Towards Sustainable Urban Water Management in the Global South

The Case of Mozambique

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Preface & Acknowledgements

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Dear reader,

This thesis is the fruit of my three years studying Industrial Ecology at TU Delft and Leiden University. It was during this master's that I learned what I really desired to do, in academics and further working-life. Which is working towards a sustainable and just world, with special regard to water, sanitation and hygiene. Or its abbreviation: *WASH*. It is this intrinsic desire that is at the core of this thesis.

I have truly enjoyed writing this thesis, and I hope the same goes for you reading it. Even though it was hard at times, given the complexity and size of water operations in metropolitan areas, I always tried to find innovative and creative solutions within academic boundaries. However, without the guidance of my supervisors, it would have been a lot harder. Therefore, I would especially like to thank prof. dr. ir. Arjan van Timmeren from the Urbanism Department at the Faculty of Architecture for his inspiring comments, which pushed me to go beyond the obvious, and cross-check everything. In advance, I would like to thank dr. ir. André Arsenio, with whom I developed the framework of this thesis, the forecasting and who got me started in Maputo. And at last, I would like to thank prof. dr. ir. Luuk Rietveld from the department of Water Management at the Faculty of Civil Engineering for his useful comments and knowledge on the Greater Maputo Region and who always kept me focussed on the standout points of this report.

Furthermore, I would like to express my gratitude to the Lamminga Fund for allowing me to travel to Mozambique to comprehend the local context of this report. Even though the fieldwork here was ended abruptly due to COVID-19 I was lucky enough to experience the amazing Mozambican culture, kindness of its inhabitants and beautiful sceneries. Due to the early termination of the fieldwork in Mozambique, the Leiden International Study Fund (LISF) provided me with funding to return to Mozambique to finish the fieldwork. However, COVID-19 did not let me and called upon our innovation to acquire local knowledge from Mozambique whilst being locked down in the Netherlands. It was here that I decided to make a digital serious game that would let me. Luckily, LISF allowed me to use the travelling fund to develop a digital serious game. It was here that I teamed up with two talented informatics students who carried out the programming for the game. Therefore, I would like to thank Luit Verschuur and Kylian Kropf for their patience with me and their proactive and professional attitude.

At last, I would like to thank my family, friends and girlfriend for always listening to me rambling on about this report, encouraging me and helping me wherever possible. You made the work so much easier!

All that remains for me to say is that I hope you will enjoy reading this report as much as I had writing it,

Yours sincerely,

Gijs J. van Nes

"When the well is dry, we know the worth of water."
- Benjamin Franklin

Contents

List of Abbreviations

AdeM	= Águas de Moçambique (later Águas de Região de Maputo)
AdeP	= Águas de Portugal
AHP	= Analytical Hierarchy Process
AIAS	= Administração de Infraestruturas de Abastecimento de Água e Saneamento
ARAs	= Administração Regional de Águas
BGI	= Blue-Green Infrastructure
BIP	= Beluluane Industrial Park
CRA	= Conselho de Regulação de Águas
CW	= Constructed Wetlands
DNA	= Direção Nacional de Águas (*National Directorate of Water*)
FIPAG	= Fundo de Investimento e Património do Abastecimento de Água
IPCC	= International Panel on Climate Change
LGs	= Local Governments
MCDA	= Multi Criteria Decision Analysis
MIZ	= Matola Industrial Zone
MOPH	= Ministry of Public Works and Housing
NBS	= Nature Based Solutions
NRW	= Non-Revenue Water
NWP	= National Water Policy
PEUMM	= Plano de Estrutura Urbana do Município de Maputo
PVC	= Present Value of the Costs
PWTP	= Potable Water Treatment Plant
RCP	= Representative Concentration Pathway
RWA	= Regional Water Authority
SSA	= Sub-Saharan-Africa
SSIPs	= Small-Scale Independent Providers
SUWM	= Sustainable Urban Water Management
UWDM	= Urban Water Demand Management
WASH	= Water, Sanitation and Hygiene
WTP	= Water Treatment Plant
WWTP	= Wastewater Treatment Plant

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Abstract

Many cities in Sub-Saharan Africa struggle to access reliable and adequate quantities of potable water for diverse water requirements. Under pressure of climatic change, urbanization and economic development, freshwater resources are becoming scarcer. These pressures combined with outdated infrastructure, pose a giant challenge to the Greater Maputo Region to meet their water demand in 2050. This report aims at identifying and analyzing pathways, using stakeholder preferences, that support SUWM and bear the potential to close the supply-demand gap in 2050.

This report utilizes population and demand forecasting to determine the gap between future supply and demand. Hereafter, alternative technical, social, and environmental methods to augment the Greater Maputo Region's water supply are identified through a literature study. Furthermore, two distinct methods are used to develop scenario's that augment the supply demand gap. The first being a technical analysis using multi-criteria decision analysis and the second a serious game that is to be played with stakeholders. At last, these scenarios are used to develop a framework that is technically feasible and approved by stakeholder opinions in the serious game.

It was found that the population of the Greater Maputo Region will grow from 2,8 million in 2017 to 6,9 people in 2050. Furthermore, under the pressure of economic development, population growth and urbanization, water demand increased from 9 million m^3/day in 2017 to 22 million m^3/day in 2050. This increase in demand, in the case of a business-as-usual scenario, amounts to a deficit of 1,2 million m^3/day in 2050. The sector that consumes most water is agriculture, followed by industries and households. Furthermore, under climate change precipitation decreases over time whereas temperatures increase. Especially during the dry period, more evaporation and less rainwater is expected, highlighting the need for alternative water supply methods to ensure a steady availability of water.

Alternative methods that support SUWM such as dams, stormwater harvesting, rainwater harvesting, wastewater reuse and desalination were found to be most suitable approaches to augment the Greater Maputo Region's water supply. However, it was also found that these approaches are not very efficient without the right urban context and socio-political and economic measures. Economic and social-political measures should incentivize water savings and fair distribution.

Two distinct methods were used to create scenarios to close the Greater Maputo Region's supply demand gap. The first, multi-criteria decision analysis showed that that in the case of a high weight attributed to the cost of approaches, rainwater harvesting, stormwater harvesting, and dams are the most suitable options given the selected criteria and their respective rank. Whereas in the case of a low weight of the cost, wastewater reuse, stormwater harvesting, and rainwater harvesting are the most suitable. The second, a serious game that mimics the WASH situation in the Greater Maputo Region which showed that players focus on sustainable, circular, solutions, but that they are hard to implement because of financial limitations.

Ultimately, this report indicates that both decision analysis and serious gaming provide valuable insights for enhancing water supply in an urban context. In this report, both methods indicate that there is a preference for circular (sustainable) approaches. Such an ideal, circular, and sustainable, water system in the Greater Maputo Region, was found to be supported by decentralization of the water sector. In this case, decentralization of the water sector to a neighbourhood scale shapes niches for sustainable water supply approaches and within these niches, the local context of the neighbourhood determines the type of water supply infrastructure that is most suitable. Furthermore, the technical approaches are to be supported by socio-political and economic measures. Altogether, a combination of SUWM supporting approaches supported by political and socio-economic measures can close the supply-demand gap in 2050.

1. Introduction

1.1 Background

As is widely known, water is not only a vital source for life, it is also essential to (sustainable) development: socio-economic development, flourishing ecosystems and human survival (UNDESA, 2015; Yildiz, 2017). However, urbanization and economic development increase pressure on water resources. In advance, climate change, is threatening water availability; increasing temperatures and more intense, less predictable weather conditions have been projected to affect water availability and quality. Especially low-income countries, already extremely vulnerable to water scarcity, are expected to be affected the worst (UN - Water, 2019).

Most of these low-income countries are located in sub-Saharan Africa (The World Bank, 2019), making Africa's already scarce water supply highly vulnerable to climate change. Mainly because of factors such as poverty, too much dependence on rainfall for agriculture, recurrent droughts and unbalanced land distribution (Ehrhart & Twena, 2006). Mozambique and its capital Maputo are no exception to this.

The rapidly growing city of Maputo lies on the coast of the Southern area of the country. Just like similar cities Maputo faces tremendous challenges regarding water supply and sanitation. Several trends have been identified for Maputo that are expected to increase the pressure on the already existing challenges. The most dominating trends that have been identified are urbanization and population growth (Ministry of Foreign Affairs of the Netherlands, 2018) , climate change (WSUP, 2018) and economic development (UNM & FCD, 2015).

Figure 1-1: Location of Maputo

1.2 Knowledge Gap and Relevance

Challenges

The main issues that are identified in literature are urbanisation (Gumbo, 2004; Jimenez-Redal, Parker, & Jeffrey, 2014), climate change (Beck & Bernauer, 2011), physical water losses due to poor quality of pipes (Gumbo & Van Der Zaag, 2002), the inability of policy makers to address urban water management in a holistic manner (De Carvalho, Carden, & Armitage, 2012) and monetary inequality amongst Mozambicans (Farolfi & Gallego-Ayala, 2014; Monteiro et al., 2016). Furthermore, it is stated that as human populations become more urban, new challenges emerge for decision-makers. These emerging challenges are the growing complexity of cities and their networks and the increasing scale of service provision (Rietveld et al., 2016).

Solutions

What becomes evident whilst comparing the different papers, is that there is no straightforward solution for the water-issues in Maputo. Moreover, it becomes evident that no integral solutions are provided. The solutions that are presented consist of a variety of economical, technical and social measures. It is argued that tariff revision in Mozambique can result in more equally distributed water resources (Farolfi & Gallego-Ayala, 2014). Regarding economic solutions, it is shown that flexible payment arrangements can bring water services within reach of low-income households in peri-urban Maputo (Jimenez-Redal et al., 2014). Furthermore, an action plan aligned with the national strategy division was developed and made adaptable to every town or city in Mozambique. This plan includes two decision support tools for stakeholders: (i) the Water and Wastewater database and the (ii) Dynamic Economic tool to support investments in water and sanitation services (Monteiro et al., 2016).

Knowledge gap

The challenges and solutions presented indicate that there is the need for an integrated tailor-made approach towards urban water management in the Greater Maputo Region. Therefore, it needs to be understood which social, technical and environmental approaches are available and how these would interact. Therefore, this report will function as a bridge between technical, social and environmental aspects of augmenting the Greater Maputo Region's water supply whilst incorporating local knowledge and stakeholder preferences through decision analysis.

1.3 Structure

The structure of this master's thesis follows the research flow. **Chapter 2** entails the historical context of Greater Maputo's water and sanitation sector. The contemporary context of the water and sanitation sector will be set in **chapter 3**. Hereafter **Chapter 4** will use the results of **chapter 3** to determine the future water demand of Maputo. In **chapter 5**, methods for closing the gap are identified, from a social, technical and environmental perspective.
These methods are analyzed using decision analysis in **chapter 6**, the criteria in the analysis are ranked by stakeholders through a questionnaire. In **chapter 7**, a serious game is developed. The game also simulates the complexity of different solutions and stakeholders with different interests. In advance, it allows stakeholders to find the most suitable solution which can be compared with the technical analysis of the solutions found in chapter 6. The previous chapters will all be combined in an overarching framework in **chapter 8**.

1.4 Research Questions

Main Research Question

How can the gap between Maputo's future water demand and availability be closed by involving stakeholders through an active engagement game, and which pathways will support this?

Sub-Research Questions

- How large is the gap between Maputo's current water demand and supply, compared to future demand and supply? (Chapter 4)
- Which alternative combinations of water sources are possible in Maputo? (Chapter 5)
- How can serious gaming aid to incorporate stakeholders' preferences into decision making? (Chapter 6 & 7)

The objective that can be derived from the main research question is the ultimate 'goal' of this report. However, it is fed by *multiple context related questions*, that lead to this objective. Because it needs to be understood:

- Which stakeholders are involved in Maputo's water sector?
- What is the current WASH situation in Maputo?
- Which current pathways and programs are active in Maputo and how do they perform in terms of SUWM?

2. History of Maputo and its Water and Sanitation sector

This chapter entails the historical context of Maputo and its water and sanitation sector. The history of the sector and the city itself is of tremendous importance to understand the current situation.

2.1 Short History of Maputo

2.1.1. Eearly Period

Archaeological remains have indicated that humans have settled in and around the Maputo bay in the first century of the common age. The location was suitable for seafood gathering, hunting and agriculture. However, no permanent settlement was established, since the settlement was based on shifting cultivation (Jenkins, 2000).

When the Portuguese discovered the bay mid 16th century, several African clans had established settlements in the area and even shared a common language. For the next century the Portuguese had periodic trade with the clans around the bay, mainly ivory, without establishing themselves there, as their main trade posts were further up north. Once the Dutch settled at the Cape of Good Hope mid 17th century, and the Portuguese reign over the Indian Ocean was over, interest in trade in the area increased. Therefore, the first European settlement at the bay was established early 18th century, after competition amongst European sea-faring nations, the Portuguese established their own settlement at the bay in 1781 and named it after one of their early navigators; Lourenço Marques (Jenkins, 2009).

From the first half of the 19th century, several powerful states started developing in the South of Africa, amongst others the Nguni states in the south and new republics established by the Boers, Transvaal and the Orange Freestate in the west. However, for most of the 19th century the Portuguese influence was restricted to the direct area of their settlement. This all changed after the discovery of gold ores in Witwatersrand in the Republic of Transvaal.

2.1.2. Colonial Period

The gold discovery combined with the continuous development of the Boers, led the small settlement of Lourenço Marques to develop into an important port (South African History Online, n.d.). This development was awarded by the Portuguese government by declaring Lourenço Marques a village in 1876, and soon after city (The Editors of Encyclopaedia Britannica, 2019). In order to increase connectivity to the growing port of Maputo, the South-African Railway Company constructed a railway linking the capital of the Republic of the Transvaal, Pretoria, to Lourenço Marques in 1895 (Arnold, 2007).
These developments led to the expansion of Lourenço Marques from the sandbank it was situated on, to the reclaimed swamp surrounding it, 'pantano' in *figure 2* and the escarpment next to it that was annexed by the Crown of Portugal (Jenkins, 2000).

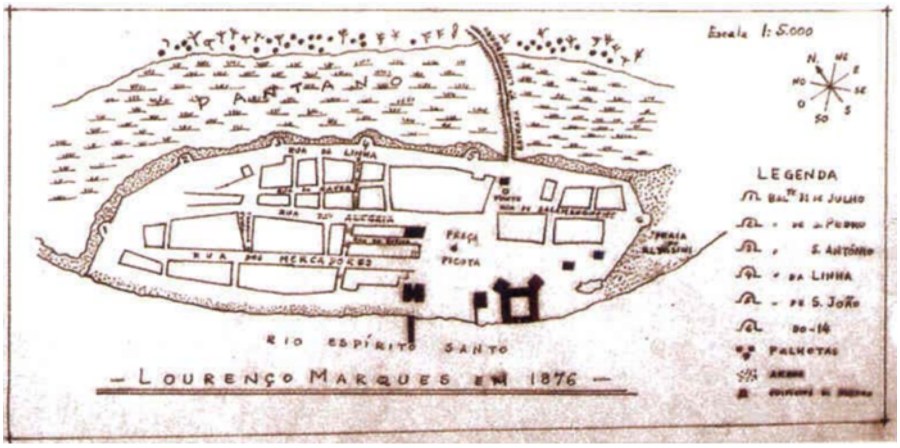


Figure 2-1: 1876 City plan of Lourenço Marques (Jenkins, 2009)

During the expansion the Portuguese also started establishing political and military authority over the southern part of Mozambique. Hereby subordinating the local clans and Nguni kingdom in the north.

In 1878, when Portugal's powers had decreased, it was decided to leave the larger northern territories to mostly British traders. In 1886 the first land registry was established and in 1887, an expedition led by the Portugeuese ministry of Public Works led to the development of the first expansion plan for the city. This expansion plan incorporated a 2 km radius to the north from within the city (*see figure 2-2)*. However, it took some 10 years for the plan to be incorporated (Jenkins, 2009). Eventually, the capital city of Portuguese Mozambique was changed from the northern Island Ilha de Moçambique to the city of Lourenço Marques in 1907, with at this point in time approximately 5000 inhabitants (Thomashausen, 2003).

Figure 2-2: Lourenço Marques in 1900, showing the 2 km radius (Jenkins, 2009)

However, in 1932 Portugal decides to take direct control over Mozambique and an influx of Portuguese immigration was witnessed as poor and landless Portuguese inhabitants were encouraged to immigrate to Mozambique. At this stage, the Mozambicans were given a choice; forced labor or becoming "assmimlados", which meant giving up their culture and endemic beliefs and following Portuguese primary education (Thomashausen, 2003).

Figure 2-3: Lourenço Marques City Plan, 1929 (Contente, 1996)

Still, Mozambique remained heavily economically depended on South-Africa, despite Portuguese efforts to develop the colony. As all semi-skilled jobs were retained for the Portuguese, most Africans in the city were employed in un-skilled labor such as in railways or in the port. Therefore, spatial distribution of the inhabitants of Lourenço Marques was solely based on racial segregation, whereby the Africans were living outside the planned urban area, visible as outside of the radius in *figure 2-2 and 2-3,* in so-called "suburbios" or "caniços" (Jenkins, 2000). These areas were treated as temporary and were not given any construction rights. Therefore, the buildings in these areas were often rented and made out of non-permanent materials such as corrugated iron sheets and reed (Jenkins, 2000).

In 1955, the *Plano de Urbanização de Lourenço Marques (figure 2-4)* drawn up by the Gabinete de Urbanização do Ultramar (Office for Overseas Urbanization) was approved by the Portuguese Ministry of Overseas Affairs. As this Urbanization Plan was designed during Estado Novo, the style and discipline of the plan adopted a style to exhibit the grandeur of the regime. As the city developed itself as a regional center, the population growth quadrupled between 1950 and 1960. It was also in this period that informal urban growth in the outskirts, outside of the ring road, increased heavily. Also, in this area, the traditional rural types of houses were replaced by more solid construction techniques. (Correia, Fernandes, & Lage, n.d.). However, re-development of the caniços did not occur, mainly due to the lobby of the small-scale settler class that depended on exploitation of the land (Jenkins, 2009).

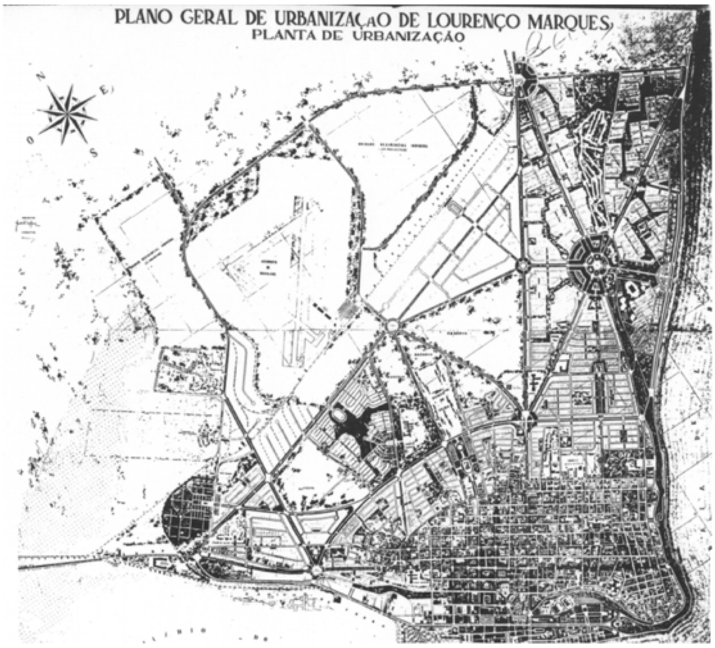


Figure 2-4: Plano de Urbanização de Lourenço Marques (Jenkins, 2009)

In the late colonial period, in the late 1960's it was accepted that the implementation of the *Plano de Urbanização de Lourenço Marques* would be impossible. Therefore, a local Urban Planning Office was established in the city's town hall. The new plan, Plano Diretor, was different from the previous plans as analysis of actual land use and potential development were incorporated (Correia et al., n.d.). Even more, the new plan was not limited to the area of the city council. Therefore, the upcoming 'sister' city of Matola was included. Development in Matola started in the mid 1960's, mainly due to a change in Portugal's legal structure making foreign investment easier and the choice of large industries to install themselves outside the cramped areas that were available in Lourenço Marques (Jenkins, 2009). These large industries include, but are not limited to a mineral port, oil refinery and cement factory. The installation of the large-scale industries brought not only the development of high-end markets and new middle-income suburban residential areas, but more importantly led to the first attempt to develop low-income housing areas. In contrast to previous plans, these plans with a focus on partial urban land development, were functional. Plans were proposed for new transport routes, a new airport location and new tourist developments. These plans served as a starting point for a new master plan, also the final Plano Diretor (*master plan*), which was to be developed by Portuguese urban planning engineer Mario de Azevedo (Correia et al., n.d.; Jenkins, 2009).

From 1967 to 1969 Mario de Azevedo worked on his urban plan, the Azevedo plan, for Lourenço Marques and Matola. During this period, in 1968, similarly to Luanda, Lourenço Marques was assigned the status of great city, which had already only been assigned to Porto and Lisbon (Correia et al., n.d.). The Azevedo Plan can be regarded as the first modern era urban plan and was developed by a myriad of experts from different fields including a traffic engineer, a sociologist, a historian and more. The plan was ultimately approved in 1972. This plan also included proposals to develop the informal areas outside of the city center. Furthermore, the combination of a lack of area for urban expansion and the investments from the state and private sector triggered to the construction of high-rise buildings within the city center (Gaviria, 2016).

However, even though this plan was based on improved understanding of the reality of a rapid growing city, it failed to incorporate the broader political context (Jenkins, 2009). Since 1962, a Marxist group led by Eduardo Mondlane under the name of Frelimo (Frente de Libertação de Moçambique) had been fighting for independence (Newitt, 1995). Once the 1972 urban plan was published, many new urban projects in the city had been abandoned due to the contemporary political and economic climate in Portugal (Jenkins, 2009). The Carnation Revolution in Portugal in April 1974 was not only the end of the authoritarian dictatorship Estado Novo in Portugal, it also marked the abrupt end of colonization in Mozambique. With limited violence, the power in Mozambique was handed over from Portuguese authorities to Frelimo. However, simultaneously an exodus of the settler population was witnessed (Jenkins, 2009; Newitt, 1995). Formal urban development was halted at this stage, however, the indigenous residents opted for bringing in their families from hinterland. This influx led to rapid expansion in the caniço, including the land that had been cleared for the 1972 Plano Diretor (Jenkins, 2009).

2.1.3. Post-independence period

After Mozambican independence, in 1976, the city was renamed Maputo, after one of the important historic chiefdoms of the south of the bay. At this stage, almost all urban development activities were halted as the private sector either abandoned its operations or were waiting for the position of the new regime (Jenkins, 2009; Newitt, 1995). However, some developments were undertaken with state engagement. For example, a flood resettlement scheme was developed together with the United Nations and abandoned, or unfinished buildings were used to provide new government facilities (Jenkins, 2009). The new Marxists-Leninist orientated government nationalized all land upon independence, and directly assured relocation for needy families. The state also overtook most of the banks (who funded most urban development), construction materials and construction companies. As agriculture was seen as the backbone for the desired 'giant leap forward' in industrial capacity, the regime's main orientation was on rural development and ultimately overcoming under-development (Correia et al., n.d.).

However, as many population growth measures were lifted by the new regime, a rapid increase of informal urban development was witnessed in the caniços. In order to guide this informal growth, a new city council urban planning and construction department was created in 1980. However, this new urban planning unit had very limited means and only focused on the development of an outer ring with basic residential areas. These areas had very limited services as state investment was widely lacking.

The first structural Plan after independence was drawn up in 1985 (Correia et al., n.d.). However, the growing demand for land exceeded supply and combined with increasing corruption led to the closure of the city council urban program (Jenkins, 2009). It was also at this stage that the city experienced a new spurt of urban growth of people from the countryside to the urban areas due to the devastating internal civil war (1977 – 1992). As a result, Maputo expanded rapidly, mostly through the informal semi-rural outskirts of the city (Roque, Mucavele, & Noronha, 2020). This influx combined with the military blocking urban expansion led to extreme densification of the informal areas as well as the city center (Jenkins, 2009).

In 1992 the Rome General Peace Accords were signed by both the fighting parties in Mozambique, meaning the end of the civil war and initiated the transition from a Marxist-Leninist regime towards a liberal economy and multi-party democracy (Newitt, 1995).

The change in regime has led to continual changes in the city, and at this point in time, in-migration is overtaken by natural population growth within the city. The newly liberalized housing market and the increasing socio-economic capacity of the elite led to the re-development of the city center and urban coastal areas.

In 1999, a new urban plan, sponsored by the World Bank, was developed. This plan was developed as a Metropolitan Structure Plan for the novel autonomous municipal areas of Maputo, Matola and the expanding urban areas in the province of Maputo. However, just like other internationally sponsored urban plans have failed in its implementation. This was mainly due to a lack of legislation, technical capacity, fiscal shortages of the novel city council and the lack of political will (Jenkins, 2009).

More recently the Faculty of Architecture and Planning of the Eduardo Mondlane in Maputo produced a new structure plan for Maputo and Matola. This new plan mainly used project land-use and incorporated and improved the ideas of the 1999 Metropolitan Structure Plan. This plan is ultimately seen as the basis for the planning law and land use regulations that were approved around 2008 (SEED, 2010). In the following period Maputo came back to life as commercial and cultural activities rapidly intensified. Tourism received new attention and old tourist attractions were re-developed and new ones were built. Unfinished high-rise buildings that were left in the 1970's, were re-developed and constructed. At this current stage, Maputo's city center is still in transition, heavily influenced by strong international investments.

2.2 Historical Context of Maputo's Water and Sanitation sector

In the *early period*, the sandbank that the first settlement of Lourenço Marques was situated on was provided with public water supply in the form of a well (*fonte*). After the rapid growth in the 19th century, the infrastructure for piped water was laid out and made functional. However, this infrastructure did not expand beyond the planned formal urban areas.

When the civil war ended in 1992, water supply infrastructure had been deteriorated. In order to restore the infrastructure, the government adopted an extensive institutional reform for the development, delivery, and regulation of urban water supply services in large cities, including Maputo, in 1998 (The World Bank, 2009). This new framework is called the Delegated Management Framework (DMF). Simultaneously with the creation of the DMF, two autonomous public bodies were created; an asset management agency called FIPAG and an independent regulator called CRA. In 1999, FIPAG signed a 15-year contract for water supply in Maputo and water management in four provincial capitals (Beira, Quelimane, Nampula and Pemba) with Águas de Moçambique (AdeM). AdeM is a consortium of foreign water supply operators led by the French operator SAUR (The World Bank, 2009).

However, in 2001 AdeM faced severe financial difficulties, worsened by the floods of 2000 and the delay in the implementation of new investments. Therefore, in 2001, SAUR terminated its involvement in AdeM. its leading role was taken over by Águas de Portugal (AdeP) who also negotiated new contracts, with higher fees and improvements in the service obligations and producers as a result. This new Revised Lease Contract became effective in April 2004 and would end in November 2014.

In 2004, FIPAG signed a three-year contract with the Dutch water company Vitens, which aimed at supporting and training in four small cities in the south of Mozambique, Xai-Xai, Chokwe, Inhambane and Maxixe. In 2006 this contracted was expended for services in five additional cities in central Mozambique (The World Bank, 2009). This contract was seen as a transitional arrangement, as it aimed at preparing for a more conventional delegated management (AMCOW, 2011).

The performance of AdeM was generally mixed but despite several hiccups, AdeM improved services and the foundation for financial viability and sustainability were established. In advance, Vitens performance was considered very good (The World Bank, 2009).

However, in 2010, four years before termination of the contract, the Mozambican government, through FIPAG, bought the shares in AdeM held by AdeP. Hereby ending the era of private sector participation in urban water supply in Mozambique. In 2011, AdeM changed its name to *Águas da Região de Maputo*, whereby reflecting on their true geographical coverage (MacauHub, 2011).

The case of France supports the wise decision of the government to buy shares in 2010. In France, where almost 75% of urban water management is privatized, it would take companies such as Veolia and Suez 140 years to completely replace current water supply network. This means that by the time replacement is complete, the companies can start preparing for new replacements again, as the average lifetime of such infrastructure is 40-80 years.

Key findings chapter 2

- Archaeological remains have indicated that humans had settled around the Maputo Bay in the first century of the common age.
- In 1781 Portugal established the settlement of Lourenço Marques on the shores of Maputo Bay.
- In 1886 when gold was discovered in Witwatersrand, South-Africa, Lourenço Marques swiftly expanded backed by the Portuguese government.
- As most of the Africans living in the city were employed in un-skilled labor, they were forced to live outside the city center that was reserved for the better paid Portuguese in so-called "suburbios" or "caniços" which lacked basic services such as formal water supply.
- Between the year 1950-1960 the population of the city quadrupled, boosting informal population growth outside the center.
- In 1976 Mozambique acquired its independence from Portugal and Lourenço Marques was renamed Maputo.
- During this period, almost all urban development activities were halted by orders of the new Marxist-Leninist regime.
- In the civil war (1977-1992) started, and Maputo faced a tremendous influx of people from the countryside, which boosted further expansion of the informal peri-urban areas.
- Due to the civil war, almost all water supply infrastructure had been deteriorated.
- In 1998 efforts to restore water supply led to the establishment two public bodies: FIPAG and CRA.
- Hereafter, the water supply agency of AdeM was created, leading water supply projects in urban areas.
- The performance of AdeM was generally mixed, but a foundation for financial viability and sustainability was established
- In 2010 the government and FIPAG bought shares of AdeM, whereby ending private sector participation in Maputo's water sector.

Outlook

In this chapter, the foundation for the coming chapters is laid out. It is understood how European urbanism dynamics influenced the development of the city and its peri-urban areas. This knowledge, especially on the water supply and sanitation structures is used to understand how different solutions can be located and connected to existing structures.

3. Current state of Maputo's water and Sanitation Sector

3.1 Specifics of Maputo

3.1.1. Physical characteristics

Maputo is geomorphologically divided into two areas: the coastal plain (lower areas) and a higher area with inland dunes (JICA, n.d.). The city's soils are characterized as porous sandy soils in the higher areas, overlaying clay layers that are visible in the valleys and coastal plain. Throughout the valleys, coastal plain and lower areas the water table is high and in the eastern sections of the city, subterranean aquifers are found.
The city is located around Maputo Bay, where three rivers, the Maputo, Incomati and Umbeluzi, confluence. All of these rivers originate in other countries, either Swaziland or South-Arica (JICA, n.d.). Maputo's location on the Indian Ocean, means that storms will occur annually, these are characterized by intense wind and precipitation and are usually linked with the passage of tropical cyclones (Urban Resilience Hub, 2020).
Maputo's climate can be characterized as a modified tropical coastal climate, or a tropical savanna climate (Aw) according to the Köppen index, with a daytime climate that is warm to hot and relatively humid. The predominant winds are East, Southeast and South, whereby soothing the humid conditions (Jenkins, 2000).
Mozambique has two seasons, the dry winter running from April to September and the wet summer from October to March (Mavume, Banze, Macie, & Queface, 2021). Annually 860 mm of precipitation falls in Maputo, however rainfall in Maputo varies heavily per month, hence the wet and dry season (Sušnik, 2016b). Most precipitation falls in January, with on average 175 mm and the driest month is august with only 15 mm (Climate-Data, 2020).

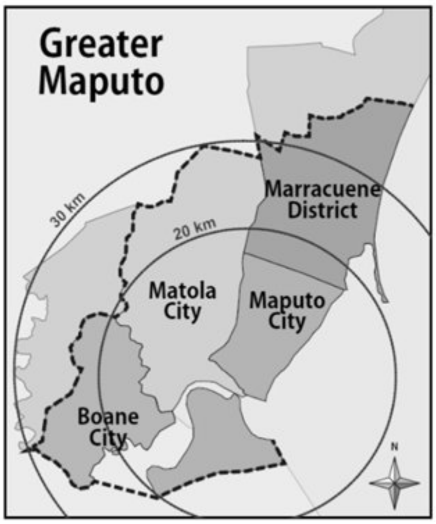


Figure 3-1: Overview of the Greater Maputo Metropolitan Area (Batran et al., 2018)

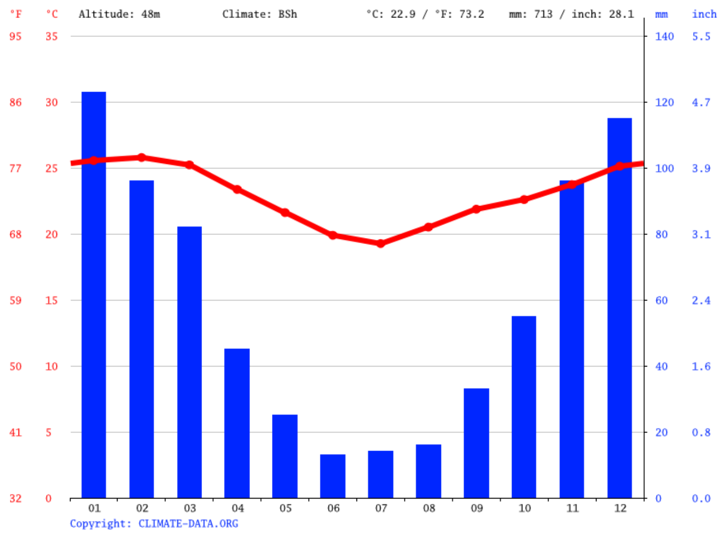


Figure 3-2: Climate in Maputo (Climate-Data, 2020)

3.1.2. Population

The conglomerate of Greater Maputo is home to 2,8 million people and includes the municipalities of Matola, Boane, KaTembe and Maputo and spans over some 675 km2, even though 96% of the urban population occupy only 320 km^2 (CIA, 2020; Jenkins, 2000). It is estimated that 53% of Maputo's inhabitants live in absolute poverty (Paulo, Rosário, & Tvedten, 2007). The large majority lives in informal settlements on the outskirts of the conglomerate. The municipality lacks resources to provide these informal settlements with water, electricity, sanitation and tenure security (Paulo et al., 2007). One of the reasons for this poverty is the lack of formal employment opportunities. Therefore, people depend on insecure informal economy with low returns (Paulo et al., 2007). Over the last 20 years migration from the countryside and an overall high fertility rate have led to a population growth of 3,5% per year in Maputo, compared to a country-wide 2% (UN Habitat, 2010). This led to a population density that reaches 3200 inhabitants per square kilometer in some suburban neighborhoods with all the inherent consequences thereof (UN Habitat, 2010).

