



GROUNDWATER MANAGEMENT INSTITUTE

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

**Groundwater Dependency Assessment:  
Dar es Salaam**

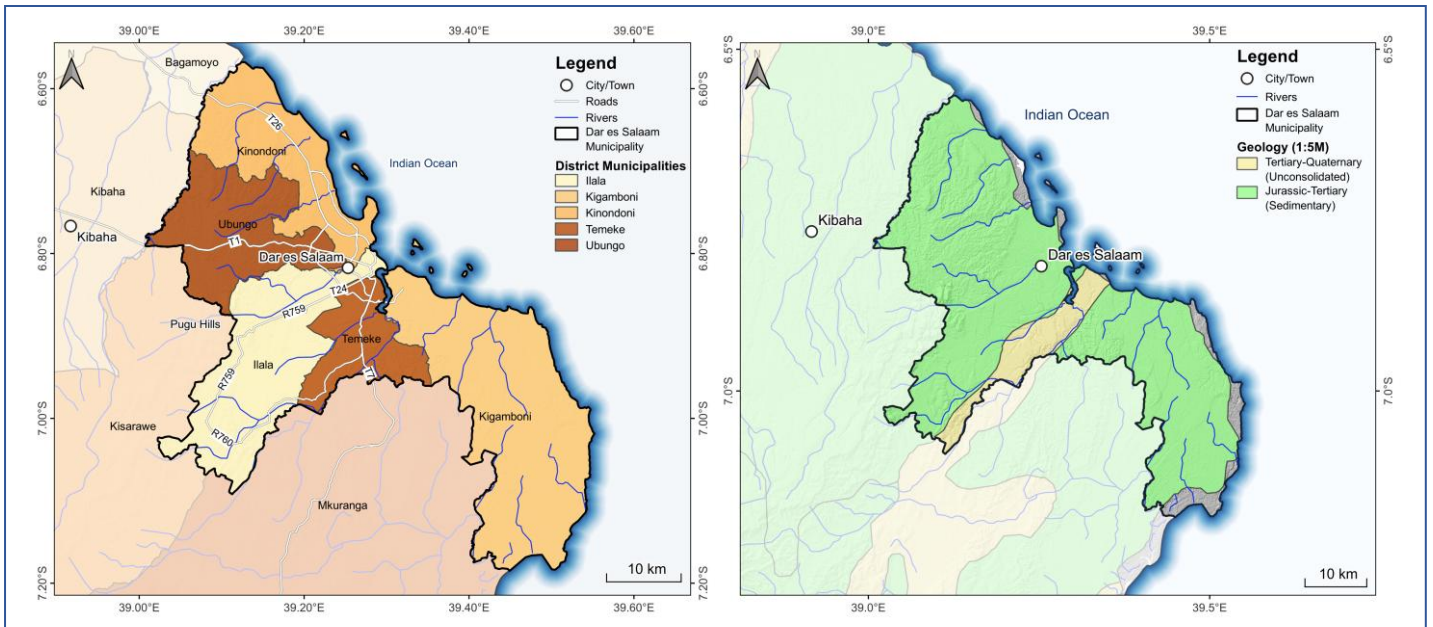
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**THE WORLD BANK**



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



Version 1

Prepared for:  
SADC-GMI



# GROUNDWATER DEPENDENCY ASSESSMENT (DAR ES SALAAM)

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

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

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## List of Abbreviations

|          |   |   |
|----------|---|---|
| BWB      | - | Basin Water Board   |
| CBWSO    | - | Community Based Water Service Organisations                             |
| CCI      | - | Climate Change Index  |
| COWSOs   | - | Community-Owned Water Supply Organisations                              |
| DAWASA   | - | Dar es Salaam Water and Sewerage Authority                              |
| DAWASCO  | - | Dar es Salaam Water Supply Company                                      |
| EIA      | - | Environmental Impact Assessment   |
| EWURA    | - | Energy and Water Utilities Regulatory Authority                         |
| GDE      | - | Groundwater Dependent Ecosystems  |
| HSG      | - | Hydrological Soil Group   |
| IWRM     | - | Integrated Water Resources Management                                   |
| km       | - | kilometre   |
| Maji-IS  | - | Maji Information System   |
| Mamsl    | - | Metres above mean sea level   |
| mm       | - | Millimetre  |
| MoW      | - | Ministry of Water   |
| NEMC     | - | National Environmental Management Council                               |
| NWB      | - | National Water Board  |
| ODSS     | - | Operational Decision Support System                                     |
| OSM      | - | Open Street Map   |
| RUWASA   | - | Rural Water Supply and Sanitation Agency                                |
| SADC     | - | Southern African Development Community                                  |
| SADC-GMI | - | Southern African Development Community Groundwater Management Institute |
| TBA      | - | Transboundary Aquifer   |
| TGS-     | - | Tanzania Geological Survey  |
| WRBWB    | - | Wami-Ruvu Basin Water Board   |
| WRMA     | - | Water Resource Management Act   |
| WUA      | - | Water User Association  |
| WUG      | - | Water User Group  |
| WUIMS    | - | Water User Information Management System                                |
| WUP      | - | Water use permit  |
| WUPAT    | - | Water Use Permitting Analysis Tool                                      |
| WWTP     | - | Wastewater Treatment Plant  |

## 1. INTRODUCTION

### 1.1. Background

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

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

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

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

#### ***Groundwater Dependency and Vulnerability in Coastal Cities***

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

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

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

## 1.2. Project Aims and Objectives

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

This groundwater dependency assessment is the first main technical task that assesses how municipalities, communities, industries and the environment rely on groundwater in Dar es Salaam based on existing information. This report also includes relevant legislation and authorities responsible for groundwater management in the city, a detailed hydrogeological assessment and an overview of how socioeconomics and gender equality and social inclusion factors influence groundwater dependency in Dar es Salaam. This information is critical for understanding the city's reliance on groundwater and serves as a foundation for developing a conjunctive management strategic action plan that will guide the sustainable use of groundwater resources in Dar es Salaam.

## 1.3. Definition of Terms

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

**Groundwater vulnerability** refers to how susceptible an aquifer is to the risks and threats affecting the groundwater resource itself, the ecosystems it supports, and its availability for human use. In the context of this study, the term also includes the vulnerability of the communities that depend on the groundwater resources.

Vulnerability can 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** 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.

**Risk** is usually defined as the product of likelihood and severity of adverse effects on the groundwater resource, water users and receiving environment due to the exposure to hazards. Key risks include contamination, over-abstraction, climate change impacts, seawater intrusion, and the degradation of groundwater-dependent ecosystems. These factors can compromise the availability and quality of groundwater for the people and ecosystems that depend on it.

Risk is also sometimes expressed as product of likelihood of a hazard occurring and vulnerability of the receiving environment, divided by coping capacity (or resilience).

## 2. Groundwater Management and Governance

### 2.1. Policies and Legislation

#### 2.1.1. The National Water Policy 2002

Tanzania has just approved the National Water Policy 2025, The major difference between Tanzania's National Water Policy of 2002 and the updated National Water Policy of 2025 lies in their strategic focus and response to evolving national challenges. The 2002 Policy made provisions for the Water Resources Management and development, water and wastewater quality management; access and management of water supply services and sanitation. It also provided for Private sector participation, climate change and environmental and social safeguard, as well as gender and water governance arrangements.

The groundwater aspects were mostly enshrined in quality and pollution control, management of abstractions and permitting, community participation though active involvement of beneficiaries in planning, constructing, operating, and maintaining community-based domestic water supply schemes, as well as a shift in the government's role from being a direct service provider to focusing on coordination, policy formulation, and regulation. Ground water was noted as a key component of Water Resources Management, Rural Water Supply, and Urban Water Supply and Sewerage, each aiming to improve access and sustainability in their respective areas. Despite these offers, there were no concerted efforts and dedicated programming on ground water management, except for the holistic water sector reforms which was implemented through the Water Sector Development Programme (2006–2025), with groundwater as one of many other components.

The National Water Policy 2025 is more generous on groundwater and is more focused on Modernisation and Resilience as themes. It represents a significant evolution, addressing contemporary challenges such as population growth, climate change, and technological advancements. Groundwater is placed at the centre of the supply chain with key aspirations such as establishment of a National Water Grid, a transformative initiative aimed at interconnecting water sources and infrastructure across the country to ensure equitable and uninterrupted water supply, particularly to historically underserved regions; and Climate Change Adaptation, to mitigate the effects of climate change on water availability, emphasising the need for early preparations and improvements to manage these challenges effectively.

Groundwater aspects are also improvised in the private sector engagement in financing water projects, aiming to diversify funding sources through mechanisms like green financing and other emerging opportunities, such as the use of technological advancements in water distribution and management, and the engagement of youth with technological skills to develop innovative solutions. Conventional elements such as environmental conservation and protection of water sources as a collect responsibility are incorporated and emphasized in this updated policy. Collectively it urges citizens to safeguard water infrastructure and harvest rainwater to ensure continued access to safe and reliable water. The new policy aligns with Tanzania's goal of achieving 85% rural and 95% urban water access coverage by December 2025 (NEC, 2020).

#### 2.1.2. Water Resources Management Act, no 11 of 2009

Water resource management in Tanzania is governed by the Water Resources Management Act (WRMA) No. 11 of 2009 and its amendment of 2022, which outlines regulations for the management, utilisation, and protection of all water resources. This act replaced the Water Utilisation Act of 1974, prioritising several key provisions. The WRMA provides a legal framework for water management and recognises water as a public resource that requires allocation, protection, and sustainable management. It provides the institutional and legal framework for the sustainable management and development of water resources. Specifically, it outlines the principles for water resource

management and prevention and control of water pollution.

The Act specifies that any person who wants to construct a deep well or borehole in groundwater-controlled area or any other area" needs a groundwater permit. It further stipulates that any person who uses water in excess of amount authorised in the water use permit or uses water contrary to purpose authorised by water use permit commits an offence. The Act also, prohibits the discharge of waste into any water body, including groundwater, without a written permit. It also defines guidelines and standards for the construction and maintenance of water resources structures, the issuance and operation of water permits, and the registration of boreholes. The act introduces the Ministry of Water to oversee national policies, the National Water Board to advise the government on water policy and regulations, Basin Water Boards to manage water resources on basin level, and Water User Associations to promote community involvement in local water management. This is an example of how the act attempts to decentralise the governance of water resources in Tanzania.

A key principle of the Act is Integrated Water Resources Management (IWRM), which emphasises managing water resources at the river basin level. Currently, seven out of nine river basins have successfully developed basin IWRM and development plans, while the remaining two are in the process of finalising their plans.

### 2.1.3. Other Relevant Legislations

Apart from the principal Water Resources Management law which is guiding permitting for groundwater abstraction and drilling, there are also a number of other relevant legislations that guide ground water management in Tanzania. The Environmental Management Act No. 20 of 2004 regulates groundwater protection from pollution and mandates Environmental Impact Assessments (EIAs) for activities that could affect groundwater, providing enforcement tools for controlling pollution of water sources.

The Water Supply and Sanitation Act No. 5 of 2019, provides for sustainable management and adequate operation and transparent regulation of water supply and sanitation services. It also provides for the establishment of Water Supply and Sanitation Authorities, Rural Water Supply and Sanitation Agency, National Water Fund and Community Based Water Supply Organisations. Furthermore, the Act regulates the delivery of clean and safe water, from groundwater sources and governs service provision, standards, and accountability for water utilities and rural water service providers, most of which are using groundwater sources.

Although not as directly but due to the riparian and fugitive nature of the water resource, the Land Act No. 4 of 1999 and Village Land Act No. 5 of 1999 addresses water issues related to land rights and land use, including access to and use of underground water sources, and provides linkages of groundwater access to land tenure and user rights.

In pollution control, the Mining Act No. 14 of 2010 regulates groundwater use in mining operations, especially with regard to dewatering and environmental safeguards.

### 2.1.4. Governance Structure

Tanzania established a comprehensive institutional framework under the Water Resources Management Act No. 11 of 2009 and the National Water Policy of 2002 to ensure the sustainable management and protection of its water resources (see **Figure 2-1**). The primary water governance structures that operate at various levels to govern water resources in Tanzania and their responsibilities include:

- **The Ministry of Water (MoW)** is responsible for developing national strategies and policies for water resources management like the national integrated water management plan (IWRM). The ministry provides policy formulation, strategic oversight, and sector coordination. The Water Resources Division is responsible for managing both surface and groundwater.

