GROUNDWATER MANAGEMENT INSTITUTE

DETERMINING DEPENDENCY AND VULNERABILITY OF GROUNDWATER OF COASTAL CITIES (CAPE TOWN AND DAR ES SALAAM)

Groundwater Vulnerability Assessment: Cape Town

July 2025

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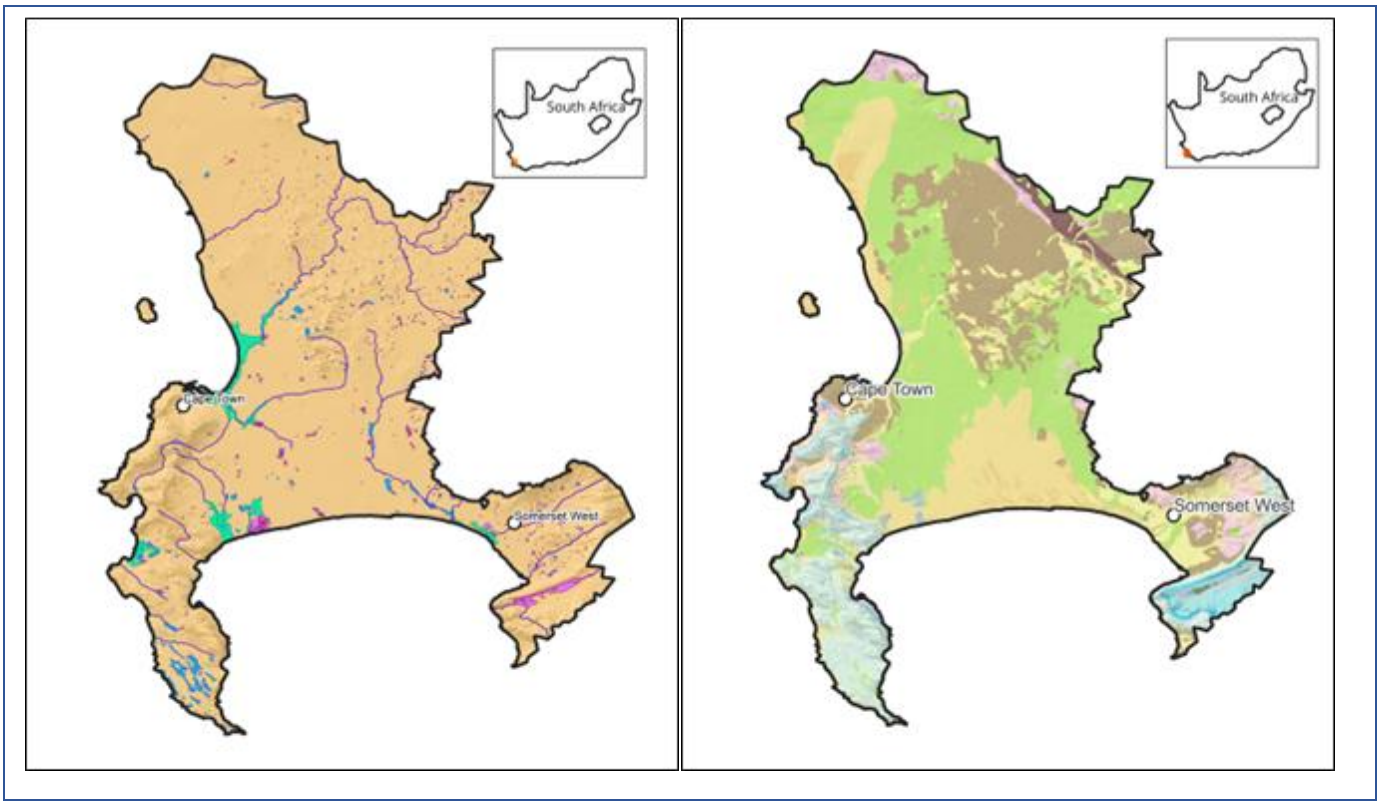
Groundwater Vulnerability Assessment: Cape Town



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SADC-GMI

GROUNDWATER MANAGEMENT INSTITUTE

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List of Abbreviations

~ - approximately
° - degrees
> - greater than
< - less than
% - percent
BMB - Biodiversity Management Branch
BOCMA - Breede-Olifants Catchment Management Agency
BHN - Basic Human Needs
CBA - Critical Biodiversity Areas
CBD - Central Business District
CCT - City of Cape Town
CFA - Cape Flats Aquifer
CMA - Catchment Management Agency
DAWASA - Dar es Salaam Water and Sewerage Authority
DM - District municipality
DWS - Department of Water and Sanitation
e.g. - example
EIA - Environmental Impact Assessment
EWR - Environmental Water Requirements
GESI - Gender Equity and Social Inclusion
GDE - Groundwater-dependent ecosystems
GIZ - German Agency for International Cooperation
GRACE - Gravity Recovery and Climate Experiment
GWP - Global Water Partnership
Hydstra - Hydrological Data Management System
HSG - Hydrological soil group
i.e. - in other words
IPCC - Intergovernmental Panel on Climate Change
IT - Information Technology
IWRM - Integrated Water Resource Management
KBAs - Key Biodiversity Areas
km - kilometre
m - metre
m/s - metres per second
mamsl - metres above mean sea level
MAP - Mean Annual Precipitation
MAR - Managed Aquifer Recharge
mm - millimetres
mm/a - millimetres per annum
NEMA - National Environmental Management Act
NFEPAs - National Freshwater Ecosystem Priority Areas

NGA	-	National Groundwater Archive
NGO	-	Nongovernmental Organisation
NWA	-	National Water Act
NWRS	-	National Water Resource Strategy
PCAs	-	Potentially Contaminated Activities
PHA	-	Philippi Horticultural Area
SADC	-	Southern African Development Community
SADC-GMI	-	Southern African Development Community – Groundwater Management Institute
SADC-GIP	-	Southern African Development Community – Groundwater Information Portal
SAWS	-	South African Weather Services
SLR	-	Sea-level rise
SuDS	-	Sustainable Drainage Systems
SVI	-	Social Vulnerability Index
TBA	-	Transboundary Aquifer
TMG	-	Table Mountain Group
TOR	-	Terms of Reference
UNICEF	-	United Nations International Children's Emergency Fund
WMA	-	Water Management Area
WASH	-	Water and Sanitation Hygiene
WARMS	-	Water Authorisation and Registration Management System
WCWSS	-	Western Cape Water Supply System
WMS	-	Water Management System
WSA	-	Water Service Authorities
WSP	-	Water Service Providers
WUA	-	Water Use Associations
WUL	-	Water Use Licence

1. Introduction

1.1. Background

Southern Africa is home to approximately thirty (30) transboundary aquifers (TBAs) and numerous national strategic aquifers that support the primary water needs and livelihoods of a significant portion of the region's population. Because of climate change, reliance on groundwater has increased. Although there is a fair understanding of the strategic aquifers, increased data collection will enhance the capacity of institutions to sustainably manage groundwater resources. Furthermore, developing groundwater-specific data-sharing protocols among riparian states contributes to the integrated management of shared aquifers. There is a unique opportunity to establish groundwater monitoring networks and strengthen institutional frameworks for shared water management.

The Southern African Development Community Groundwater Management Institute (SADC-GMI), a subsidiary of the SADC Secretariat, is established as a Section 21 Not-for-Profit Company under South African law. The vision of the SADC-GMI is to ensure the equitable and sustainable use and protection of groundwater and be a Centre of Excellence in groundwater management and management of groundwater-dependent ecosystems in the region. The role of the SADC-GMI is to:

- Promote sustainable groundwater management and provide solutions to groundwater challenges in the SADC region through building capacity, providing training, advancing research, supporting infrastructure development, and enabling dialogue and exchange of groundwater information.
- Conduct and support the SADC Member States in groundwater research, and serve as a focal interlocutor with national, regional, and international groundwater initiatives.
- Promote the sustainable conjunctive use of surface and groundwater.

As part of their programme to provide solutions to groundwater challenges, SADC-GMI embarked on a project to investigate and provide management strategies for **Groundwater Dependency and Vulnerability in the Coastal Cities of Dar es Salaam and Cape Town.**

Groundwater Dependency and Vulnerability in Coastal Cities

The dependency and vulnerability of coastal cities stem from multiple factors. Rapid urban growth and population increases drive higher water demand, often met by groundwater due to insufficient surface water sources. Many urban authorities struggle to supply water through reticulated systems, leaving informal settlements reliant on shallow wells and boreholes.

Coastal cities are particularly susceptible to saltwater intrusion into aquifers, especially during dry seasons or due to excessive groundwater abstraction. Pollution from urban runoff, industrial activities, agricultural activities, and improper sanitation can degrade groundwater quality, making it unfit for consumption. Additionally, climate change has given rise to changing precipitation patterns, increasing temperatures and affecting groundwater recharge rates. These changes may increase water demand due to higher temperatures and evaporation, or reduced surface water availability, potentially leading to over-exploitation.

The urban sprawl in coastal cities, inadequate enforcement of regulations and improper management of groundwater resources can exacerbate these vulnerabilities. Given these challenges, this project aims to assess groundwater dependency and vulnerabilities of groundwater in the selected coastal cities of Cape Town and Dar es Salaam in the SADC region.

1.2. Project aims and objectives

The overall objective of this project is to determine the dependency and vulnerability of groundwater in coastal cities, using Cape Town and Dar es Salaam as case studies. This will involve engaging with stakeholders, conducting high-level hydrogeological and environmental assessments, identifying gaps in the current monitoring networks, assessing vulnerability factors, evaluating the impacts of pollution and climate change, and incorporating socio-economic and gender dynamics. As part of this, a conjunctive management strategic action plan will be developed to build resilience in each city. These strategic action plans will provide frameworks to guide sustainable groundwater use, mitigating risks and enhancing resilience to climate change and environmental stresses in coastal cities.

This groundwater vulnerability assessment evaluates the risks to groundwater quality and availability posed by contamination from human activities, over-abstraction, reduced recharge and sea level rise using existing data and information. This assessment also evaluates the implications of groundwater vulnerability on various groundwater users, such as municipalities, communities, industries and the environment. These findings are crucial for identifying high-risk areas and form the basis for developing a conjunctive management strategic action plan that will guide the sustainable use of groundwater resources in Cape Town.

1.3. Methodology

This assessment adopts a qualitative risk-based approach to evaluate groundwater vulnerability in Cape Town, focusing on the combined influence of hazards, aquifer vulnerability, and the socio-economic vulnerability and coping capacity of groundwater users and ecosystems. The aim of the qualitative risk-based approach was to use available data and expert judgement to highlight key areas of concern and priority risk zones for further management focus.

For the context of this project, the following terms are defined and described below:

Groundwater dependency refers to the reliance on groundwater for both human consumption and aquatic ecosystems (i.e., groundwater-dependent ecosystems, GDEs).

- In coastal cities like Cape Town and Dar es Salaam, increasing urbanisation and population growth increase water demand for human consumption, resulting in an increased reliance on groundwater due to inadequate surface water sources.
- Groundwater also plays a vital role in sustaining groundwater-dependent ecosystems, such as coastal wetlands and estuaries, which are crucial for maintaining biodiversity and ecological balance.

Groundwater vulnerability refers to how susceptible an aquifer is to the threats affecting the groundwater resource itself, the ecosystems it supports, and its availability and suitability for human use.

- In the context of this study, the term also includes the vulnerability of the communities and ecosystems that depend on the groundwater resources. E.g.:
    - Is groundwater used? How much groundwater is used? What is it used for? (e.g. domestic supply, agriculture, garden watering, etc.). What are the health implications of contamination? If surface water/soil is in contact with contaminated aquifer, are people in direct contact with contamination?
    - Do industries/agriculture use water? Do they have alternative sources, if groundwater is polluted or reduced in yield?
    - If municipal water supply is disrupted as a result of contamination or reduced water availability, what other sources exist?

- Vulnerability of ecosystems can also usefully be split into three main components, sensitivity (i.e., the extent of **dependency** of an ecosystem or water users on water resources, whether ground- or surface water), adaptive capacity or **resilience** (i.e. capacity or ability to respond to shifts in drivers, such as climate or water quality, and their consequences), and exposure to stressors or **hazards** (i.e., the probability of being exposed to a certain impact) (Stuart-Hill et al., 2012; Esterhuyse et al., 2014).

Resilience or **Coping Capacity** refers to the capacity of the affected ecosystem or community to deal with an impact, to "bounce back" (i.e. persist and recover) to status quo after a crisis or disaster, and potentially to "bounce forward" (i.e. adapt and transform) to something new that is better suited to emerging conditions.

- This includes institutional measures such as laws, regulations and by-laws, the effectiveness of their implementation, existing monitoring networks and regular data analysis, as well as the capacity of institutions, communities and individual users to cope with groundwater related disasters. It also includes the resilience of ecosystems.

Hazards or **threats** are events or circumstances that potentially negatively impact on the groundwater resources. Key hazards include land use activities leading to water pollution, contamination, over-abstraction, climate change and seawater intrusion. The exposure to hazards is expressed in terms of probability.

The overall **Risk** of negative impact on groundwater users and the environment takes into account the likelihood of a **hazard** occurring (including severity of adverse effects on the groundwater resource, water users and receiving environment), the **vulnerability** of the receiving environment, and the **coping capacity** (or resilience).

- Key risks include contamination rendering the water quality unsuitable for the users, and reduction in water storage and discharge leading to less water available for users, seawater intrusion and degradation of groundwater-dependent ecosystems. These factors can compromise the availability and quality of groundwater for the people and ecosystems that depend on it.

Hazard and vulnerability mapping was conducted for specific components of the assessment (i.e., contamination sources, aquifer vulnerability, recharge decline), using a relative scoring system (1–5) for individual factors such as hazard likelihood, aquifer sensitivity and vulnerability. For mapping outputs, hazard scores reflected the **probability and intensity** of different groundwater threats occurring, while vulnerability scores captured **the potential severity of impact** on aquifers, users, and ecosystems.

Where relevant, coping capacity considerations were included descriptively in the qualitative assessment. Rather than formally scoring coping capacity per area, the report reflects on broad socio-economic patterns, infrastructure differences, dynamic land use, and institutional capacity across Cape Town. This acknowledges the wide variability in how different user groups, municipalities, and ecosystems can respond to groundwater risks, shaped by factors such as income levels, service provision, groundwater governance, and water infrastructure investments.

This assessment extends beyond hydrogeological analysis by incorporating the social, economic, and governance dimensions that shape groundwater risk exposure and vulnerability. The aim was to produce a practical, decision-support tool that identifies where hazards, aquifer vulnerability, and user exposure overlap. The final risk insights in this report are narrative and spatially descriptive, designed to highlight priority risk areas and user groups most in need of management attention.

2. Study Area

2.1. Description of the study area

2.1.1. Locality

Cape Town is a coastal city in the Western Cape Province of South Africa. It is located at the southwestern tip of the African continent, along the Atlantic Ocean and covers an area of 2,461 km² (see **Figure 2-1**). Cape Town is South Africa's oldest city, the second-largest by population and represents the country's legislative capital (de Visser, 2016). It comprises urban, residential, commercial, industrial, agricultural, and natural conservation areas. Agriculture is the largest consumer of groundwater in Cape Town, with significant use in the Philippi Horticultural Area (PHA) and at various wine farms, particularly in Durbanville and Constantia.

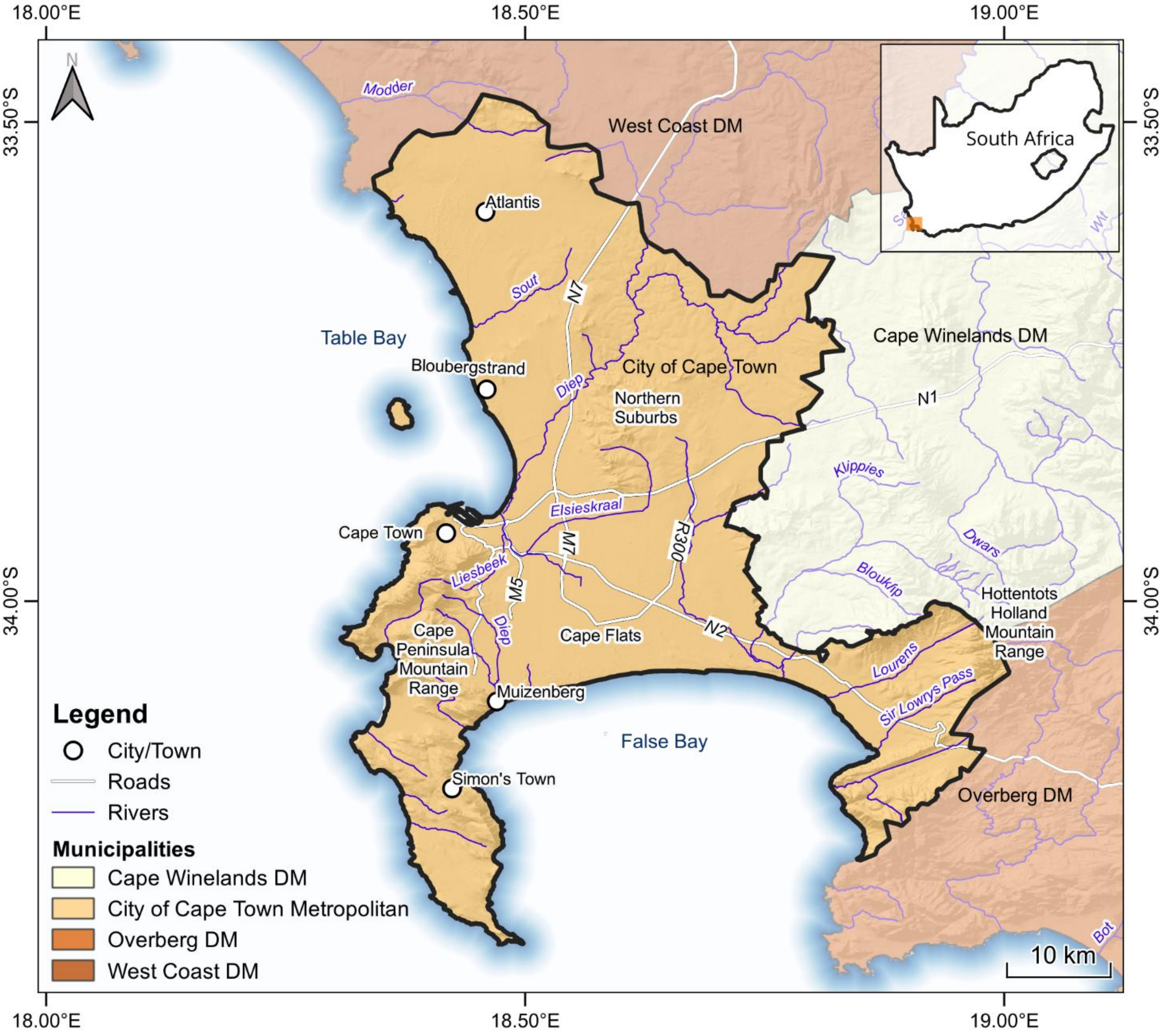

Figure 2-1 **Locality map of the study area within the City of Cape Town municipal boundary.**

The City of Cape Town's population has been growing over the years, with an estimated annual growth rate of 1.21%. The population increased from 3,740,026 in 2011 to a projected population of 4,426,062 by 2025. In 2011, 96.8% of the population relied on regional or local water schemes. By 2022, this reliance decreased to 96.6%. Borehole usage increased from 0.48% (17,779) in 2011 to 1.35% (57,474) in 2022. Other minor water reliance included rainwater storage tanks. The reliance on other informal water sources decreased from 1.72% in 2011 to 0.82% in 2022, possibly due to improved access to formal water supplies.

2.1.2. Topography and Geology

Topographically, Cape Town contains several major topographical features. The Cape Peninsula mountain chain, including Table Mountain, marks the western end of the Cape Fold Mountain range, with its highest portion sitting at 1,086 m. Its main topographical feature is its 3 km plateau, which is accompanied by another plateau extending to the south. Eastward, this mountainous terrain transitions to the low-lying, flat expanse of the Cape Flats. Flat, gently sloping plains can be found throughout the region up until the base of the Hottentots Holland in the east. This portion of the Cape Fold Belt is dominated by dramatic ridges and steep slopes before transitioning into rolling hills and agricultural plains. Further north and northeast from Cape Town Central Business District (CBD) towards the northern suburbs, the landscape becomes slightly undulating as it rises into foothills. Westwards of the northern suburbs the elevation gradually decreases to a low-relief coastal plain, which extends up north along the coast.

Geologically, the Cape Town Municipality is underlain by Neoproterozoic/Namibian Malmesbury Group, which is represented by shales, siltstones, graywacke and feldspathic sandstones of the Tygerberg Formation. The Late Namibian to Cambrian Cape Peninsula Batholith of the Cape Granite Suite intrudes the Tygerberg Formation and forms the basement rocks of the Cape Peninsula, with other batholiths of the Cape Granite Suite outcropping in Kuilsriver, Darling and Somerset West (see **Figure 2-2**). Basement rocks and granites generally form low yielding weathered aquifers with poor water quality unless a particular fault/fracture is intersected with higher groundwater potential.

The erosion resistant, high elevation Cape Peninsula mountain chain and Hottentots Hollands mountain range comprises sandstone-dominated formations of the Ordovician to Early Devonian Table Mountain Group (TMG; forming part of the larger Cape Supergroup with the Bokkeveld and Witteberg Groups). The Cape Peninsula mountain chain comprises rocks of the Graafwater and Peninsula formations of the lower TMG. Whereas the Hottentots Hollands comprises rocks of the Peninsula, Pakhuis, Cedarberg, Goudini, Skurweberg and Rietvlei formations of the TMG (see **Figure 2-2**). The rocks of the TMG form high yielding fractured rock aquifers with good water quality, particularly the Peninsula and Nardouw (Skurweberg and Rietvlei formations) aquifers.

Within the Cape Flats area and the west coast north of Cape Town CBD, the weathered Malmesbury Group and Cape Granite Suite basement rocks are unconformably overlain by fluvial, marine and aeolian Tertiary and Quaternary sedimentary deposits of the Sandveld Group. The sedimentary deposits are usually composed of interbedded sands, clay, clayey sand, calcrete, sandstone, coarse gravels, and peats. The Sandveld Group is comprised of the Elandsfontyn, Varswater, Langebaan, Velddrif, Springfontyn and Witzand formations, though not all formations are present throughout the study area (see **Figure 2-2**). These sediments form major primary sedimentary aquifers such as the Cape Flats Aquifer (CFA), Atlantis aquifer and the West Coast aquifer. These primary aquifers can be high yielding but are vulnerable to contamination due to their unconfined nature and high infiltration rates.

The basement Tygerberg Formation and Cape Granite Suite were structurally deformed (i.e., fractured, faulted and folded) by both the Late Namibian-Cambrian Saldanian and Permian-Triassic Cape Orogenies. Jurassic-Cretaceous break-up of the Gondwana supercontinent resulted in the reactivation and normal faulting of existing, generally NW-SE orientated structural trends within the basement rocks. Opening of the South Atlantic during Gondwana break-up also resulted in the intrusion of the ~NW-SE orientated False Bay Suite dolerite dyke swarm, which intruded both basement rocks and TMG in the Cape Town region.

The overlying TMG (and Cape Supergroup as a whole) was extensively deformed by folding and transpressional (strike-slip and compressional/thrust) faulting during the Cape Orogeny, and transtensional (extensional/normal and strike-slip) faulting during Gondwana break-up. **For a more detailed study area description, including sections on climate, land use and hydrology, refer to the Groundwater Dependency Report** (SADC-GMI, 2025)**.**

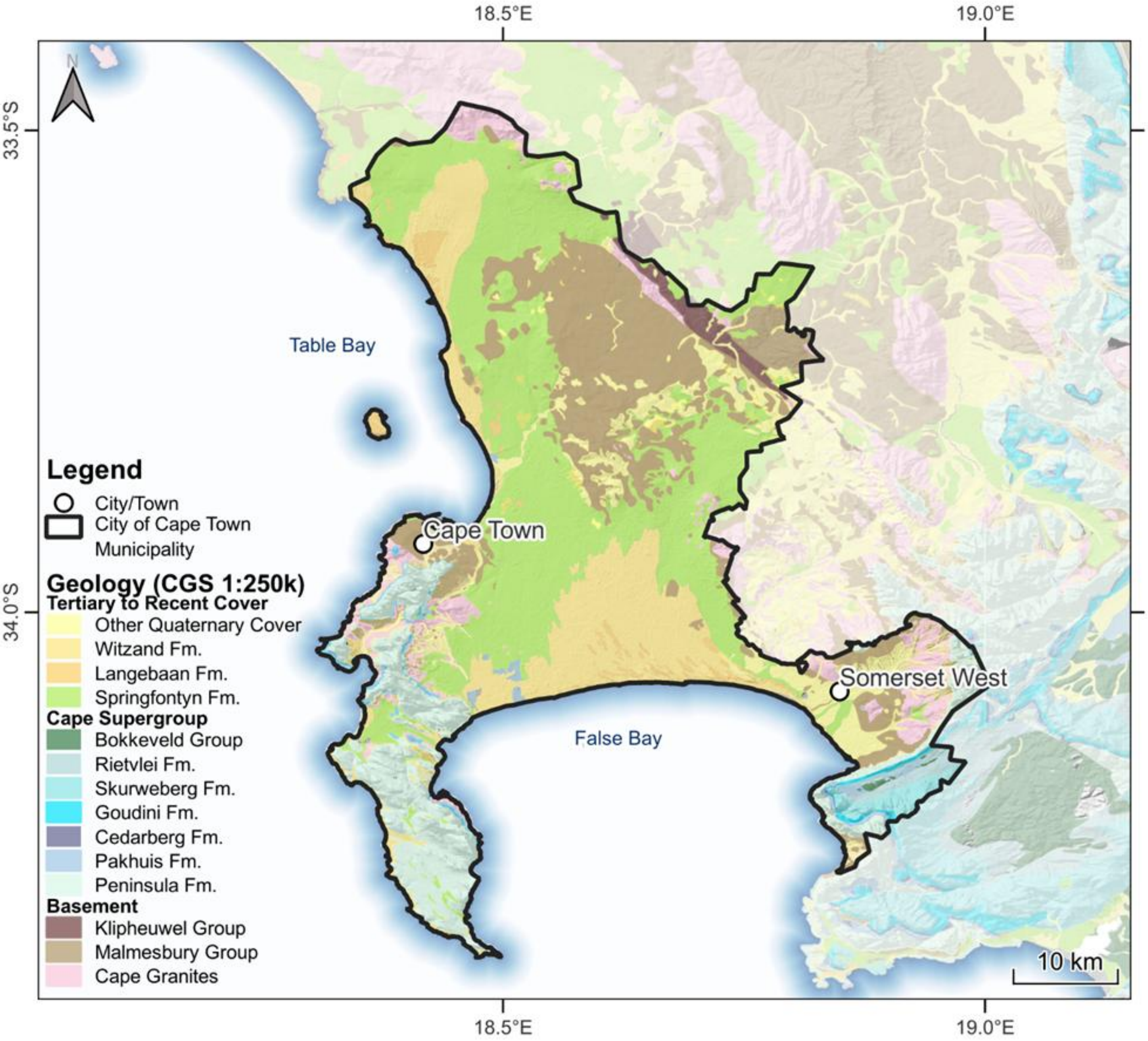

Figure 2-2 **Geological map of the City of Cape Town and surrounding areas.**

2.1.3. Hydroclimate

Cape Town lies within the greater region of the Western Cape which is classified as Csb (warm, temperate, and dry), according to the Köppen and Geiger classification system (Peel et al., 2007). This Mediterranean (semi-arid) climate regime is characterised by cold, wet winters and warm, dry summers (see **Figure 2-3** and **Figure 2-4** showing the classic Mediterranean bell curve). Precipitation is predominantly linked to frontal systems coupled with the westerly wind belt and the associated storm tracks that dominate the southwestern Cape in winter (June to August), while the South Atlantic high-pressure system dominates the austral summers (December to February) – pushing the frontal systems further south, resulting in warm, dry and windy summers (du Plessis and Schloms, 2017).

The mountainous peninsula topography, and twin-ocean setting of Cape Town, can result in localised micro-climates which provide variations to the standard Mediterranean model. Rainfall, temperature, and winds vary across the low altitude CFA and are modified and affected by the east and west high elevation boundaries of the TMG, and the proximity of weather stations to the two oceans with differing temperature regimes (du Plessis and Schloms, 2017). Atlantis is situated along the West Coast at ~180 mamsl, with a “fair topographic gradient towards the coast” whereby “Dassenberg, Kanonkop and Mamre form the highest points in the area, at heights of 210 to 410 mamsl” (Bugan et al., 2016). Comparatively, the TMG area includes some of the highest rainfall zones in South Africa, albeit very localised. In general, the regions of high rainfall coincide with topographically elevated mountain chains, mainly underlain by erosion resistant, but highly fractured TMG rocks, including the Hottentots-Holland Mountains situated to the north. Most of the annual rainfall occurs in the months from April to August brought about by successive low-pressure and low-temperature frontal systems. There is also a significant contribution to the local water balance from mist capture at altitude in the montane fynbos vegetation. Occasional snowfalls occur on the mountains during winter which contributes towards protracted aquifer recharge and stream flow once melted. The 30-year Climate Norm[1] Mean Annual Precipitation (MAP) for the City of Cape Town ranges from 431 millimetres per annum (mm/a) in Atlantis and 499 mm/a in the CFA, to 1 136 mm/a in the TMG area.

Seasonal temperature fluctuations follow the southern hemisphere Mediterranean climate trend of January/February (mid- to late-summer) maximum and July/August (mid- to late-winter) minimum average temperatures. Average winter temperatures range from ~10°C in the TMG to ~12°C in the CFA and Atlantis; while average summer temperatures range from ~19°C in the TMG to ~22°C in the CFA and Atlantis (see **Figure 2-4**). The Cape Flats is predisposed to winter temperature inversions during anticyclonic circulations, maintaining cold air close to ground level, which is capped by warmer air at elevation. This impacts the observed minimum temperature and is responsible for winter episodes of air pollution. Average temperatures in the Atlantis area closely follow the trend for the West Coast region of South Africa. The cooling influence of the Atlantic Ocean moderates the higher temperatures of the summer season, resulting in cooler summer temperatures along the coastal boundary and an increasing trend inland. The converse is true in winter with cooler temperatures in the elevated inland regions, increasing slightly towards the coastal strip (Fick and Hijmans, 2017). Lower average temperatures in Atlantis during winter coincide with the higher mean annual rainfall period from April to September and recharge rates are expected to be particularly good during these months. Average temperatures within the TMG area vary spatially based on altitude, aspect and relief. The lower temperatures, both in summer and winter, are recorded at higher altitudes in the montane regions, while the Theewaterskloof basin and Cape Flats lowlands (Somerset West) record the higher temperatures. Similarly, north facing slopes are warmer.

The Cape Flats region is subject to persistent cool and moist maritime air from Table Bay in the north and False Bay in the south. These winds have a moderating influence on temperature, cooling summer maximums and rising winter minimums, as well as overriding the winter inversion layer (during no-wind conditions). An annual NW–SE axis, orientated at 138° from the north, dominates across False Bay (Pfaff et al., 2019), and therefore winds across the Cape Flats are more southerly than southeasterly. Wind speeds are higher in the mountainous areas of the TMG, with the highest velocities being experienced along the ridge of the Hottentot-Holland Mountains towards Steenbras and around to the Kogelberg Mountains in the south. Wind speeds reduce as they approach the lower-lying areas of the CFA and Atlantis. Average winds blow at ~5 metres per second (m/s) in summer, with wind gusts exceeding 16 m/s. These peak wind events are regularly aligned with northwesterly storm events (June) and southeasterly extreme winds (the Cape Doctor, September to March). There is a southwest and northeast component to the Atlantis wind regime, suggesting that the West Coast is more inclined towards an even and four-quartered spread of winds and not as bimodal as the dominating SE/NW axis of the Cape Peninsula, however the predominate direction is from the southeast.

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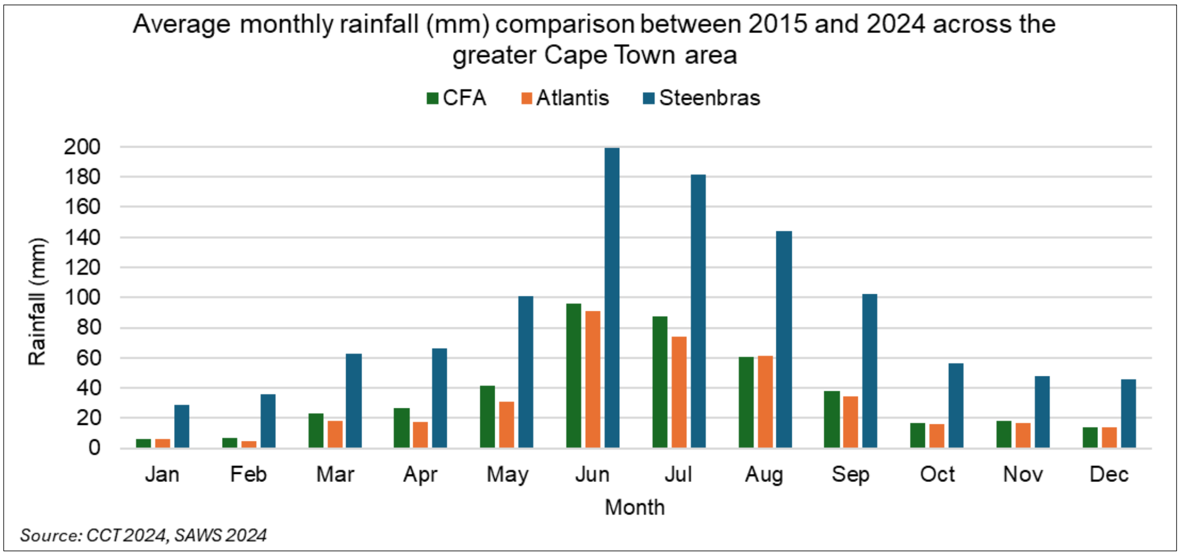
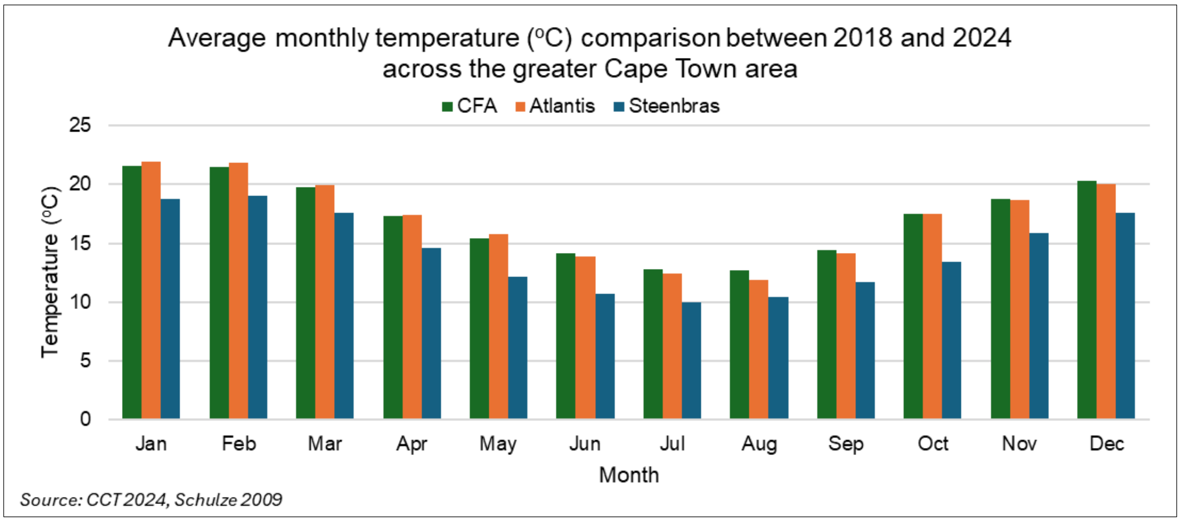
[1] Climate Norm is a three-decade average of climatological parameters, the latest of which is 1991 to 2020.

The El Niño Southern Oscillation (ENSO) is a natural, reversible and temporary event that influences the intensity and distribution of precipitation (Schulze and Schütte, 2023). Climate change is an irreversible permanent event resulting from anthropogenic activities. The drivers of climate change relative to water resources are rainfall, evaporation, and temperature and the responses are runoff, recharge, and extreme events. According to the Intergovernmental Panel on Climate Change (IPCC) and Schulze and Schütte (2023), climate change is forecast to reduce mean annual precipitation and alter precipitation patterns resulting in episodes of higher and lower than average precipitation therefore increasing the risk of flooding and droughts as seen with the 'Zero Day' event.



Source: CCT 2024, SAWS 2024

Figure 2-3 **Average monthly rainfall (mm) between 2015 and 2024 across the greater Cape Town area comparing Cape Town (green bar), Atlantis (orange bar), and Steenbras (blue bar). The Mediterranean bell curve is clearly evident with peak rains in winter (June to August). As expected, the low-lying coastal areas (Atlantis and CFA) receive substantially less rainfall than the mountainous catchment recharge zone (Steenbras) where June rains range from 91 mm to 200 mm, respectively.**



Source: CCT 2024, Schulze 2009

Figure 2-4 **Average monthly temperature (ºC) between 2018 and 2024 across the greater Cape Town area comparing Cape Town (green bar), Atlantis (orange bar), and Steenbras (blue bar). Note: long-term temperature data is unavailable in Steenbras and therefore Schulze (2009) historical data (1950-2000) is used as a proxy. As expected, the mountainous catchment recharge zone (Steenbras) reaches cooler summer temperatures than the low-lying coastal areas (Atlantis and CFA) where January temperatures range from 19ºC to 22ºC, respectively.**

2.1.4. Environmental

There are several major perennial rivers and canals that exist. Along the Cape Peninsula mountain chain in the south, major perennial rivers include the Houtbay or Disa River, Silvermine River and a number of smaller, pristine rivers in the Table Mountain National Park. The Houtbay and Silvermine Rivers remain mostly unmodified in their upper reaches on the mountains of the Cape Peninsula, with many anthropogenic impacts leading to significant modifications to the natural characteristics of the rivers in their lower reaches. This is also true of the Liesbeek River, which rises on the Cape Peninsula mountain chain, but which soon becomes a modified system as it enters the urban area, 70% of the length of the Liesbeek River is canalised. The Diep River is another partially canalised perennial river that rises on hills in the north of the City. The river flows through intensely cultivated parts of the City and then into the urbanized suburbs, becoming a severely polluted river before it flows into its estuary. On the Cape Flats, the Eerste / Kuils River and Lotus Rivers constitute the main waterways. Both systems are regarded as natural rivers which have been heavily modified by means of canalisation, and severely impacted in terms of water quality. Both river systems feed into estuaries on the City's coastline.