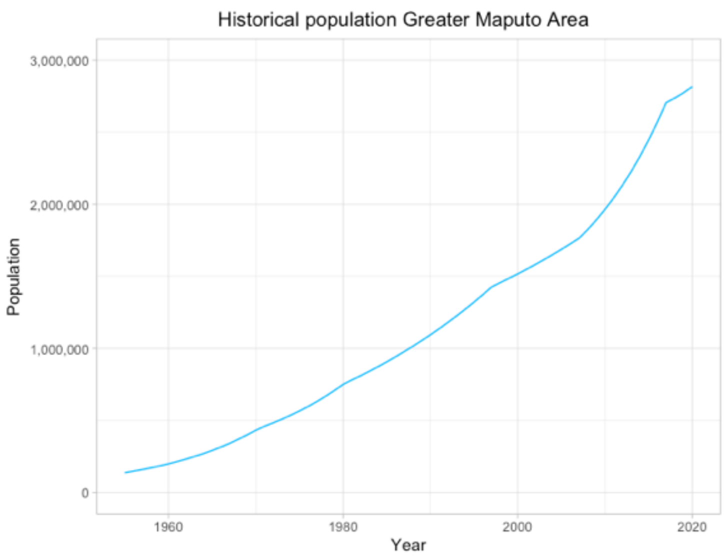


Figure 3-3: Historical Population Growth of Greater Maputo (INE, 2007; United Nations, 2020)

3.1.3 Economic Base

Mozambique is a low-income country and has a GDP per capita of 460 USD. The agriculture's and aquaculture's contribution to GDP was 24,9% in 2016. Industry and manufacturing however, only accounts for 9,6% of GDP in 2016, this share is heavily dominated by the Mozal Aluminum Smelter. The industry and manufacturing sector experienced a decline compared to 2000, wherein it accounted for 20% of GDP. This decline was due to the weak performances of Mozal. During this period, other sectors expanded. For example, the service sector expanded from 54,2% in 2000 to 55,4% in 2016 due to expansion in public transport, increased urban consumption and services to megaprojects. The extractive industries are on the rise from an 2% contribution to GDP in 2010 to 6,9% in 2016. This reflects the start large-scale coal exports and other extractive products such as natural gas, titanium and graphite (African Development Bank, 2018). It becomes evident that Mozambique has failed to transfer from an agricultural low-productivity economy to an industrial high-productivity economy (Balchin, 2017). Obviously, this does not fully represent the context in Maputo. However, it is relevant since Maputo facilitates more services than any other city in Mozambique since it is the capital city and therefore hosts numerous foreign embassies, consulates and major international organizations (JICA, 2014). Furthermore, in both Matola and Maputo the financial and service sectors dominate with employing 48% share of the available work force (Jenkins, 2000). Therefore, it can be stated that the Greater Maputo region is globally speaking not so much of an industrial region, but functions more as a regional services hub.

3.1.4. Land-use

Of the total land area in the Greater Maputo region, the largest share, some 60%, of the land has residential characteristics. Within these residential areas, a high proportion of urban agriculture exists and a low proportion of social equipment, recreation and economic activities (Jenkins, 2000). About 40% of the residential land use is unplanned and mainly found outside the city center and its suburbs. In advance, it is estimated that 75% of the population of the Maputo municipality live in non-demarcated settlements. It are these informal and unplanned residential areas that are prone to natural disasters such as flooding. At this stage, most of new residential development is spreading to Boane and Marracuene district (in the north of Maputo) (JICA, 2014).

Figure 3-4 shows that much of Boane, Marracuene and KaTembe are characterized as agricultural land, meaning either livestock, cultivation or plantation land. However, recent developments indicate that much of the agricultural landscape in Greater Maputo will rapidly change (JICA, 2014). Furthermore, *figure 3-3* shows that, agricultural land-use and residential land-use often overlap. This is in line with the *Plano de Estrutura Urbana do Município de Maputo,* the most recent urban plan for Maputo, (PEUMM). In this plan, it is stated that the rehabilitation and integration of areas suitable for urban agriculture is necessary for the survival of a high percentage of urban households (JICA, 2014).

As Matola is Mozambique's main industrial center, it is home to the largest concentration of industry in the country. As *figure 3-4* shows, most of the industries are located around the Matola river, being located along the river bears several advantages: sufficient water supply, transportation via water and an 'ideal' location to dispose waste (Brittanica, 2020). Several large industries exist in the Greater Maputo region. The first and largest being Mozambique's largest industrial Park, Beluluane Industrial Park (BIP) which spans over 60 hectares and is located within the Matola Industrial Zone (MIZ). The second is the Mozal Aluminum Smelter, which was the area's first megaproject initiated by a joint venture of companies from Japan, Australia and South Africa and the Government of Mozambique that holds a minority stake (African Development Bank, 2018). The Alumina is mined in Australia and transported to Mozal, the output of 506,000 tons of aluminum ingots is exported to the European Union. The third largest industry exists of multiple large manufacturing and processing companies. These industries produce beer, soft drinks, cement and cereal milling industries. Some examples hereof are Coca-Cola, Cervejas de Moçambique and Cimentos de Moçambique. The fourth is made up of large agri-businesses. Examples hereof are the Maragara sugar mill and Bananalandia. The products of these industries are usually used exported domestically or to South Africa. Furthermore, the ports of both Maputo and Matola are large industry hubs within the Greater Maputo Region.

In this paper institutional land-use is defined as land use which serves a community's social, educational, health, cultural and recreational needs. Thus, including hospitals, schools, higher education, governmental organizations, parks etc. Regarding institutional land-use in the Greater Maputo region, it becomes evident that most of the services; embassies, consulates, governmental organizations and education are located within Maputo center, mainly to satisfy the needs of local neighborhoods. The higher concentration of institutions in Maputo compared to Matola and Boane is obvious as Maputo is the capital city and has been the economic and institutional center in Mozambique since its colonial era.

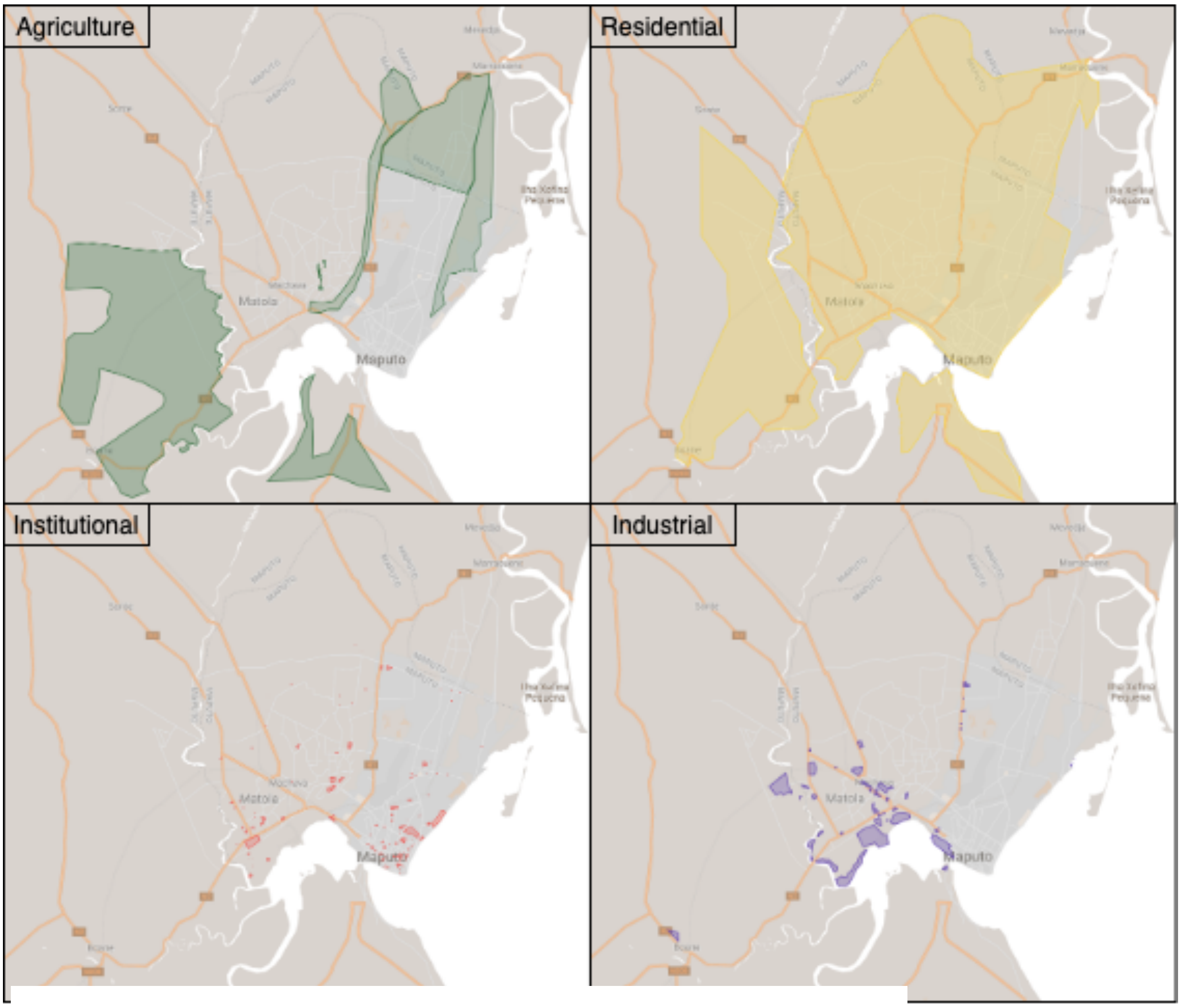


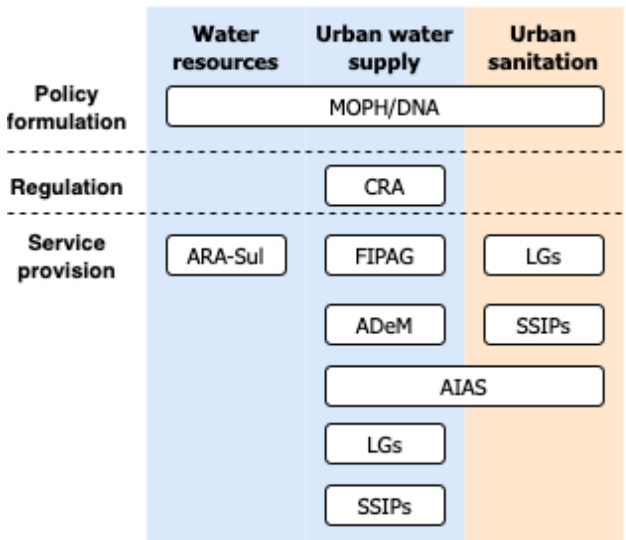
Figure 3-4: Land-use in the Greater Maputo Region (source: Author)

3.2 Institutional Framework

In the past years the main strategy of the urban water sector has been separating water resource management and water production from water supply asset holding and water services management (AMCOW, 2011). This transition process continues today. It is expected that decentralized levels of governance will be modified similar to the large urban models in secondary cities. Rural water and sanitation as well as urban sanitation have undergone minimal institutional reforms during this period. However, in 2010 a common fund was established for rural water supply and urban sanitation.

Figure 3-4 shows the institutional architecture of the water and sanitation sector in Maputo. The Ministry of Public Works and Housing (MOPH) leads the sector. Under the MOPH, the National Directorate of Water (DNA) is recognized as the sector focal point. FIPAG (asset-holder and operator of city water supplies), AIAS (asset manager of the water systems in peri-urban areas) and ARA-Sul (regional water resources board) work together with DNA whilst directly reporting to the MOPH. CRA (regulatory body of the urban water sector) reports directly to the Executive. In advance, DNA bears major responsibilities for international, hydraulic works and water resources management. The sector remains highly centralized since funding proposals and sector initiatives are solely coming from DNA or FIPAG. Therefore, two main bottlenecks in service proficiency have been identified. The first being the need for decentralization, whereby avoiding fragmentation of service delivery responsibilities. The second regards operations, specifically the need to assign responsibilities in large urban areas. The centralized system in Maputo, and other African cities, have resulted in poorly planned water supply management and insufficient defined roles and responsibilities, leading to a low performance (Jacobsen, Webster, & Vairavamoorthy, 2013).

Furthermore, from *figure 3-4* it becomes evident that no regulatory institution for urban sanitation exists. This is reflected in Greater Maputo as most of the urban residents use pit latrines, but no concrete provisions for their construction and management exist (Weststrate et al., 2019).



AIAS: Water and Sanitation Unit
ADeM: Mozambique Water Utility. Lease holder for the Maputo water supply. system
ARA-sul: Regional Water Management Unit for the Southern part of Mozambique, including Maputo
CRA: Regulatory body of the urban water sector.
DNA: National Directorate of Water. Policy lead in water supply, sanitation and water resources management.
FIPAG: Asset-holder and operator of major city water supplies.
LGs: Local Government of Maputo province and the Municipalities of Matola, Maputo and Boane.
MOPH: Ministry of Public Works and Housing. Institutional home of DNA.
SSIPS: Small-Scale Independent Providers.

Figure 3-5: Institutional Framework regarding water supply and sanitation in Maputo. Author's adaptation from (AMCOW, 2011)

When we compare this to a successful water management country such as the Netherlands, it becomes evident that their water management sector is characterized by a high degree of decentralization (Dutch Water Authorities, 2017). Furthermore, the Dutch water sector is characterized by drinking water of high quality, sufficient supply and the best flood protection in the world. The institutional framework differs greatly from the Mozambican framework. In the Netherlands two main water managing organizations are the Directorate-General for Public Works and Water Management (Rijkswaterstaat) and twenty-one regional Water Authorities.

The twenty-one regional Water Authorities form the fourth government institution in the Netherlands, besides the central government, provinces and municipalities. These Water Boards are financially independent, highly decentralized, autonomous and can be deemed sustainable (Unie van Waterschappen, 2010). The Water Boards play a pivotal role in water management in the Netherlands as they are responsible for the treatment of waste water, the quality and quantity of surface water and the state of regional flood protection measures such as dykes (Rijksoverheid, 2020a). Every four years, simultaneously with the province elections, the Water authority elections take place. Here inhabitants can vote for different Water Boards in their own region. In 2006 the local water supply company and water board of Amsterdam fused, creating the first integrated water supply and sanitation company in the Netherlands. The Directorate-General for Public Works and Water Management bears responsibility for larger water bodies such as rivers and the sea. Besides that, the RWS warns the involved governments in times of springtide or storms at sea and provides maintenance to dykes, dams, weirs and storm surge barriers (Rijksoverheid, 2020b). Furthermore, drinking water is produced and supplied through public regional water companies, many of their services such as repairs are delegated to the private sector. Groundwater quality is the responsibility of the provinces and municipalities are responsible for the sewage system and urban ground water (Dutch Water Authorities, 2017; Vewin, 2020).

To combat challenges such as climate change, urbanization and land-use change, the Greater Maputo region needs to transition towards a more decentralized water supply and sanitation sector. It has been stated that decentralized systems improve flexibility and sustainability, whereby increasing urban resilience (Sitzenfrei, Möderl, & Rauch, 2013). One of the reasons that centralized systems are more rigid, is due to the high fixed costs that make it more difficult to upgrade or retrofit the utility systems. On average these fixed costs make up 70-80% of the total investment costs. As a consequence, these high costs motivate communities to utilize their systems as long as possible. In other words, the system is designed to endure rather than to facilitate potential change (N. Leigh & Lee, 2019). In advance, due to the nature of centralized systems to be dependent on a limited number of water sources and its hierarchical network structure, they are very vulnerable to altering precipitation patterns, unexpected climatic events such as floods or droughts and political wrangling (Jacobsen et al., 2013; N. Leigh & Lee, 2019).

3.3 Water and Sanitation infrastructure

3.3.1. Sources

The main source of water for the Greater Maputo Region is the Umbeluzi river. The Umbeluzi River Basin is shared amongst Mozambique, South-Africa and eSwatini. About 40% of the area is in Mozambique, 58% in eSwatini and the remaining 2% is in South-Africa. The Umbeluzi headwater is located in Swaziland and flows eastwards where it discharges into the Indian Ocean through the Esperitio Santos estuary south of Maputo. The basin experiences two distinct seasons: a dry season between May and October and a rainy season between November to April (Droogers, De Boer, & Terink, 2014). The average annual rainfall in the catchment area is 736 mm. The Umbeluzi has two major dams in its basin, the Mnoli Dam in eSwatini with a capacity of 152 million m^3 and the Pequenos Limbobos Dam in Mozambique with a capacity of 392 million m^3. The Pequenos Limbobos Dam was built in 1987 to secure water supply for Maputo City. The intake and water treatment plant (WTP) for Maputo City is located a few kilometres downstream from the dam. This treatment plant has a maximum capacity of 240,000 m^3/s, but normally functions at 207,000 m^3/day (Sušnik, 2016a). When the water has been collected and treated, it is transported via a network of main pipelines to 11 distribution centres. From there, a network of 3000 km in length is used to transfer the water to the customers. The system consists of pipes of different diameters and materials. *Figure 3-6* provides an overview of the AdeM distribution network. At this stage however, non-revenue water (NRW) is about 36% (Sušnik, 2016a).

Figure 3-6: Umbeluzi River Basin (CRIDF, 2020)
Note: Swaziland is now named eSwatini

The second and last main water source of water in Greater Maputo is ground water. The ground water system is controlled by some 207 small-scale-independent-providers. SSIP's pump ground water into storage tanks and distribute this through standpipes and private connections via a gravity fed system. The SSIP's supply water to

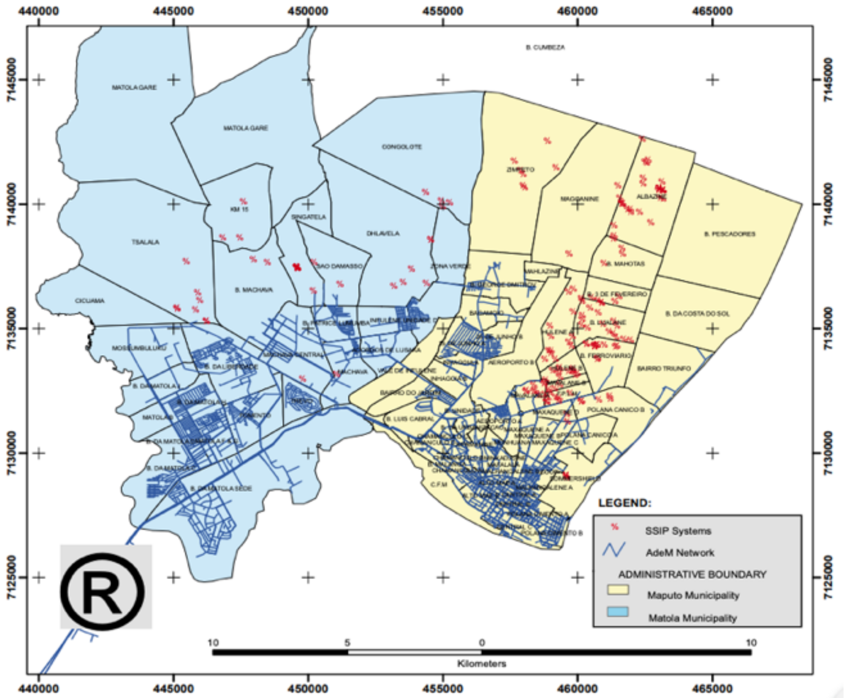


Figure 3-7: Greater Maputo's distribution network of AdeM and SSIP's (Matsinhe, Juízo, Rietveld, & Persson, 2018)

165,000 people through 210 standpipes and 11300 private connections (Bhatt, 2014; Ps-Eau, 2009). As can be seen in *figure 3-7,* the city centre is mainly served by the network of AdeM whereas the peri-urban "barrios" are mainly served through SSIP's. In Greater Maputo several systems make up the total ground water system: the Ka Tembe Autonomous Systems with a production of 760 m^3/day, the Intaka Autonomous Systems and the Combined Smaller Systems of Zona Verde, Kongolote, Matola Gare, Magoanine and Albazine with a production of 6500 m^3/day and the Intaka Autonomous Systems (Sušnik, 2016a). However, these groundwater resources are at risk due to potential over exploitation, pollution and salinization. Especially close to the city centre ground water sources were found with nitrate levels above international guidelines (Cendón et al., 2020). Furthermore, the recharge of these reservoirs is largely provided by major rainfall events (Cendón et al., 2020). Groundwater recharge ranges between 5% - 30% of total annual rainfall, dependent on soil type and vegetation cover (Nogueira, Stigter, Zhou, Mussa, & Juizo, 2019). *Figure 3-5* provides an schematic overview of these sources.

3.3.2. Wastewater Collection and Treatment

About 56% of Greater Maputo's population uses on-site sanitation (SEED, 2010). Most of these urban residents use latrines and septic tanks. Especially in the peri-urban areas, where connection to the sewage system is non-existent. Therefore, wastewater and faecal sludge is usually collected by private contractors that belong to a community and/or by residents themselves. In 2015 there were about 24 companies that use vacuum trucks to empty and transport faecal sludge from septic tanks to the Infulene treatment plant on the border between Maputo and Matola (SEED, 2010; Weststrate et al., 2019). However, as a consequence of poor maintenance and construction of latrines and septic tanks and the practice of open defecation, ground water is prone to nitrate contamination due to onsite sanitation runoff (Marques Arsénio et al., 2018a).

On the other hand, a sewage network has been constructed for off-site sanitation. However, this network does not extend beyond the old colonial centre of Maputo and thus only serves 5% of the total population of Greater Maputo. Two different systems exist in downtown Maputo. System I, the oldest of the two constructed in 1940, is a combined storm water and wastewater collection system. Storm water and effluent from septic tanks is collected by an underground pipe-system and is directly discharged into Maputo Bay. System II is the existing sewage network, constructed in the 80's and connects dwellings directly to the Infulene treatment plant via pipes and pumping stations (SEED, 2010). However, the treatment plant has not been sufficiently maintained and therefore wastewater is disposed of without sufficient treatment into Maputo Bay, posing many risks to public health and the environment. Moreover, it is estimated that only 6% of wastewater and faecal sludge is treated in Greater Maputo (Marques Arsénio et al., 2018a; Weststrate et al., 2019). It is recommended that the WWTP is expanded, and more faecal sludge and wastewater is collected and treated. This even bears the opportunity to reclaim and re-use water.

3.3.3. Planned

With the help of foreign financial aid, the 'Greater Maputo Water Supply Expansion Project' was developed to improve water security in Maputo. The plan is developed and monitored by the World Bank (The World Bank, 2013b). The main installations that are planned in this project are doubling the storage capacity of the Corumana Dam on the river Sabie, the construction of a pumping station adjacent to the dam, a water treatment plant north-west of Sabié in the proximity of the dam and 94 km of pipes to transport treated water from the treatment plant to a distribution centre Machava in Greater Maputo (The World Bank, 2013a). It is expected that the current capacity of 60,000 m^3/d will be increased to 120,000 m^3/d in 2024 (COWI & FICHTNER, 2013). The Corumana Dam was initially constructed for the production of hydroelectricity and irrigation and does therefore not contribute to the current water balance for Greater Maputo (Renardet, 2020). Even though dams are being removed throughout the world, especially in less developed countries, the benefits of water and hydroelectricity supply can offset the hazards and ecological consequences thereof (Roy et al., 2018).

Another project by the Government of Mozambique and carried out through the Ministry of Public Works, Housing and Water Resources is the Moamba Major Dam. The main objectives of this dam are mitigation of droughts, reducing flood impact, ensuring water supply to Greater Maputo and irrigation in the low, medium and high Incomáti (ARA-Sul, 2020). It is expected that the Moamba Major Dam will reinforce Greater Maputo's water supply by 250 million m^3/year (ARA-Sul, 2020). However, this reinforcement is only expected to operational in 2030.

Table 3-1: Overview of the current water supply system in the Greater Maputo Area (Sušnik, 2016a)

Greater Maputo Water Supply	*Method*	*Source*	*Capacity (m^3/day^{-1})*	*Current production (m^3/day^{-1})*
Umbeluzi System	Catchment, Water Treatment, distr.	Pequenos Libombos Dam	240000	207000
Ka Tembe Autonomous System	Holes, small reservoirs, distribution	Groundwater	760	760
Vila Olimpica Autonomous System	Holes, small reservoirs, distribution	Groundwater	-	-
Intaka Autnomous System	Holes, small reservoirs, distribution	Groundwater	-	-
Smaller Systems	Holes, small reservoirs, distribution	Groundwater	6500	6500

Key findings chapter 3

- The Greater Maputo Region is made up of the municipalities of Maputo, Boane, Matola and KaTembe.
- The region sits on the convergence point of 3 rivers and the Indian Ocean, and therefore has a relatively high groundwater table.
- Due to the region's close proximity to the Indian Ocean, storms occur annually and are linked with the passage of tropical cyclones.
- Annually, 860 mm of rainfall falls in Maputo, however, this amount varies heavily per month.
- The region is home to 2,8 million people of which 53% live in absolute poverty, mainly in the peri-urban areas.
- This population grows by 3,5% annually, the rate in the whole of Mozambique is 2% annually.
- Matola is the industrial center whereas Maputo hosts most institutions and Boane, KaTembe and Marracuene are home to most agricultural activities.
- In recent years, the urban water sector focused on separating water resource management and water production from water supply asset holding and water services management.
- The sector remains highly centralized to date as funding proposals in sector initiatives are solely coming from DNA or FIPAG.
- In order to increase resilience, a decentralized water and sanitation sector is recommended to co-exists with the centralised system.
- The main water source for the Greater Maputo Regin is the Pequenos Limbobos dam on the Umbeluzi river which has a capacity of 392 million m3 and provides 207,000 m3 of freshwater per day.
- The other major water source is groundwater. This system is controlled by SSIP's and serves 165,000 people through 210 standpipes and 11,300 private connections.
- The peri-urban areas are mainly served by groundwater, whereas the old center is connected to the formal water network.
- Only 56% of the population uses on-site sanitation. Especially in peri-urban areas, sewer connections are widely lacking.
- The sewage system does not extend beyond the city center and 94% of fecal sludge and wastewater is disposed of into the Maputo Bay, untreated.
- However, with the help of foreign aid, two new projects are being implemented. The Corumama dam on the Sabié river (with a pumping station and WTP) with a capacity of 120,000 m3/day and the Moamba Major Dam with a capacity of 140,000 m3/day.

Outlook

In this chapter, the baseline for the forecasting is established. In the next chapter the Greater Maputo Region's climate, population, water demand and water availability are analyzed and forecasted until the year 2050. The institutional framework and land-use are used in *chapter 7* and *8* later on.

4. Forecasting Maputo's Water Demand

To provide a detailed pathway towards closing the supply-demand gap for the Greater Maputo Area in 2050, it needs to be understood how factors such as climate change, urbanisation and economic development influence supply and demand over time. Therefore, this section entails a detailed forecasting of water demand and supply for the Greater Maputo Area until 2050.

4.1 Population Forecast

As water demand is inextricably linked with the size of the population, it is determined how the population of the Greater Maputo Area is going to develop over time. The population is to be computed in total and for the 3 different urban areas of the area; Maputo, Matola and Boane.

4.1.1. Baseline

First, it needs to be determined which period is used as a reference or baseline period. Since the last population and housing census in Mozambique was held in 2017, this year is used as reference or baseline. The population of the Greater Maputo Area in that year was 2,8 million, the distribution of this population is provided in *table 4-1*. To be able to create a realistic forecasting, population growth rates from the years before the reference year have been incorporated (Instituto Nacional de Estatística, 2017).

Table 4-1: Population and growth rates of the Greater Maputo Area with sub-cities and districts (Instituto Nacional de Estatística, 2017)

City	***Urban District***	***Population (2017)***	***Pop. Growth Rates (2007-2017)***
Maputo	DU1: KaMphumu	80,550	0,01
	DU2: Nlhamankulu	129,306	0,01
	DU3: KaMaxakeni	199,565	0,012
	DU4: KaMavota	331,968	0,025
	DU5: KaMubukwana	321,438	0,02
	DU6: KaTembe	23,248	0,09
	DU7: KaNyaka	6095	0,014
Total Maputo		***1,019,675***	***0,025***
Matola	Matola	1,032,197	0,035
Boane	Boane	210,367	0,051
Total	***Greater Maputo Area***	***2,846,440***	***0,029***

4.1.2. Assumptions

It was found that population growth is best represented by a logistic function (Agegnehu Matintu, 2016; Tong, Yan, & Chao, 2020). In logistic functions, the carrying capacity is incorporated. This means that when a population increases, the ability of the environment's capacity to support the population, decreases (Agegnehu Matintu, 2016). Therefore, this report assumes that the population of the Greater Maputo Area follows a logistic function.

Furthermore, it is assumed that the population growth rates, besides 'regular' population growth, also account for urbanization. This is assumed since the process of urbanization has been ongoing in the reference period, and its rate is not expected to change significantly (JICA, 2014).

4.1.3. Forecast

In *figure 4-1 and 4-2,* the results of the logistic population forecast are presented, using data from *table 4-1*. The logistic function was ran a thousand times with an uncertainty of 0,2. Respectively, the total population for the Greater Maputo and the per-city forecasting of the area. For visualization purposes, it was chosen to use line plots instead of boxplots. The shaded areas around the line depict the highest and lowest values of each year. The line itself depicts the average population, derived from the 1000 runs the model made for each year, with an uncertainty of 0,2.

From the forecasts, it becomes evident that the population of the Greater Maputo Area will more than double in the coming 30 years. From 2,8 million inhabitants in 2017 to 6,9 million in 2050. More developed African cities such as

Johannesburg (South-Africa) and Addis Ababa (Ethiopia) have experienced similar trends in the past, even at higher rates (UNDESA, 2018). In Johannesburg the population tripled from 1,8 to 5,8 million over a 30-year period between 1990 and 2020.

Furthermore, this forecast is in line, although slightly higher, with other projections that have been developed. For example, another forecast predicts the population of the Greater Maputo Area in 2035 to be around 3,7 million people, whereas this study predicts a population of 4,1 million people for the same year (JICA, 2016). The difference can be assigned to the reference period. The forecast by JICA used the years between 1997-2007 as a reference period. During these years the population growth rates were lower than the 2007-2017 period used as a reference period in this report.

Another interesting aspect is that Matola, even though being smaller in population than Maputo in 2017, surpasses Maputo's population in 2020. It is confirmed that this occurred in reality (PopulationStat, 2021). The higher population growth rate of Matola is likely to be the consequence of an increase in industrial and commercial activities in Matola (JICA, 2016). Another reason is that Matola is becoming a dormitory home for the new urban poor and middle-class, as they cannot afford to live in or in the proximity of central Maputo (The World Bank, 2017)

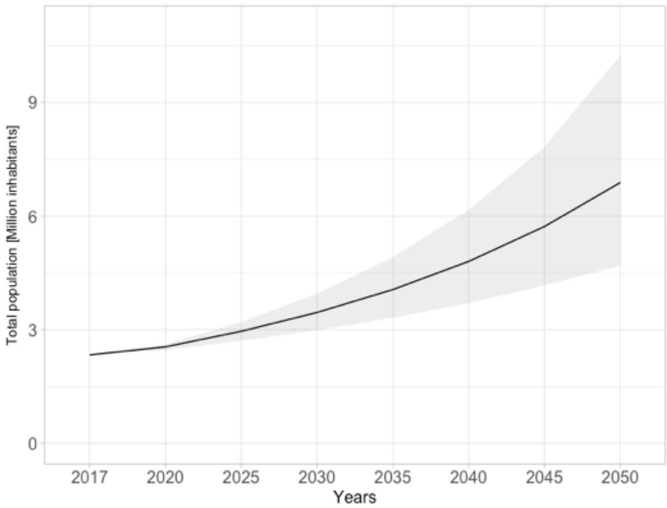


Figure 4-1: Population forecast Greater Maputo Area

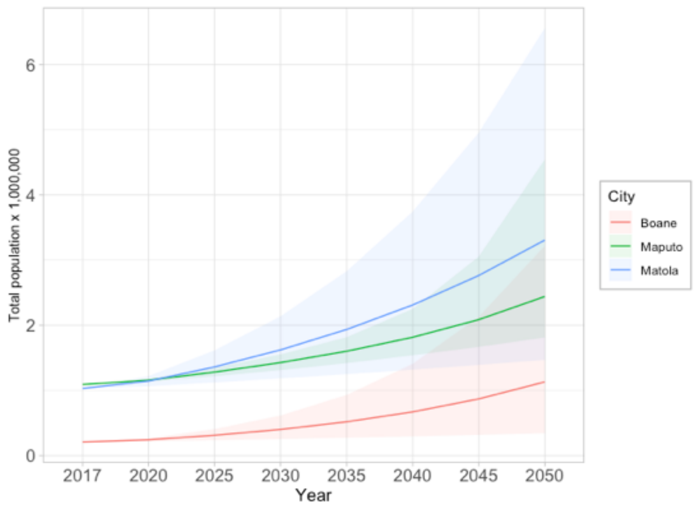


Figure 4-2: Population forecast per city

Table 4-2: Average outcomes population forecast

City	2017	2050	Factor
Maputo	1,019,675	2,442,209	2,4
Matola	1,032,197	3,308,691	3,2
Boane	210,367	1,131,962	5,4
Total	***2,846,440***	***6,882,862***	***2,4***

4.2 Water availability forecast

As stated in *chapter 3*, Maputo's water supply system relies mainly on two sources: ground water and surface water. Plans for expansion of the surface water system have also been described in *chapter 3*. These plans are integrated into the forecasting as well.

