Trouble in Paradise: Water Scarcity & Quality in the Maldives

Insights from southern outer island communities on Muli and Kolhufushi

M.S.c. Thesis by Noortje Eline Lensvelt

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Water Resources Management Group

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RETENUE D’EAU

Water retainment

Water slips through your fingers, but the sculpture shows a way to grab it in a monumental way; using hundreds of plastic bags, almost holding 200 litres of water here. Water is not as easily available as we think, especially in times of climate change, pollution and wastefulness. In this work, artist Michel François, explores cause and effect and how human actions affect the status of everyday materials and objects.

This photo was taken at Museum Voorlinden in Wassenaar, the Netherlands, on 29 May 2024 and the sculpture is made by Michel François. It can be seen as representative of this thesis research. This water retainment artwork illustrates that every drop of water counts and that creative solutions are needed to best use our available water resources. In addition, proposed water management solutions need to be critically evaluated. Some systems and solutions are in use despite hanging by a thread, as illustrated in the artwork.

Abstract

Freshwater is a vital resource for inhabitants in the Maldives. Rainwater is mainly used for drinking and cooking, and groundwater for domestic household water needs like bathing, specifically by outer island communities. However, islanders face significant challenges with freshwater scarcity and quality. These climate and human-induced water freshwater challenges demand holistic strategies to tackle them. Aligned with UN Sustainable Development Goal 6, the Maldivian government tried to install desalination plants on each (outer) island by the end of 2023, intending to provide all inhabitants access to safe piped drinking water. However, local knowledge and interactions with the water supply systems have been understudied.

Instead of only focusing on building supply infrastructure, this research wants to understand better how local communities cope with freshwater scarcity and quality challenges and whether the installed pipe drinking water system matches the needs and wishes of the local communities. Therefore, this research provides insights into how local outer island communities in Muli and Kolhufushi, cope with freshwater scarcity and quality challenges in the waterscape, and how their sociotechnical imaginaries align (or not) with the dominant public water management paradigm. 25 household interviews and 5 key informant interviews were conducted on each island to examine this. In addition, two government officials working in the water sector were interviewed.

The research shows that having a dominant focus on supplying extra water tends to overlook other more informal and local methods, such as rainwater harvesting and groundwater extraction. Rainwater can fulfil many domestic water needs on the islands but is currently unused to its full potential. Better rainwater harvesting utilization could be considered and re-evaluated to cope with water scarcity and quality. Moreover, aquifer recharge methods, landscaping techniques and better wastewater management can offer alternatives and be supplementary to desalination water.

Moreover, the research emphasises that water services and quality could be more tailored to the users' needs, instead of always seeking new sources and supplies. In addition, attention could be paid to structural differences between groups in society and households, such as low-income households, to make solutions for sustainable water management more inclusive.

These insights aim to foster more dialogue and collaboration between stakeholders about water management and current practices to cope with freshwater scarcity and quality challenges in the Maldives via individual, community, and institutional efforts and support.

Acknowledgements

A leap of faith was my motto during the graduation process. I am very grateful for the opportunity to conduct my research in the Maldives as part of the 3SWater Project of IHE Delft. I tried to fully immerse myself in Maldivian culture by learning and exchanging as much as possible, and I could not have done this without the support of some very important people whom I would like to thank.

First, I would like to thank my project supervisor, Assela Pathirana, for his encouragement and support in conducting my thesis research. I am also very grateful to my study supervisor Alex Bolding, for his valuable feedback that enriched my learning curve by constantly asking challenging questions, his listening ear and continuous support throughout the process.

During my data collection phase, I received much support and a warm welcome on the islands. Therefore, I would like to thank the people who helped me in the field sincerely, the 3SWater Project members and Community Engagement Linkage (CEL) team members. In particular, I would like to thank Ahmed Hassan, Luayyu Adam, Ali Mishal and Tharika Fernando for their invaluable support during the data collection and my stay in Kolhufushi and Muli. I would also like to thank the Island Council members on Muli and Kolhufushi for their hospitality, tour of the island, and support during my data collection phase. In addition, I would like to thank Arthu Rasheedha and Haleemath Hanaan Habeeb for their translation support during the interviews and focus groups.

Moreover, I would like to thank my host families for their hospitality and for making me feel at home. On Kolhufushi I was hosted by Mariyam Aqula and Tholhath Sobeeb. Thank you for making your home feel like mine. On Muli, I was hosted by: Rukhsana Mohamed, Ali Riza, Fathimath Raya Ali, Mohamed Rizan Ali, and Sarooj Mohamed. Thank you for your warm welcome, kindness and support. In addition, I want to thank the women's volleyball team on Muli and the women's handball team on Kolhufushi for allowing me to be a part of their teams and for the great friendships formed by playing together almost every day. I also want to thank Paula Heron. We met on Muli, and a special friendship blossomed despite our age difference. Thank you for sharing so many wonderful experiences with me.

Finally, I would also like to thank family and friends for their support during the process, and for offering a listening ear and for discussing topics and ideas. Patrick Marriott, thank you for bearing with me during the thesis process and reading along. I also want to thank my study friends Matthieu Gasowski, Sjoerd Pieters, Isabel Romijnders and Maartje Scholten. We started the thesis process together and supported each other in different phases during our thesis process. Thank you for sharing the experience, the insightful feedback and endless support!

I hope you will enjoy reading my thesis and that it will provide you with some food for thought!

Contents

Figures, tables, boxes and pictures

List of Figures

List of Tables

List of Boxes

List of Pictures

Abbreviations

IC	Island Council
MMS	Maldives Meteorological Services
MTCC	Maldives Transport and Contracting Company
NWP	National Water Policy
PPP	Public Private Partnership
RO	Reverse Osmosis
SDIS	Small Developing Island States
URA	Utility Regulatory Authority
WDC	Women Development Center
WHO	World Health Organization

1.Introduction

1A. Background

The vulnerability of the Maldives, a small island developing state

Small Island Developing States (SIDS) are extremely vulnerable to climate change. Due to their relatively low elevation and high coast-to-land area ratio, they face risks such as sea-level rise, marine heatwaves, and cyclones, leading to marine inundation, coral bleaching, and habitat loss (IPCC, 2022; Hoegh-Guldberg, 2019; Barnett & Waters, 2016). There is also limited capacity to respond to extreme events. Challenges arise, such as competition for land use and inadequate urban planning, parallel to unsustainable resource extraction, and ineffective water management (Thomas et al., 2020; Kelman, 2014; Bambrick, 2018). SIDS economies rely mostly on sectors like tourism and can be severely affected by events like the COVID-19 pandemic (Gu et al., 2022). This all together, heightens their vulnerability, which varies per island based on context, scale, and socioeconomic differences (Stennett-Brown, 2018; Voccia, 2012). Notably, certain groups such as squatters and female-headed households, reliant on natural resources, can face higher vulnerability due to factors such as gender disparities and cultural norms (Thomas et al., 2020; Shah et al., 2013).

The Maldives, categorized as a SIDS, also faces these vulnerabilities. Situated southwest of Sri Lanka and India, the Maldives comprises 1192 islands organized into 26 flat coral atolls (Thoha, 2020; see Figure 1.1). The archipelago covers some 90,000 square kilometres and these contain 3.1% of the world's coral reefs (Stevens & Froman, 2019). Only five per cent of the reef surface is land in the Maldives (Jaleel, 2013). Of the 1192 islands, only 187 are inhabited, of which approximately one-third of the population resides in the greater Malé area, including the capital Malé (with 153,904 residents on 205.54 ha of the total 401,695 Maldivian citizens). Most other inhabited islands are sparsely populated, and about 168 islands are tourist operations and holiday resorts. Part of the remaining uninhabited islands are used for agriculture and commercial development (Maldives Bureau of Statistics, 2023; Ministry of Tourism Republic of Maldives, 2021). The terrain of the islands is mostly low and flat, typically elevated 1 meter above the average sea level. Hence, they are highly impacted by the impacts of climate change, such as rising sea levels and unpredictable rainfall (Mohamed et al., 2020).

Figure 1.1: Map of the Maldives (Maldives Facts, 2023).

The economy relies heavily on fishing and tourism, leading to a high dependency on the import of services and goods (Ghina, 2003). High-end tourism is the main economic driver for growth, that lifted the country to its upper-middle-income status (de Alwis Jayasuriya, 2022; World Bank Group Poverty

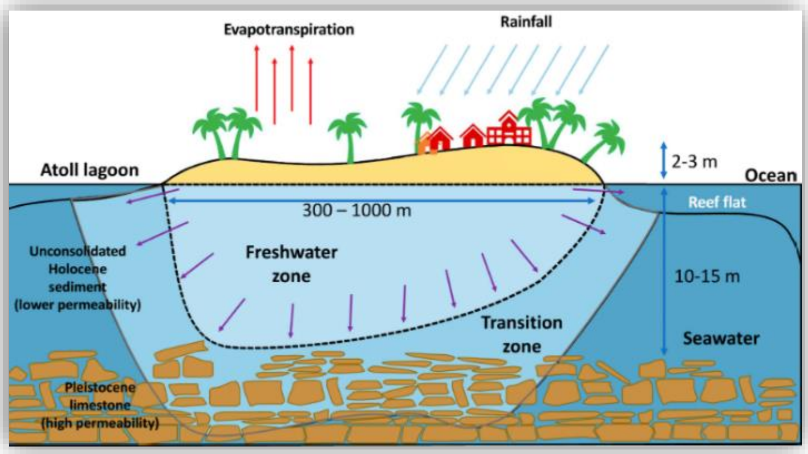
& Equity, 2023). However, overall national indicators and progress mask underlying disparities. Regional differences exist in human development indices, notably between the capital, Malé, and the outer atolls, where 93% of the poor live (Green Climate Fund, 2015; World Bank Group Poverty & Equity, 2023). Currently, there is an increasing number of discouraged youth leaving the labour market in the atolls, leading to overcrowding in urban areas. This becomes reinforced because the greater Malé area also offers the best public services (Maldives Bureau of Statistics, 2023; Green Climate Fund, 2015). In addition, gender disparity worsens spatial differences; women in atolls beyond the capital face disproportionate challenges due to unequal opportunities (Green Climate Fund, 2015).