The Cape Peninsula mountain chain and the Hottentots-Holland mountains around the Steenbras Dam are known for many groundwater-fed springs which feed into tributaries, major rivers, wetlands, surface water bodies and the ocean.

There are over 7000 wetlands within the boundaries of the City of Cape Town. These wetlands fall into five broad types, based on their hydrogeomorphic characteristics: seeps, depressions, floodplain wetlands, and channelled or unchannelled valley-bottom wetlands (Snaddon and Day 2009).

- Seeps (either connected to or disconnected from the riverine network) predominate in most of the City's catchments, most of which include mountainous areas and steep slopes, which is where seeps tend to dominate. Many of these seeps are sustained by groundwater, especially in high groundwater discharge areas. Seeps are also important ecosystems for recharge of groundwater and for streamflow regulation, as they regulate the infiltration and discharge of water to surface by virtue of their ability to retain water in organic soils and plant communities ("green water[2]") for longer than dryland soils.
- Depressions tend to occur in the lowlands, which represent a large proportion of several of the City's catchments – such as Atlantis, Eerste / Kuils River, Mitchell's Plain / Khayelitsha, Salt River and Sout River catchments. The Noordhoek Valley in the west of the Peninsula also supports a number of depression wetlands that are connected to a network of streams draining off the surrounding mountain slopes. Depressions tend to be fed by precipitation and sometimes groundwater.
- Floodplain wetlands are dominant in the Diep River (Milnerton) and Sand River catchments, and are numerous in the Eerste / Kuils River catchment. The Diep and Sand rivers both have extensive floodplain flats associated with the lower reaches of the rivers – these are Rietvlei and Sandvlei respectively. Floodplain wetlands are sustained by surface flow from the lowland rivers associated with them.
- Channelled (with an obvious channel) and unchannelled valley-bottom wetlands are associated with many of the City's rivers, and tend to form when water seeps out of the river channel, or overtops the channel's banks during high flows.
- Estuaries (in the form of estuarine channels or depressions, and river mouths) are located in the Diep River, Eerste / Kuils River, Hout Bay River, Lourens River, Noordhoek, Sand River, Silvermine River, Sir Lowry's Pass River and South Peninsula catchments.

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[2] "Green water" is held in plants and soil, and is available for use only by plants.

2.1.5. Socio-economic

The City of Cape Town is South Africa's second-largest metropolitan area and serves as an economic and legislative centre, hosting both national parliament and a vibrant urban economy. With a population of more than 4 million people, it continues to experience significant growth and urbanisation (City of Cape Town, 2023a). This growth places considerable pressure on existing infrastructure, resources, and services, including water supply and sanitation.

Cape Town's economy is diverse, driven primarily by finance, tourism, agri-processing, manufacturing, and logistics (Western Cape Government, 2022). Despite its economic prominence, the city faces considerable socio-economic disparities. Income inequality is pronounced, with a Gini coefficient estimated at around 0.61, indicating deep-rooted socio-economic divides (City of Cape Town, 2022a). The unemployment rate stands at approximately 27%, with youth unemployment considerably higher, posing challenges for social and economic stability (Stats SA, 2022).

Historically entrenched spatial segregation continues to influence patterns of development, access to resources, and service delivery. Affluent suburbs enjoy reliable water infrastructure and services, whereas peripheral townships and informal settlements often face inadequate provision, limited access to reliable potable water, and increased vulnerability to water-related hazards (Turok and Scheba, 2019). According to data provided by the Department of Human Settlements (WCPP, 2022), there are currently 269 811 structures located across 806 informal settlements within the metro area. These informal settlements typically have limited basic services. Service backlogs have direct implications for groundwater quality (due to poor sanitation and pollution) and indicate the socio-economic vulnerability of a large segment of Cape Town's population.

Understanding this socio-economic context is essential when assessing groundwater vulnerability, as social disparities directly influence community resilience, adaptive capacity, and dependence on groundwater resources, especially during periods of water stress, such as the recent severe drought events (2015–2018), which highlighted the critical role of groundwater in sustaining Cape Town's water security (Ziervogel, 2019).

2.2. Description of Cape Town's Aquifers

Cape Town contains three main aquifer types, including the primary unconfined aquifers of the Sandveld Group, mainly the CFA and Atlantis Aquifer, secondary fractured rock aquifers of the TMG and weathered and fractured basement rock aquifers of the Malmesbury Group and Cape Granite Suite (see **Figure 2-5**).

The CFA, Atlantis Aquifer and TMG aquifers are moderate to high-yielding and can supply significant volumes of water, hence, the City of Cape Town has developed groundwater schemes that involve the abstraction of groundwater from these aquifers to diversify bulk water supply in the City. In addition to municipal use, these aquifers are essential to other groundwater users such as farmers within the PHA, which depend on the CFA. Industries, private users, and groundwater dependent ecosystems across the municipality also rely on these aquifers.

The primary aquifers have high permeability and recharge rates but are more vulnerable to contamination due to their shallow, unconsolidated nature. In contrast, the deeper TMG Aquifer offers better water quality and is less prone to contamination, though it recharges more slowly and is at risk of over-abstraction.

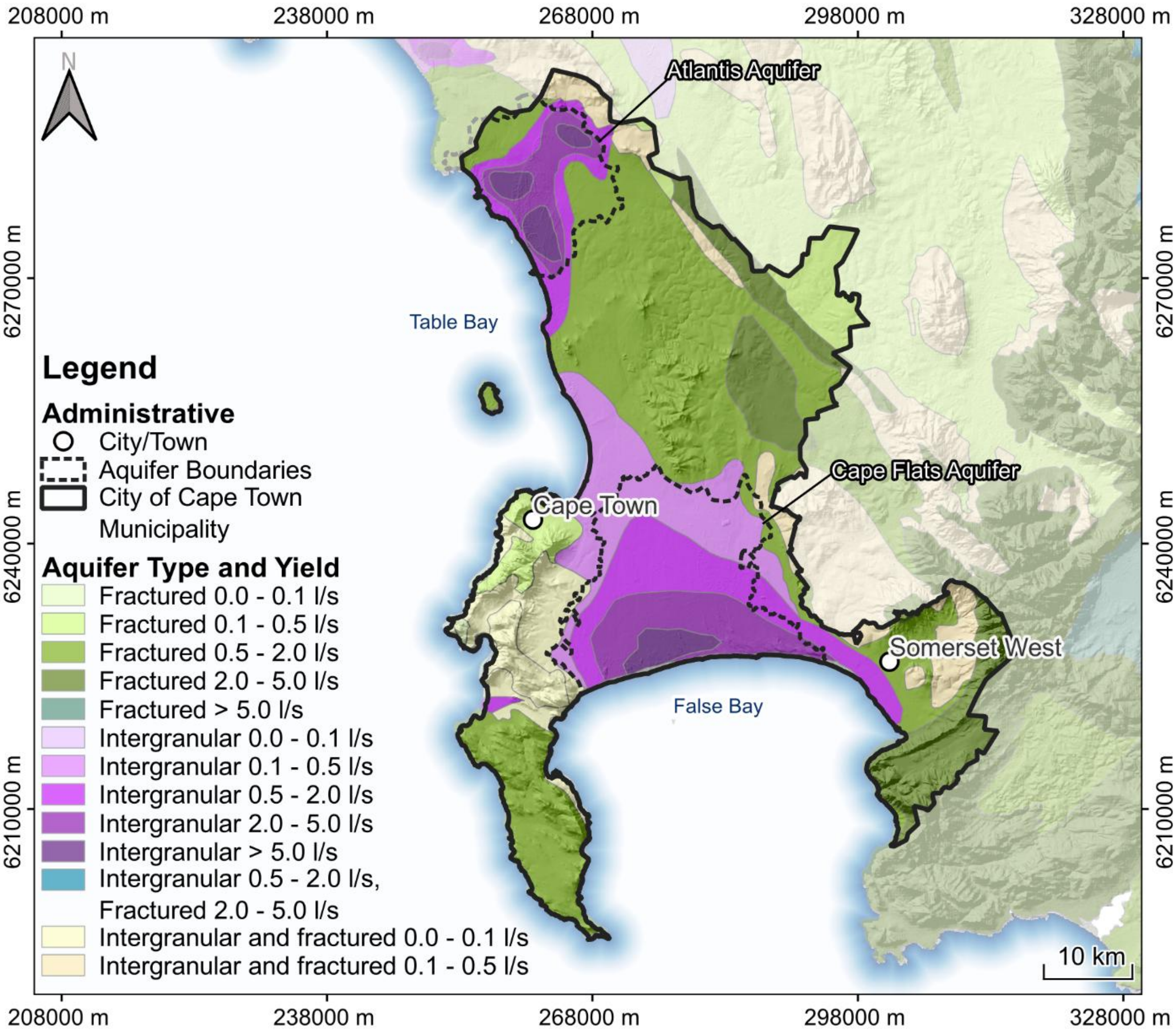


Figure 2-5 **Hydrogeological map of the City of Cape Town Municipality.**

2.2.1. Primary Aquifers

Cape Flats Aquifer

The Cape Flats covers an area of approximately 430 km², and extends from False Bay in the south to Tygerberg Hills and Milnerton in the northeast and northwest, respectively. Topographically, the region is characterised by a very low relief (hence the name "Cape Flats"), with elevations ranging from 0 mamsl along the False Bay coastline to approximately 110 mamsl in the northeast (Umvoto Africa, 2009; CCT, 2018).

The Cape Flats area is densely populated with formal and informal township residential areas, which form the major land use. The southeast sections comprise agricultural lands of the Philippi Horticultural Area (PHA), which produces approximately 60% of Cape Town's fresh produce. Industrial areas are located in the central, northern and northeastern parts of the Cape Flats. The region also contains important wetlands and conservation areas (e.g., Rondevlei and Zeekoevlei), primarily situated in the southern sections.

The CFA is a major unconfined coastal aquifer system underlying the Cape Flats region. It consists of fluvial, marine and aeolian Tertiary and Quaternary sediments (interbedded gravels, sands, clays, clayey sands, calcrete, sandstones and peat) of the Sandveld Group which overly basement shales of the Malmesbury Group and granites of the Cape Granite Suite. The CFA reaches a maximum thickness of 50-60 m within a palaeochannel (Elsieskraal old river channel) within the central portion of the aquifer and towards the coast. The palaeochannel contains fluvial deposits of the Elandsfontyn Formation which has coarse grained sands and gravels and then towards the coastline these are replaced by gravels and shells of the Varswater Formation. The CFA's heterogeneity results in varying aquifer conditions across the region. In some areas, localised clay layers, peat deposits and calcrete formation create localised semi-confined to confined conditions. This stratification leads to a dual aquifer system in portions of the CFA, with distinct hydrogeological characteristics between the upper unconfined and lower semi-confined/confined units.

At the broadest scale, the aquifer is predominantly unconfined (with groundwater within a few metres below the surface), and rivers and wetlands are likely to be hydraulically connected to the relatively shallow groundwater. Where the aquifer is semi-confined (e.g., within the deep gravels in the palaeochannels), or at small local scale, where the aquifer is semi-confined by laterally discontinuous calcrete or clay lenses, rivers and wetlands are only likely to be in hydraulic connection with the shallow groundwater in the uppermost unconfined sand unit.

Hydrostratigraphically, the Elandsfontyn, Varswater and Springfontyn formations form the major aquifer units within the larger CFA, which is a large heterogeneous, stratified, intergranular or primary (i.e., porous sedimentary/sandy) aquifer within the Sandveld Group. The CFA transmits water relatively rapidly with an average hydraulic conductivity of ~15-50 m/day, and a transmissivity of ~30-600 m^2/day (Adelana et al., 2010). Borehole yields range between 0.1-5 l/s yields but can be >30 l/s in areas of high hydraulic conductivity (where the thickest Elandsfontyn Formation gravels and Varswater Formation shells are intersected) (see **Figure 2-5**). Additionally, the CFA is characterised by high infiltration rates of ~10-250 mm/day.

These favourable hydrogeological conditions have supported decades of groundwater use by farmers in the PHA, which supplies a significant portion of agricultural goods to the Cape Town metropolitan region. However, the unregistered and unregulated use by these farmers poses challenges to the sustainable groundwater management of the aquifer. Following the 2015-2018 drought, the City of Cape Town targeted the CFA for bulk water supply, with the addition of managed aquifer recharge to supplement its response in groundwater levels to bulk water abstraction.

While beneficial for water supply, the high infiltration rates and unconfined nature of the CFA's surface sediments create an environment where the groundwater system is highly vulnerable to surface contamination, particularly in an urbanised environment with a multitude of different landuse activities (see **Figure 3-2**). Due to elevated levels salinity within the PHA some farmers in the PHA have opted to instead establish boreholes deeper into the Malmesbury Basement Aquifer. For the City of Cape Town, the quality of water in the CFA is still suitable for its abstraction and treatment.

With the growing dependency on the CFA for groundwater supply, the system has become increasingly susceptible to over abstraction. This can result in lowered water levels and yields, and may also result in saline intrusion due to the aquifers close proximity to the coastline. Consequently, the CFA faces significant vulnerability from both pollution and salinisation.

Atlantis Aquifer

The Atlantis Aquifer represents another major unconfined sandy aquifer system in Cape Town. Situated along the west coast between Melkbosstrand and Silwerstroom, this intergranular aquifer has served as a critical groundwater resource, supplying the industrial town of Atlantis with water for the past 40 years. Consisting of Sandveld Group sediments, its basal layer forms part of the Varswater Formation with its overlying material comprised successively of the Langebaan, Springfontyn and Witzand Formations. These sediments were deposited in shallow marine and aeolian environments producing distinct layers of shelly, calcareous, and quartz-rich sands.

The Atlantis Aquifer has a general thickness of ~40-60 m and is mainly classified as unconfined, however, due to the presence of intermittent clay and calcrete lenses in the Springfontyn formation, semi-confined conditions may occur (Theron et.al.,1992).

The intergranular Atlantis aquifer is classified, using the 1:500 000 Cape Town 3317 hydrogeological map, as having varying yield potentials based on location. On the outer margins where the aquifer is thinner, a moderate yield potential (0.5-2.0 l/s) is seen. Where the aquifer becomes thicker, the yield potential increases to moderate-high (2.0-5.0 l/s) and high (>5.0 l/s), which is also verified through the last ~40 years of groundwater production by the City, with some boreholes yielding >20 l/s.

The basement topography of the Atlantis Aquifer is uneven due to the nature of the Pre-Cenozoic surface which it overlies. This also effects the depth, thickness and composition of the aquifer units intercepted at any given locality, as sub-terranean ridgelines and paleo channels exist within the basement. Generally, groundwater within the aquifer drains to the Atlantic Ocean in the southwest of the project area, with some exceptions in the northern and eastern extents (Vandoolaeghe and Bertram, 1980).

The Atlantis Aquifer exhibits high infiltration and recharge rates (10-30% of MAP). Primary recharge zones occur where these sands are thickest, particularly in the Alantis dunes (see **Figure 2-6**). These favourable hydrogeological characteristics have made the Atlantis Aquifer an ideal site for Managed Aquifer Recharge (MAR), which has supplemented water supply for Atlantis and, more recently, Cape Town's municipal distribution network. Like the CFA, the Atlantis Aquifer's unconfined portion, composed of unconsolidated sands and sediments, remains highly vulnerable to contamination. Although the Atlantis Aquifer is adjacent to the Atlantic Ocean, the underlying basement topography ensures that all boreholes targeting the aquifer have end depths above mean sea level, thereby mitigating the risk of seawater intrusion due to abstraction.

While the aquifer faces contamination risks from the Atlantis industrial zone, its overall risk to pollution is lower than for the CFA due to limited development across its extent, and both the aquifers geology and topography. The overlying land of the Atlantis Aquifer remains predominantly vegetated and undeveloped.

Minor Primary Aquifers

There are also minor primary localised aquifers exist within the greater City of Cape Town Municipality (see **Figure 2-5**). Along the eastern slopes of the Cape Peninsula Mountain chain, primary unconfined systems exist of late quaternary boulder-rich mountain scree, talus sediments, and or thin deposits of Quaternary alluvial/fluvial sediments, sands and calcareous soils that overly basement granites of the Cape Granite Suite.

Groundwater from these primary aquifers is primarily used for domestic purposes in more affluent areas of the City of Cape Town. Wellpoints are commonly installed to access shallow groundwater for irrigation, domestic use, and as a backup supply during municipal service disruptions caused by maintenance or drought. In addition to these areas, thin deposits of Quaternary cover, such as those found in parts of the City where the CFA begins to thin, also support shallow wellpoint abstraction for residential irrigation and domestic use.

The dependency on these minor aquifers and their vulnerability are relatively low, as municipal supply is the main source of water to these areas and land use is restricted to mainly residential developments with a lower risk of contamination to groundwater. However, since domestic groundwater use falls under Schedule 1 of the NWA and does not require registration, managing and quantifying the dependency of these minor primary aquifers presents significant challenges. These minor primary aquifers are generally low yielding, therefore an increased dependency on these aquifers makes them vulnerable to over abstraction.

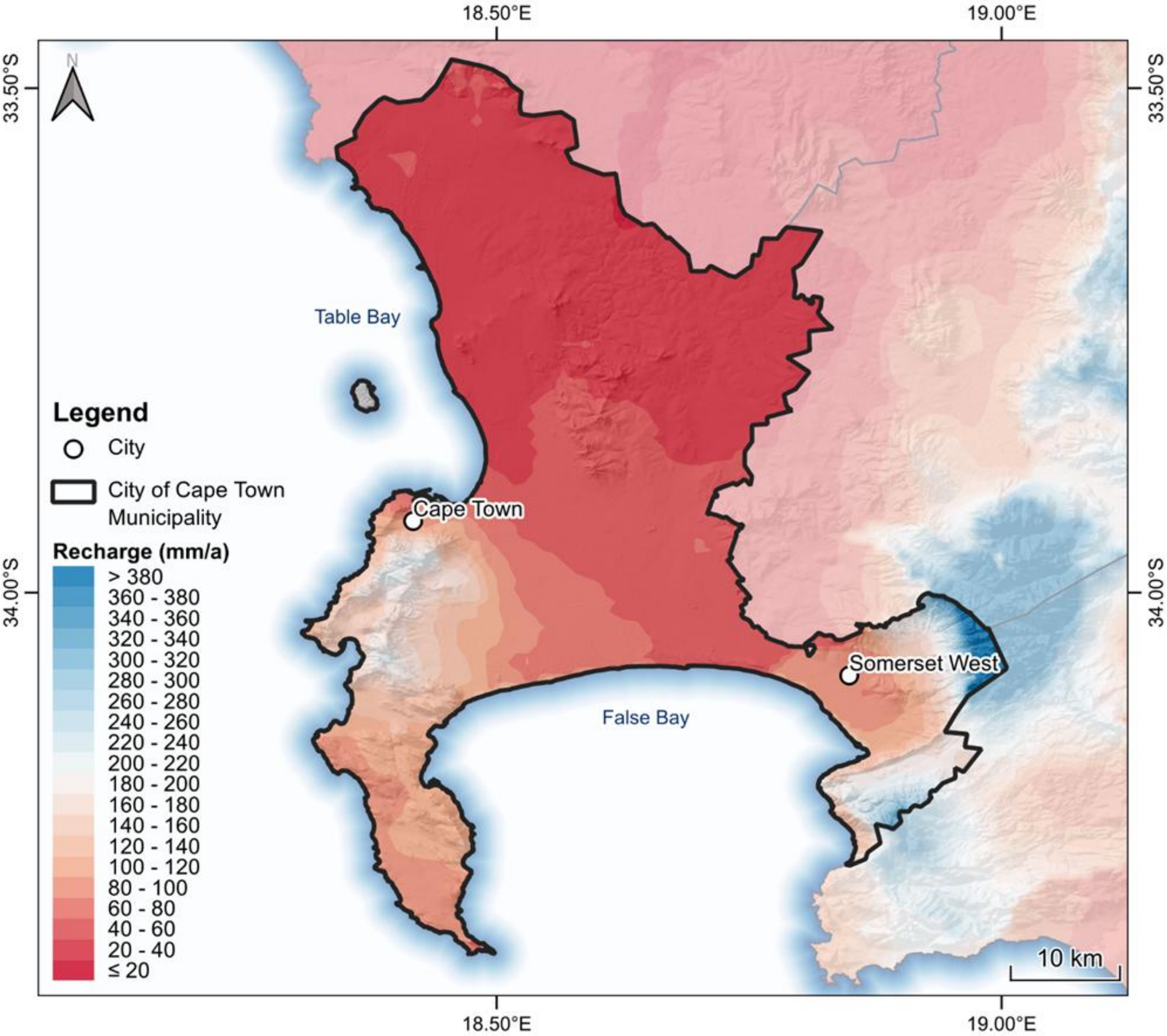


Figure 2-6 **Groundwater recharge zones for aquifer systems in the City of Cape Town Municipality (DWAF, 2006).**

2.2.2. Secondary Fractured Rock Aquifers

Table Mountain Group Aquifer

The Table Mountain Group aquifer area is predominantly mountainous and covered with karoo and fynbos shrublands with minor human inhabitation.

The TMG aquifers, like the CFA and Atlantis Aquifer are major aquifers used to supply the City of Cape Town water supply network. Comprised of layered sandstone, the TMG consists of two main water bearing aquifers, the Peninsula Aquifer and Nardouw Aquifer (see **Table 2-1**). The locations of these aquifer units vary according to location within the City of Cape Town Municipality. The Peninsula aquifer is comprised of the Peninsula formation (lower TMG), while the Nardouw Aquifer is comprised of the Skurweberg and Rietvlei formations (upper TMG).

The Peninsula aquifer can be found along the Cape Peninsula mountain chain on the southwest of Cape Town and below the Winterhoek Mega-aquitard, a layer separating the Nardouw and Peninsula aquifers beneath the Steenbras dam on the south to south-east side of the Hottentot Hollands mountain range (see **Figure 2-6**).

TMG aquifers are characterised as fractured aquifer systems with medium to high yields (2 – 5l/s and > 5l/s). The fractured setting of TMG aquifers is defined by three main components, namely faults, joints and bedding. Highly connected and permeable structures within the TMG are largely attributable to bedding fractures and structural brittle faulting. These structures can result in high density fracture networks with preferential flow paths. Overall complex geological structures originating from primarily, mechanical and some chemical processes, have resulted in a major secondary fractured system.

Recharge of the TMG aquifers can be difficult to quantify due its variability and complex geological structures, however the main mechanism of recharge is thought to be by precipitation over fractured outcrops with high recharge potential, and spatially where its main water-bearing formations are present and overlain by unconfined sediments.

Groundwater discharge features such as springs and seeps in the Cape Peninsula are closely linked to the structural and lithological controls within the TMG. Springs/seeps (groundwater dependent ecosystems) in the Cape Peninsula form primarily due to groundwater recharge in the fractured Peninsula Formation Aquifer, which occurs in high-relief areas through rainfall. The groundwater flows along faults and fractures, driven by topography, and interacts with underlying formations. Springs and seep zones form where the permeable Peninsula Formation meets the relatively impermeable Graafwater Formation aquitard or Cape Granite Suite aquiclude. This contact prevents further downward movement of groundwater, causing it to discharge at the surface. In some cases, vertical fractures allow groundwater to flow into the Graafwater Formation, saturating its permeable shale and siltstone layers. Water may then seep out along bedding planes or at contact points with the Cape Granite Suite. Groundwater from the Peninsula Formation may also recharge overlying alluvium, which can discharge at contact points with the Graafwater Formation or Cape Granite Suite. In rare cases, large faults or fractures may extend through the Graafwater Formation into the Cape Granite Suite, recharging deeper aquifers (Blake and Wise, 2023). **Figure 2-7** presents a conceptual model illustrating these groundwater flow paths and discharge mechanisms.

The quality of water from TMG aquifers typically exhibit good water quality, however groundwater from TMG systems can be acidic and low in both nutrients and salinity. Elevated levels of iron and manganese have also been known to occur. Notably, during times of water decline, the quality of groundwater from these aquifers have remained relatively unchanged.

Both the Peninsula and Nardouw aquifers are targeted for water supply to the City of Cape Town water supply scheme. Groundwater from boreholes in the Steenbras wellfield are pumped into the Steenbras Dam, bringing in a factor of conjunctive management (surface and groundwater). Most groundwater abstracted from the TMG, by the City, is from the Steenbras wellfield. Which is in a critically protected biodiversity area, therefore no formal developments occur within this area, minimising the risk of contamination to these systems. Moreover, the topographic location and layout of these aquifers also minimize contamination from the surface and prevent saltwater intrusion.

Both the Peninsula and Nardouw aquifers are targeted for water supply for the City of Cape Town's water supply scheme. Groundwater from boreholes in the Steenbras Wellfield is pumped into the Steenbras Dam, enabling conjunctive use of both surface water and groundwater resources. The majority of groundwater abstracted from the TMG by the City is sourced from this wellfield. Located within a critically protected biodiversity area, the Steenbras Wellfield is safeguarded from formal development, significantly reducing the risk of contamination. However, the recent influx of people into Cape Town has led to the rapid expansion of informal settlements across the region, including areas near Grabouw, which may pose a potential contamination risk to the underlying aquifer systems.

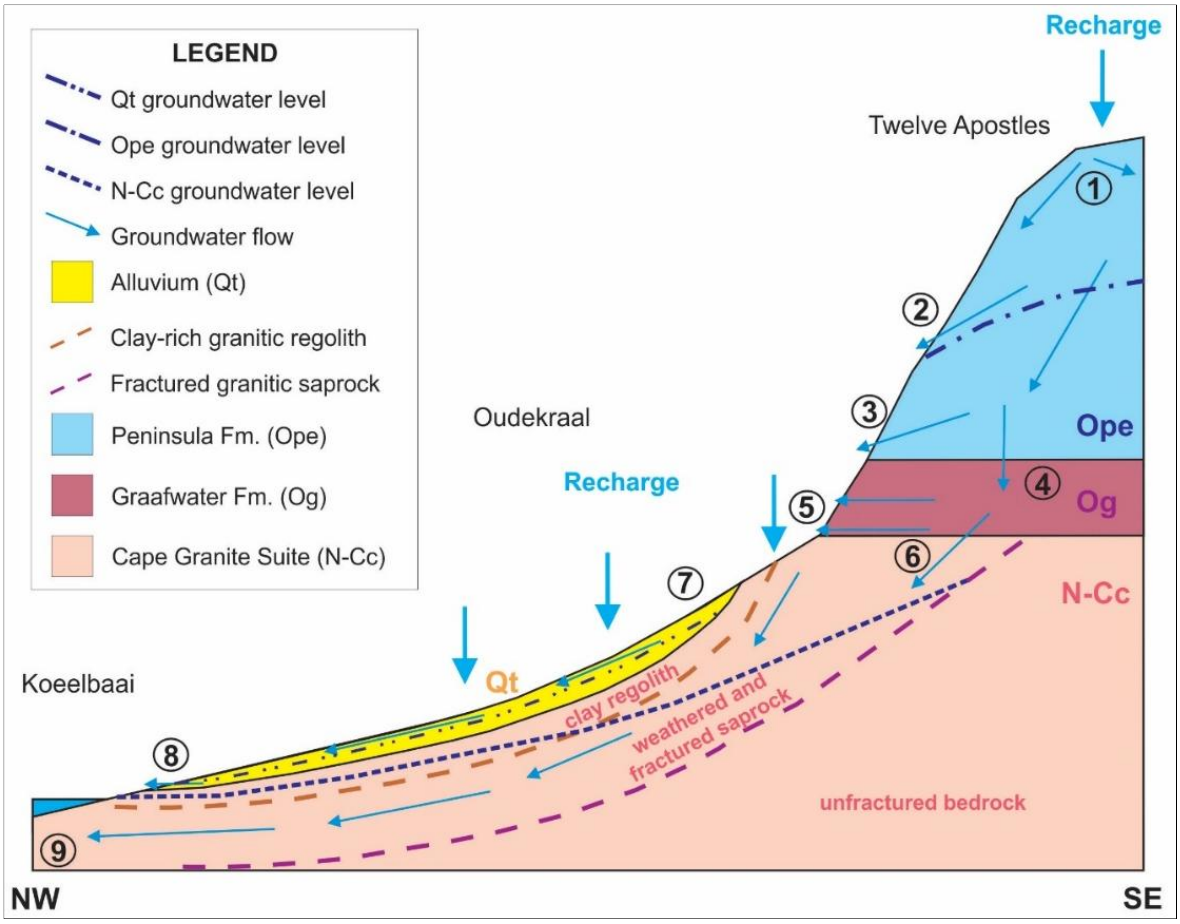


Figure 2-7 **Conceptual groundwater flow and surface water-groundwater interactions for the Cape Granite Suite basement aquifer, Peninsula Aquifer, and surface Quaternary primary aquifer within the Cape Peninsula area, resulting in spring or seep discharge (Blake and Wise, 2023).**

Water abstracted from the TMG along the Southern Peninsula is confined to private domestic use in residential areas and for irrigation in some few agricultural holdings. Domestic use of groundwater in some residential areas is limited to a back-up supply in instances where there are municipal disruptions or restrictions because of drought. Similarly to its counterpart in Steenbras and the surrounding areas, Vulnerability is quite low due to the land use activities which take place and the geological structure of the aquifer's formations. The dependency on groundwater, from the TMG aquifer, in the southern peninsula is low. The Steenbras wellfield is the main access point to TMG groundwater.

2.2.3. Intergranular and Fractured Basement Aquifers

Malmesbury Group Aquifer

The Malmesbury basement aquifer forms the geological foundation underlying most primary aquifers in the Cape Town Municipality (see **Figure 2-2**, **Figure 2-5** and **Table 2-1**). Composed of Tygerberg Formation sedimentary rocks, this system includes shales, phyllite, schist greywacke, limestone and quartzite. The faults and fractures in the basement rock create a secondary system, where groundwater is restricted to preferential flow along these pathways. However, the weathered area above the consolidated bedrock (consisting of saprolite and regolith) is typically the main water bearing zone. This portion of the aquifer forms an aquitard, storing water under semi-confined conditions.

Due to this dual structure, the Malmesbury Basement Aquifer is classified as both an intergranular and fractured aquifer system. Yields for the Malmesbury Basement aquifer range between low to moderate quantities (0.1 – 5 l/s). This is dependent on the thickness (controlled by the presence of weathered fracture zones) and clay content of the regolith/saprolite/saprock, as well as the presence of any major fault or fracture zones, intrusive contact zones (with the Cape Granite Suite) and/or intrusive dolerite dykes (with higher borehole yields possible in these zones of increased brecciation).

The high residence time of groundwater within the clay-rich regolith/saprolite (where present) and low transmissivity parent Tygerberg Formation shales usually results in relatively poor groundwater quality (due to the dissolution of natural salts present within the marine-deposited rock) e.g. high EC, high fluoride and high iron/manganese concentrations. Despite the general poor water quality, in some areas, such as the PHA, better water quality has been noted, which is potentially linked to recharge from dykes for faults propagating from the TMG, recharging the aquifer with better quality water. Overall, there is a relatively low dependency on its groundwater resources when compared to the primary aquifers in the region.

Natural recharge into the Malmesbury Group basement aquifer (through the thin overlying surface primary aquifer) is usually meteoric (rainfall), or via surface water (rivers, streams and wetlands) in areas with natural, non-urbanised cover. Lateral recharge may occur from the higher yielding, overlying Peninsula Aquifer into the basement aquifer, if large Saldanian/Cape Orogeny and Gondwana breakup-related regional structures such as fractures, faults and False Bay Suite dolerite dykes extend from the Cape Peninsula into the shales at depth (see **Figure 2-7**). Artificial recharge via unlined stormwater canals and domestic/sports field irrigation may also occur.

Cape Granite Suite

The hard-rock of the Cape Granite Suite is another source of groundwater from fractured basement aquifers in Cape Town. Located along the Southern Peninsula mountain chain, the northern suburbs and in east of the CBD, this system comprises of mostly gneiss and coarse grained porphyritic granites, with deformation structures forming its major water bearing zones (see **Figure 2-2**, **Figure 2-5** and **Table 2-1**. Faults and fractures in the granites were formed during the Saldanian and Cape Orogenies, with the later break-up of the Gondwana supercontinent, resulting in the reactivation and normal faulting of these existing structures.

Similarly to the Malmesbury Basement Aquifer, most groundwater is found within the weathered regolith (residual soil and saprolite) and saprock (weathered, fractured rock) above the un-weathered granites, this water is typically stored under unconfined or semi-confined conditions depending on the thickness of overlying weathered material (typically clay). Fractures and faults along this interface can also sometimes be filled with weathered clays, inhibiting the movement of water and resulting in geological units with a low hydraulic conductivity.

The Cape Granite Suite can be characterised as either a fractured aquifer, or a combination of a fractured and intergranular aquifer, with yields ranging between 0.1 – 5 l/s within fractured zones and 0.1 – 0.5 l/s in intergranular and fractured zones. Recharge to basement granites is typically through overlying primary aquifers, by either precipitation or via surface water in non-urbanised areas, with little to no changes to the natural landcover. Where faults, fractures and dykes extend into the Cape Granite Suite, recharge may also occur. Additionally, zones where the TMG overly the Cape Granite Suite, recharge through fractures in the TMG geology may also occur (see **Figure 2-7**). The presence of these potential hydrotect systems could increase the groundwater potential of the granitic basement aquifer.

The relatively high residence time of groundwater within the clay-rich regolith, saprock and low transmissivity granitic parent rock can result in relatively poor groundwater quality (due to the dissolution of natural salts and elements present within the rock) e.g. relatively high electrical conductivities. Consistent fresh surface and lateral recharge via more transmissive fractured zones will improve groundwater quality within the granitic basement aquifer. Other hydrochemical constituents of concern that are known to occur in elevated quantities within the Cape Granite Suite are fluoride, iron, manganese and arsenic. The Cape Granite Suite Aquifer is less depended upon by groundwater users within Cape Town, and is typically utilised for domestic use and agriculture. Due to location, landcover activities and their lithology, potentially contaminating activities are less likely to occur and reach its groundwater. The vulnerability and risk of contamination is therefore low.

Table 2-1: Stratigraphy and hydrostratigraphy of the City of Cape Town Municipality.

Age (Ma)	Period	Group	Formation	Origin	Description	Aquifer
25 - 0	Neogene / Quaternary	Sandveld	Witzand	Aeolian	Shelly calcareous sand	Primary/Sandy Unconfined (Atlantis and CFA)
			Springfontyn	Aeolian	Well Sorted and rounded fine to medium clean quartzose sand. Local lenses of calcrete, clay and peat	Major Primary/ Sandy Semi-confined to Unconfined (Atlantis and CFA)
			Langebaan	Aeolian	Calcrete and very calcareous sand	Primary/Sandy Semi-confined (Atlantis Aquifer and CFA)
			Varswater	Marine	Fine to Coarse, often silty, shelly, quartzose to calcareous and phosphatic sand and gravel.	Primary/Sandy Semi-confined (Atlantis and CFA)
			Elandsfontyn	Fluvial	Fluvial channel gravel	Major Primary/Sandy Semi-confined (CFA)
~~ Major Unconformity ~~~~						
~136	Cretaceous	False Bay Suite		Igneous	Dolerite dyke intrusions	Minor secondary/ Fracture aquifer.
~~Cape Orogeny (~280-230 Ma) and Major Unconformity / Gondwana break up (180-110 Ma) ~~~~						
~390-375	Devonian	Bokkeveld	Gydo	Marine	Shales and minor sandstone	Aquitard
~500-390		Table Mountain	Rietvlei	Fluvial	Felspathic sandstone, minor shale	Major Secondary / Fracture aquifer (TMG Nardouw Aquifer)
	Silurian		Skurweberg	Fluvial	Thickly bedded quartzite	
			Goudini	Fluvial	Reddish brown quartzitic sandstone	Winterhoek Mega-aquitard
			Cedarberg	Estuarine/ Marine	Dark grey shale and siltstone	
	Ordovician		Pakhuis	Glacial	Tillite and quartz sandstone	
			Peninsula	Fluvial/marine	Thickly bedded, fractured quartzitic sandstone	Major Secondary/Fracture Unconfined/Semi Confined (TMG Peninsula Aquifer)
	Cambrian		Graafwater	Marine	Purple siltstone, shale and sandstone	Aquitard
~~ Major Unconformity (Erosional Time Break) ~~~~						
~550-510	Namibian-Cambrian	Cape Granite Suite	Cape Peninsula Batholith	Igneous	Coarse grained, porphyritic granite	Basement/Regolith Aquifer/Aquitard
~800-550		Malmesbury	Tygerberg	Marine	Shale and sub-ordinate felspathic sandstone	Basement/Regolith Aquifer/Aquitard

2.3. Overview of Groundwater Use in Cape Town

Groundwater in the City of Cape Town is utilised across multiple sectors, including municipal supply, agriculture, industries and communities. Irrigated agriculture for both commercial and subsistence farming operations is the largest registered user, accounting for approximately 56% of total groundwater use in the City (WARMS database). The majority of this use occurs in the Philippi Horticultural Area (PHA) situated in the Cape Flats region of the City. This area produces a significant proportion of Cape Town's fresh produce, with farmers in the area targeting the CFA for groundwater supply for irrigation purposes (WRC, 2020). Most of the groundwater use within the Cape Flats region is concentrated within the PHA (see **Figure 2-8**). Other notable agricultural areas that use groundwater include the outskirts of Atlantis, which rely on the Atlantis aquifer, as well as northern parts of the City, such as Durbanville and sections of Klipheuwel and Somerset West in the southeast, where groundwater from the TMG supplements surface water supplies.

The industrial sector is the second largest user of groundwater in the City of Cape Town, accounting for about 35% of all groundwater use. This sector uses groundwater for manufacturing processes and cooling, with registrations varying from general authorisation to licensed users. Industrial areas in Cape Town, such as Epping Industrial, which target the Malmesbury Group Aquifer, are suspected to have a high prevalence of private boreholes and a great dependency on groundwater for their operations. The Atlantis Industrial area also relies on groundwater from the Atlantis Aquifer, largely due to the MAR scheme.

Most communities in Cape Town primarily depend on municipal water supply, however, some communities also rely on groundwater as a supplementary water source, particularly during times of drought. According to Statistics South Africa (2022), 65% of the total number of groundwater users reside in formal settlements. High-income areas of Cape Town, such as Constantia, Bishopscourt, Newlands, and Claremont along the Cape Peninsula, often have greater access to groundwater resources. These areas are located in the Table Mountain area and rely on springs that occur along mountain slopes (e.g. Newlands Spring). The town of Atlantis is also highly reliant on groundwater through the Atlantis Managed Aquifer Recharge (MAR) Scheme, although aquifer stress is moderate in this region.