4.2.1. Reference period

Here, it is determined what the water availability in the reference period was. This data can directly be abstracted from *chapter 3.* As surface water is abstracted from dams in the Greater Maputo Area, their capacities are used to determine surface water availability. *Table 4-3* provides an overview of the dams that are constructed, and the ones currently under construction.

Table 4-3: Surface water available, abstracted from chapter 3

Dam	2017	2020	2025	2030	2035	2040	2045	2050
	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)
Umbeluzi	200000	200000	200000	200000	200000	200000	200000	200000
Corumana	0	60000	120000	120000	120000	120000	120000	120000
Moamba Major	0	0	0	140000	140000	140000	140000	140000
Total	**200000**	**260000**	**320000**	**460000**	**460000**	**460000**	**460000**	**460000**

In order to determine the groundwater availability, this report uses the sustainable groundwater potential for the Greater Maputo Area. This potential entails the maximum sustainable abstraction rate whereby considering natural recharge and a 35% outflow to hold back saltwater intrusion (SWECO, 2009). This potential allows for optimal utilization of resources, without harming aquifer systems (Anbazhagan & Jothibasu, 2016). For the purpose of this report, it makes more sense to use sustainable groundwater potential instead of current abstractions, as current abstractions are unsustainable, and the full extent of current abstractions remains unknown.

As shown in *figure 3-6* and stated in *chapter 3*, the Greater Maputo Area's groundwater sources are both located and abstracted in specific areas. These areas are northern Maputo, Inhaca and KaTembe (Ahlers, Perez Güida, Rusca, & Schwartz, 2013). Therefore, only those areas are discussed and provided in *table 4-4*.

Table 4-4: Sustainable groundwater potential (SWECO, 2009)

Area	Sustainable Groundwater Potential (m^3/day)
Northern Maputo	49315
KaTembe	5205
Inhaca	1917
Total	**56437**

4.2.2. Assumptions

It is assumed that an uncertainty of 0,2 represent the insecurities in the construction of the planned infrastructures. Examples of certain insecurities are, but are not limited to, delay in construction or hiccups wherefor amounts delivered are lower. (Arndt et al., 2011; Mavume et al., 2021).

4.2.3. Water availability forecast

Figure 4-3 shows the total available surface water and groundwater for the Greater Maputo Area. According to these projections, in 2050, approximately 500 million cubic metres of water are available each day. Surface water and groundwater have been merged together, as sustainable groundwater abstractions are constant over time. The forecasting function was ran a 1000 times with an uncertainty of 0,2.

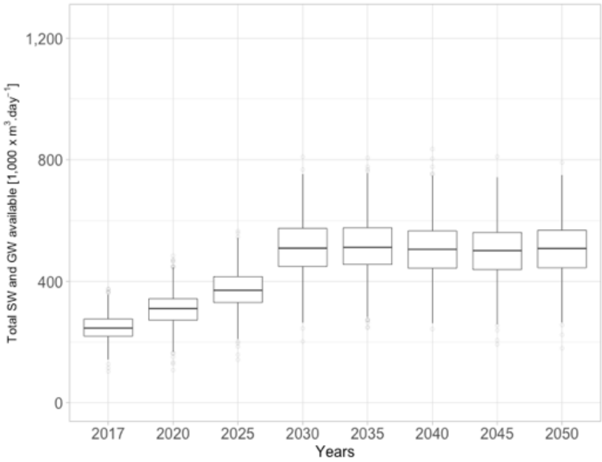


Figure 4-3: Total surface water and groundwater available

In 2017, groundwater accounts for 28% of the total available water. In 2050 this percentage is decreased to 12% due to the construction of more dams.

4.3 Climate Change forecast

The causes and consequences of Anthropogenic climate change have been widely described, however, these consequences differ greatly on a local, regional and national scale (Ministry of Foreign Affairs of the Netherlands, 2018). Therefore, this report aims at identifying the local effects of climate change on the Greater Maputo Region's water availability. The two main indicators that characterize the state of the climate and continuously effect living conditions throughout Africa are temperature and precipitation (Mavume et al., 2021). The complete forecasting can be found in *Appendix A*, including tables and figures.

4.3.1. Baseline

In Mozambique, an increase in mean annual temperature of + 0,6 °C was observed between the years 1960-2006. The largest increase was observed in the south of the country where the average annual temperature increased + 1 °C in 100 years. Average annual rainfall has decreased significantly, at a rate of 3,1% per decade. However, the share of rain falling during heavy rain events increased at a rate of 2,6% per decade, mainly during the rainy season (Ministry of Foreign Affairs of the Netherlands, 2018; The World Bank, 2021).

The baseline scenario in the climate forecasting by Mavume et al. (2021) is the 1961-1990 period and is based on climate data from the Mozambican Meteorological Institute. The parameters used are precipitation, maximum temperature and minimum temperature. The time scale used during this forecasting are 30-year periods whereby the 2040s represent the beginning of the 21st century (2011-2040), the 2070s the mid (2041-2070) and the 2100s the end of the 21st century (2071-2100). The forecast is conducted for 4 distinct regions in Mozambique: the coastal area and the inland Southern, Northern and Central areas. For the analysis of the forecasting in this paper, the two districts that are used in the forecasting and most applicable to this report are the ones located closest to the Greater Maputo Region. These districts are Namaacha (located 45 km west of the Greater Maputo Region) and Manhiça (located 50 km north of the Greater Maputo Region).

4.3.2. Forecasting

The forecasting used in this report used three different ensembles of regional climate change simulations from CORDEX-Africa. Where the first ensemble entailed 4 simulations, based on representative concentration pathway (RCP) 2.6, the second ensemble 9 simulations based on RCP4.5 and the last ensemble of 9 simulations based on RCP8.5. The RPC scenarios are developed by the international panel on climate change (IPCC) and depict different future scenarios of greenhouse gas emission into the atmosphere. Within these scenario's, RCP2.6 is the most ambitious scenario, representing radical climate change mitigation policies and slowing global warming down to 1,5 °C. RCP8.5 is the highest-level scenario, representing a business as usual scenario, which, without any climate action leads to global warming up to 4 °C (IPCC, 2014). The forecasting was conducted for four regions in Mozambique, southern, northern, central and coastal. The Greater Maputo Region is located within both the Southern and coastal region and therefore it is assumed that the local climate is influenced by both forecasting.

4.3.3. Temperature

Forecasts by Mavune et al. (2021) show that future warming is not uniform throughout Mozambique. In the RCP2.6 scenario, the temperature anomaly reaches up to 2 °C, except in the coastal region, suggesting that the coastal region will experience less temperature variation. In the RCP4.5 scenario, temperatures stabilize around 2050 indicating that the temperature anomaly will not exceed 2 °C in the coastal region. In other regions, temperatures stabilize around 4,5 °C in RPC4.5. The RPC8.5 scenario shows the highest increase, with almost 6 °C in the southern region and 5 °C in the coastal region. Compared to the reference period (1961-1990) and in all RCP scenario's, the largest increase in temperature is observed during the winter months June, July, August, September and the summer months October and November (ibid).

The projected changes indicate that the average annual temperature will be higher than the average annual temperature of the reference period. Especially towards the middle and end of the century, an increase is observed. Especially inland regions will experience greater temperature changes as compared to the coastal region (ibid).

4.3.4. Precipitation

In general, the behaviour of the annual precipitation patterns is characterized by a high variability, dependent on the scenario, geographic location and period chosen. In the southern region, except the coastal region, precipitation is likely to increase by 40% in the 2040s compared to the reference period. For the coastal area however, that precipitation is likely to decline from 0 to 20% for all RCP scenarios in every period. Furthermore, the southern region faces a higher interannual variability regarding precipitation compared to the coastal region, which even shows a relatively large interannual variability as well.

The behaviour of seasonal precipitation shows the same patterns as annual precipitation, which is probably influenced by the same factors. During the months December, January and February precipitation in the Greater Maputo Region increases in RCP2.5 by max. 20% and the inland area to the west by max. 40%. RCP4.5 and RCP8.5 show no significant anomalies compared to the reference period. In the months March, April and May, a decrease of 20% is observed in the Greater Maputo Region whereas the hinterland to the west faces an increase of 20%. During the months June, July and August the Greater Maputo Region faces a decrease of up to 60% in precipitation. The inland region to the west also faces a decrease, albeit 20%. In the months September, October and November a decrease up to 40% for the Greater Maputo Region and also for the inland regions except under RPC2.5, where the inland region's precipitation is likely to increase by 20%. A summary of these observations under RCP4.5 is found in *table 4-5 (ibid)*.

4.3.5. Implications for the Greater Maputo Region

As becomes evident from the forecasting by Mavune et al. (2021), temperatures in the Greater Maputo Region and the inland regions to the west are going to increase over time. In the coastal region specifically, precipitation is most likely to increase under the most optimistic RPC scenario and decrease in the other RPC scenarios. In the inland regions, precipitation most likely increases in the most optimistic scenario and decreases in the other scenarios, but at much lower rates than the coastal region. Even more, in both regions interannual precipitation variations are becoming larger.

Furthermore, the driest and hottest months in the Greater Maputo Region (June, July and Augusts) are likely to experience increasing temperatures and decreasing precipitation amounts. However, the months December, January and February will receive more precipitation in the 2070s. In a broad sense, for the inland region to the west of Maputo, it can be stated that the dry period becomes drier, and the wet period wetter. Whereas for the Greater Maputo Region itself it can be stated that both the wet and dry period become drier. This ultimately highlights the demand for an increase in water storage between the dry and wet season in both regions. *Figure 4-6* gives an indication of the Greater Maputo Region's climate according to the forecasting by Mavune et al. (2021) at the end of the 2040s period.

An increase in ambient temperatures directly increases evaporation, whereby reducing ground- and surface water availability (du Plessis, 2019). Therefore, it is expected that the reservoirs that ensure water supply to the Greater Maputo Region, located in the inland southern region, will face increasing evaporation rates and thus experience a loss in supply (especially during the dry season). Research in Australia indicated that an increase of 1,1 °C of the mean annual temperature led to an increase in reservoir evaporation of 8%. This reservoir is located close to Brisbane (Helfer, Lemckert, & Zhang, 2012). Extrapolation of that data provides a rough estimate for the percentual increase in evaporation in reservoirs in the inland areas of the southern region of around 10%. It must be noted that a lot of factors influence evaporation, and that these differ greatly between Australia and Mozambique. For example, the humidity in Maputo is much higher than it is in Brisbane(Climate-Data, 2020).

In advance, the same is expected for groundwater reservoirs. Furthermore, rising temperatures increase agricultural water demand, as plants evapotranspiration rates increase and the soil's evaporation rates increase (Nhemachena et al., 2020). In advance, it was stated that agriculture is highly dependent on precipitation, therefore the decreasing and more variable precipitation patterns pose a great risk to food security in the region.

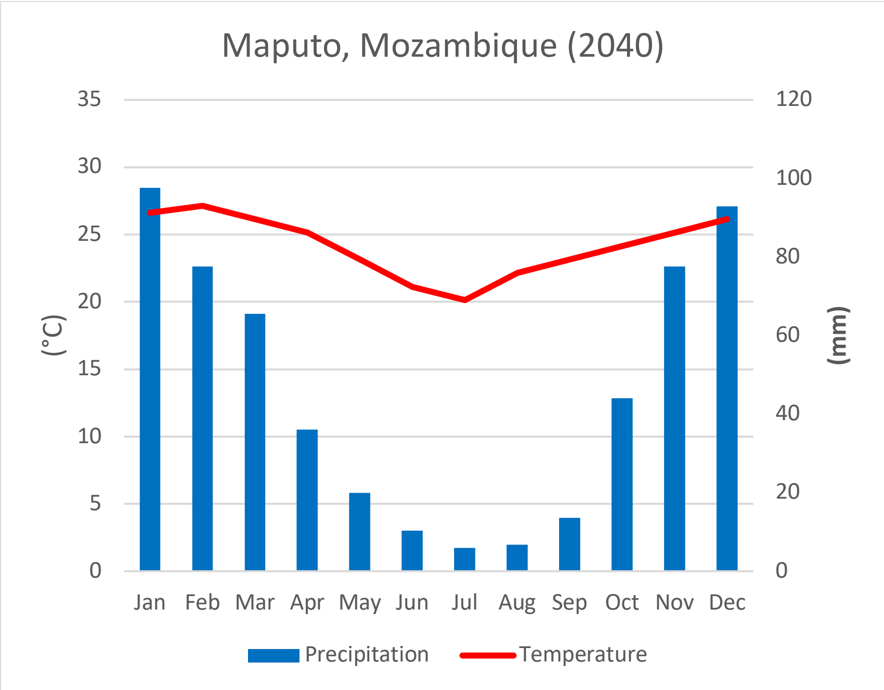


Figure 4-4: Estimation of Maputo's climate in 2040 (RPC4.5) (source: author)

4.4 Water demand forecast

Here, it is determined what the water demand of the Greater Maputo Area in 2050 is. The demand is computed for households (domestic), agriculture and industries. A myriad of factors influences water demand, especially on such a timescale. It was found that population growth, economic development and climate change are the most important drivers of water demand in urban areas (EEA, 2021). In advance, in order to determine and comprehend the total demand, it needs to be understood through which methods and by whom water is distributed, how much water is lost and how water demand is distributed across different sectors.

4.4.1. Reference period

NRW

From 2013 until now, NRW has been close to 50%. Therefore, for the forecasting 50% is used for the reference year 2017 (Zuin & Nicholson, 2021). NRW can be divided into apparent losses and real losses. Apparent losses entail metering errors, illegal abstraction or meters that have been tempered with. Whereas real losses entail physical water losses due to leakages during distribution, storage or connections. In the Greater Maputo Area, apparent losses and real losses are both at 50% (Sušnik, 2016a).

4.4.2. Assumptions

NRW

In Eastern African cities such as Nairobi and Dar es Salaam, NRW was reduced by 6% and 3% respectively between 2006 and 2009 (Water Operators' Partnerships, 2010). Therefore, it is assumed that NRW in the Greater Maputo Region will eventually reach 25% of the total water supplied and that physical losses are 50% of that, as is currently the case. Furthermore, according to IWA Best Practice, it is assumed that unbilled authorized consumption, unbilled metered consumption, unbilled non-metered consumption and unbilled non-metered consumption is water that *is* available for consumption (Alegre et al., 2016). Therefore, these values are left out of the forecasting. In other words, only physical losses are dealt with in this report.

Supply

The main organizations in the Greater Maputo Area's water supply are AdeM and the SSIP's. It is assumed that AdeM will eventually take over the SSIP's, whereby improving efficiency and realizing more equitable water pricing. This assumption is supported by similar trends observed in Kenya (Boakye-Ansah, Schwartz, & Zwarteveen, 2019). Currently, households acquire their water from in-house connections, standpipes or yard-connections. It is assumed that in-house connections will gradually take over standpipes and yard-connections as the supply system is expanded, improved and more water will be available.

Furthermore, it is expected that a higher water availability through interventions and economic development have a significant impact on the per-capita water consumption (M. A. Cole, 2004; Thomas, Channon, Bain, Nyamai, & Wright, 2020). Therefore, it is assumed that for each type of connection, per capita water demand increases.

Water demand per sector

Because of the strong correlation, it is assumed that *domestic water demand* experiences the same logistic growth rate as the Greater Maputo Area's population is subject to. Furthermore, it is assumed that agricultural water consumption is mainly fed by rivers and rainfall, and therefore is not connected to the water supply system (Nogueira et al., 2019). Therefore, agricultural demand is included in total demand, but not in forecasts with regards to the supply network.

Regarding industrial water demand, it is expected that industrial demand will eventually surpass domestic demand. This is assumed by observations in more developed nations, such as the Netherlands and South-Africa, this is depicted in *figure 4-5*. *Figure 4-5* shows that in South Africa, one of the most developed nations in Africa, industrial demand reached the same percentage as domestic in 2017. It must be stated that at this stage, South Africa is far more industrialized and developed compared with Mozambique, but it provides an outlook of what is likely to happen in other African countries, including Mozambique. In the Netherlands, the point where domestic and industrial water demand surpass each other, occurred before the data available. But it can be seen as a 'final' scenario, in which a high level of efficiency is achieved. As the largest share of industrial activities in Mozambique are located within the Greater Maputo Region, it is expected that industrial demand surpasses domestic demand around 2040 here and later in the rest of the country.

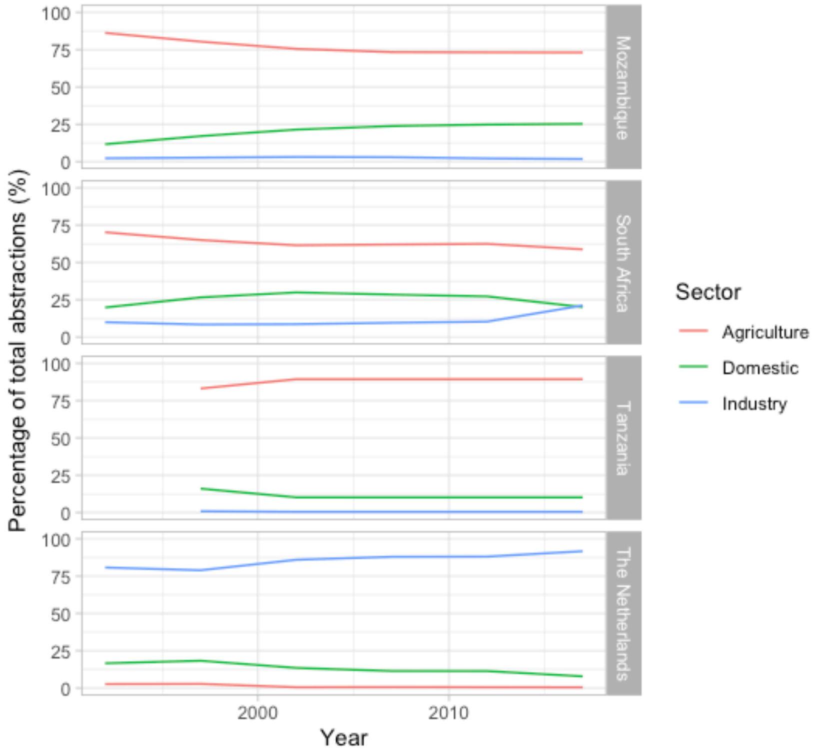
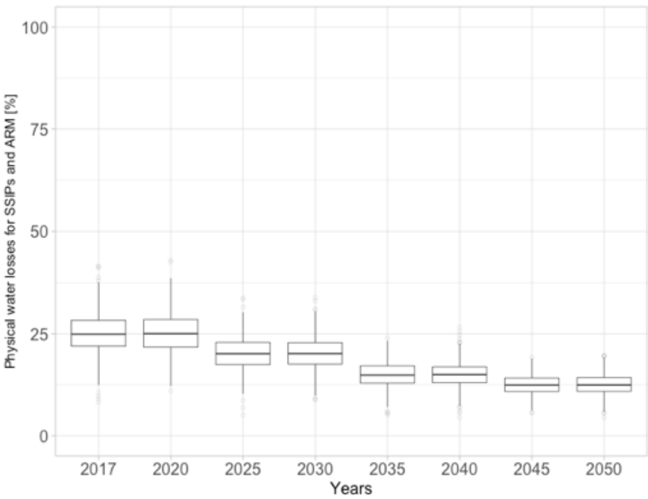


Figure 4-5: Percentage of freshwater abstractions across countries of different development levels (The World Bank, 2020)

4.4.3. Forecast

The forecasting function was ran a 1000 times, with an uncertainty of 0,2. *Figure 4-8* shows the decrease of physical losses in the Greater Maputo Area. As shown, physical losses are around 12,5% in 2050. It must be noted that *total* physical losses in 2050 may approach the total losses in 2017, as the supplied water is higher as well. *Figure 4-7* shows the coverage of AdeM, the formal supplier and the informal SSIP's. The plot shows that the coverage rate of SSIP's will decrease from almost 50% in 2017 to 10% in 2050. This means that AdeM network will continue expanding from now on, meaning that more houses become connected to the centrally supplied water network. Historical data support this, as AdeM's coverage grew 35% between 2002 and 2007 (The World Bank, 2009). Furthermore, it is likely that AdeM takes control over groundwater resources in the peri-urban areas, instead of solely focussing on surface water.



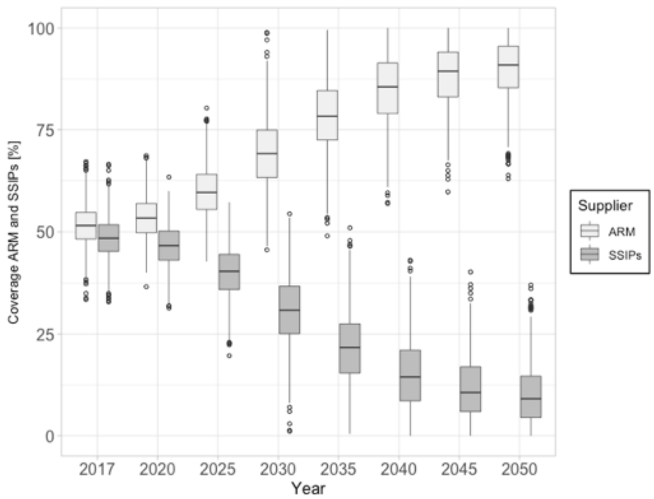


Figure 4-6: Physical water losses in the Greater Maputo Area

Figure 4-7: Water supply organizations over time

Furthermore, different types of connections to the water system are considered. In the Greater Maputo Area, three types of connections dominate: in-house, standpipes and yard connections. Whereas in-house connections are most common in the central area, the peri-urban areas are characterized by standpipes. Obviously, houses with in-house connection use more water on average, as it is simply easier to acquire. Therefore, these two factors, coverage of different access points and per capita water consumption per access point are important to determine future water demand. *Figure 4-8* shows that in-house access to water is going to increase over time, whereby replacing standpipes and yard connections. This is in line with *figure 4-7*, wherein it is observed that AdeM's network will expand and increase access to the central water supply. *Figure 4-9* shows that per capita water demand is going to increase over time. When multiplied with *figure 4-8* it becomes evident that the total demand is going to increase significantly, especially with regard to in-house demand. This increase is also observed and expected in other SSA cities. For example, the water authority in Dar es Salaam, Tanzania, expects that per capita water consumption is going to double from 145 to 295 l/cap/day between 2018 and 2035. This increase in demand is mostly attributed to economic growth (Andersson, 2019).

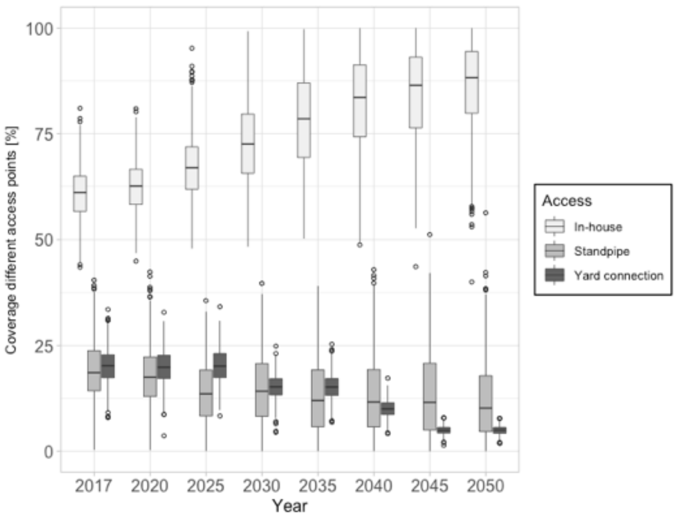


Figure 4-8: Coverage of different access points

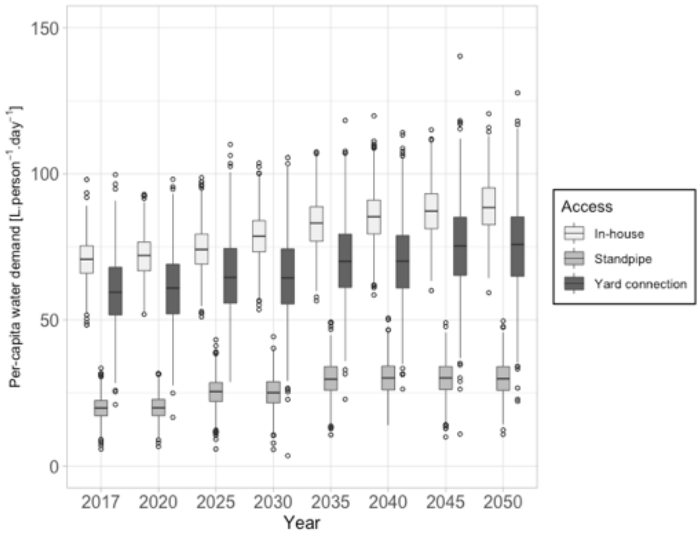


Figure 4-9: Water demand per capita for different access points

Figure 4-10 shows the demand for the three different sectors. Domestic (household) water demand is determined by multiplying *figure 4-9* by the population of the same year. It is known that industrial demand is currently 40% of domestic demand, therefore this factor was used to calculate industrial demand. Initial agricultural demand was calculated using data from the World Bank, and the logistic function was used to calculate future demand (The World Bank, 2020). Agricultural, domestic and industrial demand in the year 2050 are respectively on average 2,7^{E}8, 1,9^{E}8 and 2,38^{E}8 m^3/year. Meaning that the total demand in 2050 is approximately 7^{E}8 m^3. *Figure 4-11* shows the average total demand per day per year.

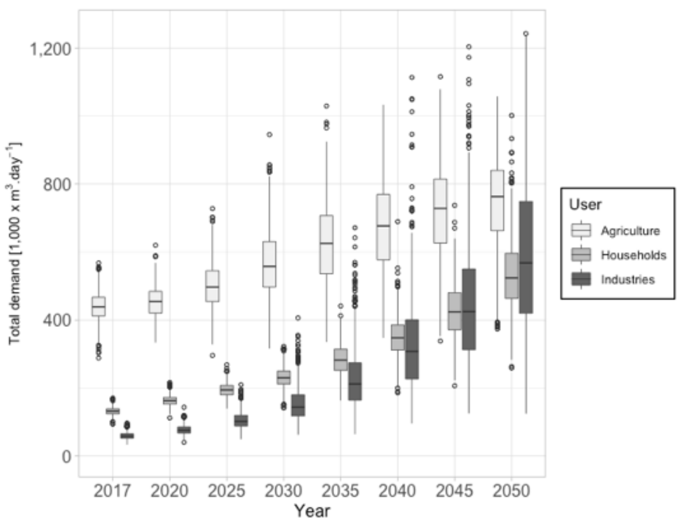


Figure 4-10: Demand per sector

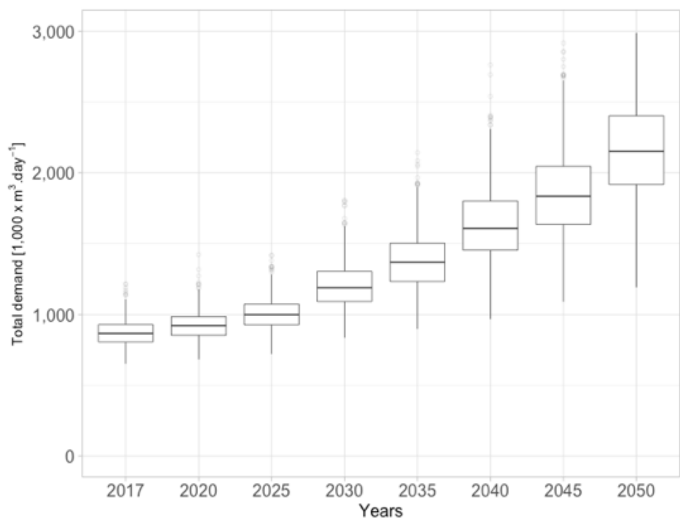


Figure 4-11: Total demand

As stated before, it is important to note that water for agricultural purposes is usually not connected to the central supply system. Especially in less-developed countries, water is simply abstracted from rivers or dependent on rainfall, this is supported by *figure 8* where it is shown that all agricultural activities are located within the proximity of rivers.

Therefore, in the coming section, unless stated otherwise, agricultural water demand is separated from domestic and industrial demand.

Regarding water demand, it is important to understand what amount of water is lost in the system. *Figure 4-12* shows the physical water losses in the AdeM network until 2050. What stands out is that is that there is an increase in total physical losses. This is due to the development and connection of new dams to the network, whereby increasing the input to the supply network. Even though *figure 4-6* shows the decrease in the percentage of water that is lost, the total amount of physical losses remains higher than in 2017 and is not reduced nor contained. *Figure 4-13* shows the deficit between water availability and demand, including physical water losses. In 2017 a deficit of 32,000 m^3/day is observed. This deficit decreases in the years until 2030, in this year even a surplus of 7500 m^3/day is observed. Hereafter however, when no additional water sources are utilized, the deficit increases dramatically and ultimately reaches a shortage of approximately 850,000 m^3/day in 2050.

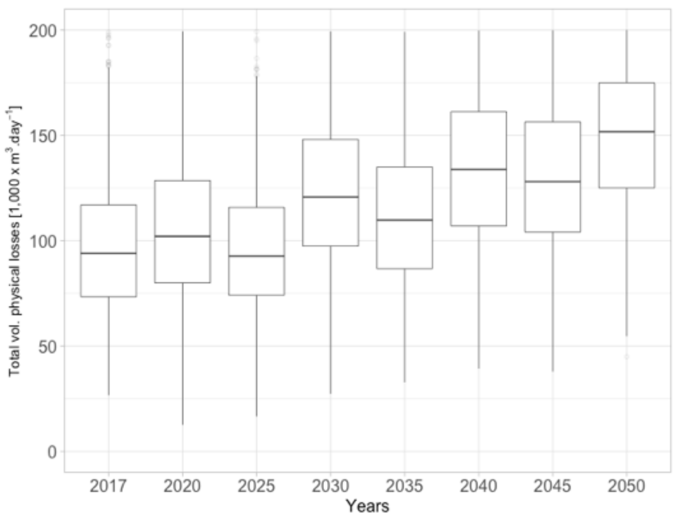


Figure 4-12: Total volume of physical water losses AdeM network

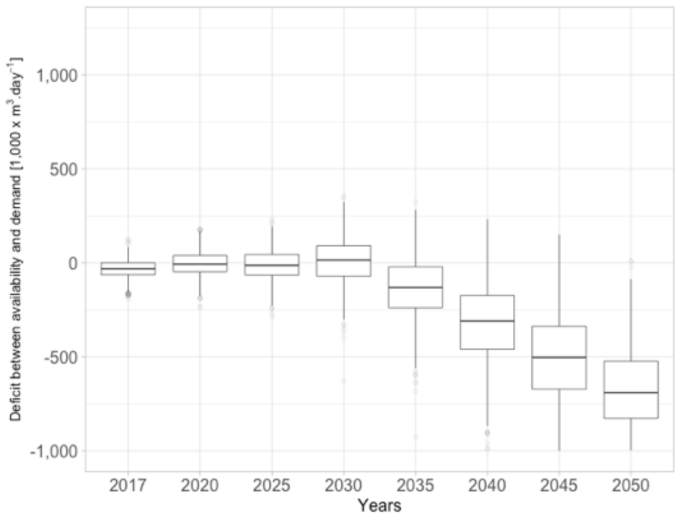


Figure 4-13: Coverage of water demand over time

When groundwater is abstracted at the same rate until 2050, the regenerative nature of the aquifers is deteriorated and will eventually dry out. *Figure 4-14* shows the amount of over-exploited groundwater, in the case of a business-as-usual scenario (BAU), considering the sustainable groundwater potential. It shows that in 2050, under a BAU scenario, abstraction exceed sustainable limits by approximately 75,000 m^3 per day.
Especially in the light of SUWM, it is important to understand rest-flows in the water system. Therefore, the wastewater production if forecasted. *Figure 4-15* shows the total amount of wastewater produced by households and industries per day. It is expected that wastewater production quintuples between 2017 and 2050. With an average wastewater production of approximately 1 million cubic metres per day in 2050.

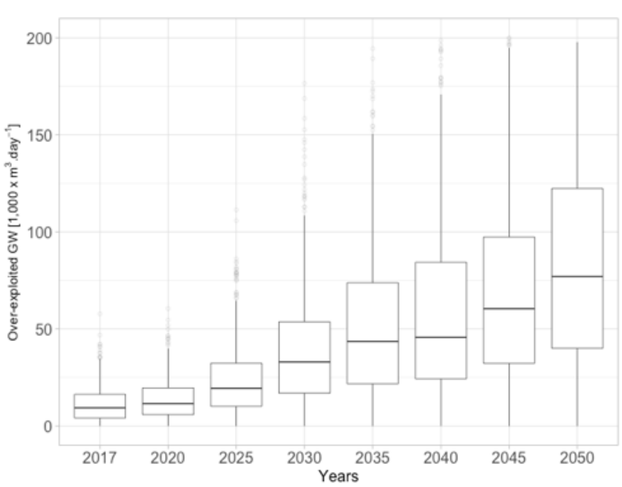


Figure 4-14: Overexploited groundwater

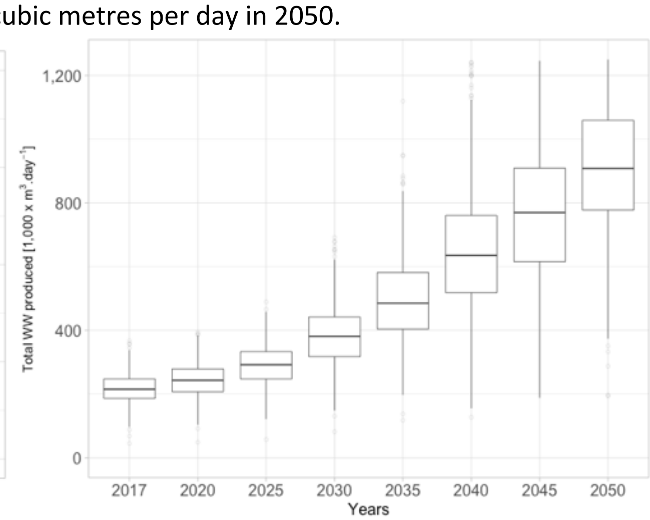


Figure 4-15: Total production of wastewater

Figure 4-16 provides an overview of the most serious pressures on the Greater Maputo Region's water supply. Is must be noted that the blue-dotted line represents availability and not necessarily direct supply. A lot of factors influence the amount of water that is ultimately delivered, e.g., physical losses, illegal abstractions and evaporation.

