



GROUNDWATER MANAGEMENT INSTITUTE

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

**Groundwater Vulnerability Assessment:  
Dar es Salaam**

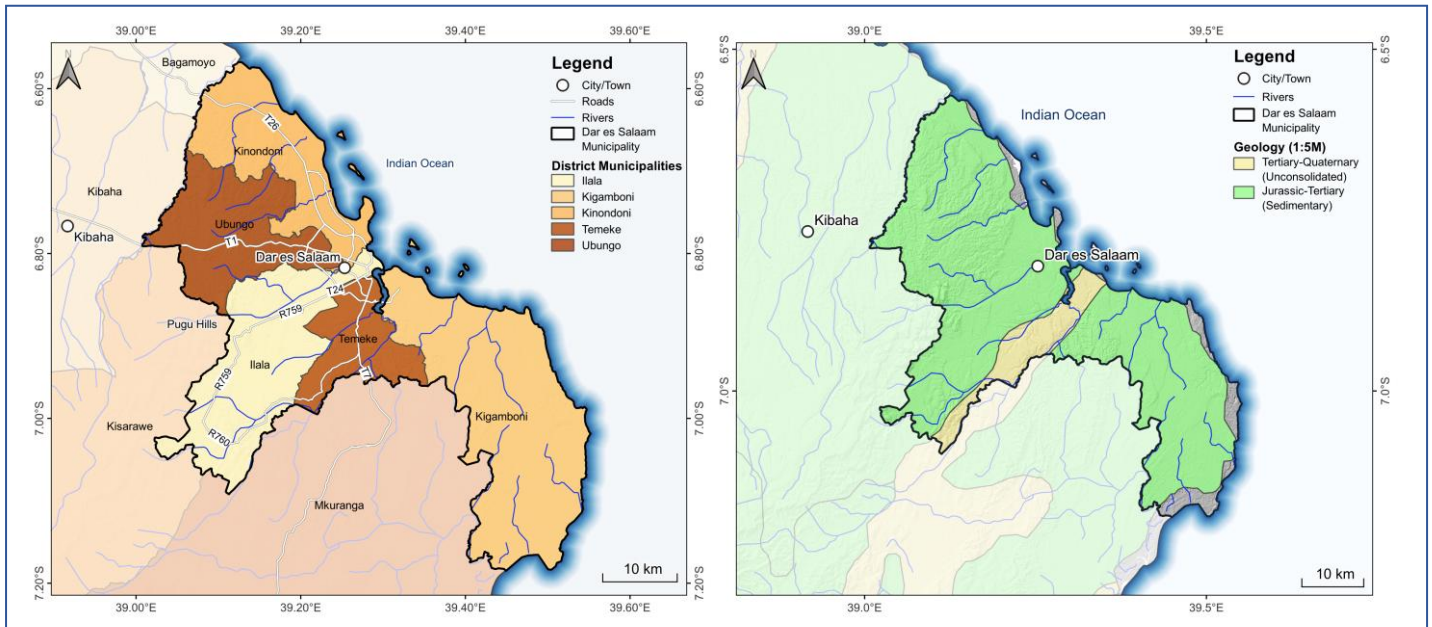
**July 2025**



**THE WORLD BANK**



## Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam) *Groundwater Vulnerability Assessment: Dar es Salaam*



Version 1

Prepared for:  
SADC-GMI

**PROJECT** : **Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam)**

**REPORT TITLE** : **Groundwater Vulnerability Assessment Dar es Salaam**

**CLIENT** : **SADC-GMI**

**AUTHORS** : **Sebastian Stenzl  
Errol Malijani  
Keanan Woolf  
Kornelius Riemann  
Aqeelah Benjamin  
Gemma Bluff  
Kate Snaddon  
Mark Bollaert  
Leodgard Otmar Haule  
Charles Sokile  
Edward Hunja**

**REPORT STATUS** : **Final**

**VERSION** : **Version 1**

**UMVOTO REPORT NUMBER** : **1074/3/2/2025**

**CLIENT REPORT NUMBER** : **ZA-SADC-GMI-418181-CS-CQS**

**DATE** : **July 2025**

**APPROVED BY** :



**UMVOTO Africa (Pty) Ltd  
Director  
Kornelius Riemann**



**UMVOTO Africa (Pty) Ltd  
Technical Reviewer  
Keanan Woolf**

---

**SADC-GMI  
Technical Advisor  
Kevin Pietersen**

## Referencing

This report is to be referred to in bibliographies as:

SADC-GMI. (2025). Groundwater Vulnerability Assessment (Dar es Salaam), Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam). Prepared by S. Stenzl, E. Malijani, K. Woolf, K. Riemann, and A. Benjamin of Umvoto Africa (Pty) Ltd; M. Bollaert of Hydrologic Consulting (Pty) Ltd; K.Snaddon of Freshwater Research Centre; and E. Hunja, C. Sokile and L.O. Haule of WEMA Consult (T) Ltd, on behalf of SADC-GMI. Final; Report No. 1074/3/2/2025, pg.77.

## Conditions and Disclaimer

Any documentation, reports, opinions, interpretations or otherwise, generated by Umvoto Africa (Pty) Ltd and contained in this report or submitted separately, are solely for the internal use of the Client to whom the information is addressed and are not to be circulated, published, or reproduced, whether in whole or in part, outside of the Client’s organisation or with specific approval in writing by Umvoto Africa (Pty) Ltd. Umvoto Africa (Pty) Ltd will not be held liable for loss or damages resulting from work undertaken or reported in terms of this assignment, or decisions taken on the basis of such work and/or report.

## Report Status

Version	Status	Reviewed By	Date
1	Draft	Keanan Woolf	25/07/2025
1	Draft	Kornelius Riemann	29/07/2025

## Distribution List

Version	Name	Institution	Date
1	Kevin Pietersen	SADC-GMI	30/07/2025
1	James Sauramba	SADC-GMI	30/07/2025
1	Mampho Ntsekhe	SADC-GMI	30/07/2025

# Table of Contents

Chapter	Description	Page
<b>1.</b>	<b>INTRODUCTION .....</b>	<b>1</b>
1.1.	Background.....	1
1.2.	Project aims and objectives.....	2
1.3.	Methodology .....	2
<b>2.</b>	<b>STUDY AREA .....</b>	<b>4</b>
2.1.	Description of the study area.....	4
2.1.1.	Locality.....	4
2.1.2.	Topography and Geology .....	5
2.1.3.	Hydroclimate .....	7
2.1.4.	Environmental.....	8
2.1.5.	Socio-economic .....	10
2.2.	Description of Dar es Salaam’s Aquifers.....	10
2.2.1.	Quaternary Aquifer .....	11
2.2.2.	Neogene Aquifers .....	13
2.2.3.	Basement Fractured Aquifers.....	13
2.3.	Groundwater Use in Dar es Salaam.....	14
<b>3.</b>	<b>HAZARDS .....</b>	<b>16</b>
3.1.	Aquifer Contamination: Due to Human Activities .....	16
3.1.1.	Introduction .....	16
3.1.2.	Major sources of groundwater contamination.....	16
3.1.3.	Hazard Mapping .....	21
3.2.	Over-abstraction .....	24
3.2.1.	Introduction .....	24
3.2.2.	Hazard Mapping .....	25
3.3.	Sea-level Rise: Due to Climate Change.....	28
3.3.1.	Introduction .....	28
3.3.2.	Affected Areas .....	28
3.4.	Reduced Recharge: Due to Climate Change and Urbanisation.....	29
3.4.1.	Introduction .....	29
3.4.2.	Potential changes in Recharge.....	30
<b>4.</b>	<b>VULNERABILITY .....</b>	<b>33</b>
4.1.	Aquifer Vulnerability.....	33
4.1.1.	Contamination: Due to Human Activities .....	33
4.1.2.	Over-abstraction .....	35
4.1.3.	Sea-level Rise: Due to Climate Change .....	36
4.1.4.	Reduced Recharge: Due to Climate Change .....	40

4.2.	Vulnerability of Groundwater Users.....	43
4.2.1.	Municipalities .....	43
4.2.2.	Communities, Agriculture and Industrial Use .....	47
4.2.3.	Ecosystems.....	56
<b>5.</b>	<b>COPING CAPACITY.....</b>	<b>59</b>
5.1.	Introduction .....	59
5.2.	Coping Capacity of Groundwater Users.....	59
5.2.1.	Contamination: Due to Human Activities .....	59
5.2.2.	Over-abstraction .....	61
5.2.3.	Sea-level Rise: Due to Climate Change .....	62
5.2.4.	Reduced Recharge: Due to Climate Change .....	65
5.3.	Ecosystems .....	68
<b>6.</b>	<b>RISK.....</b>	<b>70</b>
6.1.	Contamination: Due to Human Activities.....	70
6.2.	Over-abstraction .....	71
6.3.	Sea-level Rise: Due to Climate Change.....	72
6.4.	Reduced Recharge: Due to Climate Change .....	72
<b>7.</b>	<b>SYNTHESIS AND RECOMMENDATIONS.....</b>	<b>74</b>
7.1.	Summary of Key Risks and Interactions .....	74
7.2.	Climate Change as a Multiplier Across Hazards .....	75
7.3.	Recommendations for Conjunctive Use Management.....	75
7.3.1.	Groundwater Management.....	75
7.3.2.	Sustainable Groundwater Development.....	76
7.3.3.	Climate-Responsive Management .....	77
<b>8.</b>	<b>REFERENCES.....</b>	<b>78</b>

## List of Tables

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).....	19
Table 3-2	Population, area, impervious surface coverage and groundwater use by district in Dar es Salaam.....	26
Table 3-3	Rainfall, Runoff, PET and Recharge for the Kimbiji Aquifer, between 1996 and 2016 (adapted from Mussa et al. 2021). HS refers to the Hargreaves-Samani method, and PM refers to the Penman-Monteith method of calculating evapotranspiration. ....	32
Table 4-1	Impacts of aquifer contamination (human-induced) (Umvoto Africa, 2009).....	33
Table 4-2	Primary, secondary and tertiary impacts on aquifers due to sea-level rise.....	37
Table 4-4	Primary, secondary and tertiary impacts of reduced groundwater recharge .....	40
Table 4-3	CMIP6 Medium term Projections (2041-2060) SSP5-8.5 (IPCC, 2021a; C3S, 2024).....	41

## List of Figures

Figure 2-1	Locality map of the study area within the Dar es Salaam regional boundary. ....	4
Figure 2-2	Geological map of the Dar es Salaam region (Van Camp et al., 2014). ....	6
Figure 2-3	Cross-section across the central Dar es Salaam region (Figure 2-2) showing coastal terraces in Dar es Salaam (Sappa et al., 2014 after Msindai, 1988). ....	7
Figure 2-4	Aquatic ecosystems that are likely to be groundwater fed in Dar es Salaam. ....	9
Figure 2-5	Geological map of the central Dar es Salaam region (Van Camp et al., 2012, after Bartholomew, 1963). ....	11
Figure 2-6	Schematic cross section across the central Dar es Salaam region (Figure 2-5), showing the distribution of the lower and upper Quaternary Aquifers (Van Camp et al., 2012). ....	12
Figure 2-7	Dar es Salaam's groundwater use per sector per administrative district (data obtained from the Wami Ruvu Basin Water Board (WRBWB). ....	15
Figure 3-1	Sanitation facilities of households in Dar es Salaam (Karutz et al. 2019). ....	17
Figure 3-2	Sources of groundwater contamination (Zaporozec and Miller, 2000). ....	17
Figure 3-3	Land use activities in the Dar es Salaam Region. ....	22
Figure 3-4	Groundwater Contamination Hazard Map of Dar es Salaam. ....	23
Figure 3-5	Dar es Salaam's water supply pattern (Connecting Cities to Basins Project, 2017). ....	25
Figure 3-6	Over-abstraction hazard map of Dar es Salaam. ....	27
Figure 3-7	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). ....	28
Figure 3-8	Average yearly rainfall distribution of central Dar es Salaam (Mjemah and Walraevens, 2015). ....	31
Figure 3-9	Average 5-yearly precipitation of Dar es Salaam for the period between 1961 and 2010 (Sappa et al. 2015). ....	31
Figure 4-1	Schematic representation of unsaturated and saturated zones (WRC, 2007). ....	34
Figure 4-2	Influence of sea-level rise on the Dar es Salaam Metropolitan Area according to NASA (n.d). ....	38
Figure 4-3	Total Precipitation Relative Change (historical baseline 1981-2010) CMIP6 Medium term Projections (2041-2060) SSP5-8.5. ....	42
Figure 4-4	There are three Key Biodiversity Areas in and close to Dar es Salaam, located to the west of the city centre. These are areas of global biodiversity importance, that are sensitive to the impacts associated with groundwater-related hazards. ....	57
Figure 4-5	Areas of potentially higher risk of impact to wetlands (DAWASA, 2017). ....	58

## List of Abbreviations

~	-	approximately
°	-	degrees
>	-	greater than
<	-	less than
%	-	percent
CBO	-	Community Based Organisations
CEC	-	Contaminants of Emerging Concern
CMIP5	-	Coupled Model Intercomparison Project Phase 5
CMIP6	-	Coupled Model Intercomparison Project Phase 6
COP	-	Copernicus
Dar-MAERT	-	Dar es Salaam Multi-Agency Response Team
DAWASA	-	Dar es Salaam Water and Sewerage Authority
DM	-	District municipality
DRR	-	Disaster Risk Reduction
DURP	-	Dar es Salaam's urban Resilience Programme
ENSO	-	El Niño-Southern Oscillation
EOCC	-	Emergency Operations and Communications Centre
e.g.	-	example
FBO	-	Faith Based Organisations
GCM	-	Global Climate Model
GDP	-	Gross Domestic Product
GESI	-	Gender Equity and Social Inclusion
GDE	-	Groundwater-dependent ecosystems
GRACE	-	Gravity Recovery and Climate Experiment
GPZ	-	Groundwater Protection Zones
HSG	-	Hydrological soil group
i.e.	-	in other words
IPCC	-	Intergovernmental Panel on Climate Change
IWRM	-	Integrated Water Resource Management
KBA	-	Key Biodiversity Areas and Ramsar
km	-	kilometre
m	-	metre
Maji-IS	-	Maji-IS
m/s	-	metres per second
mamsl	-	metres above mean sea-level
MAP	-	Mean Annual Precipitation
MAR	-	Managed Aquifer Recharge
MoW	-	Ministry of Water
mm	-	millimetres
mm/a	-	millimetres per annum
MSL	-	Mean Sea-level

NEMC	-	National Environment Management Council
NGO	-	Non-governmental organisations
NRWSSP	-	National Rural Water Supply and Sanitation Program
ODSS	-	Operational Decision Support System
PCA	-	Potentially Contaminating Activities
PET	-	Potential Evapotranspiration
RCP	-	Representative Concentration Pathway
SADC	-	Southern African Developing Community
SADC-GMI	-	Southern African Developing Community-Groundwater Management Institute
SADC-GIP	-	Southern African Development Community- Groundwater Information Portal
SAWS	-	South African Weather Services
SEA	-	Strategic Environmental Assessment
TaWaSaNet	-	Tanzania and the Tanzania Water and Sanitation Network
TBA	-	Transboundary Aquifer
TMA	-	Tanzania Meteorological Authority
TOR	-	Terms of Reference
UNDP	-	United Nations Development Programme
UNICEF	-	United Nations International Children's Emergency Fund
WAMI	-	Water Resources Integration Development Initiative
WGS84	-	World Geodetic System 1984
WHO	-	World Health Organisation
WRBWB	-	Wami Ruvu Basin Water Board
WSDP	-	Water Sector Development Program
WUA	-	Water Use Association
WUIMS	-	Water User Information Management System
WUL	-	Water Use Licence
WUPA	-	Water Use Permitting Analysis Tool
WWTW	-	Wastewater Treatment Works
WWF	-	World Wildlife Fund

## 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 to 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, seawater intrusion, and climate change, using existing data and information. This assessment also evaluates the implications of groundwater vulnerability on 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 Dar es Salaam.

## 1.3. Methodology

This assessment adopts a qualitative risk-based approach to evaluate groundwater vulnerability in Dar es Salaam, 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 is 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 limited accessibility, infrastructure gaps and increased pressure on existing 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 a 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; Esterhuysen 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 the 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 Dar es Salaam. 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.

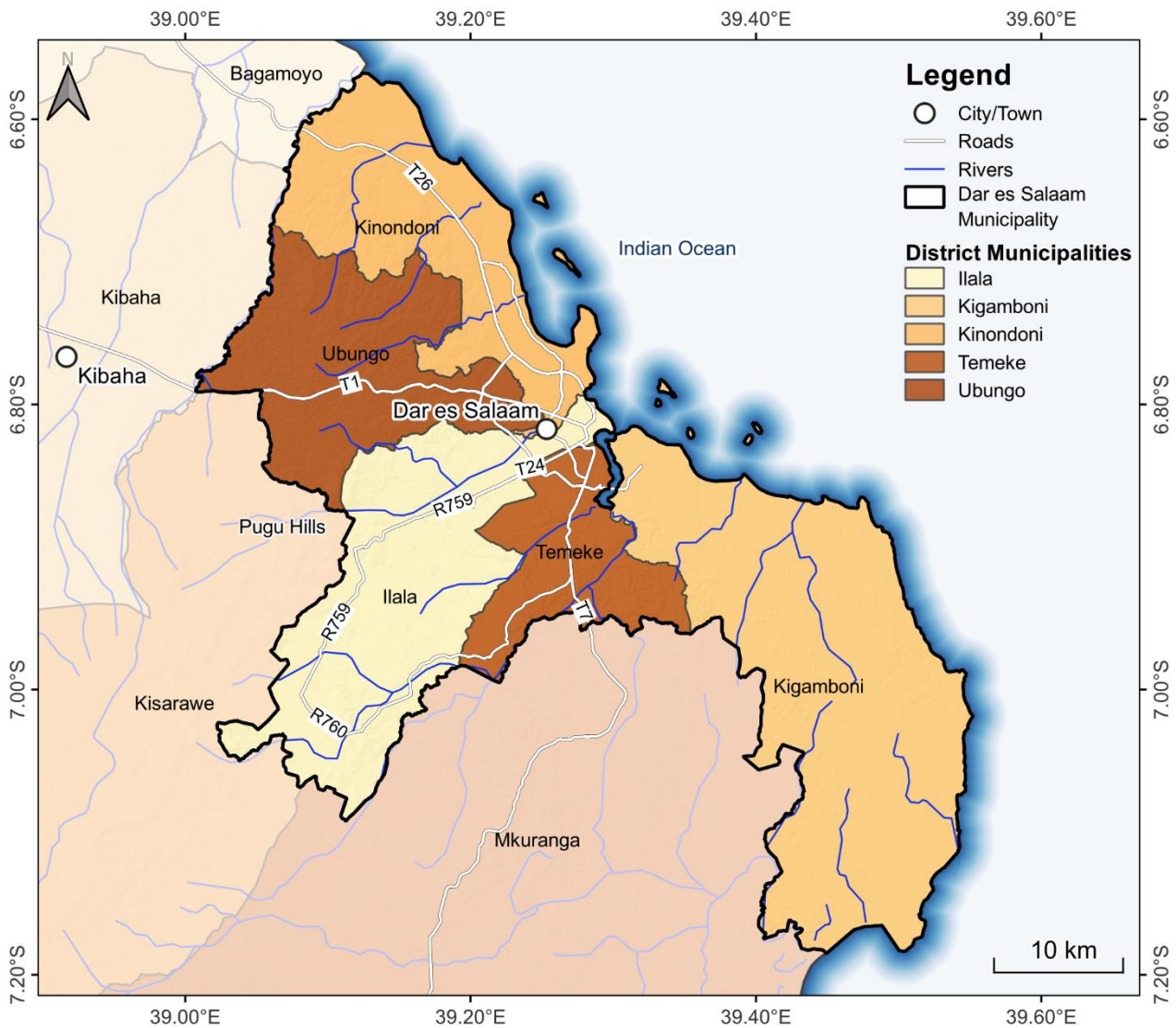
This assessment extends beyond hydrogeological analysis by incorporating the social, economic, and governance dimensions that shape groundwater risk exposure and vulnerability. The aim was to produce a practical, decision-support tool that identifies where hazards, aquifer vulnerability, and user exposure 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

Dar es Salaam is the largest city in Tanzania, representing the country's industrial and commercial centres. It is located on the east African coast along the Indian Ocean (see **Figure 2-1**). The region is regarded as Tanzania's largest urban centre (1,393 km<sup>2</sup>) and one of the most rapidly growing cities in Sub-Saharan Africa. Dar es Salaam is located in the Wami-Ruvu Water Basin and is divided into five district municipalities (also often referred to as administrative districts). These districts, namely: Ilala, Kinondoni, Temeke, Kigamboni, and Ubungo, each serve distinct roles in governance, commerce, and residential development (URT, 2022b; Lukenangula, 2023). Similarly to Cape Town, it comprises various land uses, including residential, commercial, industrial, and agricultural land uses, informal settlements, natural conservation areas, and a series of water bodies and wetlands.



**Figure 2-1** Locality map of the study area within the Dar es Salaam regional boundary.

These urban and peri-urban areas have seen significant growth over the last three decades, mainly due to natural population growth and rural-urban migration (Van Camp et al., 2012). As of 2022, the region's population was counted at 5,383,728 inhabitants, with estimates predicting a 4 – 5% annual growth rate (Msuya et al., 2021; URT, 2024). The consequence of larger populations and urbanisation is an increased impact and dependency on natural resources. Due to this growth, Dar es Salaam has seen an increase in use and dependency on groundwater, especially as upgrades to water treatment and water distribution infrastructure are still ongoing in the region (Van Camp et al., 2012; Smiley, 2013; Sappa and Luciani, 2014; The World Bank, 2024). The Wami-Ruvu Basin Water Board, in particular, has seen an increase in water use permits and borehole drilling permits, reaching 124% of their planned target for 2026 in 2024, further emphasising the growing dependency on groundwater in the basin (MoW, 2024).

### 2.1.2. Topography and Geology

Topographically, Dar es Salaam exhibits a relatively low-relief coastal plain, where its elevation ranges from sea-level at the coast, in the east, to approximately 200 metres above mean sea-level (mamsl), further inland in the west. The general topography is characterised by a gently undulating landscape interspersed with a series of low ridges and shallow valleys, shaped primarily by fluvial and marine processes during the Quaternary and Neogene periods (Msindai, 2002).

The terrain becomes more elevated toward the west, reaching its highest points in the Pugu Hills and southern highlands, which form part of the Neogene sandstone formation. These hills represent the highest natural elevations in the region and are geologically significant due to their kaolinitic sandstone beds (Msindai, 2002). These elevated areas are also important groundwater recharge zones and are thought to influence local drainage patterns.

The region of Dar es Salaam comprises a Precambrian crystalline basement overlain by a succession of sedimentary formations ranging from the Karoo Supergroup to recent Quaternary deposits. Inland areas are dominated by weathered basement and Neogene sandstone units, such as the Pugu Hills sandstone, while the coastal strip features younger marine and alluvial sediments (see Figure 2-2 and Figure 2-3). This layered stratigraphy reflects both tectonic evolution and marine influences, and it plays a significant role in shaping the region's groundwater systems.

The basement rocks consist of Precambrian Mozambique belt metamorphic rock, composed mainly of meta-sedimentary rocks, which occur mostly in the Uluguru Mountains and the Ngerengere sub-basin located further inland (IUCN, 2010). These meta-sedimentary basement rocks can be divided into three main lithological groups, acid gneisses, granulites and crystalline limestone (IUCN, 2010). The basement rocks have undergone thrusting and uplift, resulting in distinct fault zones in the rocks (JICA, 1994).

The overburden above the basement consists of unconsolidated sediments with interspersed and relatively thin layers of Jurassic to Cretaceous sandstones, clays and Pliocene-Pleistocene coral limestones (Msindai, 2002).

The continental Karoo sequence represents the oldest part of the sedimentary layers in Tanzania's coastal basin. Throughout the Jurassic, Cretaceous, and Tertiary periods, the region experienced alternating phases of marine regression and transgression. During regressions, deposition was dominated by clays, silts, and silty limestones, whereas transgressions led to the accumulation of calcareous, sandy, and shelly limestones (Van Camp et al., 2014). The Karoo deposits unconformably overlay the Precambrian basement complexes. The tectonic structure accommodating these Karoo deposits was a result of occasional subsidence followed by the down-faulted low relief depressions, which were filled with clastic sediment (JICA, 2005).

The Neogene period (Miocene and Pliocene) was marked by significant tectonic activity, which played a key role in shaping the current landscape. In the highland areas located to the south and west of the city centre, Neogene sandstone formations that are interbedded with siltstones and mudstones are predominant. These formations exhibit a variety of sandstone types, covering more than three-quarters of the region. One of the most prominent Miocene exposures is the kaolinitic

sandstone of the Pugu Hills (DAWASA, 2017), characterised by thick, kaolinitic, and cross-bedded layers, with calcareous sandstones present in back reef upland zones. Terrace development in the area is controlled by the underlying massive terrace sandstone. Overlying these Pugu Hill sandstones are Neogene (Miocene and Pliocene) deltaic deposits, referred to as “clay bound sands”, outcropping north and south of the city centre (see Figure 2-2). These Neogene deposits can reach a thickness of > 750 m (Van Camp et al., 2014).

During the Quaternary period, sedimentation and erosion were influenced by tectonic shifts, sea-level changes, and climatic variations. In the coastal region near Dar es Salaam, Quaternary deposits (up to 150 m thick) can be categorised into three main geological units: alluvial, coastal plain, and coral reef limestone layers (Van Camp et al., 2014). Alluvial sediments, comprising a mix of fine to coarse-grained sands, clays, and occasionally gravel and pebbles that fill the river valleys of the Mzinga, Kizinga, and Msimbazi rivers (see Figure 2-2). The coastal plain consists of unconsolidated sediments, predominantly sand, with evidence of multiple marine incursions. Coral reef limestone deposits are located along the coastline, consisting of coralline limestones where carbonate rocks occur in the form of fringing reefs and elevated reef structures, with fringing reefs being sparse in the northern area and raised reefs dominating the western upland margins (see Figure 2-2) (Msindai, 2002). Overall, the geological composition of the area includes unconsolidated sediments from the Neogene and Quaternary periods. The alluvial and coastal plain deposits, dating from the Pleistocene to the present, are mostly found along river valleys extending inland from the coast (Sappa and Luciani, 2016).

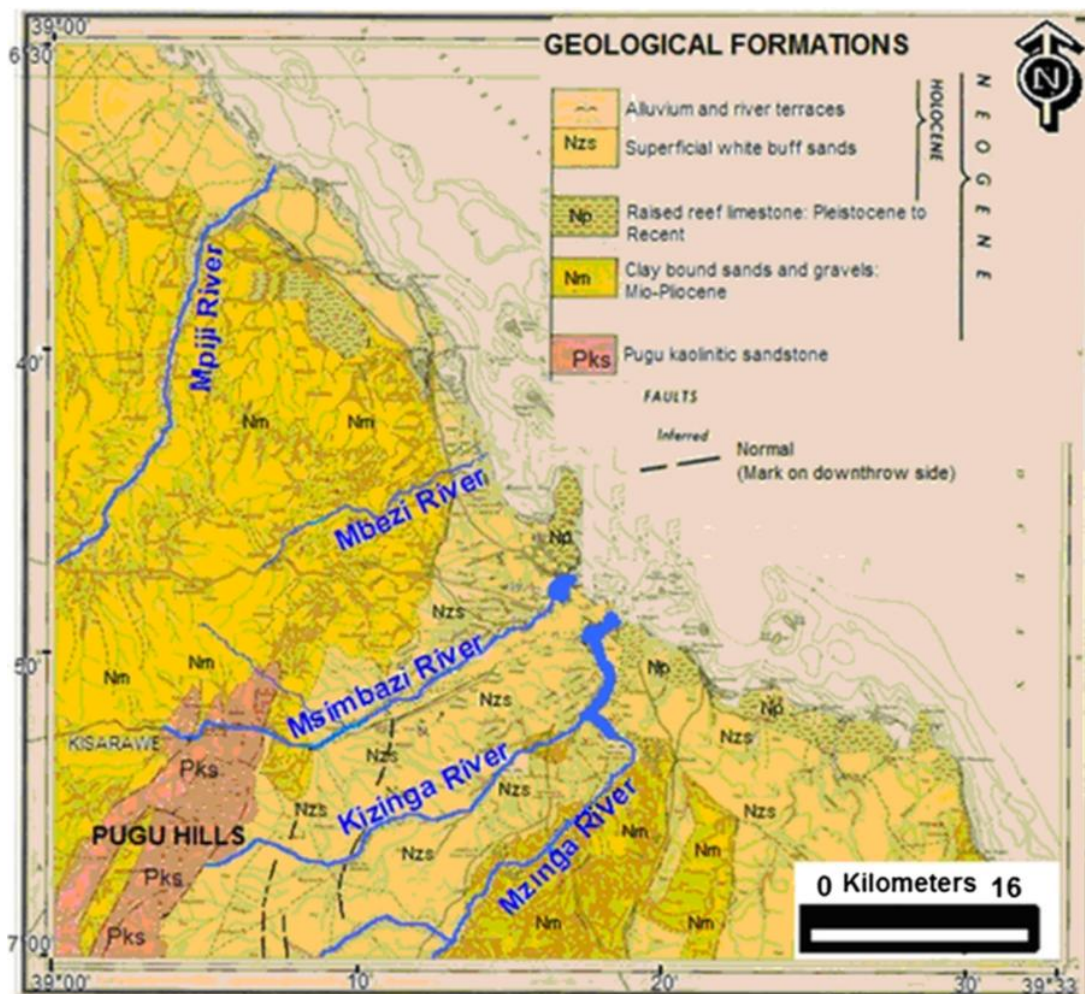
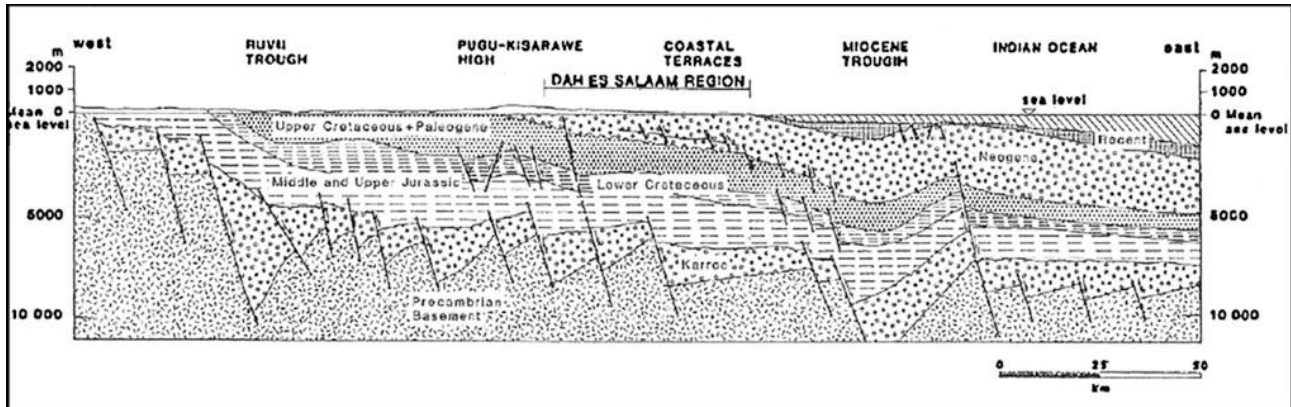


Figure 2-2 Geological map of the Dar es Salaam region (Van Camp et al., 2014).