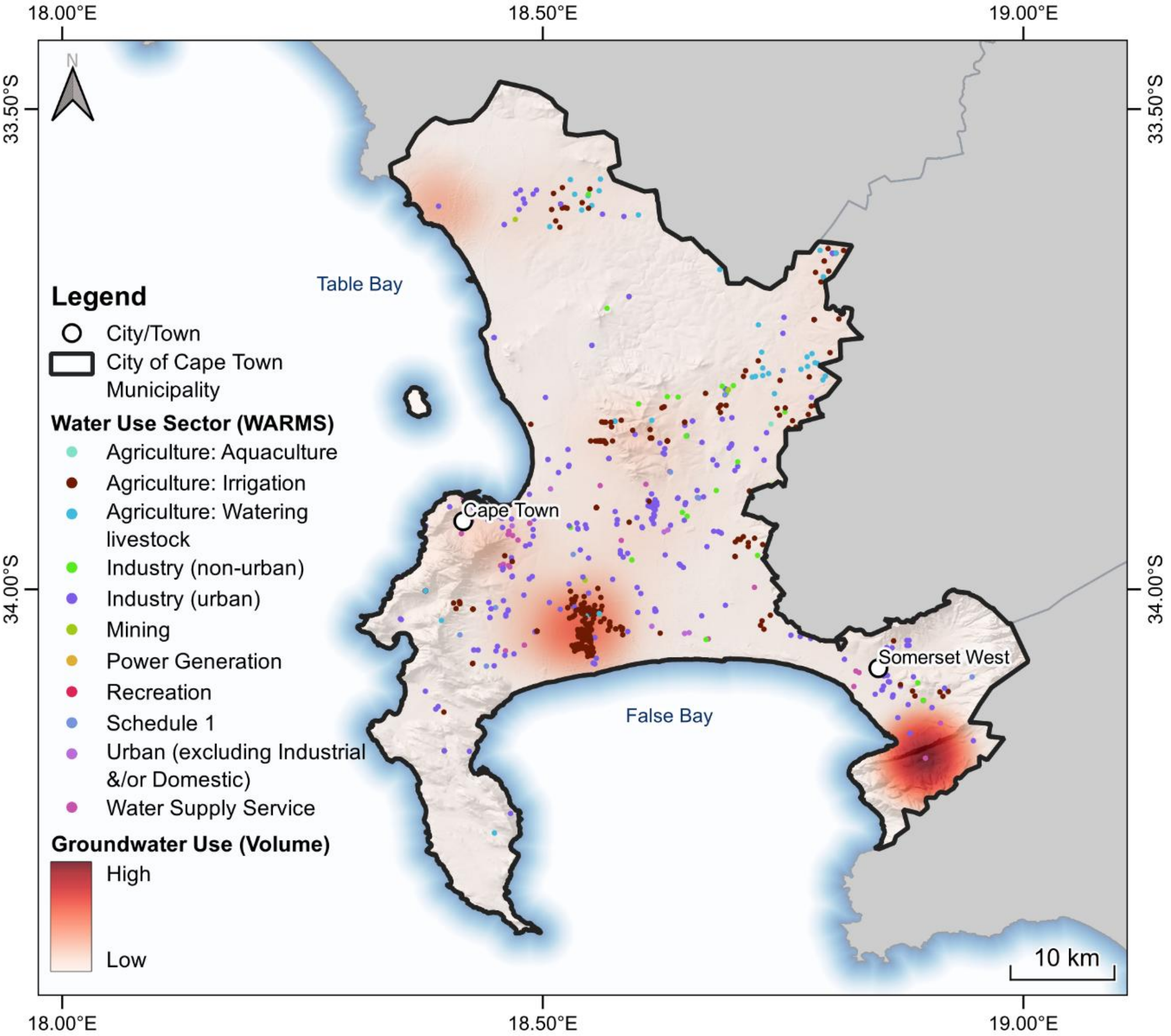


Figure 2-8 Groundwater use and the distribution of authorised water uses, based on the WARMS database, including boreholes, wellpoints and springs (including groundwater schemes) of the City of Cape Town.

3. Hazards

3.1. Aquifer Contamination: Due to Human Activities

3.1.1. Introduction

Aquifer contamination can occur due to various human activities involving the widespread use of chemicals and waste generation. It poses a serious threat to water security, especially in sectors or regions that are groundwater dependent. In Cape Town, the combined effects of a growing water demand and a drying climate have led to a reduction in surface water supply, prompting a greater reliance on groundwater resources as a supplementary supply (CCT, 2019). To ensure long-term availability of high-quality groundwater and prevent aquifer degradation, it is essential that groundwater management strategies address both sustainable abstraction and the protection of aquifers from contamination.

Assessing the risk of aquifer contamination requires the determination of potential sources of groundwater contamination, referred to as **Hazards** in this assessment. This includes:

- Identifying the contamination sources (e.g. waste site).
- Determining the associated contaminants (e.g. nitrate).

The major sources of groundwater contamination and their associated contaminants are described below.

3.1.2. Major sources of groundwater contamination

Major sources of groundwater contamination in urban areas across South Africa were identified by Usher et al. (2004). In this assessment, Usher et al. (2004) evaluated the risk of different sources of groundwater contamination across the City of Cape Town and ranked on-site sanitation as posing the greatest threat to groundwater contamination. Other contamination sources, such as cemeteries, industries (particularly in the Cape Flats area), leaking underground storage, petrol and diesel tanks, were also noted as major threats.

Sources of contamination of groundwater in urban areas are associated with the following activities (summarised in **Figure 3-1**):

- Urban settlements and services (e.g. on-site sanitation, waste water, underground storage tanks, storm-water runoff, accidental leaks and spills, cemeteries, sports grounds);
- Mining (e.g. mine tailings and mine water);
- Industry (e.g. solid waste, processed water and effluent, evaporation ponds, spills and leaks);
- Waste disposal (e.g. solid waste sites, uncontrolled dump sites, effluent disposal ponds); and
- Agriculture (e.g. pesticides, fertilisers, sludge application, spills, disposal of animal waste).

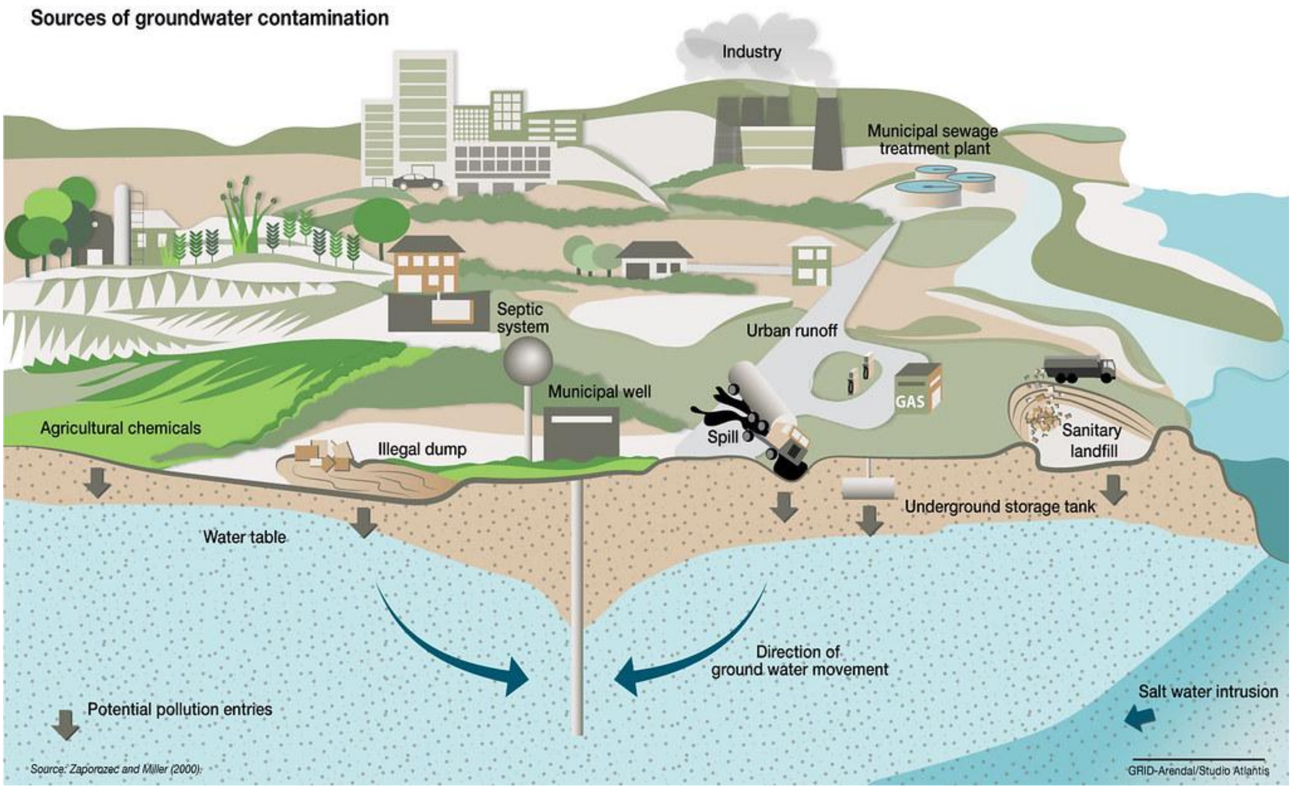


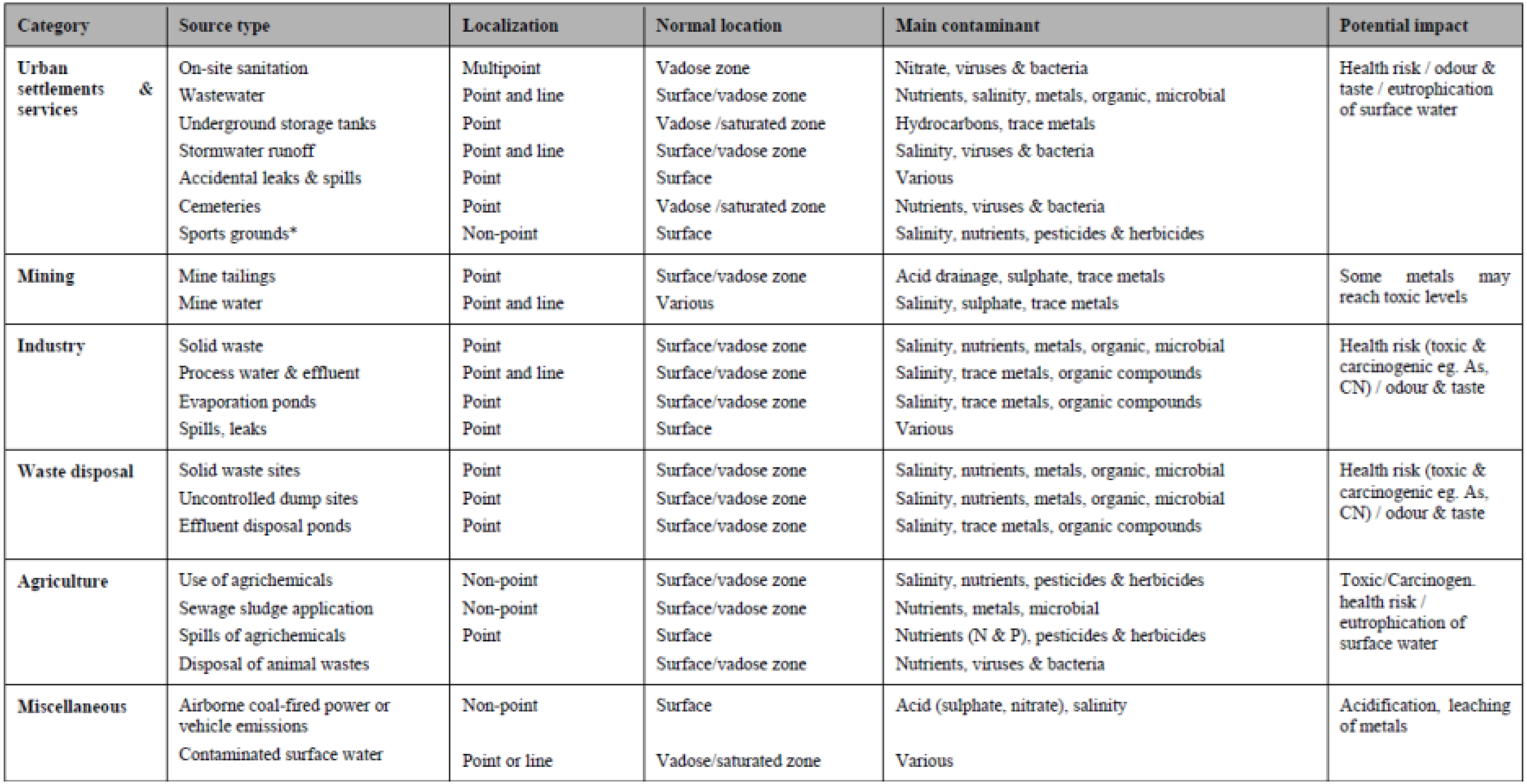
Figure 3-1 **Sources of groundwater contamination (Zaporozec and Miller, 2000).**

Groundwater contaminants can typically be grouped as:

- **Inorganic contaminants**, which include subcategories such as major cations and anions (e.g. sodium, chloride and sulphate), nutrients (e.g. nitrate, phosphate), trace metals (e.g. copper, chromium), radionuclides (e.g. uranium) and other inorganic species (e.g. strontium, fluoride). These contaminants can be naturally occurring in groundwater or can be from anthropogenic sources such as fertilisers and pesticides from agricultural activities, or waste generated from industrial and mining activities and sea water intrusion.
- **Organic contaminants**, which can be subdivided into natural hydrocarbons (e.g. petroleum) and synthetic organic compounds (e.g. pesticides, solvents and pharmaceuticals) mainly from agricultural and industrial waste.
- **Microbial contaminants**, which include bacteria, viruses, protozoan and metazoan parasites that enter groundwater from human or animal waste.
- **Contaminants of emerging concern (CECs)**, which include substances like pharmaceuticals, microplastics, personal care products and PFAS, which are still mostly unregulated in South Africa. Major sources of these contaminants include effluent from wastewater treatment plants, leaching from landfills and urban runoff.

Table 3-1 summarises groundwater contamination source types in terms of their degree of localisation, main contaminants and potential impact. The degree of localisation of a contaminant source refers to point and non-point (diffuse) sources (Domenico and Schwartz, 1990). A point source (or line source) is characterised by a well-defined, small-scale source (e.g. leaking storage tank, a landfill, an unlined stormwater canal, etc.) producing a well-defined contaminant plume. While non-point sources are characterised by larger-scale, relatively diffuse contamination emanating from numerous smaller, often poorly defined contaminant sources.

Table 3-1 **Classification of groundwater contamination sources as well as the location of the affected area, typical contaminants and potential impacts (Usher et al, 2004).**



Category	Source type	Localization	Normal location	Main contaminant	Potential impact
Urban settlements & services	On-site sanitation Wastewater Underground storage tanks Stormwater runoff Accidental leaks & spills Cemeteries Sports grounds*	Multipoint Point and line Point Point and line Point Point Non-point	Vadose zone Surface/vadose zone Vadose /saturated zone Surface/vadose zone Surface Vadose /saturated zone Surface	Nitrate, viruses & bacteria Nutrients, salinity, metals, organic, microbial Hydrocarbons, trace metals Salinity, viruses & bacteria Various Nutrients, viruses & bacteria Salinity, nutrients, pesticides & herbicides	Health risk / odour & taste / eutrophication of surface water
Mining	Mine tailings Mine water	Point Point and line	Surface/vadose zone Various	Acid drainage, sulphate, trace metals Salinity, sulphate, trace metals	Some metals may reach toxic levels
Industry	Solid waste Process water & effluent Evaporation ponds Spills, leaks	Point Point and line Point Point	Surface/vadose zone Surface/vadose zone Surface/vadose zone Surface	Salinity, nutrients, metals, organic, microbial Salinity, trace metals, organic compounds Salinity, trace metals, organic compounds Various	Health risk (toxic & carcinogenic eg. As, CN) / odour & taste
Waste disposal	Solid waste sites Uncontrolled dump sites Effluent disposal ponds	Point Point Point	Surface/vadose zone Surface/vadose zone Surface/vadose zone	Salinity, nutrients, metals, organic, microbial Salinity, nutrients, metals, organic, microbial Salinity, trace metals, organic compounds	Health risk (toxic & carcinogenic eg. As, CN) / odour & taste
Agriculture	Use of agrichemicals Sewage sludge application Spills of agrichemicals Disposal of animal wastes	Non-point Non-point Point	Surface/vadose zone Surface/vadose zone Surface Surface/vadose zone	Salinity, nutrients, pesticides & herbicides Nutrients, metals, microbial Nutrients (N & P), pesticides & herbicides Nutrients, viruses & bacteria	Toxic/Carcinogen. health risk / eutrophication of surface water
Miscellaneous	Airborne coal-fired power or vehicle emissions Contaminated surface water	Non-point Point or line	Surface Vadose/saturated zone	Acid (sulphate, nitrate), salinity Various	Acidification, leaching of metals

3.1.3. Hazard Mapping

To assess the likelihood of groundwater contamination from human activities in the City of Cape Town, land use types and major Potentially Contaminating Activities (PCAs) were mapped (**Figure 3-2**). A hazard scoring system (1 representing very low and 5 representing very high) was then applied to each land use category based on its potential to cause groundwater contamination to generate a contamination hazard map (**Figure 3-3)**.

The City of Cape Town Metropolitan consist of two main primary unconfined aquifer systems of the Sandveld Group, namely the CFA and Atlantis aquifers, described in **Section 2.2.1** of this report**.** These aquifers are moderate to high-yielding and can supply significant volumes of water; hence, the City of Cape Town has developed groundwater schemes that involve the abstraction of groundwater from these aquifers to diversify bulk water supply in the city. In addition to municipal use, these aquifers are essential to other groundwater users such as farmers within the Philippi Horticultural Area, which depend on the CFA. Industries, private users, and groundwater-dependent ecosystems across the municipality also rely on these aquifers. Due to their shallow, unconsolidated nature, these aquifers have high permeability and recharge rates, but are more susceptible to contamination from surface land use activities.

The unconsolidated nature of the CFA, combined with dense human settlements (formal and informal) as well as the presence of industrial and agricultural activities, makes this area particularly prone to contamination in some sections. Due to this mix of land use activities and a large number of PCAs (see **Figure 3-2**)**,** the CFA region has the most variable hazard scoring within the City of Cape Town.

A large portion of the CFA area is characterised by low-hazard land uses, such as formal residential settlements and commercial areas. Cultivated lands such as those in Philippi and Strandfontein, as well as light industrial areas (e.g. logistics and distribution companies, food processing and packaging facilities) such as those in Philippi North, Parow and Bellville South are associated with a moderate hazard rating. Meanwhile, informal settlements (e.g. Khayelitsha and sections of Philippi and Guguletu) and industrial areas such as Epping that are considered more hazardous than those categorised as light industries were assigned a high hazard score.

Figure 3-3 shows that the Atlantis Aquifer region is predominantly rated as having a very low to low hazard rating, as land use in the region primarily comprises shrublands and barren land, with small sections of commercial and formal settlements to the east. However, the Atlantis Industrial area, which is split into a light industrial area with a moderate hazard and a heavy industrial area with a very high hazard score, is also present within the region.

The TMG aquifers, which are secondary fractured rock aquifers, are comprised of layered quartzitic sandstones. They are characterised by great depths (especially the Peninsula Aquifer) and a low permeability, making them less susceptible to contamination from the surface. **Figure 3-3** shows that the TMG aquifers along the Cape Peninsula and in the Steenbras area predominantly have a very low hazard score. This is largely because most of the Steenbras and Cape Peninsula areas are within nature reserves, which are protected. Although the Steenbras area is located within a protected area, the development and expansion of the Grabouw informal settlements pose a significant threat to contamination in the area. The Somerset West area, northeast of Steenbras, consists of commercial zones and formal areas with a low hazard, while cultivated lands to the east have a moderate hazard score.

Similarly, the Cape Peninsula region, although mostly protected, also consists mostly of formal settlements with a low hazard score (e.g. Newlands, Constantia and Bishops Court). However, small sections of informal settlements with a high hazard score and industries to the northeast with a very high hazard score also exist in the Somerset West region of Cape Town.

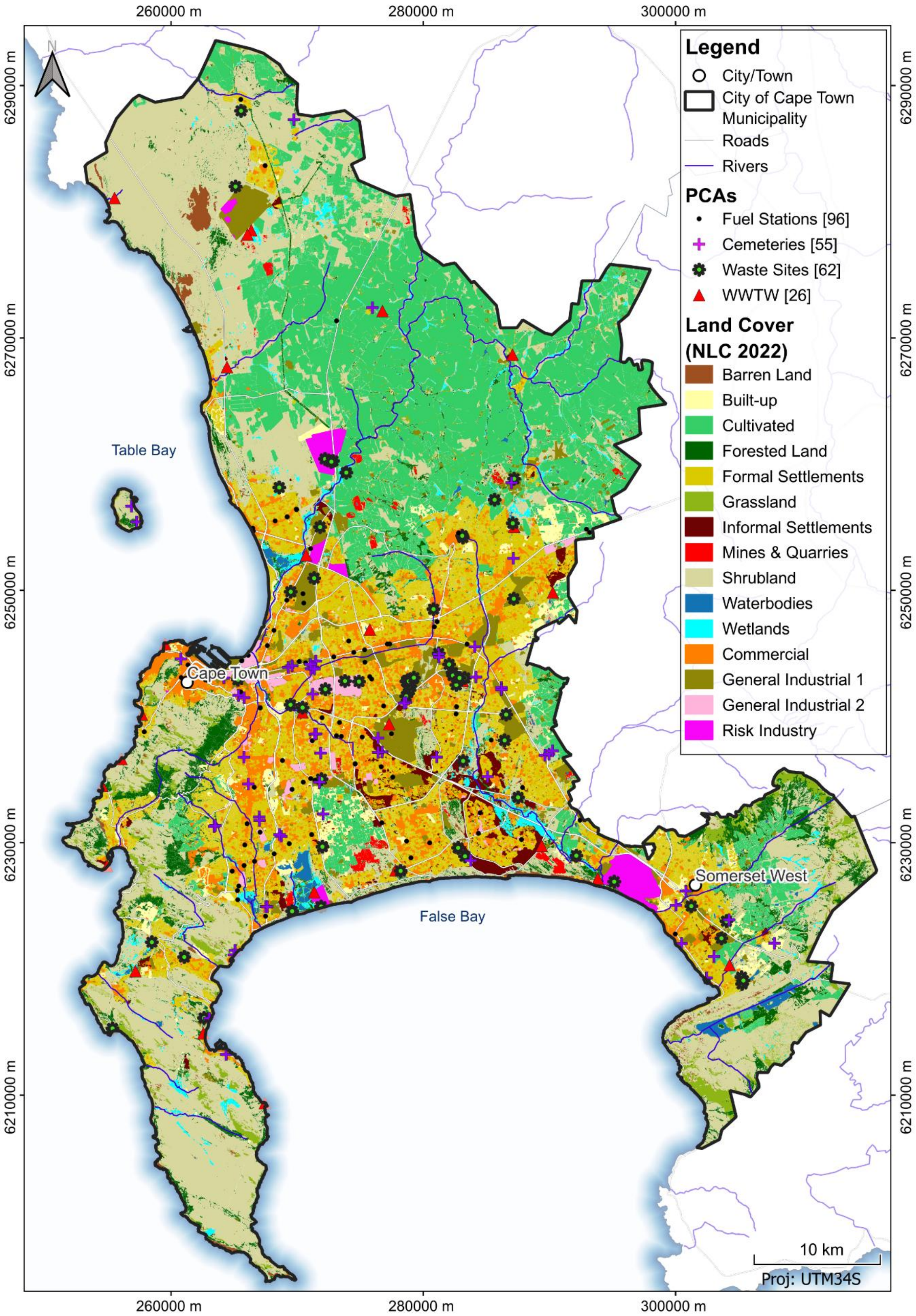


Figure 3-2 Land use and major Potentially Contaminating Activities (PCAs) in Cape Town, adapted from NLC, 2022.

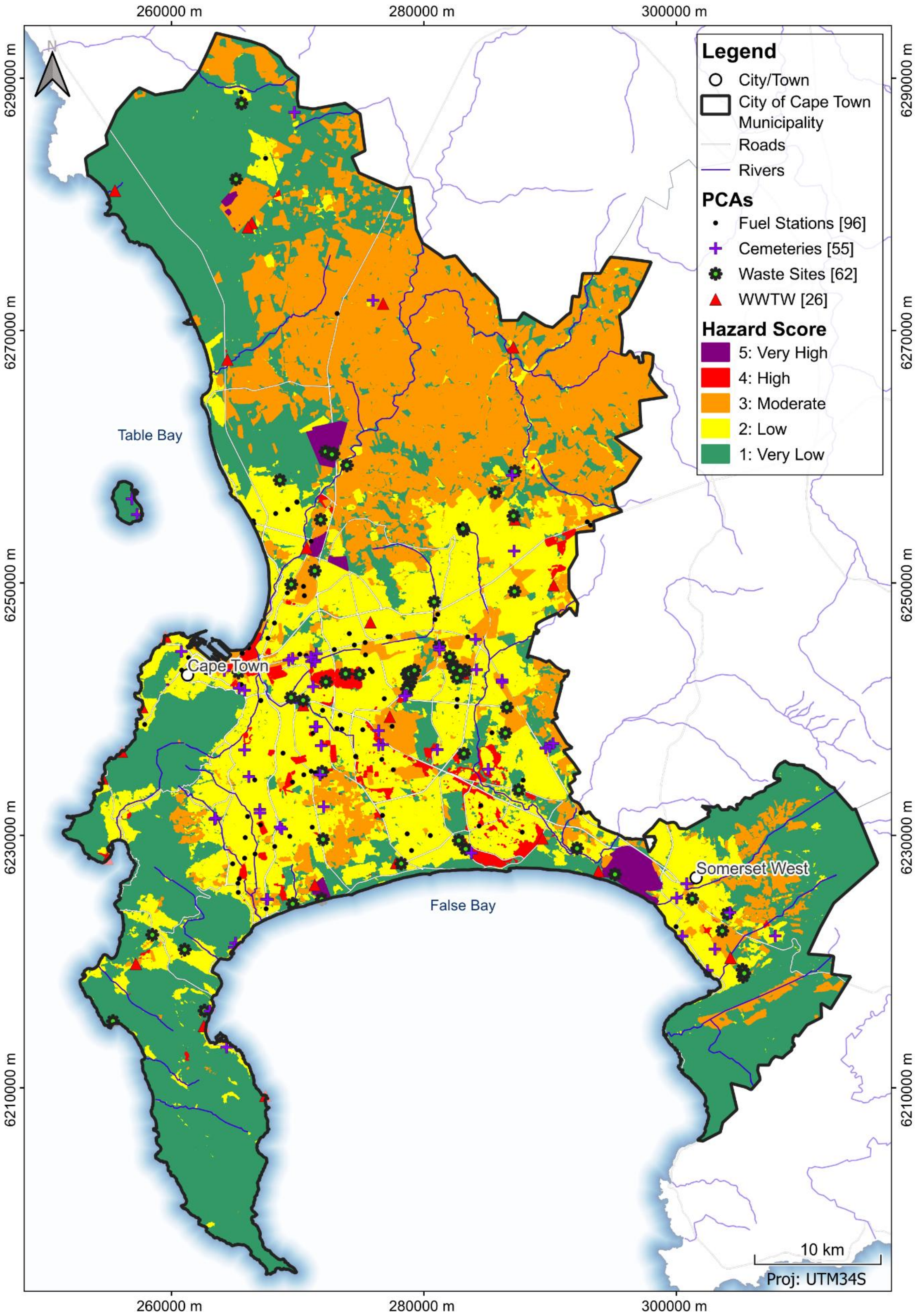


Figure 3-3 Groundwater Contamination Hazard Map of Cape Town.

3.2. Over Abstraction

3.2.1. Introduction

Over-abstraction occurs when groundwater is abstracted from an aquifer at a rate that exceeds its natural recharge (DWS, 2024). This unsustainable practice poses a significant threat to groundwater resources globally (Van der Gun, 2021), including many parts of South Africa. According to The National Groundwater Strategy (DWS, 2016), national monitoring networks indicate that karst and coastal aquifers, the country's major aquifers, are under pressure in many locations due to over-abstraction.

The combined effect of growing water demand and a drying climate has led Cape Town to make groundwater a key part of its resilience strategy (CCT, 2019b), which will increase groundwater abstractions. Model-based analyses of the water–food nexus confirm that, even with planned augmentation, aquifer exploitation will rise sharply and must be managed to avoid over-abstraction (Hofmann et al., 2024).

Groundwater abstractions usually significantly increase during drought periods, exceeding recharge and lowering the water table. This was evident during the severe drought crisis experienced from 2015 to 2018, a drought described as a 1 in 590-year event (CCT, 2023a; Faragher and Carden, 2023). During this period, many communities in Cape Town relied on groundwater as a supplementary water source. **Figure 3-4** shows how the national average groundwater level status fell below normal during the drought period, but recovered since 2019 due to increased recharge and reduced abstractions after the drought period.

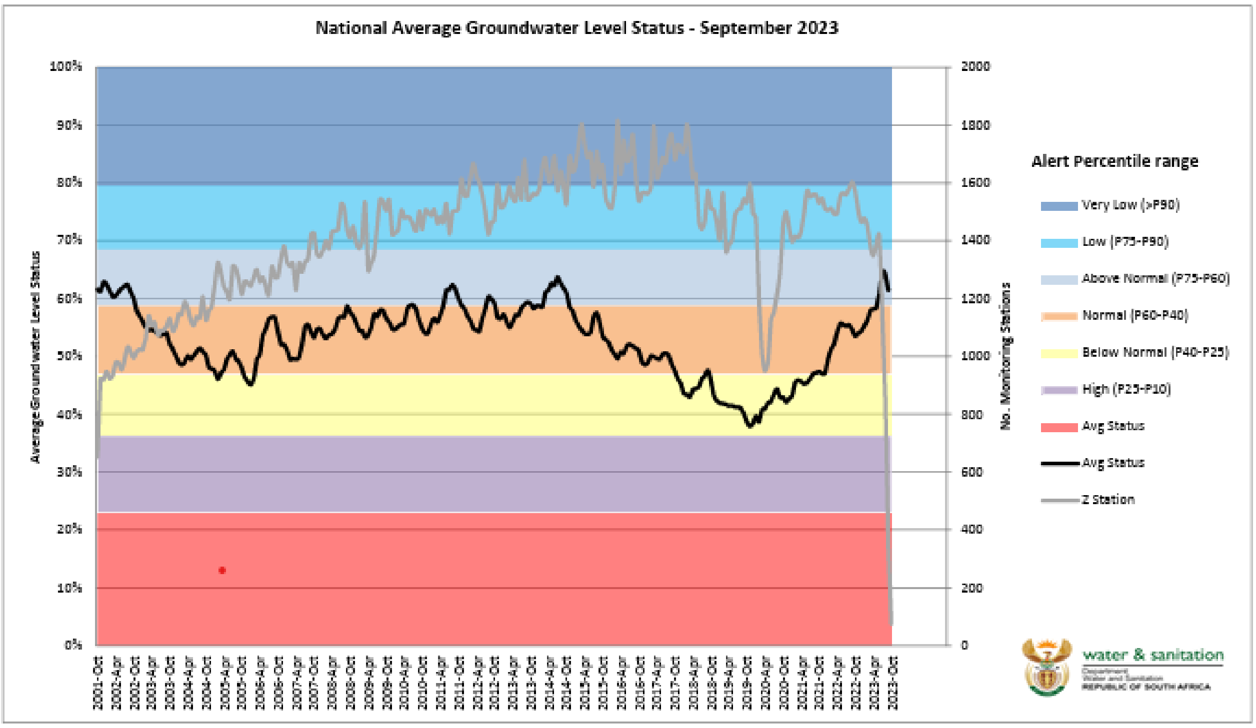


Figure 3-4 National Average Long-Term Groundwater Level Status (DWS, 2024).

The key impacts of the over-abstraction of groundwater include:

- **Declining groundwater levels/pressure**: occur due to over-pumping, which causes the water table to drop, resulting in a reduction in the availability of groundwater and an overall degradation of the aquifer. The reduction in water levels can also results in a reduction of a borehole yields. In severe cases, aquifer depletion and storage losses can occur, resulting in aquifers becoming permanently damaged. The reduction in water availability as a result of over-abstraction affects sectors and communities that rely on groundwater for various uses (e.g. the farming community in Philippi relies on groundwater for irrigation purposes).
- **Reduced baseflow:** A decline in groundwater levels results in a reduction in groundwater discharge, which limits the baseflow of rivers. A decrease in baseflow leads to a reduction in surface water flows, affecting aquatic ecosystems and river flows downstream.
- **Seawater intrusion**: The over-abstraction of coastal aquifers can cause groundwater levels to drop below sea level. This disrupts the natural pressure gradient that normally causes freshwater to flow towards the sea, leading to a reversal of flow direction within the aquifer. This reversal of flow direction causes seawater to flow into the freshwater zone of the aquifer, causing groundwater to become saline.
- **Ecosystem degradation**: Groundwater-dependent ecosystems (GDEs) such as rivers, wetlands, springs and seeps depend on groundwater for the maintenance of their ecological processes, structure and function, particularly during dry periods when rainfall is limited. If groundwater availability for GDEs is reduced, GDEs may dry out or suffer ecological stress, which may lead to the loss of biodiversity.
- **Land subsidence**: Excessive groundwater abstractions can cause the ground to sink or collapse.

3.2.2. Hazard Mapping

The allocation factor was used in this section of the assessment to identify regions in Cape Town that are likely to be threatened by over-abstraction. This analysis is based on data and methodology from the Groundwater Reserve Determination Study of the Berg Catchment (DWS, 2022).

In the DWS (2022) study, an allocation factor was calculated for each groundwater resource unit in the City of Cape Town using the following equation:

$$\boldsymbol{Allocation\ Factor} = \frac{\text{Still Allocable Volume}}{\text{Recharge}}$$

Where:

Still Allocable Volume = Total Allocable Volume – Groundwater Use

Total Allocable Volume = Recharge – Groundwater Reserve

Groundwater Reserve = Environmental Water Requirements Reserve (EWR) + Basic Human Needs Reserve (BHN)

The resulting values were then classified into different categories based on the classes described in **Table 3-2** to produce an aquifer allocation Map for groundwater systems in the City of Cape Town (see **Figure 3-5).** This map highlights areas or zones where groundwater resources are under stress and where the likelihood of over-abstraction is elevated.

Table 3-2 Guide for determining groundwater allocation categories (adapted from DWS, 2022)

Allocation Category	Description	Allocation Factor
A	Understressed	>0.95
B	Slightly Stressed	0.75-0.95
C	Moderately Stressed	0.5-0.75
D	Moderately to Potentially Highly Stressed	0.35-0.5
E	Potentially Highly Stressed	0.15-0.35

The aquifer allocation map (**Figure 3-5**) shows that the majority of the City of Cape Town is moderately stressed, except for the Atlantis Aquifer (slightly stressed), the TMG Aquifer within the Hottentots Holland Mountain region (slightly stressed) and the TMG Aquifer along the Cape Peninsula (potentially highly stressed).

Figure 3-5 indicates that the TMG aquifer along the Cape Peninsula has the highest allocable factor, highlighting this aquifer as the most stressed and the most likely to be threatened by over-abstraction. This aquifer receives relatively low recharge (**Table 3-3**), likely due to its impermeable nature, which limits infiltration. Additionally, data from DWS (2022) also shows that nearly 50% of the total recharge received in the area is reserved for ecological water requirements (EWR). This high EWR allocation is attributed to the presence of several protected areas, including national parks, nature reserves and groundwater-dependent ecosystems such as springs, wetlands and seeps that support unique and sensitive biodiversity. Due to this large groundwater allocation for EWR, a limited amount of groundwater is available for use, increasing the likelihood of over-abstraction should groundwater use increase in the region.

The CFA and the Malmesbury Aquifer, which cover the majority of the southern and northern sections of the city, are classified as moderately stressed, despite having relatively high volumes already allocated for use. This is primarily because these regions receive relatively high recharge (**Table 3-3**), which supports this large use. As a result, only about 30% of the total allocable volume in the CFA and Malmesbury Aquifer is allocated, suggesting a moderate likelihood of over-abstraction.

The Atlantis Aquifer is one of the least stressed aquifers in the city. This is because the amount of groundwater allocated for use from the aquifer is relatively low (16%), leaving a large amount (83%) of the total allocable amount available. This indicates that the aquifer is less likely to be threatened by over-abstraction in comparison to the CFA and TMG aquifer along the Cape Peninsula **Figure 3-5.**

Similarly, the TMG Aquifer within the Hottentots Holland Mountains area is also slightly stressed because the region receives relatively high recharge, has a low EWR reserve compared to that of the Cape Peninsula, and only about 14% of the total volume available for use has been allocated. The remaining surplus of available groundwater for use makes the aquifer less prone to over-abstraction.

In summary, the regions in Cape Town that are the most likely to be threatened by over-abstraction are the TMG area along the Cape Peninsula and the moderately stressed CFA and Malmesbury area. While, the Atlantis Aquifer and TMG Aquifer within the Hottentots Holland Mountain region are less likely to be threatened by this hazard.