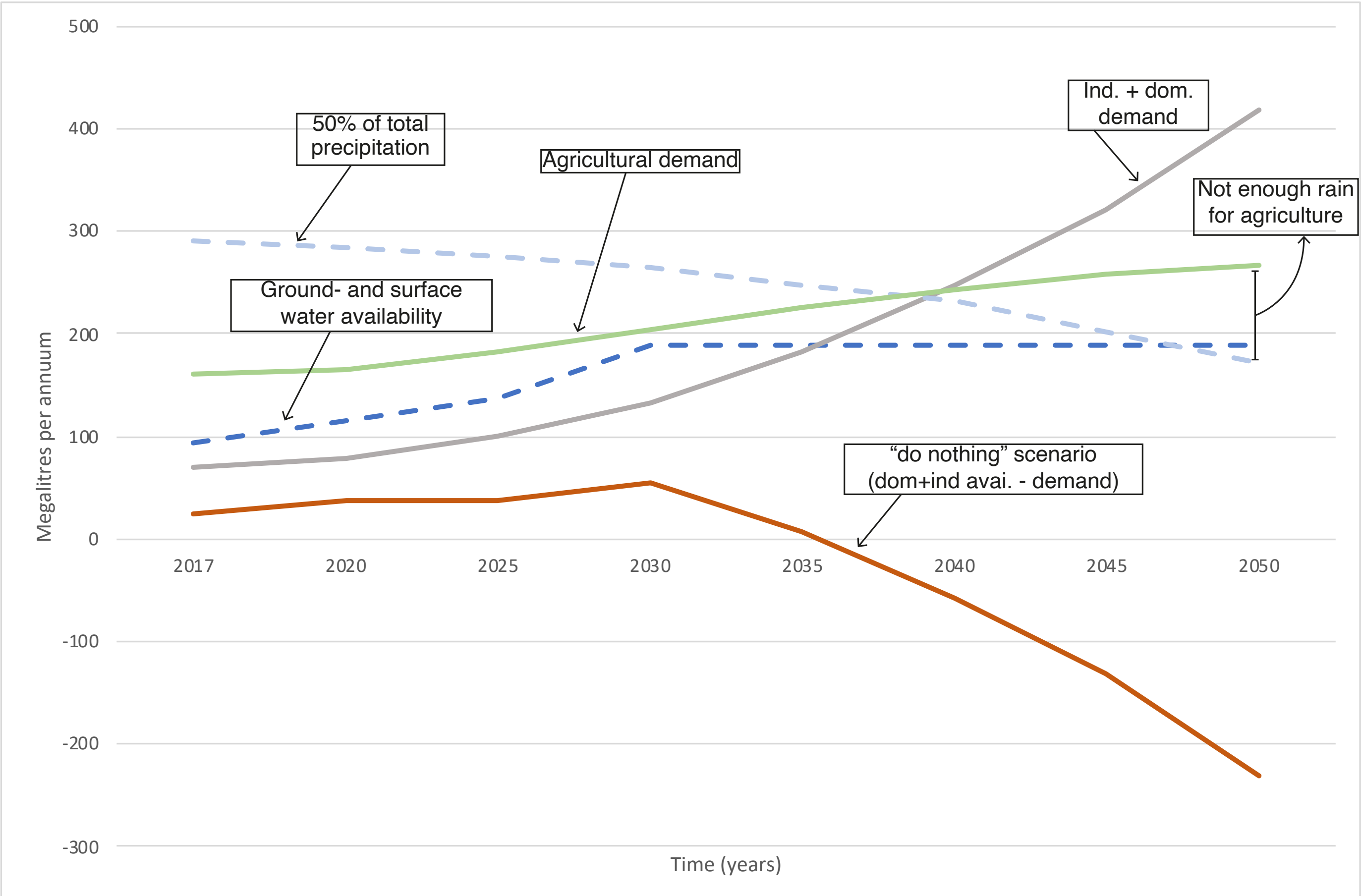


Figure 4-16: Overview of pressures on water availability and demand (source: Author)

Key findings chapter 4

- The population of the Greater Maputo Region will increase from 2,8 million people in 2017 to 6,9 million in 2050.
- Based on existing and planned infrastructure and the sustainable groundwater potential, 500 million m3 of freshwater is available in 2050.
- In the most likely RCP scenario, precipitation in the Greater Maputo Region decreases by ±20% and average annual temperatures increase by 1,5 °C. Both directly affect water supply due to the lesser amount of precipitation and an increase in evaporation.
- Water demand in the Greater Maputo Region increases from 9 million m3/day in 2017 to 22 million m3/day. The sector that consumes most water is agriculture, followed by industries and households.
- In the case of a business-as-usual scenario, the Greater Maputo Region will face a deficit of 850,000 m3/day in 2050.

Outlook

The findings in chapter 4 highlight the need for alternative water supply methods, especially during the dry periods (that are becoming drier), serious water shortages are expected in a business-as-usual scenario. Therefore, chapter 5 aims at identifying the alternative water supply approaches, their trade-offs and advantages for the Greater Maputo Region.

5. Closing the Gap in Maputo's Future Water Demand

In this section, social, technical and environmental approaches to improve the Greater Maputo Area's water supply are identified. These approaches are specified for the context of the Greater Maputo Area. In advance, the translation of these approaches from the Global North to the Global South is provided.

5.1 Strategies for Closing the Gap

As became evident in the previous section, Maputo will face an enormous deficit in their water supply in 2050, with all the consequences thereof. However, a myriad of different systems and methods is available to increase the water supply in terms of quality, quantity and efficiency. In this section, the most applicable methods for the Greater Maputo Area are elaborated in order to be used in the serious game and MCDA. For the purpose of the serious game, the different strategies are mainly compared in sustainability and economic indicators. These methods can either be of a technical, social and or environmental nature and be used to enhance efficiency, increase water supply through additional sources and enhance water quality. In order to compare different solutions, they are evaluated and quantified as 'environmental footprint and 'dollar' per cubic meter.

Sociotechnical systems such as urban water management systems are regarded key in adapting to climate change and achieving resilient cities (Herslund & Mguni, 2019). As stated in *chapter 3* the Greater Maputo Area traditionally relies on conventional methods to extract surface water, mainly from rivers, and groundwater. Wastewater and stormwater are managed in similar conventional methods i.e., disposed of into Maputo Bay. It are exactly these methods that have been questioned in the light of pressures such as climate change and urbanization (Herslund & Mguni, 2019). There is a consensus amongst urban water practitioners on the need to change conventional urban water management towards more sustainable configurations that rely on decentralised, nature-based systems (Herslund & Mguni, 2019). The main aspect of sustainable urban water management is the utility of decentralized and integrated or multifunctional physical water infrastructure with small ecological footprints that typically use locally available water sources, whereby increasing urban water systems sustainability and resiliency (N. G. Leigh & Lee, 2019).

Besides SUWM approaches, conventional methods are discussed, as they are currently of great importance for the GMA's water supply. Therefore, the idea is that within the time frame of this report, existing conventional methods co-exist with novel methods that support SUWM. Ultimately, existing infrastructure is slowly phased out (in downtown Maputo) and replaced by sustainable solutions. In the peri-urban areas, where barely any official WASH infrastructure exists, it is possible to leapfrog over the costly universal systems and move directly towards SUWM (Herslund et al., 2018). These SUWM approaches together with the current infrastructure will provide the solution towards closing Maputo's water gap in a sustainable and economically feasible way.

Figure 5-1 illustrates the nexus in which SUWM exists. The top of the pyramid represents social justice priorities, bearing that urban water supply should be at equitable cost and through democratic decision-making processes. The bottom right of the triangle asserts the economic goal of efficiently providing adequate water quantity and quality to ensure the area's vitality and water security. The bottom left depicts environmental goals, such as long-term viability and renewability of freshwater reservoirs and flows. It is inevitable that conflicts arise between the three areas. Therefore, it is required that a balance is found amongst those three areas. *This demands the incorporation of various individual and organizational stakeholders, the use of innovative infrastructure technology and the regulation of the system by institutional actors* (N. G. Leigh & Lee, 2019). As the priorities within the triangle are continuously shifted and altered, SUWM calls for a system that is responsive and sustainable, or in other words: *resilient* (Folke, 2006).

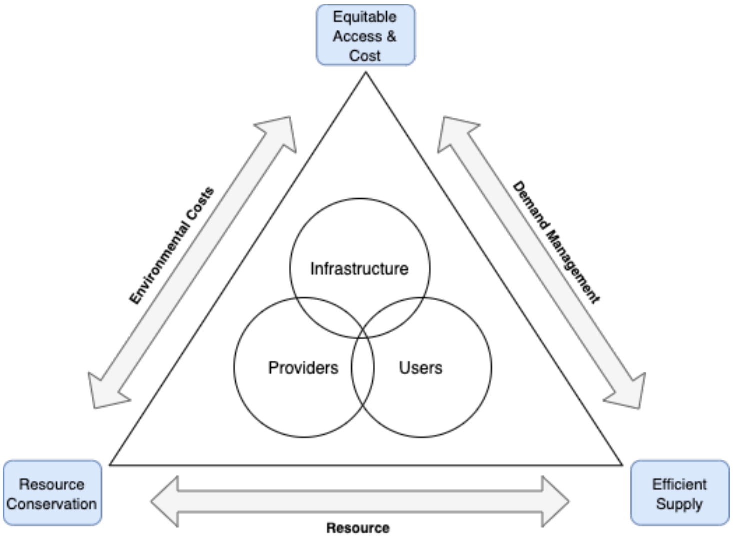


Figure 5-1: Triangular model of SUWM adopted from (N. G. Leigh & Lee, 2019)

5.1.1. From North to South

As most of the strategies that are discussed in the coming paragraph have been implemented and studied in OECD countries, relatively little is known about the transition to sustainable urban water management the Global South (Habtemariam, Herslund, & Mguni, 2019). To put things into perspective, it needs to be understood why the Global South lags behind the Global North regarding SUWM. Obviously, the Global North is much more capable of financing the renewal of urban water networks due to its ample wealth, technical capacity and well-functioning governments (Henriquez & Van Timmeren, 2018). Where 95% of the Global North's population has access to enough food and shelter and participates in the educational system, the Global South lags behind with only 5% of the population having access to enough food and shelter. Furthermore, the Global South is more often characterized by corrupt governments and deteriorated (water) infrastructure (ibid). Most developing countries lack sufficient funds to construct and/or scale up large public infrastructures (water and sanitation) and implement climate adaptive strategies because the population is too poor to extract taxes or tariffs from. Finally, governments are more often corrupt and lack resources, skills and know-how to do so (ibid).

Studies have indicated that inequality and poverty are inextricably linked to corruption (Chetwynd, Chetwynd, & Spector, 2003; Sulemana & Kpienbaareh, 2018; Ullah & Ahmad, 2016). Therefore, the question arises why the Global South remains so poor to date, even when international foreign aid from OECD countries sums up to €104 million annually. One of the reasons is, as stated, corruption. It is estimated that government corruption in the Global South is responsible for the loss of € 830 billion a year, whereby depriving people of their basic needs (Henriquez & Van Timmeren, 2018).

Furthermore, research has shown that developing countries have lost €13,35 trillion (!) through leakages in the balance of payments, trade misinvoicing and capital flight. A large share of capital outflow is dedicated to repayments of foreign debt, as most of the large industries in the South are still controlled and owned by the Global North, countries in the Global South sought loans from western institutions such as the World Bank and the IMF. These loans were accredited with sky-high interest rates, pushing less developed nations into debt with western countries. Since 1980, the Global South pays on average €3,5 trillion in interest payments to banks in London, New York and Frankfurt (ibid).

The largest share of lost income in the Global South, originates from corporations and high asset individuals, foreign and domestic. This happens through the false reporting of income, whereby funnelling money to tax havens such as The Netherlands, Bermuda and Panama (Galaz et al., 2018; Henriquez & Van Timmeren, 2018). This amount sums up to €2,5 trillion. Meaning that every euro that is sent by the OECD countries as foreign aid, the South sends back 24 euros. Money that could potentially be used to fund health services, water infrastructure and education (Brandt, 2020; Henriquez & Van Timmeren, 2018). Four strategies are recommended for governments to combat corruption and interlinked inequality (Heinrich, 2017):

- Stopping the merry-go-round between business leaders and governmental positions.
- Holding the corrupt accountable instead of letting corrupt official hide behind political immunity.

- Implementing more fierce control on banks, luxury good sellers, lawyers and real-estate agents that aid with laundering money.
- Outlawing the use of secretive companies that hide their true owners.

5.1.2. Technical Approaches – Unconventional Water Sources

Before explaining the different types of water supply approaches, for which purposes water is used in the urban context, and which quality is desired. In urban areas, the three main water demanding sectors are (urban) agriculture, households and industries. The types of water used in these sectors are usually referred to as potable or non-potable. However, non-potable water covers a wide variety of water of different qualities such as wastewater, greywater, rainwater and stormwater (Government of Western Australia, 2021). Non-potable water can be used directly for non-potable purposes or indirectly through treatment whereafter being directed to environmental barriers such as lakes, rivers or groundwater (EPA, 2021).

Non-potable water uses are found in the three main urban water consuming sectors. In agriculture, non-potable water can be used for irrigation, however, this is depended on the quality of the water and might demand basic treatment (Nyanda & Mahonge, 2021). Furthermore, an already practiced non-potable water purpose is landscape irrigation (Azbari, Ashofteh, Golfam, & Loaiciga, 2021). In the domestic sector, non-potable water can be used for toilet flushing, car washing and garden irrigation. And in industries, non-potable water can for example be used for cooling and floor washing (Mohammed & Elbably, 2016). However, for most purposes some degree of basic treatment is required, as e.g., the direct use of blackwater bears risks for human and environmental health.

Stormwater harvesting

Stormwater is defined as the runoff from permeable and impermeable surfaces, mainly in the urban context (Goonetilleke & Lampard, 2018). Stormwater harvesting refers to the collection and storage of stormwater when water is abundant, and the reuse when less water is available (Akram, Rasul, Khan, & Amir, 2014). The benefits of stormwater capture are trifold. First, urban runoff, which washes pollutants into inland and coastal waterways is reduced. Secondly, water of a better quality than untreated sewage and industrial discharge is retained (Akram et al., 2014). And thirdly, flood risks can be reduced, as retaining water within the urban area attenuates river flow downstream or simply drains stormwater from the streets (Fisher-Jeffes, Carden, Armitage, & Winter, 2017). Moreover, stormwater harvesting reduces the negative effects of pollutants in aquatic ecosystems and is a sustainable method to capture freshwater whilst simultaneously reducing flood risks (Cooley, Phurisamban, & Gleick, 2019b). Maputo is known to suffer from flooding during periods of rain, as the drainage in place is unable to drain the amount and flow of water, directly increasing the risk of endemic diseases such as malaria (Sušnik, 2016b).

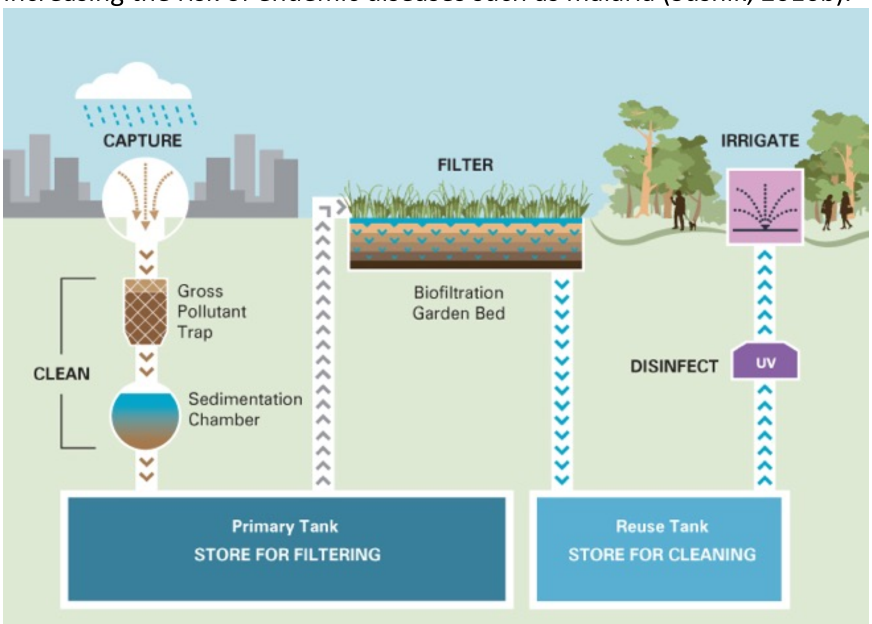


Figure 5-2: System overview of SWH where harvested water is used for irrigation purposes (City of Melbourne, 2021)

Given the quality of stormwater, it is most suitable for non-potable water uses such as irrigation or toilet flushing, whereby reducing the consumption of centrally supplied water and ultimately reducing the supply-demand gap (National Academies of Sciences, 2016; Sušnik, 2016a). Furthermore, on regional scale, stormwater can be used to increase groundwater recharge and ultimately be used as potable water (National Academies of Sciences, 2016).

An average potential stormwater supply has been determined for four different neighbourhoods in Maputo, these neighbourhoods differ greatly in physical, social and economic background (Yahaya, 2019). Extrapolation of the data gives an average potential stormwater supply of 196 million cubic metres for the whole Greater Maputo Area annually from 2015 to 2018 (Yahaya, 2019). This means that in the year 2017 SWH would roughly cover 60% of total demand. However, it must be stated that this is a very rough estimate and based on best-case scenarios, but it provides insight in the order of magnitude of the potential of stormwater harvesting. However, as stated in *paragraph 4.3*, especially in the Greater Maputo Region, the amount of total precipitation is likely to decrease by 20%. Therefore, the amount of potentially harvestable stormwater is decreasing by the same rate.

The costs of stormwater harvesting depend on the desired quality of the stormwater, i.e., if treatment is necessary or not. Research in California has shown that the average cost of stormwater harvesting, without treatment, is approximately 0,66 $\$/m^3$. This includes the whole life cycle of the system and includes initial and operating costs (Cooley et al., 2019b; Diringerid, Shimabuku, & Cooley, 2020). This research, that is based on 50 different stormwater harvesting projects has indicated that economies of scale play in important role in the costs, the larger the project, the lower the costs per m^3 of water (Diringerid et al., 2020). Obviously, it is difficult to compare the Greater Maputo Area to California, as there are of lot of social, economic and climatic differences between those two places.

A viable solution to decrease the effects of flooding, and its associated health risks, in the Greater Maputo Area would be the construction of excavated reservoirs at strategic locations. In downtown Maputo, most streets that contribute to flooding cross the Tunduro garden. Therefore, this garden would be a strategic location to drain and store stormwater (Sušnik, 2016b). Identification of strategic locations would be essential to ensure efficiency of this strategy.

However, the peri-urban areas are not served by sewer networks and are largely unpaved. Therefore, the construction of the networks and collection drains are expected to be expensive. In advance, the existing treatment plants are already operating on full capacity, therefore new treatment plants and connecting pipelines need to be constructed at large cost. Furthermore, an impervious soil as is found in the peri-urban areas makes it more difficult to collect stormwater, as a large share of water is expected to drain into the soil. Besides that, large infrastructural projects such as the above come at great cost. Which FIPAG, AdeM and the municipality are most likely lacking.

Rainwater harvesting

Public surveys indicate that social acceptance amongst inhabitants of Maputo is higher for rainwater harvesting than it is for stormwater harvesting (Yahaya, 2019). Rainwater harvesting consists of the concentration, collection, storage and treatment of rainwater from rooftops, terraces, courtyards and other impervious building surfaces for on-site use (Campisano et al., 2017). Therefore, rainwater harvesting provides water of a higher quality than stormwater harvesting (Hamdan, 2009). However, harvested rainwater is usually not of the same standard as potable water, mainly due to microbiological contamination (Meera & Ahammed, 2006). However, when harvested rainwater is sat in a well-designed storage tank for the appropriate time, it should be safe for drinking without further treatment (Martinson, 2007).

However, the most common usage of rainwater harvesting is to reduce the consumption of centrally supplied water. Examples hereof include toilet flushing, laundry, irrigation and car washing and many more applications. Over the last twenty years, rainwater harvesting has been described as a Low Impact Development or Sustainable Drainage System approach and can also be used to reduce frequency, peaks and volumes of urban runoff (Campisano et al., 2017). Furthermore, harvested rainwater can be used to recharge (shallow) groundwater aquifers (WaterAid, 2011). For example, in the densely populated Indian city of Chennai, top-down approaches to increase rainwater harvesting for artificial recharge have led to a water table rise of 50% (Henriquez & Van Timmeren, 2018).

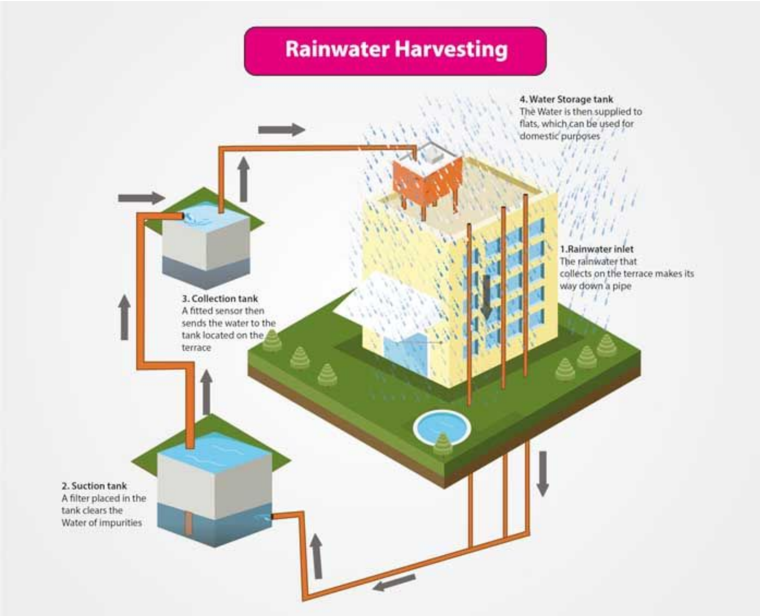


Figure 5-3: Schematic overview of rainwater harvesting (Masterbuilder India, n.d.)

An analysis of annual potential rainwater harvesting for the same four neighbourhoods as stormwater harvesting has also been established. Extrapolation of that data indicates that the Greater Maputo Area can potentially harvest 7 million m^3 of rainwater per year (Yahaya, 2019). Obviously, stormwater and rainwater cannot be harvested in the above-described quantities simultaneously, as rainwater becomes stormwater when it reaches impermeable layers on the earth's surface. Furthermore, there is policy in place in Mozambique to support rainwater harvesting; Law no. 16/91[2], article 23, section d states that water falling on roofs of houses is subject to the private use regime, and therefore may be exploited by the property owners (Reública de Moçambique, 1991; Sušnik, 2016b). However, according to *chapter 4.3*, the dry season in the Greater Maputo Region is becoming drier, therefore a reduction of about 20% of total precipitation is expected in the year 2050. Therefore, it is expected that rainwater harvesting will not be able to function as a storage method between the wet and dry season.

As an example, it can be calculated how much rainwater could be haversted for an average home of 45 m^2, using the following formula (Martinson, 2007):

$$Q = 0.85 \times R \times A$$
$$Q = 0{,}85 \times 860 \times 45$$
$$Q = 32{,}895 \text{ litres/year}$$

R *is the annual total rainfall in milimeters (ch. 2)*
A *is the guttered roof area in squared metres*
0,85 *is the run-off coefficient.*

The high price of storage installations have been identified as the main hurdle for domestic rainwater harvesting practices , even though most people indicated that they would like to have it (African Development Bank, 2008; Fisher-Jeffes, Armitage, & Carden, 2017). The costs of rainwater harvesting vary per technology. The cheapest options are underground storage, which ranges from 4 $/m³ for bottle shaped underground tanks to 15 $/m³ for underground ferrocement tanks. Above ground tanks range from 30 $/m³ for ferrocement tanks to 130 $/m³ for plastic tanks. These costs are obtained from published sources, expert consultations and experiences by SEARNET in Eastern Africa and include initial costs and operating costs (Mati et al., 2006; Parker, Cruddas, Rowe, Carter, & Webster, 2013). Also, rainwater harvesting installations are subject to economies of scale, the average price per unit of water decreases when projects increase in size (Parker et al., 2013). However, research in Liesbeek, a socially mixed neighbourhood in Cape Town, has shown that rainwater harvesting was only economically viable for the most affluent in the area and only when the largest possible catchment area is connected to the storage tank and the harvested rainwater is used for as many end uses as possible (Fisher-Jeffes, Armitage, et al., 2017).

Wastewater reclamation

Wastewater reclamation refers to the capture and treatment or processing of wastewater in order to make it reusable (Asano, 1987). Reclaiming and reusing wastewater has been done for centuries, but since a few decades it is becoming recognized as an effective water conservation tool and pollution-control method (Heaton, 1981). The benefits of wastewater reuse or plentiful; recovering and reusing wastewater eliminates a potential pollution load to a receiving waterbody (in the case of Maputo: Maputo Bay), reclaimed water may be utilized for the many purposes ordinarily served by high-quality potable water, reuse of wastewater may result in economic benefit due to its nutritional load, the need for communities to use unprotected water sources is reduced and highly treated wastewater can be used to recharge underground aquifers (Heaton, 1981).

Domestic, industrial and agricultural sectors produce most wastewater (Gothandam, Ranjan, Dasgupta, & Lichtfouse, 2020). *Domestic wastewater* includes water from household activities and is either grey, black or yellow water. Grey water can be treated and reused within 48 hours for onsite flushing, irrigation and other non-potable uses (Tilley, Ulrich, Lüthi, Reymond, & Zurbrügg, 2014). In the peri-urban areas, all types of domestic wastewater are mixed due to the use of septic tanks or greywater is discharged directly onto the streets (Marques Arsénio et al., 2018b; Raude, Mutua, Chemelil, & Sleytr, 2009). *Manufacturing industries* release tremendous amounts of wastewater, containing a wide range of pollutants, dependent on the type of industry. Both industrial and domestic wastewater are usually high in organic and inorganic contents (Gothandam et al., 2020). In Mozambique, where metal, food and drinks, textile and clothing and wood industries are predominant, industrial wastewater is expected to be highly contaminated (CEEG, 2018). For example, wastewater from the food and beverages industries typically contains high quantities of carbohydrates such as sugar and pectin. Whereas the steel and iron industries usually provide wastewater containing high amounts of cyanides, sulphur compounds, phenol, dust, metal ions, ashes, slag and ore particles (Heaton, 1981). *Agricultural wastewater* is the excess water that runs off the fields at the low end of the furrows. These fields are usually heavily contaminated by crop remains, pesticides, artificial fertilizers, chemicals and animal waste (Gothandam et al., 2020). The use of organic fertilizer would drastically reduce the toxicity of wastewater (Moss, 2008).

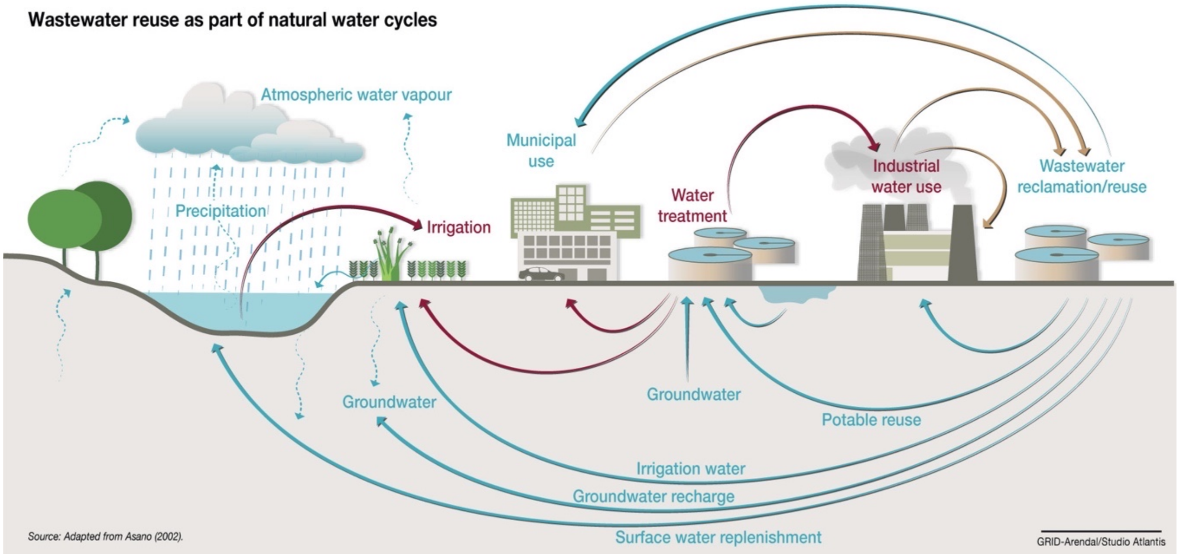


Figure 5-4: Overview of the potential water flows during wastewater reclamation (Grid-Arendal/Studio Atlantis, 2020)

In 2014, it was estimated that the two officially planned wastewater systems in Maputo discharge 25,000 m^3 of wastewater per day. Of which 55,6% originated from domestic sources, commercial and public respectively contributed 25% and 12,5% and industries contributed 6,9% (van Ramshorst & van Esch, 2014). As most wastewater is currently untreated and discharged into the Maputo Bay, reuse of wastewater reduces the negative impacts of wastewater on the environment (SEED, 2010). It must be stated that the amount of wastewater is higher in reality, as this amount lacks data from the peri-urban areas which are not served by AdeM.

Moreover, wastewater can be reused and recycled for a multitude of water demanding activities. However, the potential application of wastewater strongly depends on the hydraulic and biochemical characteristics of wastewater (Vigneswaran & Sundaravadivel, 2004). These characteristics determine the method and degree of treatment necessary. Agricultural irrigation usually requires lower quality levels of treatment compared to domestic purposes that require the highest treatment levels (either potable or non-potable). All other reuses of wastewater lie between these two extremes (Vigneswaran & Sundaravadivel, 2004).

On global scale, agricultural irrigation is the main user of wastewater, with for instance about 41% of recycled water used for such purposes in Japan and 60% in California (USA) (Vigneswaran & Sundaravadivel, 2004). Many urban food markets in Maputo rely on crops from peri-urban agriculture. Currently, farmers in the peri-urban areas of Maputo use untreated wastewater for irrigation, especially in the Infulene neighbourhood (Mati, Cumbane, Raude, & Hettiarachchi, 2015). However, the use of untreated wastewater poses great risks to human and environmental health (Blumenthal, Duncan Mara, Peasey, Ruiz-Palacios, & Stott, 2000; Janeiro, Arsénio, Brito, & van Lier, 2020). Therefore, some type of treatment is necessary for wastewater to be safely used for agricultural irrigation. In addition, the use of domestic wastewater for agricultural purposes can reduce the amount of artificial fertilizer required, whereby reducing its impact on the environment and bringing economic benefit for farmers (Janeiro et al., 2020).

An example of such a project is found in Larnaca, Cyprus. Here, wastewater is treated and used to irrigate 150 hectares of agricultural land. The treated water is also used by hotels, the International Airport and Larnaca municipality for the irrigation of gardens, parks and fields during the summer season. The cost of the entire project was 50 million euros of which 9,3 million euros were the costs of a tertiary treatment plant. The Larnaca treatment plant has a capacity of 18,000 m^3/day, and the cost for producing tertiary treated water is around 0,50 €/m^3 (Hidalgo & Irusta, 2005; Neocleous, 2016). Furthermore, average costs of water recycling and reuse have been determined by analysing 7 different projects in California. It was found that the costs for small projects with non-potable purposes (<12 million m^3) range from 0,44 \$/m^3 to 0,93 \$/m^3. When distribution (\$0,77) is included, the total average cost of non-potable water reuse is 1,25 \$/m^3 (Cooley et al., 2019b). For small projects with the aim of providing potable water from wastewater, through an environmental reservoir, the costs are on average 1,43 \$/m^3, of which 0,37 \$ are dedicated to conveyance, groundwater pumping and treatment (Cooley et al., 2019b). Obviously, Cyprus is considered a more developed country than Mozambique is and the same goes for California, however, it still provides insight in the order of magnitude of such an approach to reclaim water.

There is a potential for re-using wastewater in SSA, especially for industrial purposes such as mineral extraction, cooling in thermal power plants and in other non-food manufacturing industries such as metal processing, paper textile, chemicals and construction. However, as data and information is widely lacking, more research on both technical and governmental aspects are necessary (Gulamussen, Arsénio, Matsinhe, & Rietveld, 2019).

In advance, in *paragraph 4.4.3* it can be read that wastewater production, from households, agriculture and industries is going to increase over time and is going to provide a much larger share of total demand in 2050 as it is now.