- **The National Water Board (NWB)** advises the Ministry of Water on policy and legislative matters concerning water resources related to IWRM, ensuring that national strategies align with sustainable development goals. NWB is also involved in the coordination of Basin Water Boards (BWB).
- **Basin Water Boards (BWB)** are decentralised authorities established under the Water Resources Management Act No. 11 of 2009 to manage and protect water resources, including groundwater, within the country's nine hydrological basins. Each Basin Water Board operates within a specific basin and is responsible for water resources management, including planning, water resource monitoring, water allocation, permitting, stakeholder coordination, and conservation. For groundwater resources, the responsibility includes issuing water use and drilling permits and monitoring groundwater use and quality at the local level. Dar es Salaam falls within the Wami-Ruvu Basin.
- **Catchment/Sub-catchment Management Committees** operate under the Basin Water Boards, coordinating the conservation and protection of water sources, facilitating community participation, and implementing water management plans at the catchment level.
- **Water User Associations (WUA)** are community-based organisations that work closely with the BWBs to support conservation efforts, monitor permit compliance, support the collection of water permit fees, and regulate conflict between water users.
- **Municipalities** collaborate with relevant water supply authorities to treat and distribute water to residents and other water users where infrastructure is available and operational. Dar es Salaam comprises five (5) district municipalities (i.e. Kinondoni, Ilala, Temeke, Ubungo and Kigamboni).
- **Rural Water Supply and Sanitation Agency (RUWASA)** is created under the Water Supply and Sanitation Act No. 5 of 2019, and is mandated to ensure rural communities in Tanzania mainland have access to clean and safe water supply services. RUWASA is to provide water services to specific urban areas. RUWASA supervises the Community Based Water Service Organisations (CBWSOs) at district level. CBWSOs collect water charges from communities and are responsible for maintenance while RUWASA constructs, supervises and regulates water supply services in the rural areas.
- For Dar es Salaam City, the **Dar es Salaam Water and Sewerage Authority (DAWASA)** is the institution responsible for the development and management of water supply and sanitation assets, including the water generation and the supply network. Following some recent reforms, DAWASA has assumed roles that were under the now defunct Dar es Salaam Water Supply Company (DAWASCO), including the provision of water and sanitation services to consumers and the collection of revenue.
- Other institutions of interest include
  - The **National Environmental Management Council (NEMC)** implements the Environmental Management Act (above) and ensures that groundwater development projects comply with environmental safeguards.
  - The **Tanzania Geological Survey (TGS)** conducts geological and hydrogeological surveys and provides scientific data on groundwater aquifers and their potential.
  - The **Energy and Water Utilities Regulatory Authority (EWURA)** regulates water utilities, including pricing and service standards where groundwater is a key source. Groundwater tariffs for example, cannot change without approval from EWURA.

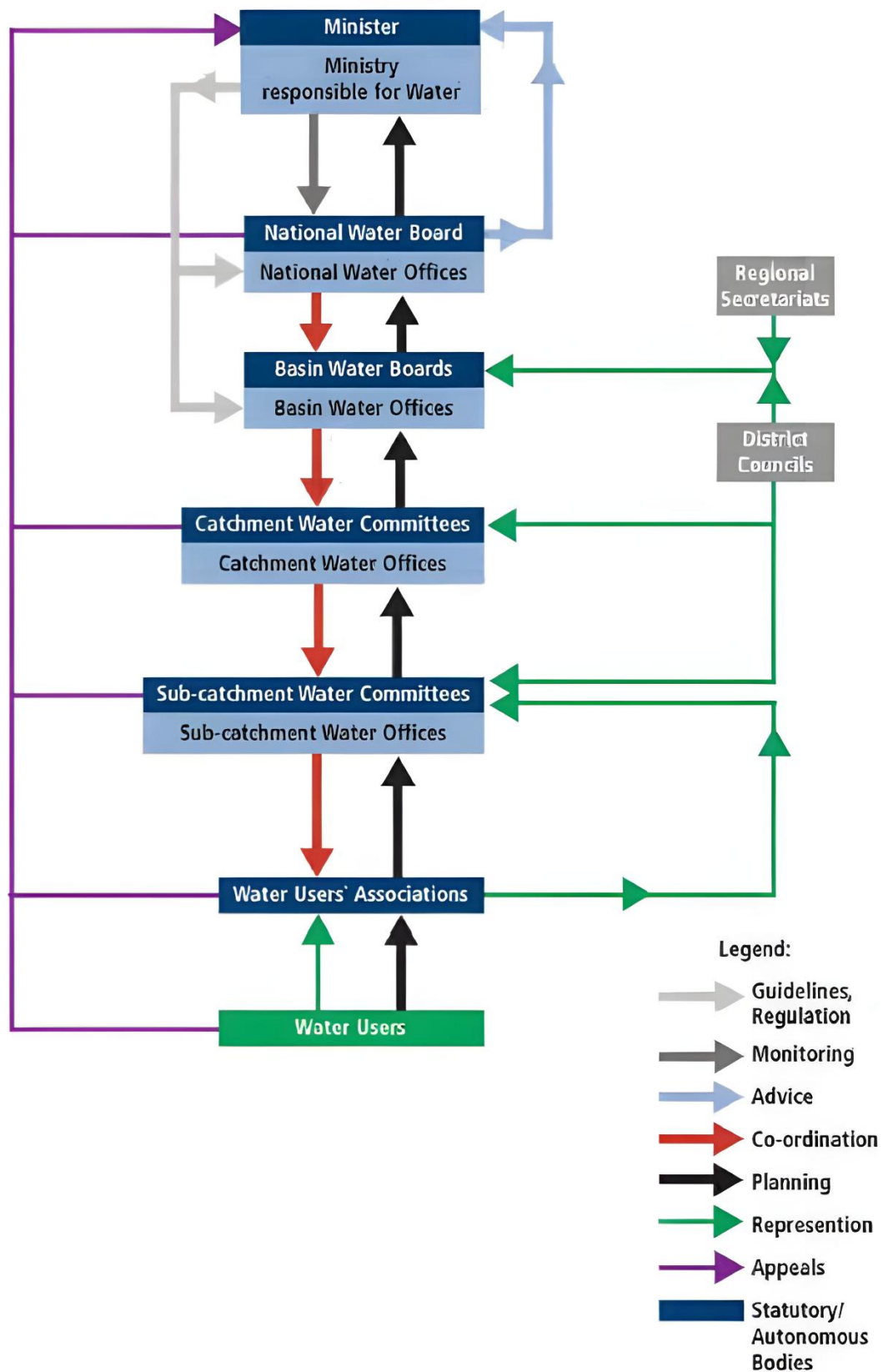


Figure 2-1: Governance Structure for Water Resource Management in Tanzania (World Bank, 2016).

## 2.2. Groundwater Use Authorisation and Registration

The introduction of water rights and permits, as part of the WRMA, was introduced to regulate water use, ensuring the allocation of water to water users is fairly distributed and provides a means of preventing over-exploitation. Through water allocation and prioritisation, water use is prioritised first for domestic use and basic human needs, then water supply for livestock, environmental conservation, irrigation and industry. Under the act, water is considered public property, requiring legal authorisation for its access. Authorisation for large scale use is granted through water use permits (WUP), while small scale domestic use for households and livestock do not require a permit. Permits pertaining to the establishment of infrastructure for water abstraction and discharge are also covered under the act. The drilling of boreholes requires a drilling permit, while discharging permits are required for the releasing of agricultural, industrial and sewage runoff into water bodies.

To strengthen the implementation and enforcement of the Water Resources Management Act No. 11 of 2009, 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), and the Operational Decision Support System (ODSS) – Water Use Permitting Analysis Tool (WUPA). The WUMIS is a web-based platform designed to manage water use, discharge, and drilling permit applications. This system was initially developed for the Wami-Ruvu Basin Water Board (WRBWB). It is the only system currently accessible to the general public and can be accessed through <https://wumis.maji.go.tz>. Maji-IS is a sector-wide information management system that, among other functions, holds records of all existing water uses and users, supports water permit applications, assesses customer water usage during different periods, and ensures that customers receive accurate water invoices based on their consumption. ODSS-WUPA, which is currently in the development stage, will interface with both Maji-IS and WUMIS to analyse the effects of potential new water abstractions on the system's overall water balance and, in particular, on existing water uses.

## 2.3. Role of Local Government in Groundwater Management

The District Council is considered the local government level. The sector departments of the municipality that deal directly with water resources development and environmental management are the District Water Engineer and the District Natural Resources (see **Figure 2-2**). However, according to IWRM, water management is integrated with all sectors. It should be noted that considerable power and responsibilities have been devolved to the district level, but there is insufficient capacity to implement all government programmes (IUCN, 2010).

Water resources management is the responsibility of the National Water Board, Basin Water Boards, Catchment Committees, and Water User Associations or Groups. Representatives from district councils and local government authorities sit on the Basin Boards and Catchment Committees

The National Water Policy of 2002 prescribes that District Councils shall participate fully in Basin Boards and Catchment Committees. The Districts are responsible for planning and development of water resources in accordance with basin plans, protection and conservation of natural resources in the villages and wards, establishment of by-laws on the management of water resources and conflict resolution in accordance with established laws and regulations. In addition, the District Councils will make assessment of water demands of their respective districts and participate fully in the preparation of Basin plans. However, the provision of water and sanitation services within the Dar es Salaam Region is delegated to the Dar es Salaam Water and Sewerage Authority (DAWASA), a public entity (see **Figure 2-2**).

WUAs or Water User Groups (WUGs) are the lowest level of management within the Tanzanian water management structure. WUAs aim to assist the Basin Water Office in managing water sources in the basin (IUCN, 2010).

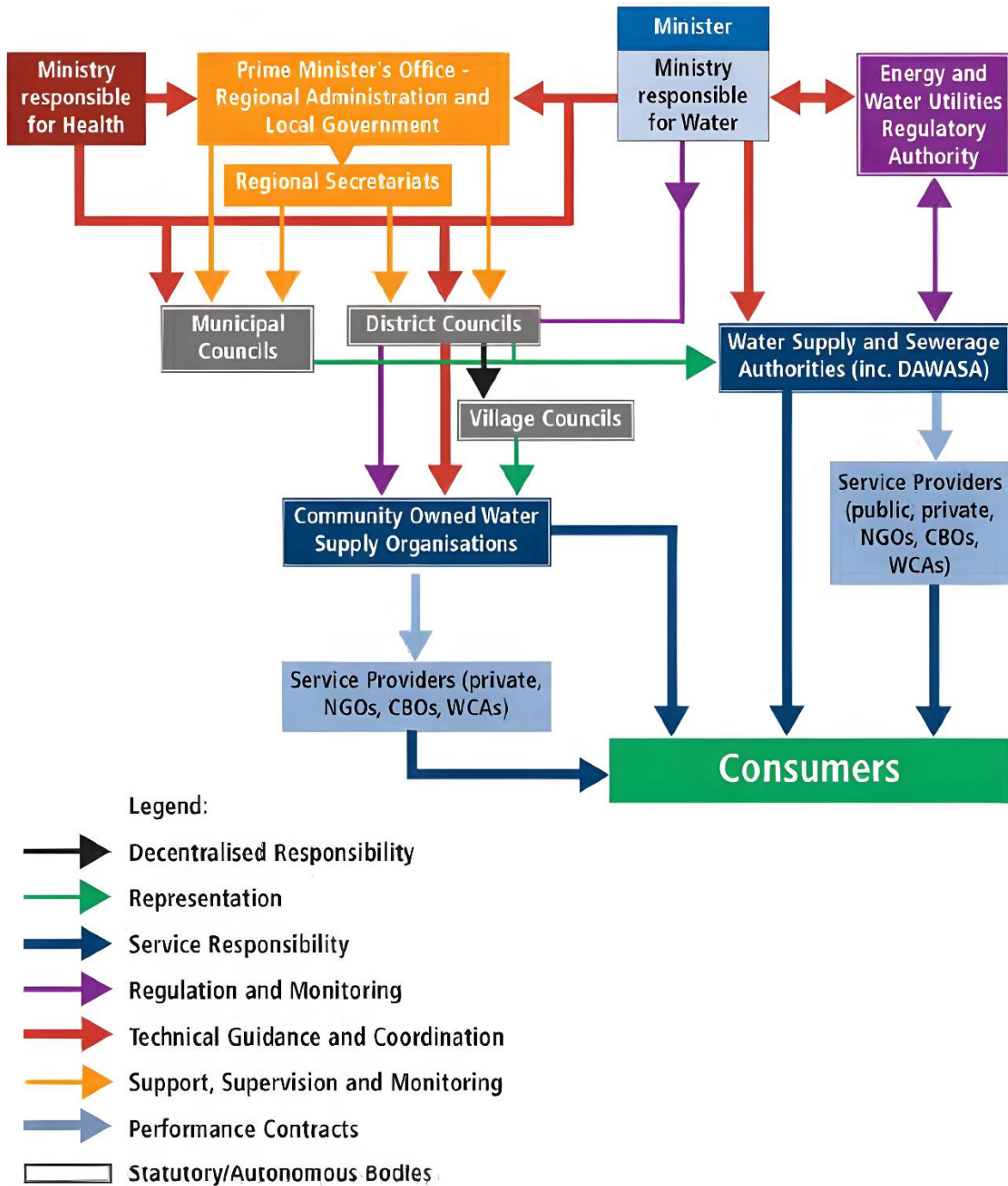
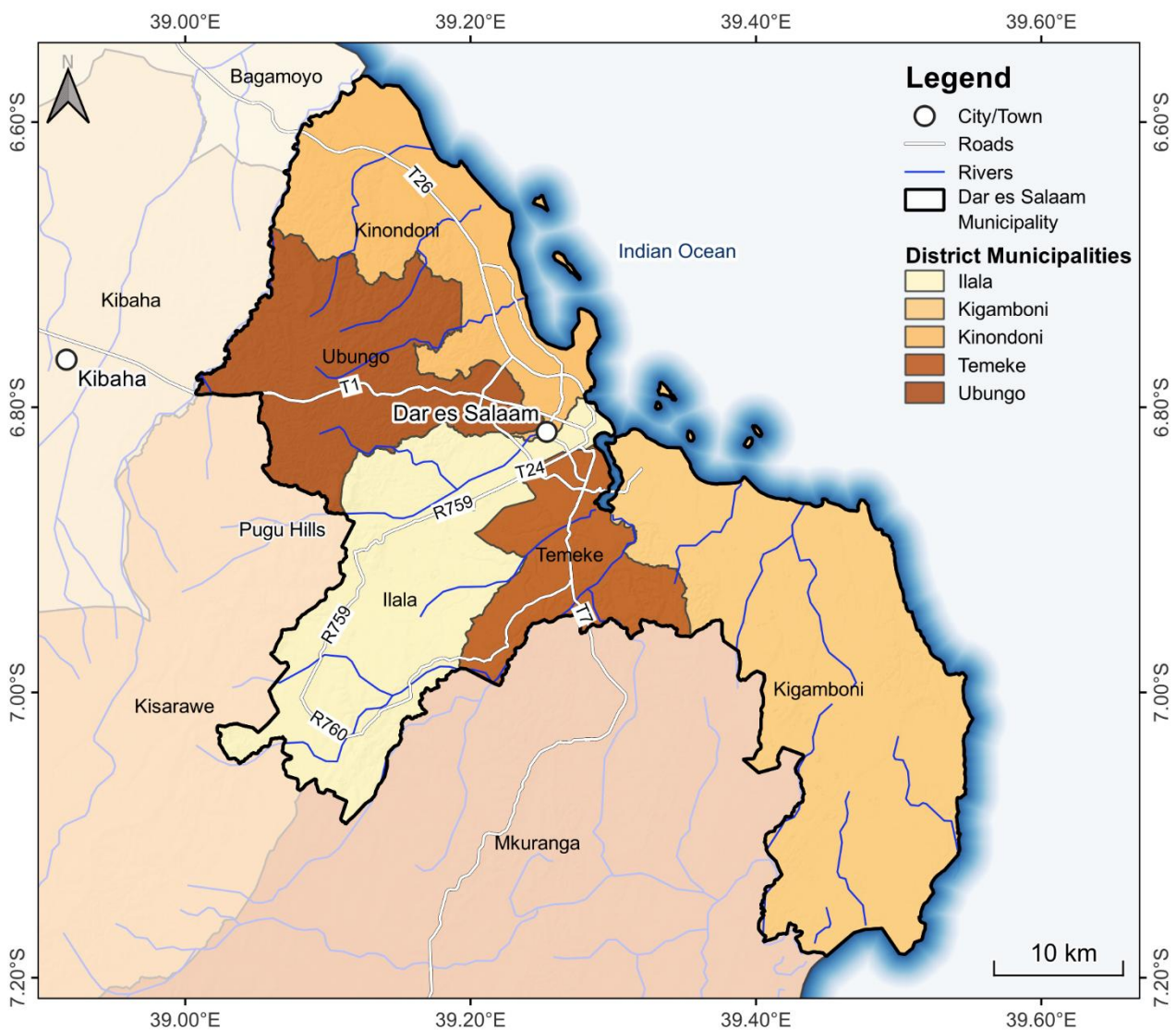