Table 3-3 **Aquifer allocation determination for groundwater resource units in Cape Town (red – moderately to potentially highly stressed, orange – moderately stressed, yellow – slightly stressed).**

GRU	Recharge (Mm^3/a)	EWR Reserve (Mm^3/a)	BHN Reserve (Mm^3/a)	GW Reserve (Mm^3/a)	Total Allocable Volume (Mm^3/a)	Water Use (Mm^3/a)	Still Allocable (Mm^3/a)	Aquifer Stress Index
Cape Flats	41.25	0.51	0.7	1.21	40.04	12	28.04	0.68
Atlantis	22.74	0.98	0.03	1.01	21.73	3.84	18.79	0.83
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49
Steenbras–Nuweberg	58.76	1.16	0.02	1.18	57.58	8	49.58	0.84
Malmesbury	52.65	1.18	0.34	1.52	51.13	15.14	36.38	0.69

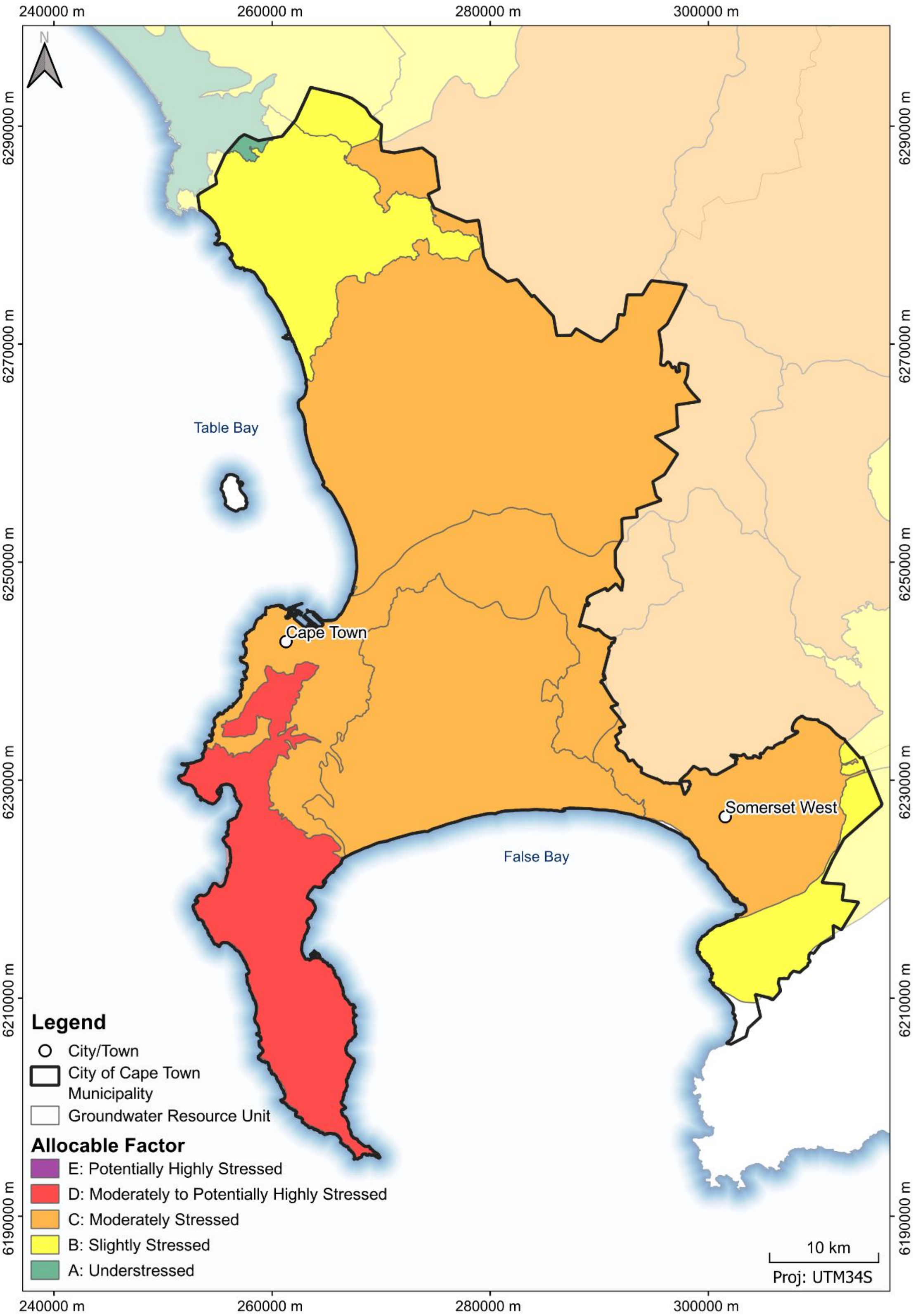


Figure 3-5 **Aquifer allocation indicating areas where aquifers are stressed in the City of Cape Town Municipality (DWS, 2022).**

3.3. Sea Level Rise: Due to Climate Change

3.3.1. Introduction

The rise of global sea level due to climate change can have significant impacts on coastal groundwater systems. Both the magnitude and timing of future sea level rise is difficult to predict. However According to the Intergovernmental Panel on Climate Change (IPCC) sea levels are expected to rise between 0.29 – 1.1 m by 2,100, depending on different greenhouse gas emission scenarios (Oppenheimer et al., 2019). The two main impacts of sea level rise are saline intrusion and groundwater level rise. The salinisation of an aquifer reduces the amount of freshwater in the resource, while rising sea levels can alter the water table, creating a risk of groundwater flooding. Through these two impacts, seawater intrusion can significantly affect coastal aquifers, surface cover and the groundwater users who are highly dependent on these freshwater resources.

Conceptually, saline intrusion is often best described by what is known as a saline wedge, a freshwater-saltwater interface within a coastal aquifer (see **Figure 3-6**). This interface seldom remains stationary, advancing and retreating due to sea level rise, rainfall recharge, and groundwater abstraction. Rising sea levels can cause this interface to advance further inland and create brackish aquifer conditions. The risk to the aquifer and users is further exacerbated when climate change induced reductions in groundwater recharge occurs. Natural systems such as estuaries and mangroves which mitigate the effects of seawater intrusion, are also affected by sea level rise. Estuaries and mangroves both act as buffers for saltwater intrusion, reducing the impact and risk to both system and user (Van Drunen et al., 2006; Basyuni et al., 2025). Rising sea levels, however, can erode these systems, reducing their surface cover and therefore its ability to inhibit seawater intrusion.

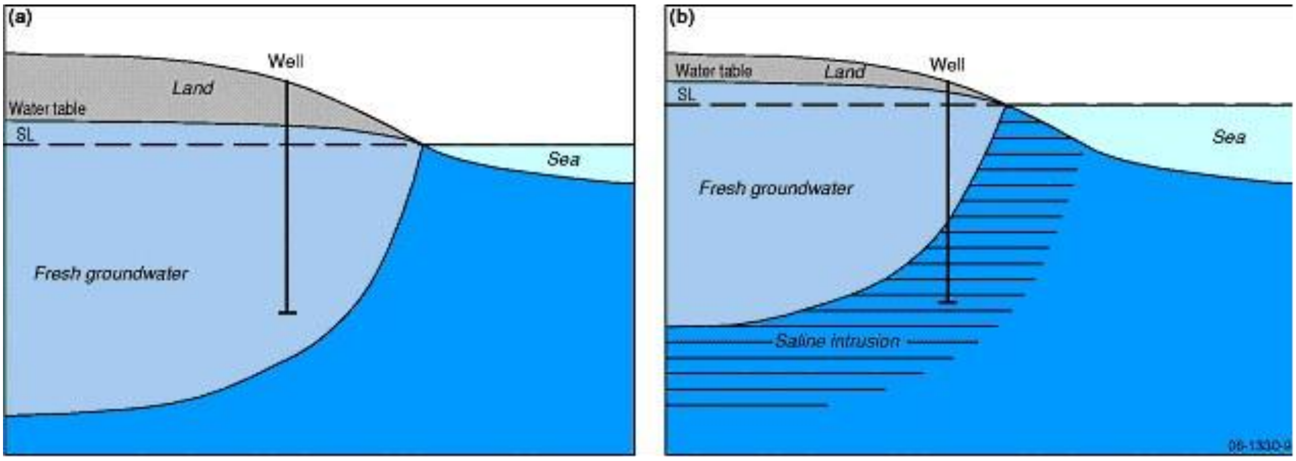


Figure 3-6 **Saltwater-freshwater interface under sea level rise. (a) an unconfined (hypothetical) coastal aquifer; and (b) the same aquifer under a sea level rise scenario. In the sea-level rise scenario abstraction from the coastal boreholes would be reduced or stopped altogether due to the intrusion of saline water into the aquifer (Ozoasts, 2009).**

3.3.2. Affected Area's

The hazard of sea level rise is a global problem for many countries and regions. Within Cape Town, much of the City's boundary with the ocean is expected to be affected by sea level rise, however when considering the aquifers and their boundaries outside of the City's limits, most of the Cape Town Municipality is not considered as a high hazard. The steep topography of the Cape Peninsula mountain range in the southwest and the Hottentots Holland Mountains in the southeast, along with the geological characteristics of the Cape Granite Suite and TMG, minimise the risk of sea-level rise impacts on these aquifers. In the northwest along the West Coast, the Atlantis Aquifer is also considered at low risk due to its elevated position and the protective influence of the underlying Malmesbury Basement. The only aquifer considered to be at more moderate to high risk of sea level rise and its associated impacts is the CFA. Due to the nature of the aquifer (comprises of a paleochannel extending from the ocean, inland), sea level rise may impact deeper inland into the CFA. When considered with over-abstraction and reduced recharge, seawater intrusion as an impact becomes more pronounced due to the change in hydraulic head created. This is unique to the CFA as due to topography and or the elevation of geology, the rest of the Cape Town Municipalities aquifers are less susceptible to sea level rise and its impacts.

3.4. Reduced Recharge: Due to Climate Change and Urbanisation

3.4.1. Introduction

Reduced recharge refers to the declining replenishment of groundwater systems, ultimately leading to diminished aquifer storage. As global dependence on groundwater grows, sustainable recharge has become increasingly critical, this is especially true in South Africa, where reliance on groundwater has intensified due to recurrent droughts and declining rainfall (Foster et al., 2020; Jude, 2020). Water scares regions in particular have been the most impacted by these conditions.

Climate change is widely predicted to impact upon the sustainability of water resources. Surface waters are particularly susceptible to the predicted decrease in rainfall and increased occurrence of drought (Al Atawneh et al., 2021). Groundwater sources rely on rainfall to recharge its systems to maintain its capacity and provide the services that many of its users rely upon. Estimates put change recharge at between 4.1 – 6 mm/a within the Cape Town municipality (see **Figure 3-7**). Disruptions to this system can significantly impact groundwater availability, especially when rainfall decreases. **Figure 3-7** utilises global climate models to display the predicted changes to rainfall over the Western Cape Province. The area within the Cape Town municipality is expected to experience between 5 - 20 mm/month less rainfall between 2030 – 2040, depending on the time of year (Western Cape, 2007).

Semi-arid and arid areas of the country are especially vulnerable, as groundwater abstraction has become a key strategy to offset diminishing surface water supplies (CCT, 2019a). While climate change induced rainfall variability is a major driver of reduced groundwater recharge, urbanisation further exacerbates the problem by reducing the infiltration surface area and further reducing aquifer storage (Patra et al., 2018). The expansion of impermeable surfaces, such as roads, buildings, and stormwater drainage systems disrupt natural infiltration. Rainfall in coastal areas in particular are often diverted away from aquifers and channelled directly into the ocean.

The key impacts associated with reduced recharge include:

- **Reduced Storage**: The most influential impact from reduced recharge is the decrease in groundwater availability and aquifer storage. Less rainfall and less infiltration of the available surface runoff, results in less water reaching and recharging the groundwater system. The reduction in availability and aquifer storage has several implications, resulting in additional impacts.

- **Declining water levels**: reduced recharge directly affects the volume of water stored in an aquifer. Less rainfall reduces the amount of water available to recharge a groundwater system, while less permeable surface cover can reduce infiltration of surface runoff to the system. Individually and or combined, these conditions can impact the total volume of water recharged into an aquifer, consequently preventing recovery of the water table during wet months when net recharge is at its highest. Lowering of the water table affects water users by hindering their access to available water (exacerbated by over abstraction) and causes a deterioration of water quality due to saturation of salts.
- **Deteriorating water quality**: reduced groundwater recharge of freshwater limits dilution, the result is a groundwater system saturated with salts and various constituents that at higher concentrations can have implications for both consumption and its uses.
- **Saltwater intrusion**: Insufficient recharge of coastal aquifers can result in a head difference thereby shifting the salt water-freshwater interface deeper into the aquifer, creating brackish conditions in the system. This directly affects users as saline waters are often avoided by most water users.
- **Reduced baseflow**: reduced recharge results in a reduction of groundwater discharge, which limits the baseflow of rivers. A decrease in baseflow leads to a reduction in surface water flows, affecting aquatic ecosystems and river flows downstream.

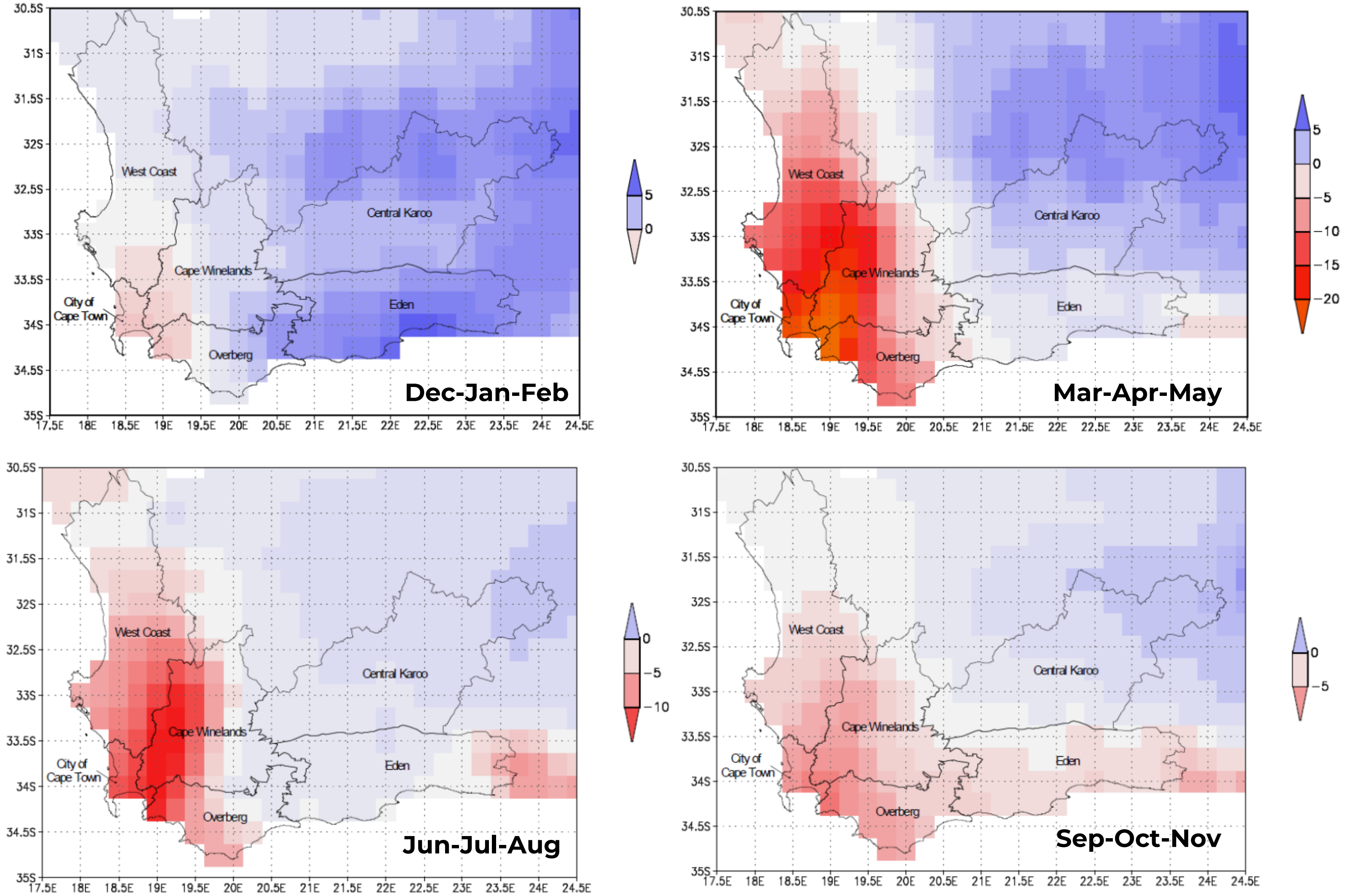


Figure 3-7 Changes in average monthly precipitation (mm/month) - Projected changes are based on multiple GCM simulations for the future using SRES A2 scenarios of greenhouse gas concentrations and scaled to the period from 2030-2040 (Western Cape, 2006).

3.4.2. Hazard Mapping

The reduction in recharge across the City of Cape Town Municipality was mapped to identify areas or regions within the municipal boundary, which are expected to experience these reductions in groundwater recharge due to climate change. Modelled change in recharge was incorporated from the work of Dennis and Dennis (2012). Their research looked at developing a climate change vulnerability index for South African aquifers. Part of their project modelled change in recharge by incorporating long term climate data into the Meteorological Research Institute Coupled General Circulation Global Climate Model, where the A2 SRES emissions scenario was considered between the 2046 to 2065 time period. For this report, the output of their results were overlayed over the City of Cape Town Municipality to produce **Figure 3-9**. The reduction categories within the City were limited to two broad classes (4.1 mm/year and 6 mm/year [Dennis and Dennis, 2012]), which were categorised as high and very high hazard given the negative impact any recharge decline poses.

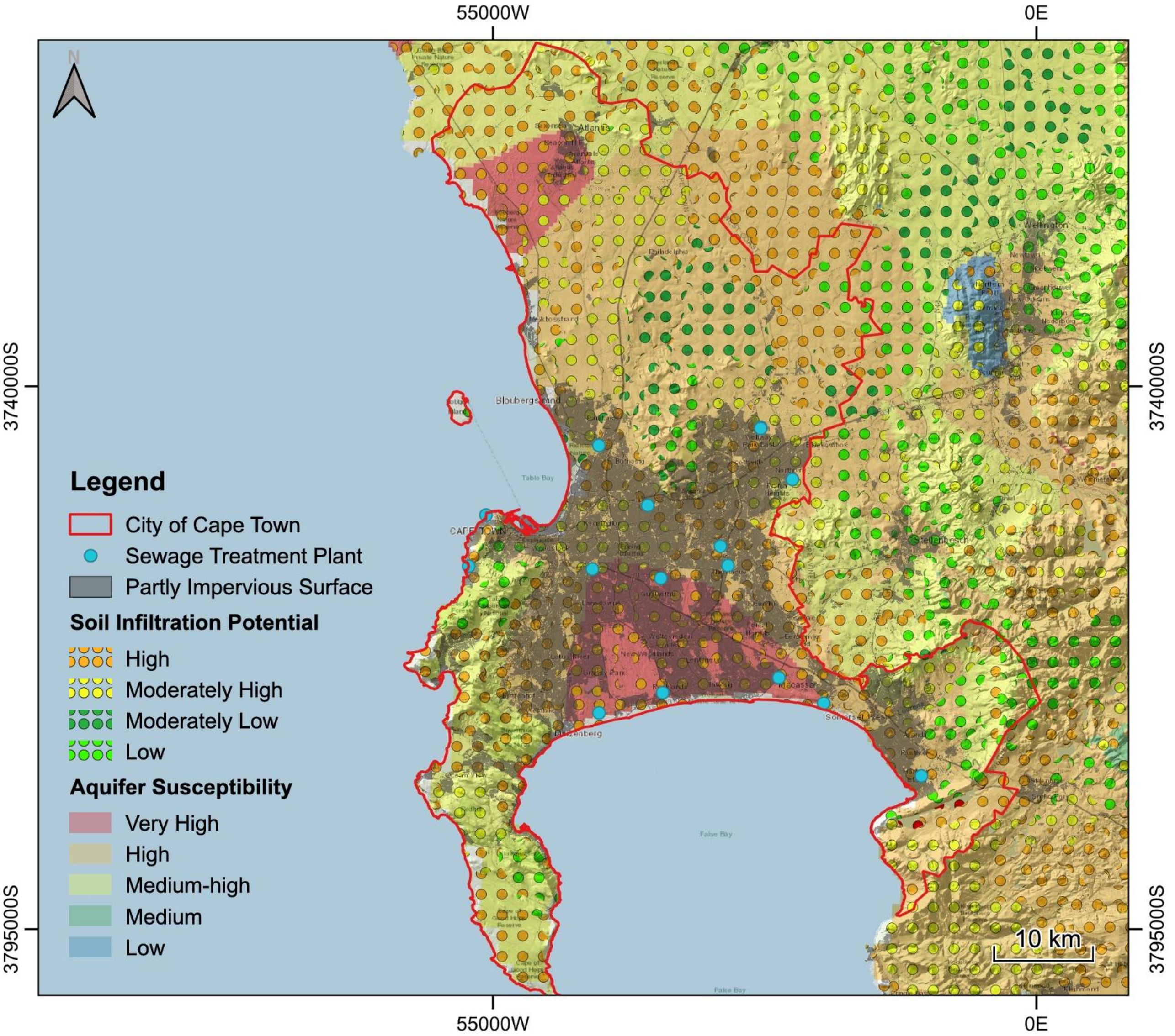


Figure 3-8 **Aquifer recharge potential map across the City of Cape Town area. Aquifer recharge potential is shown as a function of aquifer susceptibility, soil infiltration capacity (based on HSGs), derived from hydrological soil group (HSG), impervious surface coverage from DFEE 2022 land-cover data, and locations of sewage treatment plants that may enhance streamflow and local recharge (SADC-GMI, 2025).**

The change in recharge map (see **Figure 3-9**) shows majority of the Cape Town Municipality is predicted to experience a decrease in recharge by 6 mm/a, with the northern and south eastern parts a 4.1 mm/a decrease (Dennis and Dennis, 2012). Compared with annual recharge for the municipality (see **Figure 2-6**), where most of Cape Town experiences between ≤20 – 80 mm/a, this reduction would decrease annual recharge by 7 – 30%. Only along the Cape Peninsula (80 – 220 mm/a) and Hottentots Hollands (80 – 380 mm/a) mountains does recharge reach higher volumes. When considering the aquifers found within the municipality, reductions in recharge are considered a high or very high hazard in the Primary unconfined sandy aquifers of the CFA and Atlantis Aquifer, and a high or very high hazard for the secondary fractured rock aquifers of the TMG.

Reduced recharge of this magnitude in the primary aquifers could result in a deterioration of water quality, lowering of water tables, reduction in aquifer storage and exacerbation of conditions which facilitate over-abstraction. The unconsolidated and hydraulic properties of these aquifers are what ensure these systems are able to receive sufficient enough recharge. Considering **Figure 3-8**, the CFA is most affected by urbanisation and its impermeable surfaces, the Atlantis Aquifer in comparison does not possess the same extent of urbanisation as the CFA. Increased urbanisation in the middle to longer term will likely result and increase of impermeable surfaces and further reduce recharge.

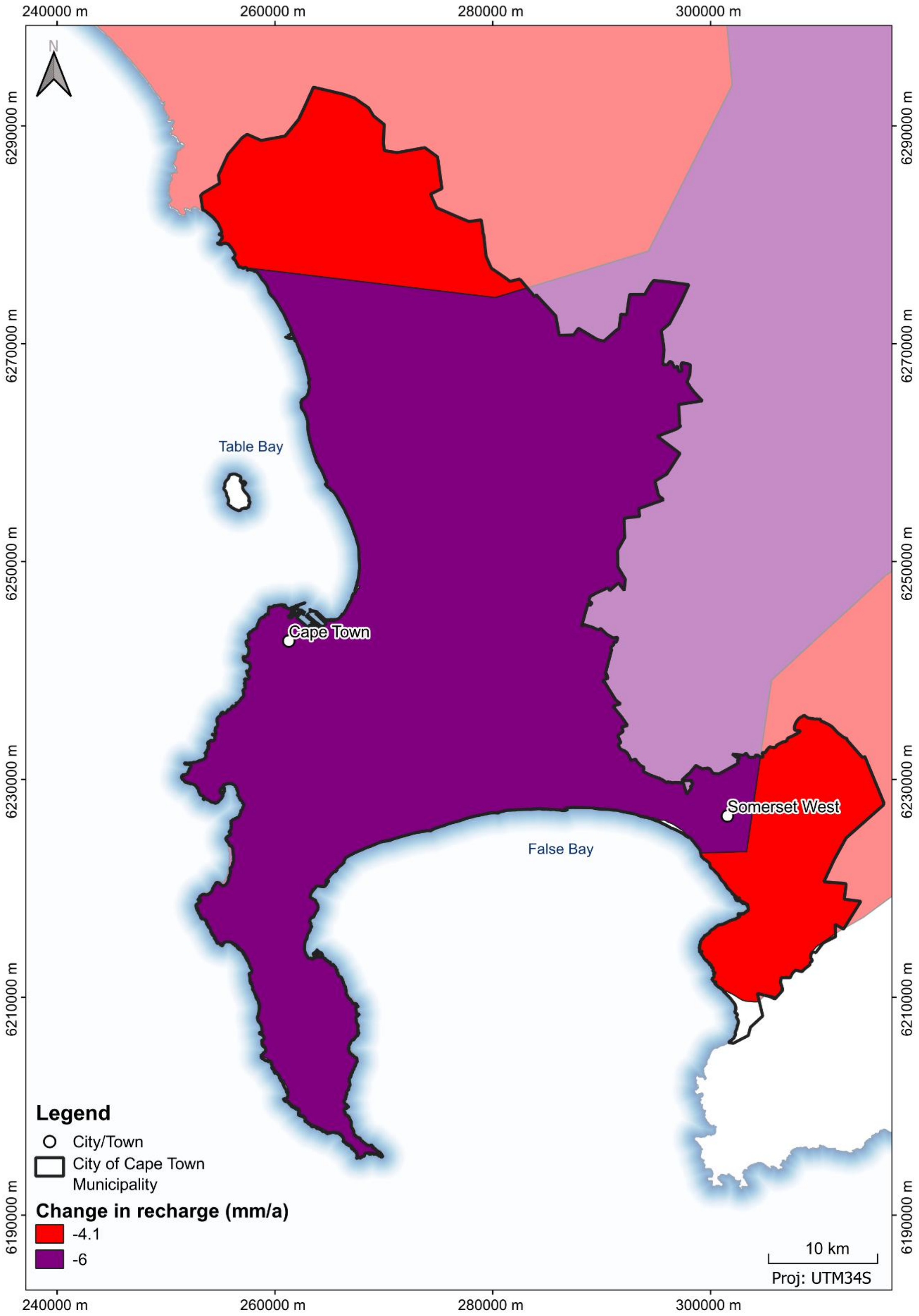


Figure 3-9 **Change in recharge according to the Meteorological Research Institute Coupled General Circulation Global Climate Model A2 SRES Emissions scenario, representing the time period between 2046 and 2065 (Dennis and Dennis, 2012). High recharge reduction equates to a reduction of 4.1 mm/a, very high recharge reduction equates to a reduction of 6 mm/a.**

4. Vulnerability

This section provides an overview of groundwater vulnerability in Cape Town, focusing on both the vulnerability of the aquifers themselves and the vulnerability of the groundwater users who depend on them. Vulnerability is assessed in relation to four key hazards: contamination, over-abstraction, sea-level rise, and reduced recharge. Groundwater vulnerability refers not only to the physical susceptibility of aquifers to degradation but also to the vulnerability of the ecosystems and human communities that rely on these resources for drinking water, agriculture, industry, and ecological function.

4.1. Aquifer Vulnerability

4.1.1. Contamination: Due to Human Activities

4.1.1.1. Introduction

Aquifer vulnerability to contamination refers to the likelihood that pollutants from the surface will reach the groundwater table and impact water quality within the aquifer (WRC, 2009). It is influenced not only by the nature of the pollutant but also by a number of physical and chemical processes within the aquifer, both within the unsaturated zone and the underlying saturated zone (see **Figure 4-1**).

Assessing aquifer vulnerability involves considering the physical characteristics of the aquifer (e.g. whether the aquifer is confined/unconfined and its dilution/attenuation capacity) and the aquifer's links with the wider environment (e.g. interaction with surface water and groundwater abstraction). It accounts for the vulnerability of the aquifer itself (i.e. the primary impact), as well as the secondary and tertiary impacts (see **Table 4-1**).

Table 4-1 Impacts of aquifer contamination (human-induced) (Umvoto Africa, 2009).

Primary, secondary and tertiary impacts
Primary impact • Aquifer contamination (human-induced)
Secondary impact • Social and economic impact: Water quality renders groundwater unfit for purpose (e.g. drinking, domestic use, agriculture, industry) • Environmental impact: potential damage to surface water and groundwater dependant ecosystems such as wetlands
Tertiary impact • Social impact: Risk of poisoning if contamination not adequately monitored and acted upon • Social, economic and environmental impact: Land may be rendered unsuitable for desired purpose (e.g. human habitation or agriculture) • Critical infrastructure: Alternative water source required

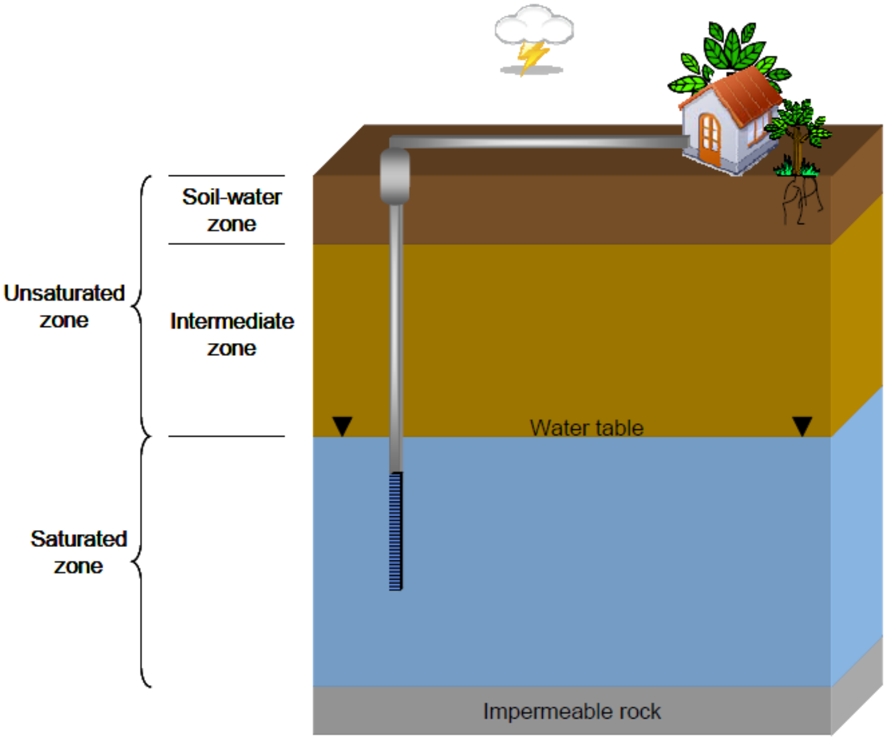


Figure 4-1 **Schematic representation of the unsaturated and saturated zones (WRC, 2007).**

Several factors can impact aquifer vulnerability, including:

- Contaminant type: The occurrence/rate of degradation, sorption, dilution etc in the aquifer is highly dependent on the contaminant;
- Composition of the unsaturated zone and aquifer: For example, high organic matter or clay content increases sorption and thus lessens the potential for contamination.
- Depth to the water table: Short flow paths decrease the opportunity for sorption and biodegradation, thus increasing the potential for contaminants to reach groundwater. Preferential flow pathways in the unsaturated zone, however, potentially allow contaminants to pass into the saturated zone relatively quickly.
- Groundwater recharge rate: This affects the extent and rate of transport of contaminants through the unsaturated zone.
- Environmental factors (e.g. temperature, pH and water content): These can significantly influence the degradation of contaminants by microbial transformations.
- Aquifer composition (rock type, amount of clay/organic material, porosity, degree of fracturing).
- Aquifer confined/unconfined, hydraulic gradient, surface water/groundwater interaction.

The main geological and hydrogeological features that will influence an aquifer’s vulnerability are:

- Low Vulnerability – Thick unsaturated zone, with high levels of clay and organic material; and
- High vulnerability – Thin unsaturated zone, with high levels of sand, gravel or fractured rocks with high permeability.

4.1.1.2. Aquifer Vulnerability Mapping

To assess aquifer vulnerability in this section, existing information from a study by DWAF (2005), which undertook a regional DRASTIC analysis of South Africa, was used to create the vulnerability map in **Figure 4-2**. The vulnerability scores from DWAF (2005) used to generate this map were between 40 and 187. These vulnerability scores were reclassified into 5 classes (Very low: 0-103; Low: 103-124; Moderate: 124-146; High: 146-167 and Very High: >167) for the purposes of this assessment.

Figure 4-2 shows that regions of high and very high vulnerability (particularly, the southwestern sections of the CFA) to groundwater contamination in Cape Town are primarily underlain by the CFA and Atlantis aquifers. The CFA and Atlantis Aquifer are shallow, unconfined aquifers with high permeability rates, making them more vulnerable to contamination from human activities that occur on the land surface (e.g. agriculture practices, informal settlements and industries).

The Cape Peninsula area, underlain by the secondary fractured rock aquifer of the TMG, which has a low permeability, generally has a moderate vulnerability, particularly in the southern sections of the region. While the northern sections of this area have a more variable vulnerability, with a mix of low, moderate and high vulnerability sections. Meanwhile, the TMG Aquifer area within the Hottentots Holland Mountain region has a low vulnerability to contamination, although Somerset West, to the north west of this area shows areas of high vulnerability.

In comparison, the north-east regions of the city near Durbanville, extending north (see **Figure 4-2**), have the lowest vulnerability to contamination within the City of Cape Town.

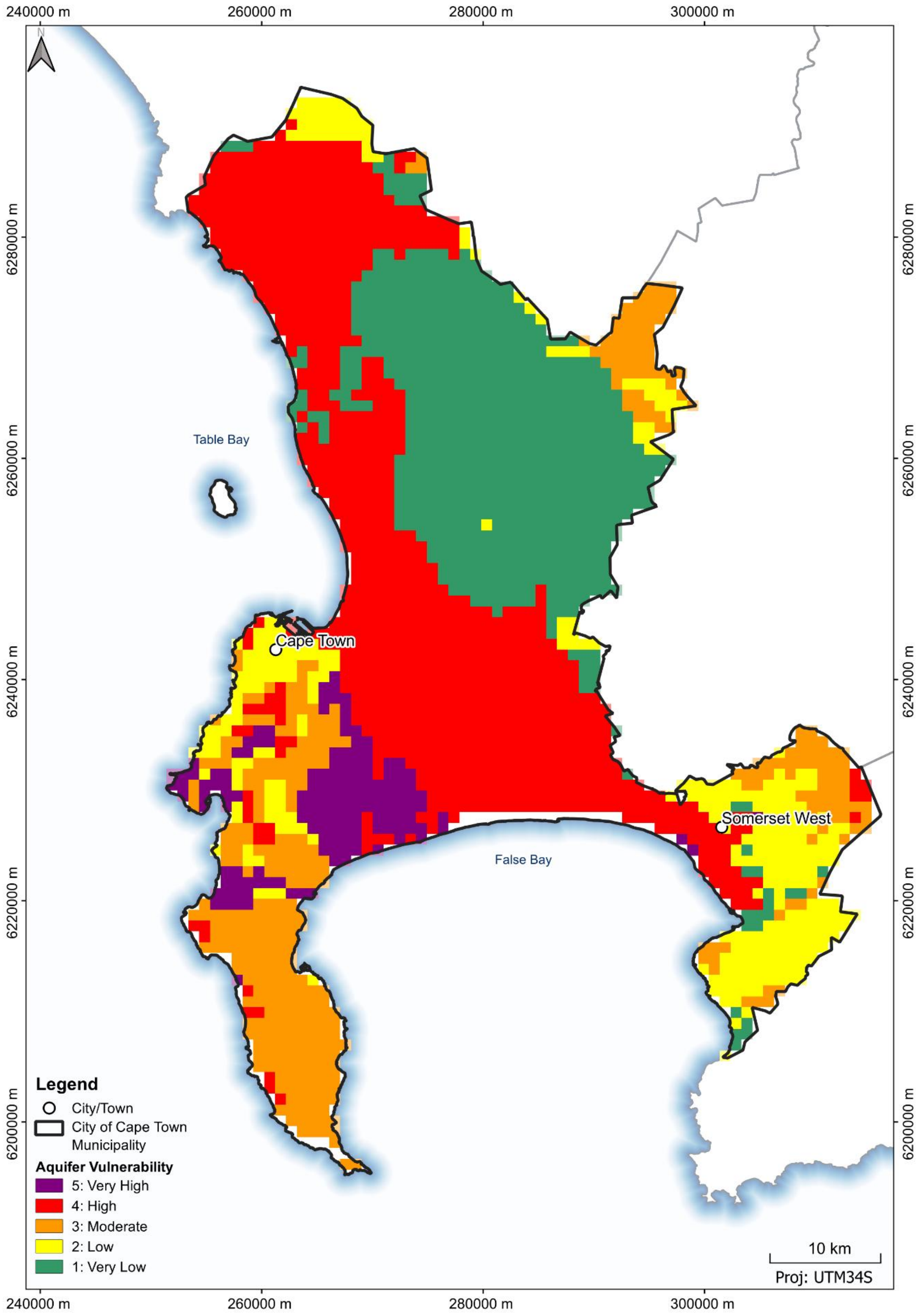


Figure 4-2 Aquifer contamination vulnerability map (DWAF, 2005).

4.1.2. Over Abstraction

4.1.2.1. Introduction

An increase in water demand due to climate change, a growing population due to urbanisation and the need for economic development can lead to the over-reliance on groundwater. This over-reliance increases groundwater abstractions in the city, which may lead to over-abstraction of the aquifer. The over-abstraction of groundwater has negative impacts on the aquifer itself and the environment and people that depend on the resource. These include:

- **Declining groundwater levels/pressure**: occur due to over-pumping, which causes the water table to drop, resulting in a reduction in the availability of groundwater and an overall degradation of the aquifer. The reduction in water levels can also results in a reduction of a borehole yields. In severe cases, aquifer depletion and storage losses can occur, resulting in aquifers becoming permanently damaged. The reduction in water availability as a result of over-abstraction affects sectors and communities that rely on groundwater for various uses (e.g. the farming community in Philippi relies on groundwater for irrigation purposes).
- **Reduced baseflow:** A decline in groundwater levels results in a reduction in groundwater discharge, which limits the baseflow of rivers. A decrease in baseflow leads to a reduction in surface water flows, affecting aquatic ecosystems and river flows downstream.
- **Seawater intrusion**: The over-abstraction of coastal aquifers can cause groundwater levels to drop below sea level. This disrupts the natural pressure gradient that normally causes freshwater to flow towards the sea, leading to a reversal of flow direction within the aquifer. This reversal of flow direction causes seawater to flow into the freshwater zone of the aquifer, causing groundwater to become saline.
- **Ecosystem degradation**: Groundwater-dependent ecosystems (GDEs) such as rivers, wetlands, springs and seeps depend on groundwater for the maintenance of their ecological processes, structure and function, particularly during dry periods when rainfall is limited. If groundwater availability for GDEs is reduced, GDEs may dry out or suffer ecological stress, which may lead to the loss of biodiversity.
- **Land subsidence**: Excessive groundwater abstractions can cause the ground to sink or collapse.

4.1.2.2. Over Abstraction Vulnerability Mapping

To assess the vulnerability of aquifers in Cape Town to over-abstraction, an over-abstraction vulnerability map was generated based on the aquifer type and recharge. **Figure 4-3** classifies areas based on their vulnerability to over-abstraction. The map shows that the majority of the City of Cape Town has a moderate or high vulnerability to over-abstraction.