Therefore, the dispersed population, due to geographical distribution in the Maldives, faces challenges to inclusive development, leading to significant disparities in healthcare, education, and employment opportunities between urban and rural areas in the outer atolls and islands. This results in marginalized communities, mainly in the outer islands (Thoha, 2020). The vulnerability of the inhabitants on these islands is further shaped by the fragile nature of its water systems, which the communities rely heavily on. Yet, these freshwater resources are threatened in the Maldives.

Threatened freshwater resources in the Maldives

Water sources can be divided into conventional and non-conventional sources (Falkland, 1999). Conventional sources include groundwater, rainwater, and surface water, and non-conventional sources include treated wastewater, imported bottled water, and desalinated water (Wickramagamage, 2017). In the Maldives, conventional water sources are limited to groundwater and rainwater. Apart from a few mangroves and wetlands, the Maldives lacks rivers and streams (Ibrahim et al., 2002). Hence, rainwater and groundwater are the primary freshwater sources for the Maldivian islands.

Figure 1.2: A conceptual image of a typical aquifer of the islands, adapted from Terry et al., (2013). The vertical scale is highly exaggerated (Mohamed et al., 2020).



Groundwater scarcity is a significant challenge due to the island's composition in the Maldives. The islands primarily consist of coral reefs and sand bars, resulting in an unusually shallow aquifer (Lee et al., 2008; Leoni et al., 2021). Groundwater in these coral islands is stored in thin basal aquifers, at 1–1.5 m below the surface, forming a thin layer, referred to as a *freshwater lens*, which floats on denser seawater (see Figure 1.2; Mohamed, 2020). This shallow freshwater lens is being recharged by rainwater seeping through coral sands (White et al., 2007). The vulnerability of groundwater in coral islands like the Maldives arises from the carbonate rock bedrock (Pleistocene limestone), which dissolves in rainwater, creating permeable karst landforms (Mohamed et al., 2020). These landforms, with open fractures and caves, allow easy contaminant transport, especially saltwater intrusion, making the aquifer fragile (Hartmann et al., 2014; Medici et al., 2019).

The size of a freshwater lens depends on factors such as island shape and size, vegetation cover, hydraulic conductivity (high conductivity results in depth decrease), and island elevation (Bailey et al. 2009; Hartog & Stuyfzand 2017; Chen et al., 2021). Moreover, coral islands' freshwater lens size and quality depend on rainfall, human activities such as pollution and extraction, and ocean interactions linked to rising sea levels and salinity. The freshwater lens is fragile to saltwater intrusion, and specifically, after the Indian Ocean tsunami in 2004, the freshwater lens was heavily damaged and became brackish (Acciarri et al., 2021; Saeed & Ibna, 2021). Moreover, salinity in the freshwater lens increases with a higher population density in the Maldives (Mohamed et al., 2020; Julca & Paddison, 2010). The limited aquifer capacity can only support small island populations (Wickramagamage, 2017).

The demand for freshwater comes from different sources, including domestic use of islanders, the tourism industry, agriculture, and industrial activities. Traditionally, Maldivians relied on groundwater for their daily water needs, including drinking, under low populated densities. However, as the population grew, three main problems arose (Wickramagamage, 2017). First, there was the inadequacy of the freshwater lens in supplying the increased per capita water needs due to the growing and larger population. Second, the volume of the groundwater lens decreased due to decreasing recharge caused by: increasing impervious surfaces, rainwater harvesting systems, and more water pumps (over-extraction). The third problem was pollution of the groundwater lens, mainly through the non-existent or inadequate sewer system network on islands (Wickramagamage, 2017). Previously, there were often poorly maintained septic tanks by households, leading to pollution through the discharge of wastewater in the groundwater. In addition, most households' septic tanks and groundwater wells are near each other, which resulted in more groundwater pollution (Mohamed et al., 2020).

The government advised not to drink groundwater anymore because of the bad water quality, specifically after the tsunami in 2004 (Wickramagamage, 2017). Nowadays, groundwater is primarily utilized for activities such as washing, bathing, and flushing toilets and it is occasionally used for cooking (Wickramagamage, 2017; Mohamed et al., 2020; Pathirana, 2022). Rainwater replaced groundwater as the primary drinking source in the Maldives around the 1980s (Wickramagamage, 2017). Rainwater is captured through rainwater catchments (rooftops) and stored in rainwater tanks. The climate in the Maldives is affected by monsoons, and between the monsoons, a dry period (from January to April) occurs (Maldives Meteorological Service, 2023). Even though the Maldives has substantial annual rainfall, ranging from 2320mm in the south to 1700mm in the north, the rainwater stores can run out during the dry season, because of a lack insufficient water capacity storage system for a dry period lasting for more than two months (Shakeela, 2015). Moreover, rainwater has become more unreliable due to climate change and higher rainfall variabilities (Mohamed et al., 2020; Ministry of Tourism Republic of Maldives, 2021).

In the dry monsoon period, potable water is currently shipped from Malé to the outer islands when the Island Councils (face emergencies (Castaldo & Malatesta, 2021). Approximately 80 to 88 islands (out of the 187 inhabited islands) depend on these annual deliveries, coordinated by the National Disaster Management Centre (NDMC) and alerted by the Ministry of Environment through local municipalities. Utility companies (like Feneka) handle water treatment, collection, and shipment, utilizing ships leased from private firms. However, this method is costly and risky due to long lead times and potential contamination during transportation. Some islands frequently request emergency water, revealing a dependency trend that worsens as local municipalities often do not cover shipping costs (Castaldo & Malatesta, 2021). This leads to an (over) reliance on expensive bottle-packed water, which is not affordable for everyone. Moreover, empty plastic bottles are often not properly recycled and are instead discarded in public spaces, harming the island's environment and ecosystems (Pathirana, 2022).

The bigger islands and tourist resorts, however, primarily rely on desalination plants for their water needs. Desalination is a method that separates dissolved salts from saline water (Panagopoulos, 2021). The first municipal water and sewage supply project began its services in 1995 in Malé and was subsequently extended to other highly populated areas, including all tourist resorts. The tourists' requirements are fulfilled entirely by desalinated water, with drinking water being imported as bottled water from other areas (Wickramagamage, 2017; Jaleel et al., 2020). By the end of 2017, a public desalinated water system became available to 49% of the local population (Jaleel et al., 2020). The government aimed further to extend desalination water systems to all inhabited outer-islands by the end of 2023 with new policies.

Safe and secure water provision commitments of the government

It is a human right and part of the UN Sustainable Development Goal 6 to access clean water and sanitation (United Nations, 2023). The Maldivian government committed to ensuring equitable access to safe water and improved sewerage services for all inhabited islands by 2023, due to the freshwater challenges, specifically in the dry monsoon period (Ministry of Environment Republic of Maldives, 2020; Thoha, 2020). The National Water and Sewerage Strategic Plan (NWSSP 2020-2025) was endorsed in 2020, with the main target to implement piped drinking water systems on all the inhabited islands by 2023. This piped drinking water system utilizes desalinated water and rainwater (Ministry of Environment Republic of Maldives, 2020).

Although the aim is that all households are connected to this piped system, a significant number of residents did not make use of tap water yet on the outer island Mulah, part of the Southern Meemu atoll, where a piped drinking water system was installed in 2018. Even though all the households were connected, many residents did not use the tap water mostly due to cost reasons (Pathirana, 2022). In most outer islands, it remains unknown how local communities interact and adapt to the water resources and systems in place and which coping strategies they employed previously to ensure freshwater security. This knowledge gap needs to be addressed to safeguard secure and safe water resources.

1B. Problem Statement

Freshwater is a vital yet scarce resource for the inhabitants of the Maldives. The complex interactions between climate-related and human-induced factors impact both freshwater scarcity and quality (Leoni et al., 2021). Simultaneously, with the Climate Change and the shifting socio-economic and demographic landscape of the Maldivian population, there is a need to enhance and update the water supply facilities (Saeed & Ibna, 2021). The government recently (by the end of 2023) installed piped drinking water systems on all inhabited islands. However, two issues remain unclear (1) how local communities currently cope with freshwater scarcity and quality issues and (2) whether the current proposed technology of the installed pipe drinking water system matches the needs and wishes of the local communities.

Instead of only focusing on building supply infrastructure, this research wants to create a better understanding of how freshwater resources are currently used, how the various sources of freshwater are experienced and how people cope with freshwater resource scarcity and quality. The study also examines how current and proposed technologies influence people's coping strategies.

In addition, there is often the perception that awareness needs to be created about the advantages of sustainable drainage systems and water systems and the quality of water and that knowledge is limited amongst the general public and the target populations (Saeed & Ibna, 2021). The starting point of this thesis research is to assume that there is a lot of knowledge of local people's water-related problems since they need to cope with them in their everyday lives. The specific case study islands are Kolhufushi and Muli, which are both also part of the Meemu atoll in the South of the Maldives.

1C. Objectives

Short-term research objective

To create a better understanding of (1) the island-level water supply system in connection to the water sources available and (2) the water users' access, preferences, and coping strategies of households portrayed in (3) the waterscape of the physical water environment, as well as the organisational forms of institutions, regulations and different societal actors like the government and the water suppliers. The emphasis will lie on understanding the local ways of knowing and interacting with the water supply system.