However, the transition towards a more circular water system in the Greater Maputo Region seems challenging. First, wastewater is known to be a threat to human and environmental health and should therefore be handled with care (Adewumi, Ilemobade, & Van Zyl, 2010). The current infrastructure is known to be suffering from leakages, which makes it unsuitable for the transportation of wastewater from households and or industries. Even in the case of a new pipeline system, the financial resources should be available to maintain the conduction lines. Furthermore, little is known regarding the exact types of industries and the quality of their wastewater, which enlightens the demand for research to investigate the feasibility of wastewater reuse.

Desalination

A broad definition of desalination includes the treatment of all non-potable water sources such as seawater, brackish (ground) water, wastewater and stormwater runoff (Younos & Lee, 2020). This section will focus on the desalination of seawater and brackish water. Three basic approaches to separate water from salt exist:

- The first method is distillation, here thermal means are used to induce a phase change in water (liquid to vapor), whereby physically separating the new phase from the remaining salt solution. Besides the thermal component, distillation processes often include vacuum components to induce evaporation at lower temperatures (Miller, 2003).
- The second method is through the use of membranes. Here, the components are separated by a membrane due to their response to an externally applied gradient. The two main types hereof are Reverse Osmosis and Electrodialysis. The third and last method is of chemical nature and is due to its inefficiency compared to the previous two methods beyond the scope of this report (ibid).

- The third and last method is of chemical nature and is due to its inefficiency compared to the previous two methods deemed of no use to this report (ibid).

Prior to these three processes, usual water treatment occurs, which typically includes coagulation, flocculation, filtration and disinfection (Stokes & Horvath, 2006). After desalination, water is made potable during post-treatment, where the freshwater is remineralized, boron and chloride are removed and further disinfected (Elimelech & Phillip, 2011). After these steps, freshwater can be distributed. However, during these processes a brine is produced that is twice as saline as seawater and also includes the chemicals used in pre-treatment and membrane cleaning protocols. Obviously, discharging this brine into marine environments could pose a threat to public health and marine ecosystems (Elimelech & Phillip, 2011).

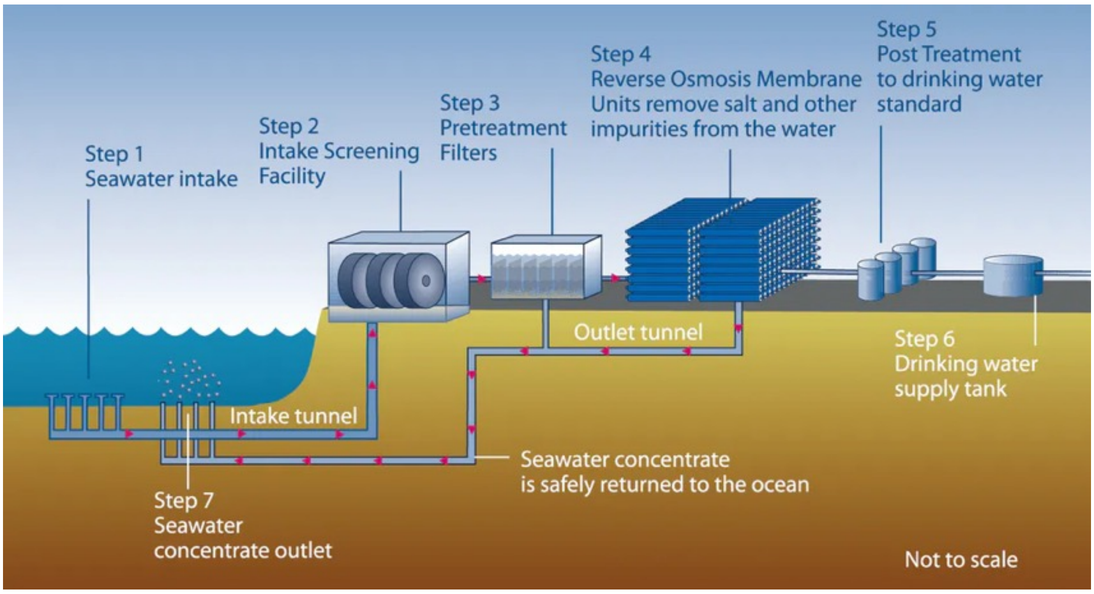


Figure 5-5: Schematic overview of desalination using reverse osmosis (Wright & Reynolds, 2019)

Transportation costs of influx saline water and brine disposal have been identified as major hurdles for feasibility of desalination plants (Miller, 2003). Within this context, the location of the Greater Maputo Area seems promising, due to its proximity to the Indian Ocean. However, in various papers, desalination has been described as one of the most expensive alternative water supply approaches (Cooley, Phurisamban, & Gleick, 2019a; Elimelech & Phillip, 2011; Plappally & Lienhard V, 2013). Almost 50% of the costs per m^3 desalinated water produced are costs dedicated to electricity (Miller, 2003). Electricity for businesses in Mozambique costs about 0,053 $/kWh, which is relatively low compared to a more developed country such as the Netherlands, where energy costs 0,111 $ per kWh for businesses (Global Petrol Prices, 2020).

It was estimated for Nacala Bay in Northern Mozambique, that the production costs of desalinated water using Reverse Osmosis, concerning construction costs, operation and maintenance costs in Mozambique are 1,01 $/$m^3$ for a plant with a capacity of 70,000 m^3/day and 0,91 $/$m^3$ for a plant with a capacity of 140.000 m^3/day (JICA, 2016). In theory, the capacity can be scaled to higher and lower capacities as seawater is obviously over-abundant in the Indian Ocean.

5.1.3. Technical Approaches – Conventional Water Sources

Dams

Dams are primarily used to store water and supply it to the right place at the right time. The benefits of dams are plentiful, particularly in the context of climate change and urbanization. However, numerous studies have indicated that dams have serious negative environmental, human and political consequences (Brown, Tullos, Tilt, Magee, & Wolf, 2009). Examples of such negative impacts include, but are not limited to the hindering of fish migration and reproduction, relocation of settlements, deterioration of water quality, rise in evaporation and the increase of water sourced diseases such as malaria and cholera (Kibret, Wilson, Ryder, Tekie, & Petros, 2017; Tahmiscioğlu & Durmuş, 2007).

As can be read in paragraph two, dams are currently responsible for supplying the largest share of freshwater to the Greater Maputo Area. In advance, two more dams are currently being constructed, the Corumama Dam in the river Sabie and the Moamba Major Dam on the Incomati river. These two dams will reinforce the area's water supply by 800,000 m^3/day in 2030 (ARA-Sul, 2020; COWI & FICHTNER, 2013). In theory, surface water is not scarce in Mozambique and therefore, the construction of more dams is not unrealistic and provides a comparison to the alternative water sources.

It is expected that the construction of the reservoir for the Moamba Major will cost 466 million US$ and the dam is expected to achieve an installed capacity of 450,000 m^3/day (Stuyling de Lange, 2017). In advance, the pipelines and water treatment plant are expected to cost another 300 million US$, with a production of 140,000 m^3 potable water per day (Stuyling de Lange, 2017). Dams with similar capacities are most likely to costs about the same order of magnitude as the Moamba Major. However, as the Moamba Major (amongst others) is totally funded by foreign aid, it is questionable if another investment of that scope in the timeframe of this research is realistic.

5.1.4. Technical Approaches – An overview

In the paragraphs above different approaches are discussed and analysed in terms of feasibility, sustainability and potential yield. In this paragraph, an overview of those approaches is provided. Not only as an overview for the reader, but also as a starting point for *chapter 6.* It must be stated that these costs are not precise nor definite. These costs have been determined through research from locations all over the world and adjusted for Mozambican context when necessary. *Table 5-6* present an overview of the different technical approaches and their most important advantages and limitations.

Table 5-1: Overview of technical approaches (source: paragraph 5.1.2. and 5.1.3.)

Technique	Water source	Potential yield (Million m^3/year)	Costs (USD/m^3)	Limitations	Advantages
Rainwater harvesting	Rainwater	7	3,1	- Demand for new infrastructure - Yield is low - Decreases groundwater recharge	- New water source - Harvested water is of good quality - Reduces polluted run-off - Water is sourced locally
Stormwater harvesting	Rainwater	196	1,2	- Difficult to implement in peri-urban areas - Expensive new infrastructure - Decreases groundwater recharge	- New water source - Reduces polluted run-off - High potential yield - Water is sourced locally
Wastewater reuse	Wastewater	73	1,1	- Maintenance important - Quality is unknown - Whole new pipeline network necessary	- Water is reused instead of discharged into the environment - Improves human and environmental health - Water is sourced locally

Desalination – brackish	Seawater	∞	0,9	- High electricity consumption - Brine disposal	- Secure flow of water - Yield is almost endless - Cheaper than saline desalination
Desalination – saline	Seawater	∞	1,7	- High costs - High electricity consumption - Brine disposal	- Secure flow of water - Yield is almost endless
Dams	Surface water	∞	0,6	- Questionable due to the already present dams - High environmental impact	- Relatively cheap option - Not a novel approach

Figure 5-7 shows the average costs of different approaches per cubic meter. These costs include construction, transportation and treatment costs. It was chosen to use average costs per cubic meter, as the size of installations is of lesser importance and provides a more general method to compare different approaches. In advance, *figure 5-8* shows the coverage of the approaches discussed in the previous paragraph. The bars in the year 2020 show what the coverage of interventions would be in 2020 and 2050, if they were in place. In other words, there is not an upward or downward trend in the supply of these approaches, it is potential influx of water that was calculated for the Greater Maputo Area in the respective paragraphs for that intervention. The demand that is divided by the potential water supply for each intervention was calculated in *paragraph 4.3.3.* As most of the calculations regarding stormwater and rainwater were in the urban context and related to paved areas and roofs, agricultural demand is excluded from this figure.

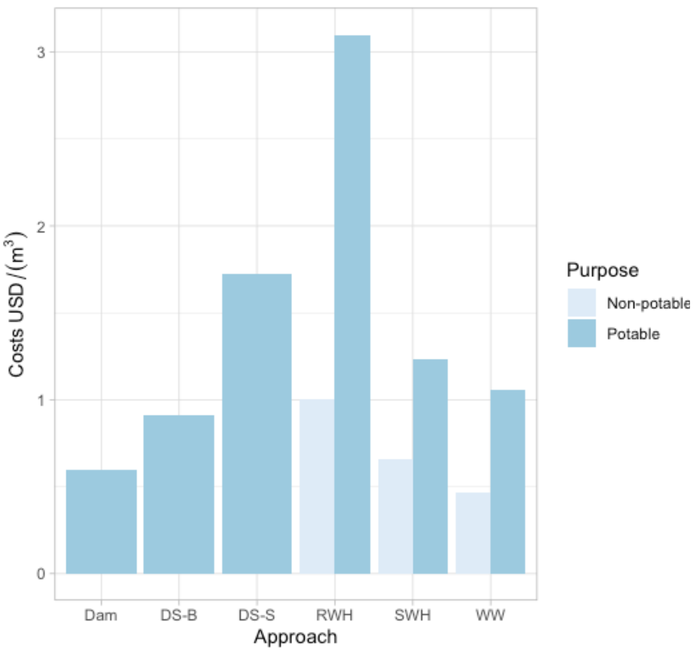


Figure 5-7: Overview of the costs of different approaches

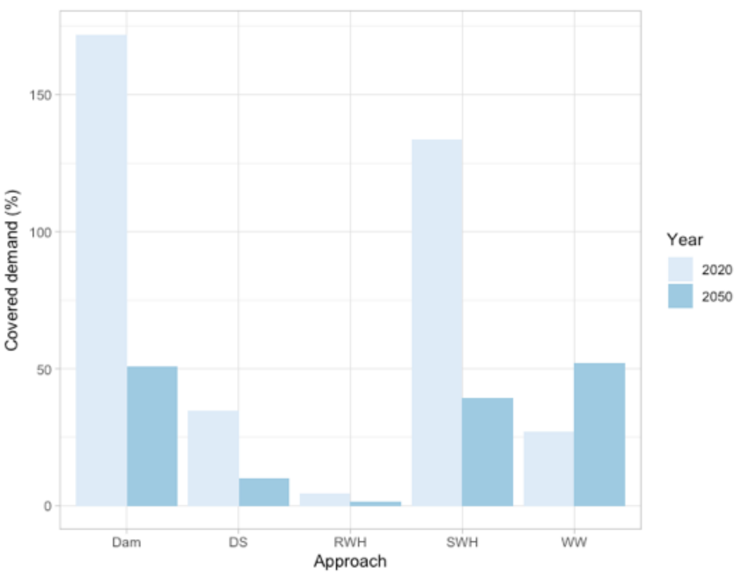


Figure 5-8: Covered industrial and domestic demand for the years 2020 and 2050 for different approaches

It must be noted that wastewater reuse and to a lesser degree stormwater harvesting and rainwater harvesting entail the introduction of a sewage network and wastewater treatment. The introduction of such systems have a tremendous positive impact on public and environmental health (Rose, 2000). Even though the initial capital costs of providing effective sanitation services can be high, the human and socioeconomic costs of under-managed and unmanaged domestic and industrial waste are also very high. In Peru, a cholera outbreak in 1999 resulted in an estimated loss of three times the expenditure of the country's water and sanitation budget for the following 10 years and in India a cholera outbreak in 1994 resulted in a loss in tourism revenue estimated at 200 million US$ (Rose, 2000).

Figure 5-9 shows where technical interventions can be implemented in the urban context. This flowchart must not be regarded as rigid, but more as plastic. The water sources (in blue) are followed by interventions discussed in *paragraph 5.1.2.* and *5.1.3*. The conventional approach and already practiced in Mozambique is on the right-hand side, here, dams are used to collect water from rivers, treat it in a wastewater treatment plant and provide this water to industries or households. Agriculture is excluded as it is mainly fed by precipitation and rivers directly. The interventions that use precipitation are rainwater harvesting and stormwater harvesting. Both techniques can be used to recharge groundwater aquifers and can also directly be used in agriculture (Hamdan, 2009). Harvested rainwater can also be directly used for some domestic and industrial purposes, but not for drinking. Stormwater needs an extra treatment step before usage in industrial or domestic purposes. Groundwater on the other hand can in most cases directly be used for all industrial, agricultural and domestic purposes (Carrard, Foster, & Willetts, 2019). Seawater needs to be desalinized before it can serve any purpose and can thereafter also be used to recharge underground aquifers.

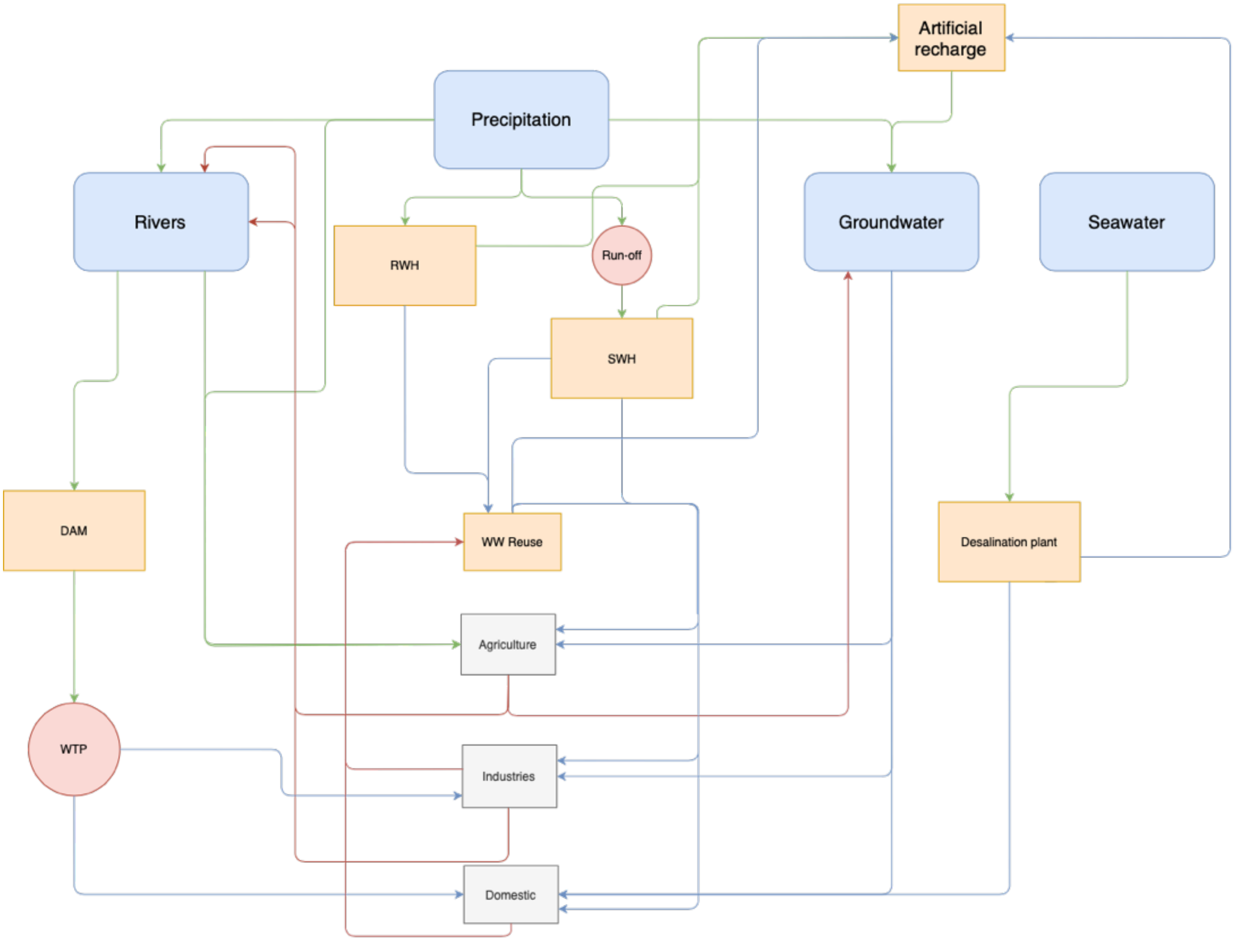


Figure 5-9: Overview of technical approaches to SUWM in the Greater Maputo Area. Green = Untreated water, blue =treated water, red = wastewater (source = author)

5.1.5. Institutional approaches

Decentralization

As can be read in *paragraph 3.2,* Mozambique's water sector remains highly centralized, even though efforts have been made to increase decentralization (Inguane, Gallego-Ayala, & Juízo, 2014). In the context of SUWM, decentralized water resources management is a crucial aspect for success (Inguane et al., 2014). From a historical viewpoint, centralised water supply systems have been unable to cope with rapid population growth, urbanisation and industrial water demand increase. Therefore, the implementation of a more local level water supply and treatment system can increase flexibility and efficiency (Bieker, Cornel, & Wagner, 2010). The semi centralized approach provides more flexibility in terms of planning and operation, reduces the investment and operational costs for supply and treatment systems, enables the strengths of high compact and reliable structures and proceedings, reduces emissions and ultimately enables a high efficiency in the use of resources (Böhm et al., 2011). Furthermore, local governments can forge new relationships with local authorities, national decision makers, and public and private sectors (Bahri, 2012). However, these decentralized systems come at a great capital commitment due to the grid that needs to be laid out (Bieker et al., 2010). Furthermore, decentralization of governmental organizations have shown to be able to control corruption, as expected bribes are lower (Carbonara, 1999).

Despite Mozambique's efforts to decentralize water resources management, the following political, institutional and socioeconomic constraints have been identified that hinder decentralization towards SUWM (Inguane et al., 2014):

- Mozambique's RWA's have not fully acquainted full autonomy, they are highly dependent on central support for human and financial resources.
- An institutional-legal guidance network to guide the implementation process of SUWM approaches is lacking. As a result, RWA's have been working as "isolated islands" on national water resources management.
- The lack of incentive from river basin water users to recognize their role as a source of revenue is a key limitation to sustainability of the RWA's. Especially given the limited financial support from the state.
- RWA's should develop more flexible interlinkages to benefit of their surrounding environment, unique characteristics and local actors and governments whereby avoiding a one-size-fit-all approach.

5.1.6. Socio-Political approaches – Demand side

As supply side approaches to increase water supply are usually met with resistance from opposition with regard to resource conservation, environmental protection, perceived risks to public health and green movements, demand side approaches are of increasing importance for many water companies (Lowe, Lynch, & Lowe, 2015). Urban water demand management (UDWM) is commonly divided in the following three categories: technical, economical and socio-political (Sharma & Vairavamoorthy, 2009). In general, consumers need incentive to conserve water, examples of such incentives are discussed in the economic and financial measures and socio-political measures (Deverill, Herbertson, & Cotton, 2001)

Structural and technical measures

These measures include NRW and leakage control, utilization of water-saving devices, water meter management and the use of alternative water resources as described before. In Maputo, NRW is about 35% of all water supplied (Sušnik, 2016a). In most developing countries the large amount of NRW is attributed to poor water meter management, meaning that water is actually used but not accounted for, and leakages from distribution mains and service pipes (Sharma & Vairavamoorthy, 2009). Reducing the amount of NRW poses the possibility to provide water to those who currently lack access and will ultimately result in a better financial situation, leading to financial self-sufficiency and long-term sustainability of the system (Sharma & Vairavamoorthy, 2009).

There is a growing body of evidence that it is cheaper, faster and better to increase water use efficiency instead of tapping into new sources of water supply for coping with a growing population (Savun-Hekimoğlu, Erbay, Hekimoğlu, & Burak, 2021; Sharma & Vairavamoorthy, 2009). When compared to other approaches, water conservation is the cheapest and largest source of water in urban areas (Haddad & Lindner, 2001). Approaches to make urban water systems more efficient include reducing the amount of water used in toilets and bathrooms and reducing leaks in the distribution system. As can be read in chapter 3, supplied water is going to increase over time and so are the absolute water losses when NRW is not decreased.

In the case of the Greater Maputo Area, total reduction of NRW results in an additional 72,450 m^3/day that is supplied. Not only is this water not lost, but it is also chargeable, resulting in an estimate of 35% increase in profit.

Economic and financial measures

Economic and financial measures aim at providing incentives to promote efficient use of water. Incentives such as rebates and tax credits and disincentives such as real costs, penalties and fines can be used to promote efficient use of water (Sharma & Vairavamoorthy, 2009). Full-cost water pricing is one of the most important approaches to control water demand. Full-cost pricing includes full supply costs, full economic costs and environmental externalities and aims at recovering the full cost of water supply, providing a steady basis for improvement and expansion. It is believed that full-cost pricing achieves a specified standard of services, for current and future generations (Wu, 2011).

However, especially in developing countries such as Mozambique it is of great importance to not deny the poor access to water by means of pricing. Which is also in line with the Dublin statement, where it is stated that water is not only an economic good, but also a social good, meaning that water should be affordable for the poor (ICWE, 1992).

It is stated that Mozambique's low domestic water access is not due to natural constraints, only to infrastructural and financial ones. At this stage, the poor people in the peri-urban areas pay higher prices, because the lack of a connection to the formal network makes them dependent on the free market, where water is much more expensive (Bhatt, 2014). Hence, improving Mozambique's urban water provision and assuring that services are safe, desirable and affordable, requires heavy investments. Water tariffs are essential for water managers to recover investment and O&M costs which are necessary to improve water provision. It was found for the peri-urban areas of Maputo, that for households with in-house access to piped water, in the ranges between 5 m^3 and 20 m^3 per month, the households that consume more, are the wealthier and the smaller (Farolfi & Gallego-Ayala, 2014).

Furthermore, three considerations to improve the *equity* of water pricing and tariff structure are provided (Farolfi & Gallego-Ayala, 2014):

- The current water tariff structure is not equitable enough due to the high fixed component of the two-part increasing block tariff system. The first block (up to 5 m^3/month) is the most expensive.
- The connection cost is too high, posing a giant barrier for poor households and thus posing a barrier to expansion of the network into unserved areas.
- Water demand analysis has shown that consumers that are currently using piped water are very sensitive to price changes. High prices for initial block rates and high averages prices due to a fixed component of the water tariff negatively affects water consumption, even at basic levels.

It is therefore recommended that those who can afford to pay economic prices (industries and more developed urban areas) should pay a high price, whereby cross-subsiding the poorer share of the society (Frone, 2012; Savenije & van der Zaag, 2002). Block-tariff is also an important factor towards equity in water supply, as the poor, who usually use less water than middle and high income families, can use water at lower tariff (Magnusson, 2004; Sharma & Vairavamoorthy, 2009)s. However, it should be noted that full-cost pricing and universal metering without complementary approaches such as education, leak detection and recycling, may not be very effective (Sharma & Vairavamoorthy, 2009). In advance, industries should be incentivised to utilize water-saving devices through tax credits or subsidies.

Socio-political measures

Socio-political measures play a pivotal role in ensuring the sustainability of UWDM programmes and are complementary to technical and economic measures. These measures include the legal framework and regulations that promote water conservation, educational programmes, awareness campaigns and demonstration projects (Franco-Torres, Rogers, & Harder, 2020). Top-down governmental policies, marketing and regulations should aim at promoting water-saving devices and water saving and water recycling in industries (Sharma & Vairavamoorthy, 2009).

Research has indicated that a key focus towards water conservation should be on changing consumer attitudes towards water consumption (Lowe et al., 2015). A social marketing campaign, combined with regulations on outdoor water use has led to a staggering decrease of household water consumption from 279 litres/person/day to 142 litres/person/day (Lowe et al., 2015).

For example, Singapore has been able to maintain NRW below 10% for the last 16 years. The main reasons for this success are (i) keeping NRW low, (ii) promotion of water conservation for consumers and (iii) the use of appropriate tariffs and economic incentives and disincentives (Sharma & Vairavamoorthy, 2009). Another example in Windhoek, Namibia showed that the use of adequate water pricing, information campaigns, legislation and technical measures led to a decrease in water demand from 201 L/person/day to 130 L/person/day between 1992 and 1999 (Magnusson, 2004).

However, without *good governance*, it will be difficult to achieve SUWM. Good governance is necessary to control water pollution, flood prevention and the effectiveness and efficiency of novel water supply approaches (Havekes et al., 2016). Especially since the global socio-political framework has been focussed on supporting conventional water systems, whereby neglecting valuable streams such as wastewater. (Brown, Sharp, & Ashley, 2006). In the case of the Greater Maputo Area, good governance is good urban governance. This is a multidimensional concept that is concerned with improving the living quality of local citizens, with special regard to those of marginalised and disadvantages communities and ultimately fosters social-political, economic and physical resilience in urban areas. Three dimensions of good urban governance exist. The first being *community participation and stakeholder involvement*, the *second effective urban management* and municipal administrations and the third being *council transparency and accountability* (Meyer & Auriacombe, 2019). The socio-political and institutional approaches that support SUWM, are provided in an overview in *figure 5-10.*

Figure 5-10: Factors contributing towards SUWM, adopted from: (Meyer & Auriacombe, 2019)

5.1.7. Environmental approaches

Environmental approaches to achieving SUWM, such as Nature Based Solutions (NBS) have the potential to underpin SUWM. NBS can manage, protect and restore natural or modified ecosystems. It is an multidisciplinary approach to combat societal challenges and natural hazards whilst providing human well-being and ecological benefits (Oral et al., 2020). The three main focuses of NBS implementation were found to be: stormwater management, water food-energy nexus whereby water is utilized for food and energy production and water pollution control. It was found that not only NBS are effective and efficient but are also widely accepted by people living in the proximity of such facilities. The most common methods to implement NBS are through Blue-Green Infrastructures (e.g., wetlands, river parks, rain gardens), open green spaces (e.g., urban parks) and at a building level through green roofs or green walls (Ramírez-Agudelo, Porcar Anento, Villares, & Roca, 2020).
However, a major hurdle for NBS implementation is the complexity of a comprehensive and coordinated approach, leading to social, technical, institutional and economic uncertainty. Especially in SSA, the lack of institutional and economic capacity remains a major barrier for NBS (Fluhrer, Chapa, & Hack, 2021; Ramírez-Agudelo et al., 2020).

However, as NBS have shown promising results in the Global North, it is most likely that NBS can also benefit cities in the Global South, especially considering the multifunctionality of Blue-Green Infrastructures. Multifunctionality means that Green-Blue Infrastructures provide a variety of benefits in the ecological, social and economic context (Fluhrer et al., 2021).

As stated before, one of the main pillars of NBS is urban pollution control. The most commonly applied NBS method in the urban context regarding pollution control are constructed wetlands (CW). Usually, wastewater is treated to protect downstream waters from contamination. The main principle of CW is to exploit natural materials such as plants, gravel and sand and naturally occurring processes in a controlled environment for water treatment purposes (Stefanakis, 2016). CW are especially useful for the treatment of rainwater, combined sewer overflow, greywater and the outflow of existing wastewater treatment plants (Oral et al., 2020). In the Greater Maputo Area, all types of wastewater are discharged directly into the Maputo Bay without any treatment, whereby posing risks to environmental and human health. If wastewater would be led through CW prior to dischargement into the Maputo Bay, environmental and human risks are most likely reduced (Oral et al., 2020). The coastline of Maputo city naturally consists of a large alluvial plain where large extensions of mangrove forests occur within the city. These mangrove forests are referred to as the Costa do Sol wetlands and are shown in *figure 5-11*. The existence of such large wetlands imply that the area is suitable for the construction of artificial wetlands. This is confirmed by research in the peri-urban areas of 3 SSA cities, including Maputo. It was found that CW, using replanted and rehabilitated mangroves, may have a lower cost than conventional sewage treatment (Beja da Costa & Faria Ribeiro, 2017). However, the areas where most wastewater is produced are usually densely built, meaning that these wetlands seem to be more applicable to the outskirts of urban areas. Another important consideration is that CW need to be built outside floodplains in order to avoid environmental damage (Sudarsan, Roy, Baskar, Deeptha, & Nithiyanantham, 2015).

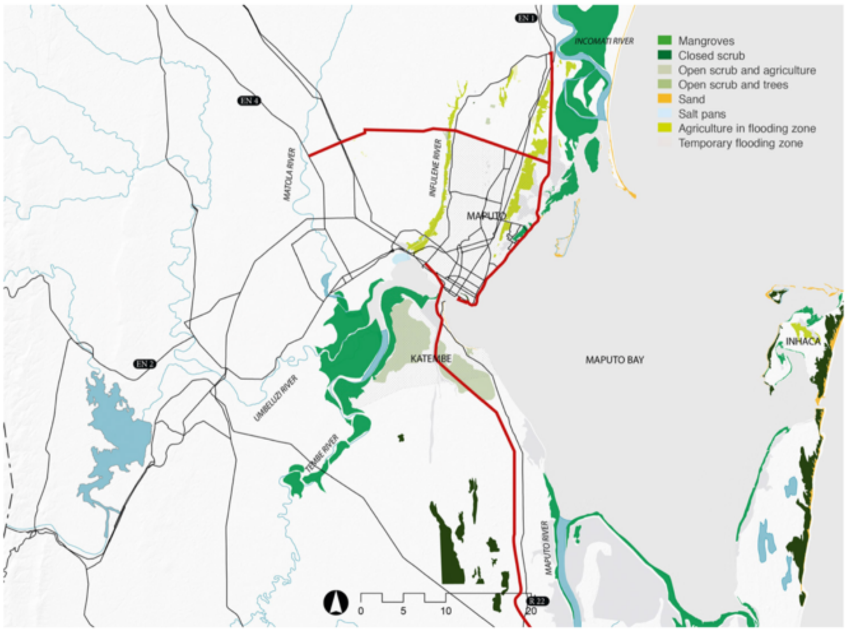


Figure 5-11: Location of wetlands/mangroves in the Greater Maputo Region (Beja da Costa & Faria Ribeiro, 2017)

Furthermore, CW are inextricably linked to the water-energy-food nexus (Avellan, Ardakanian, & Gremillion, 2017). Energy and/or food can be produced by plants growing whilst cleaning water passing through their root system. For example, research across several developing countries has shown that constructed wetlands that are used to treat *wastewate*r show the potential to provide sustainable bioenergy. It was found that the accumulated biomass achieved high densities, and could, converted to solid or gas fuel, even meet up to 55% of the cooking needs of the community they serve. Furthermore, the wastewater effluent, that has been treated through biological and physical processes in the rootzone of wetland macrophytes, can be used to irrigate (energy)crops (Avellán & Gremillion, 2019). Especially for the peri-urban areas in the Greater Maputo Area, this combination can be of use.

Key findings chapter 5

- Socio-technical systems such as sustainable urban water management are key for urban areas to adapt to climate change and realize resilience.
- Technical approaches to augment water supply and support SUWM are stormwater harvesting, rainwater harvesting, wastewater reuse, desalination and riverine reservoirs.
- An institutional approach that supports SUWM is decentralization, which can co-exist alongside the centralized system. Decentralized systems generally reduce operational costs, enables the strengths of high compact reliable structures and proceedings, reduce emissions and ultimately enable a high efficiency in the use of resources.
- Socio-political approaches can mitigate the supply-demand gap through demand reduction. I.e., through structural and technical measures such as leakage control, water saving devices, water meter management and the use of alternative water resources.
- The same goes for economic and financial measures, which aim at promoting efficient use of water through full-cost pricing, penalties and fines. Especially in developing countries, pricing should be fair in order to ensure access to the poor.
- In advance, nature-based solutions, such as constructed wetlands, have the potential to underpin SUWM. NBS approaches mainly concern stormwater management, the water-energy-food nexus and water pollution control.

Outlook

This paragraph has identified the technical, social and environmental approaches towards SUWM in the Greater Maputo Region. However, most of these approaches have been developed in the context of the Global North, therefore, implementation of SUWM in the Global South demands deep understanding and close engagement with local idiosyncrasies. Otherwise, it is expected that negative consequences, linked to time and resources during implementation, arise (Bichai & Cabrera Flamini, 2018). Furthermore, holistic solutions such as SUWM need to be handled with care, in terms of ensuring that the local citizens' interests and goals are taken into account, particularly in the Global South where top-down approaches led by donors and governments are common (Bichai & Cabrera Flamini, 2018). Especially since urban governments in SSA have the tendency to be disconnected from actual urban developments on the ground (Herslund et al., 2018). Furthermore, as can be seen in *figure 13*, urban (stakeholder) engagement is closely linked to good urban governance and stakeholder engagement is an important tool to develop broad-carried understanding of the context that is necessary to make SUWM related decisions (Megdal, Eden, & Shamir, 2017).