Figure 2-2 Governance Structure for Water and Sanitation Services (World Bank, 2016).

### 3. Description of Study Area

#### 3.1. Locality

Dar es Salaam is the largest city in Tanzania, representing the country's industrial and commercial centres. Located on the east African coast along the Indian Ocean (see **Figure 3-1**). 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 (NBS, 2022; URT, 2019). 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 3-1:** Locality map of the study area within the Dar es Salaams 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).

Like Cape Town, Dar es Salaam is both a geographically expansive and diverse region, with marked socio-economic differences between its various areas and districts. While the informal settlements in Cape Town are concentrated on the outskirts of several suburbs and make up a smaller portion of land cover relative to formally zoned land, the five districts of Dar es Salaam all house informal settlements, all to varying degrees of extent. Estimates suggest nearly 70-80% of settlements and land in Dar es Salaam are informal (Kombe et al., 2015; Todd et al., 2019; Nuhu et al., 2023).

The Kinondoni district is considered to possess the most affluent and contain the most well-planned residential areas. The Kigamboni district is economically diverse, housing both formal and informal settlements along the coast. In contrast, the Ubungo and Temeke districts are considered less affluent with fewer planned areas and higher populations (URT, 2024). Both the Ubungo and Temeke districts are focused on industry, with the Temeke district housing a large area of informal settlements (WBO, 2016). The Ilala district houses the commercial hub of the region and is considered the most densely populated district in Dar es Salaam (URT, 2024).

Municipal supply to residents in Dar es Salaam is strongly correlated to the district's access to the main rivers of the region, specifically the Ruvu and Kzinga rivers. Much of the South is solely reliant on groundwater as a source of water supply. The development of the Kimbiji Aquifer in the south is intended to supply groundwater to the districts of Kigamboni, Ilala, and Temeke. Reliance on groundwater in these areas is especially high, as they are often the most accessible source of freshwater for their water users.

### 3.2. Climate

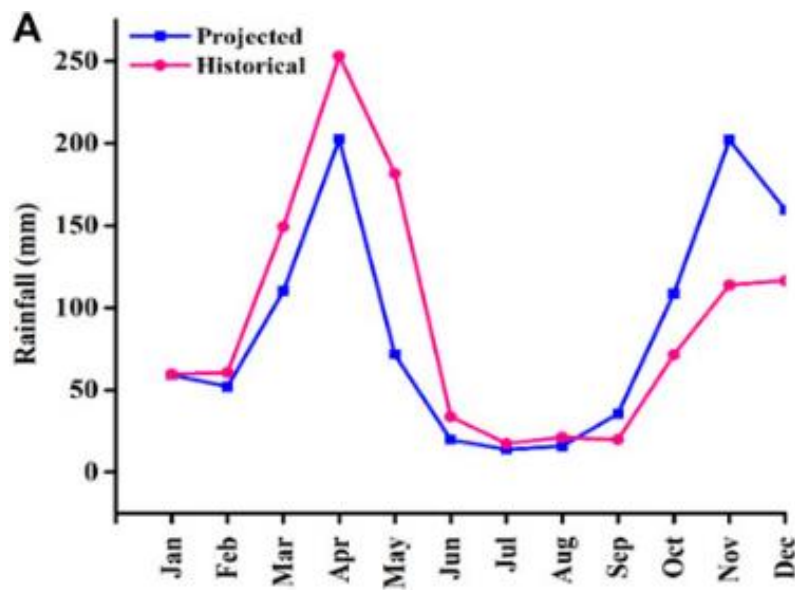
Dar es Salaam experiences a tropical climate, characterised by wet and dry seasons where hot and humid conditions are prevalent throughout the year. According to the Köppen–Geiger climate classification system (Peel et al., 2007), Dar es Salaam's climate is classified as a tropical savanna (Aw). Monthly 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. The wet season occurs over two periods in Dar es Salaam, the first period between March to May, is characterised by long and intense rainfall events, while the second period between November to December, by less intense and short rainfall events **Figure 3-2**. The dry season occurs from June – October, however the region still experiences some rainfall during this period, albeit significantly lower than the wet season.

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 rainfall pattern in Dar es Salaam is largely influenced by monsoons, where winds blow south to southeast and north to northeast from April to October and November to March respectively. During the dry season, potential evapotranspiration often exceeds precipitation resulting in reduced rainfall to replenish and recharge essential surface water and groundwater

resources (Mwakalila, 2007). Annually, the total average evapotranspiration is estimated at 1965 mm (Mjemah and Walraevens, 2015). Historically, rainfall has only exceeded evaporation and evapotranspiration from March to May. As a result, very little to no runoff and groundwater recharge occurs during the rest of the year. Much of the scattered rainfall received during the course of the year is taken up by vegetation, however as deforestation continues, less vegetation cover is available to prevent runoff.

The monthly mean rainfall projections for Dar es Salaam (see **Figure 3-2**) indicate an expected shift in rainfall distribution between the two wet seasons. Forecasts for the period 2021–2050 suggest a decline in rainfall during the first wet season from March to May (long rains) and a notable increase in rainfall during the second wet season from November to December (short rains), when compared to historical averages from 1983–2019 (Nyembo et al., 2022). These projected changes point to increasing variability and intensity in seasonal rainfall, which may further affect the recharge dynamics of surface and groundwater resources in the region.

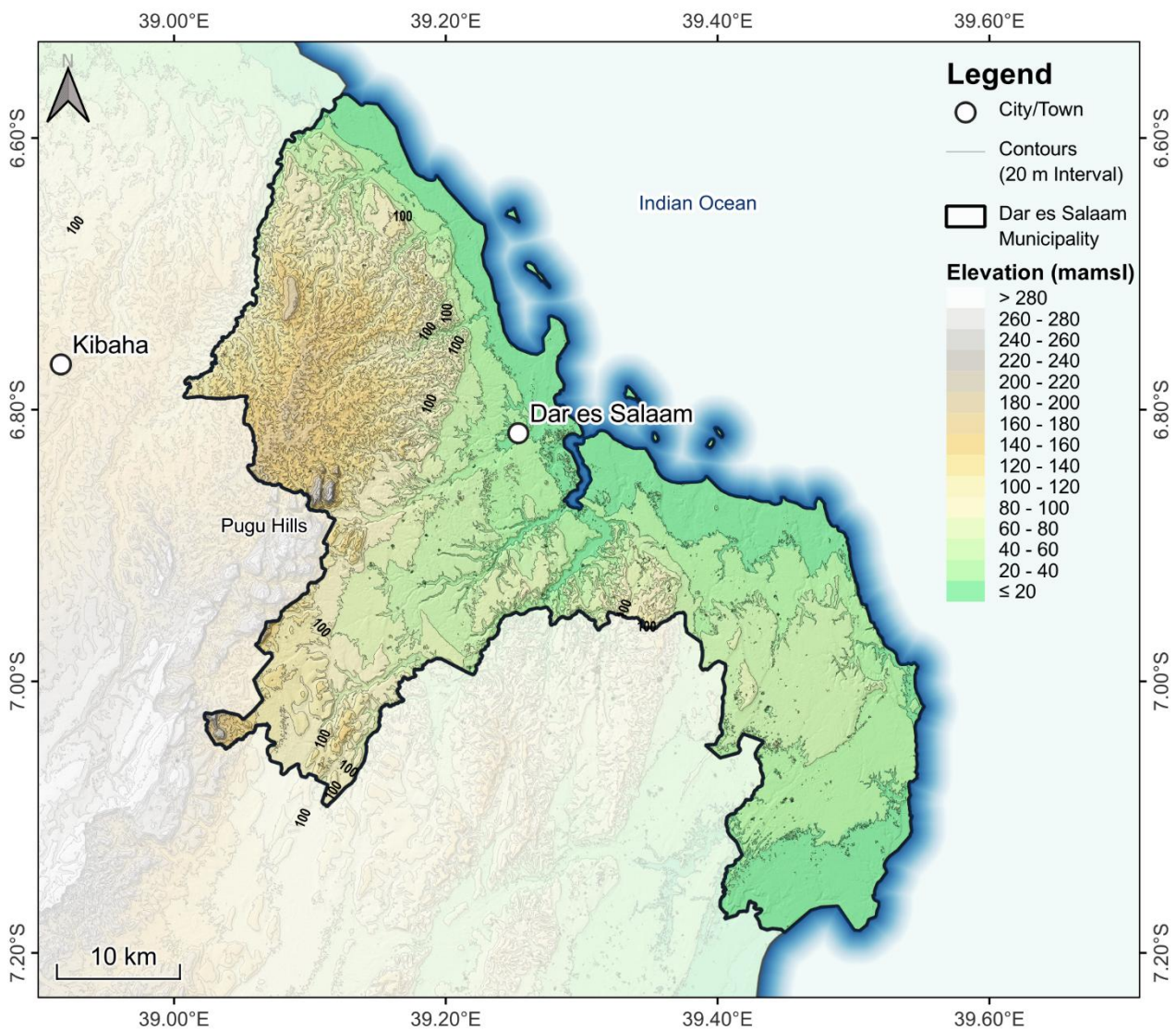


**Figure 3-2:** Project monthly mean rainfall (2021-2050) compared to historical (1983-2019) rainfall of Dar es Salaam for Julius Nyerere International Airport (Nyembo et al., 2022).

### 3.3. Topography

Dar es Salaam exhibits a relatively low-relief coastal plain (see **Figure 3-3**), the city's 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).

Further west, the terrain becomes slightly elevated, where it is at its most pronounced toward the Pugu Hills and southern highlands, these 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 to be important sources of groundwater recharge and are thought to influence local drainage patterns.