Long-term societal objective

The short-term insights are crucial for enhancing residents' ability to have access to secure and safe water. I hope this research will start more dialogue between the different actors in the water sector (supply-demand side) and that the insights provided can serve as a foundation for improving water security and quality on the islands, using individual, community and/or institutional efforts and support.

1D. Research Questions

Main research question

How do local communities in Kolhufushi and Muli in the Maldives cope with freshwater scarcity and quality in the waterscape, and how do their sociotechnical imaginaries align (or not) with the dominant public water management paradigm?

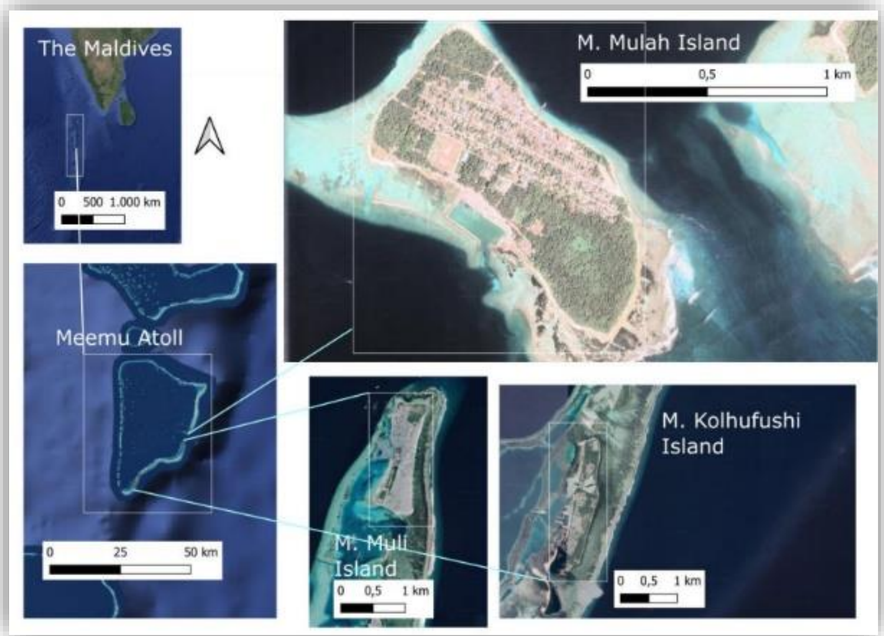
Sub research questions

1. *How did the waterscape of Kolhushi and Muli evolve over time and what are its main characteristics?*
2. *What are the general freshwater usage experiences, access obstacles, and coping strategies of local communities, and how do these differentiate amongst relevant social groups in Muli and Kolhufushi?*
3. *What dominant public water management paradigm has emerged in the Maldives, and how do the sociotechnical imaginaries of local communities on Muli and Kolhufushi align (or not) with this paradigm?*

1E. Focus Study Area

This research is part of the IHE Delft 3SWater Project, which started in 2022. The project's overall objective is to transform the social-ecological system from a degraded state to a sustainable and climate-resilient one to support the livelihoods of marginalized groups who critically depend on them. The project focuses on three outer islands, Muli, Kolhufushi & Mulah within the Meemu Atoll, which is seen as one administrative unit, see Figure 1.3 (IHE Delft, 2022). General information on the Maldives is provided first, followed by background information on the Meemu Atoll, including the islands Kolhufushi and Muli.

Figure 1.3: Three candidate islands of the Meemu Atoll: Mulah, Kolhufusi, and Muli for the 3SWater Project of IHE Delft (IHE Delft, 2022).



Republic of Maldives

The Republic of Maldives has a unique geography and cultural homogeneity, primarily regarding language (Dhivehi) and religion (Islam). Unlike many nations, the Maldives was never fully colonized. However, the Portuguese attempted to assert control in the 16th century, and it was a British protectorate from 1887 to 1965, with no interference in internal affairs. In 1968, the Maldives gained independence and became a republic. The 25 atolls are organized into 20 administrative atolls, and the capital island, Malé, forms a separate administrative unit (Shaljan, 2004).

The climate in the Maldives is affected by the monsoons. Due to its equatorial location, the average temperature remains around 28°C, and the area receives approximately 2121 mm of rain annually (Ministry of Tourism Republic of Maldives, 2021). The terrain of the islands is mostly low and flat, the maximum elevation is 2.5m. and 80% of the islands are below 1m from mean sea level (Wickramagamage, 2017). Only 6% of the islands feature wetlands and/or mangroves, many of which face clearance or degradation due to housing, tourism, commercial activities, and agriculture. Rapid economic growth, particularly driven by tourism in the past decades, has led to notable eutrophication in lagoon waters around tourist resorts and inhabited islands, along with an increase in seagrass beds in these regions (Stevens & Froman, 2019). Intense pressure is put on the limited land area of the country and individual islands due to both tourism and population growth (since the 1960s, the population has approximately doubled every 25 years) (Maldives Bureau of Statistics, 2023; Ministry of Tourism Republic of Maldives, 2021; Duvat, 2020).

In 2019, tourism contributed almost 30% to the country's GDP (see Figure 1.4). Tourism sector growth elevated the country to upper-middle-income status and the high human development category (de Alwis Jayasuriya, 2022). Yet, despite its socioeconomic progress, the nation embodies the typical 'island paradox' (UN, 2012). Its relative prosperity, stemming from domestic income, exists alongside growing vulnerability to external shocks, such as tourism sector contractions, climate change, rising global fuel prices, and high structural costs due to its unique geographical features (Green Climate Fund, 2015). In specific, the Maldives suffered heavily from the tsunami in 2004 and the COVID-19 pandemic. (Ministry of Tourism Republic of Maldives, 2021). Even though the country has an upper-middle-income status and the poverty rate is low (in 2019 – 3.9%). Welfare disparities across atolls remain a big concern, see Figure 1.5 (de Alwis Jayasuriya, 2022; World Bank, 2023).

Figure 1.4: GDP contribution by major economic sectors of the Maldives in 2019 (Ministry of Tourism Republic of Maldives, 2021).

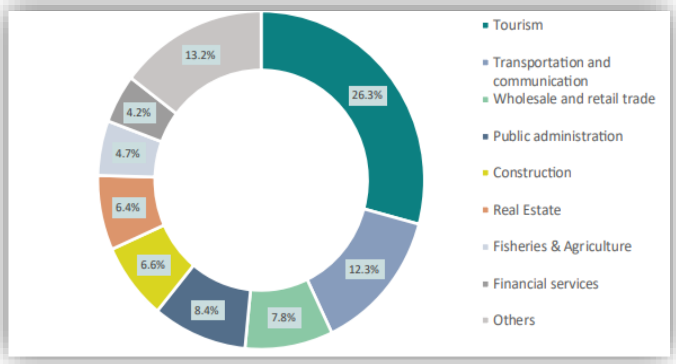
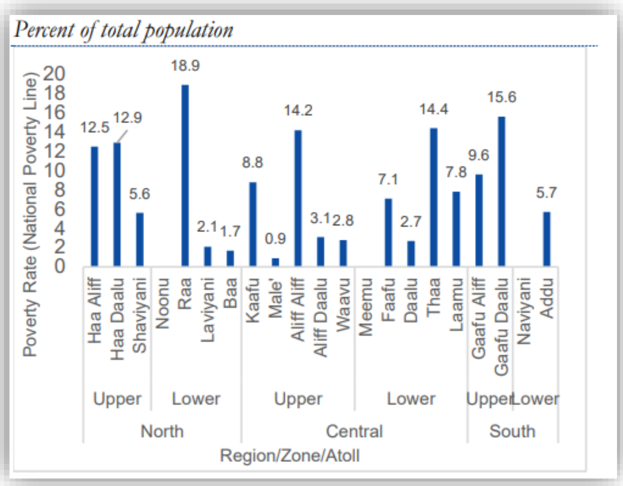


Figure 1.5: Welfare disparities across atolls in the Maldives based on poverty rates. Note: Upper middle-income poverty line = 6.85 US dollars per day (World Bank, 2023).



Meemu Atoll

Each atoll in the Maldives is governed by an atoll council based on the main island of that atoll. Moreover, each island has its own Island Council (from now on referred to as the IC). The IC oversees the island's development plans and has similar functionalities to a municipality. The Island Council consists of five people, is elected by the islanders, and rules for five years. Moreover, each island has a Women Development Center (WDC), consisting of five women. The WDC aims to support women in the community through various initiatives. It organises projects such as domestic violence awareness sessions and sports activities. Women are also responsible for coordinating a waste clean-up project on the island (W.M. Wafir[1], personal communication, November 19, 2023).

The Meemu Atoll is characterized as an isolated atoll, with an open lagoon enclosed by straight, wide barrier reefs on its western side (Tharika, 2023). The lagoon inside has smaller shoals compared to those in the Northern Atolls, featuring numerous coral patches and sandy areas in water depths ranging from 28 to 40 fathoms (1,829m/fathoms). It is also part of the UNESCO Biosphere Reserve (Tharika, 2023). The Meemu Atoll stretches 48 km in length and consists of eight inhabited islands, namely

[1] . M. Wafir is the senior council officer of the Island Council of Kolhufushi

Kolhufushi, Maduvvaree, Dhiggaru, Mulah, Muli, Raimmandhoo, Naalaafushi and Veyvah (Aleem, 2016). Muli is the capital island of the atoll, however, Mulah has the most residents of the islands (Maldives Bureau of Statistics, 2023). The islands Kolhufushi and Villufushi islands were hit hardest by the tsunami in 2004, which were the islands where maximum tsunami amplitudes were recorded (Rasheed et al., 2022).