**Figure 2-3** Cross-section across the central Dar es Salaam region (Figure 2-2) showing coastal terraces in Dar es Salaam (Sappa et al., 2014 after Msindai, 1988).

### 2.1.3. Hydroclimate

The City of Dar es Salaam is a coastal city in Tanzania situated on the East coast of Africa, and according to the Köppen and Geiger classification system, it has a tropical wet and dry climate. There are distinct wet and dry seasons, characterised by high humidity and moderately warm temperatures. Dar es Salaam's climate is classified as a tropical savanna (Aw). Monthly humidity ranges between 70–90%, with an annual mean of 80% (DAWASA, 2017). During its warmest months (November to March), Dar es Salaam can experience average daily maximums between 31.2–32.8°C, and average daily minimums of 22.0–24.9°C. During the cooler months (April to October) average daily maximums reach 29.7–31.5°C, and average daily minimums between 19.1–23.2°C.

According to historical trends, the two wet seasons are from October to December and March to May, with the latter experiencing higher rainfall volumes. The dry seasons, from January to February and June to September, still experience rainfall, but at a much lower volume than the distinct wet seasons (University of Cape Town, 2017). Precipitation during the long rainy season averages at 253 mm, with the second rainy season averaging at 117 mm (Mtoni et al., 2012). The mean total annual rainfall experienced by Dar es Salaam is 1149 mm, with monthly averages between 25 – 250 mm (Mjemah and Walraevens, 2015; DAWASA, 2017).

The coastal climate is influenced by the Indian Ocean Walker Cell and El Niño-Southern Oscillation (ENSO), which are temporary and reversible conditions influencing climate conditions and weather events (IPCC, 2021a). According to the IPCC Sixth Assessment Report (Chapter 9: Africa), the Indian Ocean Walker Cell and climate change-induced warming of the Indian Ocean have increased rainfall and wetting periods in the region, contributing to variations in aquifer recharge rates (IPCC, 2022). The shift in hydroclimate has a noticeable and significant impact on coastal aquifers, which are a key source of water for both domestic and industrial use.

The effects of climate change vary, but the drivers of water resources resulting from climate change include precipitation and temperature. These drivers influence the seasonality of climatic conditions and the extent of episodic events (IPCC, 2001). The noticeable influences of climate change in Dar es Salaam include increased precipitation, temperature, evaporation, and runoff. These factors influence and are influenced by anthropogenic activities, affecting the City's water resources. According to the findings of the Dar es Salaam Climate Profile (University of Cape Town, 2017), observed trends indicate an increase in rainfall during the wet seasons and a decrease in the number of days with rainfall, resulting in increased rainfall intensity. Additionally, the period between rainfall events was shown to increase. The projection of data was conducted using the Coupled Model Intercomparison Project Phase 5 (CMIP5) Global Climate Models (GCMs) (RCP 8.5 present to 2040). The observed data showed minimal to no change up to 2040; however, the report states that models indicate an increase in rainfall intensity and frequency after 2040, continuing up to 2100.

(University of Cape Town, 2017). According to Hausfather (2019), the CMIP6 model has a wider range of climate sensitivity included in the models, which accounts for the increase in greenhouse gas emissions (SSP5-8.5), in contrast to the Representative Concentration Pathways (RCPs), which utilised different emission scenarios for modelling. The inclusion of this report data is intended to provide insight into past projections and future projections, and the validity of the results.

#### 2.1.4. Environmental

In Dar es Salaam, there are a number of ecosystems that may be groundwater-dependent to some extent. These include:

- Rivers and their associated riparian areas: Rivers, especially those with perennial flow, are likely to be reliant on groundwater discharge, especially during the dry season (June to October). Perennial rivers tend to support riparian areas that often support forest tree species. There are a number of rivers that flow through the City of Dar es Salaam. The main rivers are the perennial Mzinga, which is fed by springs in the Msongola Highlands to the west of the City (Mwakalobo et al. 2013), and Kizinga Rivers, which flow through the City into the Mzinga Creek or estuary (see **Figure 2-4**). The perennial Msimbazi River is located in the central Dar es Salaam District, flowing into the Harbour Area, and the Nguva/Ukooni Rivers to the east (see **Figure 2-4**). There is also a network of smaller, non-perennial rivers that flow out of the Pungu Hills to the west in the interior, and small rivers that flow over the coastal plains to the north and south-east of the City. The seasonal Mpji River forms the northern boundary of the City (see **Figure 2-4**). The larger rivers that flow through Dar es Salaam tend to be sandy systems that allow infiltration of water and recharge of groundwater (Tibesigwa et al. 2023).
- Wetlands and estuaries: Wetlands, including mangrove and swamp forests, may be dependent on groundwater as either a direct or indirect source of water. Mangroves tend to occur at the mouths of rivers, which themselves may be groundwater-fed, at the interface between freshwater and marine ecosystems. Mangroves and estuaries provide important habitat and feeding grounds for a number of plant and animal groups. Very few wetlands are mapped in the Dar es Salaam District, but there are mangrove forests that have been mapped along the Kizinga and Mzinga Rivers, as they flow into the Mzinga Creek or estuary (see **Figure 2-4**). There are a few other mangrove forests mapped to the west and east of the City. These are not associated with large rivers, but rather are sandy coastal flats that support mangrove trees (see **Figure 2-4**).
- Springs: Springs are surface expressions of groundwater and are crucial for maintaining freshwater habitats, supporting wildlife, and providing water for human use. Springs are an important source of water for the rivers that flow through the City, supplying water to the City's residents.
- Forests and other terrestrial ecosystems: Some terrestrial ecosystems, like particular kinds of forests, may also depend on groundwater, particularly during the dry season. The Pugu Hills Forest Reserve is located near Kisarawe, which is to the west of the City. The Kasarawe District Coastal Forest is one of a few Key Biodiversity Areas located in and around Dar es Salaam, pointing towards the high biodiversity value of these forests. The Vikindu Forest Reserve also lies just to the south of the City. The well-forested Pande Game Reserve is located in the northern part of the City.



### 2.1.5. Socio-economic

Dar es Salaam is characterised by a rapidly growing population and fast urbanisation, leading to increased demand for basic services and infrastructure. It is a leading commercial city and the economic hub of Tanzania, and is expected to be a megacity by 2030 (Todd et al., 2019). The city's economy is driven by both formal and informal sectors, with the latter contributing significantly to the Gross Domestic Product (GDP) of the city, though its potential is not fully captured in formal economic planning.

Economic activities are diverse, including manufacturing, transport and communication, trade, hospitality, industry, transport, industry, fisheries and urban agriculture (URT, 2021a; Kaale et al., 2023). The city also has an active informal sector that includes wholesale and retail trade and repair of motor vehicles and cycles that employ 47.6% of the informal sector population (URT, 2020).

Dar es Salaam has a large and rapidly growing population of about 5.4 million people, comprising approximately 2.8 million women and 2.1 million men, with an annual growth rate of 4-5% (Msuya et al., 2021; URT, 2024). Between 2012-2022, the population grew by 23.4% (URT 2024). Over 70% of the population reside in informal settlements (UN Habitat, 2010, Dodman et al., 2011, Kombe and Muheirwe, 2024) and lack access to basic services, such as water, sanitation and secure housing. Only 22% of the city population is connected to the public water supply, while the rest, largely those living in unplanned settlements, access water from other sources such as boreholes, shallow wells and rainwater harvesting (Kyessa et al., 2019; URT, 2020; The World Bank, 2025).

The majority of city residents (40%) rely on privately delivered, mostly informal services (Allen et al., 2017). However, government census reports state that 79.5% have access to piped water, 18.1% have access to other protected water sources, and 2.5% have access to unprotected water sources. Due to poor waste management and overcrowding, sanitation is often poor, with water contaminated and the environment polluted. Climate change-related hazards often exacerbate these conditions, especially when these hazards reduce the availability of groundwater (Kombe and Muheirwe, 2024).

Gender disparities exist with women facing cultural and social barriers that limit their access to various services and economic opportunities. People in informal settlements are socially, economically and environmentally vulnerable. Due to low economic productivity, the purchasing power of most households in the city has been declining in recent years, and poverty in Dar es Salaam is high. Inequality is high, with 84% of the population clustered in the lowest wealth quintile and 0.3% in the wealthiest (Nyyssölä et al., 2021).

## 2.2. Description of Dar es Salaam's Aquifers

Dar es Salaam contains three main aquifer types, including the primary unconfined and semi-confined Quaternary Aquifer, the confined and semi-consolidated Neogene Aquifer, and the fractured and weathered groundwater systems of the Precambrian Basement Aquifer.

Dar es Salaam's Quaternary Aquifer varies in yield, but due to its hydraulic properties is typically regarded as a moderate to very high-yielding aquifer. This is why many groundwater users target this aquifer for private, communal and agricultural supply. While many users rely on water from this aquifer, its favourable hydraulic characteristics also facilitate its susceptibility to contamination from anthropogenic sources.

The Neogene Aquifer is considered a high-yielding aquifer and, for that reason, has been investigated and targeted by Dar es Salaam Water and Sewerage Authority (DAWASA) to supplement the municipal supply. Areas in the south of the City, where infrastructure is unable to transport treated surface water from the Ruvu River, have opted to develop this aquifer as the main source of water supply to various groundwater users. The depth and confining nature of the aquifer appear to protect it from contamination that may enter the Quaternary Aquifer above. However, areas where these Neogene deposits outcrop are susceptible to contamination. They also form important groundwater recharge zones.

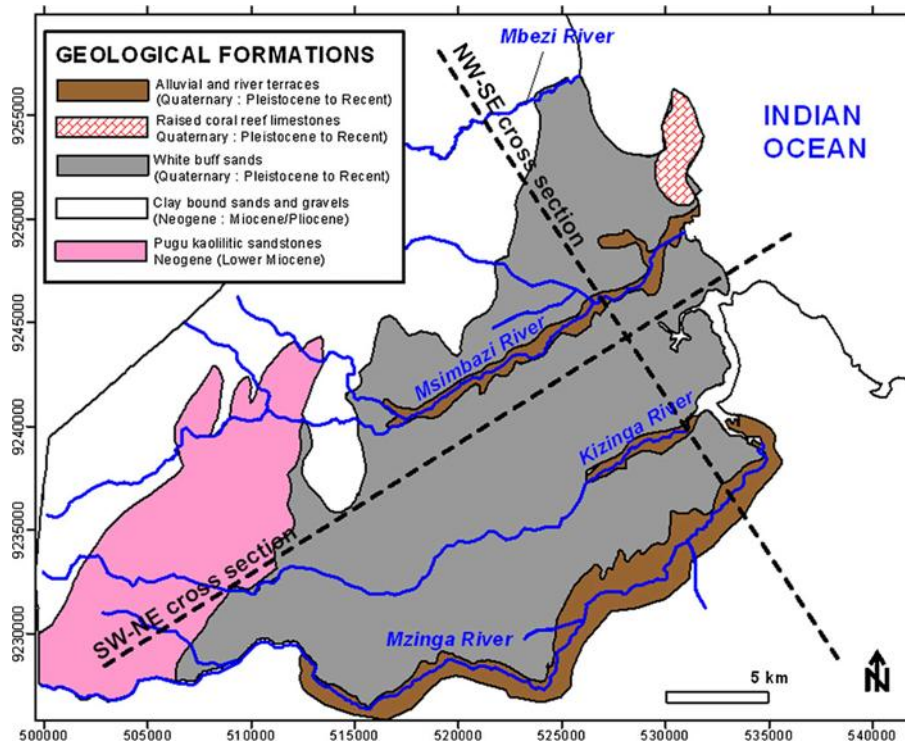
The weathered and fractured Precambrian Basement aquifers are typically very low to low-yielding (Mjemah et al., 2011) and are primarily utilised in rural settings where access to piped infrastructure and high-yielding aquifers are absent. Due to their fractured and weathered nature, these systems often exhibit low storage capacity and transmissivity, making them vulnerable to over-abstraction and contamination, particularly in areas where the aquifer is closer to the surface.

**2.2.1. Quaternary Aquifer**

The most utilised aquifer system in the central Dar es Salaam area is the Quaternary Aquifer (see **Figure 2-5**), a primary sandy system characterised by its unconfined and semi-confined conditions. Known as the Quaternary Groundwater Reservoir, this formation consists of fluvial and deltaic sediments from the Pleistocene.

This key aquifer supplies water both publicly and privately to the population and various sectors and extends across four of the five administrative districts of Dar es Salaam, namely: the Kinodoni, Ilala, Temeke and Kigamboni districts. It is found north of the city centre along the coast in Kinodoni and southwest of the city centre, where it tapers out inland towards the Pugu Hills. This forms a paleochannel that is bounded on either side by the Neogene deposits that extends out towards the ocean. South-east of the City centre the same sands can be found within the Kigamboni District (**Figure 2-2**).

This sequence of sediments consists of two aquifer systems; a lower semi-confined aquifer of medium to coarse sands, with gravels and clay; and an upper unconfined aquifer made of fine to medium sands with silt and clay, with coral reef limestone deposits present along the coastline. These two aquifer systems are separated by a clay aquitard, which becomes fragmented near the coast (see **Figure 2-5** and **Figure 2-6**) (Van Camp et al., 2012).



**Figure 2-5** Geological map of the central Dar es Salaam region (Van Camp et al., 2012, after Bartholomew, 1963).

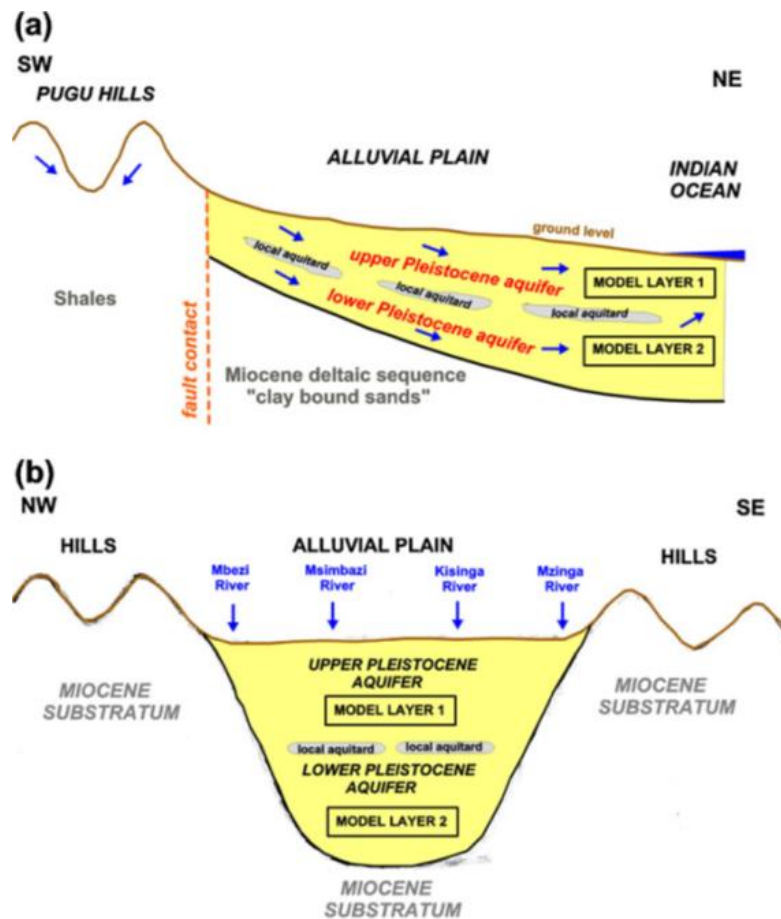


Figure 2-6 Schematic cross-section across the central Dar es Salaam region (Figure 2-5), showing the distribution of the lower and upper Quaternary Aquifers (Van Camp et al., 2012).

Aquifer thickness varies between 20-80 m, depending on location and proximity to the coastline. In certain instances and to maximise borehole yields, boreholes are screened across the aquitard to abstract water from the lower and upper aquifers. However, this presents challenges with mixing of water quality of the lower with the upper aquifer, which generally has poorer water quality, for example, nitrate contamination that is common in shallow urban wells, exceeding World Health Organisation (WHO) limits (Sappa and Luciani, 2014). Due to the geological setting of the area, the lower aquifer can reach depths which are below mean seal level, particularly closer to the coastline, increasing the risk of saltwater intrusion, particularly with the growing dependency on groundwater in the region.

Hydraulic conductivity for the upper aquifer averages ~1.6 m/day, whereas the lower semi-confined aquifer has higher hydraulic conductivity, averaging ~2.1 m/day (Van Camp et al., 2012). Borehole yields range between 1.6 – 8.5 l/s, but can be as low as 0.2 l/s (GLWS-FIU, 2014).

Water from the upper unconfined aquifer is mainly accessed by shallow hand-dug wells, wellpoints, and small-diameter boreholes, serving households and small industries. In contrast, the deeper lower aquifer supplies water to agricultural and industrial users, and select municipal sources (Ngasala et al., 2019). In peri-urban and coastal areas like Kigamboni, where piped infrastructure is absent, this aquifer system often acts as the sole water source (Van Camp et al., 2014).

### 2.2.2. Neogene Aquifers

The Neogene Aquifer System consists of semi-consolidated of fine to coarse-grained sandstones, interbedded with clays and siltstones and extends across southern and inland parts of Dar es Salaam (see **Figure 2-2**). These units, which include the Pugu deposits and other Miocene-age sediments, lie beneath the Quaternary deposits and typically form confined aquifers. One of the most significant groundwater systems within this formation is the Kimbiji Aquifer, situated in the southern and eastern portion of Dar es Salaam and extending into the Mkuranga District.

The aquifer can reach depths of over 200 m, thickening toward the coast. These aquifer layers are separated from shallower Quaternary Aquifers by continuous aquitards, which reduce vertical exchange and enhance the aquifer's protection from surface contaminants. The depth of sediments can reach up to 900-1,400 m in areas such as Kimbiji (IUCN, 2010). Boreholes are estimated to have high yields and be able to produce over 15 Ml/day (IUCN, 2010).

The aquifer receives recharge from direct precipitation and lateral inflows. Hydrochemical analyses suggest long groundwater residence times, contributing to favourable water quality and low levels of anthropogenic contaminants.

The Kimbiji Aquifer is being developed to improve municipal water supply in southern Dar es Salaam, where the existing piped infrastructure from surface water sources is unable to supply the southern districts. Wellfields are being developed at Kimbiji and Mpera, and are identified as critical to long-term water security in the region. The aquifer is viewed as a key strategic source for bulk supply expansion, due to its relatively large storage, good yield, and water. Additional to municipal boreholes, private boreholes have also been drilled in these areas for water supply (DAWASA, 2017).

Despite being more protected than shallower Quaternary Aquifers, the Neogene Aquifers faces potential risks including over-abstraction, salinisation (especially in low-lying areas near the coastline), and insufficient monitoring (DAWASA, 2017). Efforts to manage this aquifer sustainably will require regular monitoring, wellfield performance assessments, and regulation of unregistered drilling.

### 2.2.3. Basement Fractured Aquifers

The Precambrian basement complex beneath the sedimentary cover hosts localised fractured and weathered aquifers. These occur in areas with thin sedimentary cover or where basement rocks are exposed, particularly to the far southwest of the main Dar es Salaam city.

Water is stored in fracture networks and weathered horizons, with limited lateral continuity. These aquifers have low storage capacity and generally low transmissivity values. Reported borehole yields are often <1 L/s, and water quality varies spatially (Mjemah et al., 2011).

These aquifers are used primarily in inland and peri-urban areas lacking access to more productive systems. They serve rural households, small farms, and occasionally institutional facilities. Given their low yield and limited recharge, these systems are vulnerable to over-abstraction and contamination when weathered zones are closer to the surface.

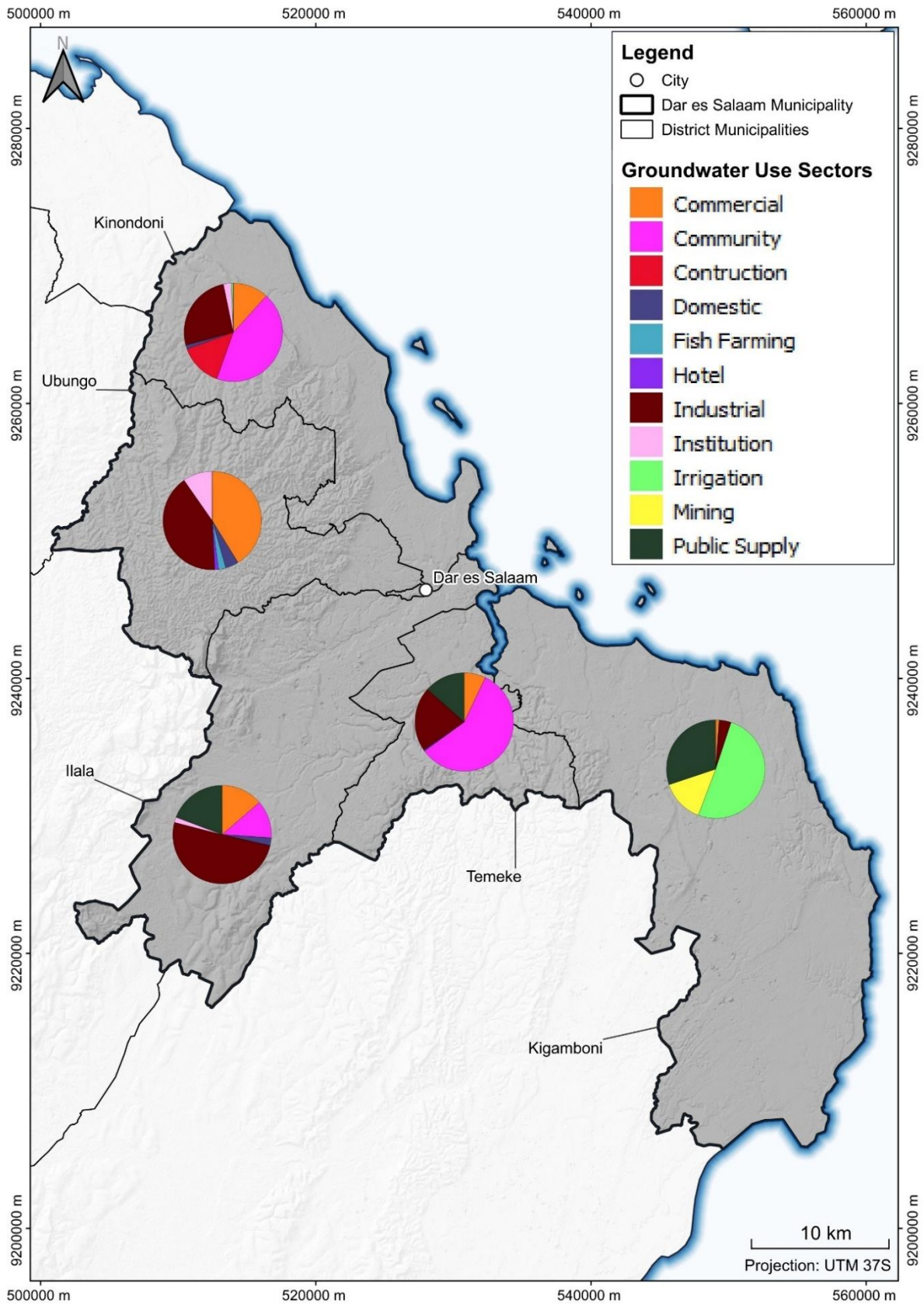
### 2.3. Groundwater Use in Dar es Salaam

Groundwater plays a critical role in meeting the water needs of Dar es Salaam's rapidly growing population, particularly in areas where surface water infrastructure is limited or unable to meet demand (SADC-GMI, 2019). Dar es Salaam has the largest water supply deficit in Tanzania, driven by rapid urbanisation and population growth, which have significantly increased the city's water demand that surface water resources cannot supply. While the Upper and Lower Ruvu and Mtoni Rivers supply over 90% of the water distributed through the municipal network (DAWASA, 2019; Andersson, 2019), the baseflow of the Ruvu River, Dar es Salaam's primary surface water source, has been declining due to climate variability, increased upstream abstractions, and catchment deforestation (Andersson, 2019). To substitute the surface water supply, DAWASA extracts water from the shallow coastal aquifer, however, this aquifer is sensitive to climate change and is prone to seawater intrusion as a result. Furthermore, deeper boreholes, up to 600 m in the Kimbiji aquifer, were also drilled by DAWASCO (before the merger with DAWASA) for portable water supply for the city (DAWASA, 2008; SADC-GMI, 2019). To bridge the surface water supply gap, many communities, particularly in the south of Dar es Salaam and in unplanned informal settlements, also privately supplement surface water supply with groundwater and water from private vendors. Due to the large deficit of water supply in Dar es Salaam, groundwater dependency is likely to increase in the city to meet the increasing water demands.

The industrial and agricultural sectors further contribute to the city's groundwater use. Urban farming often relies on shallow wells and other informal sources, while peri-urban and rural farming shifts toward groundwater use during dry periods (Wessels et al., 2024; SADC-GMI, 2019). Industries, facing similar limitations in municipal supply, increasingly depend on privately drilled boreholes to maintain operations (GLOWS-FIU, 2014; SADC-GMI, 2019).

Across Dar es Salaam's administrative districts, it is evident that the major use of groundwater varies. In the north, groundwater in Kinondoni is predominantly for supply to its communities, this is where most higher-income households are found. Ubungo possesses a strong industrial and commercial presence, which makes use of groundwater for its operations, with industrial groundwater users in Ilala also possessing a high dependency on groundwater. In Temeke, groundwater is mostly used by low-income communities and those who reside in unplanned areas. The regional south in Kigamboni is highly dependent on groundwater, since municipal supply from the Ruvu River does not reach this far south of Dar es Salaam. Within this district, groundwater is mostly used for the irrigation of peri-urban agriculture. Hence, the biggest users per district are (see **Figure 2-7**):

- Kinondoni ~ Communities
- Ubungo ~ Commerce and Industrial
- Ilala ~ Industrial
- Temeke ~ Community
- Kigamboni ~ Irrigation



**Figure 2-7** Dar es Salaam's groundwater use per sector per administrative district (data obtained from the Wami Ruvu Basin Water Board (WRBWB)).

### 3. Hazards

#### 3.1. Aquifer Contamination: Due to Human Activities

##### 3.1.1. Introduction

In densely populated, low-income urban areas such as Dar es Salaam, inadequate sanitation services, poor wastewater management practices, and widespread human activities involving chemical use and waste generation contribute significantly to aquifer contamination (Ngasala et al., 2019). Aquifer contamination poses a serious threat to water security, especially in sectors or regions that are groundwater-dependent.

In Dar es Salaam, the combined effects of a growing water demand and climate variability have led to a reduction in surface water supply from the Ruvu River, prompting a greater reliance on groundwater resources as a supplementary supply (Ngasala et al., 2019; Rao et al., 2021). According to Mtoni et al. (2013) and Ngasala et al. (2019), more than 50% of residents in Dar es Salaam rely on groundwater for their daily use.

To ensure long-term availability of high-quality groundwater and prevent aquifer degradation, groundwater management strategies must address both sustainable abstraction and the protection of aquifers from contamination, especially in coastal areas.

Assessing the risk of aquifer contamination requires determining 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 Dar es Salaam were identified by Mato (2002). According to Mato (2002), many activities within the city have become sources of groundwater pollution, however, poor sanitation services were highlighted as the most concerning contamination source due to the prevalence of pit latrines in households in Dar es Salaam. According to Figure 3-1, 76% of households in Dar es Salaam have pit latrines.

Other notable sources of groundwater contamination summarised in **Figure 3-2** include:

- Urban settlements and services (e.g. wastewater, underground storage tanks, stormwater runoff, accidental leaks and spills);
- Industry point source discharges (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);
- Filling stations (e.g. the dispensing of petroleum products through leaking tanks)
- Agriculture (e.g. pesticides, fertilisers, sludge application, spills, disposal of animal waste).

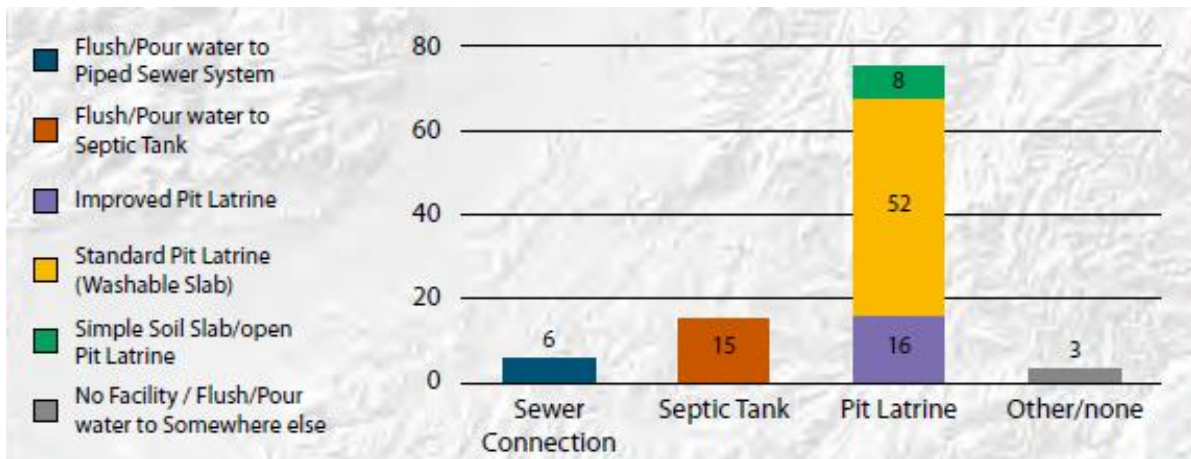


Figure 3-1 Sanitation facilities of households in Dar es Salaam (Karutz et al. 2019).