**Figure 3-3: Topographical map of regional Dar es Salaam**

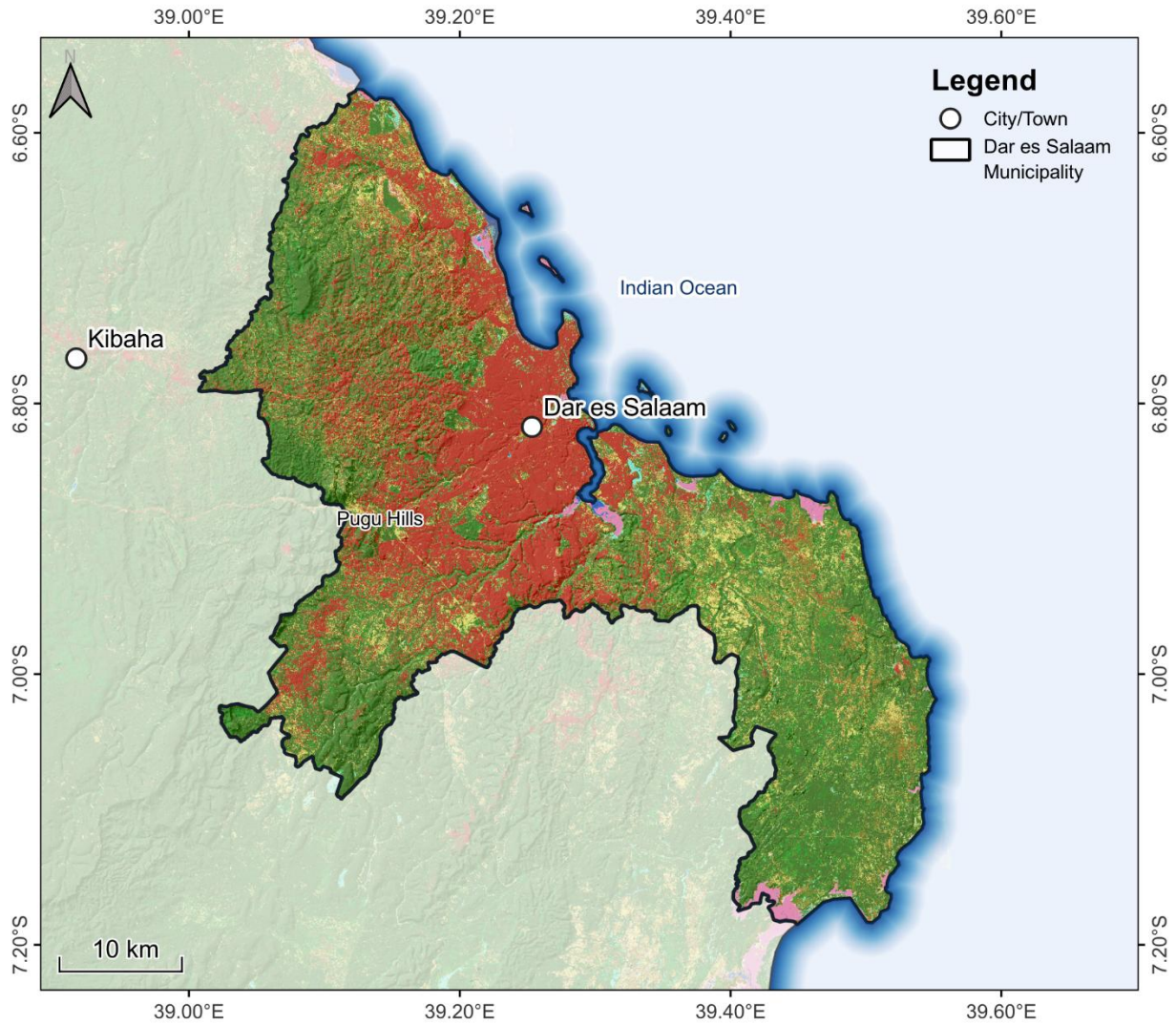
The coastal zone in the east is characterised by flat, sandy beaches, coral reef terraces, and mangrove-lined estuaries, particularly along the Msimbazi, Mzinga, and Kizinga rivers. These rivers have incised shallow valleys into the coastal plain, forming flood-prone alluvial flats dominated by unconsolidated sediments such as sands, silts, and clays (Mjemah 2007).

To the southeast, the Kigamboni Peninsula features more rugged terrain with higher elevations and visible coral limestone outcrops, particularly in raised reef zones. The combination of geological uplift and historical sea-level changes have created marine terraces, which contribute to the city's varied topographic features (Msindai, 2002; Mjemah 2007).

The north consists of gentle hills in the form of the Msasani Peninsula, while inland, the Mbezi River separates the Dar es Salaam region from the Pwani region (Van Camp et al., 2012). The regional south is made of mostly flat lowlands and floodplains

Over the past several decades, Dar es Salaam has undergone rapid urbanisation and land use transformation driven by population growth, economic development, and informal settlement expansion. This growth has dramatically altered the city's land cover. Analysis of land cover trends during 2002-2012 indicated that urban areas increased from approximately 40% to 65%. Concurrently, land classified as soil cover declined by around 20%, dropping from about 47% to 27%. This expansion of impervious urban surfaces has reduced overall landscape permeability. As a result, areas of groundwater recharge potential are thought to be reduced (Sappa et al., 2013). This has a direct influence on water users in Dar es Salaam who depend on groundwater for domestic use and irrigation.

Land use in Dar es Salaam has shifted significantly from natural vegetation and agricultural lands to built-up urban environments. The expansion of impervious surfaces such as roads, buildings, and concrete infrastructure has increased impermeable land cover, particularly in central districts (see **Figure 3-4**). Loss of wetlands and green spaces which acted as natural floodplains and vegetated buffers along rivers such as the Msimbazi and Mzinga, have been encroached upon by informal settlements and land reclamation. (GLOWS–FIU, 2014). Coastal and peri-urban areas have experienced a loss of mangrove forests and woodlands, reducing evapotranspiration and soil infiltration capacity (GLOWS–FIU, 2014).



**Land Cover (OpenLandMap)**

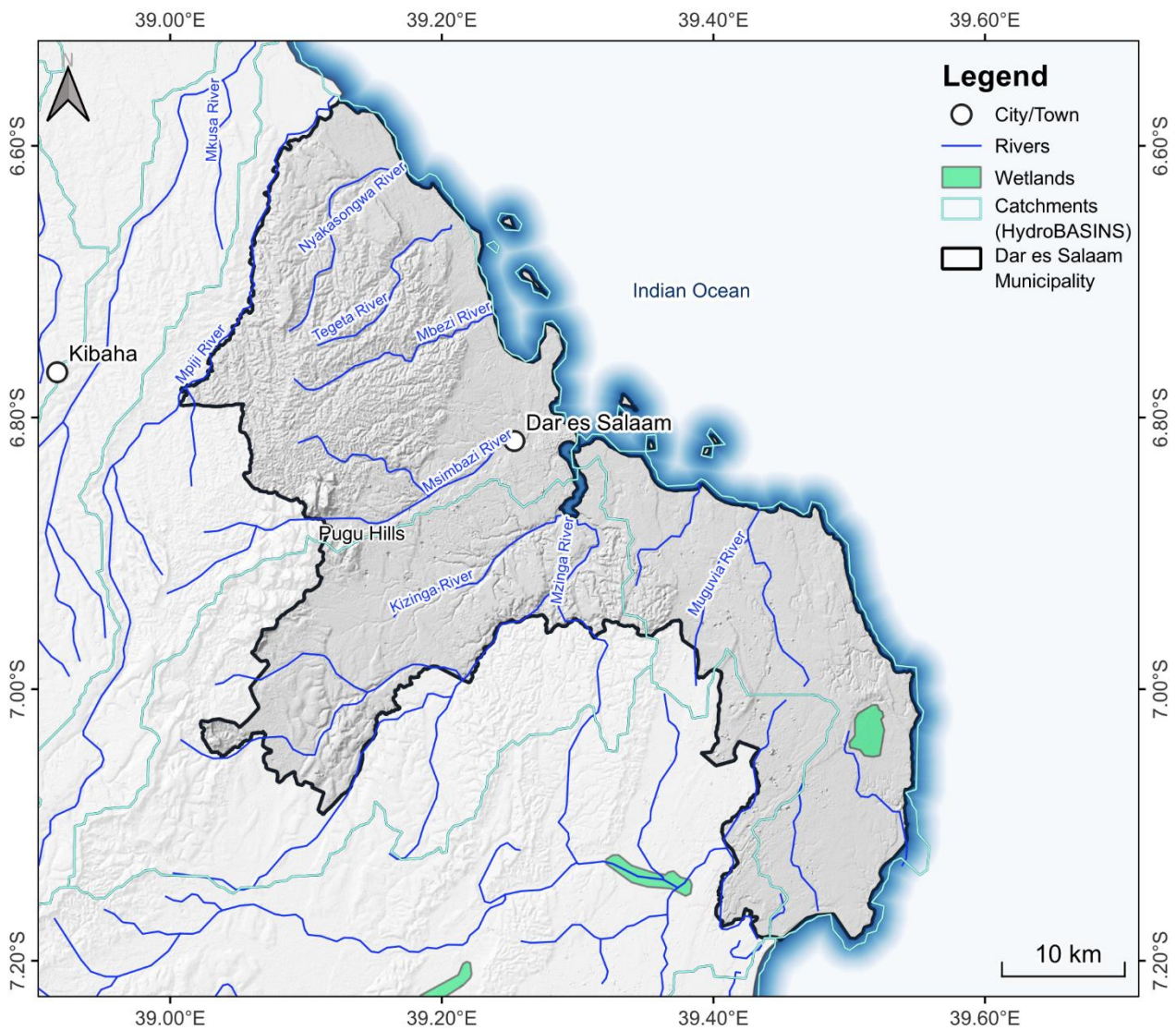
- |  |   |
|--|---|
| <ul style="list-style-type: none"> <li>■ Rainfed cropland</li> <li>■ Herbaceous cover cropland</li> <li>■ Tree or shrub cover (Orchard) cropland</li> <li>■ Irrigated cropland</li> <li>■ Open evergreen broadleaved forest</li> <li>■ Closed evergreen broadleaved forest</li> <li>■ Open deciduous broadleaved forest</li> <li>■ Closed deciduous broadleaved forest</li> <li>■ Open evergreen needle-leaved forest</li> <li>■ Closed evergreen needle-leaved forest</li> <li>■ Open deciduous needle-leaved forest</li> <li>■ Closed deciduous needle-leaved forest (fc &gt;0.4)</li> <li>■ Open mixed leaf forest (broadleaved and needle-leaved)</li> <li>■ Closed mixed leaf forest (broadleaved and needle-leaved)</li> <li>■ Shrubland</li> <li>■ Evergreen shrubland</li> <li>■ Deciduous shrubland</li> <li>■ Grassland</li> </ul> | <ul style="list-style-type: none"> <li>■ Lichens and mosses</li> <li>■ Sparse vegetation</li> <li>■ Sparse shrubland</li> <li>■ Sparse herbaceous</li> <li>■ Swamp</li> <li>■ Marsh</li> <li>■ Flooded flat</li> <li>■ Saline</li> <li>■ Mangrove</li> <li>■ Salt marsh</li> <li>■ Tidal flat</li> <li>■ Impervious surfaces</li> <li>■ Bare areas</li> <li>■ Consolidated bare areas</li> <li>■ Unconsolidated bare areas</li> <li>■ Water body</li> <li>■ Permanent ice and snow</li> </ul> |
|--|---|

**Figure 3-4:** Land cover map showing extent of urbanisation in the Dar es Salaam region using a 30m, 35 land-cover class Landsat dataset from 1985-2022 (OLM, 2024).

### 3.4. Hydrology

Dar es Salaam is situated in the Wami-Ruvu Water Basin (WRWB) which is one of the nine major drainage basins in Tanzania and the key source for surface water in the city (Winrock International, 2021). The Ruvu River, draining from the Uluguru Mountains in the north is the major perennial river supplying the city with its surface water. Three other perennial rivers in the city serve as surface water sources namely the Kizinga, Msimbazi, and Mzinga Rivers which originate from the reaches of the Pugu and Kisaware Hills (**Figure 3-5**) (Mjemah et al., 2011).

Despite the perennial nature of the coastal rivers, there is a great variability in the flow levels due to seasonal influence. In discussing the nature of surface water in Dar es Salaam, reference must be made to groundwater due to bidirectional flow. During the wet seasons, rainfall recharges the surface water and, in turn, the groundwater (primarily the Coastal Quaternary Aquifer), which preserves baseflow levels in the dry season. When the region experiences less rainfall during the dry season, some surface waters are recharged by groundwater baseflow (Mjemah et al., 2011).



**Figure 3-5: Hydrological map of the Dar es Salaam region.**

In the dry season, the Mzingira River is recharged by tributaries upstream and (with greater supply) from groundwater in the alluvial plain, where surface water levels are lower than those of the groundwater table (Mjemah et al., 2011). The Kizingira and Msimbazi Rivers have homogenous hydrogeological conditions and are recharged by tributaries and groundwater; however there is less distinction between their contributions. Surface water recharge is greatly dependent on land cover, slope, and soils, as recharge of surface flows during the wet seasons occur, once groundwater and soils are saturated (Sappa and Luciani, 2014).

Growing demand for water in the coastal sub-catchment for irrigation and domestic use, has led to the depletion of both surface and groundwater due to over-abstraction, and development impacting soils and land-cover (Sappa and Luciani, 2014). Change in land-cover and soil-water interaction has led to higher runoff and faster catchment drainage, resulting in flash floods which impede groundwater recharge. This is often exacerbated by the growing presence of impervious surfaces in the city (Kibugu et al., 2022). These changes to surface characteristics and the interface between soil and water increase the risk of both flooding during the wet season and drought during the dry season (Winrock International, 2021).

Anthropogenic activities in the city can reduce the quantity and quality of surface water, as inflows carry heavy metals from mining effluent and effluent from wastewater (Skinner and Walnycki, 2016). Additionally, over abstraction from boreholes in the coastal aquifer can affect the quantity and quality of fresh water due to the inflow of salt water and reduction of fresh groundwater (Skinner and Walnycki, 2016). These activities under the right conditions, can influence the level of salinity in important water supplying rivers.

### 3.5. Geology

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 3-6** and **Figure 3-7**). This layered stratigraphy reflects both tectonic evolution and marine influences, and it plays a significant role in shaping the region's groundwater systems.