The CFA has a variable vulnerability to over-abstraction, which closely aligns with aquifer yield across the region. In the southern sections, where aquifer yields are relatively high, the vulnerability is low, while the central areas of the aquifer, which have a moderate yield, show moderate vulnerability. In contrast, the northern parts of the CFA characterised by low yields display a high vulnerability.

The northern sections of the city, including the Atlantis area, are primarily characterised by a high vulnerability to over-abstraction. However, sections of moderate vulnerability are also present within this region, especially where aquifer yields are greater. Although recharge and aquifer yields in CFA and Atlantis are relatively good due to their unconsolidated nature, these aquifers are at risk of over-abstraction should the water demand in the city continue to increase.

Very high vulnerability to over-abstraction is limited within the city and occurs only in localised areas, including along the Table Bay coastline, and in small sections along the northeastern municipal boundary, where aquifer yields are lower. The very high vulnerability along the false bay coastline

Areas of the TMG, such as the Cape Peninsula, have a moderate vulnerability to over-abstraction, likely due to limited recharge in the area (see **Table 3-3**). The Steenbras region, which has high recharge, is characterised by a low vulnerability, although Somerset West to the northwest has a moderate vulnerability.

The impact of seawater intrusion has also been included in **Figure 4-3**, due to elevation of basement geology and topography Cape Town’s aquifers, the CFA is the only major aquifer affected by sea water intrusion as a result of sea level rise. Along the False Bay coastline in the South of the CFA, a very high vulnerability has been mapped. This portion extends approximately 1 km inland from the ocean and has implications for groundwater users in the area should over abstraction result in in seawater intrusion.

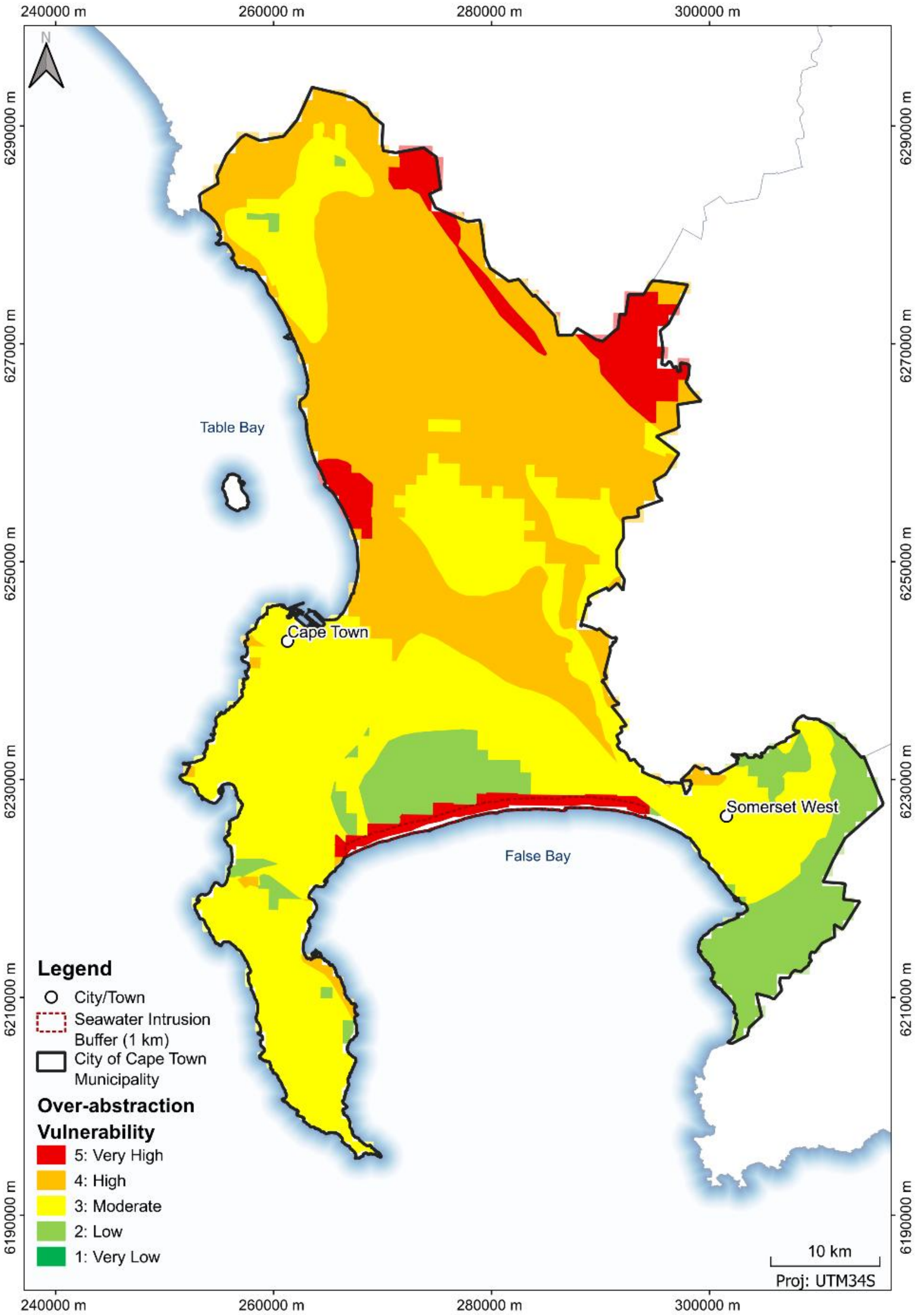


Figure 4-3 Over-abstraction vulnerability map for the City of Cape Town.

4.1.3. Sea Level Rise: Due to Climate Change

4.1.3.1. Introduction

Sea Level Rise is classified as global (GSLR), regional (RSLR), and coastal (CSLR) depending at the location and scale at which the rise is assessed. According to IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (IPCC ,2019), rising sea levels result from multiple factors. These factors include thermal expansion of ocean water due to decreased density from increasing temperatures, melting of glaciers and ice sheets increasing water mass, storm surges, increased runoff, and change in on-land water storage conditions. Furthermore, anthropogenic activities including land use changes, urbanisation, and groundwater abstraction exacerbate sea level rise due to changes in the elevation and recharge potential.

There are three main factors affecting aquifer vulnerability to sea level rise (see **Table 4-2**), namely:

- Saline intrusion: People, industry and agriculture are vulnerable to sea level rise if groundwater becomes too brackish for its desired purpose. In addition, over-abstraction of groundwater can further enhance salinisation by drawing in saline water from the coast or elsewhere in the aquifer. Aquifers where the volume of groundwater abstraction is significant are most vulnerable.
- Groundwater flooding. If an area is low-lying and has a shallow water table, it may be vulnerable to groundwater flooding. As the water table reaches the surface, rain/flood water is impeded from percolating into aquifers. Such flooding often lasts longer than flooding from e.g. burst riverbanks. Housing, industry and critical infrastructure situated in these areas are vulnerable to groundwater flooding.
- Saline intrusion / groundwater flooding: If the chemical composition (e.g. salinity) of water in rivers, wetlands and other groundwater dependent ecosystems changes, the biodiversity and integrity of the watercourse/water body will alter (but may improve if e.g. estuary flushed out more).

Table 4-2 Primary, secondary and tertiary impacts on aquifers due to sea level rise

Primary, secondary and tertiary impacts
Primary impact • Intrusion of saline water into the aquifer • Change in discharge regime of aquifer
Secondary impact • Social/economic: Salinisation of groundwater: Water quality renders groundwater unfit for purpose (e.g. drinking, domestic use, agriculture, industry) • Critical facilities: Groundwater flooding can impact water treatment plants, WWTWs, electricity sub-stations, transport, hospitals etc
Tertiary impact • Critical facilities: Alternative water source required • Environmental impact: potential damage to fresh water ecosystems (e.g. wetlands). Salinisation of soils if saline/brackish water used for irrigation

Inundation modelling:

A sea level inundation map shown in **Figure 4-4** was created to illustrate the impacts of climate change indued sea level rise on the coastal city of Cape Town.

The IPCCs Coupled Model Intercomparison Project (CMIP) by Seneviratne et.al (2021) indicates that the increase in sea level rise around Cape Town is 0.26m (SSP5-8.5 relative to 1995-2014 to 2041-2060; medium term). The same reference period is used by NASAs Sea Level Projection Tool (NASA, n.d.). This includes two station points along the coast of Cape Town namely Granger Bay (0.31m increase) and Simons Bay (0,351m increase). In considering a conservative approach (where higher sea level rise is conservative) the projected increase of 0.351 m has been adopted for this study.

To consider the influence of this increase, **Figure 4-4** used the Copernicus 30m (COP30) digital surface model and applied the 0.351m increase in sea level to illustrate the added area of inundation relative to mean sea level. COP30 is referenced to the WGS84 ellipsoid, which is the same ellipsoid as used in the South Africa’s Hartebeeshoek datum. When considering sea level rise, the increase is based on the land levelling datum (LLD). In South Africa, the LLD and mean sea level are, however, nearly coincident (considered equal for the purposes of this report).

The results in the map indicate that based on the IPCC SSP5-8.5 projection, a negligible area of low-lying terrain along the coast of Cape Town may be permanently inundated or recurrently flooded due to the sea level rise.

4.1.3.2. Aquifer Vulnerability

Given sea level rise is considered a low hazard for most of Cape Town’s aquifers, their vulnerability has been classified as very low. The CFA is the only aquifer which has been assigned a very low to low level of vulnerability. The assignment of this level of vulnerability is due to the predicted changes in sea level should it rise by 0.31m. Unlike the Atlantis Aquifer which due to the elevation of its basement geology, is likely to remain unaffected should a rise in sea level of this magnitude occur, the CFA is not at a higher elevation and therefore has a direct interface with the saline water of the ocean. From **Figure 4-4**, it is apparent the coastline will be the most likely affected by sea level rise, consequently this coastal margin is considered the most vulnerable (moderate vulnerability) of the CFA. Over long term change this level of vulnerability may change, however a conservative increase of 0.31m is likely to have a negligible influence on the CFA’s vulnerability.

Figure 4-4 Influence of sea level rise on the Cape Town Metropolitan area according to NASA (n.d).

4.1.4. Reduced Recharge: Due to Climate Change

4.1.4.1. Introduction

In the national assessment of climate change impacts by Schulze and Schütte (2023) reduced groundwater recharge is exacerbated by the various influences of climate change (primarily decrease in rainfall). The assessment provides what it terms as “baseline” (naturalised) hydrological projections of runoff whereby anthropogenic impacts are not considered.

Anthropogenic activities (e.g. increased impervious areas) are also relevant to reduced recharge, however, that is not the focus of this section.

Schulze and Schütte (2023) includes a dataset of mean annual change in drainage to groundwater. This dataset was provided by Stefanie Schütte and has been used to define the reduced recharge resulting from climate change relative from present (1961-1990) to the near future (2015-2044) for SSP5-8.5.

The data is presented according to quinary catchments and was clipped to extent of the City of Cape Town (see **Figure 4-6**). Using area weighting, it was noted that the average reduction in drainage to groundwater is 33.5%. Schulze and Schütte (2023) indicate a medium confidence in their estimate of drainage to groundwater.

Figure 4-6 presents the original dataset (without area weighting) and also outlines the different aquifer types for which change in recharge would be more impactful (i.e. intergranular). Impervious areas are also illustrated since these areas are not considered in the mean annual change in drainage to groundwater by Schulze and Schütte (2023), yet will have a significant influence on recharge.

Change in mean annual rainfall was also evaluated as a proxy to change in recharge. In **Figure 4-7** in Schulze and Schütte (2023) present this change from present (1961-1990) to the near future (2015-2044) for SSP5-8.5 with a reduction of between 10-20% noted (with high confidence in the estimate). By comparison, the CMIP6 results show an area weighted reduction in mean annual runoff of -15.73% (likewise with high to very high confidence). There is consequently reasonable agreement between CMIP6 and Schulze and Schütte (2023).

Table 4-3 presents additional relative changes in parameters as determined by CMIP6, informing on reduction in recharge. The level of confidence in results is also presented. The reduction of shallow soil moisture, as shown in **Table 4-3**, limits the recharge potential as water is retained in the upper most layers and limits the ability to transmit to the shallow zones (IPCC, 2019). There is low confidence in the decrease in runoff, however this can be attributed to the seasonality and variation in surges and attributed to the reduction in precipitation.

4.1.4.2. Aquifer Vulnerability Mapping

The vulnerability of Cape Town's aquifers to impacts of recharge reduction were assessed through the mapping of the ratio between recharge reduction and annual recharge. Recharge reduction was incorporated from the work done by Dennis and Dennis (2012), who modelled recharge reduction under the A2 SRES Emissions scenario. These ratios were organised into 5 classes and then assigned recharge reduction factors ranging from 1 – 5, where 1 represents a very low vulnerability and 5 a very high vulnerability.

The output of this analysis (see **Figure 4-5**), indicate both the TMG aquifers have a very low to low vulnerability to recharge reduction. Given the volume of annual recharge that occurs over these areas, reductions of between 4.1 – 6 mm/a are negligible. Between these two aquifers the CFA is shown to possess a low to moderate vulnerability to recharge reduction. This is because annual recharge is relatively lower across the Cape Flats than what can be found in the mountainous parts of the Cape Town Municipality.

The Atlantis Aquifer along the west coast can be seen to possess a moderate to very high vulnerability to reduction in recharge, as this predicted reduction would result in a 30% decrease to recharge in certain portions of the aquifer. The northern suburbs exhibits the highest vulnerability range in Cape Town, where aquifer vulnerability to reductions in recharge were identified as high and very high. The groundwater in this region of the municipality is typically from either the Cape Granite Suite or Malmesbury Basement aquifer. Some portions are also known to possess think sections of quaternary sediments overlying these groundwater systems. Due to the hydraulic properties of these aquifers and climatic conditions of the Municipalities northern interior, reduced recharge would be a significant decrease to an already low annual recharge.

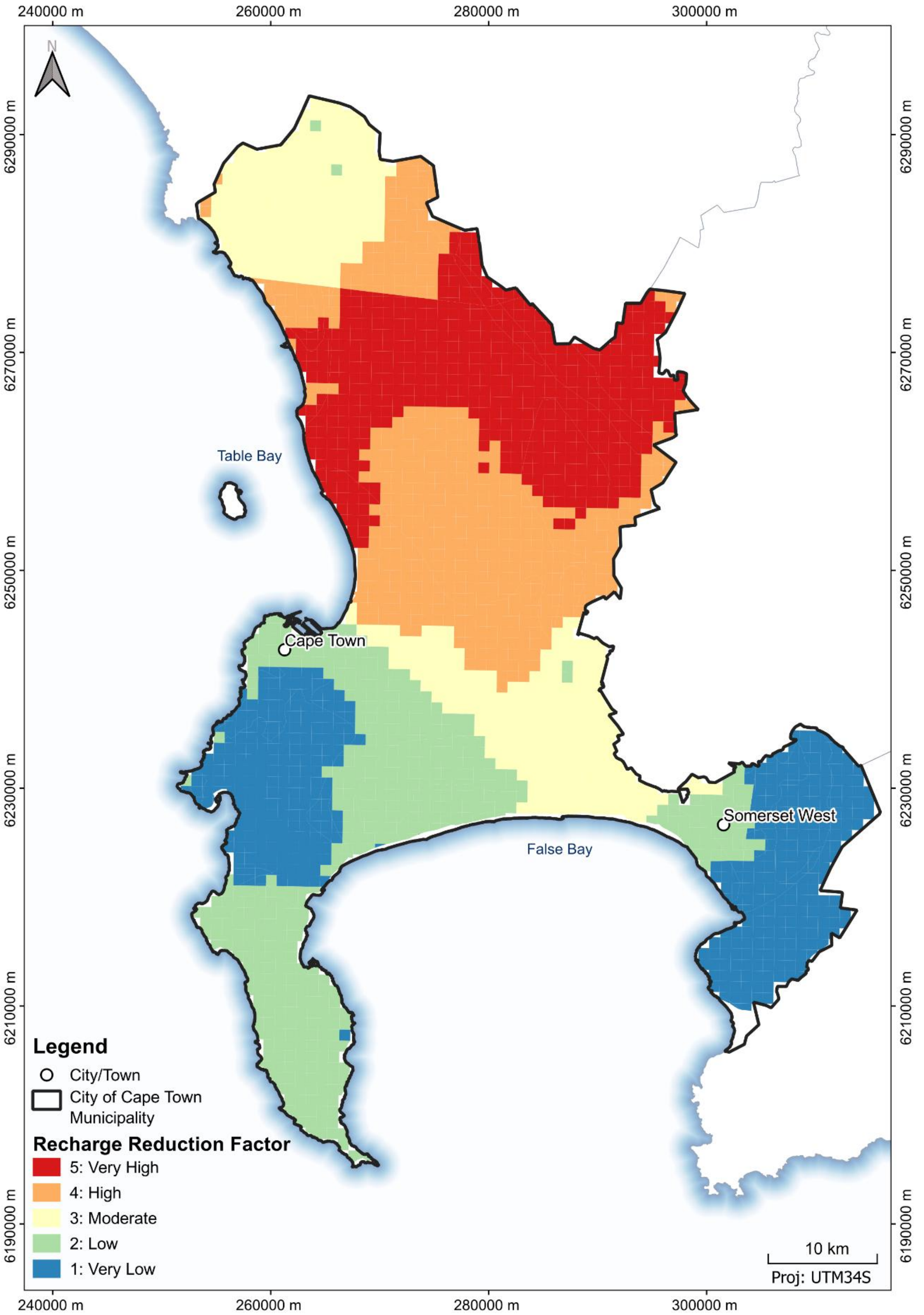


Figure 4-5 **Recharge reduction factor map illustrating the ratio of predicted recharge reduction (mm/a) (Dennis and Dennis, 2012) to annual recharge (mm/a). Depending on the degree of recharge, a descriptive factor from 1 to 5 was assigned, with 1 indicating a very low factor and 5 a very high factor.**

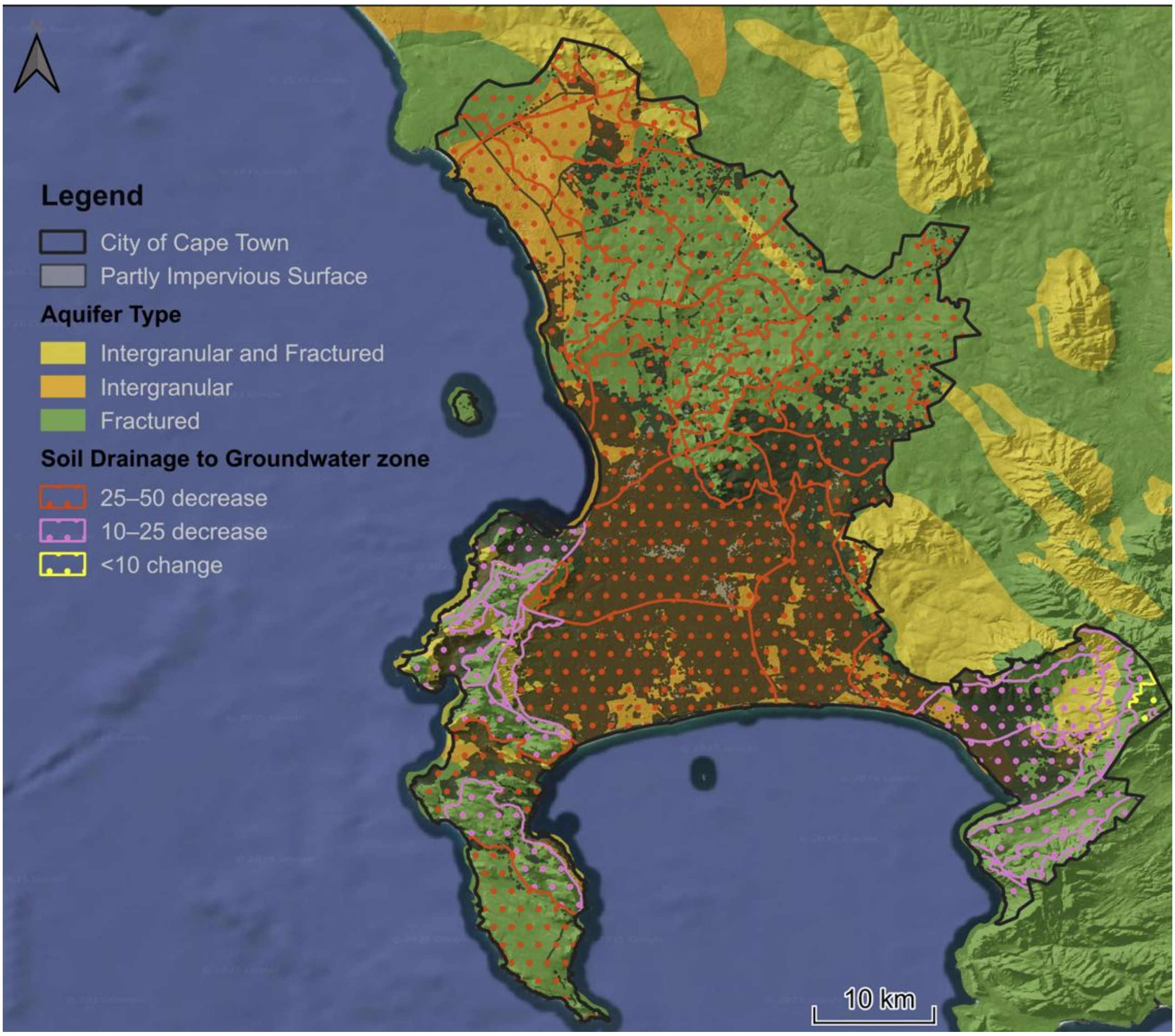


Figure 4-6 **Mean annual soil water drainage to the groundwater zone derived from GCM generated climate input, with projected changes from the present (1961-1990) to the near future (2015-2044) according to Schulze and Schütte (2023).**

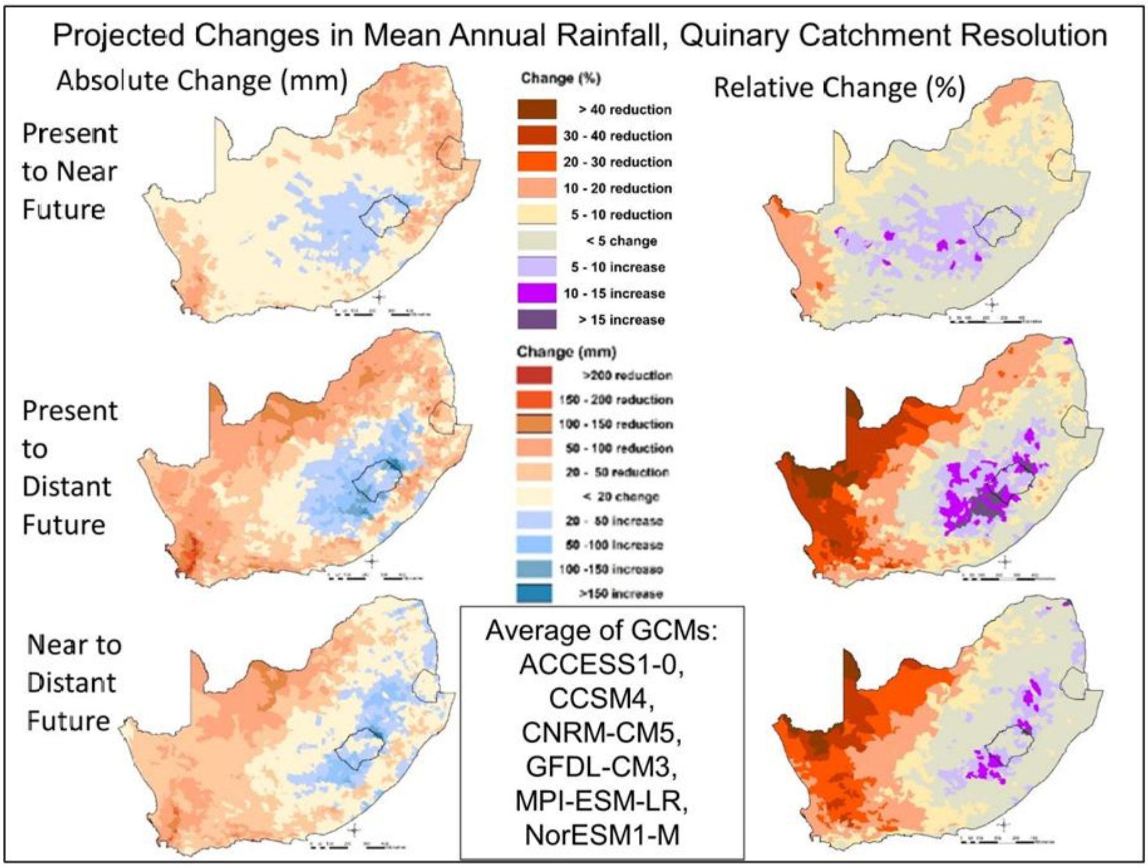


Figure 4-7 Projected changes in mean annual rainfall showing absolute changes (mm) on the left and relative changes (%) on the right, with changes from the present (1961-1990) to the near future (2015-2044) [top row], from the present to the distant future (2070-2099) [middle row] and changes from the near to the distant future [bottom row], at Quinary Catchment resolution (after Schütte and Schulze, 2023).

Table 4-3 CMIP6 Medium term Projections (2041-2060) SSP5-8.5 (IPCC, 2021; Copernicus Climate Change Service, n.d.)

Variable	Confidence Level	Value
Mean soil shallow moisture % (1981-2010)	High confidence	-5.59
Mean daily accumulated runoff % (1981-2010)	low confidence- no change or no robust signal	-36.21
Total precipitation % (1961-1990)	High confidence of decrease	-15.73
Total precipitation % (1981-2010)	High confidence of decrease	-13.69
Mean daily evaporation % (1981-2010)	West coast (High confidence) East coast (Low confidence) (1/2 Robust 1/2 No change or no robust signal)	-3.00

Table 4-4 Primary, secondary and tertiary impacts of reduced groundwater recharge.

Primary, secondary and tertiary impacts
Primary impact • Reduced groundwater levels • Water scarcity • Change in discharge regime of aquifer • Drying of shallow springs and wells • Reduced baseflow to rivers and waterbodies
Secondary impact • Social/economic: insufficient sources of water and decreased water quality renders groundwater unfit for purpose (e.g. drinking, domestic use, agriculture, industry) • Saline intrusion: increased salinity in coastal aquifers • Environmental: increased threat of desertification in arid areas and loss of waterbody ecosystems • Food scarcity: insufficient water resources can lead to crop failure • Critical facilities: insufficient groundwater can impact water treatment plants, WWTWs, electricity sub-stations, transport, hospitals etc
Tertiary impact • Critical facilities: Alternative water source required • Environmental impact: potential damage to freshwater ecosystems (e.g. as wetlands). Salinisation of soils if saline/brackish water used for irrigation

4.2. Vulnerability of Groundwater Users

4.2.1. Municipalities

Municipalities, as key institutional groundwater users, face specific vulnerability factors related to their role in water supply, groundwater management, and infrastructure protection. The City of Cape Town has developed three major groundwater schemes: the Atlantis Water Resource Management Scheme, the Cape Flats Aquifer Management Scheme, and the Table Mountain Group Aquifers Management Scheme. Each scheme contains aquifer monitoring systems, management protocols, and infrastructure designed to minimise vulnerability and enhance resilience.

4.2.1.1. Vulnerability of Municipalities to Contamination of Groundwater

The City's groundwater schemes are vulnerable to contamination risks due to both natural aquifer characteristics and surrounding land-use pressures. Municipal production boreholes, especially those located in shallow, unconfined aquifers like the Cape Flats Aquifer (CFA), are at increased risk of pollution from surface-based activities. Broader land-use patterns, including urban densification and informal settlements with inadequate sanitation infrastructure, contribute to this vulnerability. In many parts of the Cape Flats region, leaking sewers, pit latrines, and unregulated dumping introduce nitrates, pathogens, and organic contaminants into the shallow aquifer systems. These same aquifers supply water to some of the municipal wellfields, making proactive land-use control and water quality monitoring essential to protect supply integrity.

To address these risks, the City has adopted a proactive and structured approach to managing contamination risks for its groundwater schemes. Key initiatives include the delineation and implementation of Groundwater Protection Zones (GPZ) for each groundwater scheme.

A key component is the delineation of Groundwater Protection Zones (GPZs) around production boreholes. These zones are based on contaminant travel time and proximity to boreholes, and include (CCT, 2022b):

- Zone I – Wellhead Protection (10 m radius): Fully restricted with no activities allowed. Boreholes are equipped with sanitary seals, housed in concrete chambers, and fenced with lockable cages to prevent tampering and direct contamination.
- Zone II (2-year travel time): Designed to protect against microbial contamination, with activity restrictions unless prior approval and risk assessments are conducted.
- Zone III (5-year travel time) and Zone IV (10-year travel time): Provide buffers for chemical contaminants, allowing time for detection and intervention before contaminants reach production wells.

These GPZs aim to prevent future pollution by restricting high-risk land uses and guiding land-use planning processes. Included with the GPZs were detailed vulnerability mapping and potentially contaminating activity (PCA) mapping. This approach helps identify areas of high vulnerability and ensures that PCAs are not permitted near production boreholes. Furthermore, PCA mapping has been undertaken to identify existing contamination threats. This spatial risk information helps to guide groundwater treatment processes at each water treatment works by informing which contaminants may need to be addressed to ensure that the water treatment works are robust to treat the contaminants. Notable PCAs that have been identified include historical waste sites, waste water treatment works, cemeteries, petrol stations, heavy duty industrial areas, agricultural activities and expanding informal settlements with associated poor waste disposal practices.

The City has also developed groundwater pollution incident response management plans to provide step-by-step guidance on how to respond to contamination events. In the event that contaminants pass through to a water treatment works, an incident management protocol is in place to guide operational decisions, ensuring the protection of water quality before it enters the municipal distribution system.

These interventions are supported by a robust, ongoing groundwater quality monitoring programme, which includes routine sampling and trend analysis across production and monitoring boreholes. This allows the City to identify emerging water quality issues early and respond effectively.

4.2.1.2. Over Abstraction

The City’s groundwater schemes are vulnerable to over-abstraction, both from municipal operations and increasing private use. With over 22,000 registered private boreholes across Cape Town, many concentrated within the same aquifer systems used by the City, cumulative abstraction pressures continue to grow (Arup et al., 2019). During drought periods, such as the 2015–2018 “Day Zero” drought, unmonitored private groundwater use placed significant additional stress on aquifers like the Cape Flats Aquifer (CFA). This overlap between municipal production boreholes and dense private abstraction zones heightens the risk of over abstraction.

The situation is further complicated by the presence of unregistered boreholes and limited reporting on private abstraction volumes, making it difficult for the City to calculate total aquifer use and implement fully integrated groundwater resource management. Declining groundwater levels could also create indirect socio-political challenges. If municipal pumping contributes to drawdown that affects nearby private users, such as farmers or industries, the City may face complaints, compensation claims, or external pressure to reduce abstraction rates.

In response, the City has implemented a range of engineering, monitoring, and management controls to mitigate over-abstraction risks. Both the Atlantis and CFA schemes incorporate Managed Aquifer Recharge (MAR), which allows the City to artificially replenish aquifer levels. This not only helps sustain groundwater availability but also improves water quality over time, particularly in aquifers impacted by historical surface contamination, like the CFA.

All municipal abstraction boreholes are fitted with flow meters, and each wellfield operates under predetermined operating water levels to maintain sustainability. Water level monitoring is conducted both within production and monitoring boreholes, as well as in surrounding environmental points such as wetlands, streams, and other groundwater-dependent ecosystems (GDEs). This enables the City to adopt adaptive management strategies if monitoring data indicate environmental impacts.

Competition with other user groups, especially farmers drawing from the CFA, remains an ongoing consideration. However, the MAR strategy helps balance these competing demands by supplementing groundwater levels. It also enables "aquifer banking", allowing the City to store water during times of surplus for use during droughts, when groundwater stress from all users typically increases.

Saline intrusion is a potential risk associated with over-abstraction, particularly in coastal aquifers. The Atlantis Aquifer, however, is not vulnerable to this risk due to its basement topography where the aquifer base is above mean sea level. In contrast, the CFA does face a higher risk of saline intrusion. To mitigate this, the City has implemented MAR, which creates a hydraulic barrier between its wellfields and the coastline to prevent saline intrusion. Additionally, monitoring boreholes have been installed along the coastline to track any signs of saline intrusion linked to scheme operations. This enables adaptive management, allowing the City to adjust borehole yields if needed. Furthermore, the scheme design proactively reduces this risk by setting operating water levels for wellfields near the coastline, ensuring they do not fall below zero metres above mean sea level (mamsl) during abstraction.

4.2.1.3. Vulnerability to Sea-Level Rise

The City’s groundwater schemes most vulnerable to sea-level rise (SLR), are the two coastal groundwater schemes (Cape Flats Aquifer and Atlantis Aquifer). While the wellfields for these schemes are generally located further inland, reducing direct vulnerability, the City’s MAR programme further mitigates this risk by maintaining a positive hydraulic gradient between the wellfields and the coastline. This creates a hydraulic barrier that helps reduce the risk of seawater intrusion, which could otherwise degrade groundwater quality under rising sea levels.

4.2.1.4. Vulnerability to Reduced Recharge

Climate change-induced reductions in natural recharge present a long-term risk to the sustainability of the City’s groundwater schemes. Declining recharge affects not only municipal wellfields but also intensifies competition between municipal supply and other groundwater-dependent users especially during drought periods. Historical drought events, including the 2015–2018 “Day Zero” drought, have shown that groundwater demand from all sectors, including municipal, private domestic, industrial, and agricultural users, can increase sharply during times of surface water scarcity. This surge in demand raises aquifer vulnerability and highlights the need for integrated groundwater and surface water management approaches to ensure resource sustainability.

To mitigate the impacts of reduced recharge, the City’s MAR infrastructure plays a dual role. MAR is used to supplement groundwater levels to support sustainable abstraction. In addition, it allows for “aquifer banking”, where water is stored in the subsurface for future drought resilience or times of increased demand. This combined approach helps ensure the long-term reliability and resilience of the City’s groundwater supply

In addition, the City uses numerical groundwater models to simulate aquifer responses under various climate change and drought scenarios. These models support long-term planning by informing future MAR volumes, refining operational limits, and identifying priority monitoring sites.

The City also holds regulatory authority to impose groundwater use restrictions on private users during times of scarcity, providing an additional tool to manage aquifer stress and protect municipal water security during recharge deficits.

4.2.2. Communities, Agricultural and Industrial Use

4.2.2.1. Aquifer Contamination: Due to Human Activities

Groundwater contamination in Cape Town arises from various human activities in aquifer recharge areas. Major pollution sources include informal settlements with poor sanitation, leaking sewers, cemeteries, agricultural runoff (pesticides/fertilizers), industrial effluent, landfills, and wastewater treatment works.

These contaminants leach into shallow aquifers like the Cape Flats Aquifer, degrading water quality. Socio-economically, communities in or near these pollution sources are highly vulnerable, for example, residents of informal settlements often lack proper sewage disposal, leading to pathogen contamination of local groundwater

They are also more likely to rely on untreated groundwater or nearby streams to meet household needs, increasing exposure. By contrast, wealthier areas are usually served by municipal piped water and have better waste management, reducing direct exposure. Cape Town’s recent drought experience highlighted this vulnerability. According to the City of Cape Town’s Water Outlook Report, the City looked to extract from the Cape Flats Aquifer for emergency supply, it found that much of the groundwater was “not suitable for immediate human consumption” without extensive treatment. The highest-yielding boreholes tended to have the worst pollution, indicating that areas with abundant groundwater often coincide with heavily impacted locations.

Thus, communities hoping to use groundwater (e.g. for drinking or gardening) in these areas face health risks or higher costs for treatment. Vulnerability is especially high for low-income households who may resort to shallow wells or boreholes because they lack access to safe municipal water. These households often cannot afford proper treatment systems, leaving them at risk of waterborne diseases if the aquifer is contaminated. In summary, socio-economic vulnerability to groundwater contamination is driven by exposure to polluted aquifers (geographic factor), reliance on untreated groundwater (economic factor), and lack of infrastructure like sanitation and water treatment (development factor).

In addition to communities, industries and farmers are also significant users of groundwater. Industries rely on groundwater for manufacturing processes, cooling, and sometimes general domestic use within their facilities. Farmers use groundwater extensively for irrigation of crops, livestock watering, and household needs on agricultural properties. Their dependency typically increases during times of water shortages or drought, when surface water supplies are limited. These users are also at heightened risk of contributing to and being affected by groundwater contamination. This is because industrial and agricultural activities are typically concentrated in designated zoning areas, which tend to cluster PCAs. For example, oil refineries are located within heavy industrial zones, while herbicide and pesticide use is common in agricultural areas. This spatial clustering increases the risk of localised groundwater pollution, affecting both the users and the surrounding environment

Population Exposure and Sensitivity

A large population lives above and around contaminated groundwater zones. The Cape Flats Aquifer spans ~630 km² under densely settled areas from False Bay to Milnerton (Adelana et al, 2010). This includes many low-income neighbourhoods and informal settlements, about 12% of Cape Town’s households live in informal dwellings (CCT, 2023b). These communities are often characterised by insufficient sanitation which leads to sewage leaching into shallow groundwater, contaminating the resource they live above. Vulnerable populations groups (children, the elderly, people with poor health) are exposed in these high-density areas and are more susceptible to water-borne diseases if groundwater or soil is polluted. Cape Town has a youth dependency ratio of 31.6% and an old age dependency ratio 9.4% (CCT, 2023b).

Industrial and agricultural zones are also significant exposure points due to their role as concentrated PCA hotspots. PCA mapping for Cape Town has identified industrial parks, fuel depots, and intensive farming zones (such as the Philippi Horticultural Area) as areas where both soil and groundwater contamination risks are elevated. Communities living near these industrial and agricultural zones face higher contamination risks, particularly if aquifer flow paths direct pollutants toward residential boreholes or communal groundwater sources. Generally lower income communities are located within close proximity to industrial areas and therefore have a higher risk.

Dependency on Groundwater

The proportion of people directly drinking groundwater is relatively low (since most have municipal water), but specific groups depend on it for livelihood or supplementary use. Private boreholes and wellpoints are common. Over 22,000 private boreholes exist in Cape Town (Arup et al., 2019), predominantly in formal suburban areas. Many households (especially in affluent areas) use groundwater water for garden irrigation or even flushing toilets, while peri-urban farmers rely on boreholes for crop irrigation or livestock watering. In the Philippi Horticultural Area (PHA), farmers draw from the aquifer to produce ~100,000 tonnes of vegetables annually (Seeliger, 2020). These users are vulnerable to contamination as polluted groundwater can harm crops and livelihoods or require costly treatment. Most low-income households do not consume groundwater directly, with 98.3% of households have access piped water, either on the property or within 200 m. This widespread access to municipal water limits direct consumption of polluted groundwater. However, if municipal supply is disrupted (e.g. during drought), communities might turn to wells or shallow boreholes, increasing their exposure to contamination.

