cape			
City of Cape Town Metropolitan Municipality (40 Ml) Project 1	20 -40% deficit	40-60% deficit	>80% Extremely High
Drakenstein Local Municipality (10 Ml)	0 - 20% surplus	0 – 20% deficit	>80% Extremely High
Indicative Projects			
City of Cape Town Metropolitan Municipality (40 Ml) Project 2	20 -40% deficit	40-60% deficit	>80% Extremely High
City of Tshwane Metropolitan Municipality (30 Ml) Project 2	40-60% deficit	60-80% deficit	>80% Extremely High

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