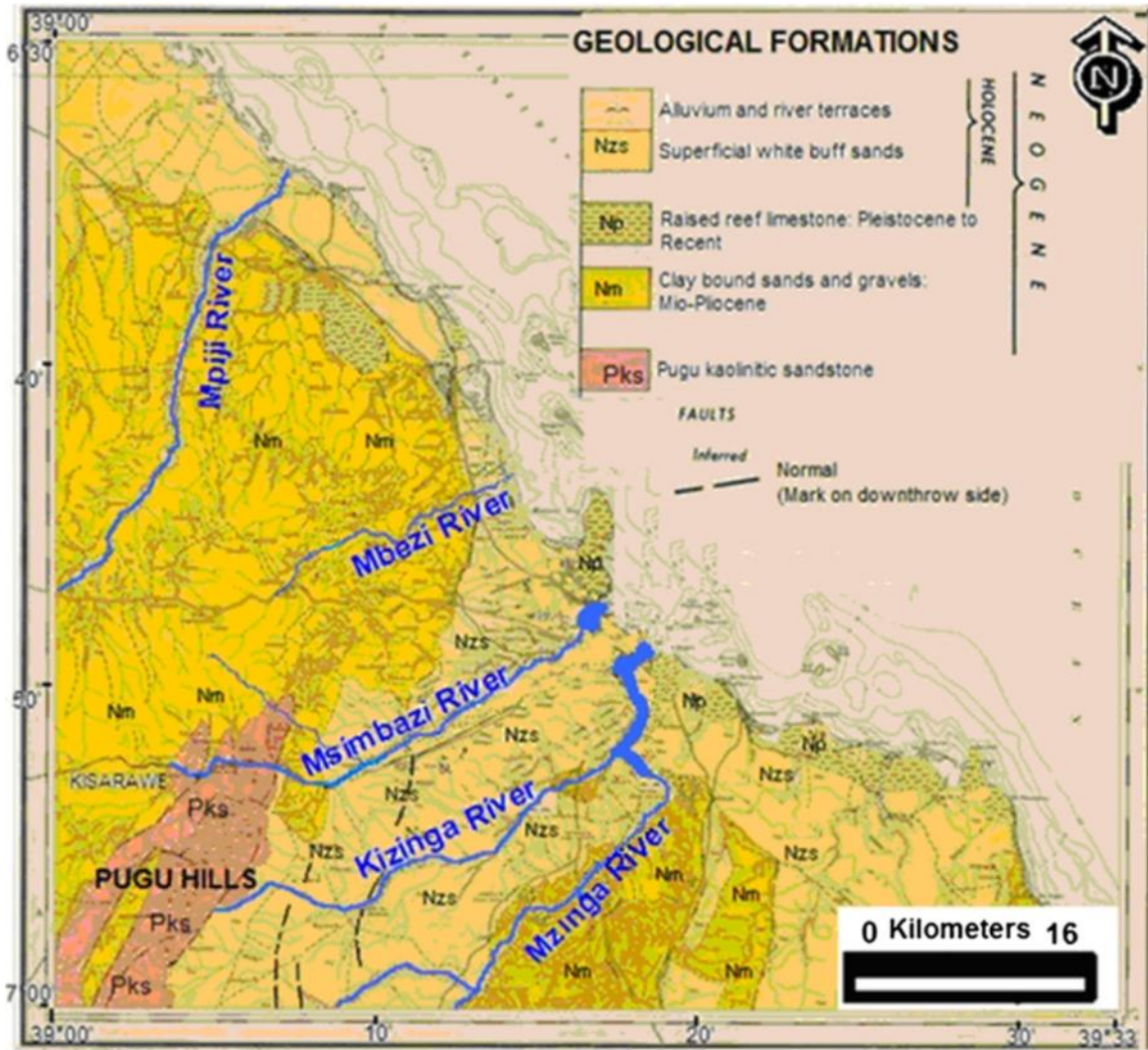


Figure 3-6: Geological map of the Dar es Salaam region (Van Camp et al., 2014).

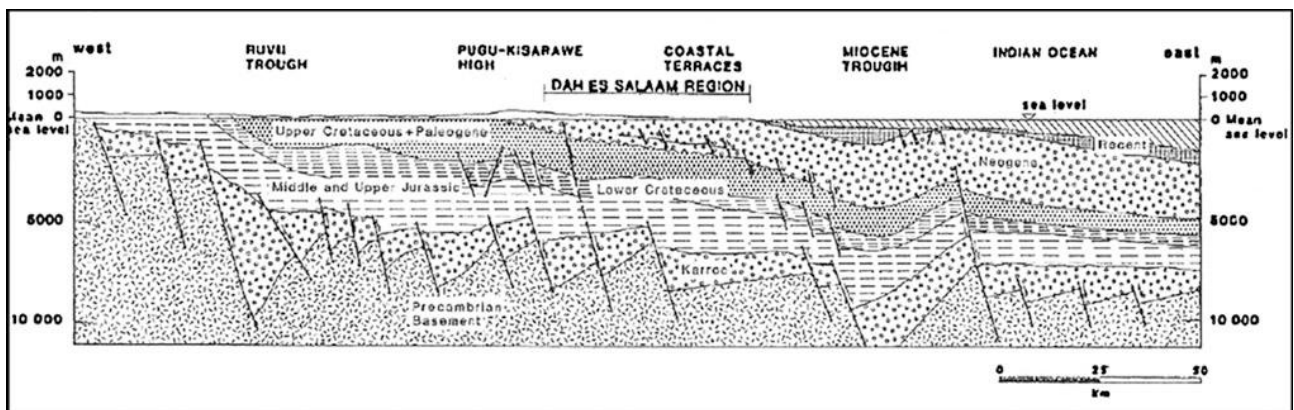


Figure 3-7: Cross-section across the central Dar es Salaam region (Figure 3-6) showing the coastal terraces in Dar Es Salaam (Sappa et al., 2014, after Msindai, 1988).

### 3.5.1. Basement Complex

The basement rocks consist of Precambrian Mozambique belt metamorphic rock, composed mainly of meta-sedimentary rocks, 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).

### 3.5.2. Karoo Rocks and Mesozoic Sediments

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).

### 3.5.3. Neogene Deposits

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). Terrace development in the area is controlled by the underlying massive terrace sandstone. The Pugu sandstone formation is characterised by thick, kaolinitic, and cross-bedded layers, with calcareous sandstones also present in back reef upland zones. Overlying these Pugu Hill sandstones are Miocene deltaic deposits, referred to as "clay bound sands", outcropping north and south of the city centre (see **Figure 3-6**). These clay bound sands reach a thickness of > 750 m (Van Camp et al., 2014).

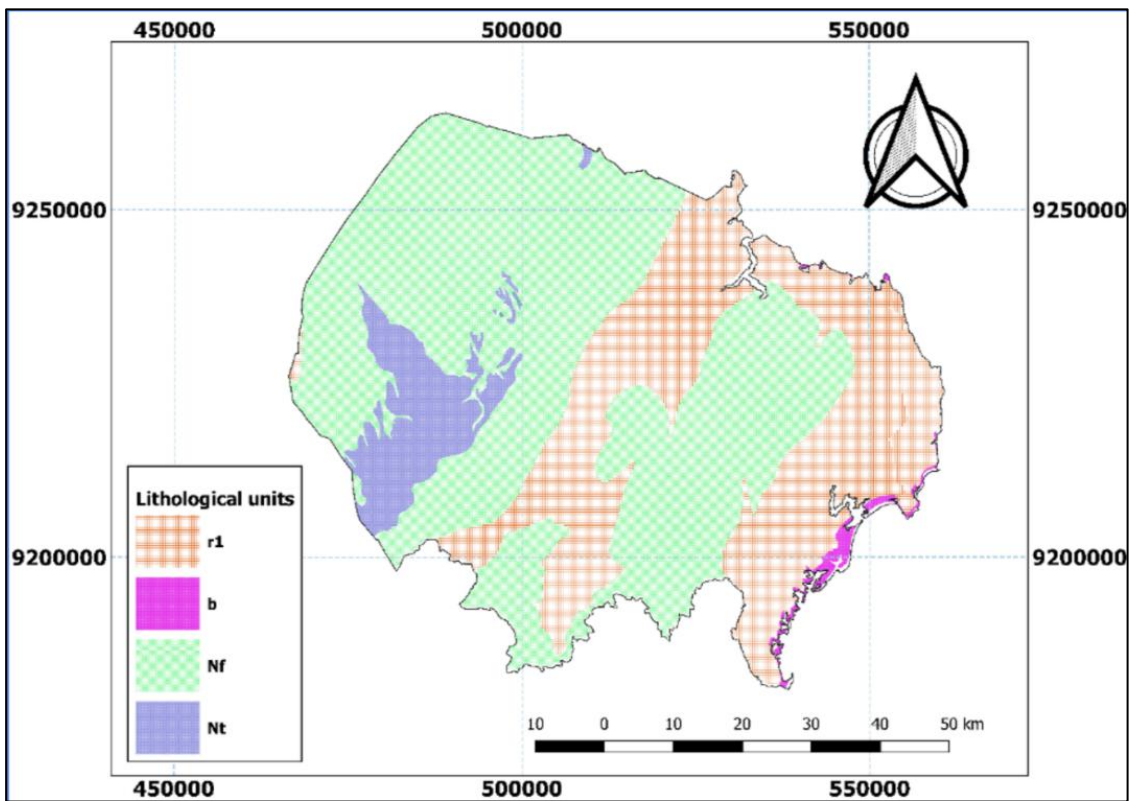
### 3.5.4. Quaternary Deposits

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 sands, clays, and occasionally gravel and pebbles that fill the river valleys of the Mzingu, Kizingu, and Msimbazi rivers (see **Figure 3-6**). 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 3-6**) (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).

### 3.6. Hydrogeology

Dar es Salaam’s hydrogeology is made up of a mix of aquifer systems, including coastal sedimentary layers of Quaternary and Neogene age, and deeper fractured formations (**Figure 3-8**). Dar es Salaam is underlain by alternating sequences of unconsolidated Quaternary sediments, Neogene sandstones and clays, and underlying fractured Precambrian basement rocks. These hydrostratigraphic units host a series of aquifers, both unconfined and confined, varying in productivity, vulnerability, and strategic importance. Groundwater is a vital source of domestic, agricultural, and industrial supply, particularly in areas where surface water infrastructure is limited, such as the southern parts of Dar es Salaam, in the Temeke and Kigamboni municipal districts, where municipal piped water from surface water schemes is not available. In these regions, groundwater is the primary, and often only source of water (Van Camp et al., 2014; IUCN, 2010).

These aquifer systems are recharged predominantly through direct rainfall infiltration, with annual recharge estimates ranging between 50–150 mm/year depending on land cover and soil permeability (Mjemah et al., 2011). Groundwater flow is generally from inland areas toward the coast, though abstraction-driven gradients and local heterogeneities influence actual flow paths and aquifer responses (Van Camp et al., 2014).



**Figure 3-8:** Regional geological map of Dar es Salaam showing the distribution of Quaternary and Neogene deposits which form the major aquifer units of the region. r1 – Quaternary fluvial deposits; b – Quaternary beach sand dune deposits; Nf – Neogene fluvial marine sand; Nt – Neogene terrace deposits (Mussa et al., 2021).

### 3.6.1. Quaternary Aquifers

Dar es Salaam's key aquifer supplies water both publicly and privately to its population and various sectors. The most utilised system in the central Dar es Salaam area is the Quaternary Aquifer (see **Figure 3-8**), a primary sandy system characterised by its unconfined and semi-confined conditions. Known as the Quaternary Groundwater Reservoir, this formation is made of fluvial and deltaic sediments from the Pleistocene.

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 coast (see **Figure 3-9** and **Figure 3-10**) (Van Camp et al., 2012).

Aquifer thickness varies between 20-80 m, depending on location and proximity to the coastline. In certain instances to maximise borehole yields, boreholes are screened across the aquitard to abstract water from the lower and upper aquifer. 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 WHO limits (Sappa and Luciani, 2014). Due to the geological setting of the area, the lower aquifer can reach depths which are below mean sea 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 (see **Figure 3-11**).

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).

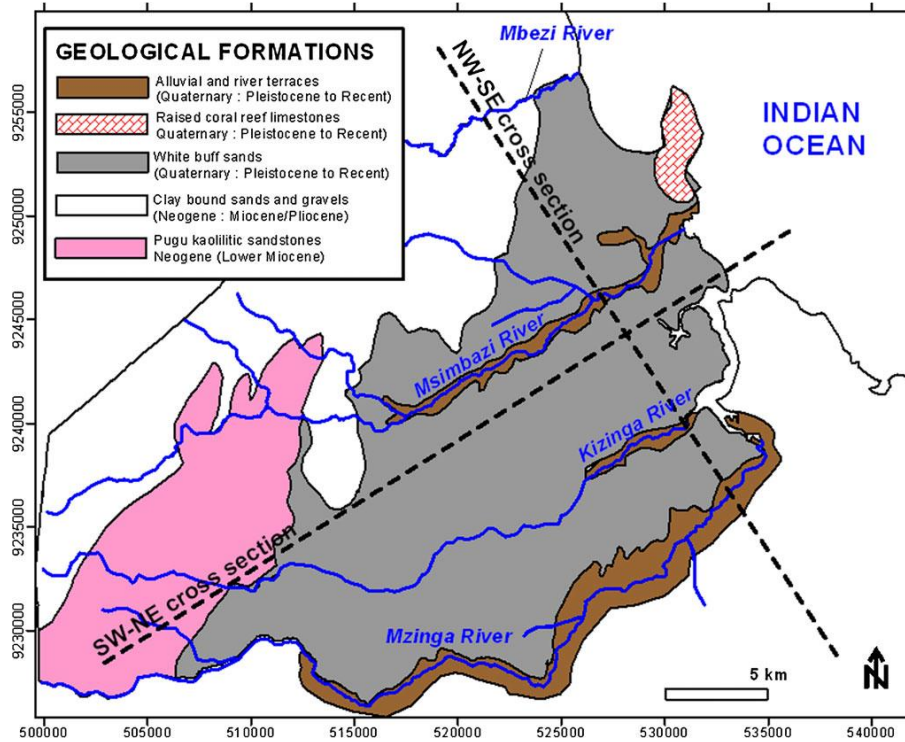


Figure 3-9: Geological map of the central Dar es Salaam region (Van Camp et al., 2012, after Bartholomew, 1963).