The specific islands, Kolhufushi, Muli, and Mulah are part of the 3SWater project area. The communities living there are relatively voiceless and underprivileged due to a combination of economic, geographic, socio-economic and hydrologic factors (IHE Delft, 2022). Moreover, they are also more vulnerable because of freshwater resource issues and climate change (sea level rise and less reliable rainfall patterns), impacting their water systems. More information about the islands Kolhufushi and Muli will be given in Chapter 4.

Mulah has had a water supply system with connections to all the households on the island since 2018 (Aleem, 2016). However, it is not in optimal use yet. The system was only recently installed on Kolhufushi and Muli. By the end of 2023, and during the data collection phase, it was in a trial period. This research will focus on the Kolhufushi and the Muli islands since there is a knowledge gap about the islanders' practices and interactions with the water supply system(s).

2. Theory Conceptualization

The aim of the research is to create a better understanding of what is happening on the ground with the water supply system by looking at human, technology and water interactions. Hence, this research was conducted through a grounded theory method, with the aim to develop theories that are ''grounded'' in systematically collected and analysed data. Rather than pre-testing or confirming existing theories, this method takes an inductive approach where researchers try to discover themes, patterns and concepts that emerge directly from the data. This thesis tries to give an alternative and innovative conceptualisation of looking at water management. This chapter starts by providing a theory conceptualization overview of the concepts and linked theories. This is followed by more detailed explanations of the concepts and theories applied per chapter; see the three numbers in Figure 2.6.

2A. Overview Theory conceptualization

First, some clarification of concepts will be given, in order to answer the main research question: *How do local communities in Kolhufushi and Muli in the Maldives cope with freshwater scarcity and quality challenges in the waterscape, and how do their sociotechnical imaginaries align (or not) with the dominant public water management paradigm*?

There are different water resource types this research will emphasize; **freshwater resources** for domestic household needs and potential drinking water, and domestic wastewater. Other water resources, which will not be addressed in the research, are; water for industry; industrial wastewater; water for irrigation—from surface water sources; drying water.

Water quality can be defined as the chemical, physical, and biological characteristics of water necessary to sustain desired water uses (United Nations Economic Commission for Europe, 1995). Contamination levels are determined by various components, like pathogens, organic matter, macronutrients, salts, heavy metals, and chemicals like plastics and pesticides (Vörösmarty et al., 2005).

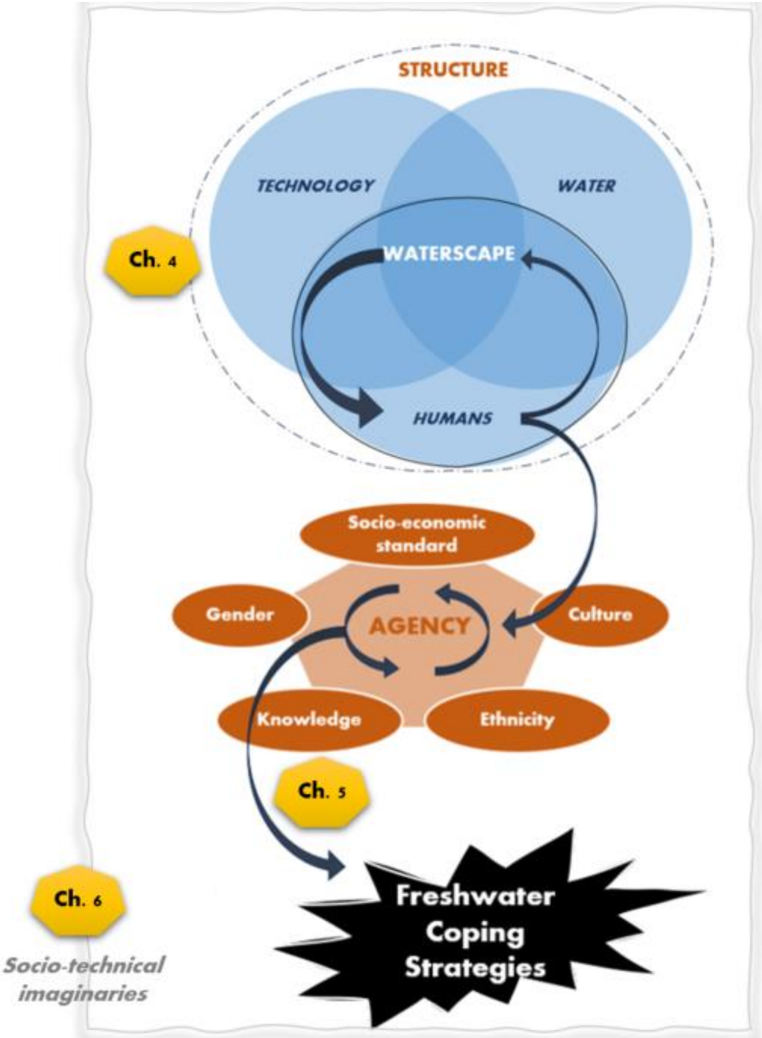
Water scarcity can be seen as: "*The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*'' (UN-Water, 2022). Water scarcity is determined than more than just biophysical availability of water, but also by social, political, economic, and technical factors that shape it (Zeitoun, 2011). Water scarcity is disproportionately experienced by marginalized and poor social groups (Ribot, 2010; Zeitoun, 2011).

Coping strategies can be defined as the responses and adaptations individuals and households employ to address water challenges (Venkataramanan, 2020). These responses and adaptations can manifest themselves in concrete and practical actions that people undertake to address their problems. This makes them tangible; hence, the research will focus mostly on this. Coping strategies and activities need to be understood in their particularity, and it is important to study motives and interpretations intimately from the inside, not just remotely from without (Whittington, 2010). The research will also address this since it highlights why certain people make certain choices and what their agency is to do so.

How islanders cope with freshwater scarcity and quality challenges depends on the setting in and their own behaviour and capacity to act. Giddens's **structuration theory** (1984) is the guiding line in this research. It helps to understand the interplay between structures (such as institutions and norms) and individual agency (the ability of individuals to act independently). It argues that social structures not only limit and facilitate individual actions but that individuals can also influence, renew, and change these structures through their actions and interactions. Structure and agency recursively reproduce and constitute each other.

This study will refer to the structure and context in which water users navigate as **the waterscape**. A waterscape is a natural social space that is co-shaped by power practices and relations in which social and material processes interact and integrate historical contexts and decisions (Swyngedouw, 1999). The waterscape's key elements in this research are: humans (their interactions and institutions), water, and technologies (and infrastructure). Although the water landscape is dynamic and constantly changing, it provides insight into the setting and specific structure in which people can manoeuvre in. The waterscape can be analysed on different levels. The waterscape and its evolution over time on island level on Kolhufushi and Muli will be described in Chapter 4.

Figure 2.6: Schematic overview of theory conceptualization to showcase linkages and relations between the concepts. The chapters where the main concepts will be applied are included, referred to as e.g. Ch. 4 – Chapter 4 (author's work, 2024).



The research then zooms in on humans' interactions within the water landscape and their agency (ability to act) to apply certain coping strategies to secure freshwater sufficiently and of reliable quality in the waterscape. Agency is the ability to implement coping strategies and manage water resources in this case (Giddens, 1984). Common strategies employed by households will need to be examined, with particular attention paid to intra-household dynamics and individual choice, since not all households can be painted with the same brush.

Someone's agency and coping strategies depend on resource access, decision-making power, and vulnerability to water-related issues (Venkataramanan et al., 2020; Hale et al., 2015). This is shaped by an interplay of individual factors like someone's race, class, and socio-economic status, also referred to as **intersectionality factors** (Atewologun, 2018). The intersectional factors and their interrelationships create a network of variables that form the context in which human agency manifests. People's agency is, therefore, to a large extent, moderated by intersectional factors, such as race, age, gender, wealth, education, and things like the strength and span of one's social network. Emphasising intersectionality creates an understanding of why specific groups (such as women) might have different experiences and coping strategies.

Lastly, structure-agency relationships in society are embedded in institutional institutions and social structures. Chapter 6 examines the government's dominant water management paradigm for addressing water scarcity and quality challenges. A **dominant water paradigm** refers to the prevalent framework of beliefs, practices, and methods that shape how water use and management are understood and carried out in a particular society or given context.

The dominant water paradigm is then mirrored against the sociotechnical imaginations about desalination technology of local communities on Muli and Kolhufushi. **Sociotechnical imaginaries** are *"collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology"* (Jasanoff, 2015, p.6). Analyses of these representations explore how communities create narratives about technological development and its potential to improve lives (Tidwell & Tidwell, 2021). It can help to show how people value technology and their willingness to support various technological development paths (Kuchler & Bridge, 2018). Because desalination technology has recently been installed on Muli and Kolhufushi, narratives about this technology will be examined to understand whether desalination technology works for islanders on Kolhufushi and Muli for whom and why.

2B. Overarching Theory: structure-agency relations

The structure-agency theory of Giddens (1984) helps to understand the interplay between social structures and individual agency in shaping society and behaviour. Individuals can act within existing structures and can even change them by using, challenging or transforming resources, ideas and rules (Whittington, 2010). Agency can be seen as the capacity, skill and will to act within a certain context. The structure can be seen as the framework or context where an individual or group agents make choices. The structure determines the resources available to agents, and includes formal and informal rules guiding the behaviour of agents, and influencing their strategies (Healey & Barrett, 1990). Hence, social structures can limit and enable human actions (Whittington, 2010). The agency of an agent depends on the resources available in the structure, the control of the agent over resources and the ability to influence rules to act. Rules have a broad meaning and include legal rules and less formal customs, routines, conventions, and procedures (Whittington, 2010). Resources can exist in the form of materials and objects, but also control of people, also known as authoritative resources.