A myriad of methods to actively engage stakeholders within decision-making analysis regarding water management and urban planning exist. The most common methods include questionnaires and interviews (Jeffery, 2009). Since these methods are rigid in their dynamics and therefor hinder creative solutions, co-creation and are prone to bias, they are deemed not useful for the purpose of this report (Alshenqeeti, 2014). Studies have indicated that *Serious Gaming* is a promising method to enhance social learning between stakeholders and provide the context that is necessary to make decisions that support sustainable water management (Medema, Furber, Adamowski, Zhou, & Mayer, 2016; Sušnik et al., 2018). Therefore, this report will adopt Serious Gaming as *the* method to engage with stakeholders. Serious Gaming is very functional to the purpose of this report as it bears the opportunity for stakeholders to actively engage in- and try to solve the problem that is at the core of this report.
In order to do so, in the next chapter a serious game that mimics the integration of SUWM approaches is developed.

6. Multi-Criteria Decision Analysis

Due to the complex nature of water resources management, this chapter aims at integrating multiple criteria, models and data sources into MCDA in order to select and identify new water supply infrastructure for the Greater Maputo Region (Amorocho-Daza, Cabrales, Santos, & Saldarriaga, 2019). MCDA methodologies have been utilized in multiple sustainable water management applications. For example, urban drainage planning, sustainability of water resources and wastewater infrastructure and planning (Amorocho-Daza et al., 2019). MCDA provides insight into the trade-offs and benefits of different water supply alternatives through a quantative approach (J. Cole, Sharvelle, Grigg, Pivo, & Haukaas, 2018). For the purpose of this paper, a MCDA framework that considers economic and non-economic criteria. In this way, social and environmental criteria can be integrated more easily (Amorocho-Daza et al., 2019). In this chapter, first the framework is explained and hereafter, the framework is used to analyse the situation in the Greater Maputo Region. This MCDA interacts with the serious game in *chapter 7*. As both methods ultimately provide a scenario. This chapter statistically analyses the "most suitable" options to augment the Greater Maputo Region's water supply whereas *chapter 8* does so by involving stakeholders and their preferences. The differences between those two methods provide insight between what is technically possible and locally acceptable.

6.1 Framework

In order to conduct a thorough MCDA, the framework from Amorocho-Daza et al. (2019), is followed. This framework is especially designed for the decision analysis of water supply systems. *Figure 6-1* summarizes the framework of the MCDA methodology. In this section, all the steps of the framework are discussed.

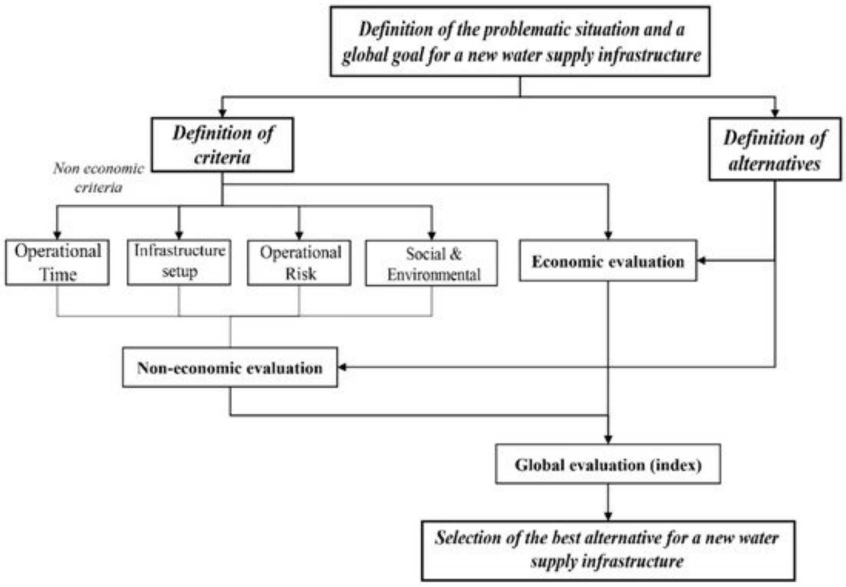


Figure 6-1: Overview of MCDA methodology (Amorocho-Daza et al., 2019)

6.1.1. Definition of the Problematic Situation and a Global Goal for New Water Supply Infrastructure

The first step in this approach is to describe the context, scope and boundaries of the drinking water problem. It is suggested that three principles must be met to obtain the correct decision-making context:

1. The decision context must capture the current situation
2. The decision ownership must match the decision context
3. The feasibility of the study

Besides these principles, it is also recommended that the current water supply infrastructure is evaluated and the same goes for current and future water demand. In this report, *chapters 3 and 4* describe the current status of infrastructure and current and future demand.

6.1.2. Definition of Criteria

In this section, the criteria against which the performance of the system is going to be assessed is defined. The most common approaches consider environmental, social, technical and economic aspects. These criteria are separated as economic and non-economic criteria.

Non-economic Criteria that are used are defined as infrastructure setup, operational risk, operational time and socio-environmental criteria. These criteria try to capture the complexity of these systems and their different trade-offs. *Infrastructure setup* refers to the operational characteristics of different alternatives. In this criterion, the distinction between centralized systems or decentralized systems become evident. For example, a centralized system with few treatment plants is easier to manage than a decentralized system with a lot of different components. *Operational risk* is defined as the risk of losses arising from problems from internal controls, systems, people and external event. With regard to water supply systems, the criterion is concerned with the reliability of a system to extract sufficient water from water sources. In developing countries such as Mozambique, the criterion also concerns the risk of sabotage to the system. As an example, the risk of water losses due to theft is proportionally related to the accessibility of the pipelines to the population. *Operational time* refers to the time that it takes for an innovation to be constructed and connected to the water supply system. Especially in developing countries this is of importance, as the current infrastructure is usually lacking capacity. When an innovation takes a long time to be constructed, that means that the deficit in water supply will be present for a longer time. *Social and environmental impacts* of water supply infrastructure should be revised solely. However, a common approach is to minimize the impact of the project in social and environmentally protected areas.

6.1.3. Economic evaluation

Besides the above discussed assessment, the respective costs of water supply alternatives should be evaluated. Costs can be calculated by a myriad of different methods and for this report, the present value of the costs is (PVC) is used. This method included both operating and construction costs. The main operative costs are usually pumping and treatment equipment. However, the variety of water sources, treatment, geographic conditions and general planning represent the difference between alternatives.

6.1.4. Definition of Alternatives

Hereafter, the alternatives that can potentially mitigate the problem that is core to the MCDA are to be determined. These alternatives should be feasible and suitable considering the economic, social and environmental restrictions. It is recommended that these alternatives are discussed with different stakeholders to allow for optimal diversity and relevance. When the alternatives have been defined, they are analyzed against the criteria defined earlier.

6.1.5. Non-Economic Evaluation

Due to the complex nature of non-economic criteria, the decision-making process is to be supported by a MCDA model. The selection of a model should best be performed via agreement amongst stakeholders. In that way, stakeholders are satisfied with the way in which the model operates. The results from the MCDA should be presented in a ranking of the alternatives. Optionally, a sensitivity analysis can be performed to determine the robustness of the decision model.

6.1.6. Global Evaluation

For each decision, positive and negative aspects are psychologically interpreted in the form of benefits and costs. As this is not easily directly performed, a formula consisting of benefits (B) and costs (C) is utilized to do so.

$$I_i = (1-w_C) \cdot B_{Ni} - w_C \cdot C_{Ni}, \ \forall \ i \in A$$

Here, I_i is the value of the index for alternative i; w_C is the weight given to the costs; B_{Ni} represents the normalized benefits; C_{Ni} represents the normalized costs for alternative I, respectively; and A is the set of alternatives. The range of the performance index varies between -1 and 1.

6.2 Application of MCDA framework to the Greater Maputo Region

Here, the framework that is described in *paragraph 6.1* is applied to the situation of the Greater Maputo Region. The stakeholder dialogue that is recommended throughout the framework has been conducted in *chapter 5* and the results hereof are assimilated within the MCDA.

6.2.1. Definition of the Problematic Situation and a Global Goal for New Water Supply Infrastructure

An elaborate description of the problematic situation of the Greater Maputo Region can be found in *chapter 3 and 4* of this report. A briefer description is therefore provided.

The problem that is core to this report is that by the year 2050 the Greater Maputo Region faces a deficit of 850,000 m^3/day in its water supply. Furthermore, the current infrastructure does not extend beyond the city center and is outdated.

6.2.2. Definition of Criteria

Table 6-1 provides an overview of the selected criteria. The ultimate goal of the MCDA is at the highest point in the hierarchy. Level 2 of the hierarchy describes the main non-economic criteria, level 3 the sub-criteria within each main criterion and level 4 the second level of the sub-criteria from level 3.

Table 6-1: Overview of criteria

Goal	*Criteria*	*First Level Sub-Criteria*	*Second Level Sub-Criteria*	*Description*
Find the best alternative of new water supply infrastructure for the Greater Maputo Region	Infrastructure setup	Ensure operational ease	Keep the number of WTP at a minimum	Number of WTP and its required expansions
			Keep the number of pumping stations at a minimum	Number of pumping stations required
		Provide the possibility to have future expansions		Possibility to have expansion options after 2050
	Operational risk	Ensure system reliability		The relation between the minimal river flow rate and demand in 2050
		Reduce system vulnerability	Reduce network maximum pressure	Estimated network pressure
			Increase the number of water conduction lines	Conduction lines required by the alternative
		Reduce the risks of losses during adduction		The risk of water adduction is proportional with the access to the pipelines
	Operational time	Reduce time for operation beginning		Time in which the first stage of alternative will be in operation
		Reduce time to meet water demand		Time in which the demanded water is equal to the water supplied in the city
	Social and environmental	Minimize influence area at Nature Reserves		The intersection area between a 100 m influence area of the alternative route and the area of the Nature Reserves
		Reduce environmental impact	Energy consumption	The amount of electricity per unit of potable water
			Reduce percentage of water withdrawn	Relation between ecological flow and flow withdrawals
			Reduce polluted run-off	The relation between run-off from the streets into the environment and different alternatives

		Guarantee bringing water to peri-urban areas		Ensure that the peri-urban areas are served save water

6.2.3. Definition of Alternatives

Here, the alternatives are defined. The purpose of these alternatives is to enhance the potable water supply in the Greater Maputo Area. It must be noted that a lot of values here are assumptions. This is mainly due to the lack of research on these methods in Mozambique or let alone, the Global South. Furthermore, all approaches are regarded to be treated up to potable standards, for comparison reasons. In advance, not enough potable water is available currently and even though some approaches can be used to augment potable water demand, that distinction is regarded beyond the scope of this MCDA.

Table 6-2: Definition of alternatives; 1 = (Al-Karaghouli & Kazmerski, 2013) 2= (Vieira, Beal, Ghisi, & Stewart, 2014)

Alternatives						
	A1	A2	A3		A4	A5
Approach	Stormwater harvesting	Rainwater harvesting	Desalination		Wastewater reuse	Dam
Time for operation beginning (years)	3	2	3		4	12
Percentage of demand (-)	37	1,5	30		61	60
Water source	Precipitation (streets)	Precipitation (roofs)	Indian Ocean (Saline)	Maputo Bay (Brackish)	Households Industries	Rivers
New PTWP	2	2	1	1	2	1
Number of expansions	0	0	3	3	0	2
New treatment capacity 2050 (-)	20	1	10	10	30	20
Number of pumping stations	10	8	8	8	6	5
Possibility of future expansions	No	No	Yes	Yes	No	Yes
System reliability (-)	0,5	0,4	0,9	0,7	0,8	0,8
Number of conduction lines	5	6	3	3	5	3
Pipeline length in populated area (km)	120	120	90	70	70	50
Conduction line length (Km)	150	150	110	90	90	110
Share of freshwater resources withdrawn (0-1)	0	0	0	0,1	0	0,5
Reduction of polluted run-off into the environment (0-1)	1	0,5	0	0	0,3	0
Energy consumption (kWh/m^3)	2,5	1,4[2]	5[1]	2[1]	3	1,5

6.2.4. Non-Economic Evaluation

In order to perform the non-economic evaluation of the alternatives, analytical hierarchy process (AHP) is utilized (Saaty, 1987). AHP considers both objective and subjective criteria during the decision-making process. With AHP, a problem is represented using a hierarchical structure, this helps in understanding how the alternatives and criteria interrelate in relation to the problem (Amorocho-Daza et al., 2019).

The hierarchy that is used in AHP can either be determined by the author or by stakeholders involved. For this report, it was chosen to involve stakeholders through the serious game in chapter 7. The results of a post-game questionnaire hereof represent stakeholders' preferences and priorities regarding the 4 criteria. Based on this, the ranking in *figure 6-3* was determined.

Table 6-3: Criteria ranked

Position	**Criteria**
1	% Demand
2	New Treatment Capacity
3	Reduction of Environmental Impact
4	Reliability
5	Construction Time
6	Energy Consumption
7	Urban Pipeline Length
8	Future expansions
9	Share of freshwater
10	Number of expansions
11	Conduction Line
12	New PTWP

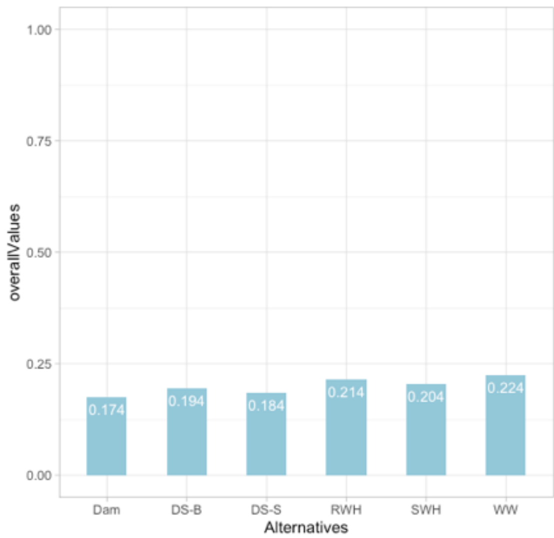


Figure 6-2: Non-economic evaluation

In order to perform the AHP, *table 6-1* was loaded into RStudio and hereafter, the hierarchy as stated in *table 6-3* was added accordingly. The RStudio 'MCDA' package was utilized in order to perform the AHP (Bigaret, Hodgett, Meyer, Mironova, & Olteanu, 2017). The function that performs the AHP creates a pairwise comparison. The first within each level and secondly among levels, whereby determining the preferences of stakeholders (Amorocho-Daza et al., 2019). The results hereof are provided in *figure 6-2*. It becomes evident that 3 alternatives stand out: stormwater harvesting, rainwater harvesting and desalination of brackish water. Most likely because of their sustainable aspects. What also stands out is the 'missing' bar for the dam. This is most likely due to the long construction time and environmental impact, which are ranked high in the hierarchy.

6.2.5. Economic evaluation

In this section, an estimation of annual and construction costs is provided. It must be noted that especially the construction costs are an estimation, as it is beyond the temporal and spatial scope of this report to determine costs of transportation, excavation, pumping stations and PWTPs exactly. *Therefore, the most important aspect of figure 6-4 is not so much the absolute costs, but the ratio between the different alternatives.* This was opted due to the high volatility of such calculations and the high influence of local context.

The costs of saline desalination are determined by using available data on existing plants in Australia and the Middle East. The capacity of this desalination plant is 136,000 m^3/day (Advisian, 2013). Due to a lack of data regarding large-scale alternative water supply infrastructure, extrapolation was used to determine the cost of the alternatives. This is done by using a cost analysis of estimated average costs of stormwater harvesting, brackish desalination and wastewater reuse to extrapolate the cost of saline desalination to the corresponding alternatives (Cooley et al., 2019a). Furthermore, all costs have been determined over a 50-year period

Table 6-4: Rough estimation of the costs of different alternatives

Alternatives	*Treatment costs (US$/year)*	*Pumping costs (US$/year)*	*Variable Costs (US$/year)*	*Construction costs (US$)*	*Total costs over 50 years (US$)*
Stormwater harvesting	5,254,884	2,252,093	7,506,977	55,813,953	431,162,791
Rainwater harvesting	3,678,419	2,252,093	5,930,511	66,976,744	363,502,325
Desalination Saline	15,871,000	11,029,000	26,900,000	200,000,000	1,545,000,000
Desalination Brackish	6,174,128	6,174,128	12,348,256	200,000,000	817,412,791
Wastewater reuse	11,642,641	2,587,253	19,404,402	314,285,714	1,284,505,814
Dam	3,678,419	2,694,767	4,070,853	65,934,065	269,476,744

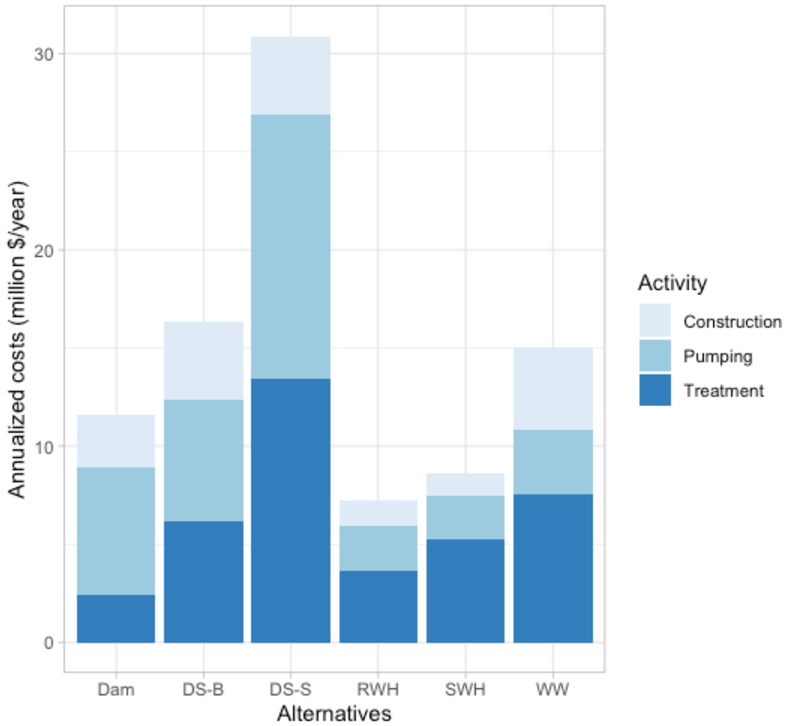


Figure 6-3: Overview of annualized costs of different alternatives

What becomes evident from *table 6-4* and *figure 6-3* is that desalination of saline water and wastewater reuse are the most expensive options. For both options it becomes evident that especially treatment costs are high for those water sources. This is most likely due to the amount of treatment necessary to treat water from those sources to potable standards.

6.2.6. Global Evaluation

Here, the alternatives are analyzed regarding their economic and non-economic criteria. First, the economic and non-economic scores (AHD) are normalized on a scale from 0-1. Hereafter, the formula from *paragraph 6.1.6* was used to calculate the performance index for each alternative. *Figure 6-4* depicts the performance index for the alternatives. In this graph, the weight assigned to the cost is varied along the range. The alternative with the highest performance index is the best among the group at a certain weight of cost.

Low weight of cost (<0,5)

It becomes evident that wastewater reuse is the most suitable approach when the weight of the cost is less than 0,21. When the weight of the cost is more than 0,21, rainwater harvesting and stormwater harvesting are the best approaches to augment the Greater Maputo Region's water supply regarding the above-named criteria. This is due to the high treatment cost of wastewater reuse. Hereafter, desalination of brackish water is the 4th best option when the weight of the cost is lower than 0,5. This is due to the environmental impact of the brine and high energy consumption. Furthermore, saline water desalination ranks lower than brackish due to the higher energy consumption but is still more suitable option than dams until the weight of the costs exceeds 0,18.

High weight of cost (>0,5)

When a higher weight is attributed to the cost of alternatives, rainwater harvesting still ranks as the best approach for the Greater Maputo Region. Rainwater harvesting is closely followed by the use of dams and stormwater harvesting. Stormwater harvesting is ranked lower due to the higher level of treatment required and dams because of its higher environmental impact. Hereafter, wastewater reuse is the approached that is ranked 4th, even though being the most suitable when the weight of the cost is low. Desalination of brackish water is ranked as 5th, due to the high costs and environmental impact. And at last desalination of saline water, likely due to the high cost, electricity consumption and environmental impact.

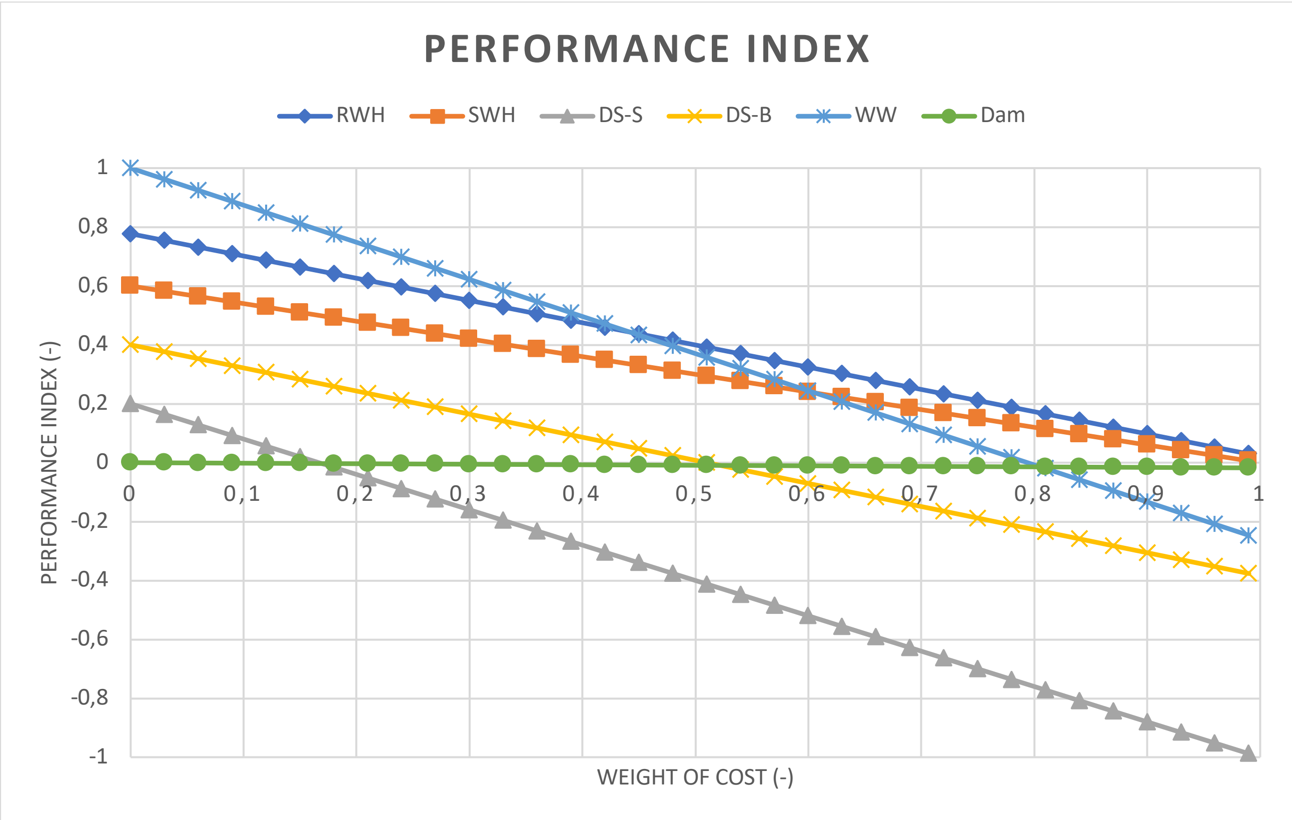


Figure 6-4: Performance index of alternatives

Key findings chapter 6

- The criteria used for multi-criteria-decision analysis are **economic** and **non-economic**
- Non-economic criteria cover **operational time** and **risk**, **infrastructure setup** and **social** and **environmental** aspects.
- The **non-economic evaluation** showed that **wastewater reuse** is the most promising approach, followed by rainwater harvesting, stormwater harvesting, desalination of brackish water, dams and desalination of saline water.
- The performance index that represents both economic and non-economic criteria shows that when the weight of the cost is **below 0,5**, wastewater reuse, stormwater and rainwater harvesting are the best options. When the weight of the cost is **higher than 0,5**, rainwater harvesting, dams and stormwater harvesting are the best options respectively.

Outlook

In this chapter, the technical approaches that were identified in chapter 5 have been analyzed using multi-criteria decision analysis. Now, the different approaches can be "ranked" according to this model. In the next chapter, a serious game is developed that allows stakeholders to develop their own scenario of these approaches. Ultimately, the difference between the computed scenario and the stakeholder scenario enlightens the factors that are necessary for success in the Greater Maputo Region.

7. Serious Game

In this section, a method is sought to incorporate stakeholders' preferences and opinions into decision analysis, provide a platform to educate them about the problems and solutions investigated in this report and ignite discussions amongst stakeholders to find creative solutions. Furthermore, the aim is to be sure that no aspects are left unregarded throughout this report and therefore the game should function as a safe area where stakeholders can share their ideas and opinions, which can be added into the framework in *chapter 8* if they were not yet considered.

A number of different definitions for Serious Games exist, however, for this report the following is used: *Serious Games are games that engage the user and contribute to an achievement of predefined objectives* (Susi, Johannesson, & Backlund, 2007). Serious Gaming is becoming more and more popular as an alternative method for education and training, for example for government entities, businesses, medical training, urban development, natural resources and the military (Bathke et al., 2019; Breuer & Bente, 2010; Mayer, 2009).

Water systems planning and management share the same roots with gaming, as they both rely on concepts in systems analysis, operations research and decision sciences (Savic, Morley, & Khoury, 2016). Furthermore, water resources management has often been described as a 'wicked' form of planning, due it's interactions amongst sectors (Hurford, Huskova, & Harou, 2014). Especially sustainable urban water management is a complex process, as it is concerned with human, technical and environmental interests. Furthermore, it involves the development and implementation of plans, projects and programs that sustain and enhance functions throughout the whole water system whilst considering of social, natural, political, economic and institutional factors within the system (Bathke et al., 2019). Examples of such factors include crosscutting mandates across different governmental levels, opposing interests between different sectors and the trade-offs between different water resources (Bathke et al., 2019). Serious Gaming can aid in sharing knowledge and aligning local stakeholders, disciplinary experts and policymakers.
Serious Gaming has been shown to be very effective for policy designers since it provides them with an analytical method to anticipate the impact of new interventions. The main advantages herein are that actor's initial assumptions, decisions and feedback mechanisms are revealed, consequences of mechanisms over time that would occur with a long delay in real-life are now demonstrated within the game and a risk-free environment is created where in actors can experiment freely (Mayer, 2009; Olejniczak, Wolański, & Widawski, 2018).

In serious game design, two different approaches exist, the first being process-oriented and the other being outcome-focused. The first mainly focuses on 'discovery', whereby providing new and different insights thus is ideal for decision-making. The second focuses more on education, as in learning essential skills through simulation. For the purposes of this report process-oriented gaming is chosen (Serious Games At Work, 2020).

In this report, the game design framework from *figure 6-1* will be used and modified to develop the game for the purposes of this report (Duke, 1980). Therefore, the steps from this framework will be followed accordingly to develop the design of the game. In game design, the four most important basic elements are the mechanics, story, aesthetics and technology, all equally important (Schell, 2008). Therefore, these will be incorporated in the framework in *figure 5-11*. In advance, an overall theme needs to be determined before the design process, in that way the basic elements and steps in the design process will support and reinforce each other (Schell, 2008). For the purpose of this report the theme of the game design and play is 'urban water supply', and this theme will be considered throughout the whole design process.

Figure 7-1: Serious game design (Duke, 1980)

7.1 Gaming objectives and desired outcomes

First, it needs to be ***determined what the games objectives and desired outcomes*** are. In this report the serious game is used to optimize the multi-criteria decision analysis in chapter 6 with local knowhow. Therefore, the objective of the game is broadly stated as the need to understand why stakeholders favour certain solutions over other solutions. This objective is broken down into sub-objectives in *table 7-1*. *Figure 7-2* shows how the results of the previous paragraphs lead up to the design of the serious game.

Table 7-1: Objectives Serious Game

Objectives Serious Game
Understand stakeholder priorities on demand
Understand stakeholder priorities on supply
Determine stakeholder favoured solutions
Understand why stakeholders favour certain solutions above others
Opinions on forecasting
Identify possible trade-offs between sectors
Compare the results of the serious game with the results from the MCDA

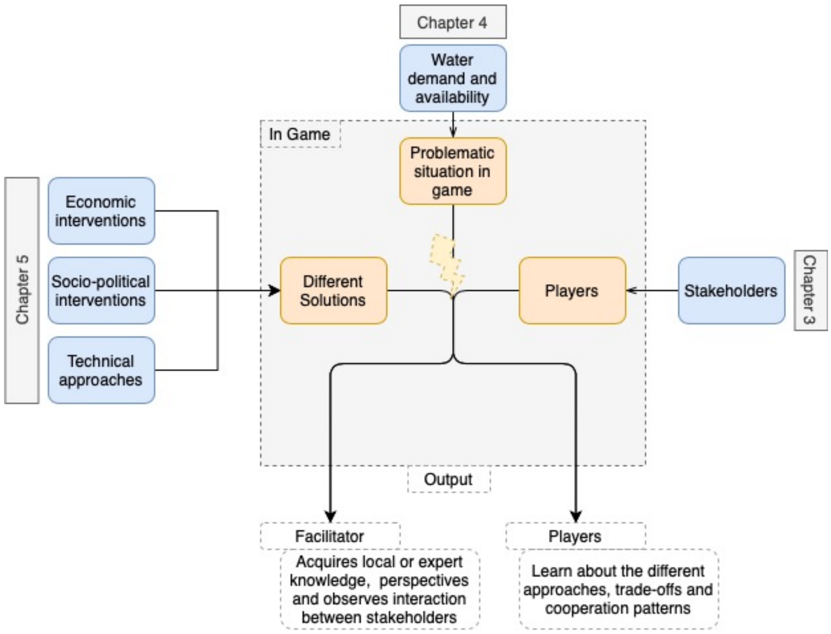


Figure 7-2: Pathway towards the serious game

Once the objectives have been stated, it needs to be determined how these are going to be achieved. In order to do so, ***the problems that players solve during game play*** are to be described. It benefits the gaming-experience and outcomes if the design process starts with a problem instead of a proposed solution as a broader creative space can be explored (Schell, 2008).

In this game, the problems that the players will be trying to solve are a combination of increasing pressure on water resources over time, the trade-offs of different solutions, the need for long-term planning and water demand over different sectors. The increasing water demand on water resources is used to mimic urbanization and economic development. Furthermore, a decreasing amount of 'natural' water is used to mimic climate change. Players will also experience those different solutions and allocations have different outcomes. For example, dams can be a quick but expensive solution, but the question is: are they more sustainable than for example a wastewater reclamation plant. Solutions will be different in terms of parameters: maintenance costs, construction time and costs, efficiency and operational energy demanded. Therefore, players will have to consider all of those different parameters whilst allocating water in the game and include it in considerations for prioritizations and long-term planning. Moreover, decision-making is very important in this game its conclusions.

After the game, the results from the serious game can be verified by through the MCDA results in the previous chapter. Both methods provide scenario, the first through computational analysis and the second through stakeholder participation and serious gaming.

7.2 Planning of the game elements

Hereafter, ***the game elements are planned***. Games and simulations are developed using 12 different elements, these will be adopted and specified for this report (Duke, 1980).

1. *Scenario*
   The scenario is basically the text outlining the plot of the game, including starting positions and circumstances. In this case the scenario is the current situation in Maputo, simplified. However, explaining the social, institutional, environmental and technical circumstances. Furthermore, roles are defined in this section. The roles that exist in the game, are based on roles that are present in current water managing roles in Maputo. The roles to be used are laid out in *figure 9*, with extra roles available for industry and a non-governmental organization.
2. *Pulse*
   This entails the problem, or problems in more complex games, that grasps the player's attention. It can either be random, player-introduced or designer-introduced. In this game, the pulse starts directly at the start of the game and is thus designer-introduced. The starting pulse is the population that needs water to survive and for which the players are responsible. This pulse continues throughout the game. More pulses start throughout the game, population will increase, and less water will be available.
3. *Cycle sequence*
   Here, it is explained which cycles exist within the game. These can either be micro or macro cycles. Macro cycles describe the preconditions to the game, meaning the introduction, final cycle and evaluation regarding the total exercise. *The macro cycle* in this game will be that of an introduction wherein the case of Maputo and the rules of the game are explained. Hereafter, in the final cycle it will be calculated if the teams 'won' their own goals and the common goal. At last, evaluation forms/talks will show if the players learned what was meant to be learned through the game. These forms/talks will also ask for opinions on the game and the situation. *The micro cycle* entails all other cycles within the game, in this case that basically means what happens in each gaming round. In this game players will experience the following steps in each gaming round; players make specific decisions, these decisions are then implemented, the players need to evaluate new situation and decide on next steps.
4. *Steps of play*
   Steps of play provide the basic guidelines for progress during the game. In this game the steps of play are defined as follows: each round mimics a period in time (+/- 1 year), herein decisions are made and the consequences of these are presented. Each time period a player can increase its water efficiency and serve more people or lose efficiency and/or people served.
5. *Rules*
   A variety of circumstances in the game that go beyond the scope of the players can arise. These are to be defined at the start of the game.
6. *Roles*
   Roles are characters that are assigned to players with a predefined behavior. In this game, 'gamed roles' are applied as these represent the real-world roles and are built into the games framework. The roles are derived from *figure 9* and are randomly assigned prior to the start of the game. Players will not play their own role in real-life, as this allows players to see the problem from a different angle, which allows for creative solutions and insights.
7. *Model*
   Models are used to keep track of logical processes within the game. These can either be heuristic, iconic or analogue. This game is characterized as an iconic model, since it is a board game and follows it follows a given system (Maputo water system) (United States Department of Defense, 2020).
8. *Decision sequence and linkage*
   This section basically described how players interact amongst each other and how their actions interact with the accounting system. In this game, players (characters) will have to find solutions and allocate water together. Some players will have more to say than others, depending on their character. Some will have the power to abstain certain solutions, veto certain solution and/or withdraw money for certain solutions. Players will negotiate, acquire the needed funds and implement and plan solutions and allocate water. These solutions can have effects on the water accounting system and work towards the goals. Normally, a matrix is used to coordinate decisions, however, in this game more freedom will be provided in order to stimulate creativity.