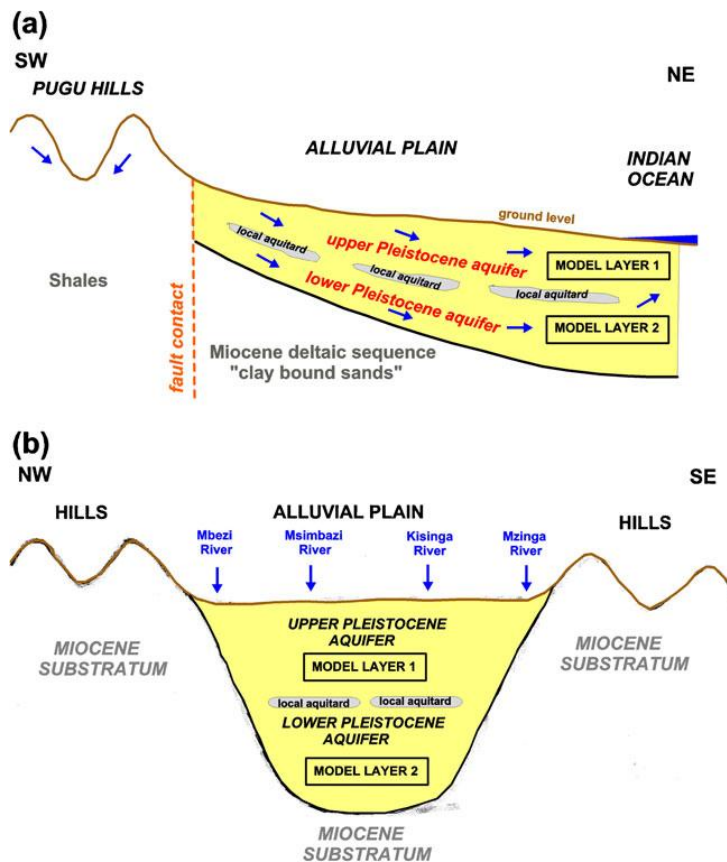


Figure 3-10 Schematic cross section across the central Dar es Salaam region (Figure 3-9), showing the distribution of the lower and upper Quaternary aquifers (Van Camp et al., 2012).

# GROUNDWATER DEPENDENCY ASSESSMENT (DAR ES SALAAM)

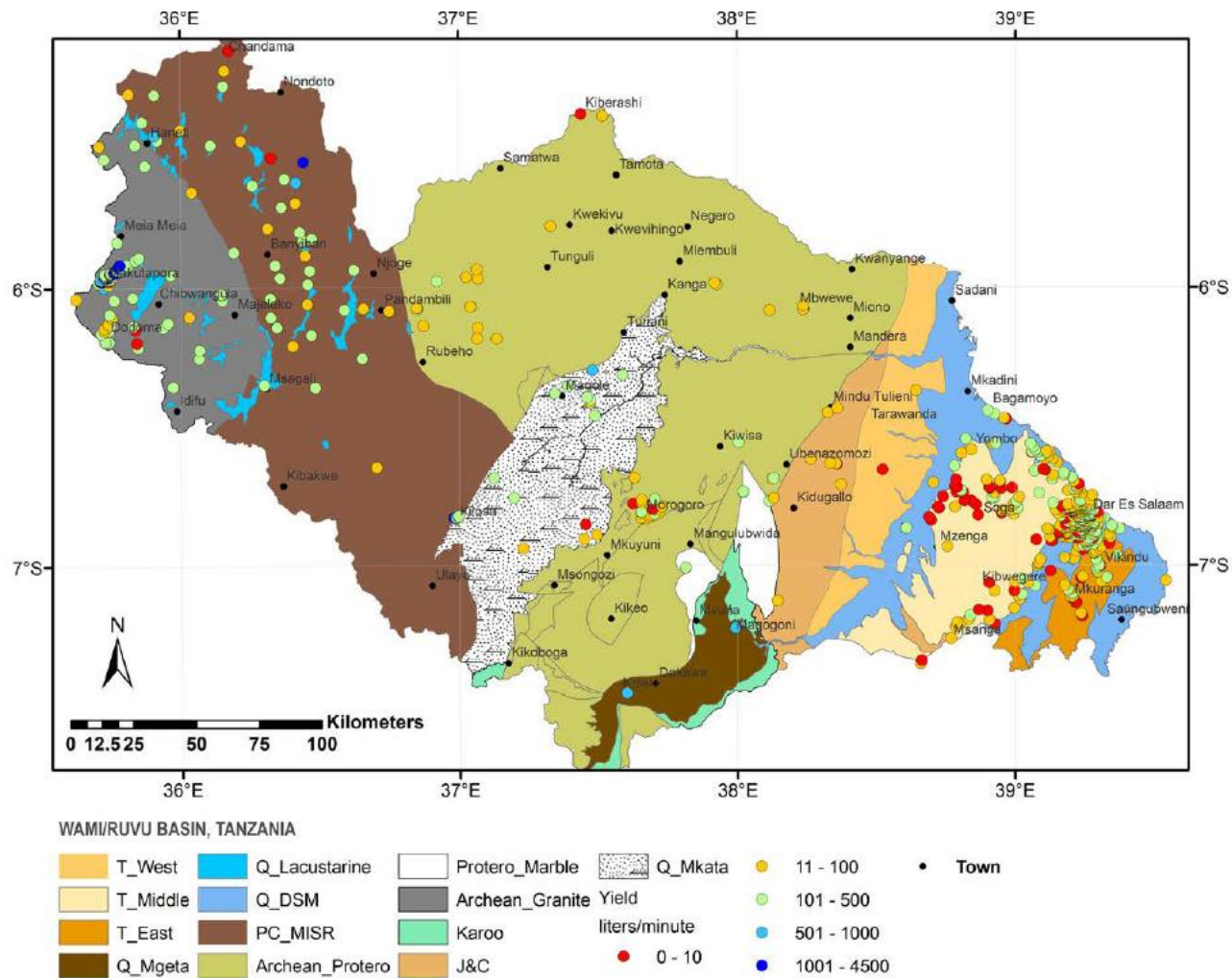


Figure 3-11 Geology map of the Wami/Ruvu Basin showing the distribution of boreholes and yields (GLOWS-FIU, 2014).

### 3.6.2. Neogene Aquifers

The Neogene Aquifer System consists of semi-consolidated sandstones, siltstones, and clays that extend across southern and inland parts of Dar es Salaam (see **Figure 3-8**). 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 portion of Dar es Salaam and extending into the Mkuranga District.

The Neogene Aquifers comprises deep, confined aquifer layers composed primarily of fine to coarse-grained sandstones, interbedded with clays and siltstones. The aquifer can reach depths of over 200 metres, 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 to 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 have been developed at Kimbiji and Mpera, 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.

### 3.6.3. 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.

### 3.7. Surface Water and Groundwater Recharge Potential

#### *Soil Infiltration Potential*

The dependency of groundwater on surface water was assessed. This was centred on the concept of aquifer recharge potential and the hydrological aspects affecting this potential.

Of relevance is that recharge potential, as outlined in this section, excludes rainfall considerations which are discussed in **Section 3.2**. Where rainfall is higher, recharge potential would be higher (although it would be affected by the aspects discussed in this section). **Figure 3-12** illustrates the datasets evaluated with regard to recharge potential.

#### *Aquifer Recharge Potential*

Aquifer types have the potential to (at a basic level) either be susceptible to recharge or resistant to recharge when they are either unconfined or confined, respectively. High soil infiltration potential with no impervious areas would not lead to recharge of a confined aquifer. There are two types of aquifers in the region of relevance: intergranular and intergranular and fractured (British Geological Survey, 2019). The intergranular aquifers are assumed to have higher infiltration due to more permeable soils; however, infiltration is influenced by surface and subsurface conditions. The quaternary aquifer system consists of two aquifers: an overlying unconfined sand aquifer and an underlying semi-confined sand aquifer. A clay aquitard serves as a hydraulic barrier between the two layers (Mussa et al., 2019).

When considered in unison, the areas of highest recharge potential are noted to occur outside of the partly impervious area that has been defined, since soil infiltration potential is otherwise similar.

#### *Infiltration Potential*

A primary determinant of recharge potential is that of infiltration potential, as the more infiltration that occurs, the higher the recharge (assuming aquifers are unconfined). To consider infiltration potential, the HYSOGs250m global gridded dataset, which defines hydrological soil groups (HSGs) according to the following runoff potential classification:

- **HSG A** - Low runoff potential. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures.
- **HSG B** - Moderately low runoff potential. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures.
- **HSG C** - Moderately high runoff potential. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures.
- **HSG D** - High runoff potential. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures.

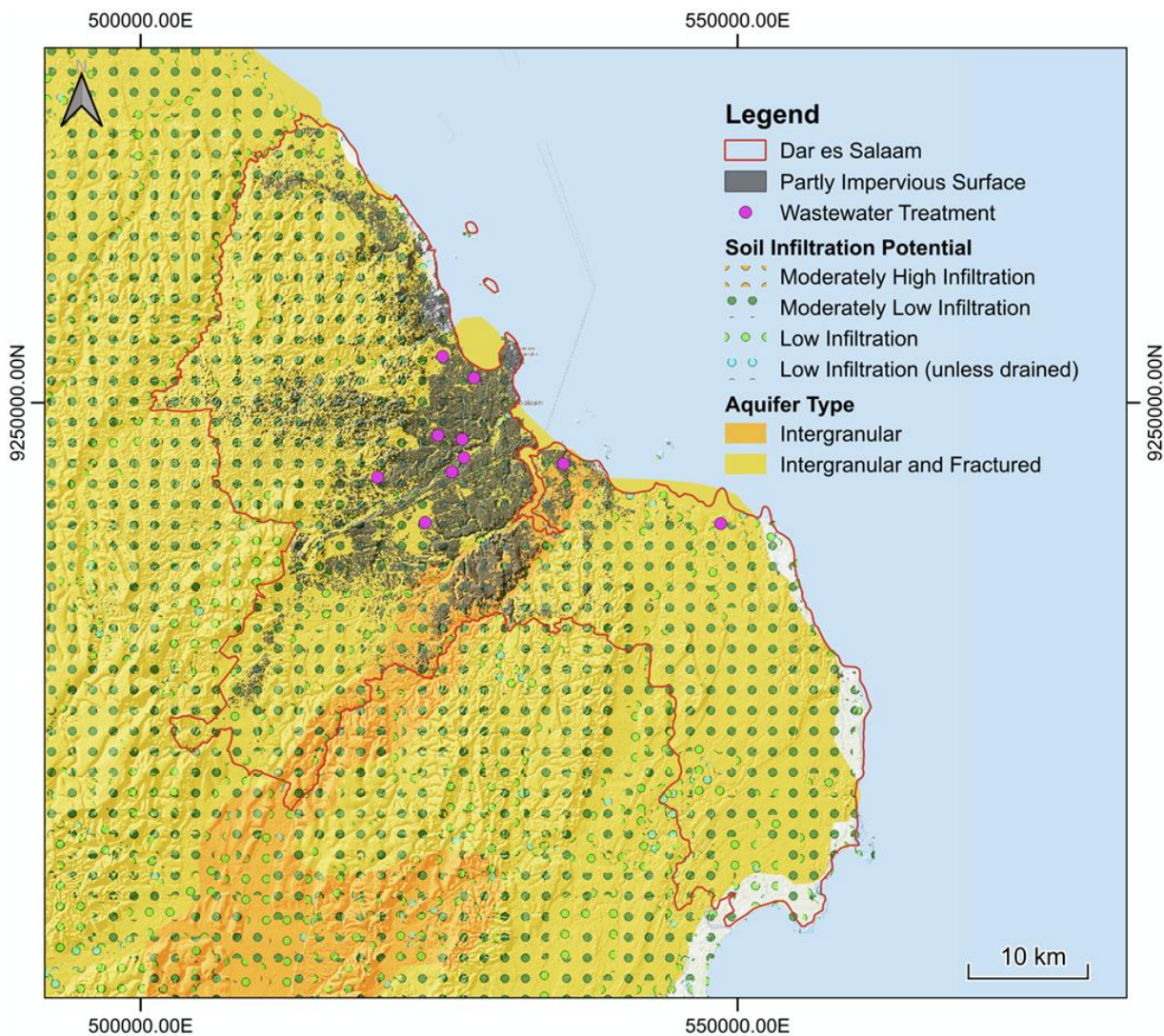
As mentioned, the HSG is a classification relating to runoff potential. As such, infiltration potential can be determined according to the inverse of the HSG (e.g. an HSG A with low runoff potential would have a high infiltration potential). Therefore, Dar es Salaam's primary HSG results in a low to moderately low infiltration potential.