I argue that the waterscape can also be seen as a structure in society, since it forms the main context in which water users (the agents) interact with water, humans and technology. Local island communities interact in this structure, resulting in certain coping strategies for (better-quality) freshwater security. Coping strategy is all about resources, both the material resources that are the subject of strategy and the authoritative resources, that grant decision-making power over these resources. People have more agency opportunities, the more structural resources they possess, and the more pluralistic the rules they can negotiate (Whittington, 2010).

However, a limitation of structuration-inspired research is that researchers often tend to neglect social structural context (Whittington, 2010). It is also necessary to address institutional bias to understand the larger social structures or institutions in which strategy takes place, and of which strategy itself is a component. Hence, structuration theory requires research across the spectrum: the broad analysis of institutions and the detailed practice study. Therefore, this research will look at the micro-level and specifically the coping strategies that people and households employ. It will also address the dominant governmental water paradigm, policies and proposed dominant solutions.

In addition, it should be acknowledged that successes and the state of today, derive from what happened in the past, also in the distribution of resources. As the critical realist scholar Bourdieu (1988) argues, agents can usually do no more than improvise within limited margins, depending on the capital distribution which can be considered fixed. Nevertheless, opportune intervention within certain limits can make a difference. Such episodes may be a strategic negotiation, where success depends less on necessity and more on personal connections and privileges. Critical Realists emphasise appreciating hierarchical power and interests within structures (Whittington, 2010).

I agree with the critical realist approach that structures are deep-rooted, resulting in different hierarchical distributions of resources and possibilities for action by various people in society. Taking the structure as a starting point, emphasizes structural differences of distribution of resources and inequalities between groups in society. This also leads to divergent ways of acting and diverse coping strategies. The critical realist approach also acknowledges that bringing about change in existing structures also requires going against elite interests and dominant power relations. Moreover, it is more likely that collective action will bring about change instead of individual struggle as scholar Archer (1995) argues. The critical realist approach doesn’t necessarily go against the conciliatory ‘duality’ of Giddens (1984), it can be seen as an addition.

2C. The Waterscape

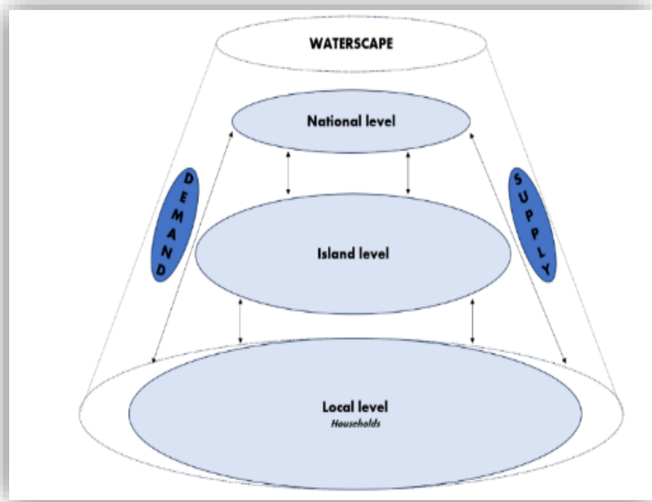
Water supply goes beyond merely observable mechanical and material considerations, such as pumps, pipelines, treatment plants, and taps. Instead, it forms an intricate web of institutions, laws, market regulations, demand fluctuations, consumer choices, rainfall trends, and hydrological processes, extending beyond the physical manifestation in concrete structures (Bakker, 2003). Technologies are often also solely seen as physical objects, focused on their creation and use. However, embracing a more anthropological perspective, technologies are understood in a way where they surpass their material form; it encompasses human bodies, skills, traditions, practices, processes, and sociotechnical systems for a comprehensive conceptualisation (Bruun et al., 2022). Policies tackling water scarcity often fail to create sustainable improvements because they overlook these dynamics (Lindqvist et al., 2021). Therefore, comprehending the co-evolution and interaction of human-water-technology systems and their social aspects is crucial for addressing challenges in sustainable water management.

This research uses a political ecology approach by looking at the waterscape. Swyngedouw (1999) introduced the term waterscape, where power practices and relations co-produce a natural social space. By seeing the social and the material as two mutually interacting and changing processes, this strategy avoids creating dichotomies between them. It places the water supply in a historical context, contending that yesterday's decisions shape today's decisions. The waterscape ties together social processes and refers to the real physical results of these historically generated phenomena (Swyngedouw, 1999; Swyngedouw, 2009). Those interactions shape how water moves, enables, or constrains water decisions, including water-related behaviours and how water quality and quantity changes through the system (Hale et al., 2015).

This entails observing all practices in relation to the island water supply, consisting of the main components of water, humans their institutions, technology and the existing infrastructure (see Figure 2.7). Those are all influenced by power dynamics, determining how water is divided, what works, and for whom. These interpersonal relationships are fluid. Through interactions between the many players and changes in their perceptions, interests, and aims, they are continuously being (re)shaped. Therefore, it is important to consider waterscapes as very dynamic.

The waterscape manifestations can be studied on different scales (on the national, island, and local waterscape level). Moreover, it differs per location (spatial and/or geographical areas), time (the periods during which processes or events take place), and domain (the specific context/different fields of study or areas of interest within a particular subject). External factors such as climate, economics, institutional arrangements, etc., can also influence the waterscape. Since the waterscape is so dynamic, the starting point of the research is looking at observable realities regarding freshwater resource availability and water supply infrastructure and systems. Those are, in turn, all influenced by different actors and their behaviours and vice versa. Therefore, sociotechnical water networks are made within a waterscape.

Figure 2.7: The different scales at which the waterscape can be studied (author's work, 2023).



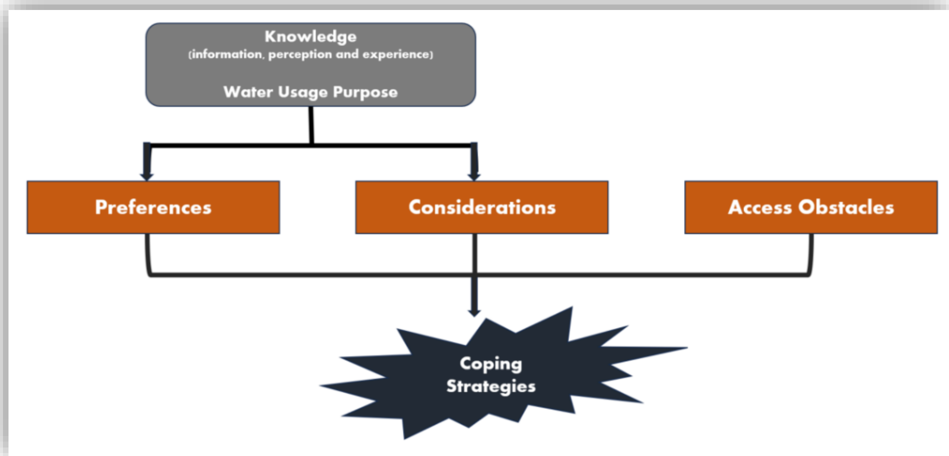
There are several approaches to analysing a water landscape. At the macro scale, this research focuses on government policies, dominant visions and policy strategies related to water and sanitation. This will be addressed in Chapter 6. At the mesoscale, the island level is studied, focusing on water sources, water and sanitation companies, the IC and the local community, which will be described at Chapter 4. At the micro-level, 25 households are examined, serving as representative units of analysis for the local communities on the islands, which is examined at Chapter 5.

2D. Domestic water management Coping Strategies and differentiation among people through Intersectionality Factors

Coping strategies are actions and tactics executed to cope with freshwater scarcity and quality challenges on the islands. They vary per area and are reliant on the availability of the requisite social, economic, and technical resources to exploit water resources (Ashton, 2002). For example, common water scarcity coping strategies are creating mini-water schemes, protecting natural springs and ponds, collecting rainwater, and using less water-intensive sanitation systems. This research will mainly look at behavioural and infrastructural coping strategies in households.

Coping strategies are based on decisions made and influenced by the available water system(s), the actors' needs, and their understanding of water quality and quantity. Hence, people base their coping strategies and decision-making process on several aspects: the water usage purpose, knowledge of the water system, and quality (Hale et al., 2015). This also creates certain preferences and considerations regarding water. This, taken together with the access to the water sources (and the obstacles) determines the coping strategies of people (Venkataramanan et al., 2020; Hale et al., 2015). This is portrayed in Figure 2.8.

Figure 2.8: A schematic overview of main factors influencing coping strategies (author's work, 2024).



Water use can be defined as any economic or social unit, that needs certain water quality to conduct its activity. Water can be used for different purposes, depending on the water quality (industry, agriculture, domestic water) (Cococeanu & Man, 2021). However, this research will focus on domestic water use, such as drinking, and washing clothes .Water usage is also influenced by domestic rules and obligations among male, female, and juvenile members within households. Therefore, intra-household relationships influence the coping strategies. The division of responsibilities within each household, especially concerning labour and resource allocation, depends on negotiations among its members (Nsenga & Mwaseba, 2021). This negotiation process significantly impacts water provision and usage within the household. In the Maldives, it is common for women perform most of the household activities, to secure e.g. water and food resources and hygiene.

Water knowledge (or awareness) is based on information, perceptions, and experiences. *Perception* relates to how people interpret sensory information, like the taste of drinking water, while *experience* results from observable knowledge gained through exposure or involvement to something, such as no rainwater scarcity during droughts. *Information* can be formal (from education or scientific sources) or based on local knowledge (Irwin, 2001; Endter-Wada et al., 2009).