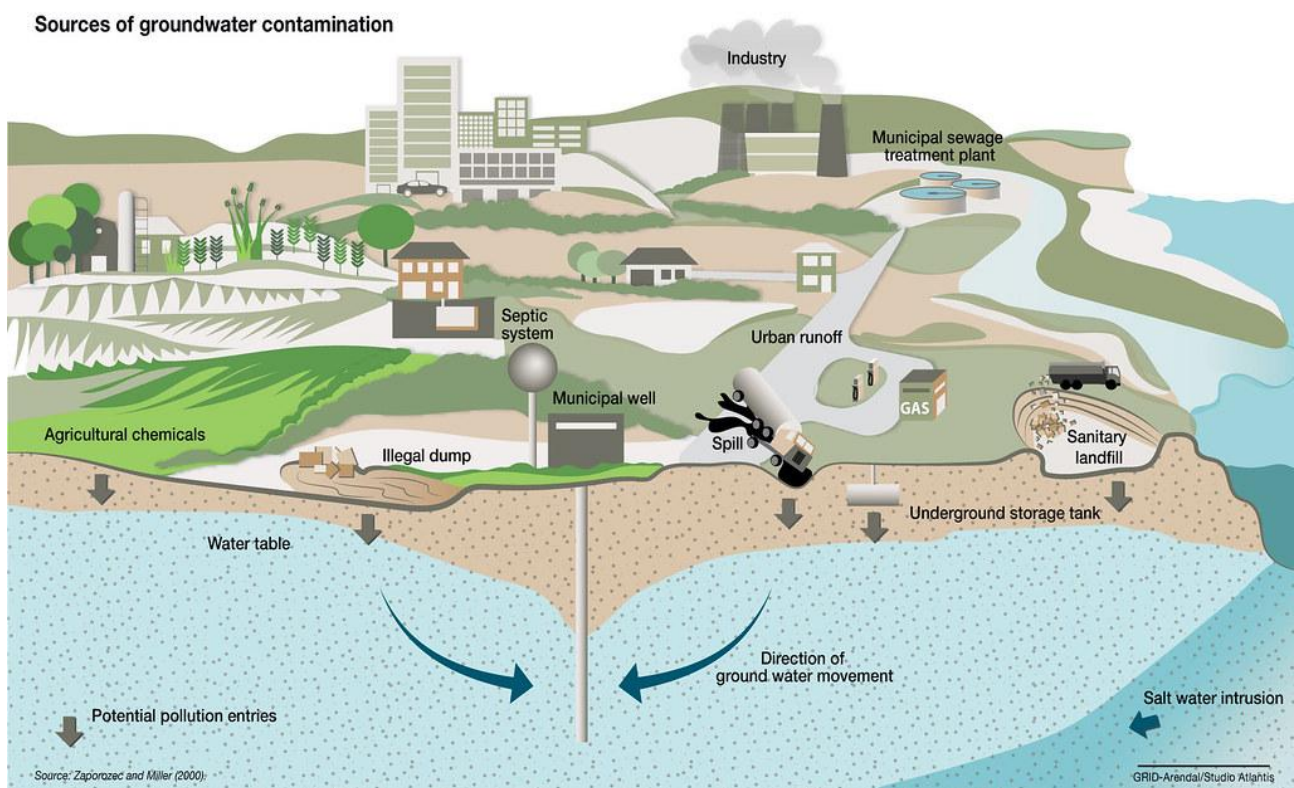


Figure 3-2 Sources of groundwater contamination (Zaporozec and Miller, 2000).

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 seawater 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. 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	Multipoint	Vadose zone	Nitrate, viruses & bacteria	Health risk/odour & taste/eutrophication of surface water
	Wastewater	Point and line	Surface/ Vadose zone	Nutrients, salinity, metals, organic, microbial	
	Underground storage tanks	Point	Vadose/saturated zone	Hydrocarbons, trace metals	
	Stormwater runoff	Point and line	Surface/ Vadose zone	Salinity, viruses & bacteria	
	Accidental leaks & spills	Point	Surface	Various	
	Cemeteries	Point	Vadose/saturated zone	Nutrients, viruses & bacteria	
	Sports grounds	Non-point	Surface	Salinity, nutrients, pesticides & herbicides	
Mining	Mine tailings	Point	Surface/vadose zone	Acid drainage, sulphate, trace metals	Some metals may reach toxic levels
	Mine water	Point and line	Various	Salinity, sulphate, trace metals	
Industry	Solid waste	Point	Surface/vadose zone	Salinity, nutrients, metals, organic, microbial	Health risk (toxic & carcinogenic e.g. As, CN)/odour and taste)
	Process water & effluent	Point and line	Surface/vadose zone	Salinity, trace metals, organic compounds	
	Evaporation ponds	Point	Surface/vadose zone	Salinity, trace metals, organic compounds	
	Spills, leaks	Point	Surface	Various	

Category	Source type	Localization	Normal location	Main contaminant	Potential impact
<b>Waste disposal</b>	Solid waste sites	Point	Surface/vadose zone	Salinity, nutrients, metals, organic, microbial	Health risk (toxic & carcinogenic e.g. As, CN)/odour and taste)
	Uncontrolled dump sites	Point	Surface/vadose zone	Salinity, nutrients, metals, organic, microbial	
	Effluent disposal ponds	Point	Surface/vadose zone	Salinity, trace metals, organic compounds	
<b>Agriculture</b>	Use of agrichemicals	Non-point	Surface/vadose zone	Salinity, nutrients, pesticides, herbicides	Toxic/ Carcinogen. Health risk/ eutrophication of surface water
	Sewage sludge application	Non-point	Surface/vadose zone	Nutrients, metals, microbial	
	Spills of agrichemicals	Point	Surface	Salinity, nutrients, pesticides, herbicides	
	Disposal of animal wastes		Surface/vadose zone	Nutrients, viruses & bacteria	
<b>Miscellaneous</b>	Airborne coal-fired power or vehicle emissions	Non-point	Surface	Acid (sulphate, nitrate), salinity	Acidification, leaching of metals
	Contaminated surface water	Point or line	Vadose/ saturated zone	Various	

### 3.1.3. Hazard Mapping

To assess the likelihood of groundwater contamination from human activities in Dar es Salaam, land use types and major Potentially Contaminating Activities (PCAs) were mapped (see **Figure 3-3**). A land cover map was generated using supervised classification in Google Earth Engine, with training data based on current satellite imagery and guided by previous land cover maps. 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 (see Figure 3-4).

The city comprises a mix of land uses, including residential (informal and formal), commercial, industrial, and agricultural zones. Natural conservation areas and a series of water bodies and wetlands are also present within this region.

Figure 3-4 generally shows that land use activities with high and very high hazard contamination scores, such as informal settlements and industries, are predominantly concentrated in and around the central urban core of Dar es Salaam. These high and very high hazard contamination zones extend across large parts of Temeke and Ilala, while smaller sections are found in parts of Ubungo and Kinondoni. Industrial areas in the Dar es Salaam City are primarily classified as heavy industries and were therefore assigned a high hazard contamination score, while informal settlements commonly associated with pit latrines and poor sanitation services were assigned a very high hazard contamination score.

The **Temeke** District is situated in central Dar es Salaam. It is the smallest district in terms of land area but holds the second-largest population in the region, according to the 2022 census. This high population has resulted in a densely populated district, predominantly covered by informal settlements, which are often associated with pit latrines and poor sanitation services. Consequently, much of the district has been assigned a very high hazard score due to the poor sanitation services within these informal areas. Mato (2002) identified poor sanitation services, particularly the widespread use of pit latrines, as the most concerning groundwater contamination source. A cluster of industries with a high hazard score can also be observed along the northeastern border of the district, while agricultural lands with a moderate hazard dominate the southeastern sections.

The majority of the **Ilala** District has been assigned a moderate contamination hazard score (see **Figure 3-4**), primarily due to extensive agricultural lands spread across the district, especially in the central and southern parts. However, the northeastern areas near the central urban core are dominated by industries and informal settlements (see **Figure 3-3**), much like Temeke, but to a lesser extent, hence this area of the district has a very high or high likelihood of groundwater contamination.

The districts of **Ubungo** and **Kinondoni**, situated in the northern sections of the Dar es Salaam region, are dominated by a moderate hazard contamination score. These districts are predominantly agricultural, embedded with formal and informal settlements. However, notable clusters of informal and industrial areas with a high hazard can be observed in the eastern sections of Ubungo and the southeastern sections of Kinondoni near the central urban core, although these regions of high hazard contamination are not as extensive as those present in the Temeke and Ilala districts.

**Kigamboni** is the most southeastern district within the Dar es Salaam region. It is the largest in terms of land area, but it is the least populated district in the region. The majority of the district is covered by agricultural lands and rangeland (grasslands and shrublands used for livestock grazing and wildlife habitat) (see **Figure 3-3**). As a result, the majority of the district has either a very low hazard score in areas covered by rangelands or a moderate hazard score in sections of the district covered by agricultural lands (see **Figure 3-4**). Agriculture, which covers a significant portion of this district, is known to be associated with the use of pesticides and fertilisers, which have the potential to introduce contaminants such as nutrients, total dissolved solids, pesticides and herbicides into the aquifer system. Additionally, although less extensive, formal and informal settlements, industries and a few mines are also sparsely spread across the northern parts, indicating a high likelihood of contamination in this section of the district.

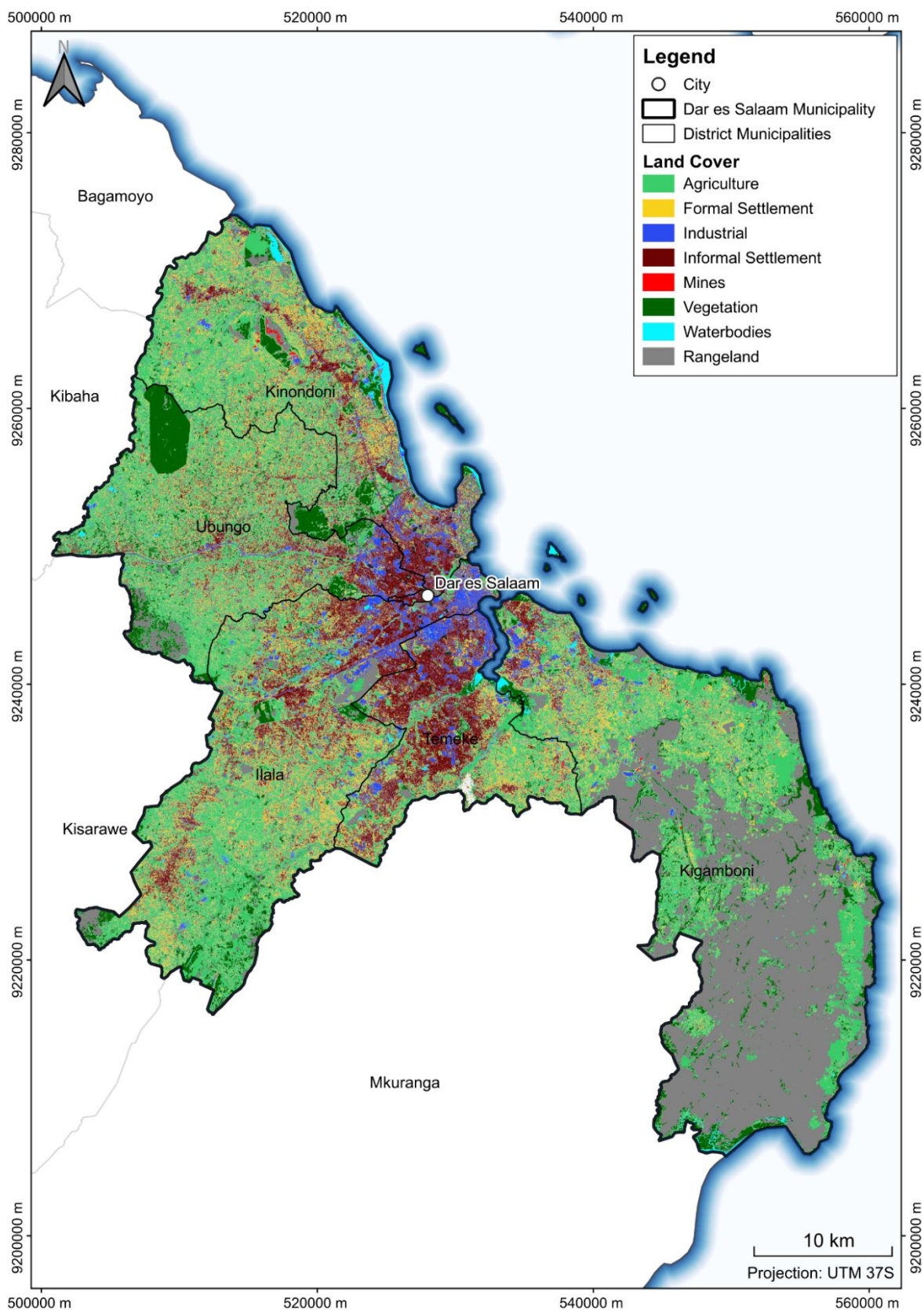


Figure 3-3 Land use activities in the Dar es Salaam Region.

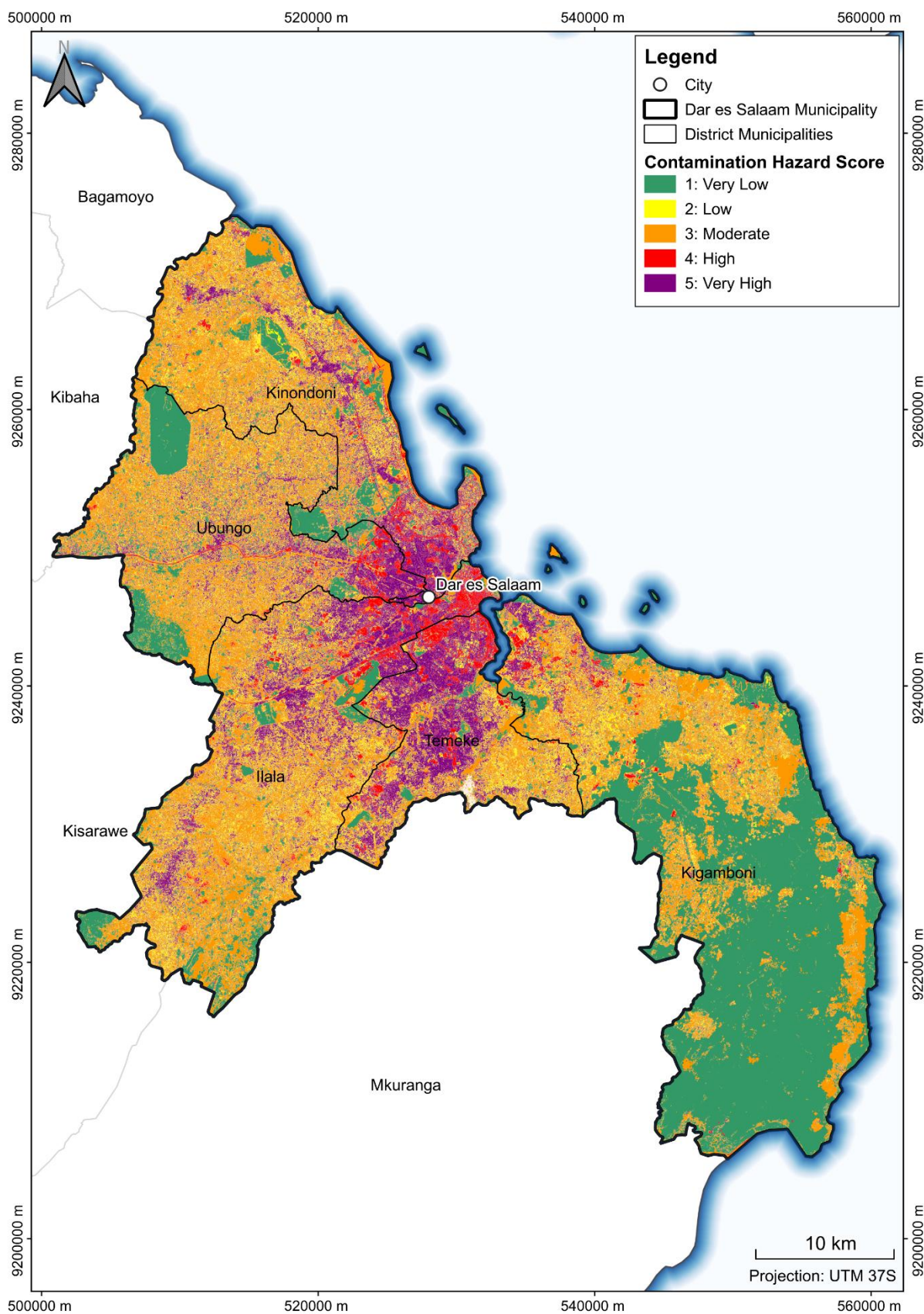


Figure 3-4 Groundwater Contamination Hazard Map of Dar es Salaam.

## 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 Dar es Salaam.

In Dar es Salaam, a growing water demand largely driven by urbanisation, reduced surface water and poor water supply coverage has led to an over-reliance on groundwater, particularly Dar es Salaam's shallow Quaternary Coastal Aquifer, which is used by many residents (Mtoni et al., 2011). To meet the city's increasing water demands, which have placed stress on the surface water supply, DAWASA has also targeted the shallow coastal aquifer. Additionally, to the south of the City, where there is a lack of tapped municipal surface water supply, DAWASA is developing a groundwater abstraction scheme from the deep Kimbiji Aquifer system (Karutz et al., 2019).

According to Mtoni et al. (2013) and Ngasala et al. (2019), more than 50% of residents in Dar es Salaam rely on groundwater for their daily use as a result of inadequate municipal water supply (**Figure 3-5**), with over 70% of the city's population only partly or not connected to the municipal water supply network, placing significant pressure on groundwater resources in the city (SADC-GMI, 2019). **Figure 3-5** shows the pattern of water supply hours across the Dar es Salaam region, indicating limited water supply in most areas and, as such, a need for groundwater as a supplementary water supply source.

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 continuously drop, resulting in a reduction in the availability of groundwater and an overall degradation of the aquifer. The reduction in water levels can also result in a reduction of 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 can result 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, causing seawater to flow into the freshwater zone of the aquifer and leading to salinisation of groundwater.
- **Ecosystem degradation:** 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.
- **Capture:** intensive groundwater abstraction can alter natural groundwater flow patterns, causing water that would discharge elsewhere to instead be diverted to pumping wells, reducing flow to groundwater-dependent ecosystems such as wetlands and rivers that are reliant on baseflow.

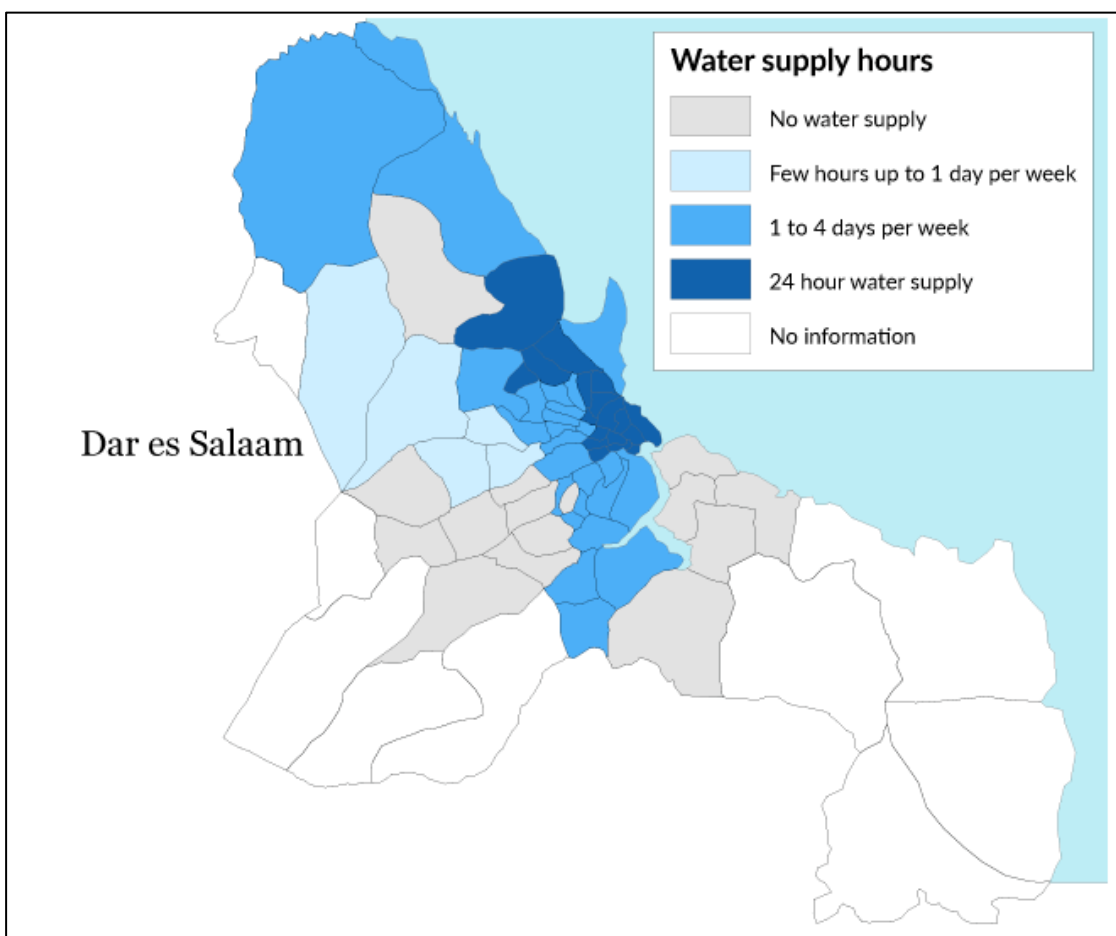


Figure 3-5 Dar es Salaam’s water supply pattern (Connecting Cities to Basins Project, 2017).

### 3.2.2. Hazard Mapping

To produce the over-abstraction hazard map (Figure 3-6), which highlights areas in Dar es Salaam that are likely to be threatened by over-abstraction, each district was assigned a hazard score based on groundwater use volumes obtained from the Wami Ruvu Basin Water Board (WRBWB) of Tanzania (normalised to the area of each district) and the extent of the impervious surface area. In the absence of recharge data for the region, impervious surface coverage was used as a proxy to deduce areas of limited direct recharge in the Dar es Salaam region. It is also important to note that the available registered groundwater use data used for this assessment likely underestimates groundwater use volumes since groundwater use registrations are not well-regulated. For example, in the current dataset used, the groundwater use volumes available for Ubungo, Ilala and Kinondoni show no groundwater use registered for agricultural use, even though these districts consist of a significant portion of agricultural lands. According to Mtoni et al. (2011), many unregistered boreholes exist in Dar es Salaam. Mato and Mjwahuzi (2010) reported that out of 500 boreholes randomly visited during a groundwater assessment, about two-thirds were unregistered. The abovementioned indicates the extent to which the data provided by the WRBWB may be lacking, which may result in an underestimation of the true extent of groundwater abstractions and consequently the assigned hazard scores. Information on the population, area and groundwater use of each district is also presented in Table 3-2.

The **Temeke** District, situated in central Dar es Salaam, has the highest population and groundwater use in the region. Additionally, a significant portion (46%) of the district is also partly covered by impervious surfaces, which limits direct recharge in the area. The district consists of extensive industrial activity as well as widespread informal settlements that have little to no municipal water supply and likely heavily rely on groundwater (see **Figure 3-5**). The combination of high groundwater use and limited recharge (due to a large extent of impervious areas) makes Temeke highly prone to over-abstraction.

The district of **Ilala**, situated centrally within the city, is the most urbanised and densely populated district in Dar es Salaam. A significant portion of the population resides in informal settlements with limited access to municipal water supply (see **Figure 3-5**), resulting in a reliance on groundwater. Industrial areas, notably present in the northeastern parts of the district, may also contribute to groundwater use in the district. Approximately 24% of the district, particularly near the city centre, is covered by partly impervious surfaces, limiting recharge in these areas. As a result, Ilala, although to a lesser extent than Temeke, is still highly likely to experience groundwater over-abstraction due to high groundwater use volumes and the extent of impervious surface coverage.

**Ubungo** and **Kigamboni** are the districts least prone to groundwater over-abstraction in the Dar es Salaam region. Despite having approximately 19% partly impervious surface coverage (see Table 3-2), Ubungo has the lowest groundwater use volume, and therefore a very low likelihood of groundwater over-abstraction. Ubungo primarily receives its municipal water supply from surface water sources (see **Figure 3-5**), which further reduces the reliance on groundwater and associated risk of over-abstraction. Kigamboni, on the other hand, has only 2% partly impervious surface coverage and a relatively low registered groundwater use and therefore is also not likely to experience over-abstraction.

The district of **Kinondoni** in the north was assigned a moderate over-abstraction hazard score due to its relatively large partly impervious surface area (29%), which limits recharge, although groundwater use volumes are low in the area. **Figure 3-5** shows that the majority of Kinondoni has some water supply, which limits groundwater abstractions in the district.

**Table 3-2** Population, area, impervious surface coverage and groundwater use by district in Dar es Salaam.

District Name	Population (2022)	Total Area (Km <sup>2</sup> )	Partly Impervious percentage	Groundwater Use (m <sup>3</sup> /d)	Groundwater use (m <sup>3</sup> /d/km <sup>2</sup> )
Temeke	1,346,674	155.287	46%	29779.305	191.769
Ilala	1,649,912	363.735	24%	29173.6194	80.206
Kinondoni	982,328	271.475	29%	8285.436	30.52
Ubungo	1,086,912	277.005	19%	2508	9.054
Kigamboni	317,902	571.869	2.6%	13632.368	23.838

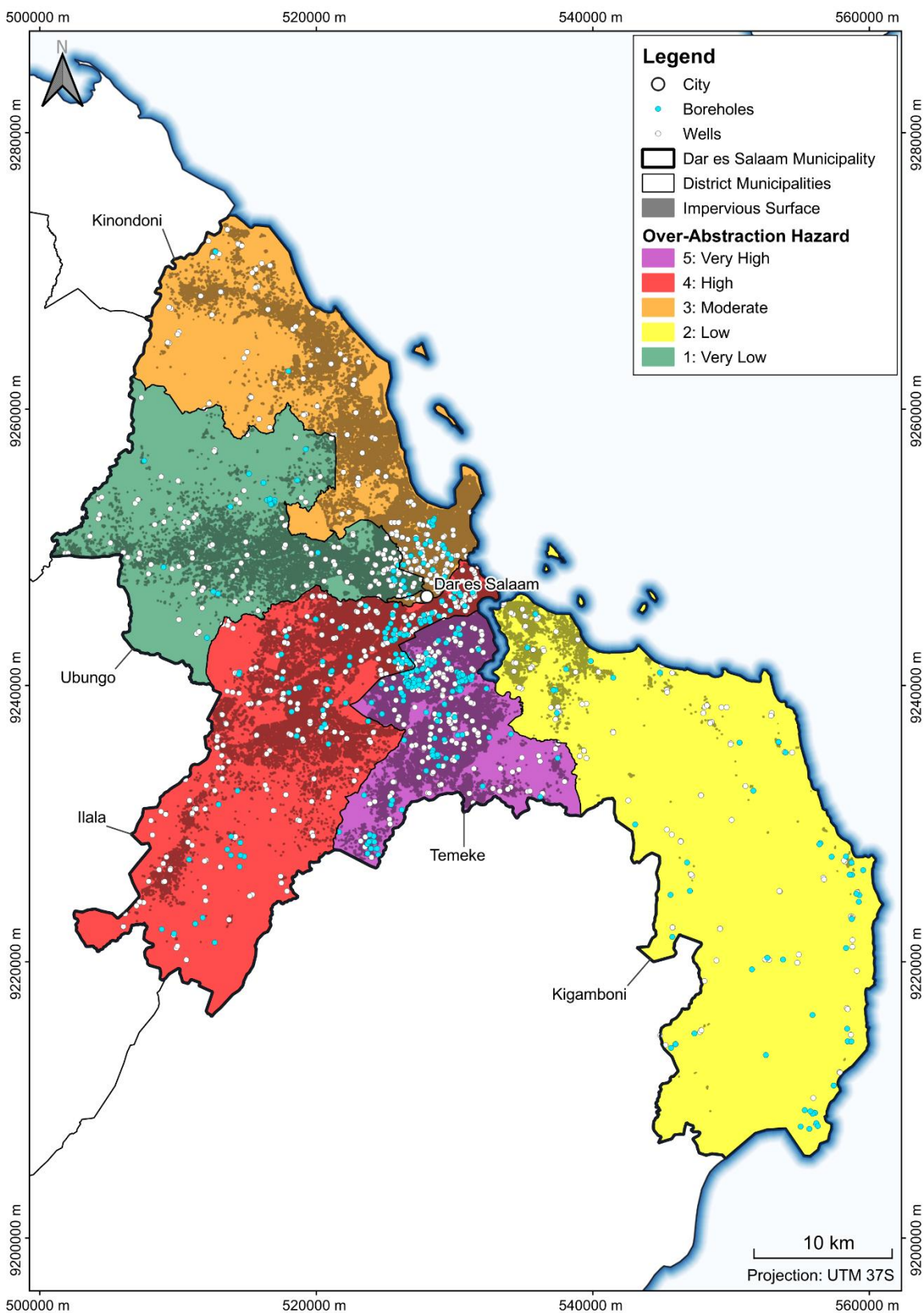


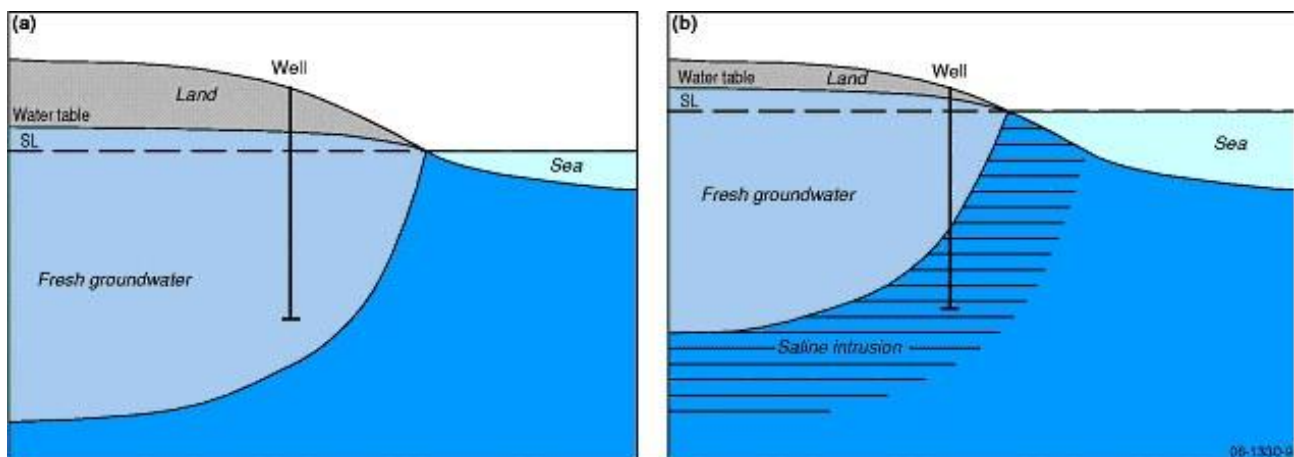
Figure 3-6 Over-abstraction hazard map of Dar es Salaam.