The industrial sector is the second largest groundwater user in Cape Town, accounting for around 35% of total use. Industries abstract groundwater for manufacturing processes, cooling systems, and washing. While most of this water use is non-potable, industries remain vulnerable to aquifer contamination as it could affect process water quality, requiring expensive pre-treatment or posing reputational risks if production contaminates the resource.

Socio-Economic Status Factors

Poverty and inequality strongly shape contamination vulnerability. Low-income communities often reside closer to pollution sources (e.g. adjacent to landfills, industrial areas or wastewater plants on the Cape Flats, Athlone) and lack resources to mitigate exposure. They also have limited ability to test or treat water. Within agricultural areas, such as the PHA, farmer workers might be exposed to potential contaminants if they consume water from boreholes if other water sources are not available and they are not educated on the potential risks. In comparison to borehole owners in affluent areas are more likely to be able to afford water-quality testing and filtration, poor households cannot easily verify if water (or even soil) is contaminated. Similarly, industries are generally better positioned to install water treatment plants to meet the required standards for both processing needs and domestic use within their facilities.

Education levels are lower on average in low-income communities, which can reduce awareness of contamination risks. By contrast, wealthier residents are less exposed since they live in formal areas with regulated sanitation and can respond to pollution issues by switching to bottled water or use home filtration systems. This socio-economic disparity means contamination events (like an *E.coli* outbreak or nitrate pollution) would disproportionately impact poorer, less-educated communities who rely on public authorities to ensure water safety.

Water Infrastructure and Service Access

Access to safe water and sanitation is a critical vulnerability factor for contamination hazards. Cape Town has relatively high service coverage overall, but gaps remain in informal settlements. 97.6% of households have access to a flush toilet, chemical toilet or a pit toilet with ventilation, with the remainder of the population still using bucket toilets or pit latrines (CCT, 2023b). These unserved or under-served sanitation households are most often concentrated in informal settlements and may contribute to groundwater pollution (e.g. pit latrines and overflowing buckets can leach pathogens into the ground). While most households have access to piped water, the 6% using communal taps (CCT, 2023b) often live in crowded settlements where any contamination of local groundwater (communal wells or open shallow groundwater) can quickly lead to health issues when alternatives are limited. In some informal areas, if municipal supply is insufficient, residents might resort to digging shallow wells or using nearby springs, which are vulnerable to contamination. Limited access to safe on-site services both increases the hazard (through pollution from poor sanitation) and the vulnerability by leaving communities with few alternatives but to live with contaminated environments.

Summary

Populations in informal settlements and areas with inadequate sanitation infrastructure are highly vulnerable to groundwater contamination. These communities may rely on shallow boreholes or springs due to lack of formal water connections and have limited means to mitigate pollution from pit latrines, waste dumps, or nearby industrial activities.

Key Factors:

- High-density informal settlements near contaminated or high-risk aquifers (e.g. Cape Flats Aquifer).
- Poor waste management and illegal dumping.
- Low awareness of groundwater protection.
- High concentration of PCAs in industrial and agricultural areas.

4.2.2.2. Over Abstraction

In Cape Town and the broader Western Cape, reliance on groundwater has grown in recent years due to drought, raising concerns about unsustainable use. If aquifers are drained, communities that depend on them could face water shortages, higher costs (drilling deeper boreholes or buying water), and livelihood losses (for those using groundwater for farming or business). Industries and commercial farms, especially those in high-consumption sectors like manufacturing and irrigated agriculture, are particularly vulnerable as their operations often rely on consistent groundwater supply for production processes, cooling, or irrigation.

Socio-economic vulnerability to over-abstraction is largely primarily driven by level dependency and access to alternatives. Communities or sectors that heavily depend on groundwater, with limited alternative sources, are most vulnerable if the aquifer levels drop. In Cape Town, this includes agricultural users who use boreholes for irrigation, and an increasing number of urban households and businesses with private boreholes. During the “Day Zero” drought, thousands of new boreholes and wellpoints were drilled in the City as residents sought emergency water. However, many of these were unregistered and unmonitored, meaning the total extraction could not be tracked. Wealthier homeowners in suburbs were more likely to afford drilling boreholes. While this provides them short-term water supply and less immediate vulnerability, the strain on the aquifer increases long-term vulnerability for all users due to the risk of over abstraction. Poorer communities often did not have the option to drill their own boreholes and relied on municipal water supply. When surface water supply ran low, these communities had limited backup options since private groundwater was less accessible to them. Over-abstraction can also dry up wetlands and rivers fed by groundwater, affecting ecosystem services, including water purification and flood attenuation, that indirectly support communities.

Areas at particular risk would be those where **groundwater use is high relative to recharge**, for example, parts of the Cape Flats Aquifer if pumping increases without regulation (Arup et al., 2019) and coastal wellfields where over-abstraction can induce saltwater intrusion. The PHA, with its high concentration of groundwater-dependent commercial farming, is a key example of a localised over-abstraction hotspot.

Key factors increasing vulnerability include the lack of regulation and lack of monitoring data (Arup et al., 2019). This governance gap increases overall vulnerability, especially for those without the financial resources to absorb shocks.

Population Exposure *and Groundwater Dependency*

Cape Town's direct dependency on groundwater has historically been moderate, with surface reservoirs providing the bulk of supply. However, this dependency increased during the "Day Zero" drought during which groundwater served as a key back-up to supplement reduced surface water supply. The communities *directly* exposed to the impacts of over-abstraction are the people and sectors **dependent on groundwater to meet their water demands**. This includes **households with wellpoints, industries with boreholes, and local farmer**. A key example is the Philippi Horticultural Area (PHA), where farmers are among the biggest groundwater users. These farmers are a key contributor to Cape Town's food security and rely almost entirely on aquifer water for irrigation. Their employees are highly sensitive if aquifer levels to drop and wells yield less or dries up, directly threatening livelihoods and food supply. Industrial zones like Epping and certain parts of the Northern Suburbs are also reliant on borehole water for production processes, making them vulnerable if aquifer levels drop and pumping yields decline. Communities on the urban fringe like smallholdings or townships using boreholes and/or communal wells would face immediate water shortages if local boreholes fail. However, it is important to note that the majority of Cape Town's population is indirectly buffered against over-abstraction as most households get water from the municipal system. Therefore, over-abstraction tends to be a more localised hazard affecting those who depend on specific aquifer pockets.

Density and Hotspots

Areas with high densities of boreholes are hotspots for over-abstraction risk. These clustered abstractions can quickly deplete shallow groundwater. Wealthier suburbs in the southern and northern parts of the City saw many wellpoints installed for irrigation and long-term overuse could lower the local water table, impacting **shallow wells or ecological feature**. Similarly, industrial zones and large agricultural zones, such as the PHA, represent concentrated groundwater abstraction hotspots. These areas feature multiple high-yield production boreholes within close proximity, intensifying the risk of localised drawdown and aquifer stress.

In contrast, low-income communities and informal settlements generally do not drill boreholes due to cost. Therefore, they are less directly affected by drawdown as their water demand is met by municipal supply. However, there are exceptions in some peri-urban informal areas that might use hand-dug wells; which would be very vulnerable to any local drop in the water table.

Socio-Economic Status

Higher-income households and commercial users are more likely to initiate over-abstraction, because they have the means to drill and pump. These same users also have access to more resources and therefore have greater coping capacity compared to lower-income user. Unemployment in Cape Town is around 23–24% (StatsSA, 2025). Unemployment is a driver of poverty and limits coping capacity. Poorer farmers might not afford new irrigation tech to use water more efficiently, leading to more stress on the aquifer per unit of production, and then larger impacts when water levels drop.

Industrial operators generally have greater ability to install deeper boreholes or invest in water-saving technologies, reducing their short-term vulnerability, but their continued abstraction adds to overall aquifer pressure.

In summary, those with lower socio-economic status have fewer cushions against over-abstraction impacts even if they are not the primary drivers of the problem.

Water Supply and Service Access

Communities **fully reliant on municipal water** are partially protected against localised groundwater over-abstraction as the City can reroute water from other areas if one source falters. However, for settlements or facilities that are off the grid or unserviced, vulnerability is high. Informal settlements or rural villages just outside the main city (but part of the metro) that have groundwater fed water supply would have no alternative if those boreholes fail. In contrast, formal neighbourhoods connected to the network might not even notice if an aquifer is being overdrawn, unless it's severe enough to affect the overall city supply. This creates unequal distribution or risk and vulnerability as **areas with diversified or multiple supply options (usually affluent, well-served areas) are less vulnerable**, while those with a single-source dependency (often poorer peripheral communities) are very vulnerable to that source being overused.

Environmental and Tertiary *Impacts*

Over-abstraction does not just affect water supply, it can also harm ecosystems that people directly and indirectly rely on. **Groundwater-dependent ecosystems (GDEs)** like the wetlands on the Cape Flats rely on a high-water table. If the aquifer is over-abstracted, these wetlands can shrink or dry seasonally. Informal settlements are often located near or even in wetlands (e.g. parts of Khayelitsha, Philippi and Delft areas) (Arup et al., 2019). As groundwater levels drop, these wetlands lose functionality compromising their ability to mitigate floods or support subsistence activities like small-scale harvesting of reeds or grazing.

Summary

Affluent households and industries are more likely to abstract groundwater privately. Vulnerability is pronounced in marginalised communities that rely on groundwater supply which may become depleted through excessive use elsewhere.

Key Factors:

- Inequity in access to boreholes and water meters.
- Weak regulation/enforcement in high-use areas.
- Dependence on shared groundwater resources.

4.2.2.3. Sea-level Rise

Sea-level rise (SLR) is a slow-onset hazard that can cause saline intrusion into coastal aquifers. If combined with heavy groundwater abstraction, saltwater can infiltrate boreholes that were previously fresh. Cape Town, being a coastal city, faces the risk of rising sea levels leading to the salinization of some aquifers. The Cape Flats Aquifer, stretches to the False Bay coast; without intervention, seawater could gradually contaminate its fringes. Saline intrusion makes groundwater unfit for human consumption and agriculture and once an aquifer zone turns brackish, it can no longer be used for drinking or most irrigation unless expensive treatment (desalination) is applied. Industries using groundwater near the coast, such as those in Milnerton, would also be at risk, particularly those that use groundwater for process water, cooling, or cleaning. Salinisation could damage equipment or interfere with manufacturing processes that require low-salinity water.

The socio-economic vulnerability to this hazard is driven by **location and dependency**. Communities drawing water from boreholes near the coastline, e.g. areas in Strandfontein, Philippi, or Milnerton near the salt marshes are at risk. If these communities rely on that groundwater for domestic use, small-scale farming, gardening, or industry, they could be impacted by saline intrusion. In Cape Town, direct domestic reliance on coastal groundwater is relatively limited. Most urban residents use municipal water. However, there are some notable uses: the Philippi Horticultural Area (PHA), a semi-rural farming area within the City, uses groundwater for irrigation. Though it is inland it is still part of the coastal aquifer system.

If intrusion happens, commercial and subsistence farmers using boreholes near the coast might see their water become too salty for crops. Communities with shallow wells in low-lying coastal settlements would also be vulnerable. Unlike contamination or drought, vulnerability to SLR is less about income level and more about geography, although financial resources can determine coping capacity can adapt. Generally, intrusion is a slow-onset hazard that might not be felt until it's advanced at which time reversal is hard. Areas with lack of monitoring for salinity are more vulnerable as proactive monitoring will not be possible.

Coastal Aquifer Dependency

Coastal communities and aquifer users are the primary exposed user groups. While these areas and communities largely rely on municipal water supply, any local use of groundwater (e.g. small-scale farming or emergency use) could be compromised by increased salinity.

Low-Lying Informal Settlements

A critical vulnerability hotspot is the low-lying informal settlements on the Cape Flats, near marshes and the coastline. Many of these areas are just a few metres above current sea level. As sea level rises, the groundwater table beneath them rises too since the “base level” of drainage is higher. This can possibly lead to groundwater flooding, essentially water seeping up into streets and homes. This is already observed during the winter season when informal settlements on the Cape Flats suffer frequent flooding due to the high water table and poor drainage (Arup et al., 2019). SLR will exacerbate this issue, potentially making what used to be seasonal flooding a year-round problem. Hundreds of thousands of people live in such conditions across Khayelitsha, Philippi, Delft South, and Masiphumelele. These communities exhibit high socio-economic vulnerability as they are low income with limited infrastructure. When groundwater rises or becomes saline houses flood or develop mold and pit latrines and septic tanks can backflow. The socio-economic status (low income, informal housing) and location (low elevation) combine to make these groups extremely vulnerable to the groundwater impacts of sea-level rise.

Economic Activities and Services at Risk

If critical infrastructure in coastal areas experiences groundwater rise, underground infrastructure, sewage systems, or building foundations could be damaged by saltwater corrosion or constant dampness. Corrosion and damage can could lead to service outages affecting the community (often it is the adjacent poorer communities that suffer if sewage infrastructure fails). Coastal agriculture (outside the City centre, toward the Cape Flats or West Coast) could see soil salinisation from below. Small-scale farmers or community gardens might find their groundwater gradually getting saltier, which can damage crops and soil over time, impacting local food security and incomes.

Industries may face operational disruptions if saline groundwater affects process water quality or if damp conditions damage facilities, underground storage, or electrical infrastructure. Businesses without sufficient capital for water treatment or site adaptations will be more vulnerable to production losses.

Differential Impact by Socio-Economic Status

There are notable differences in how SLR-groundwater impacts affect different socio-economic groups:

- **High-income coastal residents** (e.g., in areas like Camps Bay, Sea Point, or along the Atlantic seaboard) typically do not rely on groundwater for drinking, and their homes are built to higher standards. They might see effects like groundwater seepage in basements or saltwater affecting plantings, but they can afford engineering solutions. Also, many of these areas are on rocky slopes rather than flat ground, somewhat lessening groundwater flooding (though rising seas can still influence coastal springs).

- **Middle- to low-income communities on flat coastal plains** (e.g., Macassar, Mitchells Plain, Atlantis, Vrygrond) are more directly impacted. They may have fewer resources to combat saline intrusion. For instance, if Atlantis's municipal water is at risk, those residents cannot individually solve that if it turns saline; they depend on the City's response. Likewise, people in low-cost housing developments on the Cape Flats cannot just move if their groundwater becomes a nuisance (causing damp in walls or pushing up salt into foundations).
- **Informal settlement dwellers in wetlands/coastal fringes** are the worst off, with limited to no financial resources and high exposure. They often also lack insurance or healthcare, so any damage to property or health due to water inundation impacts them harder and longer.
- **High income commercial farmers** are more capable of accessing additional sources of water if groundwater becomes too saline, such as tanking in fresh water.
- **High income industries** are able to install water treatment plants to be able to use groundwater with elevated salt concentrations.

Health and Social Impacts

Contaminated or rising groundwater has health implications. If saline intrusion forces people to use salt-contaminated water, they may face dehydration or kidney problems. A more common issue is water-borne disease in areas with groundwater flooding. Stagnant water in settlements becomes breeding grounds for pathogens, combined with sewage overflows, this can lead to diarrheal diseases, skin infections, and other illnesses. In Cape Town, this is likely to disproportionately affect children and those with weakened immune systems (e.g., HIV-positive individuals common in some poor communities). Socially, there could be an impact on community cohesion and safety, if certain areas become frequently flooded, people might be relocated or informal settlers might migrate, leading to crowding in other areas or conflicts over drier land. SLR's groundwater effects could slowly render parts of the City less habitable for the poor, raising tough social justice issues about who can live safely where.

Summary

Coastal communities and users dependent on aquifers near the shoreline are more vulnerable. Communities in these zones often lack alternative water sources and are unaware of the risks of salinisation.

Key Factors:

- Proximity to the coast.
- Lack of diversified water sources.
- Low socio-economic resilience to water quality degradation.
- High concentration of industrial and agricultural groundwater users.

4.2.2.4. Reduced Recharge

Climate change is expected to alter rainfall patterns in the Western Cape. Projections generally indicate declining winter rainfall and a drier overall climate for Cape Town in coming decades. For groundwater, this means reduced natural recharge of aquifers.

Socio-economic vulnerability to this hazard entails vulnerability to drought-driven water shortages. Groundwater often serves as a buffer in droughts, as was the case when Cape Town relied on groundwater use to avoid "Day Zero". If climate change reduces groundwater recharge, communities face a new level of risk. Those most vulnerable are communities with high water demands and low adaptive capacity, often the economically and socially marginalised groups. Poor households have fewer coping mechanisms and often live in areas where the communal water infrastructure is already strained.

Additionally, peri-urban communities around Cape Town who rely on small local aquifers or rain-fed springs are highly vulnerable to recharge declines. Small farmers depending on boreholes could see yields drop over successive dry years. In the City, much of the formal economy (businesses, industrial areas) can be impacted if water restrictions become severe due to both surface and ground sources dwindling which can lead to job losses and reduced income on a community level.

During the Day Zero crisis, it was observed that coping with water shortages was hardest for informal settlement residents, even though their absolute water use was low. They already used ~ 50 litres per person or less (Arup et al., 2019) and supply cuts for them meant going below basic needs, whereas formal and affluent neighbourhoods often still had access to 50+ litres. Financial resources also allowed for the ability to buy bottled water or install tanks, while low-income communities had stood in lines when communal taps ran slow due to reduced water pressure. Therefore, the socio-economic disparities mean climate-driven water shortages will impact the poorest the hardest.

Population Sensitivity *and Vulnerable Groups*

On a City level, certain groups are more sensitive to water shortages. Informal settlement residents are highly sensitive since they often face supply challenges and access to services as the status quo. Many informal settlements experienced intermittent supply and low pressure during the drought, meaning some days taps were dry. This created long lines and competition at the few working taps. These communities, often lack storage containers and have limited ability to advocate for themselves. Children and infants in these areas are sensitive to dehydration and sanitation-related illness. The elderly and disabled are also very vulnerable when water must be fetched from across long distances, particularly females who typically fulfil these roles in lower income communities. During Day Zero planning, it was anticipated that these groups would need special assistance because a 25 litre per person per day ration, possibly collected from distribution points, would be physically challenging for them. Health-compromised individuals (of which Cape Town has many, given prevalence of HIV/AIDS, TB) require water for medication and extra hygiene. Overall, the socio-demographic profile of Cape Town, with a significant portion of households living in poverty or with health burdens, means a large number of people are acutely sensitive to water scarcity. Similarly, small-scale farmers who lack access to water storage infrastructure or efficient irrigation systems are especially vulnerable to declining groundwater availability.

Economic and Livelihood Vulnerability

Drought and reduced recharge have massive economic implications, which translate to socio-economic vulnerability. The agriculture sector in the Cape region was the first and hardest hit during the recent drought. Western Cape farms saw a **20–45% drop in production and roughly 30,000–35,000 jobs lost** as a result of water shortages (Arup et al., 2019). Many of these jobs belonged to **seasonal or low-wage farm workers**, deepening poverty and food insecurity. Within the City, water-intensive businesses (beverage manufacturers, nurseries, construction firms, hotels) either scaled back or incurred extra costs, leading to layoffs of mostly lower-income employees**. Informal economy activities** (like car washing, urban farming, informal food sellers) also suffered because water was unavailable or very expensive, cutting into livelihoods. In areas like the PHA, sustained reductions in recharge could result in long-term yield declines for vegetable farmers, threatening Cape Town's local food security and placing farmworker jobs at risk. Industrial operations that depend on groundwater as part of their production process may face similar pressures, especially those with limited access to alternative water sources.

Thus, socio-economically, those with the least financial resilience (casual workers, informal traders, small farmers) were the most vulnerable to the drought's impact on groundwater and overall water availability.

Socio-Economic Status

One striking aspect of Cape Town's drought was how socio-economic status determined the ability to endure water scarcity. **High-income households** often had swimming pools, large roofs for rainwater harvesting, and money to buy extra water or install greywater systems. Some could even move temporarily, e.g., spending a few months in another city to avoid the worst period. **Low-income households** typically live in small dwellings with no storage capacity, rely on communal facilities, and cannot afford any supplementary supplies. When water pressure was lowered by the City, some high-lying informal areas got no water at all for periods and those residents had to rely on tanker deliveries. It should be noted that an analysis indicated that informal settlements, despite being ~15% of Cape Town's population, used only ~4% of the City's water (Arup et al., 2019). This means they were very efficient, but also that **they had buffer** and any further reduction meant not meeting basic needs.

High-income farmers are generally able to invest in measures such as drilling deeper boreholes, installing large storage tanks, and adopting more water-efficient irrigation technologies to secure their operations during periods of reduced recharge. In contrast, **smaller-scale or low-income farmers** often lack the financial capacity to implement these solutions, therefore they face a higher risk of crop failure and income loss due to lack of water due to reduced recharge. **Large, well-capitalised industries** can afford to install on-site water treatment facilities, allowing them to use poorer-quality groundwater for manufacturing or cooling processes when needed. They may also have the resources to diversify their water sources or transport water from off-site locations. **Smaller or less capital-intensive businesses**, however, typically lack the financial reserves for such adaptations, leaving them more exposed to supply disruptions caused by declining groundwater levels.

Water Supply and Service Access

Areas with robust infrastructure are less vulnerable. Informal settlements with a limited number of communal faces infrastructure-induced vulnerability. Additionally, reduced recharge can cause **groundwater-dependent springs to dry up**. Cape Town has a number of natural springs historically used by communities, e.g., in Newlands, and some in poorer areas like Lotus River wetlands. During drought, many of these dried or were diverted to municipal use. Communities that might have supplemented water from springs or rivers found those sources gone. Thus, the redundancy in water infrastructure, or lack thereof, is a vulnerability factor. Formal areas had some redundancy, whereas informal areas often had single points of failure.

Summary

Areas relying on rainfall-dependent recharge are highly vulnerable. Vulnerability increases where communities are dependent on rain-fed agriculture or where surface water alternatives are lacking.

Key Factors:

- Reliance on local aquifers without recharge augmentation
- Location in drier sub-catchments
- High climate sensitivity of livelihoods

4.2.3. Ecosystems

The vulnerability of surface water ecosystems to the hazards described in Section 3 is assessed in terms of (1) the **nature of the impact**, (2) the **extent of exposure** to a particular impact, and (3) the **sensitivity** of an ecosystem to those impacts.

4.2.3.1. Nature of Impacts

The groundwater-related hazards described in **Section 3** can be expected to impact on surface water ecosystems in the following ways:

- Aquifer contamination:
  - Water quality deterioration in surface water ecosystems from polluted groundwater discharging to surface
- Over-abstraction and reduced recharge:
  - Reduced summer baseflows in rivers and estuaries;
  - Reduced water levels in wetlands and riparian areas;
  - Perennial systems become seasonal, seasonal become ephemeral;
  - Gaining river systems become losing systems;
  - Wetlands dry out;
  - Increased summer water temperatures due to reduced groundwater inflow;
  - Reduced freshwater input to coastal ecosystems due to reduced groundwater inflow, and
  - Seawater intrusion (also relates to sea level rise from climate change).

4.2.3.2. Extent of Exposure

The extent of exposure will depend largely on the degree of dependency of any ecosystem on groundwater as a source of water. In the Groundwater Dependency Assessment for Cape Town (SADC-GMI 2025), the wetlands, rivers and estuaries that are likely to be groundwater-fed were identified, and these are shown in **Figure 4-8**. It can be assumed that all of these surface water ecosystems are vulnerable, to some extent, to the negative impacts associated with groundwater-related hazards. The type of surface water ecosystem will influence the degree of dependency on groundwater, and so the extent of exposure, as follows:

- **Seep wetlands** are often sustained by groundwater, especially in high groundwater discharge areas, such as in the mountains around the Steenbras Dams, and on the Peninsula. Coastal seeps occur around the City’s coast, where interflow or groundwater flows daylight close to the intertidal zone. This creates unique freshwater habitats close to the ocean, and can sustain coastal fauna, such as amphibians, crabs, otters, etc.
- **Depressions** tend to be fed by precipitation, groundwater and river flows, depending on their location in relation to groundwater discharge areas and river channels.
- **Floodplain wetlands** are generally sustained by surface flow from the lowland rivers associated with them, but may also be supplied by shallow, alluvial aquifers.
- **Valley-bottom wetlands** (channelled and unchanneled) are generally supplied by river flows. This can be in the form of water seeping out of the river channel and flowing through the wetland as diffuse flow, or when water overtops the channel’s banks during high flows. Groundwater is not often the source that sustains these wetlands.

- **Estuaries** (in the form of estuarine channels or depressions, and river mouths) are generally sustained by river flows and tidal exchanges. While they are not necessarily dependent on groundwater, if baseflows in the rivers feeding them are reduced, this will have a negative impact on the downstream estuary, as a result of reduced freshwater supply.
- **Mountain streams** and foothill rivers in the City may be dependent on groundwater inputs for sustenance of their summer baseflows. Lowland rivers are sustained by river flows from upstream, and may also be fed by shallow, alluvial aquifers.

The likely extent of exposure to impacts, high, moderate or low, per surface water ecosystem type, has been combined in a matrix in **Table 4-5**.

4.2.3.3. Sensitivity

The sensitivity of an ecosystem to the impacts described above is likely to be a function of both current condition and the importance of the ecosystem in terms of ecosystem service provision (for people) and the maintenance of biodiversity. Ecosystems in good condition are assumed to be more sensitive to impacts, due to the desire to maintain healthy ecosystems in that state. With regards to biodiversity, it is assumed that an ecosystem that supports habitats (i.e. the physical and chemical characteristics of the ecosystem) and biota (i.e. fauna and flora) that are rare, endemic and/or threatened, is more sensitive to the impacts of groundwater-related hazards, than ecosystems of lesser biodiversity importance.

For this study, biodiversity importance was assessed using the following information:

- Key Biodiversity Areas (KBAs) and Ramsar sites – ecosystems in KBAs and wetlands registered as Ramsar sites are considered to be **globally** important for biodiversity conservation.
- National Freshwater Ecosystem Priority Areas (NFEPAs) – these are wetlands that are considered priorities for achieving the protection of biodiversity targets on a **national** scale.
- Critical Biodiversity Areas (CBAs) – ecosystems in CBAs are important for achieving **municipal and provincial** biodiversity conservation targets.

Areas of biodiversity importance, where it can be assumed that ecosystems are more sensitive and thus vulnerable to groundwater-related hazards, are shown in **Figure 4-9**. There is no spatially consistent map of ecosystem condition for the City of Cape Town, so this would need to be assessed on the ground, when evaluating the sensitivity of a particular ecosystem to groundwater-related hazards.

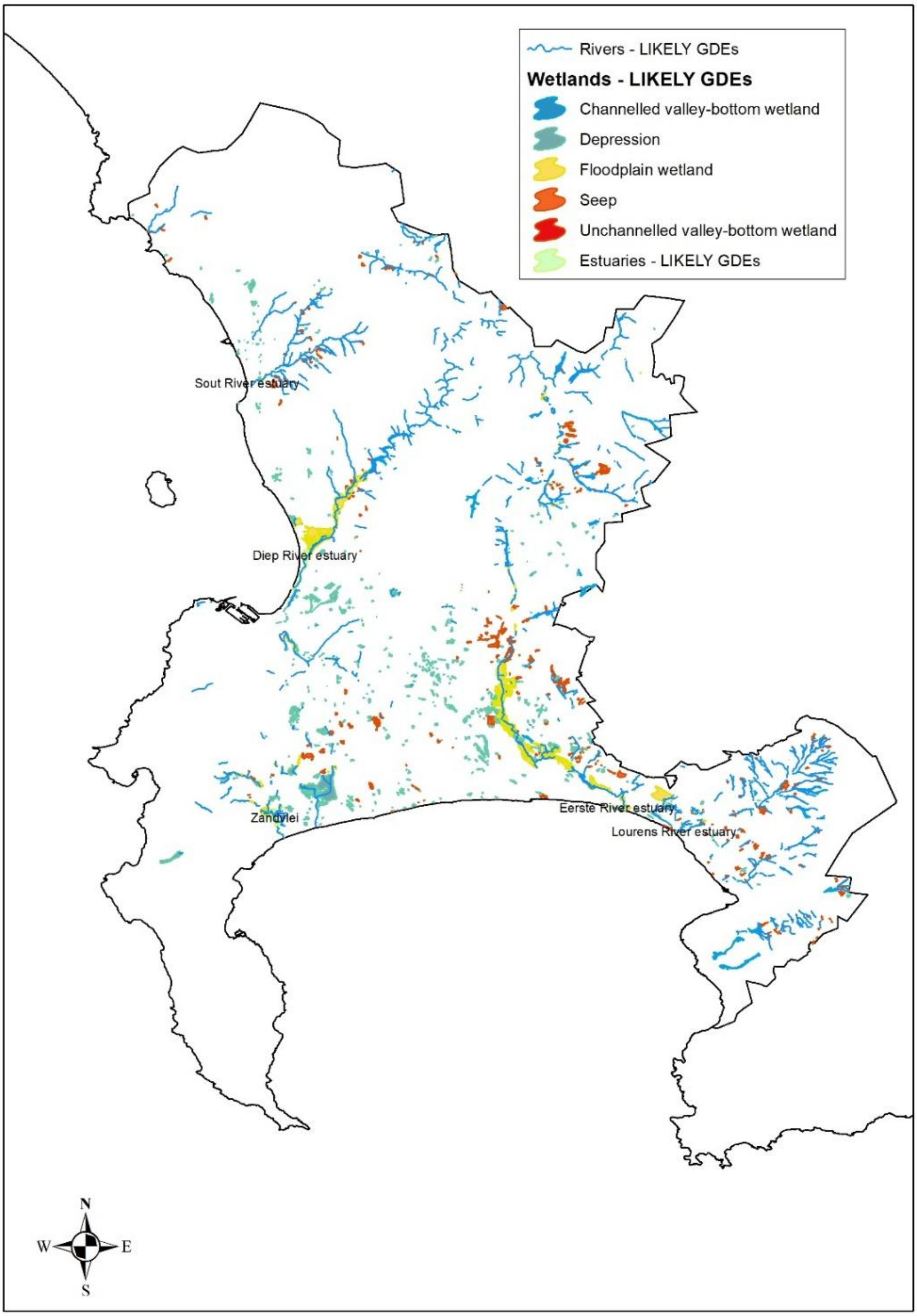


Figure 4-8 **Surface water ecosystems in Cape Town that are likely to be fed by groundwater.**

Table 4-5 Extent of exposure: high (red), moderate (orange) or low (green), to groundwater-related impacts, per surface water ecosystem type in Cape Town.

Impact:	Ecosystem type:								
	Mountain streams	Foothill rivers	Lowland rivers	Seeps	Valley-bottom wetlands	Floodplain wetlands	Depressions	Wetland flats	Estuaries
Water quality deterioration in surface water ecosystems from polluted groundwater	High	High	Moderate	Low	Moderate	Moderate	Low	Low	High
Reduced summer baseflows in rivers and estuaries	High	High	Moderate	Low	Moderate	Moderate	Low	Low	High
Reduced water levels in wetlands and riparian areas	High	High	Moderate	High	High	Moderate	Moderate	Moderate	Moderate
Perennial systems become seasonal; seasonal become ephemeral	High	High	High	High	High	High	High	High	Low
Gaining river systems become losing systems	High	High	Moderate	Low	Low	Moderate	Low	Low	Moderate
Wetlands dry out	High	High	Moderate	High	High	Moderate	High	High	Low
Increased summer water temperatures	High	High	High	Moderate	Moderate	High	High	High	High
Reduced freshwater input to coastal ecosystems	Low	Low	Low	Low	Low	Moderate	Moderate	Moderate	High
Increased salinisation of freshwater ecosystems due to seawater intrusion	Low	Low	High	Low	Moderate	High	High	High	High

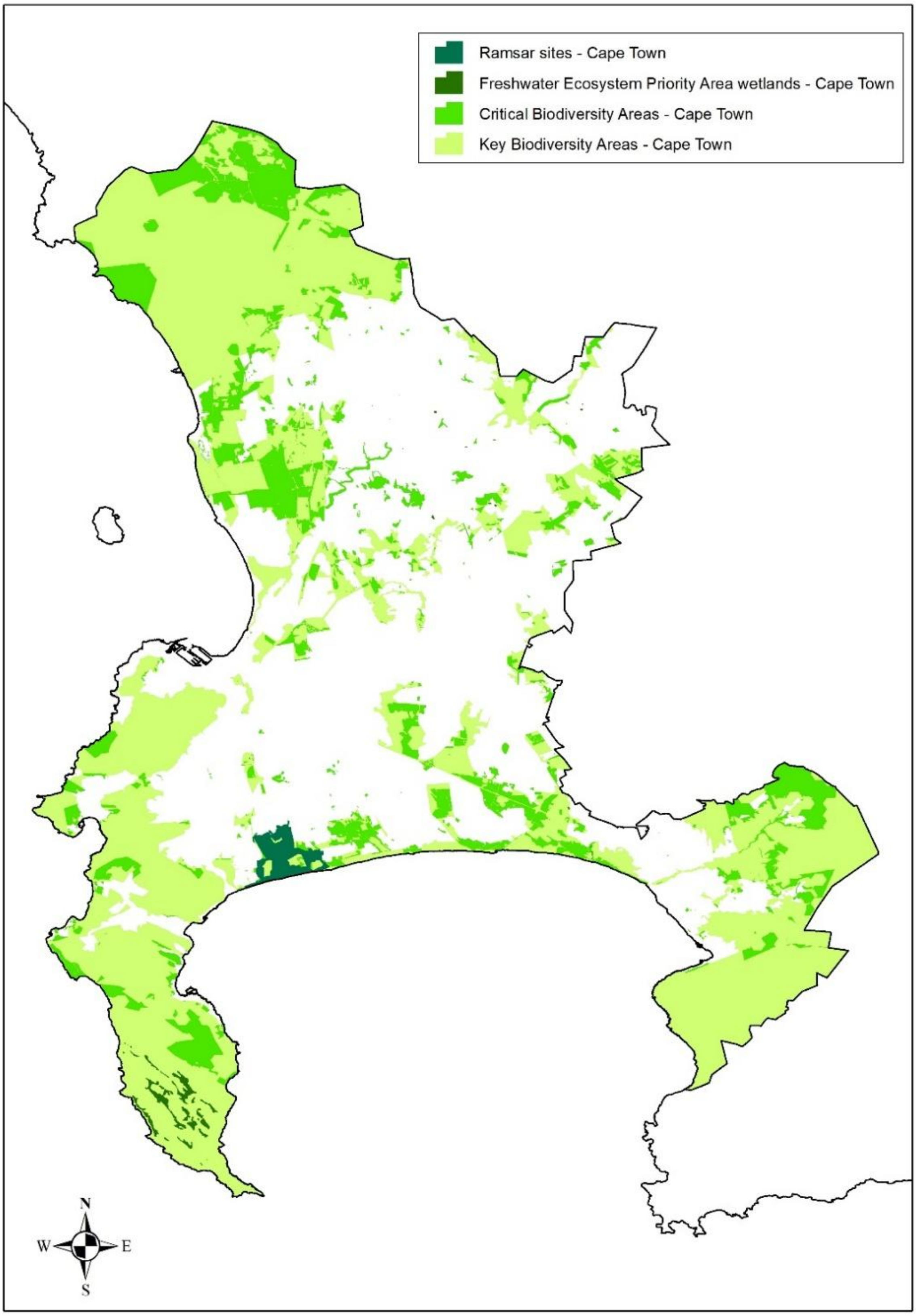


Figure 4-9 Composite map of areas of biodiversity importance in Cape Town. Due to the importance of these areas for biodiversity conservation, surface water ecosystems within these areas are considered particularly vulnerable to groundwater-related hazards.

5. Coping Capacity

5.1. Introduction

This section provides an overview of the coping capacity of different groundwater users in the City of Cape Town. It focuses on the preparedness (planning) and current level of management (legislation, monitoring and enforcement) of groundwater resources with respect to the hazards (aquifer contamination, over abstraction, sea level rise and reduced recharge) identified in this assessment. While vulnerability was focused on assessing the vulnerability of the aquifer to the identified hazards, coping capacity is discussed from the perspective of groundwater users below, in **Section 5.2.**

5.2. Coping Capacity of Groundwater Users

Coping capacity refers to the ability of groundwater users, whether communities, industries, or municipalities to avoid, mitigate, or adapt to the groundwater vulnerabilities discussed in the previous sections. In Cape Town, coping capacity varies widely between user groups, influenced by factors such as institutional governance, infrastructure, financial resources, and access to alternative water sources.

5.2.1. Contamination: Due to Human Activities

Coping capacity, as discussed below, reflects the ability of communities and institutions to avoid or mitigate the impact of groundwater contamination. In Cape Town, coping capacity depends on factors like availability of water treatment, alternative water sources, water-quality monitoring, and responsive governance. The City's approach has been to ensure that any groundwater added to the municipal supply is treated to potable standards before distribution. This technical capacity is a crucial coping mechanism at City scale. Communities connected to municipal water supply are thus buffered against groundwater contamination.

The City's coping capacity is further enhanced through the delineation and enforcement of Groundwater Protection Zones (GPZs) across all municipal wellfields. These GPZ, established based on contaminant travel times, allow for land-use control and risk reduction near production boreholes. The City's use of Potentially Contaminating Activity (PCA) mapping and vulnerability assessments helps guide monitoring priorities and ensures that emerging contamination risks are addressed before they impact municipal supply.

Coping capacity is however not uniform. High income households and businesses that could afford it installed their own groundwater treatment systems to go off-grid (Faragher and Carden, 2023), ensuring safe water for themselves. Poorer households could not do this and had to rely on City supply or unsafe boreholes, showing lower coping capacity.

Institutional capacity also plays a role. Cape Town's has recognised the need to monitor groundwater quality and enforce pollution controls. There are laws to prosecute illegal dumping or leaking fuel tanks, for example. The City's development of groundwater pollution incident response management plans and incident management protocols also strengthens its ability to respond quickly and effectively to contamination events, reducing health risks to users.

However, in practice, limitations in monitoring capacity, data availability and data transparency can hinder a proactive response. On the positive side, the City's requirement for borehole registration and inspection for household use (plumbing a borehole into a home needs permission) is a form of oversight (Faragher and Carden, 2023) that can ensure safety guidelines are followed.

Coping capacity is higher for communities with multiple water options (e.g. piped water supply, rainwater tanks) and those with education and resources to treat or avoid contaminated water. In Cape Town, formal urban neighbourhoods typically have strong coping capacity as they use municipal water and can purchase filters or bottled water if needed. Informal settlements or rural pockets depending on boreholes have weaker capacity, often lacking funds for treatment and dependent on Nongovernmental Organisations (NGOs) or government interventions for clean water during crises.