Access can be defined as a filter that determines the scope of possible opportunities, endowments, and rights a person has to obtain the entitlement of use (Sen, 1999). Resource access can be achieved through legal or illegal means and various mechanisms. For example, someone with legal rights can utilize resources. In contrast, those lacking legal access may resort to illegal methods or utilize various strategies, such as technology, finances, markets, labour, knowledge, authority, identity, or social connections (Ribot & Peluso, 2003). Hence, the waterscape also determines water access for humans to resources and the risks they face. Access acts as a gatekeeper, influencing the range of rights and opportunities available to an individual or organization for resource usage (Sen, 1999). Access to resources also relates to *ownership* and property rights. *Ownership* is a legal claim on a valuable resource or good through an existing institution, law or informal convention. *Property* is based on the legitimacy of rights determined by legal regulations, traditional practices, or societal agreements. Property relationships define who has the right to benefit from a resource, but not necessarily the ability to do so (von Benda-Beckmann et al., 2006). Bargaining power and social relations can then be crucial to establishing resource access. Nevertheless, in the end, ownership determines the ability to control water use and make institutional arrangements that directly relate to water access.

Coping capacity (the agency of humans) can be described as all preconditions that enable actions and adjustments in response to current and future external changes, and it is based on both, social and biophysical factors (Adger, 2003). The coping capability depends on a high level of ingenuity and the ability to implement plans, strategies, and tactics that will help promote more effective and efficient water use (Venkataramanan et al., 2020). Someone's agency also depends on resource access, decision-making power, and vulnerability to water-related issues (Venkataramanan et al., 2020; Hale et al., 2015). This is, in turn, shaped by an interplay of individual factors like someone's race, and socio-economic status, also referred to as intersectionality factors (Atewologun, 2018).

The **intersectional factors** and their interrelationships form a network of variables that form the context in which human agency manifests itself. People's agency is, therefore, to a large extent, moderated by intersectional factors, such as race, age, gender, wealth, education, and things like the strength and span of one's social network. Emphasising intersectionality creates an understanding of why specific groups (such as women) might have different resource access, experiences and coping strategies (Atewologun, 2018). Sensitivity to such differences enhances insights into issues of inequality and social justice for certain groups in island communities.

However, a pitfall of intersectionality is that there seems to be no coherent category other than the individual since it tends to split identity groups into even smaller subgroups. Hence, some scholars argue that common systems of oppressions can be analysed that support identity- based subordination (Ehrenreich 2002, Goldberg, 2008). Nevertheless, the aim of showing intersectionality factors and its relation to access and certain coping strategies is not to make a systemic analysis, but to reveal the complexity and some outliers. This helps to identify which groups may be left behind in society and how social inclusion can be further maximized. Intersectionality factors are used to analyse differences at different waterscape scales. It shows that there are different effects on different scales.

2E. Sociotechnical Imaginaries reflected in the Dominant water resource management Paradigm

Discourses and Water Resource Management Paradigms

A discourse, can be defined as a specific set of ideas and concepts reproduced in practices and through which meaning is given to physical and social realities (Hajer, 2006). Hence, realities are created and formed through a certain framing. Hereby, framing is not only an exercise of knowledge, but also of power. This is in line with the Foucauldian notion of knowledge and power, where various actors have a different representation of their narrative, which can become an exercise of their political power (Wagenaar & Cook, 2003; Foucault, 1980). Discourses and ideas are powerful action restraints by framing and defining parameters of what is perceived as possible solutions to societal issues (Arts & Buizer, 2009). Certain discourses also lead to a certain water management paradigm.

Over time, ideas and beliefs about water and water resource management can shift, resulting in changes in water practices, policies, and paradigms. For example, in the past, water management focused on clear-cut problems that were addressed by technical solutions (mostly large-scale) (Schwarz & Thompson, 1990). The focus shifted around the 2000s, for example, more on Integrated Water Resource Management (IWRM) and good water governance, with integrated approaches with institutional arrangements (Century, 2000; Pahl-Wostl et al., 2008; Woodhouse & Muller, 2017). Due to countries' different financial and institutional environments, the application of the paradigms varies globally.

The evolution of water resource management stems from a unique understanding and conceptualization of water. Each management paradigm advances a specific understanding of the appropriation and use of water resources and their management. It tries to advance this by charting specific solutions and gaining political support. In the Maldives, the dominant water management paradigm will be examined by looking at the specific and predominant ideas and solutions proposed by the government to (fresh)water management challenges.

Sociotechnical imaginaries

The dominant water management paradigm in the Maldives will then be mirrored against the sociotechnical imaginaries of the local communities on Kolhufushi and Muli. As already mentioned, sociotechnical imaginations are collective beliefs and visions within a society about the relationship between technology and social life (Jasanoff & Kim, 2015). A collective belief exists when it is widely shared and supported by a significant group within society. Sociotechnical representations influence the values communities and cultures assign to technologies, resulting in varying patterns of technological innovation. These representations evolve over time, leading to significant changes in how people value technologies and their willingness to support various technological development paths (Kuchler & Bridge, 2018). It is crucial to show if the proposed and implemented technologies by the government are supported locally by local communities on Kolhufushi and Muli. Social technical imaginaries and the dominant water resource management paradigm will be examined in Chapter 6.

3.Methodology

In this research, I scrutinize the waterscape by looking at the main components of available water resources, the water supply technology and infrastructure, humans' water usage, coping strategies and formed institutions. Hence, the main idea is to ''*Follow the water and to follow the people*''. To answer the research questions, I conducted two case studies: one at Kolhufushi (1 month from 18 Nov-17 Dec) and one at Muli (1 month from 17 Dec-12 Jan). These two case studies were conducted to complement data, outline common patterns and interactions, and examine differences between the islands and islanders regarding water systems and usage.

Case study selection

The islands Kolhufushi and Muli were selected, because they are part of the 3SWater project area and logistical support could be provided. Moreover, these two islands were understudied, and they can be seen as representative for the smaller outer islands in the Maldives, specifically southern outer islands. The communities living there are relatively voiceless and underprivileged due to a combination of economic, geographic, socio-economic and hydrologic factors, hence I wanted to shed light on their voices.

Mix of data-gathering techniques

This was a cross-disciplinary qualitative research with an interdisciplinary nature. The research tried to emphasize collaboration and interaction between different disciplines to tackle a common problem and examined different world-views and stakeholders in society. The research is conducted through transect walks, participant observations, unstructured interviews, semi-structured interviews, narrative inquiry, and discussion groups to better understand the water needs, practices, and coping strategies of households on the two islands. Moreover, a research desk study and a Literature review was conducted in advance during the research proposal writing, as well as during the exploration of both of the islands. With the research desk study, academic Literature, media articles, policy papers and project papers are read to create a better understanding of the current water supply system and its discourse and development. This was complemented with observations and interviews. The methods in connection to the theory and research questions are shown in Table 3.1.

Chapter	Research Question	Theoretical concept(s)	Methods
1. Introduction		Freshwater scarcity and quality	Literature review
2. The waterscape in Kolhufushi and Muli	*How did the waterscape of Kolhushi and Muli evolve over time, and what are its main characteristics?*	Waterscape Structure-agency	Transect walks Participant observation Unstructured interviews
3. Constructing local voices in the waterscape	*What are the general freshwater usage experiences, access obstacles, and coping strategies of local communities, and how do these differentiate amongst relevant social groups in Muli and Kolhufushi?*	Domestic Water Management Coping Strategies Intersectionality Factors	Semi-structured interviews Narrative inquiry Discussion groups
4. Socio-technical Imaginaries of islanders on Muli and KolhufsuhiReflected in the Dominant Water Resource Management Paradigm	*What dominant public water management paradigm has emerged in the Maldives, and how do the socio-technical imaginaries of local communities on Muli and Kolhufushi align (or not) with this paradigm?*	Socio-technical imaginaries Dominant Water Resource Management Paradigm	Semi-structured interviews Discussion groups

Table 3.1: Overview of research methods and connections to the research questions, theoretical concept(s) and chapters (author's work, 2024).

Unit of analysis

To study local communities, the unit of analysis were households, since households are an integral part of the broader community. Each household is connected to various water sources and connections and has various water uses. It provided a good micro-level understanding, to get to know struggles on the ground and day to day practices. It is a tangible unit that emphasises the individual level, but it can be related to the broader context and community. Moreover, households differ in socio-economic status and living conditions. This helps to capture the diversity in the community. However, the generalization of household-level studies vary due to different socio-economical-cultural contexts. Therefore, two case studies are examined. The island and community characteristics and respondent features and answers will be analysed to contrast the two case studies. In addition, households are not nuclear units, with different shared finances, dynamics, and activities. Therefore, water use and finances may differ per household member. Hence, light is shed on intra-household relations and the most prevalent intersectionality factors. This will figure as an illustration of the complexity and broad conclusions will be drawn from these findings. Moreover, households are only part of the community, the broader local context of the waterscape needs to be taken into account, in order to study local communities.

Active participation, ethical considerations, and my epistomology

I tried to avoid being a parachute researcher. I strived to gain more valuable insights, which can contribute to creating dialogue and connecting different actors. In order to honestly understand the waterscape, the people, their water needs and struggles, I wanted to fully immerse myself in the culture by living with a host family on both islands. Fortunately, many islanders, specifically children, speak (fluent) English which made it easier to understand each other. In practice, this gave me the opportunity to participate, observe and hear more narratives about water practices. It also helped to increase their trust in me to freely share their ideas and opinions. The drawback, though, was that I found it difficult to step back and analyse what I saw.