### 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 are difficult to predict. However, according to the Intergovernmental Panel on Climate Change (IPCC), sea-levels are expected to rise between 0.29 and 1.1 m by 2100, depending on different greenhouse gas emission scenarios (IPCC, 2019). The two primary impacts of sea-level rise are saline intrusion and increased groundwater levels. 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 3-7**). 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, creating brackish aquifer conditions. The risk to the aquifer and users is further exacerbated when climate change-induced reductions in groundwater recharge occur. 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 the system and its users (Van Drunen et al., 2006; Basyuni et al., 2025). Rising sea-levels, however, can erode these systems, reducing their surface cover and therefore their ability to inhibit seawater intrusion.



**Figure 3-7** 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 Areas

Sea-level rise is a global challenge faced by many coastal communities and the aquifers they rely on. This hazard is expected to impact much of Dar es Salaam's coastline and the floodplains of the Msimbazi Estuary (see **Figure 4-2**). Quaternary Aquifers located in the city centre and along much of the region's north and south are particularly vulnerable to inundation of groundwater and seawater intrusion. Areas in Kigamboni, such as Kibada, Mboamaji and Kimbiji, are the most vulnerable to groundwater inundation (see **Figure 4-2**). In these parts of Dar es Salaam, the Quaternary Aquifer

is likely to experience significant seawater intrusion, leading to salinisation of groundwater along the new interface. To date, salinisation has already been observed in some boreholes within the coastal parts of the Quaternary Aquifer. However, this is more likely attributed to seawater intrusion caused by over-abstraction (Van Camp et al., 2014). Given that the system is already vulnerable to seawater intrusion, rising sea-levels are expected to exacerbate saline conditions in the coastal Quaternary Aquifers.

Due to the Kimbiji Aquifer's geological characteristics (confining layers of clay and marl-bound sands) and its favourable hydraulic gradient, rising sea-levels are unlikely to significantly impact this aquifer system. Conservative estimates place the freshwater-saltwater interface several kilometres offshore of Dar es Salaam. Therefore, sea-level rise is not expected to alter current conditions (DAWASA, 2017). The exact extent of the Kimbiji Aquifer's confining layers within the Neogene Aquifer System remains poorly studied and documented in existing literature. Much of what is known has been derived from oil surveys. Localised zones where marl and clay layers are absent or thin could create potential pathways for seawater intrusion. Such scenarios, however, have not been definitively mapped or assessed in this study.

### 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 increases, sustainable recharge becomes increasingly critical, especially in coastal cities such as Dar es Salaam, where reliance on groundwater has intensified due to recurrent droughts and declining rainfall (Sappa and Luciani, 2014). Water-scarce regions have been the most impacted by these conditions.

Climate change is widely predicted to impact the sustainability of water resources. Surface waters are particularly susceptible to the predicted decrease in rainfall and increased occurrence of droughts (Al Atawneh et al., 2021). Groundwater sources rely on rainfall to recharge their systems to maintain their capacity and provide the services that many of their users rely upon. Estimates put change in recharge at approximately 184 mm/year within the Dar es Salaam region (Mtoni et al., 2011). Disruptions to this system can significantly impact groundwater availability, especially when rainfall decreases.

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, disrupts natural infiltration. Rainfall in coastal areas, in particular, is 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, resulting in 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 saltwater-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.

### 3.4.2. Potential changes in Recharge

To identify areas in the Dar es Salaam region that are more likely to experience reduced recharge due to climate change, precipitation and recharge estimates from existing literature were used, due to the absence of recharge projections.

Hydrogeological assessments conducted in the study area have indicated that active recharge of the upper and lower Quaternary Aquifer of Dar es Salaam is primarily received through coastal plain infiltration (Mjemah, 2007). Therefore, aquifer recharge is directly related to the amount of precipitation that infiltrates into the soil, which depends on rainfall and land cover. Mjemah and Walraevens (2015) estimated the groundwater recharge rate of the Quaternary Sand Aquifer to be approximately 122 mm/year using monthly precipitation data for 36 years, runoff and potential evapotranspiration calculated using the Penman-Monteith Method.

**Figure 3.8** illustrates the distribution of rainfall, showing a decrease from the Pugu Hill in the west (> 1,166 mm) to the central urban core of Dar es Salaam in the East (< 1,000 mm) near the coast. The eastern section of the mapped area (see **Figure 3-8**), which receives lower rainfall, represents Dar es Salaam's densely populated built-up urban core, which forms the majority of Tanzania's economic hub (Mtoni et al., 2011). The combination of relatively lower rainfall and extensive impervious surfaces makes this area more likely to experience lower recharge under current conditions in comparison to areas in the west (see **Figure 3-8**), and even more so in the future if precipitation decreases during drought periods as predicted by the World Bank (2016).

Sappa et al. (2015), in a study focused on determining climate change impacts on groundwater recharge of the districts of Ilala, Kinondoni and Temeke, analysed precipitation data for the last 50 years. The results (**Figure 3-9**), indicate a notable decrease in precipitation between 2001 and 2010 across the three districts due to climate change. According to the authors, this decline also likely led to a considerable decrease in recharge.

Meanwhile, Mussa et al. (2021) investigated the natural groundwater response to climate variability and land cover changes in Tanzania with a specific focus on the Kimbiji Aquifer, which underlies the southern parts of Dar es Salaam. The study presented data on rainfall, runoff, potential evapotranspiration (PET) and recharge (**Table 3-3**). The data shows a notable decrease in annual rainfall from 913 mm/year in 1996 to 823 mm/year in 2016, highlighting the effects of climate change over this period. Concurrently, an increase in runoff was observed, likely due to the expansion of built-up areas. These changes contributed to a decline in groundwater recharge in the Kimbiji Aquifer between 1996 and 2016.

Although precipitation and consequently, recharge decreased between 1996 and 2016 in the southern parts of the region (see **Table 3-3**), and in the north and central parts were precipitation trends also declined, **Figure 3-9** according to the World Bank (2016), climate change projections predict an increase in the amount and intensity of precipitation, as well as more prolonged periods of drought for Dar es Salaam. As a result, future recharge could potentially increase or decrease depending on the specific period and prevailing climate conditions. However, since the districts of Temeke and Ilala are the most urbanised and covered by impervious surfaces, should precipitation

decrease during drought periods as predicted, this section of the region is most likely to experience a reduction in recharge. Should precipitation increase, these areas are more prone to flooding. Land cover changes as part of urbanisation are therefore expected to greatly influence future recharge in the region.

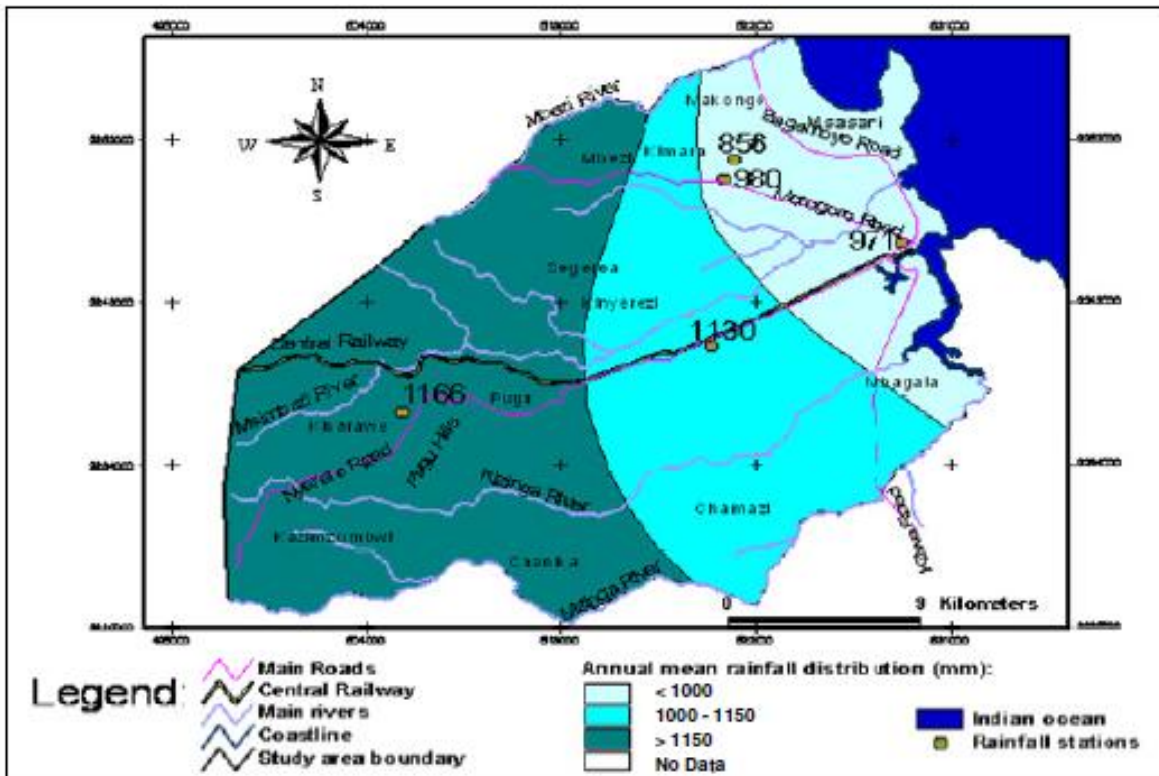


Figure 3-8 Average yearly rainfall distribution of central Dar es Salaam (Mjemah and Walraevens, 2015).

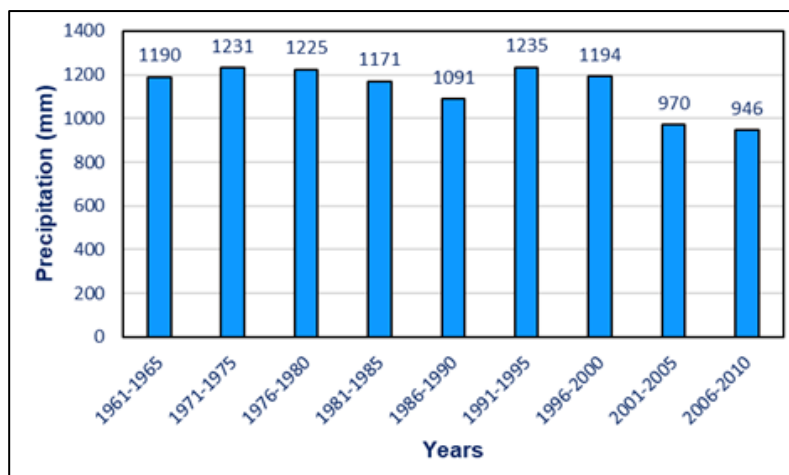


Figure 3-9 Average 5-yearly precipitation of Dar es Salaam for the period between 1961 and 2010 (Sappa et al. 2015).

**Table 3-3** Rainfall, Runoff, PET and Recharge for the Kimbiji Aquifer, between 1996 and 2016 (adapted from Mussa et al. 2021). HS refers to the Hargreaves-Samani method, and PM refers to the Penman-Monteith method of calculating evapotranspiration.

Hydrologic Year (PET Method)	Rainfall (mm/Year)	Runoff (mm/Year)	PET (mm/Year)	Recharge (mm/Year)
1996/1997 (HS)	913	23	1046	259
1996/1997 (PM)	913	23	1157	214
2007/2008 (HS)	908	42	1138	207
2007/2008 (PM)	908	42	1080	190
2015/2016 (HS)	823	110	1204	129
2015/2016 (PM)	823	110	1144	110

## 4. Vulnerability

This section provides an overview of groundwater vulnerability in Dar es Salaam. 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

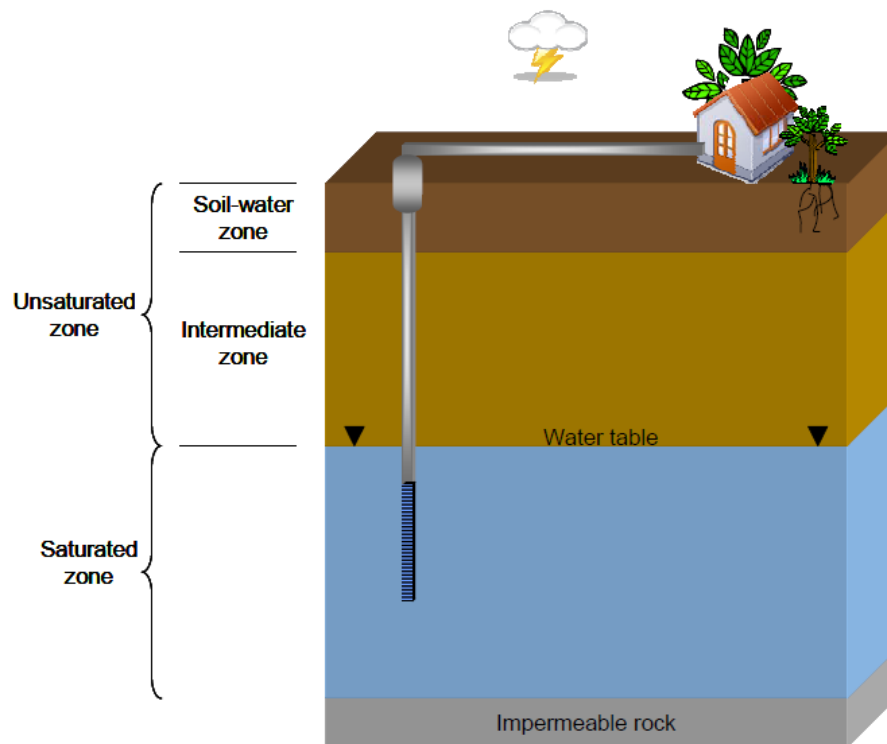
##### 4.1.1.1. Introduction

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).**

<b>Primary, secondary and tertiary impacts</b>
<p><b>Primary impact</b></p> <ul style="list-style-type: none"> <li>• Aquifer contamination (human-induced)</li> </ul>
<p><b>Secondary impact</b></p> <ul style="list-style-type: none"> <li>• Social and economic impact: Water quality renders groundwater unfit for purpose (e.g. drinking, domestic use, agriculture, industry)</li> <li>• Environmental impact: potential damage to surface water and groundwater-dependent ecosystems such as wetlands</li> </ul>
<p><b>Tertiary impact</b></p> <ul style="list-style-type: none"> <li>• Social impact: Risk of poisoning if contamination is not adequately monitored and acted upon</li> <li>• Social, economic and environmental impact: Land may be rendered unsuitable for desired purpose (e.g. human habitation or agriculture)</li> <li>• Critical infrastructure: Alternative water source required</li> </ul>



**Figure 4-1 Schematic representation of 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 to Contamination

The Dar es Salaam region relies on two types of aquifers for groundwater supply, the primary unconfined and semi-confined Quaternary Aquifer and the confined and semi-consolidated Neogene Kimbiji Aquifer.

Dar es Salaam's **Quaternary Aquifer** is widespread across the northern and central parts of the region. The aquifer system consists of an upper unconfined sandy aquifer and a lower semi-confined sand aquifer separated by a clay aquitard. The Upper unconfined sand aquifer is shallow, has no protective confining layer and is highly permeable due to its sandy nature, making it highly vulnerable to contamination from land use activities on the surface (Mjemah and Walraevens, 2015). The lower semi-confined sandy aquifer has a more moderate vulnerability to contamination due to its depth and partly confined nature as a result of the presence of a clay aquitard (Sappa et al., 2017).

The **Kimbiji Aquifer** is one of the most significant groundwater systems within the **Neogene Aquifer System**, located in the southern parts of Dar es Salaam, particularly beneath Kigamboni and extending into the Mkuranga district. It is predominantly a confined to semi-confined aquifer, comprising deep, confined aquifer layers composed primarily of fine to coarse-grained sandstones, interbedded with clays and siltstones. These interbedded clays and siltstones have a low permeability, which limits direct recharge and the infiltration of contaminants. The aquifer can reach depths of over 200 metres, thickening toward the coast. The confined aquifer layers are separated from shallower Quaternary Aquifers by continuous aquitards, which reduce vertical exchange and enhance the aquifer's protection from surface contaminants, making the aquifer less vulnerable to contamination. However, where the Kimbiji Aquifer outcrops to the surface in the west in the Pugu Hills, the aquifer becomes more vulnerable to contamination.

Beyond intrinsic aquifer properties, land use patterns and contaminant source density also influence vulnerability. Hazard mapping revealed that high and very high contamination risks are concentrated around the central urban core, particularly in Temeke and Ilala, where dense informal settlements, often reliant on pit latrines and inadequate sanitation services, are widespread (Mato, 2002). These settlements lie directly over shallow, unconfined aquifers, amplifying the risk of groundwater pollution. Industrial areas along the northeastern border of Temeke and parts of Ilala also pose a high hazard due to the potential discharge of chemical effluents.

### 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 the people who depend on the resource, as described in **Section 3.2.1**.

#### 4.1.2.2. Over-abstraction Vulnerability

Groundwater is an important water source for many residents in Dar es Salaam, with many communities relying on its availability for household use (Mtoni et al., 2011). The dependency of communities on this resource is largely driven by the need to address deficits caused by climate change, and inadequate and unreliable water supply from the city's municipal administration, DAWASA. According to Ngana et al. (2010), the majority of people (over 70% of the city's population) residing in informal settlements and unplanned areas are either partially or not connected to the municipal water supply network (Figure 3-5). Figure 3-5 which illustrates water supply patterns across Dar es Salaam, shows no evidence of water supply in the southern parts of the region, suggesting a high groundwater dependency in this area.

Dar es Salaam's **Quaternary Aquifer** is the most heavily utilised groundwater system in the central parts of the region, which forms the majority of Tanzania's economic hub (Mtoni et al., 2011). The aquifer system consists of an upper unconfined sand aquifer and a lower semi-confined sand aquifer separated by a clay aquitard (Sappa et al., 2015). Due to its accessibility, water from the shallow Quaternary Aquifer is used as a stopgap by many residents and by various sectors to fill the deficit left by the city's water supply operators, making the aquifer highly vulnerable to over-abstraction. Excessive groundwater pumping to meet the water demands of a growing region causes the water table to drop, resulting in a reduction in the availability of groundwater. According to Mjemah (2007), Mtoni et al (2011) and Andersson (2019), increased abstractions from the Quaternary Aquifer due to an over-reliance on groundwater are causing the lowering of water levels, leading to reduced storage and seawater intrusion. The central portions of Dar es Salaam are also significantly covered by impervious surfaces, limiting recharge in the area, making the aquifer more prone to depletion. In severe cases, aquifer depletion and storage losses can result in aquifers becoming permanently damaged.

The **Kimbiji Aquifer** in the southern portions of the region is currently being developed to improve the municipal water supply in southern Dar es Salaam through the development of the Kimbiji Aquifer wellfield. In addition to municipal abstractions by DAWASA, private boreholes have also been drilled for water supply, increasing groundwater abstractions in the area (DAWASA, 2017). The aquifer is viewed as a key strategic source for bulk supply expansion, due to its relatively large storage and good yield. Despite being more protected than shallower Quaternary Aquifers due to its confined nature and depths, the Kimbiji aquifer also faces potential risks of over-abstraction and, as a result, salinisation, especially in low-lying areas near the coastline. Recharge to the aquifer is likely limited due to the presence of clay layers that reduce the vertical permeability. Although the Kimbiji Aquifer is believed to have high storage and good yield, the unregulated abstraction of groundwater from the aquifer could exceed natural recharge. Furthermore, the western outcrop zones of the Kimbiji Aquifer, particularly where the Neogene deposits outcrop, likely form important recharge areas. These outcrop or recharge zones should be safeguarded from intensive development, land use change, or contamination, as this could impact the aquifer recharge and quality. It is also imperative to better regulate the groundwater use through defining and enforcing abstraction limits.

### 4.1.3. Sea-level Rise: Due to Climate Change

#### 4.1.3.1. Introduction

The coastal plains and wetland ecosystems of Dar es Salaam are vulnerable to the impacts of climate change, especially to rising sea-levels and extreme weather events. The rising sea-levels and tidal surges have the potential to erode ecosystems that serve as a buffer, leading to erosion and flooding (IPCC, 2001). According to the IPCC Report (Chapter 9: Ocean, Cryosphere and Sea-level Change) (IPCC, 2021b), there is high confidence in the warming of the Indian Ocean, which has noted the fastest surface warming since the 1950s. The increase in ocean temperatures further exacerbates this risk, as marine ecosystems are unable to withstand fluctuations in ocean temperatures. Consequently, the rising temperature leads to decreased water density, resulting in higher water levels (The Africa Centre for Strategic Studies, 2022). The IPCC Report (Chapter 9: Sea-level Rise) (2007) identifies the following anthropogenically induced factors contributing to rising sea-levels, namely: thermal expansion and the melting of the Antarctic and Greenland ice sheets, glaciers, and ice caps (IPCC, 2007). Additionally, the melting of ice, storm surges, and increased runoff contribute to the expansion of the ocean water mass (IPCC, 2019). Furthermore, anthropogenic activities, including land use changes, urbanisation, and groundwater abstraction, exacerbate impacts of sea-level rise due to changes in the elevation and recharge potential.

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

- Saline intrusion: Vulnerability of boreholes. 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: Groundwater-dependent ecology. If the chemical composition (e.g. salinity) of water in rivers and wetlands changes, the biodiversity and integrity of the watercourse/water body will alter (but may improve if, for example, the estuary is flushed out more).

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

<b>Primary, secondary and tertiary impacts</b>
<p><b>Primary impact</b></p> <ul style="list-style-type: none"> <li>• Intrusion of saline water into the aquifer.</li> <li>• Change in discharge regime of the aquifer.</li> <li>• Increased water table levels: high salinity and mineralisation of soils. Saturation of groundwater increases the risk to surface water due to the bilateral flow of water, especially in the low-lying reaches.</li> </ul>
<p><b>Secondary impact</b></p> <ul style="list-style-type: none"> <li>• Social/economic: Salinisation of groundwater: Water quality renders groundwater unfit for purpose (e.g. drinking, domestic use, agriculture, industry). Decreased potable water: dependence on shallow water extractions.</li> <li>• Critical facilities: Groundwater flooding can impact water treatment plants, WWTWs, electricity sub-stations, transport, hospitals, etc.</li> <li>• Agricultural: Decreased productivity due to mineralisation of soils. There is an increased risk in arable fluvial plains where groundwater recharges baseflow during dry seasons.</li> </ul>
<p><b>Tertiary impact</b></p> <ul style="list-style-type: none"> <li>• Critical facilities: Alternative water source required. Corrosion of infrastructure and increased pressure and conflict between industry and residents for water.</li> <li>• Environmental impact: Potential damage to freshwater ecosystems (e.g. as wetlands). Salinisation of soils if saline/brackish water is used for irrigation.</li> <li>• Social/economic: increased costs for water processing (desalination), flood damage, and groundwater pumping.</li> </ul>

4.1.3.2. Aquifer Vulnerability

Inundation Modelling

Following the review and assessment of the hazards associated with climate change, an analysis was undertaken to estimate sea-level rise by 2060. The results were used to generate Figure 4-2, a map illustrating the sea inundation level as an impact of climate change on the city of Dar es Salaam.

The modelling of the IPCC AR6 climate change data provides greater detail through the increased resolution of the Coupled Model Intercomparison Project Phase 6 (CMIP6) (C3S, 2024). The release of the AR6 Report and CMIP6 has enabled improved outcomes through various modelling options based on intervention and baseline scenarios. For the purpose of the report exploring the projected impacts of climate change, conservative values using the worst-case baseline scenarios in the CMIP6 models were utilised for increased consideration of climate sensitivity (Hausfather, 2019). Copernicus (COP30) DEM data were obtained for the study area relevant to the report.

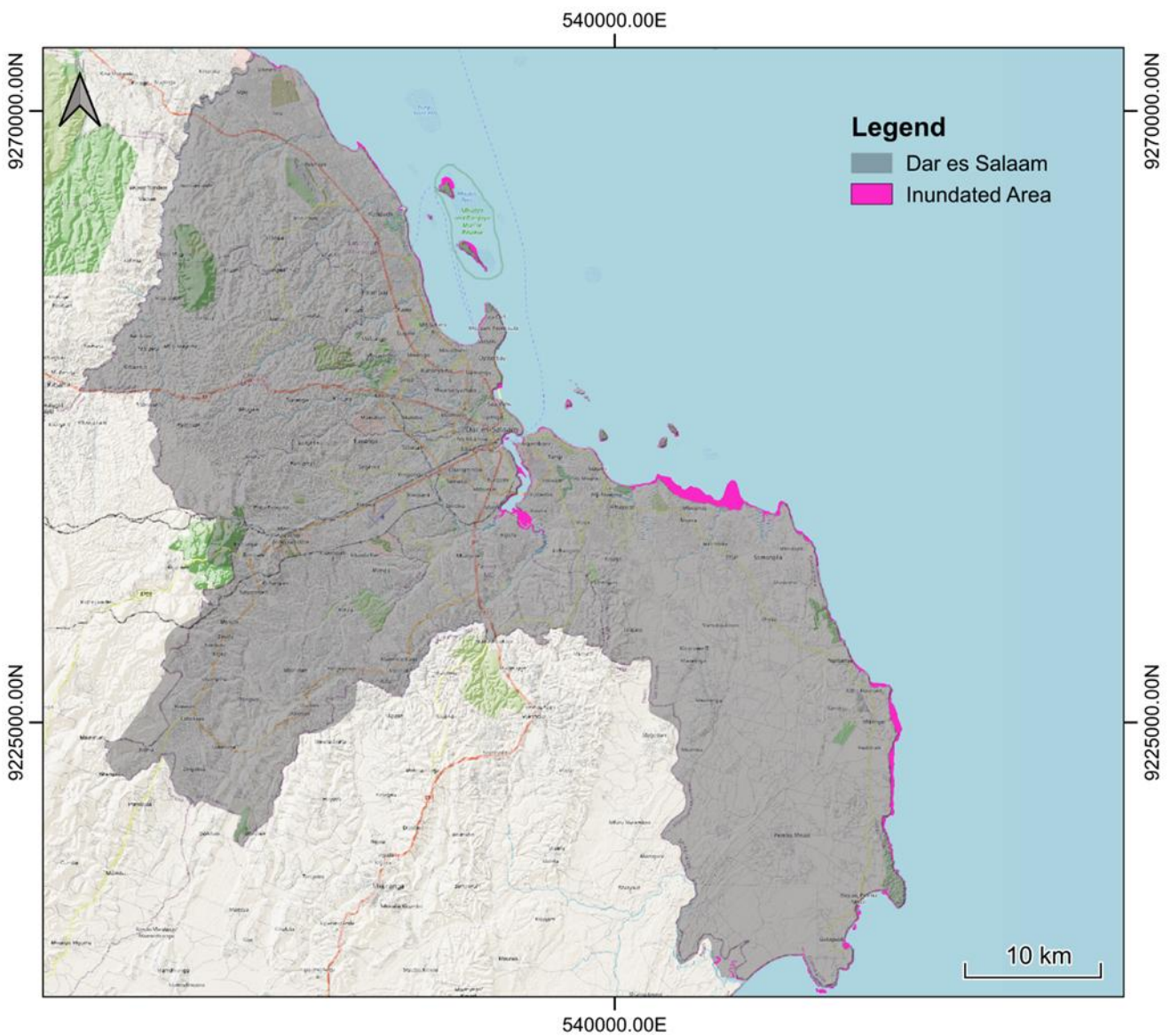


Figure 4-2 Influence of sea-level rise on the Dar es Salaam Metropolitan Area according to NASA (n.d).

The CMIP by IPCC (2021a) had no data value available for the sea-level rise around Dar es Salaam, however, the projected sea-level rise for East Southern Africa is 0.3 m (SSP5-8.5 relative to 1995-2014 to 2041-2060; medium term). The same reference period is used by NASA's Sea-level Projection Tool (NASA, n.d.) which had no data value available for the area around Dar es Salaam, the closest station point being Zanzibar which has a projected rise of 0.32 m (SSP5-8.5 relative to 1995-2014 to 2041-2060; medium term), a second point obtained from this map at -6°S, 40°E has a projected sea-level rise of 0.34 m (SSP5-8.5 relative to historical baseline (1995-2014) to 2041-2060; medium term). For conservative measures, a third site (Second Sea, n.d.) was consulted, and the projected sea-level rise for Dar es Salaam is 0.314 m (RCP\* 8.5 relative to historical baseline (1995-2014) to 2041-2060; medium term). The RCP is based on the greenhouse gas concentrations, not the emissions (SSP5), and is based on the IPCC AR5 CMIP5 model (Second Sea, n.d.). For modelling purposes (where higher sea-level rise is conservative), the RCP value is omitted, and the projected increase of 0.34 m has been adopted for this study.

To consider the influence of this increase, Figure 4-2 used the Copernicus 30 m (COP30) digital surface model and applied the 0.34 m increase in sea-level to illustrate the added area of inundation relative to mean sea-level (MSL). COP30 is referenced to the WGS84 ellipsoid (UTM Zone 37S) and assumed to be at MSL.

**Figure 4-2** illustrates that the IPCC SSP5-8.5 projection will result in some coastal inundation of Dar es Salaam and offshore islands. The port of Dar es Salaam, situated in the Kurasini Creek, a small coastal inlet, is projected to experience flooding, with greater inundation occurring in the lower reaches of the Msimbazi River.

### Seawater intrusion

The **Quaternary Aquifer** system in Dar es Salaam demonstrates a high vulnerability to seawater intrusion, particularly in low-lying coastal areas. The aquifer system consists of a shallow unconfined unit above a deeper semi-confined unit, and because of these geological characteristics, assessing the full extent of seawater intrusion in the aquifer becomes more complex. However, along the coastline, the vulnerability of the Quaternary Aquifer is considered as very high. This vulnerability stems from several factors, including: the aquifers' overall shallow depth, proximity to the coast and existing pressure from groundwater over-abstraction.

The most at-risk areas in Dar es Salaam are those found along the floodplains of the **Msimbazi Basin** and coastal villages of **Kibada**, **Mboamaji** and **Kimbiji** in the **Kigamboni** administrative district, however many parts of the northern and southern coastline are susceptible to seawater intrusion. Additional vulnerable areas include:

- **Tanga** and **Bagamoyo** are vulnerable due to flat coastal terrain and dependence on shallow groundwater sources. There is an introduction of rainwater harvesting and alternative shallow wells inland and coastal vegetation restoration programs (mangroves, grasses) to act as barriers. Bagamoyo is already experiencing impacts from saltwater affecting wells and farmland.
- **Kilwa Masoko**, **Mtwara** and **Lindi** have risk increasing with port expansion and development pressures on groundwater. Coastal erosion and saltwater contamination of shallow wells have been reported in literature.
- **Pangani** a small town, is faced with river-sea interaction that creates a dynamic saltwater intrusion risk.

In total, it is between 8 – 12 urban areas at **moderate to high risk**. Several coastal boreholes have already begun showing signs of salinisation, a process which is accelerated by over-abstraction. Modelling by Van Camp et al. (2014) found that the semi-pervious layer separating the two parts of the Quaternary Aquifer may create a complex environment for salinisation to occur, especially if over-abstraction is included, as this may further encourage salinisation.