9. *Accounting system*
The accounting system is a fixed method to follow and quantify player's decisions. In this game a certain amount of water needs to be delivered to different sectors. The amount that needs to delivered will increase over time to mimic population growth and economic development. These values will be incorporated into the gaming board or on a separate sheet. After each round, after discussion, the new solutions and allocations are quantified by the moderator. This will indicate if the set values are met or not. Ultimately, the values for 2050 should be met in order to win the game.
10. *Indicators*
These are the aspects of the accounting system that are enlarged for players to focus on. The moderator determines what is indicated by these.
11. *Symbology*
This indicates the visibility of the indicators. So, for this game it is opted to use small plastic or wooden droplets of water. The color of these chips will indicate for a certain amount of water.
12. *Paraphernalia*
As the game is developed for online purposes, no paraphernalia are required besides a computer and internet access.

7.3 Construct the game

Temporal scale
First, it must be determined what temporal scales (each time period is one playing round) are utilized. For the purpose of urban planning, it is common to use a semi-logarithmic time scale. Especially because a quasi-logarithmic scale forces the players to switch between short-term planning and long-term planning in different playing rounds. The quasi-logarithmic time scale is depicted in *figure 7-3.*

Figure 7-3: Time scale serious game

Data represented in the game
In order to be easily playable, the data that is represented in the serious game is to heavily simplified. This is done by dividing the demand and availability found in *chapter 4* by a factor 10e7. The simplified data is presented in *table 7-3 and figure 7-4.*

Table 7-3: Simplified water demand and availability over time

	Demand			Availability			Deficit in the game
	Domestic *(m^3/year)*	Industries *(m^3/year)*	Agriculture *(m^3/year)*	SW *(m^3/year)*	GW *(m^3/year)*	WW *(m^3/year)*	(excluding WW) (m^3/year)
2020	5	3	17	9	2	9	14
2021	6	3	18	9	2	10	16
2024	6	4	18	12	2	11	19
2033	10	8	23	17	2	16	22
2050	19	23	27	17	2	37	50

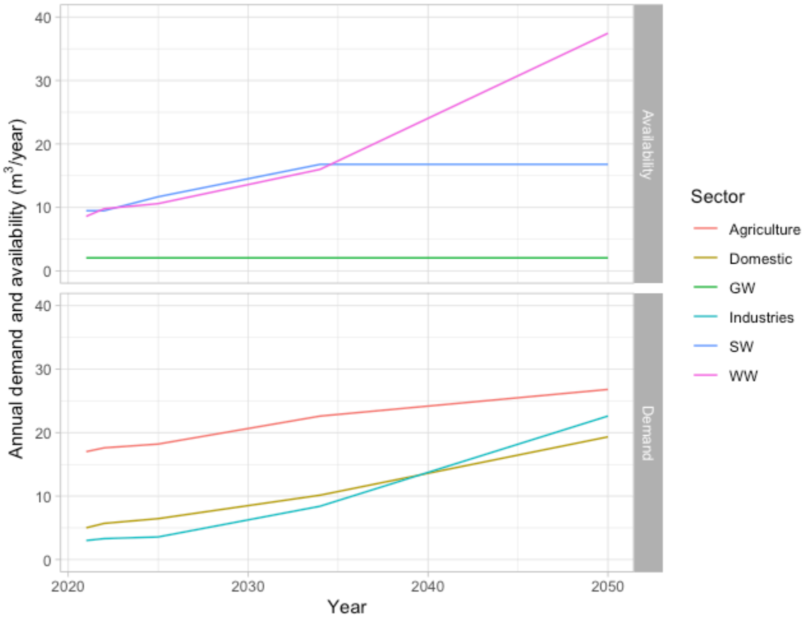


Figure 7-4: Simplified availability and demand

Characters represented in the game

Aiming to acquire useful data and opinions from the serious game, the whole spectrum of stakeholders in the Greater Maputo's water sector should be represented. In *chapter 3.2*, the institutional framework of the water sector in the Greater Maputo Area is elaborated on. *Figure 3-4* precisely depicts which institution is responsible for what and thus which institutions are to be included in the game design. However, experience has learned that the number of players during an interactive serious game should be limited to 8. Therefore, it is not possible to include all institutions from *figure 3-4*. Besides the limited number of players, too much overlap between characters is to be avoided. Furthermore, the characters in the game are not given the same name as the Mozambican institutions, therefore, not all characters from *figure 3-4* need to be included.

Function	***Real-life institutions***	***Referred to in the game as***	***Responsible for***	***Other goal***
Urban water supply	SSIP's ADeM	Water supplier	Main water supplier in the Greater Maputo Area responsible for management of potable water system operations.	Become financially stable.
Funding holder	FIPAG	Water fund	Investment in and maintenance of water supply infrastructure, expansion of the network and production of potable water.	Serve as many people as possible
Regulation of water services	CRA	Water regulating council	- Protect consumers - Regulate service quality - Improve cooperation - Approve tariff changes	
Southern regional water authority	ARA-Sul	Regional water authority	- Protecting ground water	Ensure a high level of sustainability.

			- Protecting surface water reservoirs	
Local government	Municipality of Maputo, Boane and Matola	Municipality	- No direct involvement in water supply - Water quality checks - Responsible for urban planning	Construct more houses.
Civilians	Agriculture, industries and households	Consumer	- Economic growth - Public health	Have a high economic growth.

Table 7-4: Characters to be included in game design

The stakeholders in the Greater Maputo Area are not limited to the above. There are the consumers across different sectors such as agriculture, households and industries, each with their own interest regarding water resources. These are represented in the game as one character and their main goal is to be sufficed in their water needs in order to ensure economic growth and public health. The colors in *figure table 7-4* depict the different 'purposes' of the organizations. Character cards are to be found in *figure 7-5.*

Figure 6-5: Character cards (source: author)

Interventions used in the game design

The cards that players can use to try and mitigate the supply demand gap in the game, are based on values derived from *chapter 5* and shown in *figure 7-6*. During the online game the option to use potable or non-potable for the interventions is given against a set additional price. Obviously, this is not possible for wastewater and desalination, as its quality is either too high or too low.

Table 7-5: Costs of different types of approaches. DS-B is desalination of brackish water and DS-S of seawater, prices have been tweaked for gaming purposes (Cooley et al., 2019a)

Approach	*Treatment*	*$/m3*	*Sustainability (scale 0 to 1)*	*Max yield*
SWH	Non-potable	0,7	1	19,6
	Potable	1,2	1	19,6
RWH	Non-potable	1	0,8	0,7
	Potable	3,1	0,8	0,7
WW	Non-potable	0,5	0,8	0,9
	Potable	1,1	0,7	0,9
DS-B	Potable	0,9	0,1	NA
DS-S	Potable	1,7	0,2	NA
Dam	Potable	0,3	0,4	NA

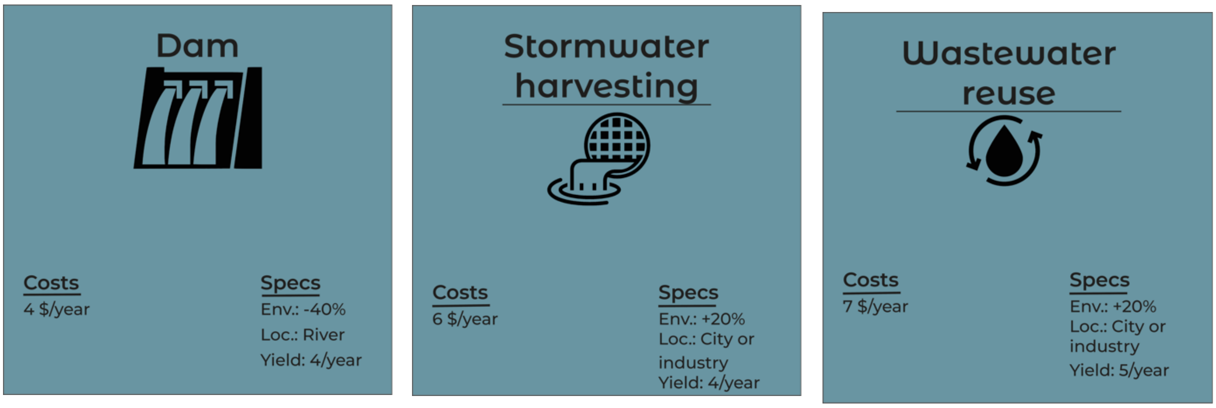


Figure 7-6: Intervention cards used in the game (source: Author)

Besides the intervention cards that are operational throughout the game, players have the option to buy cards that have a one-time effect. These cards represent socio-political and economic approaches to reduce water demand. These cards are presented in *figure 7-7*.

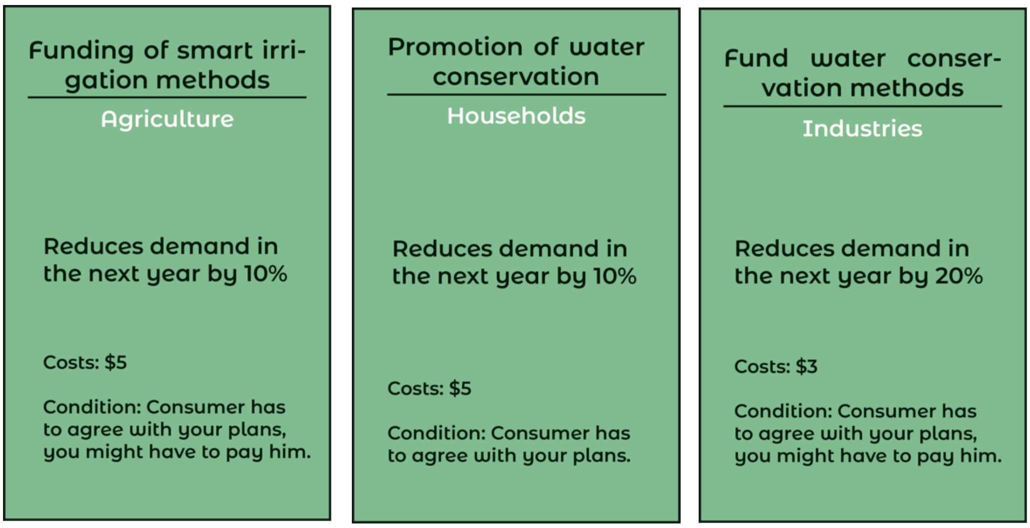


Figure 7-7: Socio-political intervention cards

Parameters to keep track of progress
In order to keep track of progress during the game, parameters are incorporated. It must be understood what data needs to be measured throughout the game:

- Water supply coverage indicator for each sector (%)
    - Industries demands potable water
    - Households demands potable water
    - Agriculture demands non-potable or potable water
- Economic growth indicator (absolute)
    - Industries served
- Sustainability indicator (absolute)
    - Environmental impact
    - Players need to be above a certain threshold to be able to win the common goal.

Design
The first step in the design process was concerned with deciding on how the gaming elements are incorporated into the design. Sketches were made with resemblance to the Greater Maputo Region, and it was decided that a grid would be of importance to the game, as that decides the location of interventions.

Hereafter, the physical sketch needed to be designed digitally. Also, indicators are incorporated to keep track of game proceedings. Indicators that are used are sustainability, economic development and the percentage of water supplied to industries, agriculture and houses. Furthermore, a timescale is applied at the bottom to show the rounds. A distinction is made between peri-urban areas and the city center in the design of industries and residents.

Due to covid restrictions, it was not possible to play the serious game 'live' and therefore the game was further developed in an online environment. The game is programmed in Google Sheets whereby providing all the options that a normal boardgame would have. In drop-down menus it can be adjusted who's turn it is and which interventions they would like to buy for potable or non-potable purposes. Furthermore, social intervention card can be bought to reduce demand in a specific year. In advance, the indicators directly show coverage for the different sectors and keep track of economic and environmental progress. At last, the option was added to pay money to a shared bank account from which interventions can be bought too. This stimulates cooperation during the game.

The visual results of this process are visualized in *figure 7-8.*

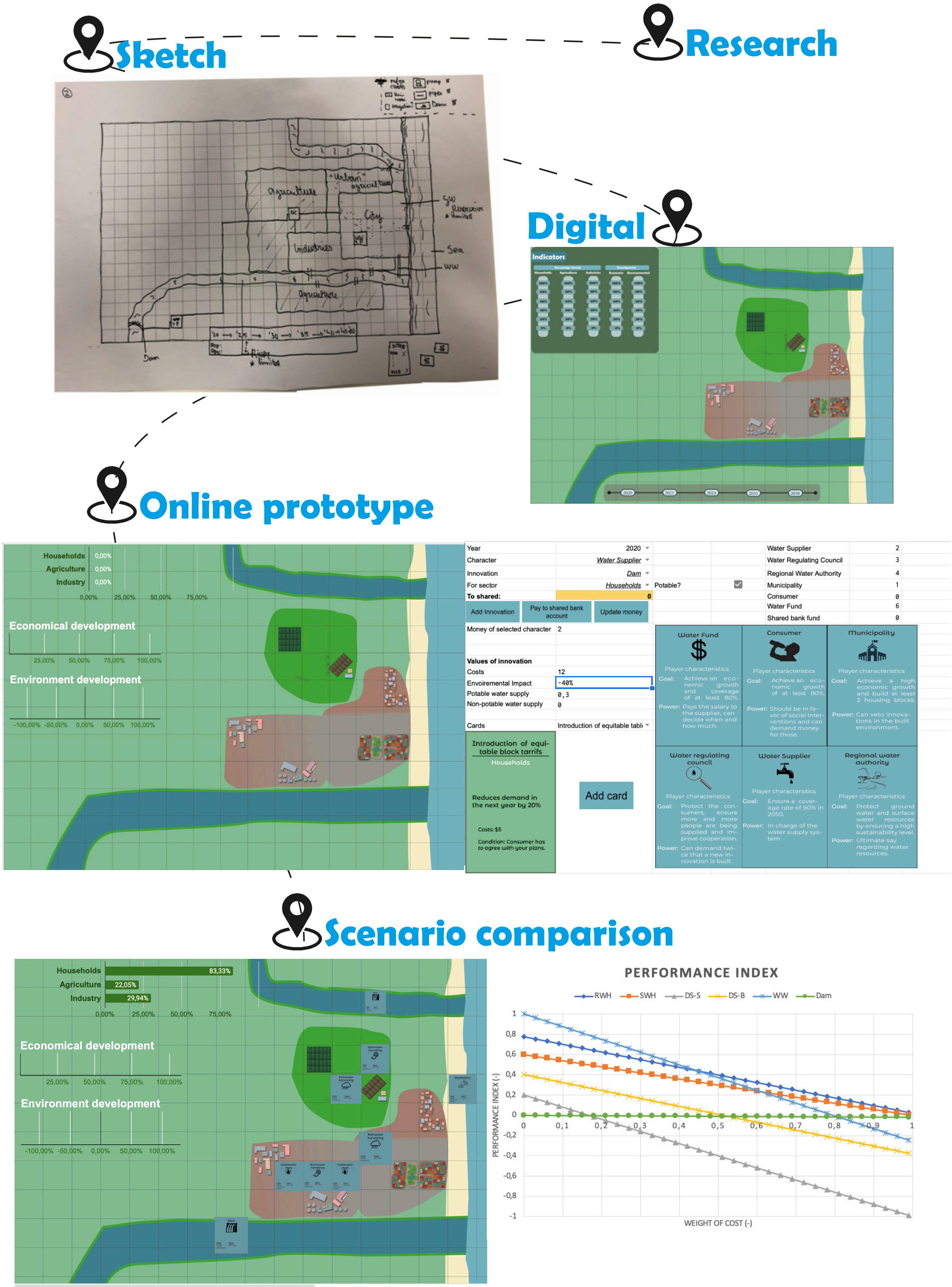


Figure 7-8: Roadmap of design process (source: Author)

Simple overview of gaming rounds
In this section, the basic flow of the game is presented in a step-by-step approach.

1. Each year is represented by a gaming round, which lasts 5 minutes. So altogether one game lasts around 25 minutes.
2. In each gaming round, it is known how much water is available and how much water is demanded.
    a. Players acquire their salary each round.
3. Players can – together or alone – buy and implement interventions and social interventions cards that have been described in *paragraph 5.1.*
4. The result of the interventions is calculated prior to the next year, accordingly, new salaries are calculated. The new salaries result from the percentage of people served and the economic growth.
5. After year 2033, the results for the year 2050 are shown in the gaming environment, this is the endpoint of the game. Here, it is decided if players achieved their own goals. At this point, players can think of 3 new gaming rules, which should be possible to implement digitally. These new rules are implemented before the start of the second game. In theory, these rules correspond to laws i.e., approaches in 'real-life'.
    a. *An example of such a rule can be that every player should always focus on sustainable solutions.*
    b. *Another example can be a rule that states that only 1 authority decides on which interventions are build.*
6. Step 1 until 5 again with the new rules.

7.4 After the game

Once players finished the game, they are asked to fill out a questionnaire. In this questionnaire their expertise in the field of water management and serious gaming is questioned and ultimately provides the author with qualitative data. The questionnaire can be found in *table 7-6*. After character questions, players' opinion is asked. It is asked what they think is necessary, in terms of for example regulations, institutions or finances, to close the supply demand gap during the next time they play the game. This step is important as it identifies the new gaming rules that were thought of and discussed between the first and second time playing the game. Hereafter, they are asked to provide a ranking of criteria that are used in the MCDA in *chapter 7*. The link to the questionnaire: *https://forms.gle/goWwfguvjjcTKXbX9*.

Table 7-6: Post-game questionnaire

Nr.	Question	Type of answer
1	Did you enjoy playing the game?	Rating (1-5)
2	Are you familiar with serious gaming?	Rating (1-5)
3	Have you ever played serious games concerned with water management before?	Rating (1-5)
4	How would you rate your educational experience in the field of water management?	Rating (1-5)
5	Rate your practical experience in the field of water management?	Rating (1-5)
6	Rate your familiarity with the Greater Maputo Region?	Rating (1-5)
7	Rate your knowledge on the types of sustainable interventions that are possible to mitigate water demand?	Rating (1-5)
8	What do you think is necessary in such a context as the serious game to overcome the supply demand gap? Think about social, technical, economic, environmental and political answers.	Open Question

9	The innovations that enhance water supply in the game all have different specifics. To your opinion, which specifics are most important and which the least. Please rank the following specifics: (*table 7-3*)	Ranking (1-13)
10	What are your main takeaways of the serious game? I.e., what did you learn?	Open Question
11	Do you have any points of improvement for the serious game?	Open Question
12	Did the serious game change your perception of the water system in Maputo?	Open Question

7.4.1. Substantiation of questions

Questions 1 to 7 are used to acquire insight in the player's character and prior knowledge on serious gaming, water management and the Greater Maputo Region. Ultimately, the more prior knowledge players have, the more weight can be attributed to their opinions and insights during decision analysis.

Question 8 is an open question that asks for the player's creativity. Here players basically give their opinion on how the supply-demand gap in the game can be closed from various perspectives. The answers provided can be translated to the real-life situation. This is of importance to the framework in *chapter 8* as also political, environmental and economic input is asked besides the technical aspects. Furthermore, the author might have overlooked certain possibilities, trade-offs or aspects which are corrected for with this question.

Question 9 is related to the MCDA in the next chapter. Here it is asked how players would rank the criteria. The ratings of multiple players can be averaged and ultimately provide an average rating for the criteria. When the questionnaire is played amongst different experts and or interested players, a consensus on the criteria is established.

Questions 10 and 11 are question to validate the results and if players paid attention whilst doing so. When the answer to those question concern things not addressed in the game, it can be concluded that the player was not involved much.

7.5. Evaluate and enhance the game

The first session showed that the online game itself had some minor technical issues. These were observed by the game facilitator and/or addressed by the players. The game was played with peers that have experience with developing and playing serious games. One of the responses to the questionnaire can be found in *table 7-7*. The players did not "win" the game. As they only achieved coverage rates lower than 60%.

Table 7-7: One of the responses to the serious game

Nr.	Response
1	4
2	5
3	1
4	3
5	1
6	1
7	4
8	I think politic is very important to overcome the supply demand gap. Companies and other organizations will almost always only make choices driven by finances, so they will not invest in water supply when it doesn't make that much money. Government regulations can really help in this regard, or setting up a governmental organization which is responsible for creating water supply. This is also definitely the case for sustainable solutions which are often more expensive.
9	1: Percentage of demand covered; 2: Total new treatment capacity; 3: Reduction of environmental impact 4: Reliability of the system; 5 Construction time; 6: Energy consumption; 7: Pipeline length in urban areas (safety); 8: Possibility of future expansions; 9: The share of fresh water that is withdrawn

	by the system; 10: Total number of possible expansions; 11: The length of transportation pipes; 12: The number of new treatment plants
10	How difficult it is to make good decisions with so many different stakeholders who al have different interests. And I learned about possible water supply technologies.
11	Not that I know of right now.
12	(No answer, this question was added later)

7.6. Results of the serious game

The serious game and associated questionnaire aim at gathering qualitative data from stakeholders. The results of the questionnaire indicate that the players enjoyed playing, meaning that they were actively engaged and tried to win. *Questions 1 to 7* indicate that this person has a lot of experience with serious gaming, a little with water management and none with the Greater Maputo Region. Meaning this opinion is more important to the game than to the region itself. The answer to *question 8* shows that this player believes that (in the game) industries are not concerned with the method of their water supply as their actions are solely driven by financial interests. Furthermore, it is stated that governmental regulations or an organization should be established to promote and enhance water supply and involve industries. Especially regarding sustainable approaches. The solution to this players' problematic situation is most likely in the form of subsidies. Where governments subsidize sustainable water supply solutions or water saving-devices for industries whereby reducing pressure on the centralized water system. The answer to *question 9* indicates how the players rank the criteria to be used in the MCDA based on their prior knowledge and what they learned during the game. During the game, all player actions are monitored and logged. In that way, the actions are saved and can ultimately be compared.

Furthermore, the serious game can be compared with the performance index from *paragraph 6.2.6.* Doing so reveals that financial resources are indeed a hurdle. Where the MCDA indicates that the best options are sustainable solutions such as wastewater reuse and both precipitation harvesting methods, the players in the game also tried to use as much sustainable solutions as possible. However, they did not achieve in meeting demand and used unsustainable methods such as dams as well, especially in the beginning of the game, as financial resources were scarcer at that point. This also highlights the need for the social and political approaches to reduce demand.

Key findings chapter 7

- Sustainable urban water management is a complex process, as it is concerned with **human**, **technical** and **environmental** interests.
- Water resources management has often been described as a '**wicked'** form of planning.
- Serious Gaming can aid in **sharing knowledge** and **aligning** local stakeholders, disciplinary experts and policymakers.
- In this report a serious game is developed to (1) acquire **stakeholder preferences** through a post-game questionnaire; (2) **validate** the chosen approaches in chapter 5; and (3) obtain **local input** for the framework in chapter 8.
- Players are motivated in the game and provide adequate feedback through the questionnaire.
- Players did not achieve in meeting the demand in the final year.
- Players did try to use as much sustainable solutions as possible, however, financial resources were not sufficient to do so. Especially early in the game, dams were used to quickly supply water.

Outlook

The serious game seems promising in both educating stakeholders and acquiring stakeholder input. Furthermore, the demand for sustainable solutions in the Greater Maputo Region is highlighted by players within the game. Combined with the previous chapters, a framework fed by both stakeholders and models can be developed.

8. Conclusion and Discussion

In this section, the framework that ties all the previous chapters together, the conclusion and discussion are found.

8.1 Framework

This chapter is the point where all previous chapters converge. The results of *chapter 2* provide an overview of the current institutional set-up and the existing water supply infrastructure. Furthermore, *chapter 3* entails the specific values of water supply and their sources. *Chapter 4* shows how the region's water demand across different sectors and availability increases over time, until the year 2050. *Chapter 5* provided the technical, social and political approaches that can help mitigate the increased demand. C*hapter 6* provided a technical approach to analyse the different approaches based on specific criteria. Hereafter players filled out a questionnaire that enables the author to integrate their opinions and preferences into decision analysis. Hereafter, in *chapter 7* a serious game resembling the situation in the Greater Maputo Region was developed and played. An overview of the recommendations can be found below in figure *8-2*.

It can be concluded that the Greater Maputo Region faces a tremendous challenge to close their water availability and demand gap in 2050 and the years before. However, this report has shown that a myriad of options is available to mitigate this gap and possibly close it entirely. In 2050, the Greater Maputo Region is expected to have a deficit in water supply of 1,2 million m^3/day, this includes agriculture, domestic and industrial water demand. In advance, climate change is expected to decrease water availability even more as precipitation is likely to decrease and evaporation to increase. In advance, interannual variation in precipitation patterns increase, highlighting the demand for water storage between the dry and wet period. However, it was also found that Mozambique's low domestic water access is not due to natural constraints, only to infrastructural and financial ones.

In order for the Greater Maputo Region to achieve SUWM, resilience and close the supply demand gap in 2050, a more flexible and efficient system is required to co-exist along the current and planned centralised system. An institutional approach that supports this is decentralization. For the Greater Maputo Region, this would entail the implementation of a more local level of water supply and treatment. Whereby the RWA's would acquire full autonomy in order to become financially sustainable instead of being dependent on central support for human and financial resources. In advance, local RWA's can then greatly benefit from interlinkages with local actors and governments. This approach is also likely to dimmish corruption and thus benefit efficiency.

In the case of the Greater Maputo Region, a decentralization on a neighbourhood or community scale seems most applicable as the differences between different neighbourhoods are large. In this way, centrally supplied water can be supplemented with decentralised sourced water. In order to optimize such a system, it is necessary to separate potable water and non-potable water demand. As treatment is fairly expensive, and not all uses demand water of potable quality.

Within this newly established decentralised form of water supply, a myriad of approaches is available to augment the water supply. In this report, the ranking of the people who played the serious game was used. Using this ranking it was determined that when the weight of cost is high, rainwater harvesting, stormwater harvesting, and dams are the most suitable options. In the case of a low weight of cost, wastewater reuse, rainwater harvesting and stormwater harvesting are most applicable. As Mozambique is one of the poorest nations in the world, it is most likely that the weight of cost is high. However, when Mozambique can acquire financial aid, more sustainable options, such as wastewater reuse, seem more profitable from a sustainability perspective. According to chapter 5, stormwater harvesting, and wastewater reuse could completely cover the Greater Maputo Region's demand. However, this is in a best-case scenario where the whole area of the metropolitan area is covered with stormwater harvesting systems and all industrial wastewater is collected and treated. This is supported by how the questionnaire was filled out after the serious game was played with peers. It became evident players felt the urgency for sustainable solutions but could not afford those themselves. To the opinion of the players the weight of the cost should be low, however, they seemed unable to achieve that within the game.

An example of a system that would be efficient and applicable in the Greater Maputo Region is described in this paragraph and visualized in *figure 8-1*. This is also the type of sustainable scenario that the players favoured during the serious game but who regarded the high costs a major hurdle. As agriculture does not demand potable water per se, the sector is separated from the potable water system. In that case, besides the existing infrastructure, 850,000 m^3 of potable water needs to be fed into the potable water supply system each day. The most efficient and sustainable method seems to be a combination of wastewater reuse, stormwater harvesting and desalination of brackish water. In the case of stormwater harvesting, the already sloping downward city of Maputo is able to create nature-based collection and storage spaces at low-lying areas, such as the already existing Tunduro garden in downtown Maputo. In each urban district, systems are to be constructed that collect, store and transport stormwater. Furthermore, the city centre of Maputo is connected to a sewage and piped water system whereas Matola, the peri-urban areas in Maputo and Boane are not. According to *chapter 5* decentralization of water supply is key in achieving SUWM, therefore, in an ideal situation, each urban area has its own treatment plant and distribution networks. The benefit hereof is that water can be locally sourced and distributed, without extreme pipeline lengths to transport water, whereby reducing the risks of NRW. Furthermore, desalination of brackish water and or wastewater reuse can be used to supplement stormwater harvesting.

When desalination of brackish water is used to supplement stormwater harvesting to meet the industrial and domestic demand, wastewater can be utilized for agricultural purposes. As agriculture does not demand water of potable quality, wastewater can be treated using NBS such as constructed wetlands, as described in *paragraph 5.1.6.*, whereby saving energy and costs on treatment to potable standards. Possibly a disinfection step is required here, depending on local standards (Nan, Lavrnić, & Toscano, 2020). The main producers of wastewater are located in central areas in Matola and Maputo, as is shown in *figure 3-3*. This eases transportation as less pipelines are required. In this specific example wastewater can directly be transported to the CW for treatment. As the agricultural practices mainly take place on the outskirts of the region, CW can easily be constructed without hindering urbanization processes.

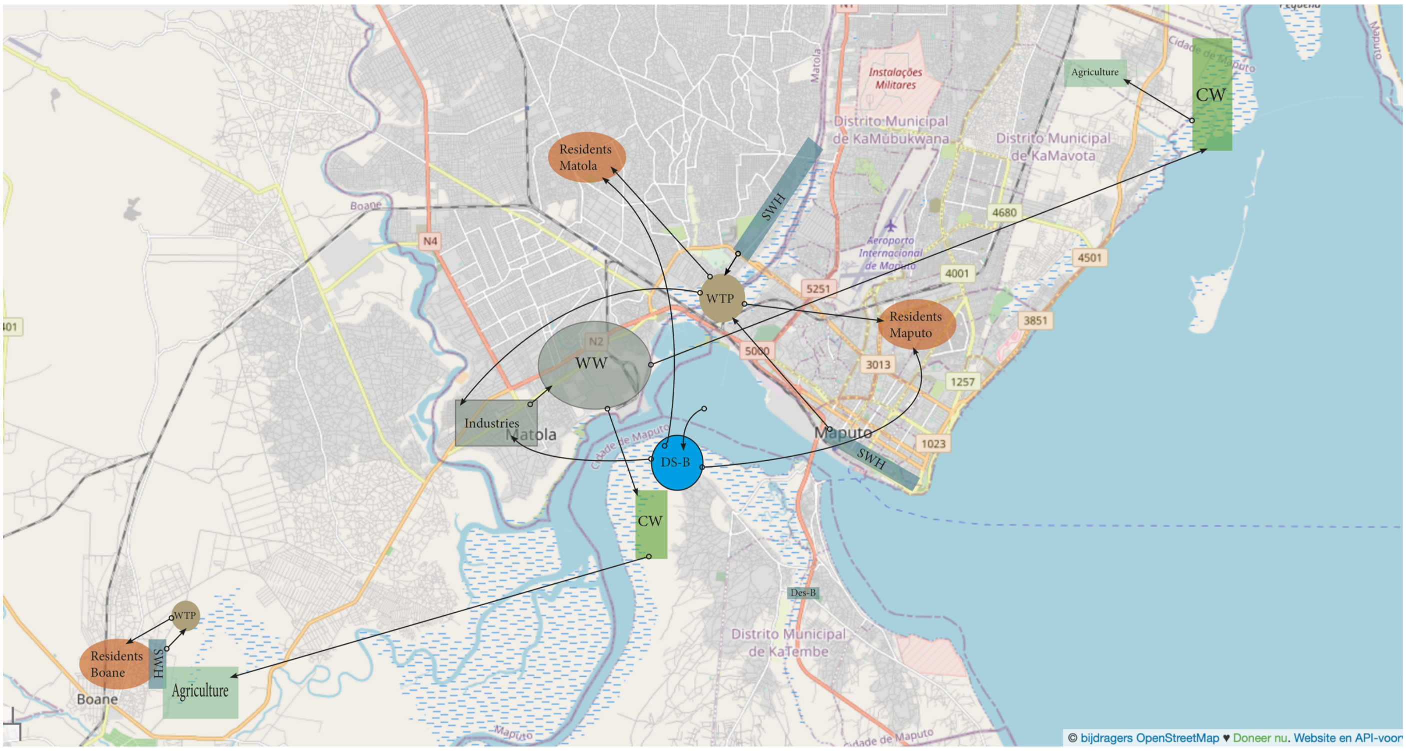


Figure 8-1: Example of SUWM in the Greater Maputo Region

Besides these technical approaches, it is recommended that socio-political and economic measures are utilized in order to decrease water demand, as found in the serious game and supported by literature. Because as stated before, water conservation is the largest and cheapest source of water in urban areas. An important first step herein is decreasing NRW, leading to a higher service rate, financial self-sufficiency and long-term sustainability. In advance, economic and financial measures are recommended in order to promote equal water access and efficiency. Especially full-cost pricing and block-tariffs are important pillars to achieve SUWM for current and future generations. In the case of the Greater

Maputo Region, the price of the first block should be decreased, whereby promoting water access for lower- and middle-income families. Furthermore, more financial resources will be available for expansion of the network into the peri-urban areas by decreasing the connection costs.
In advance, (local) governments should promote water conservation, in households, industries and agriculture. Research has shown that educational programmes, awareness campaigns, demonstrations projects on water conservation can reduce water consumption by 50%. Especially the involvement of industries within sustainable urban water management was deemed important by the players of the serious game.