Moreover, I wanted to do the fieldwork in collaboration with local people. On Kolhufushi, fewer people spoke English and therefore I collaborated with a translator. She was Maldivan, born at Kolhufshi, also 24 years old, and worked for the Women Development Center. On Muli, more people spoke English, however, I still gained sometimes some additional support for translation from a Maldivian female student, born on Muli, and 16 years of age. Collaborating with them really enriched my experience and made me understand the island, the people, and the water problems better. They were able to give me background insights and I believe this helped gaining more easily confidence among my research participants. Being part of the 3SWater Project and working together with people of the project also helped to gain more access. I'm aware this also influenced how I was being perceived in the field and that this influenced my own perceptions. Hence, I believe I will never be completely neutral as a researcher. Reflection upon my neutrality and positionality is therefore necessary, see Chapter 9 for discussion and see Appendix I for a Dutch poem about positionality.

Knowledge is socially constructed in my opinion. A research approach that fits best by this perspective is the critical realist approach. Critical Realism distinguishes between the 'real' and the 'observable' worlds. The 'real' cannot be seen and exists apart from human perceptions, theories, and constructs. The world as we know and interpret it is built from our viewpoints and experiences, via what is observable. Thus, unobservable structures cause observable events, and the social world can only be comprehended if people understand the structures that generate events (Bhaskar et al., 1998).

Research activities

This research had an inductive focus, where I did pattern recognitions out of specific participant observation and interviews, in order to theorize about those patterns. The research had five main phases:

Phase 1: Exploration phase (one-two weeks on each island)
I spent the first two weeks of my stay on each island acclimatizing to the new environment getting to know key players, and gaining a general understanding of its characteristics. I aimed to record the most important water sources on the island, the island's characteristics, and other relevant physical water and sanitation supply infrastructure features. My host family, the IC and people of the water and sanitation company Feneka showed me around on the island. I also conducted unstructured interviews with a few households. The goal was to understand the waterscape by looking at water resources and water (technological) infrastructure, and how people interact with them, and what the difficulties are they face. This would help to address the first sub-research question. The goals in this phase were:

- To get familiar with the environment, people and their community, and housing conditions
- To get familiar with the important activities and buildings on the island
- To get familiar with the governmental and institutional structure
- To describe the sanitation systems and conditions
- To generate insights in the current water system infrastructure: piped water system, communal wells, other water provision spots, traditional water infrastructure and its practices
- To get an idea about pressing issues at the island and household levels regarding water
- To get an idea of main water uses, water selection requirements, and coping mechanisms
- To explore the water needs and issues of the inhabitants
- To get an overview of the differences in the four important water sources in relation to their water quality, technology abstraction, and institutional arrangements

The methodology applied to achieve these goals and help answer the first sub-question was to do **transect walks** across the community and water supply system together with local people to gain insights into the water and sanitation conditions by observing, listening, asking, and creating a map with an overview of the current (water and sanitation) infrastructure, water resources, and the natural environment, including soils and vegetation. Photos were taken of interesting features, like housing, water sources, and sanitation. The initial plan was to make a transect diagram, but due to time constraints, this was not executed. However, the goals were still achieved by creating a map. I also did **participant observations** (observing while also participating), which were used to actively engage in interactions and activities, which can give an insider perspective. I mostly did it with my host families and while visiting other families. For example, I would observe and sit down for around two hours, while they were cooking or cleaning in the house and ask questions about their water practices, perceptions and issues for two hours. In addition**, unstructured (informal) interviews** were used to explore phenomena without constraints and to adapt to the situation. During the transect walks and household visits, I asked people about their water resources, needs, struggles and strategies employed. Moreover, I spoke to people of the IC to gain more insights about the governmental arrangements, institutions and their responsibilities, demographics, and the island community. I also took a tour with the utility company Feneka, which provides water, sanitation, and energy services to the island, and the Indian desalination company SMC Limited. I finalised this phase on each island by writing a first investigation report (of Kolhufushi 27-11-2023 and of Muli 27-12-2023).

Phase 2: In-depth household interviews *(two weeks on each island)*
The results of phase one provided insights into the setting where people interact. In the second phase, I wanted to figure out what was happening on the ground exactly by finding out what are households' main needs, issues, practices, and usage of water resources, access obstacles and coping strategies. This would help answer the second sub-research question. In addition, I aimed to create insights into

their perceptions and considerations regarding domestic water by also addressing part of their health status and livelihoods.

The specific goals were:

- To describe the seasonal differences in relation to water use and water fetching
- To understand the water needs, usage practices, and experiences of water resources in more detail
- To understand the water resource perceptions, preferences and considerations in more detail
- To understand which criteria are important for islanders in their water resource selection and domestic water needs.
- To describe the coping strategies in more detail
- To understand the access obstacles
- To understand the task division in relation to water fetching and usage
- To understand the water system arrangement and payments better
- To develop an understanding of relations between human-water system interactions and their health status and livelihoods

To perform this investigation, I conducted **25 semi-structured household** interviews **on each island.** The households were randomly selected, and I tried to cover different areas of the island. Semi-structured interviews were done, since it can offer specific insights, but leave the possibility to still being able to respond and adapt to the situation. To complement this, the **narrative inquiry** method was used. I would listen to stories people tell about their lives and experiences. This is more holistic and addresses emotions, narrative structure, and language in stories. It also looks at the interconnectedness of various events and emotions. This can be crucial when talking about health and livelihoods. Those methods were applied to primarily answer research questions two and three.

The interview consisted of two parts. The first part consisted of general details on age, nationality, primary sources of household income and the household income/month, education level, and household size. The second part was about traditional and current water usage and practices, water quality and experiences, water preferences, and source considerations. Moreover, questions were also asked about their water supply reliability and knowledge (e.g. causes of groundwater pollution and perceptions about climate change). In addition, this part also covered questions about their perceived relation between the health and water quality of groundwater and rainwater. It ended with questions about their social network and community, and more vulnerable groups were considered on the island.

First, I focused mostly on the household level and their coping strategies. However, during the research, more intra-household dynamics and personal factors became prevalent in how people deal with water sources. I tried to address this by including intersectionality factors of people and how that can influence household strategies or strategies of certain groups in society. Moreover, I had difficulties creating distance from the findings when I was there. Later in the analysis phase, I saw a clearer pattern of coping strategies and water use for certain social groups.

Phase 3: In depth-interviews with five key stakeholders on the islands (three days on each island)
This phase overlapped with phase two. The aim was to better understand the waterscape by conducting in-depth interviews with actors in different working fields related to the water resources, supply, and uses on each island. My goals were:

- To gain more insights into the vision, beliefs and role of the IC regarding water management on the islands
- To gain more insights in the water and sanitation infrastructure and management on the islands. Hence I spoke to project managers of Feneka in charge of this on both islands

- To gain more insights in the desalination plant design, project process, and usage by interviewing the project manager of SMC
- To gain more insights into the health and livelihood problems related to water on both islands by talking to a doctor or public health officer
- To explore the island community dynamics and get more insights in the construction work projects and employees on the islands

Therefore, I did on both islands **semi-structured interviews** with the vice-president of the IC, the water as well as the sanitation project manager, the SMC desalination plant project supervisor, a doctor on Kolhufushi and the public health manager on Muli, and the RCC construction project manager on Kolhufushi and the MTCC construction manager on Muli. This method was applied to supplement answering the sub research questions. I finalised phase two and three by writing a second investigation report with general outcomes (Kolhufusi at 11-12-2023 and Muli at 14-02-2024). This report includes the results of my observations, general island demographics and characteristics, and the situation during my stay.

Phase 4: Discussion Groups (one week in total)
At the end of the data-gathering phase, I wanted to create discussion groups to understand the social dynamics better and to explore shared or differing experiences and perceptions among participants. Discussion groups were used at the end of the data-gathering phase to discuss some of the research's results and to place these into perspective. In addition, I wanted to create more dialogue between different actors in Kolhufushi and Muli to ensure secure and safe water access to all inhabitants. The ultimate goals were to:

- To gain more insights into the various water needs of different actors based on quality tailored to the user's needs
- To understand better how each water source can best be utilized according to the different actors in the future and why
- Getting feedback on the main results discovered already
- Providing an opportunity to answer questions of islanders regarding the data, research, project in this research phase already, in order to avoid being a parachute researcher.
- To give some food for thought and to provoke discussion about pressing issues from islanders and the academic world about water scarcity and quality challenges of water resources on the islands

The discussion groups were conducted to complement the in-depth interviews and to help answer research questions two and three. The discussion group on Kolhufushi (08-01-2024) consisted of 12 people: the IC vice-president, two other IC members, a technician at Feneka involved in the water supply, the SMC desalination project supervisor, the five members of the WDC, the sanitation project manager at Feneka, and the RCC construction project manager (see Picture 3.1). The discussion group on Muli (10-01-2024) consisted of six people: a WDC member, the IC vice-president, another IC member, the SMC desalination project supervisor, the sanitation manager of Feneka, and the Public Health Communication Coordinator (see Picture 3.2).

I first presented the main similarities and differences between Muli and Kolhufushi in terms of research insights and differences in island dynamics and demographics. I also covered the main findings of the different water sources on the island and how islanders view and interact with them. This was followed, by asking targeted discussion questions to the group per topic and water source, such as what their preferences are for using desalinated water in the future, and challenges they face, and what possible solutions for those challenges could be. Discussion questions were also raised about, how they want and can mitigate their groundwater quality challenges or how they want to (optimally) use rainwater in the future, and what the impacts of climate change are on this, and where the responsibility for water management and climate change effects should lie.