Access to Alternative Water Supply

A major strength in coping with groundwater contamination is Cape Town's extensive distribution network. With nearly all households being supplied with treated municipal water, most communities can avoid drinking polluted groundwater by relying on the municipal supply. This reduces health impacts. The City's ability to provide safe water is a buffer against groundwater contamination. However, this coping mechanism depends on the municipal system functioning and during extreme drought or infrastructure failure this can be compromised. Wealthier households often have additional buffers: they can buy bottled water or truck water in if they suspect their borehole is contaminated, an option not available to the poor.

L*ocal Institutions and Regulations*

Cape Town's governance framework does recognise groundwater quality issues. The City's policies call for monitoring of groundwater quality and legal action against polluters. There are regulations on waste disposal, industrial effluent, and fuel storage intended to protect aquifers. Community organisations also bolster coping capacity. Local advocacy has helped raise awareness and pressured authorities to prioritise aquifer protection. Enforcement capacity remains a challenge, and some areas suffer from inadequate sanitation and aging sewer infrastructure which leads to frequent spills. The City's coping capacity is limited by these service backlogs. In summary, institutions exist and have plans on paper, but on-the-ground enforcement needs strengthening to effectively cope with contamination hazards.

Awareness and Education

Public awareness on water quality risk has improved since the Day Zero crisis. The City has run campaigns advising residents with private boreholes to test their water and use it safely (CCT, 2019c). Additionally, events like World Water Day have highlighted groundwater quality issues in Cape Town, spreading knowledge that aquifer water may be polluted. Higher-income and educated residents are more likely to be aware and proactive (testing wells, installing filters). In poorer communities, NGOs and health departments do outreach. However, gaps in awareness persist. Some informal settlers might not be aware or informed that shallow groundwater in their area is contaminated with *E.coli* or nitrates, so they may unwittingly use it for washing or even drinking. Improving community education (for instance, teaching people that discoloured or foul-smelling well water is unsafe) is an ongoing need to build coping capacity at the grassroots level.

Household Assets and Adaptation

Coping capacity at the household level varies widely. Household assets like water treatment devices, storage tanks, or simply financial savings to buy alternative water greatly increase resilience to contamination. Affluent households in Cape Town can and have installed reverse osmosis filters or UV sterilisers for their borehole water, or they only use it for non-potable purposes (gardening), thus avoiding health risks. They also typically remain connected to the municipal supply as a fallback. Low-income households generally lack such assets. During water-related emergencies, Cape Town's disaster teams do prioritise vulnerable areas considering population density and vulnerability, which would similarly help if a contamination crisis occurred. In essence, wealth provides adaptive capacity (alternate sources, treatment), whereas the poor rely on collective, external support.

Diversification and Technical Measures

The City of Cape Town is improving its technical coping capacity through diversification of water sources and treatment options. The City's Water Strategy includes developing groundwater not as raw water direct to users, but to mix into the system after treatment. This means even if one source (e.g. a wellfield) is contaminated, the City can shut it down or treat it and ramp up other sources (like reservoir water or desalination) to compensate. Additionally, managed aquifer recharge (MAR) is being assessed to improve groundwater quality. The monitoring networks set up post-drought (including community-based groundwater monitoring in some areas) provide early warning of quality issues. These measures, coupled with emergency response plans, form a multifaceted coping capacity that, if fully implemented, can protect communities from groundwater contamination impacts.

5.2.2. Over Abstraction

Coping capacity for over-abstraction refers to how well the City and communities can manage water demand and supplement or conserve groundwater to prevent harm. High coping capacity means having effective governance, alternative water sources, and community adaptation to avoid overuse of the aquifer. Cape Town's drought response demonstrated both weaknesses and strengths in this regard. Initially, the City had limited planning for a scenario of widespread groundwater use. Regulations and metering for private wells were weak, as national law exempted small users from licensing and reporting (Faragher and Carden, 2023). This led to a data gap and borehole drilling went largely unmeasured. However, the City and residents displayed strong adaptive capacity in reducing overall water demand: Cape Town cut its municipal water consumption by over 50% during the Day Zero crisis through strict conservation measures (Faragher and Carden, 2023). This indirectly protected aquifers by reducing the need for emergency pumping.

Key components of coping capacity include: water management policies and enforcement, public awareness and behaviour, and augmentation schemes. Cape Town has since taken steps to improve these. For example, there is now better monitoring. The WWF/Danish partnership helped establish a growing monitoring network and a "Table Mountain Water Source Partnership" to sustainably manage groundwater. The City's Water Strategy (2020) also explicitly incorporates groundwater as part of a diversified supply mix, aiming for 7% of supply from groundwater by 2040 under managed conditions (Faragher and Carden, 2023). On the demand side, the City uses progressive water tariffs and restriction levels to curb usage when needed (this was effective in getting even high-income households to limit use).

As part of the municipal groundwater schemes, all production boreholes are equipped with flow meters, and water levels are routinely monitored both at production sites and in surrounding areas to assess aquifer responses to abstraction by the municipality as well as private groundwater users. The monitoring also includes nearby wetlands and other Groundwater-Dependent Ecosystems (GDEs), to track potential environmental impacts from abstraction. The City also applies pre-defined operating water level thresholds at each wellfield to ensure that pumping remains within sustainable limits. Additionally, the implementation of MAR at both the Atlantis and Cape Flats Aquifers plays a critical role in managing over-abstraction risks by supplementing aquifer levels and enabling aquifer banking for future use. MAR also serves as a key mitigation measure against saline intrusion from over abstraction, particularly in the Cape Flats Aquifer where the risk of saline intrusion is the highest. By creating a hydraulic barrier between the wellfields and the coastline, MAR helps prevent saltwater intrusion caused by declining groundwater levels. Furthermore, monitoring boreholes have been installed along the coastline to provide early warning of any salinity changes, enabling adaptive management actions such as adjusting borehole yields if required.

Community coping varies by socio-economic status. Affluent individuals often have greater capacity to cope with water shortages as they can invest in water tanks, greywater systems, or deeper boreholes, or simply afford higher water tariffs when scarcity drives prices up. Poorer communities rely on the City's ability to supply water. Their coping strategies are limited to usage cutbacks and communal sharing. It should be noted that Cape Town's strong social campaign during the drought saw broad compliance across groups, indicating a high social capacity to adapt behaviour.

Regulation and Governance

Effective governance is the first line of defence in coping with over-abstraction. Currently, **regulatory capacity is limited**. Cape Town (like most of South Africa) does not have a strict local permitting system for small-scale boreholes. Many boreholes are "schedule 1" uses (domestic use) which legally do not require a licensing or registration. The City has acknowledged this challenge: "Managing groundwater supplies faces challenges of limited City regulation and enforcement and limited availability of groundwater data" (CWRA, 2019). To improve coping, the City and the National Department of Water and Sanitation have been encouraging registration of boreholes and responsible use practices, but voluntary compliance is mixed. **Post-drought initiatives have expanded monitoring** though the development of a **Groundwater Dashboard** to track aquifer levels and usage in key areas. Partnerships like the **Table Mountain Water Source Partnership** has brought together government, private sector, and researchers to coordinate sustainable use of regional aquifers. Additionally, with the City targeting three major aquifer sources (Cape Flats Aquifer, Atlantis Aquifer and Table Mountain Group Aquifers, this has resulted in the expansion of monitoring efforts across these major aquifer regions. These efforts mean Cape Town's institutions are becoming more aware and data-driven, which enhances capacity to impose restrictions or interventions before an aquifer is irreversibly overdrawn. If monitoring shows water levels dropping, the City can issue water restrictions for borehole usage similar to the way they restricted surface water usage during the drought. Overall, governance is improving but still catching up; continued strengthening of monitoring, user education, and enforcement mechanisms, like possible tariffs or limits on groundwater use in vulnerable zones, will determine how well the City copes with this hazard in the long term.

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Diversification of Water Sources

Cape Town's water resilience strategy is focused on diversifying sources (surface water, multiple aquifers, desalination, reuse), which inherently provides coping capacity against any one source being over-abstracted. If an aquifer shows signs of stress, the City can scale back abstraction from that aquifer and compensate with other sources. This flexibility was lacking pre-2018 but is improving. Currently, groundwater still provides a small fraction (<5%) of Cape Town's total supply. At the household level, diversification also helps coping capacity. Many households with boreholes still remain connected to municipal water, so they have a dual source. If their borehole dries, they can revert to the municipal supply (though this assumes the municipal system is not also strained). Wealthier households have the highest diversification while poor households typically have just one source, but that source is backed by the City's broader supply network.

Technical Capacity and Managed Aquifer Recharge (MAR)

A direct way to cope with over-abstraction is to **recharge aquifers** artificially during wet periods. The City has experience with MAR, notably, the Atlantis Water Resource Management Scheme which for decades has actively recharged the Atlantis aquifer with stormwater and treated effluent to maintain levels. The City is in the process of expanding MAR to the Cape Flats Aquifer and projects are underway to inject high quality treated effluent into the aquifer to supplement groundwater levels, improve water quality within the aquifer and to store for drought times. If done effectively, MAR can allow higher abstraction in dry years without long-term depletion. The presence of MAR infrastructure and expertise in Cape Town is a significant coping capacity. It means the City is not relying solely on natural recharge (which climate change might reduce); instead, it can actively manage aquifer levels. For communities, this translates to a more secure groundwater supply in the long run.

Community Engagement and Awareness

Coping with overuse also depends on user behaviour. The drought fostered a sense of water conservation across the City. Many residents who installed boreholes did so with an understanding, often advised by the City, that groundwater is not unlimited. **Awareness campaigns** during and after the drought have highlighted that aquifers need time to recharge and that borehole users should adhere to sustainable pumping rates. Some communities have even participated in **citizen science monitoring**, where local volunteers or community groups help measure water levels in boreholes within their communities. This inclusion builds local stewardship. Farmer groups in the PHA are also more organised, working with City officials to balance agricultural water needs with the aquifer's health. There have been proposals for forming a Water Users Association there for this area. All these efforts improve coping capacity by ensuring stakeholders are informed and part of the solution. Maintaining the high level of public engagement seen during Day Zero is a challenge as memories of the crisis fade, so ongoing education is needed.

5.2.3. Sea Level Rise: Due to Climate Change

Coping capacity for saline intrusion involves preventative and adaptive measures that keep aquifers fresh or provide alternatives if salinisation occurs. Because intrusion is often gradual and effectively irreversible once it contaminates an aquifer, coping is more about prevention and ensuring water supply resilience. Cape Town has proactively planned a major coping strategy: Managed Aquifer Recharge (MAR).

By maintaining higher water tables and forming a freshwater pressure ridge, MAR can slow or halt the advance of saltwater. The City has also implemented coastal monitoring boreholes specifically positioned to provide early warning of salinity increases, allowing for operational adjustments to protect municipal wellfields. This indicates a high institutional capacity to cope, assuming it is implemented effectively. Other coping measures include adjusting abstraction regimes, developing alternative water sources, and engineering solutions. On a community level, coping might involve treating brackish water for use, but this is costly and usually only feasible at a municipal scale or for large industries. Cape Town's coping capacity is boosted by the fact that its municipal supply is diversified. A key challenge will be the funding and maintenance of MAR and monitoring in the long term.

Managed Aquifer Recharge and Technical Measures

Cape Town has demonstrated innovative technical capacity to combat saltwater intrusion. In Atlantis, the City has run a MAR scheme specifically designed to maintain a freshwater ridge that repels seawater. They capture stormwater and treated wastewater and channel it into infiltration ponds located between the wellfield and the ocean, effectively creating a hydraulic barrier to seawater ingress. Due to the basement topography within Atlantis, the Atlantis Aquifer is not at risk of saline intrusion due to over abstraction (basement depth above mean average sea level). However the use of these coastal MAR basins builds coping capacity should saline intrusion become a risk from sea level rise. Part of the Cape Flats Aquifer development scheme involves injecting high quality treated effluent near the coastal edge of the aquifer to act as a barrier against saline intrusion. These interventions are a strong coping tool, leveraging engineering to protect groundwater quality as seas rise. However, MAR requires continuous management, funding, and monitoring. Cape Town's capacity here is relatively advanced (thanks to partnerships with researchers and agencies), but scaling up MAR City-wide will depend on budget and institutional commitment.

Water Supply Adaptability

In the event that a coastal aquifer like Atlantis did start to go saline despite efforts, Cape Town can cope by adjusting its water supply mix. For example, Atlantis could be partially supplied by water from elsewhere (transferred via pipelines from the main grid) if its wells had to be rested. The City's integration of systems means not every area is completely on its own source. Additionally, the City is exploring **desalination**, which, while mainly intended for sea water, could also treat brackish groundwater if needed. A small-scale desalination plant could, in theory, be set up to treat saline groundwater in an emergency, though at high cost. The coping capacity here is about redundancy: Cape Town's development of multiple sources (surface, multiple aquifers, reuse, and recycling) gives it options if one source (like a coastal aquifer) is compromised. The **existence of a central water grid** covering most of the City is crucial and means coastal communities are not solely dependent on local wells.

Coastal Protection and Land-Use Planning

Coping with rising groundwater also involves non-water-specific strategies. **Coastal protection infrastructure** like sea walls, dune restoration can mitigate how far inland seawater encroaches, indirectly protecting aquifers. Cape Town has begun projects to stabilise dunes along False Bay and refurbish coastal defences in places like the CBD and Sea Point. These help against storm surges and may slightly reduce SLR impacts, although they mainly address surface flooding. **Land-use planning** is a more proactive capacity measure. The City can enforce set-backs and prevent new developments in the most SLR-vulnerable zones. In practice, Cape Town's progress here is mixed. There have been contentious proposals to develop parts of the Philippi area (which is critical for recharge and flood storage), but thanks to civic action those have been stalled, preserving the area's ability to absorb water. Going forward, strengthening zoning to keep critical recharge zones undeveloped (so that inland aquifer head stays higher than sea level) will help. The City's Integrated Development Plan and Spatial Development Framework acknowledge climate change and the need to avoid high-risk zones, which is a sign of institutional awareness.

Monitoring and Early Warning

An important factor in coping capacity is the ability to **monitoring the changes in groundwater due to SLR**. Cape Town, often in partnership with universities and the national government, has begun installing monitoring boreholes that specifically measure salinity in coastal aquifers. By having an early warning of saltwater intrusion the City can take action like adjusting pumping patterns or increasing MAR before things get catastrophic. This technical capacity is still developing, but it mirrors how the City monitors other hazards. New coastal wellfields might be designed with deeper screens or placed further inland to mitigate future intrusion. Having a scientific basis for action improves long-term coping.

Community and Household Coping

At the community level, coping with SLR-groundwater impacts is challenging because it is largely outside individual control. Still, there are small-scale adaptations that are possible. In areas where saline groundwater has killed vegetation, communities can plant salt-tolerant plants to stabilise soil. Some coastal farmers might switch crops to more salt-tolerant varieties if their irrigation water gets brackish. These are modest adjustments. More impactful is the role of community organisations that actively engage with the City on coastal issues, pushing for solutions. In low-income areas, NGOs help by providing water purification options if usual sources degrade. Ultimately, household coping capacity for this hazard is limited by finances and since SLR is gradual, many low-income households simply live with worsening conditions until external help arrives. Recognising this, the City's long-term climate adaptation strategy emphasises protecting vulnerable communities as a priority (CCT, 2021a).

5.2.4. Reduced Recharge: Due to Climate Change and Urbanisation

Coping capacity in the face of reduced recharge is essentially climate adaptation capacity in the water sector. It entails how well Cape Town's communities and systems can ensure water supply despite more frequent or severe droughts. After the Day Zero drought, the City greatly improved its coping strategies. Key elements include diversifying water sources, increasing storage, enhancing conservation, and building institutional preparedness.

Cape Town's new Water Strategy sets a goal of 99.5% assurance of supply by 2030, meaning the City should be able to avoid catastrophic failure in all but the most extreme scenarios. To achieve this, they are implementing a "multiple sources" approach: adding groundwater wellfields, water reuse plants, and desalination, alongside protecting catchments and managing demand. This greatly boosts coping capacity, because even if rainfall (and thus recharge) is low, these measures provide alternate water or make better use of what is available. For example, clearing invasive alien vegetation in catchments can improve recharge/runoff, and has been undertaken to improve yield (Arup et al., 2019). On the demand side, the City's successful water conservation campaign and ongoing restrictions policy mean people are now more accustomed to lower water use which serves as a form of social adaptive capacity. The use of MAR by the City also plays a dual role in this regard: supplementing groundwater levels during normal operations and "enabling aquifer" banking for drought resilience.

At the community level, coping strategies includes the installation of rainwater harvesting tanks, greywater recycling systems, and being willing to limit non-essential water use. Many households have adopted such measures post-drought. The wealthy have an advantage in affording tanks, pumps, or even private filtration systems. The less wealthy cope through behavioural adaptation such as reusing water, using communal facilities efficiently. The City has tried to support vulnerable groups by expanding infrastructure and increasing the number of taps and toilets in informal settlements to improve basic service during both normal and dry times (Arup et al., 2019).

The City also uses numerical groundwater models to simulate aquifer responses under various climate change and drought scenarios. These models guide future MAR volumes, refine operating limits, and help identify priority monitoring sites to track aquifer storage trends over time.

Institutionally, coping capacity is also shown by drought preparedness planning. Cape Town learned to have emergency plans. If those plans are maintained and updated, the City can react faster next time, mitigating impacts on communities.

Disaster Planning and Governance

Cape Town's handling of the Day Zero drought has been internationally recognised as a case of effective crisis management. A key element of coping capacity was the development of the Critical Water Shortages Disaster Plan, which was a phased strategy to keep the City running under extreme water scarcity. This plan explicitly incorporated socio-economic considerations through the City developed a Social Vulnerability Index (SVI) to map which communities would need the most assistance if water had to be shut off. This plan indicated an ability to make decisions informed by data on taking into consideration vulnerability and economic importance and showing strong governance. Institutional preparedness and the capacity to coordinate a complex response is high in Cape Town and is a significant strength for coping with future climate-induced water shortages.

Demand Management and Public Cooperation

One of the most significant demonstrations of coping capacity in Cape Town was the City's ability to achieve a 50% reduction in water demand during the Day Zero drought. Per capita water consumption declined to approximately 50 litres per person per day, establishing one of the lowest rates of urban water use globally during that time. This outcome was facilitated by a multi-faceted demand management strategy, which combined the implementation of stringent regulatory measures (such as Level 6B water restrictions, which prohibited most forms of outdoor water use), the introduction of punitive tariffs, and an extensive public awareness campaign.

The awareness campaign included daily updates on reservoir levels, the public disclosure of high-water users, and the widespread dissemination of water-saving guidance. Importantly, the community responded with an exceptional degree of collective action. Even affluent residents significantly reduced their consumption, motivated both by a heightened sense of shared risk and by strong social messaging. This behavioural shift, frequently described as the emergence of a "new normal", has endured beyond the immediate crisis period. Water conservation practices, such as abbreviated showers, the reuse of greywater for sanitation, and vigilant monitoring of personal consumption, became entrenched at the household level, leading to a sustained decrease in water use even after the return of normal rainfall patterns. This represents a critical and durable form of social resilience that effectively enhances the City's adaptive capacity in the face of future water scarcity.

In addition to behavioural change, the municipality employed technical demand management tools, such as pressure reduction across the water distribution network. While this resulted in some intermittent supply at the household level, it was effective in reducing both losses and overall consumption. Collectively, these interventions highlight Cape Town's considerable capacity to manage demand in response to water scarcity, arguably the most effective coping response available to urban societies under severe hydrological stress.

Augmentation of Supply (Groundwater, Desalination, Reuse)

While demand management measures were central to Cape Town's drought response, the City also significantly enhanced its coping capacity by diversifying and augmenting water supply sources. In response to severe water scarcity, Cape Town expedited the development of new groundwater resources by drilling multiple boreholes into the Cape Flats and Table Mountain Group aquifers, constructed temporary desalination plants, and accelerated the implementation of water reuse initiatives. By 2018–2019, pilot projects from the Cape Flats and TMG aquifers collectively produced several tens of millions of litres per day, while temporary desalination at Strandfontein contributed approximately 7 million litres per day. Although these additions constituted a modest fraction of the City's overall restricted demand (approximately 500 million litres per day), these efforts established a foundation for long-term water security and resilience.

The City's New Water Program now aims to secure an additional 300 million litres per day from groundwater, reuse, and desalination by 2030. In particular, the development and management of groundwater resources provide a critical buffer against the risk of reduced recharge linked to climate change. The successful operation of the MAR scheme in Atlantis during the drought exemplified this approach, and future plans for the Cape Flats Aquifer aim to deliver up to 76 million litres per day, even during dry periods. While challenges remain regarding water quality and potential environmental impacts, this diversification has substantially reduced the City's dependency on rainfall-fed dams, thereby mitigating risk and strengthening overall adaptive capacity.

Community and NGO Involvement

Community organisations and non-governmental actors play a pivotal role in supporting vulnerable groups and supplementing municipal interventions. NGOs contribute to the coordination and distribution of water in informal settlements, facilitating access to water storage and filtration devices, and providing critical hygiene education under conditions of scarcity. Civil society initiatives, such as those led by Gift of the Givers and other faith-based organisations, ensured that emergency water supplies reach hospitals and underserved communities. Additionally, grassroots initiatives, including neighbourhood watch groups and community leaders, contribute to leak detection, equitable water sharing, and the effective communication of urgent needs to municipal authorities. This widespread social solidarity and community mobilisation significantly enhances the City’s collective resilience.

Household Adaptations and Assets

At the household level, the recent drought crisis prompted a substantial increase in individual resilience. Residents installed tens of thousands of rainwater tanks, adopted water-efficient technologies, and implemented greywater reuse systems. The City introduced Water Management Devices (WMDs) for indigent households, supporting equitable access to water and reinforcing the capacity of vulnerable groups to manage within limited supplies. These measures, although necessitated by crisis, have created enduring coping mechanisms; households have acquired the skills and assets to conserve, store, and prioritise water use, increasing their resilience to future events.

Policy and Long-Term Adaptation

Cape Town’s coping capacity has been further institutionalised through policy reforms and long-term planning. The City’s 2019 Water Strategy and Climate Change Policy embed the lessons of the recent drought, emphasising ongoing water conservation, the protection of ecological infrastructure, and proactive adaptation to climate risks. Formalised groundwater monitoring, improved pollution control, expansion of sewer networks, and regular updates to emergency response plans all form part of a broader adaptive governance approach. Collectively, these measures position Cape Town to respond more effectively to future water stress, with a population, infrastructure, and policy environment markedly more resilient than in the past.

5.3. Ecosystems

The coping capacity of an ecosystem to a hazard addresses both resilience, and the measures in place that allow for preparation for and appropriate human response to groundwater-related hazards. Resilience is defined as the ability of an ecosystem to withstand or adapt to change, while preserving its ecological integrity, or to recover from a disturbance. Resilience is complex, as an ecosystem's response to an impact is influenced by a number of key characteristics. For instance, a wetland that is fed by multiple sources of water, rainfall, groundwater and river flows, will be more resilient to a reduction in one source. Resilience needs to be assessed on at the level of the ecosystem, in the context of its surrounding landscape.

Mitigation and management measures that contribute towards the City's management capabilities with regards to avoiding impacts, protecting ecosystems from impacts, or enabling the restoration or rehabilitation of ecosystems that are impacted by groundwater-related hazards include the following:

- City of Cape Town's Biodiversity Network (BioNet): the Biodiversity Management Branch (BMB) of the Cape Town Municipality developed a fine-scale, systematic spatial biodiversity plan for the City, which has identified local priorities for conservation, protection, rehabilitation and management. The BioNet maps the protected areas within the City, as well as the terrestrial and aquatic Critical Biodiversity Areas, Ecological Support Areas, and Other Natural Areas. The aim is to expand protected areas, protect CBAs and manage ESAs. CBAs are provided some protection through land-use planning legislation and also through the regulations associated with the National Environmental Management Act (NEMA), such as the Environmental Impact Assessment (EIA) regulations.
- Protected Area network: there is a gazetted National Park with the City's boundaries, the Table Mountain National Park, and a number of smaller nature reserves and conservation areas (see **Figure 5-1**). These provide some level of protection from land-use related impacts, however, this does not guarantee protection from the impacts of groundwater-related hazards that may influence a wide area. For instance, the wetlands and rivers in the Steenbras Nature Reserve are not protected from the possible impacts of groundwater abstraction from the Steenbras Wellfield, just by virtue of being within a Nature Reserve. It is only the operational rules of the Wellfield that can address ecosystem protection from abstraction-related impacts.
- The City's Inland Water Quality Monitoring Programme: the City has been monitoring surface water quality since the late 1970s, and now produces regular Water Quality Reports (e.g. Day et al. 2020). The objectives of the water quality monitoring programme is mainly to monitor changes in surface water ecosystems, where water quality may be of concern, particularly for human health. The programme does not specifically address groundwater-related water quality concerns, but these can be highlighted to the City for inclusion in future monitoring activities.

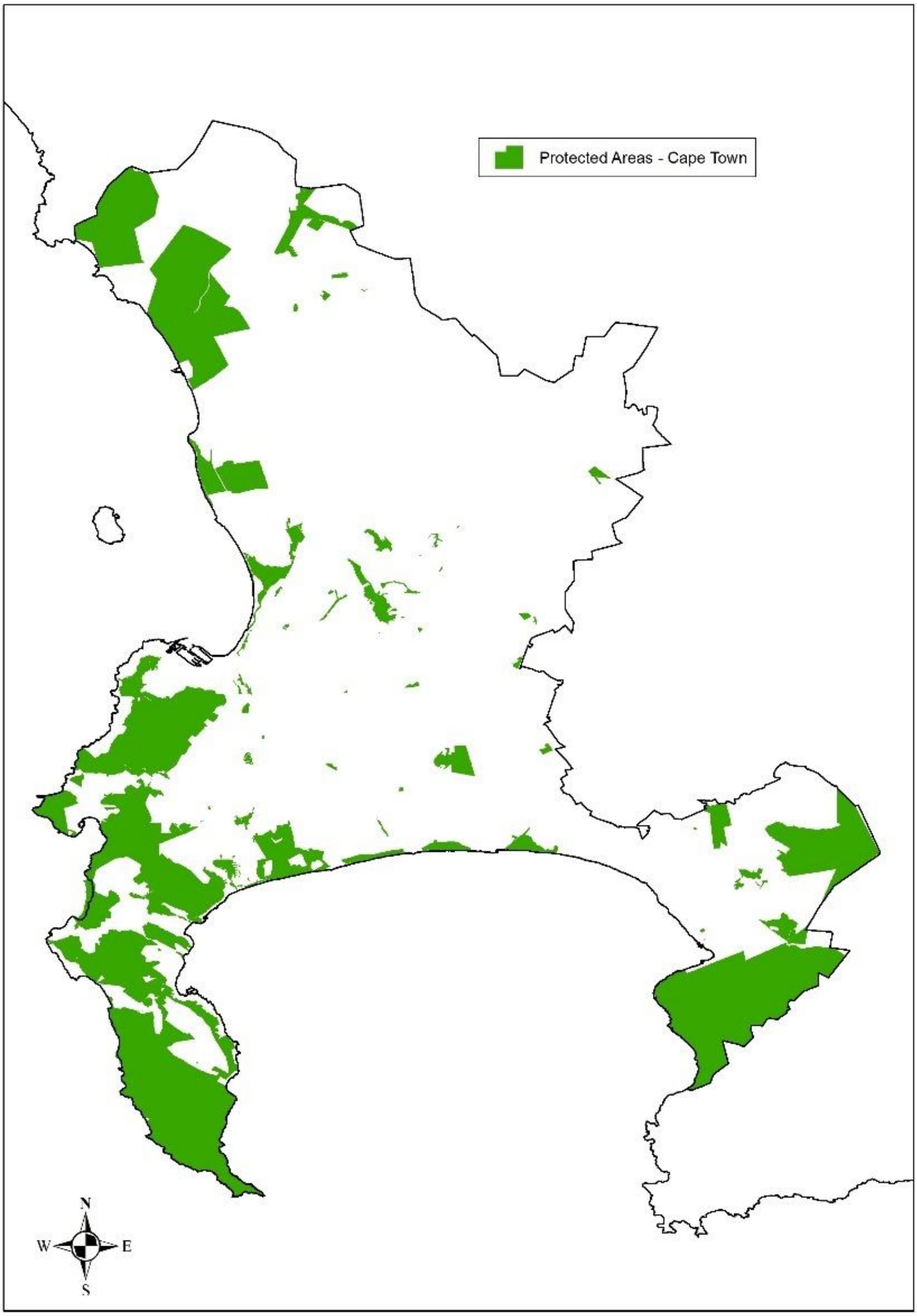

Figure 5-1 Protected Area network in the City of Cape Town.

6. Risk

This section presents an assessment of groundwater-related risks in Cape Town by integrating the identified hazards, aquifer vulnerability, and the vulnerability and coping capacity of groundwater users and ecosystems. Risk is not determined by hazard alone but by the interaction between the likelihood of the hazard occurring, the exposure and sensitivity of aquifers, users, and ecosystems, and their ability to cope or adapt. The risk assessment highlights where management interventions may be most needed to protect groundwater resources and the services they support.

6.1. Contamination: Due to Human Activities

Groundwater contamination poses a significant risk to both aquifer integrity and the users who rely on this resource in Cape Town. The risk arises from the combined influence of the identified hazard (land use related contamination sources), the aquifers physical vulnerability, the exposure and sensitivity of user groups, and the varying coping capacities across sectors.

Aquifer contamination risk is highest in the shallow, unconfined aquifers with higher infiltration rates and limited natural protection (confining layers and shallow water table) from surface contaminants. The CFA and Atlantis aquifers present the highest vulnerability, however, due to the number of concentrated PCAs, the CFA is the area which is most at risk to contamination (see **Figure 6-1**). Areas underlain by the CFA, in particular, face high contamination risk due to:

- Extensive informal settlements with poor waste management (e.g., Khayelitsha and sections of Philippi and Guguletu).
- Industrial zones like Epping and Athlone.
- Agricultural activities such as the PHA, with widespread fertiliser and pesticide use.

In contrast, the TMG Aquifer within the Hottentots Holland Mountains and the TMG Aquifers and Cape Granite Suite basement aquifer along the Cape Peninsula generally display lower contamination risks. This is largely due to their geological characteristics, including greater depth and natural confinement, as well as their location within protected or less-developed areas. These factors limit both land use intensity and the presence of PCAs, thereby reducing overall exposure to contamination hazards. However, isolated risks exist such as informal settlements create isolated risks.

Coping capacity varies significantly across user groups. Low-income communities located above vulnerable aquifers face higher risks due to both higher exposure and lower ability to mitigate impacts. Informal settlements without adequate waste management contribute to contamination while simultaneously being exposed to it. During droughts or service interruptions, these communities may resort to shallow groundwater sources, increasing direct consumption risk. Their limited financial resources restrict their ability to install water treatment systems, and low levels of awareness mean that residents may unknowingly consume water that does not meet health standards. These low-income communities are also generally located close to PCAs such as industrial areas and wastewater treatment works, increasing their risk.

In contrast, high-income communities, generally located in areas away from major PCAs, are better able to cope. Many can afford to install treatment systems such as filtration units, or switch to bottled water if needed, thereby reducing their risk from contamination events.

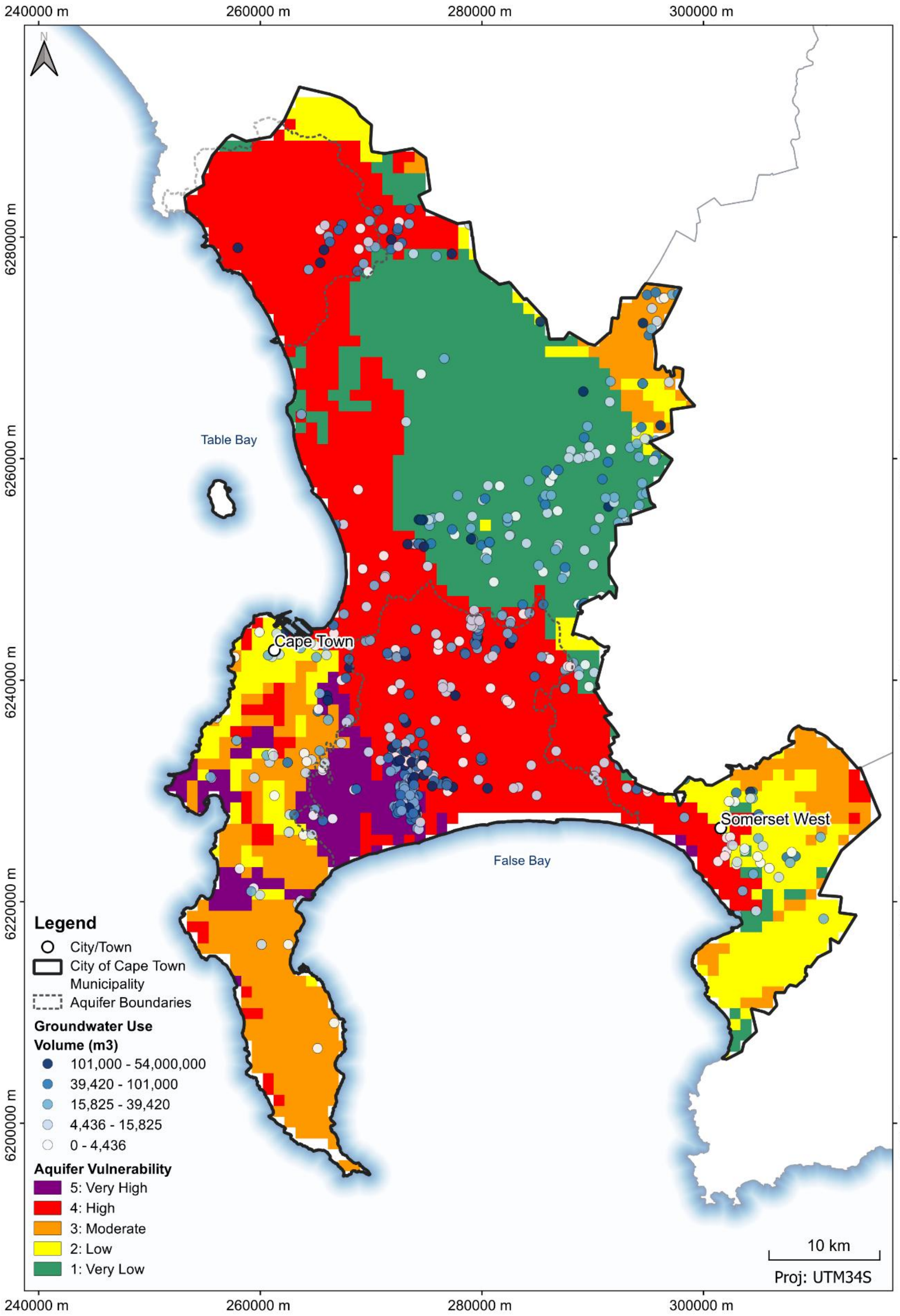

Figure 6-1 Aquifer contamination vulnerability map overlain with registered groundwater users within the City of Cape Town.

The municipal groundwater schemes, particularly those sourcing from the CFA and Atlantis Aquifers, also face operational risks from contamination. The City has implemented GPZs, vulnerability mapping, PCA mapping, and routine groundwater quality monitoring to mitigate these risks. Additionally, the City has developed incident response and management protocols for contamination events. These allow for a coordinated operational response, including targeted treatment, operational adjustments, or temporary shutdowns of water treatment works or wellfields if needed to protect public health. Furthermore, the City's ability to blend groundwater with other water sources provides institutional resilience.

Industrial and agricultural users also show variable coping capacity. Larger industries are often able to install on-site treatment facilities to meet processing and domestic water standards and can switch to alternative water supplies if needed. However, smaller businesses and farmers, particularly those with limited financial resources, may struggle to adapt to contamination-related restrictions or the need for additional water treatment.

While many GDEs underlain by the CFA have already been exposed to long-standing groundwater quality issues, likely leading to either ecosystem adaptation or decline, future risks remain for GDEs located near more pristine aquifer zones that have historically been protected from contamination. For example, areas surrounding parts of the TMG aquifers have remained relatively undeveloped and thus experience minimal groundwater quality impacts. With ongoing urban expansion and land use change, these currently low-risk areas could face increased contamination pressures in future, especially if development occurs without adequate land use controls or pollution prevention measures.

6.2. Over Abstraction

Over abstraction presents a significant risk to both the physical sustainability of Cape Town's aquifers and the users who depend on them. The risk arises from a combination of increasing groundwater demand, limited recharge potential, inadequate regulation of private use, and uneven coping capacities across user groups (see **Figure 6-2**). Over-abstraction can lead to declining groundwater levels, reduced borehole yields, and degradation of groundwater-dependent ecosystems. Given Cape Town's coastal setting, over abstraction also poses the risk of saline intrusion into vulnerable aquifer.

The risk of over abstraction is greatest in areas with high concentrations of groundwater users, where aquifers are stressed, and where the ratio of recharge to yield is low. The CFA is particularly at risk due to large-scale private groundwater use, both registered and unregistered, often concentrated in the same areas as municipal wellfields, such as the PHA (see **Figure 6-2**). Although this part of the CFA has a low to moderate recharge-to-yield ratio and moderate stress, the concentrated and increasing water demand compounds the pressure on the resource. During drought periods, these risks escalate as users increase pumping to compensate for declining surface water availability. The risk is further heightened in coastal sections of the CFA, where over-abstraction raises the potential for saline intrusion. In addition to the CFA, parts of the northern suburbs, where the basement aquifers are targeted, are also at high risk, due to moderate stress index and a low recharge-to-yield ratio (see **Figure 6-2**).

Low-income and informal communities generally do not contribute significantly to over abstraction, as they lack the financial means to drill or operate private boreholes. However, they remain vulnerable to its effects. Lower groundwater levels could reduce baseflows to wetlands, small springs, or shallow wells that some low-income peri-urban communities rely on, especially during drought periods. Additionally, the environmental degradation of nearby GDEs caused by declining water tables may indirectly affect these communities through increased flood risk (due to loss of wetland buffering capacity) or reduced ecosystem services.