In areas where rising sea-levels exceed the semi-pervious layer, seawater intrusion and its impacts will likely occur and exacerbate conditions worsened by over-abstraction. Higher sea-levels create a greater displacement of freshwater, exacerbating intrusion in these vulnerable parts of the Quaternary Aquifer. Loss of mangroves, coastal vegetation and unregulated coastal development, coupled with poor drainage and saltwater backflow during flooding, are also thought to impact groundwater salinity.

The **Kimbiji Aquifer** exhibits significantly lower vulnerability to seawater intrusion than the Quaternary Aquifer and is thought to possess a very low to low vulnerability to sea level rise. This is due to the substantial confining layers of clay and marl that act as a hydrogeological barrier and the favourable hydraulic gradient that currently maintains the freshwater-saltwater interface several kilometres offshore (DAWASA, 2017). Incomplete data on the continuity and thickness of the confining layers does however, create some uncertainty. Localised breaches in these protective layers could potentially create preferential pathways for seawater intrusion. From what is described in literature, the Neogene clay-bound sands found in Dar es Salaam largely act as an impervious layer.

#### 4.1.4. Reduced Recharge: Due to Climate Change

##### 4.1.4.1. Introduction

The recharge potential of groundwater is dependent on both subsurface and surface characteristics, including land cover, soils and soil moisture. These features influence the interaction with water but are dependent on climate conditions such as rainfall, temperature, and evaporation rates. This section of the report acknowledges the influence of anthropogenic activities, although this is not the focus of this section (which is on climate change).

Table 4-3 Primary, secondary and tertiary impacts of reduced groundwater recharge.

Primary, secondary and tertiary impacts
<p><b>Primary impact</b></p> <ul style="list-style-type: none"> <li>• Reduced groundwater levels</li> <li>• Water scarcity</li> <li>• Change in the discharge regime of the aquifer</li> <li>• Drying of shallow springs and wells</li> <li>• Reduced baseflow to rivers and waterbodies</li> </ul>
<p><b>Secondary impact</b></p> <ul style="list-style-type: none"> <li>• Social/economic: insufficient sources of water and decreased water quality renders groundwater unfit for purpose (e.g. drinking, domestic use, agriculture, industry)</li> <li>• Saline intrusion: increased salinity in coastal aquifers</li> <li>• Environmental: increased threat of desertification in arid areas and loss of water body ecosystems</li> <li>• Food scarcity: Insufficient water resources can lead to crop failure</li> <li>• Critical facilities: insufficient groundwater can impact water treatment plants, WWTWs, electricity sub-stations, transport, hospitals, etc</li> </ul>
<p><b>Tertiary impact</b></p> <ul style="list-style-type: none"> <li>• Critical facilities: Alternative water source required</li> <li>• Environmental impact: potential damage to freshwater ecosystems (e.g. as wetlands). Salinisation of soils if saline/brackish water is used for irrigation</li> </ul>

According to the IPCC (2022) Sixth Assessment Report (AR6, WGII Chapter 4), the increased variability of precipitation in tropical regions, such as Dar es Salaam, can reduce the groundwater recharge potential during extreme rainfall events, as runoff rates impede infiltration due to water draining too quickly. Furthermore, the rate of recharge is highly uncertain and disproportionate due to the increased fluctuations in seasonal rainfall patterns (IPCC AR6, Chapter 9: Ocean, Cryosphere and Sea-level Change) (IPCC, 2022). The seasonality of rainfall influences the potential for recharge, as wet seasons are characterised by higher water table levels and saturation of surface soils, resulting in higher runoff rates.

**4.1.4.2. Aquifer Vulnerability to Reduced Recharge**

In the absence of recharge projections for Dar es Salaam, projected changes in precipitation from IPCC and Copernicus Climate data have been used as a proxy. The climate dataset indicates a high confidence in an increase in total precipitation of 2.34% and 3.21% (SSP5-8.5 relative to 1961-1990 and 1981-2010, respectively) for the medium-term period (2041-2060). **Table 4-4** also presents an increase in the mean soil shallow moisture content of 1.39% and a mean daily accumulated runoff increase of 23.77%, respectively, although confidence is very low and low (SSP5-8.5 relative to the historical period 1981-2010 for the medium-term 2041-2060 projection).

**Figure 4-2** illustrates the total precipitation increase for the medium-term projection (2041-2060) compared to the baseline periods (1981-2010), based on the IPCC SSP5-8.5 data values. The data shown was used to derive a mean relative change as shown in **Table 4-4**. **Figure 4-2** includes the aquifer types in Dar es Salaam, as the types of aquifers may influence the groundwater recharge potential.

By considering the aforementioned variables as a proxy for recharge, it appears that recharge has the potential to increase due to climate change, as predicted by the CMIP6 medium-term projections. This would imply a low vulnerability of the aquifer to reduced recharge. These projections, however, are based on cumulative annual values and do not provide insight into seasonal variation. In addition, climate change-induced fluctuations in rainfall could result in extended dry periods and erratic rainfall, which may reduce effective recharge and increase aquifer vulnerability.

However, a degree of uncertainty remains regarding projected precipitation patterns. While climate models such as CMIP6 SSP5-8.5 suggest an increase in total precipitation, which could lead to higher recharge and runoff that will likely increase flooding, other predictions also point to prolonged drought periods that imply a possible decline in precipitation. This highlights the spatial and temporal variability of rainfall in the region. If recharge were to decline, particularly during predicted prolonged drought periods, the aquifers, particularly the shallow Quaternary system, would face significant risks such as over-abstraction, storage depletion and seawater intrusion. Reduced recharge would also lower water tables, decrease borehole yields and limit groundwater availability for domestic, industrial and municipal use, ultimately compromising the resilience of Dar es Salaam’s water supply system. Due to these uncertainties, the aquifers remain vulnerable to reduced recharge to some extent.

**Table 4-4 CMIP6 Medium term Projections (2041-2060) SSP5-8.5 (IPCC, 2021a; C3S, 2024).**

Variable	Confidence Level	Value
Mean soil shallow moisture % (1981-2010)	Very low, conflicting signals	1.39
Mean daily accumulated runoff % (1981-2010)	Low confidence- no change or no robust signal	23.77
Total precipitation % (1961-1990)	High confidence of increase	2.34
Total precipitation % (1981-2010)	High confidence of increase	3.21
Mean daily evaporation % (1981-2010)	High confidence of increase	3.64
Mean sea-level rise	High confidence of increase	no value

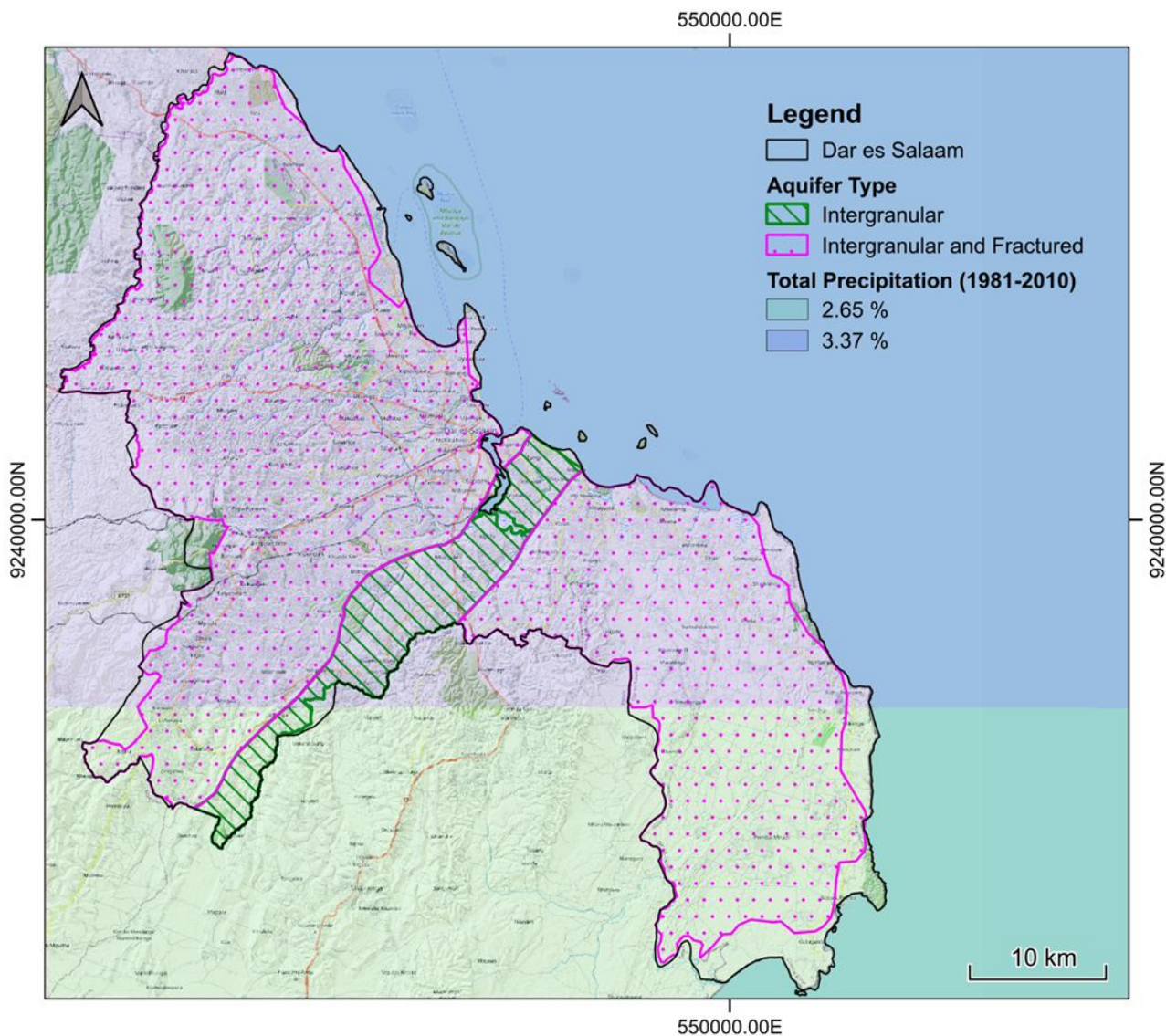


Figure 4-3 Total Precipitation Relative Change (historical baseline 1981-2010) CMIP6 Medium term Projections (2041-2060) SSP5-8.5.

## 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. DAWASA currently operates two major groundwater schemes in the region. The largest and most recently developed scheme targets the Kimbiji Aquifer, the lower confined unit of the Neogene Aquifer System. This scheme is intended to provide water to the Kigamboni administrative district and parts of the Temeke district. The second scheme targets the Quaternary Aquifer underlying most of the city through a series of shallow boreholes. Besides DAWASA, many private boreholes from formal and informal users also target this aquifer. The optimisation of management protocols, aquifer monitoring systems, and infrastructure designed to minimise vulnerability and enhance resilience is still an ongoing development for both production schemes. In some instances, these mechanisms have been developed but are still in progress towards achieving a sufficient level of efficiency.

#### 4.2.1.1. Vulnerability to Contamination of Groundwater

The vulnerability of DAWASA's groundwater abstraction schemes varies due to geology and urbanisation. Municipal production boreholes, especially those located in the shallow unconfined environments of the Quaternary Aquifer, are at an 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 Quaternary Aquifer, landfills, leaking sewers, pit latrines, septic tanks, and unregulated dumping introduce nitrates, pathogens, and organic contaminants into the aquifer (Mato, 2002). This aquifer system supplies water through several production boreholes located around the City, therefore, proactive land-use control and water quality monitoring are essential to protecting supply integrity. These boreholes are considered highly vulnerable to contamination and abstracted water in many parts requires significant treatment to be viable for distribution.

The Kimbiji Aquifer consists of various impermeable and semi-impervious layers of clay, marl, sands and sandstone, and in parts of Dar es Salaam, these layers form the basal unit for the region's Quaternary Aquifer. This limits the impact of direct contamination from overlying urbanisation to the deeper parts of the aquifer, as these layers hinder the infiltration of contaminants across its confined water-bearing units. The Kimbiji and Mpera wellfields, targeting confined layers of the Kimbiji Aquifer, are considered to be at a low to moderate vulnerability due to its geology. Although the Mpera wellfield falls outside of the regional boundary, it is still being developed as a resource for DAWASA to use for supply.

To minimise the risk of contamination, the Kimbiji and Mpera wellfields are being established in peri-urban to rural areas, and where the underlying geology maximises abstraction and minimises the vertical migration of potential contamination. Urban land use accounts for only 4% of the total area, with small-scale farming making up the remaining anthropogenic land use with 24% (DAWASA, 2017). Land use around production borehole sites consists mostly of undisturbed natural environments, with the exception of main roads and their associated infrastructure. Planning, design and development of these wellfields were according to the Dar es Salaam water master plan goals and requirements to improve water quality and operational efficiency.

#### 4.2.1.2. Vulnerability to Over-abstraction

Dar es Salaam's groundwater schemes are vulnerable to over-abstraction from both municipal operations and increasing private use (both regulated and unregulated). Registered boreholes are counted at over 2,000 with the WRBWB meeting yearly predicted trends in applications for water use permits. Due to increased dependency as a result of climate change-induced reductions in rainfall and insufficient water supply infrastructure, the number of unregulated boreholes are thought

to have increased significantly. As of 2011, it is estimated that the number of unregulated boreholes were likely greater than 10,000 (Mtoni et al., 2011), since then the region has experienced periods of extended dry seasons, which are likely to have significantly increased this number of unregulated boreholes. According to a WRBWB officer, it is estimated that approximately 25,000 unregistered boreholes exist as of 2025. Increased use, especially when unregulated, can greatly stress the City's aquifers. The combination of inefficient water supply infrastructure, reduced rainfall, and both unregulated and improper groundwater management leads to an over-reliance and increased dependency on groundwater in the city. This greatly heightens the risk of over-abstraction by DAWASA and its municipal groundwater schemes.

Improper enforcement of regulations with respect to private and unregulated boreholes can further complicate and create challenges for groundwater allocations as part of Tanzania's Water Sector Development Program (WSDP) III. This will create challenges for the WRBWB to determine appropriate water balances for the aquifer and fully achieve the objectives of the Integrated Water Resources Management approach outlined in The Water Resources Management Act (WRMA) No. 11 (2009). According to Skinner and Walyncki (2016), sustainable annual yields for the two main targeted aquifers (Kimbiji and Quaternary Aquifers) are overestimated, and based on emerging data, do not reflect an accurate account of sustainable yield. Should the City's abstraction schemes (especially those in the Quaternary Aquifer) contribute to water table decline as a result of over-abstraction, users who rely on and have access to municipal water will be highly vulnerable (Walraevens et al., 2015). Moreover, those in informal settings, who make use of private vending where water is often sourced from municipal supply and who are already highly dependent on groundwater to sell, will also be highly vulnerable. This could further stress the aquifer as it could lead to the occurrence of additional unregulated boreholes in an attempt to address water supply demands, contributing further to over-abstraction and its associated effects.

Up until the early 2000s, DAWASA and WRBWB lacked sufficient groundwater management, monitoring, and regulation of unregulated boreholes (Mato, 2002; UN-Habitat, 2007). However, as part of attempts to align with the Ministry of Water's WSDPs, efforts have been made to ensure:

- Sufficient monitoring and assessment of water resources,
- Enforcement of water use regulations,
- Improve groundwater management,
- Improve water allocation, protection and conservation.

Through these changes, DAWASA and the WRBWB are aiming to practice sustainable groundwater use, mitigate over-abstraction and its associated impacts, and reduce the risk of vulnerability to DAWASA's water supply network.

Impacts of over-abstraction include seawater intrusion and salinisation, potentially impacting both the quality and quantity of groundwater. Several studies and reports have already noted the salinisation of some localised boreholes situated along Dar es Salaam's coast and further inland (Van Camp et al., 2014; Walraevens et al., 2015; Sappa and Luciani, 2016). Insufficient management and regulation of groundwater use in the Quaternary Aquifer could further exacerbate salinisation. DAWASA production boreholes in the Quaternary Aquifer may be vulnerable to seawater intrusion as a result of over-abstraction, if they are located close to the coastline. Those situated further inland, are less susceptible to seawater intrusion as a result of over abstraction.

Due to the confining nature of the Kimbiji Aquifer and pressure from upgradient flow, which keeps the freshwater-saltwater interface several km off the region's coast, it is thought that the Kimbiji and Mpera well fields have a low vulnerability to seawater intrusion due to over-abstraction (DAWASA, 2017). Moreover, given DAWASA is amongst the few targeting this deeper aquifer system, and the resources required to target this groundwater, vulnerability to over-abstraction induced changes to salinity is considered to be low for the Kimbiji and Mpera wellfields, should sufficient management and regulation of water use in this groundwater system be practised

#### 4.2.1.3. Vulnerability to Sea-Level Rise

Climate change-induced rises in global sea-levels are thought to have significant impacts on many coastal aquifer groundwater schemes. Depending on the geology, hydraulic conditions and elevation of coastal aquifers, sea-level rise can result in varying degrees of salinisation. DAWASA's production boreholes targeting the Quaternary Aquifer are the most vulnerable to sea-level rise, particularly in coastal plain areas where the hydraulic properties and risk of over-abstraction encourage the ingress of the freshwater-saltwater interface. Given the extent of inundation (See Figure 4-2) should sea-levels rise by the predictions of the IPCC, sea water intrusion is likely only to affect production boreholes situated near the Msimbazi Estuary and along the region's northern and southern coastline. Salinity in several coastal boreholes in the Quaternary Aquifer has been reported to be increasing, especially those studied closest to the coastline (Mata, 2002; Mjemah and Walraevens, 2015; Sappa and Luciani, 2016).

Unlike the Quaternary Aquifer, the Kimbiji aquifer is thought to be confined in most of its extent, with some zones where these confining layers are absent. Despite this, the location of the Kimbiji and Mpera wellfields and the hydraulic head differences between the coastline and hinterlands are thought to minimise vulnerability. Therefore, the vulnerability to the Kimbiji aquifer wellfields is considered low as predicted changes in the freshwater-salt water interface, given current and future demands, are expected to remain several kilometres away from land into the ocean.

Rising sea-levels will likely push the saline wedge inland, and when combined with over-abstraction, could lead to significant salinisation. As a result, the DAWASA may need to invest in desalination and alternative methods to ensure safe drinking water, especially since Dar es Salaam's growing population relies heavily on these groundwater sources. During times of drought, the MoW has driven a rainwater harvesting policy aimed at equipping the most vulnerable of Dar es Salaam's residents with small-scale reservoirs to collect rainwater.

Ultimately, little can be done to combat sea-level rise, however, proactive measures to mitigate the impact of salinisation from seawater intrusion can be undertaken. The overall improvement of groundwater management could provide relief to mitigate their vulnerability. Through a combined effort, DAWASA and WRBWB could reduce over-abstraction, enhance monitoring, improve water allocation, and potentially implement Managed Aquifer Recharge (MAR). MAR could be particularly effective, as it aids in maintaining a favourable groundwater gradient, encouraging the movement of freshwater toward the ocean and thereby counteracting saltwater intrusion. By adopting these strategies proactively, DAWASA's wellfields and the users who rely on its supply of water are less vulnerable to the impacts of salinisation.

#### 4.2.1.4. Vulnerability to Reduced Recharge

Climate change-induced reductions in natural recharge present a long-term risk to the sustainability of DAWASA'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. Recent extended dry periods between 2003-2006, 2015-2016, and 2020-2022 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.

Prolonged dry season periods directly reduce the amount of available rainfall which can infiltrate the surface and recharge underlying groundwater systems. Between 1960 – 2012, rainfall decreased by 200 mm/a from 1,200 to 1,000 mm/a. Less available water for direct recharge will reduce groundwater storage and availability (Sappa and Luciani, 2016). Given the increased demand for groundwater across Dar es Salaam, this could have serious implications for the municipal groundwater supply schemes, especially in the shallow Quaternary Aquifer, where the most dependent groundwater users are situated.

Despite lacking consistency and coherence, to date, DAWASA has implemented measures to improve the management of available groundwater resources (DAWASA, 2017):

- Municipal pumping rates have been regulated to prevent overuse during dry seasons,
- DAWASA has attempted to improve the extent of its monitoring network and the coherence of data recorded. Public awareness campaigns have been undertaken to preserve groundwater,
- Drought contingency plans in the form of early warning systems have been established to prepare for such events.

Additional measures which could be implemented are MAR and a stricter enforcement and regulation of groundwater abstraction by licensed and unlicensed users. Given how stressed the Quaternary Aquifer is, municipal groundwater supply schemes targeting this aquifer are considered highly vulnerable to reductions in recharge. For the Kimbiji Aquifer, there is a need to further define recharge zones and rates. Currently, much of the recharge that occurs in the confined units is thought to be in the elevated western hinterland and in unconfined portions at the subsurface by direct recharge from rainfall (Bakari, 2012; DAWASA, 2017). Sustainable yields also vary from location to location, therefore it is a challenge to assign vulnerability, however under conservative estimates, it is thought the Kimbiji Aquifer wellfields are at a low to moderate vulnerability, as most groundwater users are not targeting this aquifer for water supply, it is mostly municipal and Community Based Organisations (CBO's) who abstract from deeper groundwater. Provided sufficient management and regulation of the Kimbiji Aquifer is followed, it is not as vulnerable as the Quaternary Aquifer.

## Summary

Due to high urbanisation, the presence of PCA's, and the hydraulic properties of the Quaternary Aquifer, DAWASA's production boreholes drawing from this system are highly vulnerable to contamination. In contrast, production boreholes targeting the deeper Kimbiji Aquifer exhibit low to moderate vulnerability, owing to the aquifer's protective confining geology, and the peri-urban to rural land cover of the Kigamboni district. Similarly, municipal water schemes reliant on the Quaternary Aquifer face the risk of over-abstraction, whereas those utilising the Kimbiji Aquifer remain at low vulnerability. This distinction stems from the significant exploitation observed in the Quaternary Aquifer, where abstraction might exceed recharge, while current use of the Kimbiji Aquifer is considered sustainable.

The vulnerability of DAWASA's Quaternary Aquifer schemes to sea-level rise varies from low to high, depending on proximity to the coast. In contrast, the Mpera and Kimbiji Wellfields are classified to have a low vulnerability due to their confining geology and favourable hydraulic head, which maintains the freshwater-saltwater interface more than 20 km offshore.

The groundwater scheme in the Quaternary Aquifer is considered highly vulnerable to reduced recharge, as current annual abstractions are thought to often surpass groundwater recharge. The Kimbiji Aquifer, however, experiences a low to moderate vulnerability, as it remains an underutilised resource in the region. Moreover, its recharge zones in the western hinterlands remain unaffected by urban development.

## 4.2.2. Communities, Agriculture and Industrial Use

### 4.2.2.1. Aquifer Contamination: Due to Human Activities

Groundwater contamination in Dar es Salaam arises from various human activities, particularly when surface activities occur over unconsolidated sands and sediments. Major pollution sources include informal settlements, leaking sewerage infrastructure, cemeteries, agricultural runoff (pesticides/fertilisers), industrial effluent, filling stations, stormwater runoff, landfills, and wastewater treatment works.

Contaminants can leach directly into the unconfined parts of the Quaternary and Neogene aquifer systems, degrading water quality. **Communities** from unplanned and informal settings are often the most vulnerable, as most of these unplanned areas lack sufficient waste disposal and sewerage infrastructure. The most utilised form of sewage disposal available in these areas are pit latrines. It is thought that up to 97% of residents are dependent on these systems (Mremi et al., 2025).

These systems often directly pollute and contaminate groundwater, leading to elevated levels of nitrates and excreta contaminants (Sweya and Salila, 2023). 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.

Given the high dependency on groundwater for communities across Dar es Salaam, their vulnerability to aquifer contamination is very high. Vulnerability is especially high for low-income households, who may resort to shallow wells or boreholes due to a lack of access to higher-quality municipal water. These households often cannot afford proper treatment systems, leaving them at risk of waterborne diseases (Mdoe and Buchweishija, 2014). 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).

Similarly, **industrial** and **agricultural** sectors represent major consumers of groundwater in Dar es Salaam (see **Table 3-2**). Industries in particular transitioned to private groundwater abstraction during periods of unreliable water supply from DAWASA. While surrounding communities often lack the financial capacity to adequately treat extracted groundwater, industrial users can typically afford an advanced treatment system to meet their specific water quality requirements. This financial and technical capacity significantly reduces their vulnerability to groundwater quality issues, classifying their vulnerability as comparatively low.

The **agricultural** sector represents another significant groundwater user in Dar es Salaam, supporting urban, peri-urban and rural farming operations. While surface water remains the preferred source where available, many farmers in peri-urban and rural areas rely on groundwater for crop irrigation and livestock watering. This dependence was reinforced by the National Rural Water Supply and Sanitation Program (NRWSSP) during the first phase of the Water Sector Development Program (WSDP). However, agricultural groundwater use poses particular risks, as the shallow unconfined aquifers typically targeted are highly vulnerable to contamination. Fertiliser-derived nitrates, agricultural chemicals (herbicides and pesticides), and livestock waste frequently infiltrate these groundwater systems. Unlike industrial users who can implement treatment solutions, most small to medium-scale agricultural operations lack both the financial means and technical capacity to mitigate such contamination. Consequently, the agricultural sector is classified as highly vulnerable to aquifer contamination.

### Population Exposure and Sensitivity

A substantial proportion of Dar es Salaam's population resides above vulnerable, shallow, unconfined aquifer systems, particularly in low-income areas and unplanned settlements. With less than 30% of households located in formally planned areas (Kombe and Muheirwe, 2024), inadequate sanitation infrastructure in these communities frequently leads to sewage and dump contamination of underlying groundwater resources. This contamination risk disproportionately affects vulnerable groups such as children, the elderly and those with compromised immune systems. Outbreaks of waterborne diseases become significantly more likely in these areas, especially within high-density settlements.

The contamination threat extends beyond residential areas. Both agricultural runoff (containing nitrates, pesticides, and livestock waste) and industrial effluents (metals, sulphates, nitrates, and chloride) introduce pollutants into Dar es Salaam's shallow aquifer systems (Addo, 2016; Mwatujobe, 2020). Of particular concern are low-income communities situated near industrial zones or downstream of agricultural areas. Groundwater gradients may direct contaminants toward residential boreholes and communal water points. Unlike wealthier residents who can choose safer locations, these marginalised populations face compounded risks from inadequate sanitation infrastructure and proximity to pollution sources.

### Dependency on Groundwater

Across socio-economic backgrounds and various sectors, dependency on groundwater is high. Despite access to piped water, some high-income households are still dependent on groundwater due to unpredictable service disruptions in DAWASA's municipal supply. Low-income households are the most reliant on groundwater, despite its often poor quality. Agricultural users are mostly dependent on surface waters, however, where these are not available, especially in rural areas of Dar es Salaam, groundwater has become the main source of water for crop irrigation and for drinking by livestock. Their dependency on groundwater and vulnerability to aquifer contamination can therefore vary between low to very high. The industrial sector of Dar es Salaam is considered a major hazard to their underlying aquifers and downgradient communities, however despite their contributions to groundwater contamination, their financial means to treat groundwater often mitigate the threat of aquifer contamination to their processes. The industrial sector is therefore considered to possess a low to moderate vulnerability, depending on its financial means for treatment. Dependency of all users, however, increases during times of drought, as reduced surface water availability prevents DAWASA from meeting supply demands, thereby pushing users to rely on groundwater more than during times of abundance.

### 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) and lack resources to mitigate exposure. Low-income and agricultural communities are the most vulnerable to aquifer contamination, as, unlike industries that may be able to afford water treatment systems, they are often financially unable to test and treat abstracted groundwater. Exposure to contaminants such as E.coli and nitrates can be found in many high-density areas of Dar es Salaam and is largely dependent on whether groundwater or treated municipal water is the main source of water. While a higher proportion of high-income households have access to piped water, not all households solely rely on it for supply due to DAWASA service disruptions (see Figure 3-5). Therefore, while low-income households are more likely to be exposed to these contaminants, infrastructure challenges for most identified groundwater users, irrespective of socio-economic background, suggest there is a universal vulnerability in the region to aquifer contamination. However, these high-income neighbourhoods are often not located near industrial areas and or points of potential contaminating activities, therefore, their vulnerability is still lower than those in less advantaged areas.

## Water Infrastructure and Service Access

Access to safe water and sanitation services is a critical vulnerability factor for contamination hazards. Establishment and development of existing water and sanitation infrastructure is an ongoing process in Dar es Salaam. According to the latest demographic and socio-economic profile report (2022), 66.2% of households in the Dar es Salaam region possess a flush toilet, with 33.6% of households still making use of pit latrines (both basic and ventilated). The latter is often found in households where water and sanitation infrastructure are unserved or underserved, and are most often concentrated in unplanned areas. Officially, it is estimated that 79.5% of households have access to piped water in their homes, however, it is thought this describes only municipal water supply for planned areas and not the estimated 75% of households in informal areas, which do not have access to piped water (Hofmann, 2022; URT, 2025). These households are the most vulnerable to aquifer contamination as they can heavily rely on shallow groundwater from hand-dug wells and or shallow boreholes without appropriate treatment. This groundwater is often polluted with nitrates and bacteria due to dumping and insufficient sanitation infrastructure (pit latrines and septic tanks). Due to a lack of infrastructure, alternatives such as rainwater harvesting and supply by private vendors are also commonly utilised. Access to this water however, is limited to availability and can often come at significant costs.

Aquifer contamination also affects the agricultural sector. Peri-urban and urban farmers tend to lack access to treated municipal water, instead, borehole distribution systems commissioned by CBOs or community-driven projects, and privately hand-dug or drilled boreholes are the main sources of groundwater to these farmers. Often, it is the case that these systems lack sufficient treatment and were established with meeting supply demands in mind. Rural farmers and communities tend to have better access to groundwater as the NRWSSP ensured wide coverage of sufficient water supply to rural users. There is essentially no water treatment in place as systems are largely based on direct abstraction and supply. Agricultural use of groundwater in peri-urban and urban areas tends to be highly vulnerable, while those in rural settings are considered to have a moderate to high vulnerability.

Industries in Dar es Salaam rely on groundwater for their processes due to historical unpredictable service disruptions. Use of groundwater in this sector is largely dependent on where processing is located (see Figure 3-5). Depending on their areas, stormwater and sanitation infrastructure can be absent, leading to untreated industrial effluent seeping into waterways and contaminating underlying aquifers. The use of water in industrial processes typically requires water of a particular quality for their operations. This can often require the installation of costly treatment systems that, depending on the scale of operations and requirements, can increase significantly. Therefore, industries are considered to possess a moderate to high vulnerability to aquifer contamination.

## Summary

Populations in unplanned and informal areas with inadequate sanitation infrastructure are highly vulnerable to groundwater contamination. These communities typically rely on shallow communal boreholes and or private hand-dug wells due to a general lack of municipal supply. Access to water in these areas varies, and therefore, private vending plays an important role in water supply. Groundwater in these areas is typically polluted due to pit latrines, waste dumps and or nearby industrial activities.

Key factors:

- High-density unplanned areas overlying contaminated or high-risk parts of the Quaternary Aquifer.
- Insufficient sanitation services
- Poor waste management and illegal dumping.
- Low awareness of groundwater protection.