**Impervious Areas**

The ESA Climate Change Initiative (CCI) Land Cover project 2016 land-cover dataset enabled the definition of impervious areas that would prevent infiltration and thereby recharge. Impervious areas were defined according to the presence of ‘built up’ areas according to the dataset. The impervious nature of these areas is not absolute, and some pervious portions remain. As such **Figure 3-12** presents an assumed ‘partly impervious surface’. Impervious areas are concentrated around the more urbanised portions of the city. The Temeke district municipality in particular displays the most impervious surfaces, with areas of the Ilala, Ubungo and Kinondoni district municipalities closest to Dar es Salaams centre, also showing significant areas of impervious land cover.

**Wastewater Treatment Plants**

A likely minor addition to groundwater recharge is treated water from wastewater treatment plants (WWTP), which serve to increase streamflow and thereby provide potential increases in groundwater recharge. The Open Street Map (OSM) dataset of WWTP’s were plotted in **Figure 3-12** to illustrate locations that may serve to increase or sustain streamflow and lead to localised increases in recharge (within the affected downstream river reach).



**Figure 3-12: Aquifer recharge potential within the Dar es Salaam regional boundary**

## 4. Groundwater Dependency in Dar es Salaam

### 4.1. Municipal Supply

The Dar es Salaam Water and Sewerage Authority (DAWASA) is the institution responsible for water supply services in the city. Historically, DAWASA served as the asset owner, responsible for financing both water supply and sewage treatment. While the Dar es Salaam Water and Sanitation Corporation (DAWASCO) functioned as the operator, overseeing the day-to-day operations and management of water supply and sanitation services. Following recent institutional reforms, DAWASA has assumed responsibilities that previously belonged to the now-defunct DAWASCO. This merger was aimed at improving the efficiency of water supply and reducing operational costs (Andersson, 2019).

The Upper Ruvu, Lower Ruvu and Mtoni Rivers provide over 90% of the water supplied from DAWASA's water supply network (DAWASA, 2019; Andersson, 2019). DAWASA faces several challenges and limitations that have significant implications for water access. The extension of DAWASA's water supply coverage has not been prioritised, leaving many residents in the city without a reliable piped water supply. Municipal piped water supply is prioritised for formal areas, only benefiting less than 40% of the population who reside in these areas. The majority of people (over 70% of the city's population) who reside in informal settlements (Limbumba and Ngware, 2016) are partly or not connected to the municipal water supply network. Additionally, most of the infrastructure is old and upgrades and maintenance efforts have not been prioritised (Ngana et al., 2010), resulting in non-revenue water losses estimated at 46.7% in 2017 by the Energy and Water Utilities Regulatory Authority (EWURA), the regulator of DAWASA (EWURA, 2018). The municipal water supply challenges described above, the continuous effects of climate change, and a rapidly growing population place significant reliance on groundwater resources in the city (SADC-GMI, 2019).

**Figure 4-1** illustrates the role of groundwater and surface water supply in major cities across Tanzania, as well as the extent of the water supply deficit in each city. The figure highlights that Dar es Salaam has the largest water supply deficit in the country. This is primarily because Dar es Salaam is Tanzania's largest city by population, with a rapidly growing population due to urbanisation. This results in an increase in the city's water demand that surface water resources cannot supply. Andersson (2019) noted that the baseflow of the Ruvi River, the main surface water supplier of Dar es Salaam, has decreased due to a combination of climate variability, increased upstream abstractions and catchment deforestation. 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 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. **Figure 3-11** shows the distribution of boreholes within the Wami/Ruvu Basin, where Dar es Salaam has the highest concentration of groundwater users highlighting the high dependency on groundwater in the region.

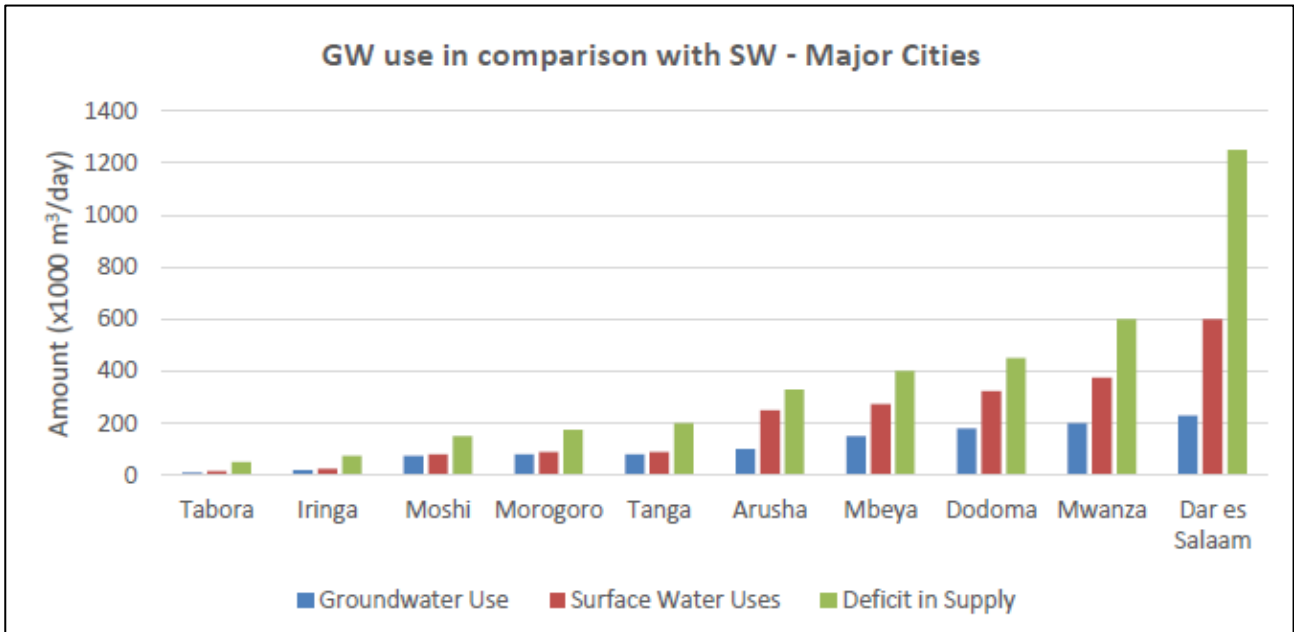


Figure 4-1 The role of groundwater in the major cities of Tanzania (SADC-GMI, 2019).

## 4.2. Agricultural and Industrial Use

Agriculture in Tanzania can be categorised into urban farming, peri-urban farming and rural farming. Urban farming refers to the cultivation of agricultural goods in backyards and vacant plots of land within and along the fringes of the city yet to experience the development associated with urbanisation, or regarded as unfit for development due to seasonal flooding. Water used for irrigation is typically collected from nearby rivers, canals, reservoirs, communal taps and shallow wells (Wessels et al., 2024). Peri-urban and rural farms rely primarily on rainfall, piped water, rivers and groundwater to irrigate crops and provide a supply of water for livestock (SADC-GMI, 2019; Wessels et al., 2024). Urban and peri-urban agriculture have grown to be a large component of the agricultural sector for Dar es Salaam's municipalities. Where possible, peri-urban and rural farmers make use of irrigation channels to transport water from springs. Rain-fed irrigation is preferred, however, during the dry season groundwater use becomes a necessity, especially in areas where surface water features are not present or accessible (Wessels and Mgana, 2024).

Dar es Salaam has been described in literature as the commercial and industrial hub of Tanzania, housing about 80% of Tanzania's industries (Andersson, 2019; SADC-GMI, 2019). The Industrial sector in Dar es Salaam is a large consumer of water (GLOWS-FIU, 2014), and as the sector continues to develop to achieve the country's development vision to lift the country to a middle-income nation, this demand is expected to increase (SADC-GMI, 2019). Due to inadequate municipal water supply, industries in Dar es Salaam have resorted to drilling private boreholes to supplement the limited surface water supply. Groundwater use for industrial purposes is concentrated in urban areas of the city, where the majority of industries are located.

### 4.3. Communities

Dar es Salaam has an estimated population of 5,383,728 people, comprising approximately 2,783,710 women and 2,125,785 men. The city is facing rapid urbanisation with an urbanisation rate of 5.6% and an annual population growth rate of 4% (Msuya et al., 2021; URT, 2024). Due to this rapid urbanisation, the city faces increased pressure on water resources and a growing reliance on a water supply infrastructure that is often unreliable (Sappa and Luciani, 2014; The World Bank, 2024).

It is estimated that over 70% of the city's population resides in densely populated informal settlements (Limbumba and Ngware, 2016; Nyssölä, 2021). Some of these informal settlements are connected to the municipal water supply network, however, water supply in these areas is limited in comparison to the supply in more formal settlements (McGranahan et al., 2016; Dakyaga et al., 2018). This deficit, coupled with the increasing population in the city, has led to the reliance on groundwater and the evolution of informal water sellers or private water vendors in the city.

Groundwater is an important water source for many residents in Dar es Salaam, with many communities relying on its availability for household use. 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. Due to its accessibility, water from the shallow Quaternary aquifer is used as a stopgap by many residents to fill the deficit left by the city's water supply operators. Many households, therefore, rely on private boreholes and wells. According to Andersson (2019), increased abstractions from the Quaternary aquifer due to this reliance are causing the lowering of water levels, leading to seawater intrusion and contamination of the aquifer.

Private vending or informal water sellers have become a crucial component of the water supply to the communities of Dar es Salaam. This informal sector relies heavily on both groundwater and available municipal supplies, and its growth has further entrenched the community's dependency on groundwater resources. Many households, particularly in informal low-income settlements with limited or no municipal water supply, are reliant on private vendors and access water from pushcarts, water kiosks, tanker trucks and private standpipes, which are also reliant on groundwater (Dakyaga et al., 2018). 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, which in some parts of the city may not be safe for human consumption (Andersson, 2019). These shallow aquifers have high chloride levels and are easily polluted by industrial effluent and sewage, particularly during the rainy season (Andersson, 2019).

With the effort of addressing water supply challenges in the city, Community-Owned Water Supply Organisations (COWSOs) were established under the Water Supply and Sanitation Act of 2009 to improve water access in informal and peri-urban settlements where DAWASCO has limited reach (Dakyaga et al., 2018). COWSOs rely on boreholes and shallow wells for the supply of water through standpipes to underserved communities.

Without effective regulations and monitoring efforts in place, the over-reliance of the city's water demands on groundwater can lead to detrimental effects on the resource. In the case of Dar es Salaam, the excessive reliance on groundwater has contributed to rising groundwater salinity in several parts of the aquifer due to seawater intrusion, posing a risk to the long-term sustainability and quality of groundwater resources in the city.

In contrast to Cape Town, where groundwater is primarily used for domestic purposes and as an emergency/supplementary supply, groundwater in Dar es Salaam plays a much more central role as a major source of water. It serves as the primary supply for entire communities, particularly in areas that municipal infrastructure does not reach. This situation is especially prevalent in informal settlements, where water supply planning was never implemented and formal infrastructure was never developed. These settlements account for approximately 76% of all residential areas in Dar es Salaam (Dakyaga et al., 2018).

#### 4.3.1. Socioeconomic Factors Influencing Groundwater Use in Dar es Salaam

Dar es Salaam is the largest city in Tanzania and serves as the country's commercial and industrial hub. An estimated 80% of Tanzania's industrial sector is located in Dar es Salaam (FAO, 2016; Andersson, 2019). As of 2022, the city's population was approximately 5,383,728, with projections indicating a minimum annual growth rate of 4% (Msuya et al., 2021; URT, 2024). Dar es Salaam is recognised as one of the fastest-growing cities, ranked as 3rd in Africa and 9th in the world.

Groundwater use in Dar es Salaam is driven by several factors, including rapid population growth and expanding industrial development. As water demand in the city continues to rise, groundwater drawn from the Dar es Salaam Quaternary coastal aquifer is increasingly relied upon to meet the city's water supply needs as well as the Neogene Aquifers. As discussed in earlier sections, over 70% of the city's population resides in densely populated informal settlements (Nyyssölä, 2021; Limbumba and Ngware, 2016; UN-Habitat, 2016). These areas not only accommodate the majority of the population but also serve as hubs of economic and social activity, which support the livelihoods of many people in the city, even though water supply is limited.

Access to water services in Dar es Salaam is shaped by two closely linked factors: location and socioeconomic status. This helps explain why many informal settlements have limited access to piped water, as the efforts of responsible agencies have primarily focused on serving formal areas (Kyessi, 2019). As a result, inner-city areas tend to have better and more reliable water infrastructure and supply compared to peripheral areas. This has made residents in informal settlements rely on boreholes, shallow wells and informal water sellers or private water vendors such as pushcarts, water kiosks and private standpipes (Dakyaga et al., 2018). Additionally, unemployment, which is currently above a rate of 17.1%, has driven many residents toward informal income-generating activities, particularly in agriculture, forestry, and fishing, which together employ around 18.4% of Dar es Salaam's population (URT, 2024). These activities have further intensified the use of groundwater resources, especially for horticultural irrigation.