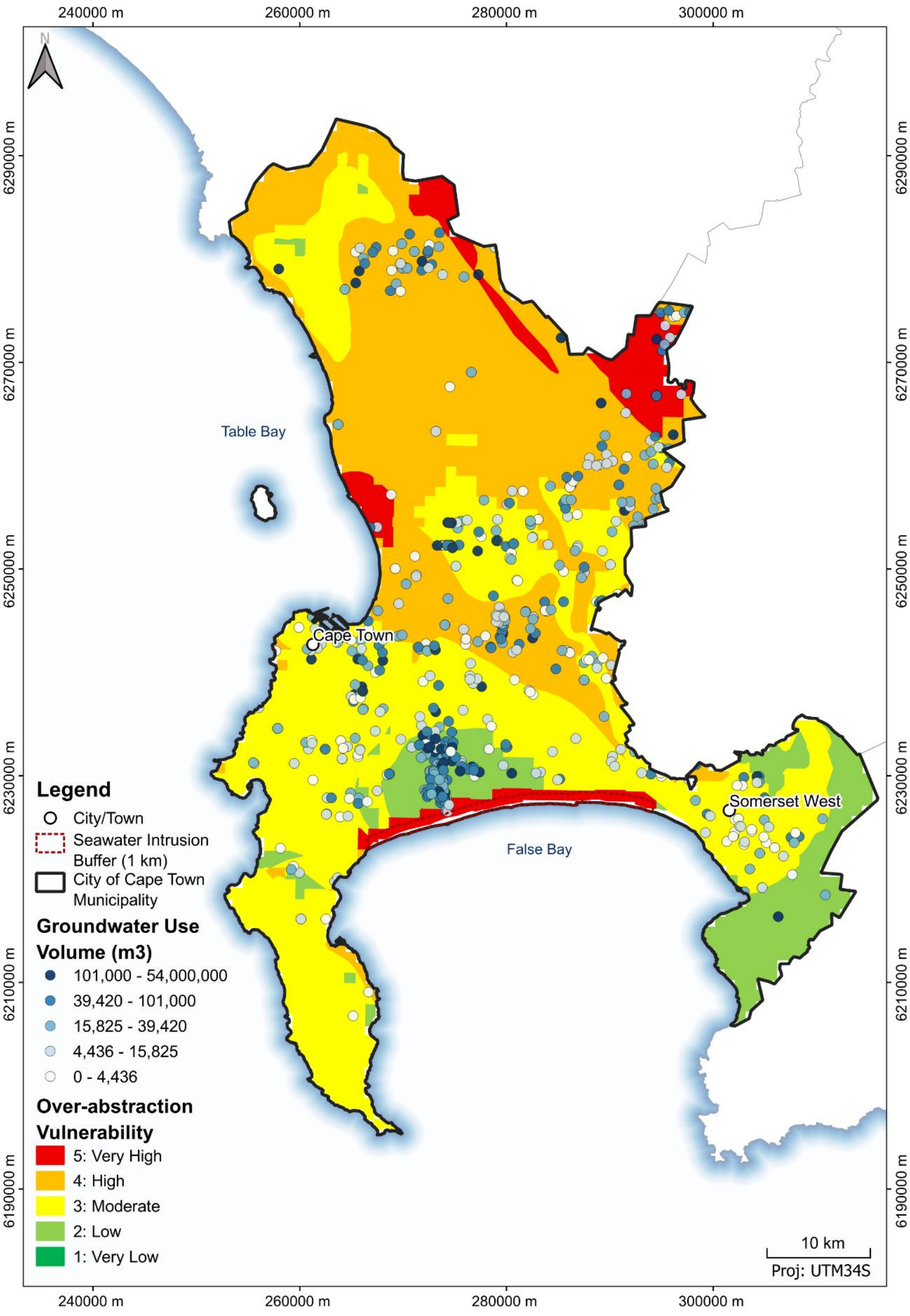

Figure 6-2 Aquifer over abstraction vulnerability map overlain with registered groundwater users highlighting areas at risk of over abstraction.

Agricultural users, particularly subsistence farmers in areas like the PHA, are highly vulnerable to the impacts of over abstraction. Declining groundwater levels can reduce irrigation capacity, threatening crop production and associated livelihoods. Many small-scale farmers lack the financial reserves to deepen boreholes, install more efficient irrigation technology, or switch to alternative water sources. By contrast, larger commercial farms with more capital can afford deeper drilling, on-site storage, and truck additional water, improving their ability to maintain productivity during periods of groundwater stress.

From a municipal perspective, over abstraction poses a direct operational risk to groundwater schemes, particularly in the CFA where municipal production boreholes are located near dense clusters of private abstraction points. However, with the implementation of MAR in the CFA and Atlantis Aquifer, this provides important recharge of the aquifers to maintain groundwater levels to allow for sustainable abstraction by both the municipality as well as private groundwater users, who previously would have been fighting over the limited resource. MAR also allows for “aquifer banking” allowing water to be stored during wet periods for use during droughts or periods of peak demand, thereby enhancing long-term supply resilience. To further mitigate over abstraction risks, the City has installed flow meters at all production boreholes, conducts routine groundwater level monitoring at both monitoring and environmental points, and operates the schemes according to critical controls such as pre-defined operating water levels.

Institutionally, the City’s ability to manage the risk remains limited by regulatory constraints. National water legislation exempts small domestic groundwater users from licensing, resulting in a substantial data gap on private abstraction volumes. To address this, the City has introduced voluntary borehole registration and is improving its monitoring capacity through initiatives like the Groundwater Dashboard and partnerships under the Table Mountain Water Source Partnership. These initiatives have increased spatial and temporal coverage of water level and abstraction data across the aquifers within the municipal boundary. Continued education on sustainable groundwater use and behaviour change is important for mitigating over abstraction risk across all user groups.

6.3. Sea Level Rise: Due to Climate Change

Sea-level rise (SLR) presents a gradual but significant risk to Cape Town’s coastal aquifers, primarily through the hazard of saline intrusion. The physical risk to the aquifers is not uniform across the City. The CFA is most vulnerable due to its shallow unconfined nature, proximity to the coast, and low elevation relative to sea level. The Atlantis Aquifer, while also coastal, is at lower risk because of the elevated position of the underlying Malmesbury geology, providing a natural barrier to seawater intrusion. Similarly, the TMG aquifers along the Cape Peninsula and in the Hottentots Holland Mountains are considered low risk due to their steep topography and confined geological settings that reduce the likelihood of saline intrusion.

From a municipal perspective, the City has incorporated MAR in the CFA as part of the scheme design to create a hydraulic barrier between the wellfields and the coastline. This artificial recharge increases groundwater levels and slows or prevents the inland movement of saline water. Coastal monitoring boreholes have also been installed to provide early warning of salinity changes. These adaptive management measures enable the City to adjust abstraction rates if rising salinity levels are detected, which reduces operational risk to the municipal groundwater schemes.

Communities living in low-lying coastal informal settlements face a different, but related, vulnerability where rising groundwater levels caused by SLR can lead to waterlogging and shallow groundwater flooding. This creates secondary health risks, including increased exposure to water-borne diseases, especially where sanitation infrastructure is poor and pit latrines may overflow or backflow. Coping capacity in these areas is limited, with residents lacking resources for engineering interventions, and often depending on municipal support for drainage and sanitation management.

6.4. Reduced Recharge: Due to Climate Change

Reduced recharge is a risk to the sustainability of Cape Town's groundwater resources as well as the users and ecosystems that depend on them. This risk is primarily related to the decline in rainfall associated with shifting climate patterns, which reduces natural recharge. The impact is further exacerbated by urbanisation, which decreases the extent of permeable recharge areas and increases stormwater runoff, limiting the amount of water that infiltrates into the aquifers.

To assess aquifer vulnerability to reduced recharge, the ratio of current aquifer recharge to the expected recharge reduction was analysed. The reduction categories within the City were limited to two broad classes (4.1 mm/year and 6 mm/year [Dennis and Dennis, 2012]), which were categorised as high and very high hazard given the negative impact any recharge decline poses. However, the severity of risk varies depending on the baseline recharge of each aquifer area (see **Figure 6-3**). For example, the Cape Peninsula and Hottentots Holland TMG aquifers currently receive relatively high annual recharge (see **Figure 6-3**). In these areas, even a moderate reduction in recharge is less likely to have a substantial proportional impact on aquifer storage and yield. By contrast, areas like the northern suburbs, where the basement aquifers already experience low recharge rates, face a more acute risk (see **Figure 6-3**). In these low-recharge zones, even small absolute declines represent a large percentage reduction (15%), significantly increasing vulnerability to long-term recharge reduction.

From a user perspective, the risk to reduced recharge is influenced by groundwater dependency, access to alternative water sources and coping capacity. This is most pronounced within the agricultural areas in the northern suburbs and in the PHA. These users face increased risk of declining borehole yields and potential crop losses.

Small-scale and resource-limited farmers are especially at risk as they often lack the capital to deepen boreholes, switch to more efficient irrigation technologies, or secure alternative water sources. By contrast, larger, well-capitalised farms in these areas have greater coping capacity. They can invest in borehole upgrades, on-site storage, and more efficient water management systems to mitigate the effects of declining groundwater availability.

Industries reliant on groundwater for processing, cooling, or other operational needs also face exposure to this risk, especially if located in low-recharge zones. However, similar to larger farms, high-income industries typically have more financial flexibility to adapt through infrastructure investments or by sourcing alternative water supplies.

At the municipal level, reduced recharge poses a risk to the groundwater schemes, particularly in the CFA and Atlantis Aquifer. The City's implementation of MAR at the CFA and Atlantis Aquifer plays a key role in maintaining groundwater levels and supporting sustainable abstraction. Groundwater models used by the City incorporate climate change scenarios to forecast aquifer responses and guide management decisions.

Cape Town's broader water supply diversification strategy, which includes surface water, desalination, and water reuse, also provides important systemic resilience against recharge-driven supply risks. However, agricultural users in low-recharge zones, small businesses, and low-income communities relying on vulnerable aquifers remain disproportionately at risk due to their limited ability to adapt.

Although many of Cape Town's GDEs, such as wetlands, springs and baseflow-supported rivers, are located in areas with relatively high recharge (e.g., the TMG aquifers along the Cape Peninsula and Hottentots Holland), these ecosystems could still be indirectly affected by reduced recharge. Additionally, ecosystems in low recharge areas, such as seasonal wetlands on the Cape Flats or in the northern agricultural zones, may experience more immediate impacts from reduced recharge, given their already limited water availability.

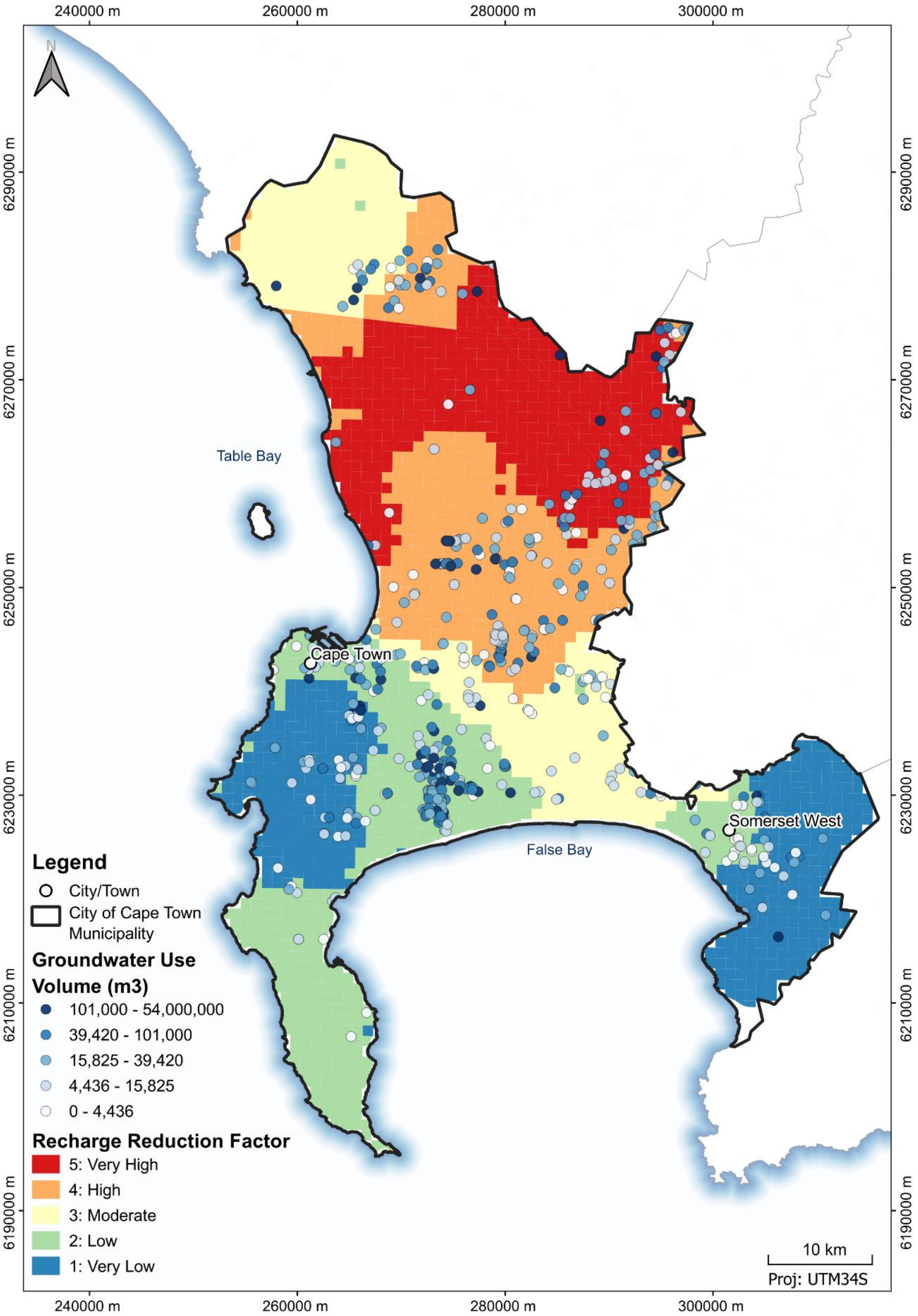

Figure 6-3 Map showing the recharge reduction factor in relation to registered groundwater users within the City of Cape Town, highlighting areas where groundwater users are at risk to reduced recharge reduction.

7. Synthesis and Recommendations

7.1. Summary of Key Risks and Interactions

Aquifer contamination risk in the City of Cape Town is highest in shallow unconfined aquifer systems such as the CFA and Atlantis aquifers due to high infiltration and limited natural protection. However, due to the number of PCAs, the CFA is the area most at risk to contamination from surface contaminants. In contrast, the deeper, confined TMG Aquifer within the Hottentots Holland Mountains and the TMG Aquifers and Cape Granite Suite basement aquifer along the Cape Peninsula generally display lower contamination risks due to their greater depth and natural confinement.

The risk of **over-abstraction** is highest in areas with high concentrations of groundwater users, where aquifers are stressed, and where the ratio of recharge to yield is low. The CFA is particularly at risk due to large-scale private groundwater use (registered and unregistered), often concentrated in the same areas as municipal wellfields, such as the PHA. Although this part of the CFA has a low to moderate recharge-to-yield ratio and moderate stress, the concentrated and increasing water demand compounds the pressure on the resource. This stress intensifies during droughts as users increase pumping to compensate for declining surface water availability. The risk is further heightened in coastal sections of the CFA, where over-abstraction increases the potential for saline intrusion. In addition to the CFA, parts of the northern suburbs, where the basement aquifers are targeted, are also at high risk, due to moderate stress index and a low recharge-to-yield ratio.

The CFA is most vulnerable to **sea level rise** due to climate change because of its shallow, unconfined nature, proximity to the coast, and low elevation relative to sea level. The Atlantis Aquifer, while also coastal, is at lower risk because of the elevated position of the underlying Malmesbury geology, providing a natural barrier to seawater intrusion. Similarly, the TMG aquifers along the Cape Peninsula and in the Hottentots Holland Mountains are considered low risk due to their steep topography and confined geological settings that reduce the likelihood of saline intrusion.

Reduced recharge due to climate change is a risk to groundwater availability in the City of Cape Town. Areas that already experience low recharge, like the northern suburbs, which are underlain by basement aquifers, have the highest risk. In these low recharge zones, even small declines in recharge have significant implications for long-term recharge reduction. Meanwhile, areas of relatively high recharge in the City, like the Hottentots Holland TMG aquifers, are less likely to be substantially impacted by reduced recharge.

The groundwater risks outlined above have serious implications for both people and the environment, particularly for **GDEs or sensitive ecosystems**. Over abstraction and reduced recharge can significantly diminish the groundwater needed to sustain GDEs, leading to the shrinking or complete drying out of these systems and, as such, the loss of critical biodiversity. Additionally, GDEs are highly sensitive to groundwater contamination, which can result from human activities and saline intrusion due to sea level rise. The CFA, in particular, is the most at risk across multiple groundwater-related hazards, also placing GDEs in this region at high risk of these hazards.

Cape Town’s **socio-economic** burnability profile reveals a consistent trend: low-income communities face greater exposure and sensitivity to groundwater hazards and have far less coping capacity than high-income communities. Whether it is pollution of aquifers, unsustainable extraction, coastal impacts from sea-level rise, or climate-driven aridity, the inequalities in income, infrastructure, and social resources translate directly into unequal risk. High-income areas, with robust infrastructure, diversified water options, and financial means, generally score low on vulnerability. In contrast, low-income areas often exhibit high to very high vulnerability. This emphasises the need for targeted interventions: protecting aquifers from contamination by improving sanitation in informal settlements, regulating private over-abstraction to prevent overuse from impacting the commons, investing in drainage and flood protection for low-lying settlements, and ensuring climate adaptation efforts prioritise the urban poor who have the least capacity to adapt. By addressing these indicators, reducing sensitivity and increasing coping capacity in low-income areas, Cape Town can move toward more equitable groundwater resilience in the face of multiple hazards.

7.2. Integrated Assessment

7.2.1. Climate Change as a Multiplier Across Hazards

Climate change is increasingly recognised not only as a standalone environmental crisis, but also as a risk multiplier that exacerbates existing hazards and creates new vulnerabilities across social, economic, and ecological systems. It exacerbates aquifer contamination through extreme weather events that mobilise pollutants from PCA’s and concentrates contaminants in diminishing groundwater and surface water resources. Rising sea levels can lead to the saline intrusion of coastal aquifers, particularly where over-abstraction has already lowered the water table and reduced both aquifer storage. Over abstraction is often a result of high dependence, and during times of drought and reduced surface water availability, can lead to a greater reliance on groundwater. In places like the CFA, over abstraction can alter hydraulic head, consequently resulting in saline intrusion. Changes in rainfall patterns and higher evaporation rates create a reduction in groundwater recharge. This reduces groundwater availability and encourages over abstraction, as dependency on groundwater often increases to meet supply demand. This stresses the aquifer and can lead to a deterioration of water quality as a result of saturation and salinisation. These interactions create feedback loops, encouraging and multiplying the effects and impacts from one hazard to another. Ultimately, climate change intensifies aquifer vulnerabilities and significantly impacts the users who are the most dependent and reliant on groundwater.

7.2.2. Liveable Urban Waterways to enhance Integrated Coping Capacity

The City of Cape Town has identified the growing need to address the health of its waterways and catchments and initiated the Liveable Urban Waterways programme (CCT, 2021b. While the water ways play an important role in delivering a range of ecosystem services, such as flood attenuation, water quality amelioration and experiential benefits, their value has been compromised by ecological degradation. Moreover, the problems associated with this degradation have affected some of the more vulnerable, poor and disadvantaged communities in the City (GIZ, 2023).

The vision is to have a water sensitive Cape Town with waterways that are safe, healthy, functional and productive. A Cape Town where waterways are protected, river corridors are restored and in doing so the quality of life for communities and the environment is enhanced. The following six criteria are used to define water ways as liveable (CCT, 2021b):

- **Have acceptable water quality** – Liveable urban waterways have water of a quality that is acceptable for the context and the purpose. At a minimum they are for the most part free from sewage, litter and invasive plants and animals; and can sustain indigenous aquatic life.
- **Make space for the water** – Liveable urban waterways accommodate flooding as a natural phenomenon and convey, store and treat flood water in a way that does not pose an unacceptable risk to surrounding communities.
- **Have a functioning ecology** – Liveable urban waterways provide a diverse habitat structure to support a functioning ecology and a healthy biodiversity of indigenous aquatic life. They provide connectivity for the movement of plants and animals.
- **Connect the waterway to the water table and the floodplain** – Liveable urban waterways are hydraulically connected to the aquifers beneath them and the flood plains and wetlands adjacent to them, allowing water to move naturally, and in doing so recharge groundwater and sustain the wetlands.

- **Connect communities and used and enjoyed by communities** – Liveable urban waterways can be linear pathways linking mountains to the sea, connecting upstream and downstream communities, and connecting communities around them. Liveable urban waterways are multi-functional spaces, places where people come to recreate, enjoy themselves, learn and exercise.
- **Provide a range of ecosystem services, economic and social benefits** – Liveable urban waterways are green infrastructure and use natural processes to treat water, store water, reduce flooding, improve biodiversity, trap sediments, recycle nutrients, reduce heat and assimilate carbon. They may provide jobs, food and materials, or the water can be abstracted for use.

7.3. Recommendations towards Conjunctive Management Strategies

7.3.1. Groundwater Management

The City of Cape Town recently developed a groundwater policy brief (CCT, 2025) with proposed solutions and actions to enhance groundwater governance and management within the municipal framework. These are grouped into four focus areas:

- **Managing Landuse Contamination**: The urban context presents a multitude of potential contaminant sources which pose a risk to groundwater quality. Spatial and land use planning can assist in limiting the potential for future contamination in areas of strategic groundwater importance, and as such solutions are proposed to this end. The prevalence of groundwater use across the CCT Municipal area, as well as the presence of existing land use practices and the occurrence of informal settlements, means that future land use planning initiatives will not solely address the risks of groundwater contamination. As such, mitigation measures are proposed for potential contaminating activities and stormwater handling.
- **Municipal Control of Groundwater Development and Use**: The National Department of Water and Sanitation (DWS) is the custodian of the country's water resources, which includes the groundwater in Cape Town. The City of Cape Town (CCT), as a groundwater user and Water Services Authority, recognizes it has a role to play in the protection and management of groundwater within its area of responsibility, but that it cannot enact legislation from a water resource management perspective.
- **Improved Data and Monitoring**: Groundwater data collection is currently mandated for groundwater users with Water Use Licenses (WULs), as well as for those with Water Services Intermediary (WSI) Agreements. Whilst less explicit, Schedule 1 users are also mandated to monitor. Awareness and clarity in terms of the monitoring mandate, as well as the relevant supporting information technology (IT) infrastructure, is needed to ensure data is used to inform future management of the resource by DWS.
- **Coordination and Governance**: DWS, as the regulator of groundwater, have the mandate to protect and govern groundwater within the CCT. However, DWS is known to have capacity and resource constraints, which in addition to the scale at which they are managing the resources (Water Management Area extent), limits the degree to which they are able to deliver the level of groundwater governance and management that the CCT desires. A prominent solution is the establishment of an aquifer advisory forum which can allow for stakeholder involvement. A forum of this nature would enable CCT to exercise its agency, influence and resources to support DWS in achieving its mandate.

It is recommended that these proposed solutions are included in the strategic action plan and implemented as per the Groundwater Policy Brief.

7.3.2. Sustainable Groundwater Development

The City of Cape Town currently develops three of the main aquifers for groundwater use to diversify the water sources for the City's water supply portfolio as part of the Water Strategy. It is recommended that this continues with an emphasis on:

- Implement and expand managed aquifer recharge (MAR) schemes, such as the Atlantis Water Resource Management Scheme and the Cape Flats Aquifer Management Scheme
- Upgrade and optimise existing groundwater schemes such as the Atlantis Water Resource Management Scheme
- Continue strategic development of additional wellfields, especially within the Cape Flats Aquifer and the Table Mountain Group Aquifer
- Enhance groundwater monitoring, modelling and governance across all schemes, including the more localised supply from springs

7.3.3. Climate-Responsive Management

The City's 2019 Water Strategy and Climate Change Policy embed the lessons of the recent drought, emphasising ongoing water conservation, the protection of ecological infrastructure, and proactive adaptation to climate risks. It is recommended to incorporate relevant aspects of the Climate Change Policy into the strategic action plans with special emphasis on:

- Integration of groundwater into climate-adaptive strategies.
- Incorporation of climate change projections into groundwater planning and management strategies
- Improved regulation of private groundwater abstractions.
- Strengthening of drought preparedness and response.

7.3.4. Green-Blue Infrastructure

Moving towards a conjunctive management strategy, it is recommended a Green-Blue Infrastructure approach is adopted. Green-Blue infrastructure refers to a strategically designed network of natural and semi-natural systems that integrate hydrological functions with ecological and social benefits. Currently many of Cape Town's water ways and infrastructure follow what is referred to as "grey" infrastructure, where concrete pipes, canals and drainage systems are the preferred mechanisms. Green-Blue Infrastructure in contrast utilises vegetation, soils, wetlands, rivers and urban water features to manage stormwater, enhance groundwater recharge, reduce flooding and improve water quality. This strategy attempts to mimic natural water cycles to support climate resilience, biodiversity and sustainable urban development. Ultimately, Green-Blue Infrastructure attempts to address the challenges of water scarcity and water pollution in a cost effective and multifunctional approach as an alternative to traditional water management systems.

Hence, the Liveable Urban Waterways programme should be rolled out across the whole of the City. In addition, the concept should be expanded to include Green-Blue Infrastructure elements, such as Sustainable Drainage Systems (SuDS), green architecture, rainwater harvesting, localised infiltration, localised bioretention treatment, water re-use etc.

8. REFERENCES

Adelana, Segun, Xu, Yongxin, and Vrbka, Petr. (2010). A conceptual model for the development and management of the Cape Flats aquifer, South Africa. Water SA, 36(4) 79502010000400011&lng=en&tlng=en.

Al Atawneh, D., Cartwright, N. and Bertone, E. (2021). Climate change and its impact on the projected values of groundwater recharge: A review. Journal of Hydrology,601, p.126602.

Arup, Organisation for Economic Co-operation and Development (OCED) and Stockholm International Water Institute (SIWI). (2019). The City Water Resilience Approach.

Basyuni M., Amukti R., Damayanti C., Stokes D., Mubaraq A., and Rahmila Y.I. (2025). Ecological features of mangroves as indicators of seawater intrusion. Global Journal of Environmental Science and Management,11(2): 609-630.

Bugan R.D.H., Jovanovic N., Israel S., Tredoux G., Genthe B., Steyn M., Allpass D., Bishop R., and Marinus V. (2016). Four decades of water recycling in Atlantis (Western Cape, South Africa): Past, present, and future. Water SA, 42(4): 577-594.

Blake, D. and Wise, E. A. (2023). Oudekraal Geological, Hydrogeological and Coastal Processes Specialist Assessment – Phase 1 Environmental Constraints Analysis. Prepared by Umvoto Africa (Pty) Ltd for Doug Jeffery Environmental Consultants (Pty) Ltd on behalf of Marblesharp 108 (Pty) Ltd. Report No. 1033/4/1/2023 (July 2023), 42pp.

City of Cape Town (CCT). (2018). Water Outlook – September 2018 – Edition 10; Bulk Water Branch, Bulk Services Department, Water and Sanitation Directorate.

City of Cape Town (CCT). (2019a). Our Shared Future: Cape Town's Water Strategy.

City of Cape Town (CCT). (2019b). City of Cape Town Resilience Strategy.

City of Cape Town (CCT), (2019c). The Risks of Groundwater Quality.

City of Cape Town (CCT). (2021a). City of Cape Town Climate Change Strategy, City of Cape Town.

City of Cape Town (CCT). (2021b). Liveable Urban Waterways, Implementation Framework. Water and Sanitation, Resilience, Environmental Management, Urban Planning and Design, Recreation and Parks.

City of Cape Town (CCT). (2022a). Integrated Development Plan (IDP) 2022–2027. Cape Town: City of Cape Town.

City of Cape Town (CCT). (2022b). New Water Programme: Cape Flats Aquifer Management Scheme - Groundwater Protection Zones and Vulnerability Mapping. Prepared by Henry, SL., Hugman, R., McGibbon, D.C., Kuhudzai, A., E. Wise, E. Van Der Berg and K. Riemann of Umvoto South Africa Pty (Ltd.) on behalf of City of Cape Town Municipality. Version 1.2; Final Draft; Report No. 896/7.1/13/2020, pg.[51]

City of Cape Town (CCT). (2023a). Cape Town Water Outlook – March 2023 – Edition 10; Bulk Water Branch, Bulk Services Department, Water and Sanitation Directorate.

City of Cape Town (CCT). (2024). Steenbras Catchment Office rain gauge 2015-2024 averaged rainfall.

City of Cape Town (CCT). (2025). Policy Brief Report. Prepared by Bigen Africa Services (Pty) Ltd, GEOSS South Africa (Pty) Ltd, Infinity Environmental (Pty) Ltd and Freshwater Consulting CC, as part of BW-WP092: Independent Review of Geohydrological Studies and Development of a Draft Groundwater By-law/Policy to Inform /Guide City of Cape Town Process. Report No. 194C/2020/21 WP-092/04.

Copernicus Climate Change Service. (n.d.). Climate Atlas. Copernicus Climate Data Store. Retrieved June 25, 2025, from https://atlas.climate.copernicus.eu/atlas

Day, E., Ollis, D., Ngobela, T., & Rivers-Moore, N. (2020). Water quality of rivers and open waterbodies in the City of Cape Town: Status and historical trends, with a focus on the period April 2015 to March 2020. Liz Day Consulting (Pty) Ltd. Report prepared for the City of Cape Town Inland Water Quality Monitoring Programme.

Dennis, I. and Dennis, R. (2012). Climate change vulnerability index for South African aquifers. Water Sa, 38(3), pp.417-426.

Department of Water Affairs and Forestry. (2005). Groundwater Resource Assessment Phase II Project 4 Methodology for Classification, Final Report. Department for Water Affairs and Forestry.

Department of Water and Sanitation (DWS). (2016). National Groundwater Strategy. Department of Water and Sanitation.

Department of Water and Sanitation (DWS) (2022). High Confidence Groundwater Reserve Determination Study in the Berg Catchment – Ecological Reference Conditions Report. Prepared by M. Misrole, A. Vicente, E. Wise and M. Mokhethi of Umvoto South Africa Pty (Ltd.) on behalf of DWS. Version 1 / Final; Report No. 1001/1/5/2022, pg.184.

Department of Water and Sanitation (DWS). (2024). National State of Water Report 2023. Integrated Water Resource Studies Report Number WII/IWRS/NSoW 2023 PRETORIA, South Africa.

Domenico, P. A., & Schwartz, F. W. (1997).Physical and chemical hydrogeology. John wiley & sons.

du Plessis J.A. and Schloms B. (2017). An investigation into the evidence of seasonal rainfall pattern shifts in the Western Cape, South Africa. Journal of the South African Institution of Civil Engineering, 59 (4): 47-55.

de Visser, J. (2016). Local law making in Cape Town: A case study of the municipal planning by-law process.

Esterhuyse, S., Avenant, M., Redelinghuys, N., Kijko, A., Glazewski, J., Pitt, L.A., Kemp, M., Smit, A., Sokolic, F., Vos, A.T. and Reynolds, D. (2014). Development of an interactive vulnerability map and monitoring framework to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing.

Faragher, T.P.T. and Carden, K. (2023) “Groundwater governance for improving city water resilience in Cape Town, South Africa.” Frontiers in Sustainable Cities, 5:1062661. doi: 10.3389/frsc.2023.1062661.

Fick, S.E. and Hijmans, R.J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas, International Journal of Climatology, 37(12), pp. 4302–4315. doi: 10.1002/joc.5086.

Foster, S., Eichholz, M., Nlend, B. and Gathu, J. (2020). Securing the critical role of groundwater for the resilient water-supply of urban Africa. Water Policy, 22(1), pp.121-132.

German Agency for International Cooperation (GIZ). (2023). Green Infrastructure Options for Improved Waterway and Catchment Management for the City of Cape Town.

Hofmann, V.S., Egieya, J.M., Parker, Y. et al. Impact of resilience policies on cape town's water-food nexus: A system dynamics approach. Bull Natl Res Cent 48, 102 (2024). https://doi.org/10.1186/s42269-024-01255-6.

Intergovernmental Panel on Climate Change (IPCC). (2019). Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC): Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. Prepared by Pörtner, H. O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., & Weyer, N. M on behalf of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321-445.

Intergovernmental Panel on Climate (IPCC). (2021). The Physical Science Basis: Contribution of Working Group 1 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Prepared by Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou on behalf of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, doi: 10.1017/9781009157896.

Jude, C. (2020). Groundwater and the discourse of shortage in Sub-Saharan Africa. Hydrogeology Journal, 28(4), pp.1143-1154.

NASA. (n.d.). IPCC AR6 Sea Level Projection Tool. NASA Sea Level Portal. Retrieved June 25. (2025). from https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool.

Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, (2019). Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321–445. https://doi.org/10.1017/9781009157964.006.

Ozcoasts. (2009). Australian Online Coastal Information. Saline Intrusion, published on http://www.ozcoasts.org.au/indicators/saline_intrusion.jsp

Patra, S., Sahoo, S., Mishra, P. and Mahapatra, S.C. (2018). Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level. Journal of urban management, 7(2), pp.70-84.

Peel M.C., Finlayson B.L., and McMahon T.A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences Discussions, 11(5): 1633 – 1644.

Pfaff M.C., Logston R.C., Raemaekers S.J.P.N., Hermes J.C., Blamey L.K., Cawthra H.C., Colenbrander D.R., Crawford R.J.M., Day E., du Plessis N., Elwen S.H., Fawcett S.E., Jury M.R., Karenyi N., Kerwath S.E., Kock A.A., Krug M., Lamberth S.J., Omardien A., Pitcher G.C., Rautenbach C., Robinson T.B., Rouault M., Ryan P.G., Shillington F.A., Sowman M., Sparks C.C., Turpie J.K., van Niekerk L., Waldron H.N., Yeld E.M., and Kirkman S.P. (2019). A synthesis of three decades of socio-ecological change in False Bay, South Africa: setting the scene for multidisciplinary research and management. Elementa Science of the Anthropocene, 7(1): 1-49.

Saayman, I. C., Beekman, H. E., Adams, S., Campbell, R. B., Conrad, J., Fey, M. V., ... & Usher, B. H. (2007). Assessment of aquifer vulnerability in South Africa. Water Research Commission, Pretoria. WRC Report, (1432/1), 07.

SADC-GMI (2025). Groundwater Dependency Assessment (Cape Town), Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam). Prepared by E. Malijani, S. Stenzl, K. Woolf, K. Riemann and A. Benjamin of Umvoto Africa (Pty) Ltd., D. Brink and A. Modack of AIVIA (Pty) Ltd, M. Bollaert of Hydrologic Consulting (Pty) Ltd, and K. Snaddon of Freshwater Research Centre, on behalf of SADC-GMI. Draft; Report No. 1074/2/4/2025, pg.51.

Seeliger, L. (2020), Water Issues in Ethical Perspective: A Case Study in the Philippi Horticultural Area (PHA), No. 2852/1/20, Water Research Commission.

Schulze, R. E. (2009). Long-term monthly minimum, average, and maximum temperature. SA Atlas of Climatology and Agrohydrology.

Schulze, R. E., & Schütte, S. (Eds.). (2023). A national assessment of potential climate change impacts on the hydrological yield of different hydro-climatic zones of South Africa – Report 2: Perspectives on adaptation to climate change in the South African water sector. Water Research Commission.

Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou, 2021: Weather and Climate Extreme Events in a Changing Climate Supplementary Material. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Available from https://www.ipcc.ch/.

South African Weather Service (SAWS). (2024). Cape Town International Airport and Atlantis weather stations 2015-2024 averaged rainfall.

Stats SA. (2022). Quarterly Labour Force Survey (QLFS) Quarter 4, 2022. Pretoria: Statistics South Africa.

Stats SA. (2025). Quarterly Labour Force Survey (QLFS) Quarter 1, 2025. Pretoria: Statistics South Africa.

Stuart-Hill, S.I., Schulze, R.E., Methner, N., WARBURTON, M., DAVIS, N., GRAY, R., HORAN, M., JEWITT, G., LUMSDEN, T., KNOESEN, D. and BULCOCK, L. (2012). An Evaluation of the Sensitivity of Socio-Economic Activities to Climate Change in Climatically Divergent South African Catchments. Water Research Commission Report, (1843/1), p.12.

Turok, I., and Scheba, A. (2019). 'Right to the City and Spatial Justice in South Africa's Urban Future.' In State of South African Cities Report, South African Cities Network.

Umvoto Africa. (2009). City of Cape Town Disaster Risk Assessment: Aquifer Hazards. Final, December 2009.

Usher, B H, Pretorius, J A, Dennis, I, Jovanovic, N, Clarke, S Cavé, L Titus, R and Xu, Y. (2004). Inorganic and Organic Contaminants and Associated Sources in South Africa's Catchments. Report 1: Identification and prioritisation of groundwater contaminants and associated sources in South Africa's urban catchments. Water Research Commission.

Vandoolaeghe, N.A.C., and Bertram, W.E. (1980). Atlantis Grondwatersisteem Herevaluasie van Versekerde Lewering. Technical report GH 3222. Geohydrology Department. Cape Town.

Van der Gun, J. (2021). Groundwater resources sustainability. In Global groundwater (pp. 331-345). Elsevier.

Van Drunen, M A, Lasage , R and Dorland, C. (2006). Climate Change in Developing Countries: Results from the Netherlands Climate Change Studies Assistance Programme. CABI

Western Cape (2007). A climate change strategy and action plan for the Western Cape Supplementary Report (Number 5 of 7): Biophysical report: Climate change in the Western Cape. Prepared by Hewiston B and Johnston P for the Department of Environmental Affairs and Development Planning by the Climate Systems Analysis Group, University of Cape Town.

Western Cape Government. (2022). Socio-Economic Profile: City of Cape Town 2022. Western Cape Provincial Treasury.

Western Cape Provincial Parliament (WCPP). (2022). Hearing on Infrastructure in the Western Cape Province following the 2022 Budget allocation. https://www.wcpp.gov.za/?q=node/13767

Water Research Commission (WRC). (2009). Assessment of aquifer vulnerability in South Africa. Prepared by Saayman, I. C., Beekman, H. E., Adams, S., Campbell, R. B., Conrad, J., Fey, M. V. & Usher, B. H. on behalf of the Water Research Commission, Pretoria, South Africa. WRC Report No. 1432/1/07.

Water Research Commission (WRC). (2020). Water Issues in Ethical Perspective: A case study in the Philippi Horticultural Area (PHA). Prepared by Seeliger L on behalf of the Water Research Commission, Pretoria, South Africa. WRC Report No. 2852/1/20.

Zaporozec, A. and Miller, J.C. (2000). Ground-water pollution.

Ziervogel, G. (2019). ‘Unpacking the Cape Town Drought: Lessons for Sustainable Water Management.’ Climate Risk Management, 26, 100202.

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