#### 4.2.2.2. Over-abstraction

Groundwater is a critical water source for communities, industries, and agriculture in Dar es Salaam, supplementing and often compensating for limitations in the region's water supply infrastructure. Over the past two decades, reliance on groundwater has grown steadily due to population growth, climate change, and increasingly erratic rainfall patterns. Longer dry spells and shorter, more intense rainy seasons have strained water resources, while droughts have reduced the availability of surface water for municipal supply, pushing demand toward groundwater. These pressures, combined with inadequate infrastructure and unreliable service delivery (see Figure 3-5), have intensified dependence on groundwater across all sectors. In many parts of the city, unsustainable extraction rates have led to aquifer overexploitation, threatening long-term water security.

The consequences of over-abstraction of aquifers affect all users collectively. Communities, especially those without a reliable municipal supply, face water shortages, higher costs from private vendors capitalising on scarcity, and increased expenses for deeper boreholes where water levels drop. Industries and commercial farms, particularly in water-intensive sectors like manufacturing and large-scale irrigated agriculture, are especially vulnerable. Their operations depend on consistent groundwater for production, cooling and irrigation, making them acutely sensitive to supply disruptions. As competition for dwindling resources intensifies, the economic and operational risks grow across all users.

Socio-economic vulnerability to groundwater over-abstraction is primarily determined by the degree of dependency on this resource and the availability of alternative sources. Communities and sectors that rely heavily on groundwater, which often lack sufficient alternative options, face the greatest risks when groundwater availability and storage decline. While groundwater dependence is widespread across Dar es Salaam, the most vulnerable areas are unplanned settlements and the southern parts of the region, where municipal water infrastructure is absent and DAWASA's river-fed supply systems do not reach. Over-abstraction also carries ecological consequences. It can deplete wetlands and groundwater-fed rivers, undermining critical ecosystem services like water purification and flood control that indirectly sustain communities and livelihoods (DAWASA, 2017).

Areas at particular risk would be those where **groundwater use is high relative to recharge**. The Quaternary Aquifer is an example of such an area where unsustainable groundwater use is thought to be affecting the ability of the aquifer to recover during recharge periods (Mtoni et al., 2011; Van Camp et al., 2013; Sappa and Luciani, 2014; Skinner and Walnycki, 2016). Along the coastline in the south and north of the region, over-abstraction is also thought to be causing seawater intrusion. Official sustainable abstraction yield estimates for the Quaternary Aquifer and Kimbiji Aquifer are thought to be overestimated. While the full stage development of the Kimbiji Aquifer is ongoing, recharge of this system may be unable to keep up with abstraction over its long-term future.

Key factors increasing vulnerability include the lack of:

- Regulations and their enforcement
- Monitoring data
- Recharge data
- Sufficient water supply infrastructure
- Governance gaps

Despite monitoring and management mechanisms in place, the efficiency and effectiveness could be improved. These governance gaps have led to an increase in vulnerability across sectors and users, especially for those without the financial resources to mitigate hazards.

## Population Exposure and Groundwater Dependency

Dar es Salaam's dependency on groundwater has grown significantly since the beginning of the millennium. While surface water from the Ruvu and Mtoni rivers has served as the main source of municipal water to the region's population, their dependency on groundwater has increased due to infrastructure challenges and climate change. 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 in planned and unplanned areas, much of the regional south where infrastructure does not reach, industries and farmers that rely on groundwater for manufacturing, cooling and irrigation. Within Dar es Salaam, Industries and farmers are highly dependent on groundwater to ensure that there is a sufficient supply for their operations. These users and their employees would especially be at risk as disruptions to industrial and food production would harm both sectors financially and the consumers of these products.

## Density and Hotspots

Areas with a high density of boreholes are considered especially vulnerable to over-abstraction and its impacts. Clustered abstractions (especially when unregulated) can rapidly deplete shallow groundwater reserves, thereby reducing availability and storage. Much of the central areas of **Temeke** and **Ilala** are especially at high risk, as these areas hold most of the industrial (high-yielding production boreholes) and what is considered unregistered borehole use in the region (see Figure 3-6). Given these areas are located over the highly transmissive Quaternary deposits, long-term overuse will likely lower the local water table, impacting shallow wells.

Unplanned areas where unregulated use has increased due to growing populations and a lack of infrastructure are also considered highly vulnerable areas. Continued unsustainable use of groundwater from the Quaternary Aquifer will likely result in significant reductions in groundwater availability. Without the financial means to drill deeper holes, these communities are highly vulnerable to over-abstraction. The identification of these wells, water points and boreholes would greatly improve groundwater management, as water resource institutions would have the necessary information to make informed decisions on aquifer management.

## Socio-Economic Status

Low-income communities and farmers with unregistered boreholes, wells and communal points are the most likely to initiate over-abstraction, as their abstraction of groundwater is often unregulated. While industrial users possess the finances to establish high-yielding boreholes, many of these businesses are required to adhere to abstraction limits. Those in the industrial sector with private and unregistered boreholes, however, could greatly contribute to over-abstraction.

## Water Supply and Service Access

Communities fully reliant on municipal water are partially protected against localised groundwater over-abstraction in Dar es Salaam. Unpredictable service disruptions ensure that groundwater abstraction infrastructure, either private or community-based, remains on standby (see Figure 3-5). **Kinondoni** and **Ubungu** are the two main administrative districts where this occurs, while parts of **Temeke** and **Ilala**, closest to the region's city centre, also experience the same conditions.

Unplanned areas and much of the regional south, where piped water is either not developed or currently in the process of being developed, would be the most affected by over-abstraction. Especially unplanned areas in **Temeke**, **Ilala** and **Kigamboni** would be highly vulnerable, as there would not be a backup supply of water to rely on. The city centre and high-income areas (i.e. Kariakoo, Oyster Bay, Masaki, Mikocheni, Upanga, Kisutu, Kivukoni and Mbezi Beach) with piped access to municipal supply would be the least vulnerable. This creates an unequal distribution of risk and vulnerability, as areas with diversified or multiple supply options (usually affluent, well-served areas) are less vulnerable, while those with limited resource dependency (often poorer peripheral communities) are very vulnerable to that resource being overused.

## Summary

Low-income households, farmers and industries with private and unregulated boreholes are more likely to abstract groundwater at unsustainable yields. Vulnerability is pronounced in marginalised communities, as well as farmers and the industrial sector, as the groundwater these users rely on may become depleted through excessive use.

Key factors:

- Inequitable access to piped municipal supply
- Weak regulation/enforcement in high-use areas
- Dependence on shared groundwater resources

### 4.2.2.3. Sea-level Rise

Sea-level rise is a slow-onset hazard caused by the melting of ice caps due to climate change. Location of aquifers, their geology and their elevation are the three factors responsible for whether users are vulnerable to sea-level rise. The Quaternary deposits and their aquifers found along the coastline of the Dar es Salaam region are thought to be the most vulnerable to sea-level rise. The two main impacts of sea-level rise are inundation due to rising water tables and salinisation of coastal aquifers due to seawater intrusion. Saline intrusion of seawater makes groundwater unfit for human consumption, agriculture and most industrial processes. Once an aquifer turns brackish, this change in quality becomes a challenge for users who consume groundwater and users who use it for irrigation and industrial processes.

Treatment of groundwater becomes a necessary measure to ensure affected groundwater is fit for use and consumption. This can become costly and resource-intensive, which can create inequalities in the groundwater landscape. Industries located along the **Msimbazi Estuary** may be the most vulnerable to seawater intrusion as rises in sea-level could shift the saline wedge further inland of the Quaternary Aquifer. Without sufficient treatment, use of this water could damage equipment and or interfere with manufacturing processes.

The socio-economic vulnerability to this hazard is driven by **location and dependency**. Communities abstracting water with shallow wells in low-lying coastal settlements would be the most vulnerable, especially those where dependency is high. Parts of **Temeke**, the regional south in **Kigamboni**, and where piped access is unavailable along the coastline of **Kinondoni**, would be vulnerable, especially in unplanned areas where finances and resources are limited and therefore the ability to mitigate these impacts is low. Domestic use, farming and industries in these affected areas would be affected by seawater intrusion. Inundation occurs along Dar es Salaam's coastline, but major impacted areas are mostly confined to parts of **Kigamboni's** coastline and **Msimbazi Estuary**. Unlike contamination or drought, vulnerability to sea-level rise is less about income level and more about geography, although financial resources can determine coping capacity and adaptation. Generally, seawater intrusion is a slow-onset hazard that might not be felt until it is advanced, at which time reversal is difficult to achieve. Areas with a lack of monitoring for salinity are more vulnerable, as proactive monitoring will not provide DAWASA and the WRBWB with the necessary information to make informed management decisions.

### Coastal Aquifer Dependency

Coastal communities and aquifer users are the primary exposed user groups. Groundwater abstracted around Dar es Salaam's coast, especially where dependency on groundwater is high, will likely be the most compromised by increased salinity due to sea-level rise, including salinisation.

### 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 lead to service outages affecting the community (often it is the adjacent poorer communities that suffer if sewage infrastructure fails). Coastal agriculture along **Kigamboni** and parts of **Kinondoni** could see soil salinisation from sea-level rise. Small-scale farmers or community gardens might find their groundwater gradually becoming saltier, which can damage crops and soil over time, directly impacting food security and incomes. Salinisation due to over-abstraction has already been observed in several locations along Dar es Salaam's coasts, which could be exacerbated by sea-level rise.

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

- **High-income coastal residents** (Oyster Bay, Masaki, Mikocheni, Kunduchi and Mbezi Beach) typically do not solely rely on groundwater as they tend to have piped access to municipal supply. Households in these areas still make use of boreholes due to service disruptions. Their main source of water is from the municipality. Many of these residences would be able to afford the necessary measures to mitigate damages from sea-level rise.
- **Low-income and informal coastal residents** (Mbweni, Mjimwema, Gezaulele, Keko Machungwa, Mtoni, and Kijichi) are the worst off, with limited to no financial resources to mitigate the impacts of sea-level rise. Little to no medium-income areas are located along the coast, with most falling under informal to low-income. These residents are less likely to have access to insurance or health care. Any damage to property or changes in their health due to water inundation would impact them harder and for longer.
- **Industries** are more likely to resist the impacts of sea-level rise, so some may have the finances and resources to relocate or install treatment systems to prevent salinity of their process water.
- **Farmers** are generally not found along the coastline, only in a few areas of Kigamboni and Kinondoni. They are less resilient to these impacts as they may not have the same access to finances and resources as Industries.

### Health and Social Impacts

Highly salinised and rising groundwater can have significant health implications for communities. The use of saline water for consumption can cause dehydration and kidney damage. Moreover, inundation of water can increase the risk of water-borne diseases. Stagnant water in unplanned and informal areas can become breeding grounds for pathogens, and when combined with sewage outflows, residents can develop diarrheal diseases, skin infections and other related illnesses. Those with weakened immune systems, such as kids and the elderly are highly vulnerable. Flooding could also cause social issues as displaced residents would need to relocate to other areas which may cause overcrowding and conflicts over land.

### Summary

Coastal communities and users dependent on groundwater near the shoreline are more vulnerable to sea-level rise and its associated impacts than those further inland and away from water lines. Communities, industries and the few areas of agriculture along the coast are exposed to the risks of salinisation and water inundation should sea-levels rise.

Key factors:

- Proximity to coast
- Lack of reliable water infrastructure
- Low socio-economic resilience to water quality degradation

#### 4.2.2.4. Reduced Recharge

Climate change-induced changes in rainfall are expected to continue across Dar es Salaam. It is likely that the meteorological conditions will continue to cycle between baseline conditions and periods of intense rainfall over shorter wet seasons and an extended dry season. Disruptions to the hydrological cycle will likely reduce natural recharge to Dar es Salaam’s aquifers.

Socio-economic vulnerability to reduced recharge is related to both drought-driven water shortages and inadequate municipal supply. Generally, groundwater is viewed as a buffer during times of drought. However, the region of Dar es Salaam has been highly dependent on groundwater over the last two decades, and despite an increased development of water supply infrastructure, frequent service disruptions have meant reliance on groundwater has remained a necessary alternative. Where water supply infrastructure remains undeveloped, groundwater is the major source of water.

Should climate change-induced reductions in groundwater recharge continue, many communities of various socio-economic backgrounds will be affected. The most vulnerable are communities with high water demands and low adaptive capacity, this is often the most economically and socially marginalised groups. Low-income households have fewer coping mechanisms and often live in areas where communal water infrastructure and private water vending are already strained. While high-income households will still experience the impacts of reduced groundwater availability, they are more likely to have access to piped water and alternatives (see Figure 3-5 and Figure 3-6).

Reductions in groundwater availability and storage due to reduced recharge will also affect the agricultural sector significantly. Many farmers in areas without surface water will rely heavily on groundwater to provide water for irrigation. Disruptions to agriculture could result in significant financial losses, as well as impact the food supply chain of the region. Famines are often closely associated with periods of drought, and it is the most economically and socially marginalised groups who will be the most affected by these disruptions.

Industries would also likely be affected by reductions in groundwater availability, as many industries in Dar es Salaam have become dependent on groundwater to maintain a consistent supply of water for industrial processes. Disruptions to their supply and associated water restrictions during times of drought could cause major financial stress on businesses and industries, and in worst-case scenarios, result in closures, further widening socio-economic disparities.

#### Population Sensitivity and Vulnerable Groups

The sensitivity of Dar es Salaam’s population to reductions in groundwater availability due to reduced recharge is quite high. Those in unplanned and informal areas, however, are considered to be at a higher sensitivity as they often face supply challenges and lack access to services. During times of drought, water supply alternatives which have become a crucial component of their daily water supply and are already strained would likely face major disruptions. These areas, in either personal, communal or through private vending, make use of groundwater. Should reductions in groundwater availability occur, these parts of the city’s population will be the most impacted.

Children and infants from these areas will be the most susceptible to dehydration and sanitation-related illness. The elderly and disabled are also considered very vulnerable, especially when water is fetched across long distances. While users in more affluent areas may also rely on groundwater due to municipal disruptions, they may still mitigate the effects of such reductions with the additional income they receive. Overall, the socio-demographic profile of Dar es Salaam indicates that many households that live in poverty are the most vulnerable to declining groundwater availability.

### Economic and Livelihood Vulnerability

Drought and reduced recharge also have significant economic and livelihood implications, which directly influence socio-economic vulnerability. Commerce, industries and sectors which require water to operate would be greatly impacted in Dar es Salaam. Generally, during times of drought, when water supply is disrupted, daily production is altered and jobs are lost. Many of these jobs belong to low-wage workers. This deepens poverty and, when examined from an agricultural perspective, causes and exacerbates food insecurity. Businesses such as Tanzania Breweries, Coca-Cola Kwanza, the textile manufacturers, tanneries, hotels and manufacturing industries all make use of groundwater during production. The combination of reduced groundwater availability and drought-induced municipal water restrictions would cause these businesses to scale back production or incur extra costs to continue operations, which would lead to layoffs of mostly lower-income employees, further contributing to socio-economic disparities.

Within unplanned and informal areas, peri-urban farming and informal traders who make use of groundwater, where municipal supply is unavailable, would also be greatly impacted by these changes as their livelihoods are directly linked to their ability to continue their operations.

Socio-economically, those with the least financial resilience (low-income workers, farmers and informal traders) are the most vulnerable to the impacts of drought and reduced groundwater availability.

### Socio-Economic Status

Regardless of socio-economic status, the effects of reduced groundwater availability would be felt by all of Dar es Salaam's population. Disruptions in water supply services in high-income areas force these households to remain connected and reliant on private and distributed borehole systems. While these areas would still be vulnerable to reductions in water availability, their access to finances and resources will likely aid in mitigating the effects of drought. Wealthier households are more likely to afford water treatment systems, install large water reservoirs and drill deeper boreholes to access deeper stored water.

Low-income households, as well as those in unplanned and informal areas, however, are highly vulnerable to the impacts of reduced groundwater availability. Low-income households do not possess the same finances and resources as high-income households, and while government initiatives have sought to provide many households in planned and unplanned areas with small-scale water reservoirs, these low-income households would not be able to afford alternative systems and or drill deeper boreholes. Residents of unplanned and informal settlements where municipal water is non-existent or communal would exhibit the highest vulnerability, as they would have a very low adaptive and coping capacity to these impacts. They do not have access to the finances necessary to drill deeper or to find alternative sources.

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 a lack of water availability. Large, well-capitalised industries can afford to install on-site water treatment facilities, allowing them to abstract 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 reserves.

## Water Supply and Service Access

While areas in Dar es Salaam with water supply infrastructure are considered less vulnerable, supply losses and service disruptions negate the expected benefit of these systems and therefore, while the presence of infrastructure would result in an improved vulnerability, much of Dar es Salaam is considered highly to very highly vulnerable to reduced groundwater availability. Those in unplanned and informal areas are considered the most vulnerable, while industries and high-income households with some forms of infrastructure are considered vulnerable but to a lesser magnitude (moderate to highly vulnerable).

## Summary

Many of Dar es Salaam's users, especially those located above the region's Quaternary Aquifers, which are highly dependent on direct meteorological recharge, are vulnerable to climate change-induced reductions in recharge and groundwater availability. Vulnerability increases for communities and those dependent on rain-fed agriculture, especially where municipal water, surface water and private vendor alternatives are lacking.

Key Factors:

- Effective governance and management of key aquifers
- Monitoring and regulation of unregulated boreholes
- Development of extensive and reliable infrastructure
- Development of water scarcity resilience to climate change for users in the agricultural sector, as well as for communities without the resources to build adaptive capacity.

### 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 the surface.
- Over-abstraction and reduced recharge:
  - Reduced summer baseflows in rivers and estuaries;
  - Reduced water levels in wetlands, riparian areas and some forests;
  - 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).

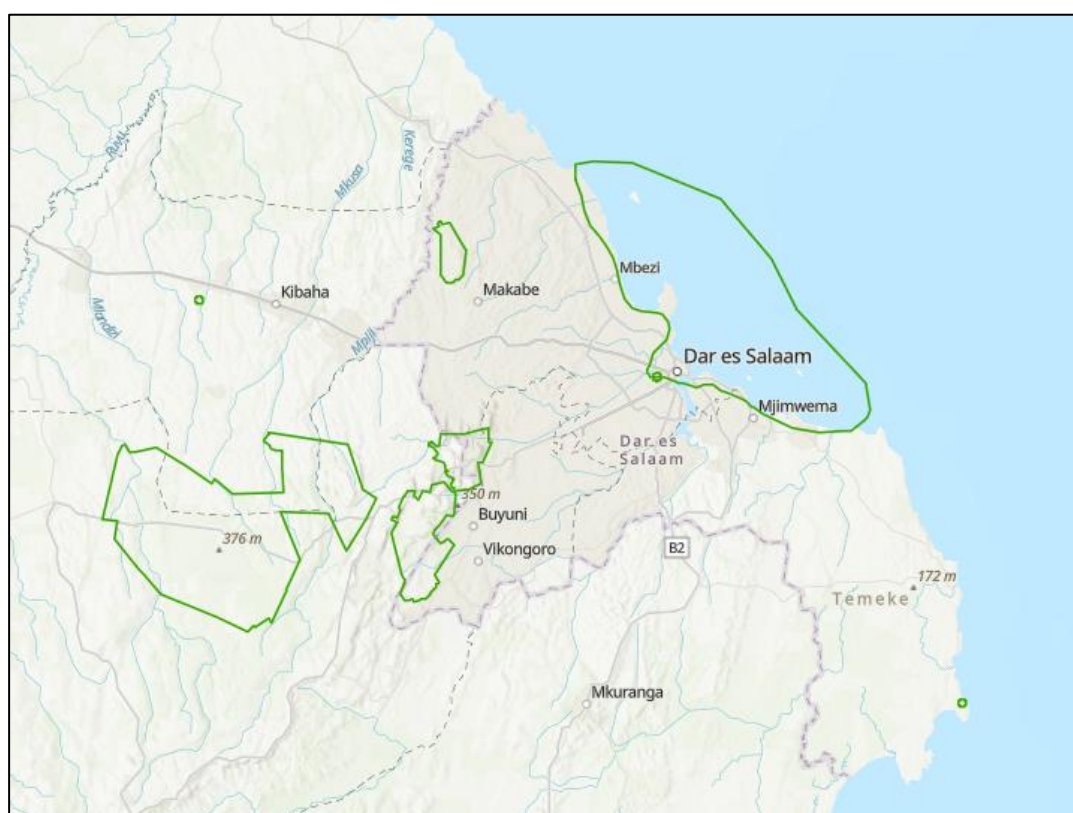
**4.2.3.2. Extent of Exposure**

The extent of exposure will depend largely on the degree of dependency of any ecosystem on groundwater as a source of water. The surface water ecosystems and terrestrial ecosystems of Dar es Salaam that may be groundwater-fed are described in **Section 2.1.4**. 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. GDEs have not been well mapped, nor have their ecosystems been described in the Dar es Salaam region.

**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 information on 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. Tanzania is a signatory to the Ramsar Convention, and there are four Ramsar sites in the country. None of these are close to the City of Dar es Salaam. The KBAs are shown in **Figure 4-4**.



**Figure 4-4** There are three Key Biodiversity Areas in and close to Dar es Salaam, located to the west of the city centre. These are areas of global biodiversity importance, that are sensitive to the impacts associated with groundwater-related hazards.

Above the Kimbiji Aquifer, pockets of wetlands have been identified during the strategic environmental assessment for the development of the Kimbiji and Mpera wellfields. These wetlands vary from surface water-dependent to groundwater-dependent. The extent of some of these identified wetlands can be observed in **Figure 4-5**, however, it was acknowledged for the purposes of that assessment that it was not feasible to delineate all the wetlands in the region (DAWASA, 2017). There remains a large gap in the complete mapping and assessment of wetlands throughout the region. It is thought these potential GDEs could potentially be impacted should the water table drop below the simulated regional water table depth (4m), during ongoing municipal abstractions of the Kimbiji Aquifer. Their findings highlight the need for improved and more detailed wetland surveying and monitoring, especially those which may be affected by wellfield operations. Wetlands situated atop the Quaternary Aquifer should also be included, as the delineation and monitoring of GDEs connected to this system is poorly described.

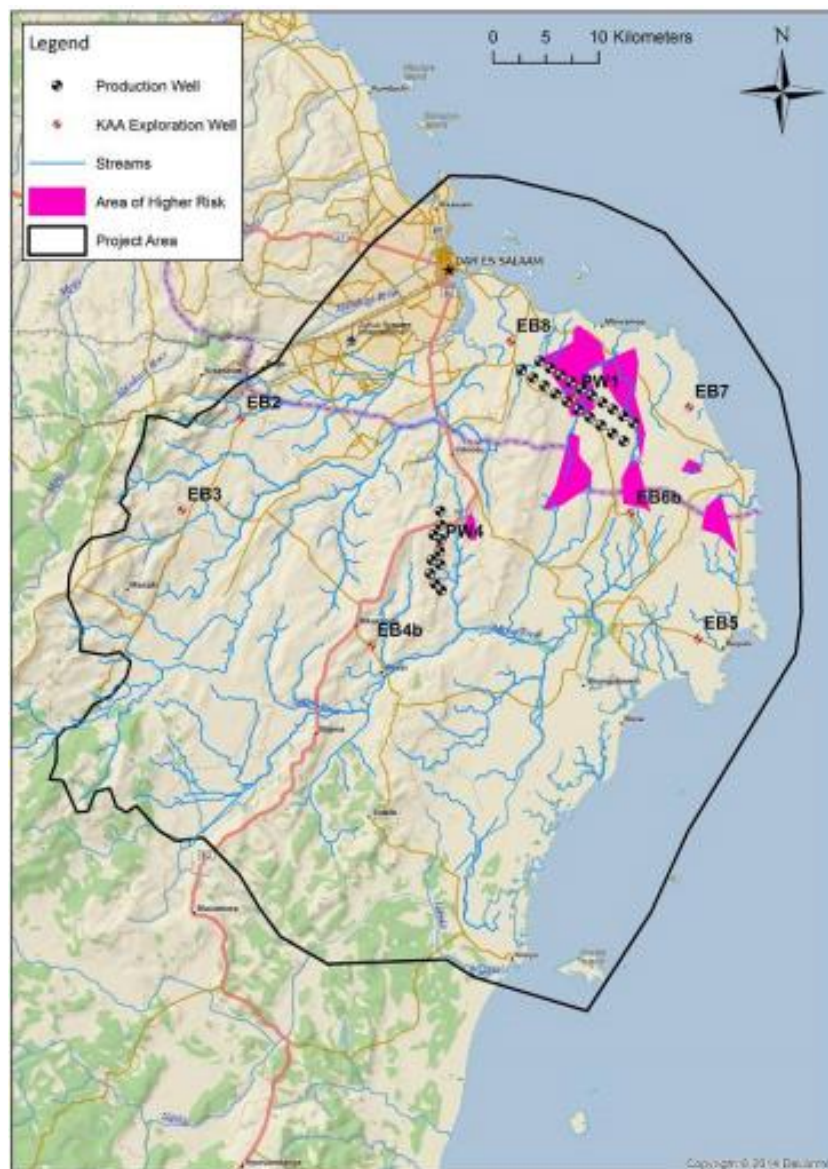


Figure 4-5 Areas of potentially higher risk of impact to wetlands (DAWASA, 2017).

## 5. Coping Capacity

### 5.1. Introduction

This section provides an overview of the coping capacity of different groundwater users in the City of Dar es Salaam. 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 5.1**.

### 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 Dar es Salaam, 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 Dar es Salaam, coping capacity depends on factors such as the availability of water treatment facilities, alternative water sources, effective water-quality monitoring, and responsive governance. In Dar es Salaam, the coping capacity to groundwater contamination is poor and unevenly distributed across the city due to infrastructure gaps, socio-economic inequalities and governance challenges.

#### Local Institutions and regulations

The Tanzanian National Water Policy (2002) version 2025 acknowledges the need to protect groundwater resources from contamination, especially in areas of rapid urbanisation, poor sanitation and industrial activity such as Dar es Salaam. The policy calls for pollution prevention as a central strategy for groundwater protection. It also emphasises that groundwater should be managed on the basis of aquifer boundaries and in conjunction with the river basin, and calls for an effective system for controlling pollution to be developed for vulnerable recharge areas, which should also be delineated and declared as protected areas. The policy also urges the need for monitoring, enforcement and cross-sector collaboration. The policy delegates responsibility to the Ministry of Water and basin water offices to establish and implement guidelines and regulations that counter groundwater pollution.

The Water Resources Management Act No. 11 of 2009 (and its 2022 amendment) provides a legal framework for the management and protection of water resources in Tanzania. It calls for the protection of water resources through regulatory standards and the identification of pollution offences, and the issuing of penalties by the basin water board. However, despite such legal provisions, the implementation and enforcement of pollution control measures in Dar es Salaam remains weak, resulting in a limited coping capacity in this regard. Improving this will require the strengthening of institutional capacity by the WRBWB, which should include enhancing enforcement, expanding monitoring networks, and improving coordination and collaboration with other government agencies, the private sector and local communities.

### Access to Alternative Water Supply

A major weakness in Dar es Salaam's ability to cope with groundwater contamination is DAWASA's poor water supply network. Only a fraction of Dar es Salaam's population is fully supplied with treated municipal water (see Figure 3-5 for water supply patterns across the region), causing many communities to rely on groundwater as an alternative source of water, particularly in the south, where water supply is even more limited. When this groundwater becomes contaminated, these communities can face serious health risks due to poor water quality.

A more extensive and reliable municipal water supply would provide a buffer against groundwater contamination. Currently, the limited reach of the treated water significantly affects the region's ability to cope with groundwater contamination. This poor coping capacity is further worsened during drought periods when rainfall is limited and evaporation rates are high, since 90% of Dar es Salaam's water supply by DAWASA comes from surface water (Upper Ruvu, Lower Ruvu and Mtoni Rivers).

In the absence of a municipal water supply, particularly in the southern parts of the region, communities also rely on private vendors such as pushcarts, water kiosks, and tanker trucks as an alternative source. However, these private vendors are unregulated and also often source their water from shallow or poorly maintained wells that may be contaminated.

### Diversification and Technical Measures

DAWASA is improving its technical coping capacity through diversifying water sources, most notably through the development of the Kimbiji and Mpera wellfields. These wellfields target the deep Kimbiji Aquifer of the Neogene Aquifer System, which is largely confined and therefore more protected from surface water contamination, resulting in better water quality. However, infrastructure challenges and constraints exist, including delays in the construction of water treatment facilities and transmission pipelines. This development aims to improve water supply security for the city of Dar es Salaam and some areas of the coastal region, e.g. Mkuranga district.

### Awareness and Education

Although several studies on groundwater contamination have been conducted for key aquifers in Dar es Salaam (Mussa et al., 2019; Van Camp, 2014; Stuart et al., 2021), their findings have not been effectively communicated to communities and other relevant stakeholders. As a result, the public remains largely unaware of the extent of groundwater contamination and the associated health risks it poses, particularly when contaminated water is ingested. This includes potential vulnerabilities and hazards that contribute to disaster risks.

Moving forward, it is essential to raise community awareness by improving education on the risks of groundwater contamination, as well as the preventative measures that can help reduce groundwater contamination and protect public health. For example, teaching communities, particularly women who are often responsible for collecting water, that discoloured or foul-smelling well water may be unsafe to use, can help reduce exposure to contamination. Strengthening grassroots-level knowledge and engagement is a key component of building long-term coping capacity.

### Household Assets and Adaptation

Coping capacity at the household level varies widely. Household assets like storage tanks for rainwater harvesting, or simply the financial means to buy alternative water, greatly increase resilience to contamination. For example, many households in informal low-income settlements with little to no municipal water supply purchase water from private vendors such as pushcarts, water kiosks, and tanker trucks. However, due to extreme poverty in some areas, residents are unable to afford sufficient water for their household needs and resort to extracting water from shallow groundwater sources, which in some parts of the city may not be safe for human consumption (Andersson, 2019). These shallow aquifers usually have high chloride levels and are easily polluted by industrial effluent and sewage, particularly during the rainy season (Andersson, 2019).

Furthermore, water treatment technologies (e.g., filters and chlorination) are often unaffordable for low-income households, leaving them more exposed to contaminated groundwater.

In essence, for some households, the financial ability to purchase water or invest in water treatment provides adaptive capacity (alternate sources, treatment), whereas the poor have no option but to rely on groundwater that may be contaminated.

### 5.2.2. Over-abstraction

Excessive groundwater abstraction to meet the growing water demands of the region has caused a decline in the water table, reducing overall groundwater availability. Studies by Mjemah (2007), Mtoni et al. (2011) and Andersson (2019) indicate that over-reliance on the Quaternary Aquifer has significantly contributed to this decline. Moreover, the central areas of Dar es Salaam are extensively covered by impervious surfaces, limiting natural recharge in the area and increasing the aquifer's vulnerability to depletion. In severe cases, aquifer depletion and storage losses can result in aquifers becoming permanently damaged.