Due to low economic productivity, the purchasing power of most households in the city has declined in recent years, and poverty is high (Nyyssölä, 2021). The cost of water per unit is also a disincentive to people in informal settlements from using clean piped water, forcing many to rely on shallow wells. In most informal areas where piped water is limited or unavailable, the informal water supply market including water kiosk, mechanized boreholes, and pushcarts, takes advantage and sells water at a higher price to meet their operational costs (Dakyaga, et al., 2018) which in turn enhances the dependency on groundwater which is cheaper.

In general, most low-income residents in Dar es Salaam depend on informal water service providers, such as private borehole owners, neighbourhood re-sellers, mobile vendors, and tanker operators. These providers source water from outside the official utility system (DAWASA) and rely heavily on the rapidly depleting groundwater from the Dar es Salaam coastal aquifer.

#### 4.3.2. Gender and Social Inclusion in Groundwater Use and Management

Gender equality is a fundamental development objective, and no society can achieve sustainable progress without transforming the distribution of opportunities, resources, and choices for both men and women. True gender equality enables all individuals to have equal power to shape their lives and contribute meaningfully to their families, communities, and the nation. The importance of gender equality is emphasised in Tanzania's National Water Policy (2002) and in the ongoing policy review (2023), which promote equitable participation in the management of water resources and in ensuring access to clean and safe water, as well as adequate sanitation services. Similarly, the National Strategy for Gender and Development (2005) aims to achieve gender equality and equity, as articulated in the Constitution and the Gender and Development Policy.

Despite the various mechanisms put in place to facilitate gender equality, cultural stereotypes and patriarchal practices contribute to gender inequality in Dar es Salaam (UN-Habitat, 2009), particularly

in informal settlements. Due to gender roles and gender task allocation, women have the responsibility for ensuring water and energy are available and pollution levels are managed in their homes and settlements. As a result, women and children are often responsible for the collection of water, usually from shallow wells and boreholes in informal settlements, resulting in a dependency on groundwater resources in these areas. However, although this custodianship falls on women, they are often excluded from participating in groundwater management and decision-making that ensures that their needs are addressed. The sustainable use of groundwater sources is threatened by the lack of effective participation of women in both formal and informal institutions responsible for groundwater management, such as community-based water supply organisations (CBWSOs) and other social services committees.

Moving forward, it is essential to promote and strengthen the representation and participation of women in groundwater management planning and the decision-making process. Groundwater issues affect all members of society and must be addressed through an inclusive and participatory approach (Global Water Partnership, 2017). It is also vital that the knowledge and expertise of women and other disadvantaged social groups are harnessed to promote the sustainable use of groundwater resources, as well as promote awareness, build capacity, equip and empower women to participate in matters related to the effective use and provision of groundwater.

## 4.4. Ecosystems

### 4.4.1. Groundwater Dependent Ecosystems

Groundwater-dependent ecosystems (GDEs) rely on groundwater to meet some or all of their water and nutrient requirements (Dabovic, 2024). In Dar es Salaam, a significant number of GDEs are located within the coastal sedimentary aquifers and alluvial aquifers. Springs, rivers, wetlands, and estuaries, in these areas are sustained by groundwater, highlighting the ecological importance of these aquifer systems. According to Eamus et al. (2006) and Richardson et al. (2011), GDEs can be broadly categorised into three types:

1. Aquatic GDEs – ecosystems where groundwater discharges to the surface, such as rivers, wetlands, and springs.
2. Terrestrial GDEs – vegetation communities that depend on subsurface groundwater for survival, particularly during dry periods.
3. Subterranean GDEs – ecosystems occurring entirely below the surface, typically in saturated zones of aquifers.

The types of GDEs that may occur in these systems and further inland of the Dar es Salaam region are (Figure 4-2):

- **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.
- **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.
- **Springs:** Springs are surface expressions of groundwater and are crucial for maintaining freshwater habitats, supporting wildlife, and providing water for human use.
- **Forests and other terrestrial ecosystems:** Some terrestrial ecosystems, like particular kinds of forests, may also depend on groundwater, particularly during the dry season.

Groundwater dependency can be analysed in terms of nature, extent and degree of dependency (Colvin et al. 2003). The degree to which GDEs depend on groundwater can be continuous or seasonal and may vary over time (Kløve et al., 2011). During dry seasons or droughts, when rainfall is limited and transpirational demands are at their highest, GDEs often become more reliant on groundwater compared to wetter months when surface water is more readily available to sustain or support these ecosystems (Eamus and Froend, 2006). Even an ephemeral or seasonal dependency on groundwater may be critical to the health or survival of an ecosystem (Colvin et al. 2003). This refers to the basic principle that where groundwater is accessible, the ecosystems (in particular, the biota) accessing the groundwater will develop some degree of dependency.

The extent of dependency can also vary depending on the type of aquifer, and due to the complex nature of the relationship between ground- and surface water, and can range from very localised to widespread. Sometimes, a GDE may be located some distance away from an aquifer, but still be dependent to some extent on the aquifer (Roets et al. 2008).

The nature of the dependency is considered as one of the most complex aspects of GDEs. This may only become apparent when an ecosystem has been stressed beyond a critical threshold (Colvin et al. 2003). GDEs rely on groundwater for the maintenance of their ecological processes, structure, and function, particularly during dry periods. Systems that are completely fed by groundwater such as springs would not exist or persist without groundwater input (Kløve et al., 2011). Groundwater provides water, nutrients and relatively stable temperatures particularly to wetlands, streams and rivers, which help to maintain aquatic plant and animal communities that rely on groundwater for survival (Dabovic, 2024). Additionally, GDEs such as wetlands also absorb excess water during floods, reducing flood risk and can filter pollutants and sediments from surface water and shallow groundwater.

In addition to the ecological functions, GDEs also provide many other services, particularly in dry and semi-arid regions. Due to limited rainfall and the overall lack of fresh water in these regions, they serve as important sources of water for livestock, domestic purposes, and for the support of vegetation. These systems also have a notable economic value as they serve as important breeding grounds for fish, supporting commercial fishing. Additionally, they also generate revenue through eco-tourism.

The condition or health of GDEs is directly dependent on access to groundwater (Rohde et al., 2017). The growing demand for water due to climate change and a growing population in the city, poses a great threat to GDEs as it limits groundwater availability. The over extraction of groundwater limits the amount of groundwater discharge into wetlands, rivers and springs, disrupting ecosystem services, functions and structure (Eamus et al., 2006; Murray et al., 2006). This also limits the amount of water in the subsurface required by terrestrial GDEs (Kløve et al., 2011). Phreatophytic plant species are sensitive to the rate as well as the season of groundwater abstraction (Eamus et al. 2006).

Other threats such as changes in land use and the intensification of agriculture and urban development also result in habitat loss and pose a significant contamination risk, resulting in a change in groundwater quality. Land use activities such as urban development, mining and agriculture can lead to elevated metals, nutrients and pesticides in groundwater, altering its chemistry (Dabovic, 2024). Introducing these pollutants impacts these ecosystems' ability to perform their regular functions (e.g. water purification).

Given the critical reliance of GDEs on groundwater, implementing a conjunctive management strategic action plan can help prevent aquifer overuse and pollution, ensuring the protection of these valuable ecosystems. The protection of GDEs is particularly challenging due to their varying degree of groundwater dependence, which is not well understood, their diversity and unique ecological water requirements. For instance, our understanding of the relationship between groundwater levels and soil moisture dynamics in wetlands is minimal, but it is clear that the sustainable operation of any borehole or wellfield needs to take these kinds of interdependencies into account.

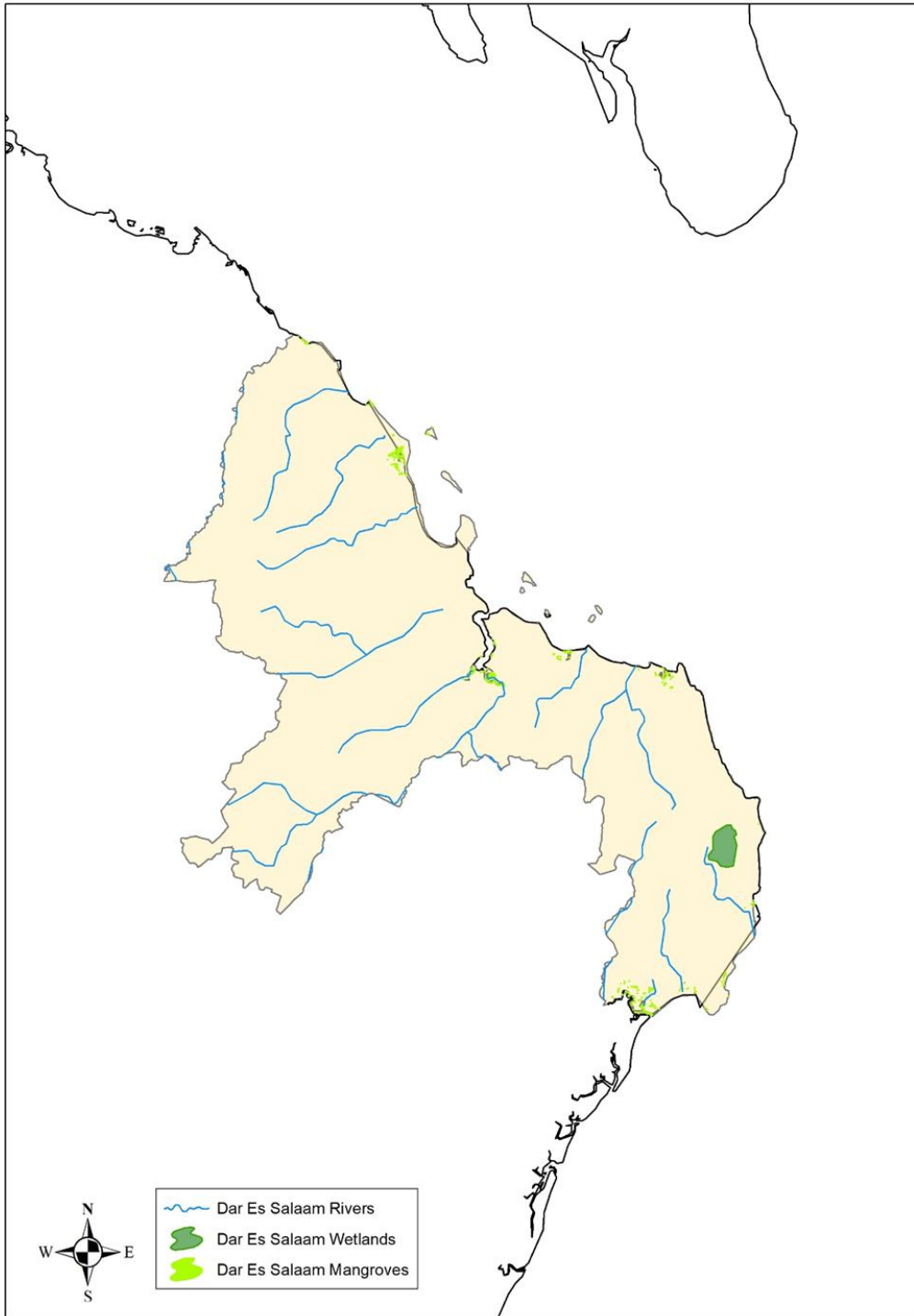


Figure 4-2: Aquatic ecosystems that are likely to be groundwater fed in Dar Es Salaam.

## 4.5. Summary

This report presents an assessment of groundwater dependency in the City of Dar es Salaam, Tanzania's largest and fastest-growing city. This assessment is undertaken as part of the broader SADC-GMI initiative to evaluate groundwater dependency and vulnerability in coastal cities. The assessment highlights the role groundwater plays across multiple sectors, including municipal water supply, agriculture, industry, and domestic use, while highlighting the socioeconomic disparities in water supply for the city.

Dar es Salaam is primarily underlain by a combination of unconsolidated Quaternary deposits and semi-consolidated Neogene deposits that contain the region's major aquifer systems. The Quaternary Aquifer System and the Neogene Aquifer System are the major sources of groundwater to the Dar es Salaam region.

The groundwater resources of Dar es Salaam are a vital component of the city's water supply network, particularly in areas where surface water infrastructure is limited or absent. In the northern regions of the city, the main water supply comes from the Mtoni River, Lower Ruvu River and Upper Ruvu River. However, within these areas, there is private groundwater use targeting the shallow Quaternary aquifer. Groundwater dependency is particularly high in the south of Dar es Salaam (Temeke and Kigamboni municipal districts), where municipal surface water supply infrastructure is unable to reach. Within these regions, the Neogene Aquifers are the main source of water supply, supporting municipal, agricultural, industrial and communal water supply needs. In addition to this, groundwater also sustains groundwater-dependent ecosystems (GDEs) such as rivers, wetlands, springs and terrestrial vegetation across the region, playing a crucial role in maintaining baseflow during the dry months.

This widespread reliance highlights the vulnerability of the resource to over abstraction, pollution and seawater intrusion, particularly in shallow aquifers and coastal zones. Without improved management, degradation of groundwater quality and availability is likely to accelerate. To ensure long-term sustainability and resilience, the report underscores the urgent need for conjunctive management of surface water and groundwater resources. Such integrated approaches are essential not only for improving water security in underserved communities but also for protecting ecosystems in the face of climate variability, urbanisation and rising water demand.

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