Essential to the success of the above-named approaches is good urban governance. With good urban governance, the focus of the governing bodies is mainly improving the living quality of local citizens, especially those of marginalised and disadvantaged communities. In the Greater Maputo Region this ultimately implies that people in the peri-urban areas should acquire more attention from governing bodies. This is done through community participation, effective urban management and transparency and accountability.

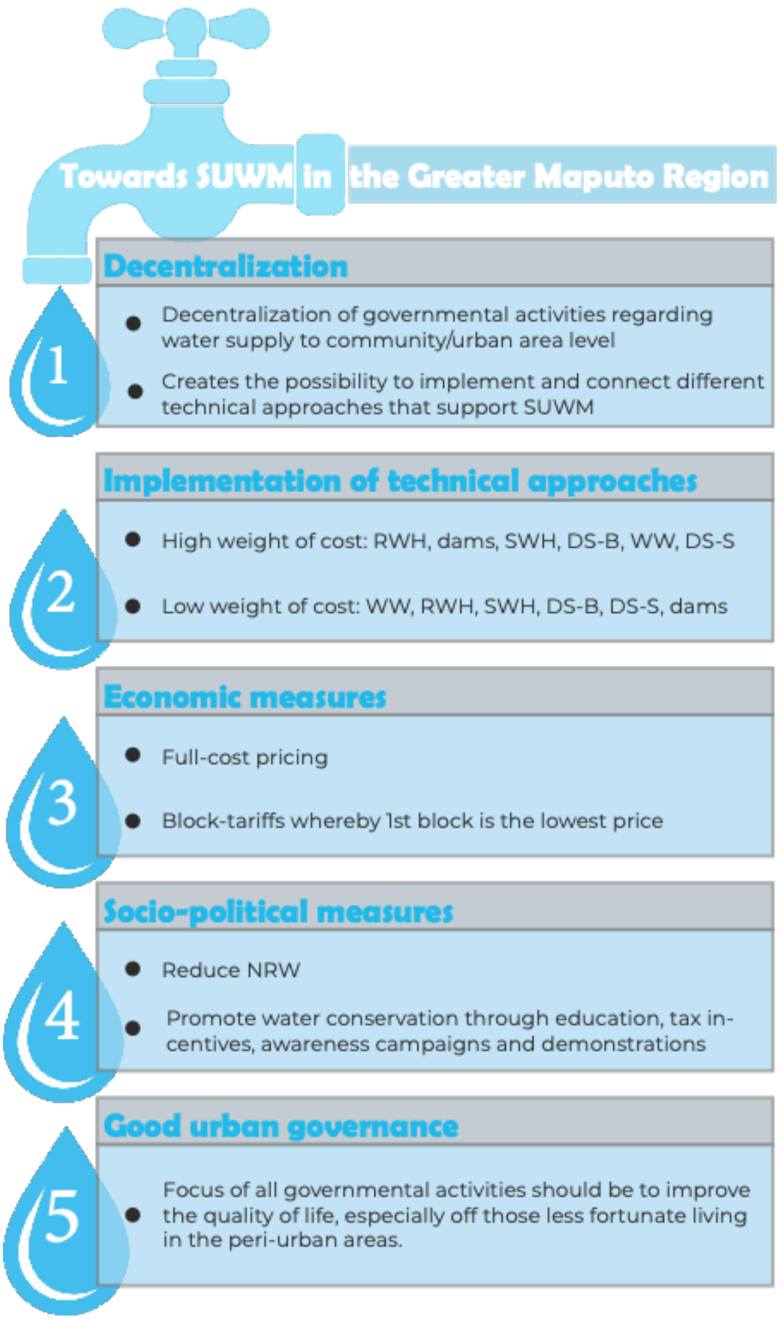


Figure 8-2: Framework towards SUWM in the Greater Maputo Region (source: Author)

8.2 Discussion

Even though this report poses a framework for the Greater Maputo Region to close the gap in their water supply in 2050, the results demand some nuance. In this discussion, assumptions and best-case scenarios are elaborated on, and their uncertainties are discussed. This discussion follows the same flow as the report in order to sustain clarity and readability.

Especially during the forecasting in *chapter 4*, assumptions were made. However, these assumptions are reflected upon by the shading areas in the population forecast and the quantiles in the water demand and supply forecasts. Therefore, it should be noted that these figures do not represent the exact water consumption or population but aim to depict current and historical trends in the best way possible. The forecasts show that especially industries, and thus the production of industrial wastewater, experience a steady increase. It is expected that this is the result of a reinforcing effect, whereby new industries attract more and more other businesses and industries. This is in line with the percentage of employment over time in industries in more developed African nations such as Tanzania and Namibia (The World Bank, 2020). Simultaneously, this encourages urbanization in the region as well. Regarding climate change, it is necessary to research its exact implications for the Greater Maputo Region. It should be understood how much water is lost (precipitation, evaporation) and where. In that way it can be investigated if it is feasible to reduce evaporation.

It was also found that agricultural water demand is highest compared to households and industries. Furthermore, it was also stated that agricultural water abstractions are regarded another system due to their use of groundwater, precipitation and surface water, which is also the case in developed nations such as the Netherlands (Deltawerken, 2020).

In *chapter 5*, where the technical, socio-political and economic approaches are laid out, it is important to note that it is more of a holistic approach instead of a truly technical study. Simply for the lack of data and knowledge on such large-scale projects, especially in SSA. However, this report has attempted to make estimations of the yield of the technical approaches, but as stated before, these merely represent a best-case-scenario in which all water from precipitation or other sources is collected. Given the current state of water infrastructure and NRW in the region, the achievement of such a best-case scenario does not seem very promising. However, the relative aspects of these interventions do present representative data that can be used to compare the different interventions.

Regarding allocation of water, it needs to be understood that water from different approaches have a different quality and can thus be used for different purposes. For example, rainwater can directly be used for some non-potable activities such as garden irrigation, toilet flushing and washing. As this report focusses more on the production of water instead of allocation, an in-depth analysis of all water sources has been left out but remains interesting for future research. For example, all the approaches would bear the opportunity to recharge groundwater and be distributed through boreholes, which might especially be an appropriate solution on the short-term, whilst distribution infrastructure in under construction (National Research Council, 1994).

Especially regarding SWH and RWH, some disadvantages arise due to the high variability of precipitation patterns in the Greater Maputo Region. Therefore, rainwater or stormwater should be stored for use during the dry periods, or other approaches such as desalination of brackish water should be scaled up during dry periods in order to supply enough water. In advance, future precipitation has not been given a lot of attention in this report. It was chosen to do so, because Mozambique's rainfall is already highly variable, and the lack of data makes future estimations very unreliable. However, it is expected that temperatures in Southern-Mozambique will rise, but this does not necessarily mean that precipitation decreases (Ministry of Foreign Affairs of the Netherlands, 2018).

It should be mentioned that the success of decentralization and the approaches depend on local capacities, in terms of knowledge and resources. Research in North-Namibia has indicated that decentralized governance is most likely to be ineffective if insufficient resources are allocated to support and enable local actors to actively participate in the governance system. Therefore, it is recommended that the policy and practice around the decentralized urban governance focusses on capacity building of local actors, so that they can absorb responsibilities and resources provided to them (Hegga, Kunamwene, & Ziervogel, 2020).

Obviously, this decentralized approach comes at great cost due to the construction of novel water supply sources, distribution and collection centres, pumping and treatment. However, in comparison to centralised water systems, decentralised water treatment has shown to be less costly, especially regarding maintenance and operational costs (Jung, Narayanan, & Cheng, 2018). As stated before, Mozambique is one of the poorest nations in the world. Therefore, from a wider perspective, with the help of foreign aid, Mozambique can leapfrog towards SUWM instead of going through all the regular phases of water supply and sanitation development. It can be argued that developed nations *should* assist Mozambique and other less developed nations to become more climate resilient, as western nations have developed whilst emitting the bulk of the greenhouse gasses of which less-developed nations are expected to feel the consequences the most (Keeley, 2012). Besides that, certain low maintenance, energy efficient and sustainable approaches might always be a better option than regular unsustainable water supply approaches.

The serious game, described in *chapter 6*, bears the same assumptions as the forecasting does, given that the data used in the game are derived from the forecasting. However, the effect of these insecurities is less important as the focus of the game is more concerned with stakeholder interaction and their preferences than quantative data. Some improvements can be made to the game in order to improve integration of the criteria into the game. This could be in the form of adding conduction lines, pumping stations, protected nature areas and by making a larger distinction between urban centres and the peri-urban areas. Furthermore, the game would benefit from the integration of climate change issues, whereby water availability is shrinking. However, with the money available to this research, that seemed to be impossible at this stage. However, the game does show promising results with regard to SUWM in urban areas, and especially in the context of stakeholder preferences. The serious game should also be played a lot amongst stakeholders and (local) experts with different field of work in order to acquire broad-carried results. Another benefit of the game is that it educates stakeholders about the trade-offs of different approaches and shows the differences and consequences of long-term and short-term solutions.

In *chapter 7*, the MCDA showed the ranking of alternative water supply approaches based on a range of criteria. Depending on each stakeholder, a different ranking can be attributed to the criteria. Some stakeholders might argue that sustainability is of lesser importance than energy consumption, given a steady water supply. Therefore, future research on this topic should involve experts from all fields: infrastructure constructers, environmental specialists, social science experts that understand dynamics within the region, stakeholders from FIPAG's treasurer and development aid specialists. In that way, the whole field of economics, environment, technical and social implications is covered and can provide a broad-carried analysis of the alternatives.
In advance, the data used for the criteria are assumptions. It is beyond the scope of this report to calculate exact construction costs, time and risks. Therefore, those data were obtained from literature and slightly adjusted for the Greater Maputo Region. Therefore, future research should focus on the exact costs and duration of such projects. In that way a more accurate MCDA can be performed.
Furthermore, an MCDA should be carried out for each urban district. Especially since the differences between the region's districts are tremendous. Soil type, abundance of green spaces, water and sanitation infrastructure and the topographic specifics can determine the potential of each alternative.
Another important aspect regarding the AHP and MCDA is its sensitivity. When the rank of the first and last criterium from table 6-3 are switched, this already has quite some impact on the results. In that case, the result for the use of dams is 0, likely because the dam has a relatively high coverage of demand. When that is of lesser importance, the negative trade-offs of the dam (environmental, construction time) become more predominant and ultimately exclude it as a viable option.

This report ultimately has a wider context, as it can be regarded a green-blue print for the sub-Saharan African city to achieve SUWM. Obviously, the differences between other African metropolis regions such as Dar-Es-Salaam and Windhoek are staggering, the steps to achieve SUWM are the same. The first step being decentralization of water supply and treatment, whereafter the most suitable sustainable approaches to water supply should be identified by involving stakeholders and experts. Hereafter, top-down socio-political and economic approaches should be used to decrease water demand. Especially when good governance is practiced, with the well-being and living standards of the inhabitants at the core of decisions, this approach seems promising to achieve SUWM in sub-Saharan African cities.

8.3 Conclusion

Under the pressure of climatic change, urbanization and economic development, freshwater resources are becoming scarcer to meet the growing demand in the Greater Maputo Region. Combined with outdated infrastructure, the challenge to meet demand is tremendous. Therefore, this report aimed at providing a holistic pathway towards meeting that demand.

Here, the previous chapters are discussed in the light of the previously stated research questions. The first sub-question was concerned *with the gap between Maputo's future water demand and currently supply.* It was found that, with the two dams under construction, the region is going to face a deficit of 850,000 m^3 of water for domestic and industrial purposes and an additional 550,000 m^3/day for agricultural purposes. Furthermore, precipitation is going to decrease over time and temperatures will increase. Especially in the driest months June, July and August, reservoirs are expected to become drier and drier. This underpins the need for storage and water supply alternatives that have the ability to store water for the drier periods.

The second sub-question was to find out *which combinations of water sources are possible in the region and could ultimately augment the deficit found with sub-question* 1. It was found that the Greater Maputo Region bears plenty opportunities to enhance their water supply. Stormwater harvesting, rainwater harvesting, dams, wastewater reuse and desalination of both brackish and saline water were found to be the most promising options. Multi Criteria Decision Analysis with as main criteria the duration of construction and sustainability showed that in the case of a high weight of cost rainwater harvesting, stormwater harvesting and dams are the most suitable options whereas wastewater reuse, rainwater harvesting and stormwater harvesting are more applicable when the weight of the cost is low. It was also found that such technical measures are not deemed useful on their own. They need to be supported by socio-political and economic measures that support efficiency and equality. It was also found that nature-based solutions such as constructed wetlands are a promising method to underpin SUWM in the region.

The third sub question is concerned with how stakeholders' preferences can be integrated into decision analysis using serious gaming. In this report, it was found that a serious game can integrate stakeholder's preferences into decision analysis by using the trade-offs of different technical approaches as gaming elements. In this way, the game facilitator can observe which stakeholders have a preference for what criteria. These criteria can then be applied to determine and rank the criteria in decision analysis. In this way, it is possible to integrate stakeholders' knowledge and preferences into decision analysis and develop a locally applicable framework.

The main research question is a combination of the above-named sub-questions and is formulated as the following: "*How can the gap between Maputo's future demand and availability be closed by involving stakeholders through an active engagement game, and which pathways will support this?".* This report showed that a serious game can integrate stakeholders' preferences into decision analysis which ultimately showed that a combination of different SUWM approaches have potential to close the gap. In the case that a high weight is attributed to the cost of approaches, RWH, SWH and dams are the appropriate options whereas in the case of a low weight of the cost, WW reuse, SWH and RWH are most appropriate. Furthermore, the niches fur such approaches to operate in need to be created through governmental decentralization, which stands at the basis of SUWM. Within this niches, technical approaches, supported by socio-political and economic measures are able to close the gap in the Greater Maputo Region's waters supply and demand.

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Appendix A: Climate Change Forecast

The causes and consequences of Anthropogenic climate change have been widely described, however, these consequences differ greatly on a local, regional and national scale (Ministry of Foreign Affairs of the Netherlands, 2018). Therefore, this report aims at identifying the local effects of climate change on the Greater Maputo Region's water availability. The two main indicators that characterize the state of the climate and continuously effect living conditions throughout Africa are temperature and precipitation (Mavume et al., 2021).

Baseline

In Mozambique, an increase in mean annual temperature of + 0,6 °C was observed between the years 1960-2006. The largest increase was observed in the south of the country where the average annual temperature increased + 1 °C in 100 years. Average annual rainfall has decreased significantly, at a rate of 3,1% per decade. However, the share of rain falling during heavy rain events increased at a rate of 2,6% per decade, mainly during the rainy season (Ministry of Foreign Affairs of the Netherlands, 2018; The World Bank, 2021).

The baseline scenario in the climate forecasting by Mavume et al. (2021) is the 1961-1990 period and is based on climate data from the Mozambican Meteorological Institute. The parameters used are precipitation, maximum temperature and minimum temperature. The time scale used during this forecasting are 30-year periods whereby the 2040s represent the beginning of the 21st century (2011-2040), the 2070s the mid (2041-2070) and the 2100s the end of the 21st century (2071-2100). The forecast is conducted for 4 distinct regions in Mozambique: the coastal area and the inland Southern, Northern and Central areas. For the analysis of the forecasting in this paper, the two districts that are used in the forecasting and most applicable to this report are the ones located closest to the Greater Maputo Region. These districts are Namaacha (located 45 km west of the Greater Maputo Region) and Manhiça (located 50 km north of the Greater Maputo Region).

Forecasting

The forecasting used in this report used three different ensembles of regional climate change simulations from CORDEX-Africa. Where the first ensemble entailed 4 simulations, based on representative concentration pathway (RCP) 2.6, the second ensemble 9 simulations based on RCP4.5 and the last ensemble of 9 simulations based on RCP8.5. The RPC scenarios are developed by the international panel on climate change (IPCC) and depict different future scenarios of greenhouse gas emission into the atmosphere. Within these scenario's, RCP2.6 is the most ambitious scenario, representing radical climate change mitigation policies and slowing global warming down to 1,5 °C. RCP8.5 is the highest-level scenario, representing a business as usual scenario, which, without any climate action leads to global warming up to 4 °C (IPCC, 2014). The forecasting was conducted for four regions in Mozambique, southern, northern, central and coastal. The Greater Maputo Region is located within both the Southern and coastal region and therefore it is assumed that the local climate is influenced by both forecasting. The results of the forecasting are shown in *figure 4-4* and the local results in *table 4-5 (ibid).*

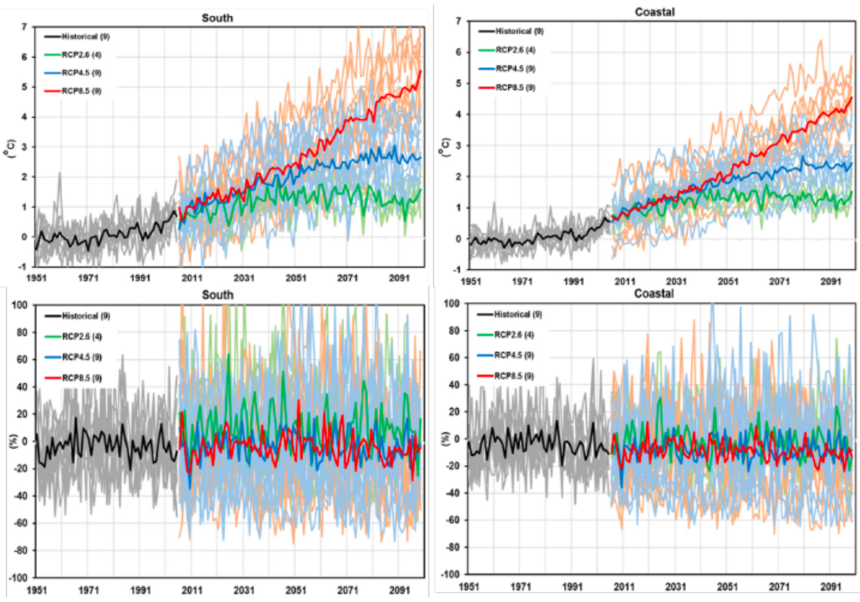

Figure A-1: Time series of annual mean temperature anomalies under 3 different RCP scenarios of coastal and southern Mozambique (Mavume et al., 2021)

Temperature

The results, shown in *figure 4-6* indicates that future warming is not uniform throughout Mozambique. In the RCP2.6 scenario, the temperature anomaly reaches up to 2 °C, except in the coastal region, suggesting that the coastal region will experience less temperature variation. In the RCP4.5 scenario, temperatures stabilize around 2050 indicating that the temperature anomaly will not exceed 2 °C in the coastal region. In other regions, temperatures stabilize around 4,5 °C in RPC4.5. The RPC8.5 scenario shows the highest increase, with almost 6 °C in the southern region and 5 °C in the coastal region. Compared to the reference period (1961-1990) and in all RCP scenario's, the largest increase in temperature is observed during the winter months June, July, August, September and the summer months October and November (ibid).

The projected changes indicate that the average annual temperature will be higher than the average annual temperature of the reference period. Especially towards the middle and end of the century, an increase is observed. Especially inland regions will experience greater temperature changes as compared to the coastal region (ibid).

Precipitation

In general, the behaviour of the annual precipitation patterns is characterized by a high variability, dependent on the scenario, geographic location and period chosen. In the southern region, except the coastal region, precipitation is likely to increase by 40% in the 2040s compared to the reference period. For the coastal area however, *figure 4-6* indicates that precipitation is likely to decline from 0 to 20% for all RCP scenarios in every time period. Furthermore, *figure 4-4* shows that the southern region faces a higher interannual variability regarding precipitation compared to the coastal region, which even shows a relatively large interannual variability as well.

The behaviour of seasonal precipitation shows the same patterns as annual precipitation, which is probably influenced by the same factors. During the months December, January and February precipitation in the Greater Maputo Region increases in RCP2.5 by max. 20% and the inland area to the west by max. 40%. RCP4.5 and RCP8.5 show no significant anomalies compared to the reference period. In the months March, April and May, a decrease of 20% is observed in the Greater Maputo Region whereas the hinterland to the west faces an increase of 20%. During the months June, July and August the Greater Maputo Region faces a decrease of up to 60% in precipitation. The inland region to the west also faces a decrease, albeit 20%. In the months September, October and November a decrease up to 40% for the Greater Maputo Region and also for the inland regions except under RPC2.5, where the inland region's precipitation is likely to increase by 20%. A summary of these observations under RCP4.5 is found in *table 4-5 (ibid)*.

Table A-1: Changes in seasonal precipitation compared to the reference period under RCP4.5 the first letters of each month are used on the left

	Coastal - Maputo		Inland – West of Maputo	
	2040s (%)	2070s (%)	2040s (%)	2070s (%)
DJF	-20	+20	-20	+20
MAM	-20	-20	+20	+20
JJA	-60	-60	-20	-20
SON	-20	-20	-20	-20

Whereas *table 4-5* shows the seasonal precipitation compared to the reference period, *table 4-6* shows the annual consequences of climate change for the Greater Maputo Region.

Table A-2: Local temperature and precipitation forecasting (Mavume et al., 2021)

	Region	District	Temperature (°C)			Precipitation (%)		
			2040s	2070s	2100s	2040s	2070s	2100s
RCP2.6	Coastal	Manhiça	0,95	1,31	1,18	7,6	8,4	7,3
	Southern	Namaacha	1,02	1,38	1,25	0,4	1,2	1,4
RCP4.5	Coastal	Manhiça	1,13	1,86	2,24	-21,2	-20,0	-22,1
	Southern	Namaacha	1,17	1,96	2,34	2,5	0,6	-0,1
RCP8.5	Coastal	Manhiça	1,21	2,41	3,93	-20,4	-22,7	-25,7
	Southern	Namaacha	1,28	2,55	3,98	1,5	-0,7	-4,5

Figures 4-5 and 4-6 depict the local projected changes in annual mean temperature and annual precipitation under the three different RPC scenarios. The Greater Maputo Region is located on the coast in the far south of the country.

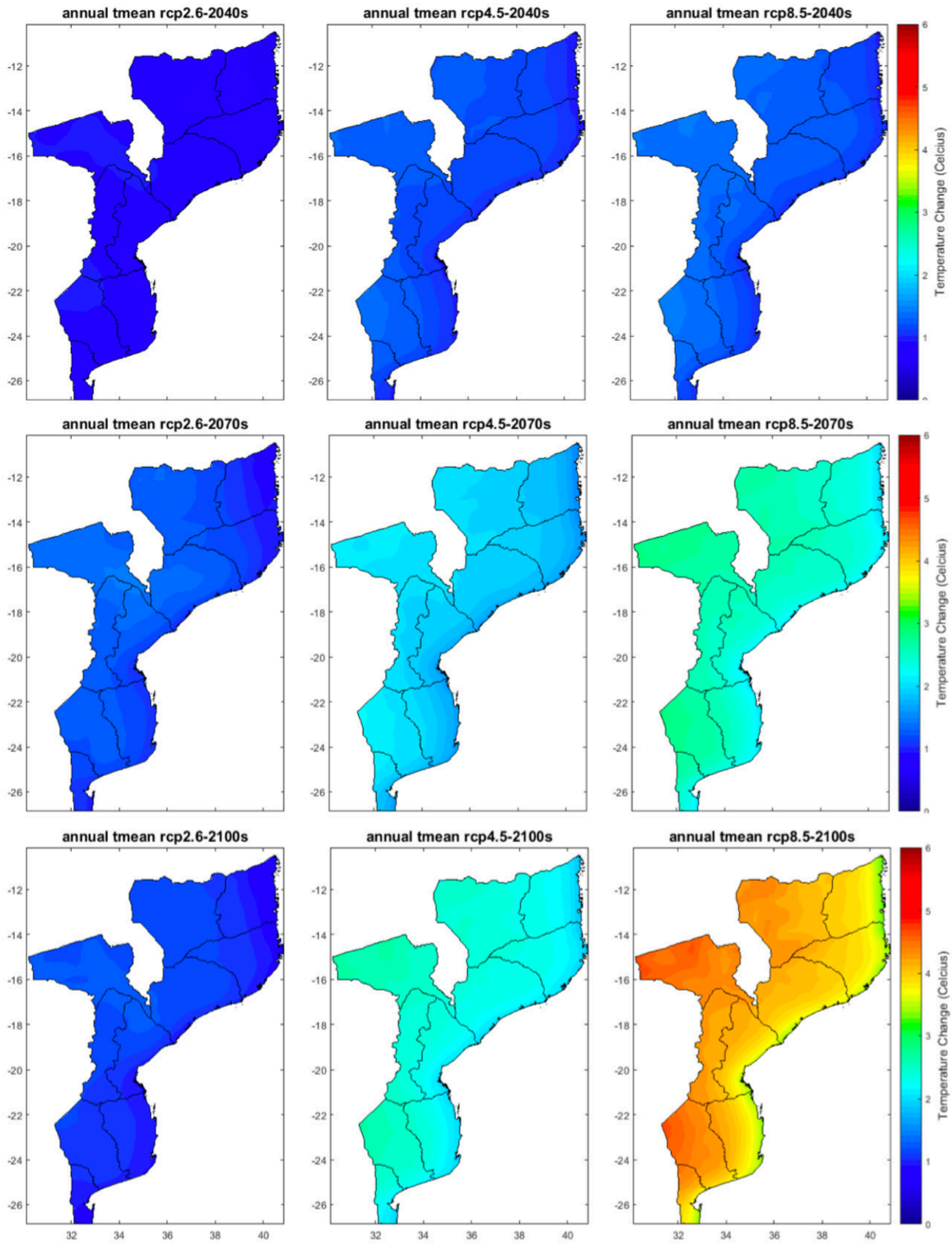

Figure A-2: Projected changes of annual mean temperatures (Mavume et al., 2021)

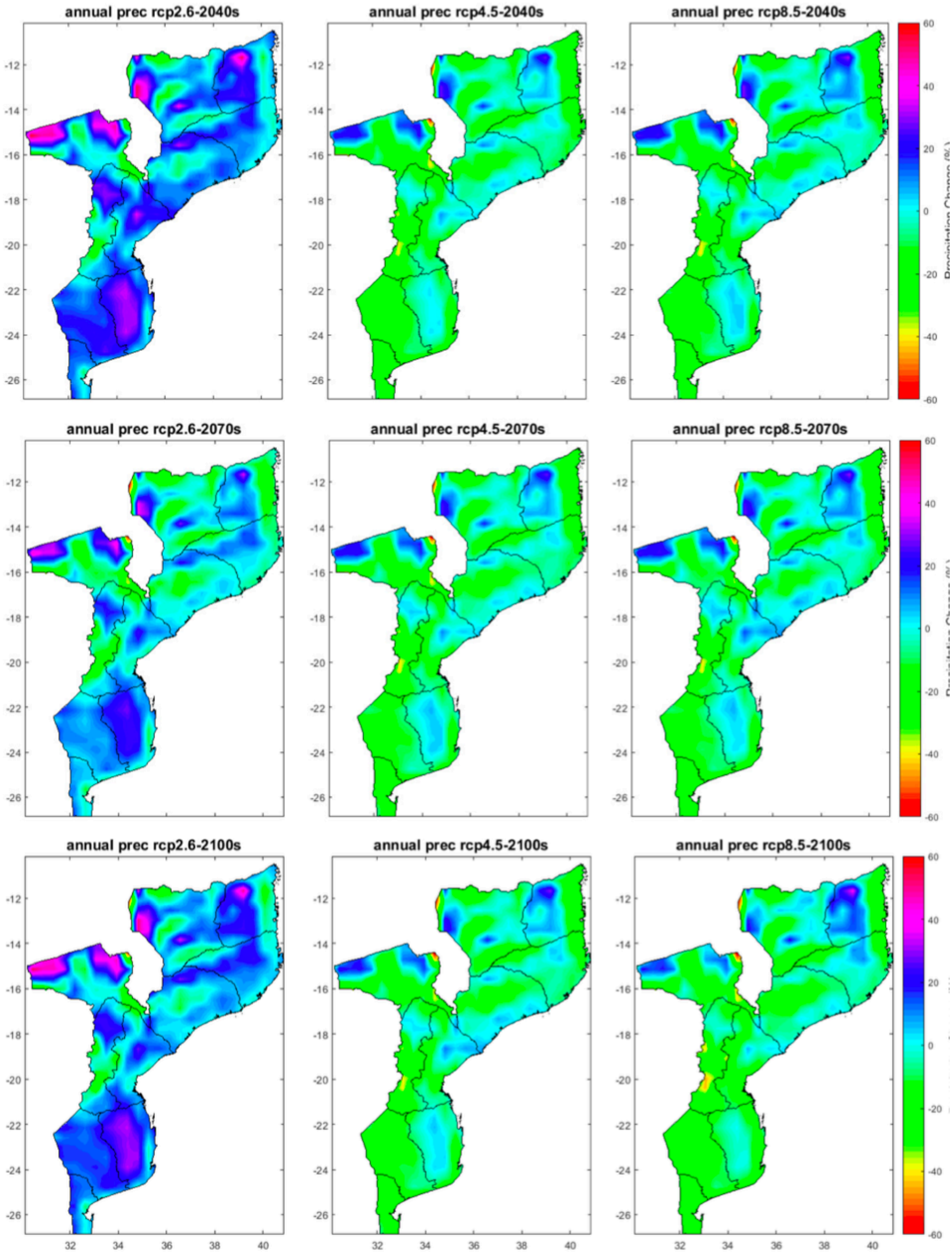

Figure A-3: Projected changes in annual precipitation (Mavume et al., 2021)

Implications for the Greater Maputo Region

As becomes evident from the forecasting by Mavune et al. (2021), temperatures in the Greater Maputo Region and the inland regions to the west are going to increase over time. In the coastal region specifically, precipitation is most likely to increase under the most optimistic RPC scenario, and decrease in the other RPC scenarios. In the inland regions, precipitation most likely increases in the most optimistic scenario and decreases in the other scenarios, but at much lower rates than the coastal region. Even more, in both regions interannual precipitation variations are becoming larger.

Furthermore, *table 4-5* indicate that the driest and hottest months in the Greater Maputo Region (June, July and Augusts) are likely to experience increasing temperatures and decreasing precipitation amounts. However, the months December, January and February will receive more precipitation in the 2070s. In a broad sense, for the inland region to the west of Maputo, it can be stated that the dry period becomes drier, and the wet period wetter. Whereas for the Greater Maputo Region itself it can be stated that both the wet and dry period become drier. This ultimately highlights the demand for an increase in water storage between the dry and wet season in both regions. *Figure 4-6* gives an indication of the Greater Maputo Region's climate according to the forecasting by Mavune et al. (2021) at the end of the 2040s period.

An increase in ambient temperatures (*table 4-6*) directly increases evaporation, whereby reducing ground- and surface water availability (du Plessis, 2019). Therefore, it is expected that the reservoirs that ensure water supply to the Greater Maputo Region, located in the inland southern region, will face increasing evaporation rates and thus experience a loss in supply (especially during the dry season). Research in Australia indicated that an increase of 1,1 °C of the mean annual temperature led to an increase in reservoir evaporation of 8%. This reservoir is located close to Brisbane (Helfer, Lemckert, & Zhang, 2012). Extrapolation of that data provides a rough estimate for the percentual increase in evaporation in reservoirs in the inland areas of the southern region of around 10%. It must be noted that a lot of factors influence evaporation, and that these differ greatly between Australia and Mozambique. For example, the humidity in Maputo is much higher than it is in Brisbane(Climate-Data, 2020).

In advance, the same is expected for groundwater reservoirs. Furthermore, rising temperatures increase agricultural water demand, as plants evapotranspiration rates increase and the soil's evaporation rates increase (Nhemachena et al., 2020). In advance, it was stated that agriculture is highly dependent on precipitation, therefore the decreasing and more variable precipitation patterns pose a great risk to food security in the region.

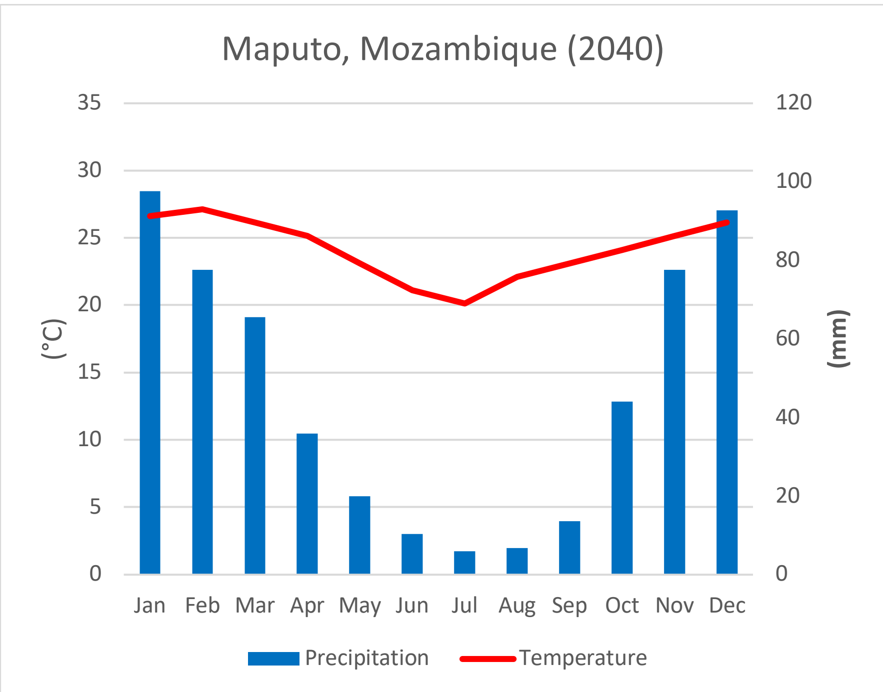

Figure A-4: Estimation of Maputo's climate in 2040 (RPC4.5) (source: author)