Coping capacity for over-abstraction refers to the ability of a city and its communities to effectively manage water demand, supplement or conserve groundwater to prevent aquifer depletion. High coping capacity is characterised by effective governance, regulatory enforcement, alternative water sources, and adaptive community behaviours described below. A critical challenge that weakens the region's resilience is the limited availability of reliable data on groundwater use and recharge rates. This lack of information creates uncertainty in identifying areas at risk of over-abstraction, which in turn undermines the ability of institutions and users to respond effectively. As a result, this knowledge gap negatively affects the coping capacity of all groundwater users. To avoid further degradation, the region's coping capacity must be strengthened.

### Regulation and Governance

Effective governance is the first line of defence in coping with over-abstraction. Currently, **regulatory capacity is limited**. While national laws such as the National Water Policy of 2002 version 2025 and Water Resources Management Act No. 11 of 2009 (and its 2022 amendment) provide a legal framework for the sustainable use of groundwater, the implementation and enforcement of this policy and act by the WRBWB remains weak. The WRBWB is responsible for issuing water use permits, managing groundwater abstractions, conducting groundwater monitoring, and overseeing planning and allocation. However, these functions are not being carried out effectively. For example, a major challenge is the city's lack of planning for a scenario of widespread groundwater use, leaving the resource vulnerable to over-exploitation.

The registration and monitoring of private boreholes in Dar es Salaam is poor. As a result of this poor enforcement, many unregistered boreholes that were drilled without permits from the basin board exist in Dar es Salaam (Mtoni et al., 2011). Mato and Mjwahuzi (2010) also reported that out of 500 boreholes randomly visited during a groundwater assessment, about two-thirds of them were unregistered. The abovementioned highlights the severity of this lack of enforcement, which ultimately results in the unregulated abstraction of groundwater in the region. As a result, the WRBWB likely underestimates groundwater use volumes to a large extent, which is evident from the dataset provided by the board for the current assessment. The current groundwater use volumes provided by the WRBWB analysed for this assessment evidently underestimates groundwater use volumes for the districts of Ubungo, Ilala and Kinondoni. For example, there are no groundwater use volumes registered for agricultural use, even though these districts consist of agricultural lands.

Even in cases where groundwater users are registered and hold water use licenses with specific conditions, such as permitted abstraction volumes, many still abstract beyond permitted limits. Such over-abstraction is rarely penalised, providing very little motivation for groundwater users to comply with regulations. Furthermore, routine monitoring of groundwater levels is limited, resulting in insufficient data on groundwater levels on key aquifers such as the Quaternary and Kimbiji aquifers, which the community and various sectors depend on. This lack of monitoring hinders the early

detection of groundwater depletion and limits informed proactive decision-making, resulting instead in a reactive approach to groundwater management. Enforcement of the various legislation and regulations remains a challenge. Effective implementation of these legislations, regulations and policies requires coordination and collaboration among government agencies, Basin Water Boards, private sector operators and local communities.

Although still lacking as described above, it is important to note that steps towards strengthening the implementation and enforcement of the Water Resources Management Act No. 11 of 2009 have been taken. The Ministry of Water has developed several digital platforms aimed at improving the management of water use and permits in Tanzania. To date, several systems have either been developed or are in the final stages of development. These include the Water User Information Management System (WUIMS), the Maji Information System (Maji-IS), the Operational Decision Support System (ODSS) and the Water Use Permitting Analysis Tool (WUPA).

**Diversification of Water Sources**

In Dar es Salaam, a growing water demand largely driven by urbanisation, reduced surface water and poor water supply coverage has led to an over-reliance on groundwater, particularly Dar es Salaam’s shallow Quaternary Coastal Aquifer, which many residents rely on (Mtoni et al., 2011). To meet the city’s increasing water demands, plans are underway to abstract groundwater from the deep Kimbiji Aquifer system through the Kimbiji and Mpera wellfields (Karutz et al., 2019). This shift is expected to improve the municipal water supply and reduce pressure on the shallow Quaternary Aquifer, thereby helping prevent over-abstraction and promoting more sustainable groundwater management across the region.

**Community Engagement and Awareness**

Risk assessments on the threats and impacts of groundwater over-abstraction have been conducted (Mussa et al., 2019; Van Camp, 2014; Stuart et al., 2021). However, the findings from these studies have not been sufficiently or effectively communicated to key stakeholders and communities, particularly women who are usually not effectively represented or included in community meetings. Consequently, the awareness of groundwater availability and the risks of overusing the resource is not well understood by those who rely on the resource. The availability and accessibility of disaster and climate risk information are limited to the national government and stakeholders (URT, 2023).

Going forward, it is essential to educate and empower communities, including women, about the risks associated with over-abstraction and the preventive measures and behavioural changes that can be made to promote responsible use (UPgro, 2025). It is especially important more is done to include and empower women in disaster risk reduction structures. Building awareness of the importance of protecting groundwater resources, particularly within recharge zones, is critical for ensuring long-term sustainability (Yadav et al., 2025).

**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. Since intrusion is often gradual and effectively irreversible once it contaminates an aquifer, coping is more about prevention and ensuring water supply resilience. The WRBWB has invested many resources and time to develop a plan for building coping capacity towards the impacts of sea-level rise.

To mitigate the impacts of sea-level rise, an approach aimed at reducing exacerbating factors and implementing sufficient monitoring has been adopted. The WRBWB started with the establishment of coastal monitoring boreholes specifically to provide early warning of salinity increases and to provide better information on current areas where salinisation has become a problem. The water board is still developing its monitoring network and where it has already been implemented across the region, efforts to meet a satisfactory level are being made. The aim of coastal monitoring is to inform governance, such that restrictions for private abstraction and or operational adjustments to

DAWASA-run production wells in the Quaternary Aquifer can be implemented and the rate of intrusion minimised. This indicates a moderate coping capacity as systems are only now being implemented and problem areas identified. Other coping measures include developing alternative water sources, engineering solutions and the protection of mangroves, which are known to buffer salinity. The development of the Kidunda Dam is an example of how the WRBWB is pursuing alternative measures to increase water supply and reduce groundwater dependency.

Building resilience is hampered by a lack of technical capacity and financial gaps, which hinder the formulation of integrated plans that connect the development of key sectors with the needs of vulnerable people. This also affects the implementation of plans, including ensuring effective groundwater management, monitoring and enforcement of regulations (Stuart et al., 2021). Dar es Salaam’s city master plan (2016-2036) notes the importance of building resilience to climate change impacts for the city, especially those of sea-level rise, flooding and rising temperatures. To reach these goals, multiple national adaptation strategies and climate adaptation project partnerships between local and international partners have been implemented.

**Policy and Long-Term Adaption**

Dar es Salaam is strengthening its institutional capacity to address seawater intrusion through policy reforms and long-term adaptation strategies. The City’s Coastal Zone Management Plan and Tanzania’s National Water Policy (2023 revision) explicitly recognises saltwater encroachment as a growing climate risk, mandating integrated approaches to protect freshwater resources. Key measures include attempts at regulated groundwater extraction in coastal aquifers, promotion of alternative water sources like expanded Ruvu River supply systems and investments in decentralised desalination pilots for vulnerable neighbourhoods. 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.

The City’s Master Plan incorporates coastal protection measures such as mangrove restoration and setback regulations for development near shorelines. This helps maintain natural barriers against saltwater intrusion. Monitoring systems for aquifer salinity levels are being upgraded through partnerships between Water Resources Integration Development Initiative (WAMI) and academic institutions (University of Dar es Salaam, Ardhi University, Stockholm Environment Institute), though data coverage remains uneven across the city’s northern and southern coastal zones, and often insufficient. As part of Dar es Salaam’s urban Resilience Programme (DURP), the Msimbazi Large Scale Redevelopment and Rehabilitation Plan was put together to integrate flood control with green spaces and land use reform. It primarily aims to upgrade drainage infrastructure in Tandale and Kigogo, through permeable paving, green belts and wastewater recycling.

The establishment of a Coastal Water Task Force in 2022 marked an important step toward interagency coordination. Looking ahead, scaling up nature-based solutions will aid in mitigating the impacts of flooding. The effectiveness of these measures will depend on sustained budget allocations, community engagement in coastal protection, and integration of sea-level rise projections into urban planning frameworks as climate change intensifies.

**Coastal Protection and Land-Use Planning**

Coping with rising groundwater also involves non-water-specific strategies. **Coastal protection infrastructure** like sea walls and mangrove protection can mitigate how far inland seawater encroaches, indirectly protecting coastal aquifers such as the City’s Quaternary Aquifer. Protection and rehabilitation of the region’s mangroves have been a priority of the government to mitigate salinisation and flooding. Proposed structural changes to the Msimbazi Estuary along its banks have been explored, while sea walls are primarily installed near the harbour of the city. However, for much of the city’s coastal plain, there is a lack of sea walls. **Land-use planning** is a more proactive capacity measure. The City can enforce setbacks and prevent new developments in the most sea-level rise-vulnerable zones, and the use of green-blue infrastructure can also be included in further developments.

## Technical Measures

Currently, technical capacity to combat saltwater intrusion in Dar es Salaam is considered low. Resources are already spread thin amongst the WRBWB projects and programmes. Funding from local and international partners is a major source of finances for the basin's projects and programmes. Strategies such as capturing and channelling stormwater and treated wastewater into infiltration ponds located between the coast and high abstraction areas are options explored by some coastal cities around the world. Due to a lack of sufficient stormwater management and distribution infrastructure in Dar es Salaam, such systems would be difficult to implement. The Kimbiji Aquifer in the south is thought to be well protected from seawater intrusion due to its natural conditions and inland wellfields not susceptible to seawater intrusion. The Quaternary Aquifer, especially located along the coastline, is the most vulnerable to sea-level rise. Building technical capacity in this regard would require significant funding and institutional commitment to ensure the successful and effective implementation and management of such measures.

## Water Supply Adaptability

Dar es Salaam's current water supply adaptability is very low. Should salinisation continue to occur in the Quaternary Aquifer (which is already stressed and fragile), the aquifer would unlikely be able to keep up with water demand. The connection of the Kimbiji wellfields to DAWASA's distribution grid may be able to assist with the deficit this would cause. However, this could also lead to over-abstraction and deterioration of water quality in the Kimbiji Aquifer. The use of **desalination** to treat brackish groundwater and saline seawater has been discussed as an alternative to improve water supply adaptability in the City. However, the associated costs with establishing and maintaining such a system permanently or in an emergency scenario would be a significant challenge to its implementation. The **absence of an extensive and efficient water supply grid** that covers coastal communities is largely responsible for the high dependency on groundwater in these areas. Focus on improving water supply adaptability has been heavily on developing the Kimbiji Aquifer, Rufiji River Water Project and increasing the current capacity of surface water reservoirs.

## Monitoring and Early Warning

An important factor in coping capacity is the ability to **monitor changes in groundwater due to sea-level rise**. The implementation of monitoring systems has become a priority for the WRBWB across the basin. Several existing boreholes have been utilised as monitoring holes, with many thought to have been drilled or planned for the future in Dar es Salaam. The monitoring network is therefore still under development. These boreholes are part of the WRBWB's approach, providing effective management of the region's coastal aquifers. By having an early warning of saltwater intrusion or further deterioration of already salinised boreholes, abstraction restrictions can be introduced and pumping patterns adjusted to reduce the rate of salinisation until groundwater recharge during the wet seasons can create seasonal changes to the groundwater gradient or levels of salinisation become catastrophic.

This technical capacity is still in its early stages of development, but is part of an early warning ecosystem the region is hoping will inform on the early stages of disaster and improve disaster management. It is part of the City's hopes to align with the Disaster Management Act, No. 6 of 2022 (which replaces Act no 7 of 2015). The act provides a comprehensive framework for preventing, mitigating, preparing for, responding to and recovering from disasters. These components have been incorporated into the National Disaster Management Strategy (2022-2027) as a response to increasing extreme natural events and the effects of climate change. The aim is to strengthen national disaster resilience through inclusive, comprehensive and integrated disaster risk management measures (URT, 2022a). Targeting the Kimbiji Aquifer is effectively the implementation of these practices by establishing wellfields designed to target deeper groundwater and further inland to mitigate against future intrusion. Having a scientific basis for action improves long-term coping.

Due to limited financing, the government is working on establishing a disaster risk reduction (DRR) financing framework to improve national coverage and leverage regional and international financing opportunities. Guidelines for the preparation of plans and budgets for all sectors to ensure DRR is mainstreamed and planning and budgeting have been developed. Regrettably, cross-sector collaboration for effective and efficient disaster risk financing management is low (URT, 2023). Furthermore, a lack of training and capacity building on gender responsive DRR to stakeholders has been an ongoing issue. Gender is not adequately integrated into all aspects (early warning systems, evacuation planning and recovery efforts) of DRR. Given the current state coping capacity is considered to be between low to moderate until all initiatives are established and sufficiently operated.

### Community and Household Coping

At the community level, coping with sea-level rise-groundwater impacts is challenging, largely due to 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 local and international community organisations that actively engage with the city's governance and stakeholders on coastal issues. In low-income areas and unplanned settlements, non-governmental organisations (NGOs), both local and international, help by providing water purification options if the usual sources are degraded. Ultimately, household coping capacity for this hazard is limited by finances and since sea-level rise is gradual, many low-income households simply live with worsening conditions until external help arrives. Coping capacity for these households is considered very low.

#### 5.2.4. Reduced Recharge: Due to Climate Change

Coping capacity in the face of reduced recharge is essentially climate adaptation capacity in the water sector. It entails how well Dar es Salaam's communities and systems can ensure water supply despite more frequent or severe droughts. At the community level, coping strategies include the installation of rainwater harvesting tanks, greywater recycling systems, and being willing to limit non-essential water use. Many households have adopted such measures as a necessity due to long-term insufficiencies in water supply. 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 and using communal facilities efficiently. Upgrades to the water supply infrastructure and maintenance of existing faulty systems have been ongoing and are steps in the right direction to ensuring water coverage to Dar es Salaam's poorest communities is improved.

Ongoing development of the Kimbiji Aquifer has included intensive groundwater modelling to determine potential for salinisation as well as sustainable use under various water demand scenarios. These models refine operating limits and help identify priority monitoring sites to track aquifer storage trends over time.

Institutionally, the implementation of plans still needs to occur, however, frameworks and strategies have been developed on a national scale. If these plans are implemented, maintaining and updating their strategies according to changing climate trends will enable Dar es Salaam to react pre-emptively and mitigate the impacts on its communities.

### Disaster Planning and Governance

Despite Tanzania's commitment to Disaster preparedness through the Disaster Management Act, No. 6 of 2022, and the National Disaster Management Strategy (2022 – 2027), little to no focus is on groundwater recharge reductions. Large-scale formal disaster preparedness by central and local government is typically focused on floods and drought. Most agencies respond to disasters as situations change instead of pre-emptively. The Dar es Salaam Water Master Plan (2016 – 2036) identifies aquifer recharge protection as a priority, however lacks detailed phased response protocols

seen in cities with more advanced water governance. While Tanzania’s National Water Policy (2023) mandates groundwater monitoring, implementation remains fragmented. Coping capacity for disaster planning and governance of reduced groundwater availability due to reduced recharge is very low. Institutional coordination gaps between DAWASA, WAMI and local governance hinder unified action. Within these gaps, however, grassroots initiatives driven by Water User Associations (WUA’s) demonstrate localised adaptive capacity. Community-based groundwater monitoring through these WUAs is an example of this adaptive capacity.

The city launched an emergency response plan in 2017 to ensure those tackling emergencies know their role and can carry out their assigned tasks. This plan also makes provisions for what resources and facilities are accessible, as well as how to work in partnerships (GFDRR/World Bank, 2018). The city has also established a multi-agency response team (Dar-MAERT), which is a tactical team of the Regional Disaster Management Committee that brings together emergency response stakeholders. Nationally, Tanzania has established an Emergency Operations and Communications Centre (EOCC) situation room for national disaster preparedness (PMOs, 2024). However, little is mentioned and planned for reductions in groundwater recharge and salinisation.

**Policy and Long-Term Adaptation**

Dar es Salaam has begun developing policy frameworks and long-term strategies to address reduced groundwater recharge. However, gaps in the implementation of these frameworks and mechanisms for long-term strategies remain a challenge. The City’s 2016 – 2036 Master Plan and the National Water Policy of (2002) version 2025 formally recognise groundwater depletion risks, emphasising recharge protection zones, sustainable abstraction limits and climate resilient infrastructure. Key measures include Managed Aquifer Recharge (MAR) pilot studies in peri-urban areas, rainwater harvesting incentives and wetland conservation programs. However, weak enforcement of zoning regulations in critical recharge areas, unregulated borehole drilling and inadequate monitoring of regulated user abstraction volumes as per conditions attached to their water permits continue to undermine these efforts.

The City’s adaptive capacity hinges on strengthening institutional coordination between water authorities (WRBWB, DAWASA, WAMI), local governments and communities. Initiatives like Water User Associations (WUAs) show promise in decentralising groundwater management, while climate-smart urban planning, such as permeable pavement requirements in new developments, could enhance infiltration into the stressed Quaternary Aquifer. Moving forward, scaling up and implementation of MAR systems, integrating groundwater monitoring with flood early warning systems and securing dedicated funding for recharge protection will be critical. Success depends on translating policy commitments into actionable regulations, particularly in fast-growing informal settlements there is friction between water demand and land use. Overall, the adaptive capacity from a perspective of current policies and long-term adaption is moderate as consistent challenges hamper its potential.

**Demand Management and Public Cooperation**

The frequency of droughts has influenced City governance to implement measures to address water demand challenges, though these measures and demand strategies remain limited. The City’s water utility, DAWASA, has introduced progressive tariff structures aimed at encouraging conservation amongst high volume users (Industries, commerce and agriculture). However, inconsistent enforcement and widespread unmetered connections undermine these efforts. Water restrictions during times of drought, like those experienced for 6 weeks in 2022, are another measure aimed at curbing demand by DAWASA. Significant improvements to ageing and underperforming water supply infrastructure are another strategy currently underway in Dar es Salaam. For many years, water losses caused by water theft, and both infrastructure and meter accuracy issues have been a major challenge to users and DAWASA. The coping capacity of demand management is therefore considered low.

Public cooperation through local NGO's and community organisations play a crucial role in promoting water-saving practices. Conducting educational campaigns on rainwater harvesting and greywater re-use has shown promise in raising awareness amongst Dar es Salaam's communities. At a household level, many residents have adopted conservation measures in response to water shortages. Practices such as shorter showers, bucket washing and greywater re-use have grown in water-stressed neighbourhoods. These behavioural changes, while demonstrating adaptation to scarcity, are driven by necessity rather than coordinated policy, resulting in uneven adoption across socio-economic groups. The coping capacity due to public cooperation is considered moderate to high.

**Augmentation of Supply (Groundwater, Desalination, Reuse)**

Efforts to augment water supply have been an ongoing process as part of Dar es Salaam's 2016 – 2036 Master City Plan. Groundwater in the Quaternary Aquifer has long been overexploited and has left the aquifer stressed as a result. Water availability is highly dependent on sufficient recharge, however, with current estimates, sustainable use of the aquifer is not implemented. This is why the water table has been observed to drop significantly, and salinisation of boreholes along the City's coast has become a challenge. The exploration and development of the Kimbiji Aquifer has been seen as an additional groundwater source to augment supply. Currently, it provides groundwater to much of Kigamboni in the south and has been connected with the city centres' distribution system across a few of the administrative districts.

Additionally, as part of building supply capacity and resilience to climate change, water sensitivity, pilot studies for desalination plants have been established to determine the viability of desalination to augment water supply (Kimbiji Desalination Plant – 100 MLD). The ongoing design of the Rufiji water production plant project (750 MLD – to be completed in 2028), construction of the Kidunda Dam (190 MLD – to be completed in 2032), proposed Ruvu Juu Dam (200 MLD – to be completed in 2030) and development of the Upper Ruvu water treatment plant (200 MLD -completed in 2016) along the Ruvu river have also been seen as measures to increase surface water supply capacity by the City. Reuse has been proposed in the Dar es Salaam Sewerage Master Plan (2016), however, only the Kurasini wastewater treatment plant (25 MLD capacity) is operational. Its water, however, is discharged and not reused. The strategy to diversify Dar es Salaam's water supply sources is clear in its message, with the city making direct intentions to move ahead with construction. Financing of these projects has required both national and international funding. However, once completed, these projects are thought to greatly improve the region's coping capacity towards reducing recharge. Currently, Dar es Salaam's coping capacity is considered as moderate until such contributors are operational.

**Community FBOs and NGO Involvement**

Community organisations, faith-based organisations and non-governmental actors play a pivotal role in supporting vulnerable groups and supplementing municipal interventions. Faith-based organisations (FBOs) and 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. A variety of informational, educational and communicative materials used to raise awareness about climate change and its impact on water resources and people's lives are distributed. These are typically provided by:

- The National Environment Management Council (NEMC)
- Ministry of Water (MoW)
- Tanzania Meteorological Authority (TMA)
- World Wildlife Fund (WWF), SNV, United Nations Development Programme (UNDP)

Particularly in informal settlements where municipal services are limited, groups like WaterAid Tanzania, SAWA Tanzania and the Tanzania Water and Sanitation Network (TaWaSaNet) distribute water storage tanks, promote rainwater harvesting and install low-cost filtration systems in vulnerable communities. Faith-based and civil society initiatives, such as those by Caritas Tanzania and local mosque networks, provide emergency water deliveries during shortages and drought periods. Grassroot efforts by community water committees and women-led collectives help monitor groundwater quality, report pipeline leaks, and advocate for equitable distribution. While these efforts enhance adaptation to water stress, their impact remains fragmented due to inconsistent funding and coordination. Strengthening partnerships between NGO's, community groups, and city planners could improve their role in building long-term resilience.

**Household Adaptions and Assets**

Due to frequent service disruptions or a lack of water supply infrastructure, Dar es Salaam's coastal households have developed practical coping strategies that are applicable to seawater intrusion. Coping mechanisms such as rainwater harvesting, small-scale desalination and greywater use have become a necessary means to overcome inconsistent or absent water supply. Rooftop catchment systems have become popular and advocated for by the City's governance as a means to mitigate the effects of salinisation. Water is captured during rainfall events and stored in small reservoirs for use. Few affluent households are able to afford treatment systems, instead, most rely on boiling water and basic sedimentation (sand) filters. In areas where urban subsistence farming takes place, greywater reuse has become a growing practice. The government FBOs and NGOs have piloted these interventions through subsidised projects. Though it is important to note that in vulnerable communities, coverage is sparse. Community training on saline-tolerant crops and water-saving techniques in peri-urban areas has also grown.

Due to the absence of large-scale equitable infrastructure, resilience is largely self-funded and fragmented. Community adaptions such as neighbourhood wells and distribution systems have created an informal network of knowledge exchange. While these adaptions demonstrate resilience, they are often reactive and unevenly distributed, with the poorest households bearing the greatest burden. Many of these residents are left dependent on FBO and NGO led projects. Finances and lack of assets to initiate change and adaption are significant challenges for many residents in Dar es Salaam.

**5.3. Ecosystems**

The coping capacity of an ecosystem to respond to a hazard addresses both resilience and the measures in place that allow for preparation for and an 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 at the level of the ecosystem, in the context of its surrounding landscape.

Mitigation and management measures that contribute towards Dar es Salaam'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:

- The Ministry of Water and Irrigation's National Drinking Water Quality Monitoring and Reporting (2018): although this is a programme that addresses drinking water quality, monitoring occurs at source, so would include the analysis of samples collected in rivers and springs. The programme also outlines the roles and responsibilities for the implementation of the programme. The rationale behind the programme is to move towards safe drinking water and good sanitation practices.

- The WRBWB: Dar es Salaam lies in the eastern part of the Wami/Ruvu Basin and the Ruvu River is an important water source for the City. The Water Basin Office has a mandate to manage and conserve the water resources within the Wami/Ruvu basin, which includes parts of Dodoma, Manyara, Morogoro, Coastal, Tanga, and Dar es Salaam region. There is a small office in Dar es Salaam. The WRBWB has produced situation analyses for the Wami and Ruvu Rivers, and these provide assessments that allow the development of priority themes and areas for action in each basin, according to the objectives of the National Water Sector Development Programme. The WRBWB is well placed to monitor the impacts of groundwater use, and to protect groundwater resources in and around the City of Dar es Salaam.
- The implementation of the Forest Act of 2002 and National Mangrove Management Strategy (2021 – 2031) have shifted priorities to rehabilitate and protect coastal mangroves, as they offer several ecological services that also build resilience against climate change-induced hazards. Several organisations have also strengthened this mandate by conducting mangrove restoration projects, entities such as the Tanzania Forest Services Agency, WWF Tanzania and Wetlands International have all led mangrove rehabilitation campaigns in the Dar es Salaam region. NGO led initiatives by groups such as Mikoko Pamoja and Sea Sense also promote mangrove conservation through education and building awareness of their value and effectiveness in mitigating against climate change-induced hazards.

## 6. Risk

This section presents an assessment of groundwater-related risks in Dar es Salaam 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 Dar es Salaam. The risk arises from the combined influence of the identified hazard (land use-related contamination sources), the aquifer's 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. Dar es Salaam's Quaternary Aquifer, particularly the upper unconfined sandy aquifer, presents the highest vulnerability and is the most at risk to contamination. This shallow aquifer faces a high contamination risk due to:

- Extensive unplanned informal settlements (where pit latrines and poor sanitation services are prevalent).
- Heavy industrial activities, particularly in the central urban core.
- Agricultural activities with widespread fertiliser and pesticide use.

In contrast, the deep Kimbiji Aquifer, located in the southern sections of the region, generally has a low contamination risk. This is largely due to the aquifer's geological characteristics, including greater depth and natural confinement, as well as its location within less-developed areas. However, where the Kimbiji Aquifer outcrops to the surface in the west in the Pugu Hills, the aquifer becomes more vulnerable to contamination.

Coping capacity varies significantly across the region. Low-income communities located above vulnerable aquifers face higher risks due to both higher exposure and lower ability to mitigate impacts. Unplanned informal settlements without adequate sanitation services contribute to contamination while simultaneously being exposed to it. Due to a lack of municipal water supply, these communities usually resort to shallow groundwater as an alternative water source, increasing direct consumption risk if the aquifer is contaminated. Their limited financial resources restrict their ability to purchase water from vendors as an alternative or 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, increasing their risk.

In contrast, formal settlements that are considered as more high-income communities have access to a treated municipal water supply and, as a result, are better able to cope with groundwater contamination as their reliance on the resource is less.

The municipal groundwater schemes developed by DAWASA, as well as industrial and agricultural users sourcing water particularly from the Quaternary Aquifer, also face operational risks from contamination. However, industrial and agricultural users 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.

Surface water ecosystems and terrestrial ecosystems of Dar es Salaam that may be groundwater-fed are at risk of exposure to groundwater contamination, particularly from the Quaternary Aquifer. However, the extent of exposure and risk will depend largely on the degree of dependency of any ecosystem on groundwater as a source of water. It can be assumed that all of these surface water ecosystems are vulnerable, to some extent, to the negative impacts associated with groundwater contamination, particularly in areas underlain by the shallow Quaternary Aquifer, which has been described to be more prone to contamination.

## 6.2. Over-abstraction

Over-abstraction presents a significant risk to both the physical sustainability of Dar es Salaam'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. Over-abstraction can lead to declining groundwater levels, reduced borehole yields, and degradation of groundwater-dependent ecosystems. Given Dar es Salaam's coastal setting, over-abstraction also poses the risk of saline intrusion into the vulnerable aquifer.

Dar es Salaam's Quaternary Aquifer has the highest risk of over-abstraction due to its shallow nature and easy access. As a result, it is the most heavily utilised groundwater system in the central parts of the region, which forms the city's economic hub. The risk of over-abstraction is greatest in areas with high groundwater use, where aquifers are stressed and recharge is low. Districts like Temeke and Ilala, which have the highest registered groundwater use and the largest extent of impervious surfaces that limit recharge, are high-risk areas. Low-income and unplanned informal communities that heavily rely on groundwater are also concentrated in these districts and contribute significantly to over-abstraction, since many of these communities have no water supply and resort to groundwater for household use. During drought periods, these risks escalate as users increase pumping to compensate for declining surface water availability across the region. The risk is further heightened in coastal areas, where over-abstraction raises the potential for saline intrusion.

From a municipal perspective, over-abstraction poses a direct operational risk to groundwater schemes in the region. The largest and most recently developed scheme aims to target the Kimbiji Aquifer, hoping to provide water to the Kigamboni district and parts of the Temeke. Meanwhile, the second scheme targets the Quaternary Aquifer underlying most of the city through a series of shallow boreholes.

Agricultural users, particularly subsistence farmers in areas like Kigamboni, 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.

Lower groundwater levels as a result of over-abstraction have the potential to reduce baseflows to wetlands and other surface water ecosystems, especially during drought periods. However, the extent of risk will depend largely on the degree of dependency on groundwater. Additionally, the environmental degradation of nearby GDEs caused by declining water tables may indirectly affect communities through increased flood risk (due to loss of wetland buffering capacity) or reduced ecosystem services.

Institutionally, the region's ability to manage the risk of over-abstraction remains limited by regulatory constraints. There is a general lack of enforcement, which results in the unregulated abstraction of groundwater in the region. Additionally, National water legislation exempts small domestic groundwater users from licensing, resulting in a substantial data gap on private abstraction volumes. Education and awareness is limited with regard to sustainable groundwater use and behaviour making it difficult to mitigate the over-abstraction risk across all user groups.

### 6.3. Sea-level Rise: Due to Climate Change

Sea-level rise presents a gradual but significant risk to Dar es Salaam's Quaternary Aquifer, particularly in low-lying areas along its coastline. The primary effects that would impact the aquifer and its users are seawater intrusion and groundwater inundation. The physical risks to Dar es Salaam's coastal aquifers are not uniform across the region. The Quaternary Aquifer is the most vulnerable due to a combination of its shallow, unconfined nature, low elevation relative to sea-level along coastal plains, and the added pressure of over-abstraction. Salinisation of boreholes due to seawater intrusion has already been observed in several boreholes targeting the Quaternary Aquifer north and south of the city centre. The Kimbiji Aquifer, while also coastal, is at a lower risk because of its confining nature and the pressure due to differences in hydraulic head between the coast and higher elevations. The latter is thought to be why the conservative estimate of the freshwater-saltwater interface is 20 km from the shoreline (DAWASA, 2017).

From a municipal perspective, Dar es Salaam is piloting various capacity-building projects and implementing monitoring protocols to improve preparedness for, and resilience against sea-level rise. The City has made efforts to mitigate against its impacts of seawater intrusion and groundwater inundation (flooding), however, institutional capacity, coordination, and funding to run these initiatives and projects have not been optimal and have consequently caused delays in building coping capacity. The establishment of a coastal salinity monitoring network and its regular monitoring is one of the first steps being taken by the City to provide early warning of salinity changes. Protection and rehabilitation of coastal vegetation and mangroves have been natural measures to protect against sea-level rise, while the approach of a more proactive land-use planning strategy to prevent development in sea-level rise vulnerable zones has been implemented to build adaptive capacity and reduce risk. Alternative water supply sources have also been an ongoing development to reduce risk and improve coping capacity. This has mostly been through the construction of reservoirs and the pilot of desalination.

Communities living in low-lying coastal areas are especially susceptible and vulnerable to rising groundwater levels caused by sea-level rise, waterlogging and shallow groundwater flooding. This creates secondary health risks, including increased exposure to water-borne diseases. Where unplanned areas and informal settlements are affected, pit latrines may overflow or backflow. Coping capacity in these areas is limited, with residents lacking resources for engineering interventions.

### 6.4. Reduced Recharge: Due to Climate Change

Reduced recharge is a risk to the sustainability of Dar es Salaam's groundwater resources as well as the users and ecosystems that depend on them. The risk is primarily related to climate change-induced meteorological patterns, which result in higher evaporation rates and shorter but more intense rainfall events. Seasonality is altered, whereby the period of rainy seasons is reduced and the dry season is extended. 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 underlying groundwater systems.

Assessing recharge reduction in Dar es Salaam proved challenging due to the scarcity of reliable recharge data, limited climatic records, and the absence of alternative datasets. Consequently, this reduced the certainty and reliability of findings. Given these constraints, risk was determined using indirect methods, including a review of existing literature, analysis of prevailing climatic conditions, and an assessment of impervious surface coverage across the region, as proxies to infer potential recharge reduction. Based on these inputs, reduced recharge is considered a high risk to the Quaternary Aquifer and a low to moderate risk for the Kimbiji Aquifer.

From a user perspective, the risk of reduced recharge is influenced by groundwater dependency, access to alternative water sources, and coping capacity. This is most pronounced in unplanned and informal areas located above the Quaternary Aquifer, particularly in those areas where water supply infrastructure is limited, and, where available, face frequent service disruptions (see **Figure 3-5**). The additional pressure on water availability, due to abstractions from shallow hand-dug wells and drilled communal boreholes, further exacerbate the risks and impacts of reduced recharge.

Small-scale subsistence and resource-limited farmers who do not have access to surface waters 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 and commerce reliant on groundwater for processing, cooling or other operational needs also face exposure to this risk. They are considered some of the largest groundwater users from the stressed Quaternary Aquifer (see **Figure 2-7**). Similar to large-scale and well-financed farming operations, 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 high risk to DAWASA's groundwater schemes, particularly the production wells targeting the Quaternary Aquifer. Unregistered use of groundwater by highly vulnerable and dependent users has made management of the aquifer challenging, as current estimated withdrawals are thought to exceed yearly recharge.

Dar es Salaam's broader water supply diversification strategy currently includes augmentation by improving surface water capacity and the use of desalination. Few wastewater treatment plants are currently capable of producing water fit for reuse. This water, however, is not redistributed but instead discharged into surface waters. The improvement in surface water capacity and desalination provides important systematic resilience against recharge-driven supply risks. However, many users who rely on the vulnerable Quaternary Aquifer remain disproportionately at risk due to their limited ability to adapt. Once these proposed improvements are finalised and implemented, it is thought their risk will decrease, provided infrastructure is in place and operational.

Many of Dar es Salaam's GDEs are at a high risk as a result of reduced recharge. Many rivers and streams are already recharged by groundwater. The additional stress of over-exploitation and reduced recharge would greatly affect GDEs dependent on groundwater from the Quaternary Aquifer. The National Adaption Report highlighted significant data gaps that contribute highly to subnational climate change policies and strategies.

## 7. Synthesis and Recommendations

### 7.1. Summary of Key Risks and Interactions

**Aquifer contamination** risk in Dar es Salaam is highest in the Quaternary Aquifer system, particularly the upper portion, due to its shallow unconfined nature that results in high infiltration rates and a limited natural protection. Areas underlain by this system (e.g. Temeke and Ilala) are also the most urbanised parts of the region, where most industries, informal settlements and other Potentially Contaminating Activities (PCAs) are located. In contrast, the deeper, confined Kimbiji Aquifer in the south generally display lower contamination risks due to its greater depth and natural confinement, except in areas where it outcrops in the west.

The risk of **over-abstraction** is highest in shallow, unconfined aquifers, in areas with high concentrations of groundwater users, where aquifers are stressed, and where recharge to yield is low. In Dar es Salaam, the Quaternary Aquifer faces the highest risk of over-abstraction due to its shallow nature, easy access and heavy utilisation, particularly in the central parts of the region, which forms the city's economic hub. Districts such as Temeke and Ilala are especially vulnerable because they have the highest registered groundwater use and extensive impervious surfaces that reduce natural recharge. Many low-income and unplanned informal settlements, which heavily rely on groundwater, are also concentrated in these districts and contribute significantly to over-abstraction, since many of these communities have no water supply and resort to groundwater for household use. Additionally, abstraction from a groundwater scheme that targets the Quaternary Aquifer through a series of shallow boreholes also adds to abstraction volumes. These risks are exacerbated during drought periods when groundwater pumping increases to compensate for declining surface water availability across the region. Coastal areas face an additional challenge, as over-abstraction increases the risk of saline intrusion into freshwater aquifers.

The Quaternary Aquifer is the most vulnerable to climate change-induced **sea-level rise** because of its shallow, unconfined nature, proximity to the coast, and elevation relative to sea-level. The low-lying coastal plains and areas such as those found in Kigamboni and the Msimbazi Basin are the most susceptible to groundwater inundation, while saline intrusion in coastal boreholes has been observed in several locations along Dar es Salaam's coast. Rising sea-levels threaten to deteriorate groundwater resources, impacting communities and industries dependent on coastal groundwater. The Kimbiji Aquifer, with its deeper, confined nature, is thought to be less susceptible; however requires monitoring to ensure long-term resilience.

**Reduced recharge** due to climate change is a risk to already impacted groundwater availability in Dar es Salaam. It is likely that climate change-induced reductions in recharge should they occur, will disproportionately affect the Quaternary Aquifer, especially in urbanised areas with limited infiltration. While, prolonged dry seasons and erratic rainfall patterns will exacerbate water scarcity, straining the groundwater resource. The Kimbiji Aquifer in contrast, is at less risk of reduced recharge as its main recharge zones are thought to be in the hinterlands of the region, where higher rainfall occurs and the area of impermeable surfaces is minimised.

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 shrinking or the complete drying out of these systems, and as such, the loss of critical biodiversity. Additionally, GDEs may be sensitive to groundwater contamination, which can result from human activities and saline intrusion due to sea-level rise. In the short term, the Quaternary Aquifer is the most at risk across multiple groundwater-related hazards, placing GDEs in this region at high risk. Over the long term, the abstraction of groundwater from the Kimbiji Aquifer is thought to also potentially affect GDEs and sensitive ecosystems, and for this reason, it is considered to be at a medium risk.

Dar es Salaam's **socio-economic** vulnerability to Groundwater-related risks is dependent on water supply accessibility and financial capacity. Low-income communities, particularly in unplanned

areas, face the highest risks due to reliance on often contaminated and over-exploited groundwater, limited access to alternative water sources, and both inadequate water supply and sewerage infrastructure. High-income areas with better access to treated municipal water and financial resources exhibit a lower vulnerability. Despite a better adaptive capacity, these areas are still at risk given frequent service disruptions. Industries and agriculture, while contributing to contamination and over-abstraction, vary in their ability to adapt based on financial capacity.

Overall, this emphasises the need for targeted interventions to achieve equitable groundwater resilience. Key priorities include protecting aquifers from contamination by upgrading sanitation systems and regulating waste disposal in both informal settings and waste sites, controlling unregistered boreholes to prevent unsustainable water extraction, implementing flood mitigation measures for vulnerable coastal communities, and prioritising climate adaptation support for marginalised populations with limited alternatives. By systematically addressing these challenges, reducing exposure to hazards and while strengthening community resilience, Dar es Salaam can work toward sustainable groundwater management that serves all residents equitably.

## 7.2. 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 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 the Quaternary Aquifer, over-abstraction and reduced recharge 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.

## 7.3. Recommendations for Conjunctive Use Management

### 7.3.1. Groundwater Management

The WRBWB has taken significant steps towards strengthening groundwater management and demonstrating a commitment to sustainable resource governance in Dar es Salaam. However, while progress has been made in monitoring, stakeholder engagement and policy implementation, many opportunities to enhance strategies for long-term water security remain. It is recommended that the following areas be included in a publicly available strategic action plan:

- **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 Dar es Salaam's urban centre, as well as the presence of existing land use practices and the occurrence of unplanned/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.

- **Groundwater Protection Zones (GPZ):** The delineation and implementation of GPZs to protect DAWASA’s groundwater schemes is recommended. These zones are typically set as a means of reducing the risk of contamination. They are delineated according to contaminant travel time and proximity to boreholes. The implementation of Stage 1 GPZs to protect and fence off the immediate vicinity of the production boreholes is recommended. Furthermore, it is recommended that further stages taking into account two, five and ten-year travel times be included as a precautionary measure to safeguard water supply. These GPZs aim to prevent future pollution by restricting high-risk land uses and guiding land-use planning processes. Included with these GPZs is a recommendation that detailed vulnerability mapping and PCA mapping be conducted to identify areas of high vulnerability and to prevent PCAs from occurring near production boreholes.
- **Pollution Incident Response Plan:** DAWASA and the WRBWB should develop a conjunctive groundwater pollution incident response management plan to provide step-by-step guidance on how to respond to contamination events that would otherwise affect groundwater abstraction schemes. These would be especially relevant to the Quaternary Aquifer, which is currently the most susceptible to contamination of the targeted groundwater systems in Dar es Salaam. In the event that contaminants pass through to a water treatment works, an incident management protocol would therefore be in place to guide operational decisions, ensuring the protection of water quality before it enters the municipal distribution system.
- **Improved Data and Monitoring:** Regular groundwater monitoring over a sufficient extent to understand changes in quality and quantity is recommended. This includes establishing an appropriate and efficient data-capturing and storage system. It should also include drilling and well permits. Data should be readily available for the WRBWB to provide insight into changing dynamics and environmental systems. To date, an online system is under development, and once completed, is expected to be released for public access.
- **Hydrogeological Assessment:** Current availability of hydrogeological data is severely lacking, and data that is available is often incomplete or at coarse resolutions, preventing detailed and localised analysis. The geology of the Dar es Salaam region should be surveyed to at least a 500 to 250 km scale. Aquifer extent and type should also be better defined at a finer resolution than what is currently available, and data should include aquifer yields. Currently, there are no formalised maps of recharge and GDEs for the Dar es Salaam region. Groundwater recharge is another dataset which needs to be further defined and improved. Effective management of groundwater resources requires a sufficient understanding of hydrogeological properties and conditions.

### 7.3.2. Sustainable Groundwater Development

Dar es Salaam is currently developing two of its main aquifers for groundwater use to augment DAWASA’s water supply. The continuation of the development of this groundwater scheme is recommended to continue, with particular emphasis on:

- Piloting and assessing the feasibility of managed aquifer recharge schemes in the Quaternary Aquifer.
- Upgrading and optimising the current Quaternary Aquifer Management Scheme
- Enhancing groundwater monitoring, modelling and governance across both schemes.
- Including climate-based scenarios in modelling for both the Quaternary and Kimbiji aquifers.
- Improving enforcement of regulations by conducting regular audits to track usage and sustainability. This is especially applicable to the already over-exploited Quaternary Aquifer.
- Implementing zoning policies (e.g., critical, semi-critical, safe zones) with tailored restrictions. This includes recharge zones.

### 7.3.3. Climate-Responsive Management

The National Climate Change Response Strategy 2021 – 2026 was created to improve Tanzania’s climate resilience while pursuing sustainable development. The WSDP – phase III (2023 – 2023), implements climate-resilient water infrastructure to develop climate resilience in the water sector. Challenges in implementation, however, are often associated with Institutional coordination gaps between **DAWASA**, **WRBWB**, and **local municipalities**, hindering unified action. Despite this, grassroots initiatives, such as **community-based groundwater monitoring** through WUAs, demonstrate localised adaptive capacity. To strengthen governance, Dar es Salaam must prioritise:

1. **A groundwater-specific crisis plan** with triggers for water rationing and alternative supply activation. It should be integrated into broader adaptive strategies.
2. **Incorporation of climate change projections** into groundwater planning and management strategies (especially seawater intrusion and reduced recharge)
3. **Vulnerability mapping** to target protections for at-risk neighbourhoods and critical infrastructure (e.g., hospitals).
4. **Legally enforced recharge zone protections**, especially in the **Msimbazi Basin** and coastal aquifers, including regional recharge zones located west, in the hinterlands of the region.
5. **Diversification of water supply**, including currently planned surface water schemes, water reuse and desalination.
6. **Strengthening of drought preparedness and response**, especially through augmentation and diversification of resources

Proactive measures such as these have the potential to shift responses from reactive coping to long-term resilience. However, achieving this requires strong political commitment and investment.

## 8. REFERENCES

- Addo, M. N. (2016). *To Assess the Level of Heavy Metal Pollution in Groundwater in Ilala Dar es Salaam*. Doctoral dissertation, The Open University of Tanzania.
- 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.
- Allen, A., Hofmann, P., Mukherjee, J., & Walnycki, A. (2017). Water trajectories through non-networked infrastructure: insights from peri-urban Dar es Salaam, Cochabamba and Kolkata. *Urban Research & Practice*, 10(1), 22-42.
- Andersson, E. (2019). Water demand and supply in Dar es Salaam: A WEAP-model to estimate future scenarios
- Bakari, S. S., Aagaard, P., Vogt, R. D., Ruden, F., Brennwald, M. S., Johansen, I., & Gulliksen, S. (2012). Groundwater residence time and paleorecharge conditions in the deep confined aquifers of the coastal watershed, South-East Tanzania. *Journal of Hydrology*, 466, 127-140.
- 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.
- Bender, M. V. (2021). Water for Bongo: Creative Adaptation, Resilience & Dar es Salaam's Water Supply. *Daedalus*, 150(4), 48-63.
- Connecting Cities to Basin. (2017). Meeting the water and sanitation SDG targets at scale: a focus on Dar es Salaam. International Institute for Environment and Development.
- Copernicus Climate Change Service (C3S), Climate Data Store. (2024). Gridded dataset underpinning the Copernicus Interactive Climate Atlas. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: [10.24381/cds.h35hb680](https://doi.org/10.24381/cds.h35hb680)
- DAWASA. (2008). Development of a Strategic Water Supply Plan for Dar es Salaam, Water Supply Improvement Plan. Final Report.
- DAWASA. (2017). Strategic Environmental Assessment of the Kimbiji Aquifer Development Plan.
- DAWASA. (2019). THEME: Integrating Challenge-Driven Education in Undergraduate Studies at UDSM. DAWASA, Dar es Salaam Wat and Sewage Authority, 19.
- 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.
- Dodman, D., Kibona, E., & Kiluma, L. (2011). Tomorrow is too late: Responding to social and climate vulnerability in Dar es Salaam, Tanzania. *Unpublished case study prepared for the Global Report on Human Settlements*.
- Domenico, P. A., & Schwartz, F. W. (1997). Physical and chemical hydrogeology. John Wiley & sons.
- 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.
- GFDRR/World Bank. (2018): Elevating Emergence Response in Tanzania-Dar-es-salaam, Tanzania
- GLOWS – FIU. (2014). Water Atlas of Wami/Ruvu Basin, Tanzania. 117 p. ISBN 978-1-941993-01-9
- Hausfather, Z. (2019, December 2). *CMIP6: The next generation of climate models explained*. Carbon Brief. <https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained/>

- Hofmann, P. (2022). Toward equitable urban water supply and sanitation in Dar es Salaam: The dialectic relationship between policy-driven and everyday practices. *Utilities Policy*, 78, 101395.
- Intergovernmental Panel on Climate Change (IPCC). (2001). *Africa. Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Pp. 487–532, Cambridge University Press. <https://archive.ipcc.ch/ipccreports/sres/regional/index.php?idp=40>
- Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Prepared by Hegerl, G. C., Zwiers, F. W., Braconnot, P., Gillett, N. P., Luo, Y., Marengo Orsini, J. A., Nicholls, N., Penner, J. E., & Stott, P. A., S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.) on behalf of the IPCC. Pp 665 – 745, Cambridge University Press.
- Intergovernmental Panel on Climate Change (IPCC). (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*. Prepared by 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 on behalf of the IPCC. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321–445. <https://doi.org/10.1017/9781009157964.006>.
- Intergovernmental Panel on Climate Change (IPCC). (2021a). 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*. Prepared by 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 on behalf of IPCC. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: <https://www.ipcc.ch/>.
- Intergovernmental Panel on Climate Change (IPCC). (2021b). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I 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 (eds.)] on behalf of the IPCC. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:[10.1017/9781009157896](https://doi.org/10.1017/9781009157896).
- Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate change 2022: Impacts, adaption and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Prepared by Trisos, C. H., Adelekan, I. O., Totin, E., Ayanlade, A., Efitre, J., Gemedda, A., Kalaba, K., Lennard, C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, N. P., & Zakieldean, S. (2022). Africa. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Lösckke, V. Möller, A. Okem, & B. Rama (Eds.) on behalf of the IPCC. Pp. 1285-1455, Cambridge University Press. <https://doi.org/10.1017/9781009325844.011>.
- IUCN Eastern and Southern Africa Programme, 2010. *The Ruvu Basin: A Situation Analysis.*, xvi + 96 pp.
- Japan International Cooperation Agency (JICA). (2005). *The study on water supply improvement in coast region and Dar es Salaam Periurban in the United Republic of Tanzania*. United Republic of Tanzania.
- Kaale, L. D., Kato, T., & Sakamoto, K. (2023). Growth with disparity in a rich diverse city: Case of the economic capital Dar es Salaam. In *Changing Dietary Patterns, Indigenous Foods, and Wild*

*Foods: In Relation to Wealth, Mutual Relations, and Health in Tanzania* (pp. 137-150). Singapore: Springer Nature Singapore.

- Karutz R., Berghöfer A., Moore L.R., and van Wyk, E. (2019). A Thematic Atlas of Nature's Benefits to Dar es Salaam. Leipzig and Cape Town: Helmholtz Centre for Environmental Research and ICLEI Africa Secretariat. 78 pages.
- Kombe, W., & Muheirwe, F. (2024). Dar es Salaam: City report. *Available at SSRN 5112868*.
- Kyessi, A., Kombe, W., & Kachenje, Y. (2019). The governance of municipal services in peri-urban areas: The case of water supply in Dar es Salaam City, Tanzania. *International Journal of Development Research*, 9(10), 30521–30533.
- Lukenangula, J. M. (2023). Informal Land Subdivisions And Their Effects On Spatial Development In Peri-urban Areas: The case of Kichangani Suward in Kigamboni Municipality, Dar es Salaam, Tanzania. *African Journal on Land Policy and Geospatial Sciences*, 6(3), 444-470.
- Mato, R. R. A. M. (2002). Groundwater pollution in urban Dar es Salaam, Tanzania : assessing vulnerability and protection priorities. [Phd Thesis 2 (Research NOT TU/e / Graduation TU/e), Chemical Engineering and Chemistry]. Technische Universiteit Eindhoven. <https://doi.org/10.6100/IR554794>.
- Mato, R., & Mjwahuzi, M. (2010). Groundwater governance case study: Tanzania, groundwater use, characterization and vulnerability. *Dar es Salaam Tanzania*.
- Mdoe, J. E. G., & Buchweishija, J. (2014). The quality of groundwater from wells in squatter and non-squatter settlements in Dar es Salaam city, Tanzania. *International Journal of Engineering Research & Technology*, 3(9), 1442-1445.
- Mjemah, I.C., 2007. Hydrogeological and Hydrogeochemical Investigation of a Coastal aquifer in Dar es Salaam, Tanzania. PhD thesis, University of Gent, Belgium, 222p.
- Mjemah, I. C., & Walraevens, K. (2015). Hydrogeological mapping and estimation of potential evapotranspiration and recharge rate of Quaternary sand aquifers in Dar-es-Salaam, Tanzania. *International Journal Of Geomatics And Geosciences*, 6(2), 1539-1555.
- Mremi, A., Kimwaga, R., Mulungu, D. M., & Izdori, F. (2025). Managing sanitation in unplanned urban areas: insights into manual emptying of onsite systems in Tandale, Dar es Salaam. *Journal of Water, Sanitation and Hygiene for Development*, 15(3), 215-231.
- Msindai, K. (1988). Engineering geological aspects of soils and rocks in the Dar es Salaam region. Turun yliopiston julkaisu. Sarja A 2. Biologica. Geographica. Geologica, 70.
- Msindai K. A. (2002). Engineering geological mapping of Dar es Salaam city, Tanzania. *Tanzania Journal of Science*, 28 (2): 83 – 96.
- Msuya I., Moshi I., and Levira F. (2021). Land Pattern of highly urbanizing cities: change in built-up area, population density and spatial development of sprawling Dar es Salaam City. *Environment and Urbanisation ASIA*, 12 (1): 165 – 182.
- Mtoni, Y., Mjemah, I. C., Van Camp, M., & Walraevens, K. (2011). Enhancing protection of Dar es Salaam Quaternary Aquifer: groundwater recharge assessment. In *Advances in the Research of Aquatic Environment: Volume 1* (pp. 299-306). Berlin, Heidelberg: Springer Berlin Heidelberg.
- Mtoni, Y., Mjemah, I. C., Bakundukize, C., Van Camp, M., Martens, K., & Walraevens, K. (2013). Saltwater intrusion and nitrate pollution in the coastal aquifer of Dar es Salaam, Tanzania. *Environmental Earth Sciences*, 70(3), 1091-1111.
- Mussa, K. R., Mjemah, I. C., & Walraevens, K. (2019). Quantification of groundwater exploitation and assessment of water quality risk perception in the Dar es Salaam Quaternary Aquifer, Tanzania. *Water*, 11(12), 2552.

- Mussa, K. R., Mjemah, I. C., & Machunda, R. L. (2021). Natural groundwater recharge response to climate variability and land cover change perturbations in basins with contrasting climate and geology in Tanzania. *Earth*, 2(3), 556-585.
- Mwakalobo, S. (2013). Assessment of faecal bacteria contamination in selected coastal waters of Tanzania. *Journal of Biology and Life Science*.
- Mwatujobe, A. (2020). *Assessment on the Impacts of Industrial Effluents to the Water Resources in Dar es Salaam Tanzania* (Doctoral dissertation, The Open University of Tanzania).
- 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>.
- Ngana, J., Mahay, F. & Cross, K. 2010. *Ruvu Basin: A Situation Analysis : Report for the Wami/Ruvu Basin Water Office*, IUCN Eastern and Southern Africa Programme.
- Ngasala, T. M., Masten, S. J., & Phanikumar, M. S. (2019). Impact of domestic wells and hydrogeologic setting on water quality in peri-urban Dar es Salaam, Tanzania. *Science of the total environment*, 686, 1238-1250.
- Nyysölä, M., Kelsall, T., & Ndezi, T. (2021). Dar es Salaam: city scoping study. *The African Cities Research Consortium*.
- Ozcoasts. (2009). Australian Online Coastal Information. Saline Intrusion, published on [http://www.ozcoasts.org.au/indicators/saline\\_intrusion.jsp](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.
- PMOs. (2024): Tanzania has made significant progress in national DRR strategies. <https://www.pmo.go.tz/news/tanzania>.
- Rao, N.S., Dinakar, A., Sravanthi, M., Kumari, B.K., 2021. Geochemical characteristics and quality of groundwater evaluation for drinking, irrigation, and industrial purposes from a part of hard rock aquifer of South India. *Environ. Sci. Pollut. Res.* 28, 31941–31961. <https://doi.org/10.1007/s11356-021-12404-z>.
- SADC-GMI, (2019). Gap Analysis and Action Plan – Scoping Report: Tanzania. SADC report: Bloemfontein, South Africa. GM
- Sappa G., and Luciani G. (2014). Groundwater management in Dar Es Salam coastal aquifer (Tanzania) under a difficult sustainable development. *WSEAS transactions on Environment and Development*, 10: 465 – 477.
- Sappa, G., Trotta, A., and Vitale, S. (2015). Climate change impacts on groundwater active recharge in coastal plain of Dar es Salaam (Tanzania). In *Engineering Geology for Society and Territory- Volume 1: Climate Change and Engineering Geology* (pp. 177-180). Cham: Springer International Publishing.
- Sappa, G., & Luciani, G. (2016). Sensitivity of Dar es Salaam coastal aquifer to climate change with regard to seawater intrusion and groundwater availability. In *Planning the Adaptation to climate change for the cities of the Tropical and Sub-Tropical Region's* (pp. 107-129). De Gruyter Open-Sciendo Migration.
- Sappa, G., Ferranti, F., & De Filippi, F. M. (2017). Assessment of vulnerability to seawater intrusion for the coastal aquifer of Dar es Salaam (Tanzania). *INTERNATIONAL MULTIDISCIPLINARY SCIENTIFIC GEOCONFERENCE SGEM...*, 17, 111-118.
- SecondSea World. (n.d.). *Dar-es-Salaam: RCP8.5 projections for 2060* (SecondSea World): <https://secondsea.world/cities/dar-es-salam/2060/RCP85>
- Skinner, J., & Walnycki, A. (2016). Dar es Salaam's water supplies need stronger, more flexible management to meet SDG6.

- Smiley S. (2013). Complexities of water access in Dar es Salaam, Tanzania. *Applied Geography*, 41: 132 – 138.
- 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.
- Stuart, J., Yozell, S., Ochanda, V., Rouleau, T., Indasi, V., and Lombardo, K. (2021). CORVI Risk Assessment: Dar es Salaam, Tanzania.
- Sweya, L. N., & Salila, E. (2023). Assessment of Spatial Distribution of Excreta Contaminants in Groundwater from Onsite Sanitation Facilities at Kibondemaji Ward, Dar es Salaam. *Journal of Applied Sciences and Environmental Management*, 27(12), 2923-2933.
- The Africa Center for Strategic Studies. (2022). *Rising sea-levels besieging Africa’s booming coastal cities*: <https://africacenter.org/wp-content/uploads/2023/02/Rising-Sea-Levels-ENG.pdf>
- The United Republic of Tanzania (URT). (2021a) Dar es Salaam Region Investment Guide:. Supported by the UNDP and ESRF. Presidents Office, Regional Administration and Local Government.
- The United Republic of Tanzania (URT). (2021b). Development of an Operational decision support system (ODSS) through enhanced Hydro-meteorological service: Inception Report: Flood Forecasting and Early Warning system for Wami Ruvu Basin.
- The United Republic of Tanzania (URT). (2022a). National Disaster Management Strategy 2022-2027. PMOS.
- The United Republic of Tanzania (URT). (2022b). Ministry of Finance and Planning, Tanzania National Bureau of Statistics and President’s Office - Finance and Planning, Office of the Chief Government Statistician, Zanzibar. The 2022 Population and Housing Census: Administrative Units Population Distribution Report; Tanzania, December 2022.
- The United Republic of Tanzania (URT). (2023). PMOs Cadri Partnership: Policy makers digest Report, Tanzania.
- The United Republic of Tanzania (URT). (2024). *Tanzania & Zanzibar Labour Market Profile – 2024/2025*. Copenhagen: Ulandssekretariatet.
- The United Republic of Tanzania, Ministry of Water (MoW). (2025). Water Sector Development Programme Phase III – Annual Water Sector Status Report 2024. Ministry of Water.
- The World Bank. (2024). Implementation Status & Results Report: Second Tanzania Water Sector Support Project. P150361.
- The World Bank. (2025). Tanzania: Economic Overview
- Tibesigwa, B., Ntuli, H. and Muta, T. (2023). Willingness to pay for Nature Restoration and Conservation in Sub-Saharan African Cities: The Case of Forests, Rivers and Coasts in Dar es Salaam, Tanzania. Environment for Development, Discussion Paper Series EfD DP 23-07, May 2023.
- Todd, G., Msuya, I., Levira, F., & Moshi, I. (2019). City profile: Dar es Salaam, Tanzania. *Environment and Urbanization ASIA*, 10(2), 193-215.
- Umvoto Africa (2009). City of Cape Town Disaster Risk Assessment: Aquifer Hazards. Final, December 2009.
- UN-Habitat. (2007). Water For African Cities (WAC) Dar es Salaam Project, Tanzania. United Nations Human Settlements Programme.
- UN-Habitat. (2010). Informal Settlements and Finance in Dar es Salaam, Tanzania. United Nations Human Settlements Programme.

- United States Agency for International Development (USAID). (2018). Climate Change in Tanzania: Country Risk Profile.
- University of Cape Town (2017). *Dar es Salaam Climate Profile: Full Technical Version*. IIED, London; KCL, London. Available at <https://www.iied.org/21701g>.
- 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.
- UPgro. (2025). Unlocking ground water Potential for the poor: Key recommendations. <https://upgro.org/tag/tanzania/>
- Van Camp M., Mjemah I. C., Al Farrah N., and Walraevens K. (2012). Modelling approaches and strategies for data-scarce aquifers: example of the Dar es Salaam aquifer in Tanzania. *Hydrogeology journal*, 21 (2): 341.
- Van Camp, M., Mtoni, Y., Mjemah, I. C., Bakundukize, C., and Walraevens, K. (2014). Investigating seawater intrusion due to groundwater pumping with schematic model simulations: The example of the Dar es Salaam coastal aquifer in Tanzania. *Journal of African Earth Sciences*, 96, 71-78.
- Van der Gun, J. (2021). 24-Groundwater resources sustainability, Editor (s): Abhijit Mukherjee, Bridget R. Scanlon, Alice Aureli, Simon Langan, Huaming Guo, Andrew A. McKenzie, *Global Groundwater*.
- 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
- Walraevens, K., Mjemah, I. C., Mtoni, Y., & Van Camp, M. (2015). Sources of salinity and urban pollution in the Quaternary sand aquifers of Dar es Salaam, Tanzania. *Journal of African Earth Sciences*, 102, 149-165.
- 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.
- Wessels, M.T., Veldwisch, G.J., van Vliet, B.J., Kyessi, A.G. and Mgana, S.M., 2024. Agriculture and the ideals of urban modernity: The case of Dar es Salaam, Tanzania. *Water International*, 49(2), pp.219-237.
- World Bank Group (WBO). (2016). Promoting Green Urban Development in African Cities, Urban Environmental Profile for Dar es Salaam, Tanzania.
- Yadav, M., Vashisht, B. B., Jalota, S. K., Kaur, S., & Yadav, S. L. (2025). Stakeholders participation and groundwater management: Raising the awareness. In *Water Sustainability and Hydrological Extremes*. pp. 293-314. Elsevier.
- Zaporozec, A. and Miller, J.C. (2000). Ground-water pollution.

**Address: 24 Meiring Naude Road,  
Brummeria, Pretoria, 0184,  
Pretoria, South Africa**

**Phone: +27 - 051 0419  
Email: [info@sadc-gmi.org](mailto:info@sadc-gmi.org)  
Website: [www.sadc-gmi.org](http://www.sadc-gmi.org)**