Picture 3.1: Discussion group at Kolhufushi at 08-01-2024

Picture 3.2: Discussion group at Muli at 10-01-2024

The discussion groups offered valuable insights. Reflecting on the first discussion group on Kolhufuhsi, the group was on the large side and the environment was static, which limited interaction. In addition, there was a clear status difference between participants, with women speaking significantly less than men. Directed questions to women often produced discomfort. In addition, language barriers hindered some participants and during heated discussions, people often spoke in Divehi, which in turn required additional translation and time. For the session in Muli, I therefore chose to do the discussion with a smaller group. I also tried to apply more stretching methods with inclusive participation, such as posters with post-its for giving opinions and ideas, which lowered the threshold for participation. These also promoted interaction and movement in the room. I also split the groups into smaller groups for discussion and used coloured cards for each participant to put up when answering yes/no questions so that everyone's opinion was more evident in the group.

Phase 5: In-depth governmental officials interviews (one day in Malé)
Besides the islanders' water needs and visions, I also wanted to explore the government's main view on water resource management in the Maldives. My objectives were:

- To understand the institutional and legal arrangements for Maldives' water and sanitation management and maintenance.
- To better understand how they think about different water resources in the Maldives, and how they want to optimise them or not and why.
- To understand the government's main vision on water resource management in the Maldives
- To describe the main challenges the government faces in water management, how they deal with them now, and how they plan to deal with them in the future.

To do this, I conducted two interviews with government officials in Malé who deal specifically with water and sanitation facilities and management. Due to the sensitivity of the information provided, these officials remain anonymous. Although two interviews with government officials do not represent the whole main government vision, it did give me a general impression. Moreover, this data was supplemented with a literature study that looked at policies, papers, and the media.

4. The Waterscape in Kolhufushi and Muli

This chapter will set the scene for the domestic waterscape. It will first look at the available freshwater resources (groundwater and rainwater). Then, it will scrutinize the people and local community at Kolhufushi and Muli and their water demands. Lastly, this chapter will explain the infrastructure development and technologies around water. In particular, it will examine the evolution of the water supply and sanitation system in the Maldives, specifically in Kolhufushi and Muli. This together shapes and sets the scene for the domestic waterscape.

4A. Freshwater resources: rainwater and groundwater

The Maldives, with its tropical climate, is uniquely positioned with the equator crossing the country, offering protection from cyclones and ensuring year-round moderately high temperatures (around 28 °C) influenced by monsoon winds. Stretching 800 km from North to South, the weather conditions vary significantly across the archipelago (Chaudhuri et al., 2021). The islands' weather is shaped by seasonal changes in the direction of the monsoon winds. The south-west monsoon (from late April to September) is more intense in the northern islands, characterized by higher humidity, wind, and more frequent cloud cover. The north-east-monsoon (October to December) is calmer and mostly experienced in the southern atolls, bringing rain and thunderstorms mostly in the afternoon or evenings. Hence, there is a higher average annual rainfall in the central and southern atoll than the northern atoll. Between the monsoons, a dry period (from January to April) occurs, particularly in the northern atolls (Maldives Meteorological Service, 2023). The islands experience a relatively high humidity of around 80%, and the rainfall events, though short in duration, can be torrential and devastating.

Average annual rainfall and rainfall variability vary considerably throughout the Indian Ocean. The Maldives Meteorological Services (MMS) runs five MET stations: Gan, Hanimaadhoo, Hulhule, Kaadedhdhoo, and Kadhdhoo (see Figure 4.9). Kolhufushi and Muli are located in the South at the Meemu Atol and Kadhdhoo is the nearest MET station with historical rainfall records. This data can therefore be considered representative for Kolhufushi and Muli.

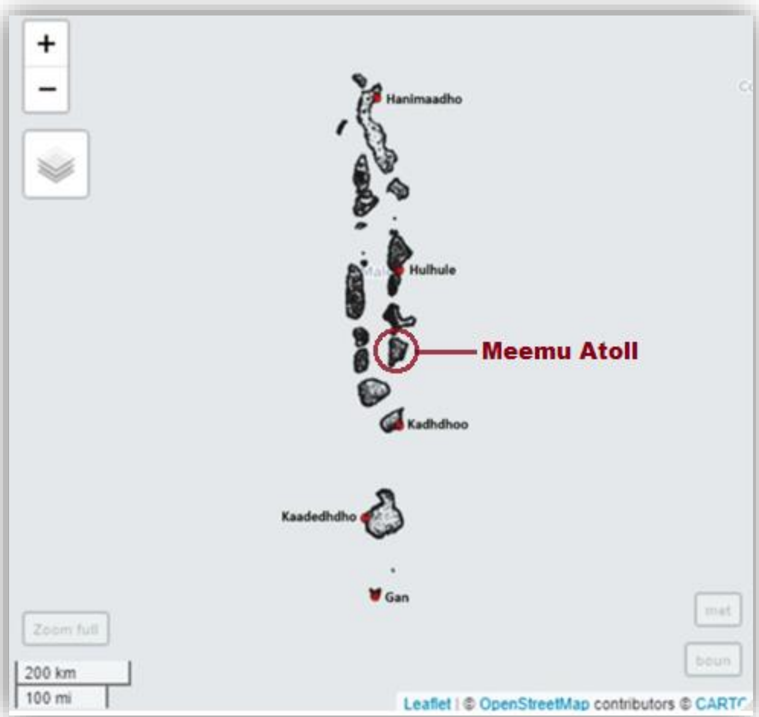
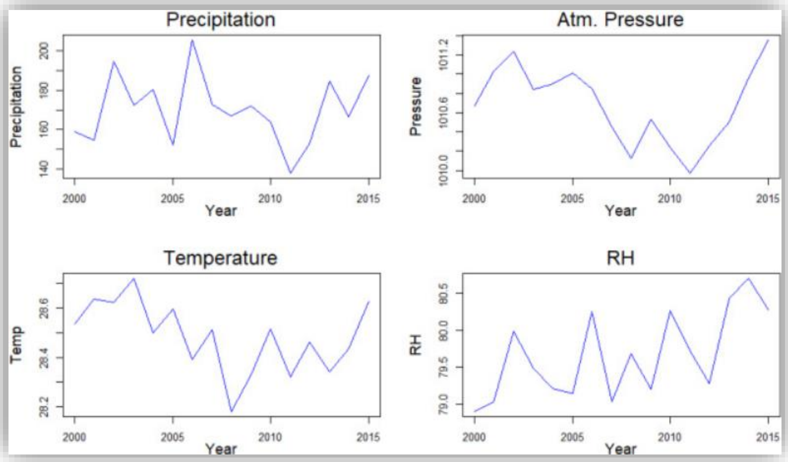


Figure 4.9: The five MET stations: Gan, Hanimaadhoo, Hulhule, Kaadedhdhoo, and Kadhdhoo of the Maldives Meteorological Services (Source: Maldives Meteorological Service, 2024).

The Maldives are particularly vulnerable to the impacts of climate change. Climate change can increase the frequency and severity of threats to small islands' freshwater resources, including increased frequency and length of droughts, rising mean sea levels, increasing temperatures (and evapotranspiration rates), and increased risk of island overtopping (Ali et al., 2001). Human activities contribute significantly to the country's vulnerability, especially through overcrowding on several islands, inadequate infrastructure facilities and destruction of coastal vegetation (Stojanov et al., 2017). From 2000 to 2015 the average annual precipitation and temperature have already increased in the Maldives see Figure 4.10 (Chaudhuri et al., 2021).

Figure 4.10: Average monthly annual meteorological records (average for all MET stations), RH stands for relative Humidity and Atm. Pressure stands for atmospheric pressure (Chaudhuri et al., 2021).



Between 1991 and 2021, the average monthly rainfall in different parts of the country varied. In Kadhdhoo the driest period is experienced in February and March over the years (1991-2021). A rainfall peak is experienced in May at the beginning and towards the end of the southwest monsoon. Maximum precipitation is around 300 mm per month, and the minimum precipitation is around 70 mm, according to Figure 4.11 (Maldives Meteorological Service, 2023). To make it more specific, in 2023, the maximum precipitation was 301 mm in May, and the minimum precipitation was 87 mm in the month of February (see Figure 4.12).

Figure 4.11: Climate average monthly rainfall conditions from 1991-2021 in the Maldives (Maldives Meteorological Service, 2023).

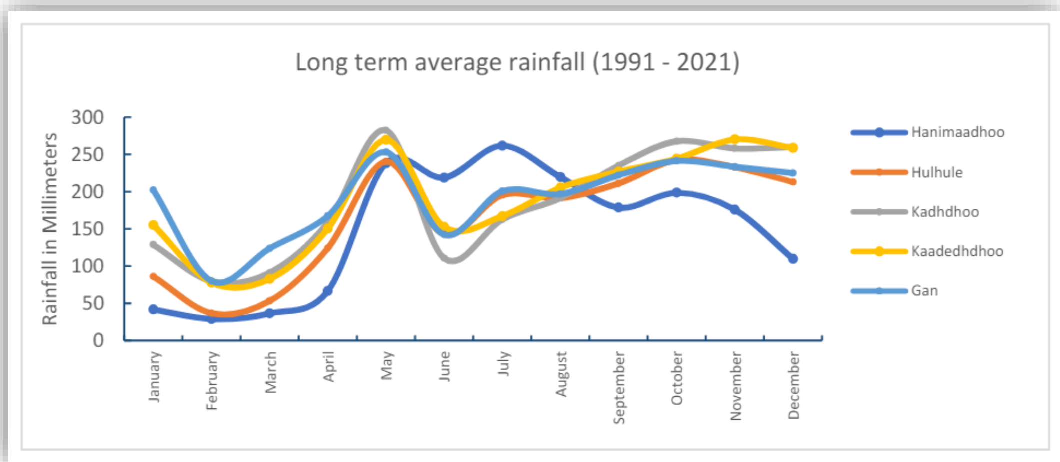
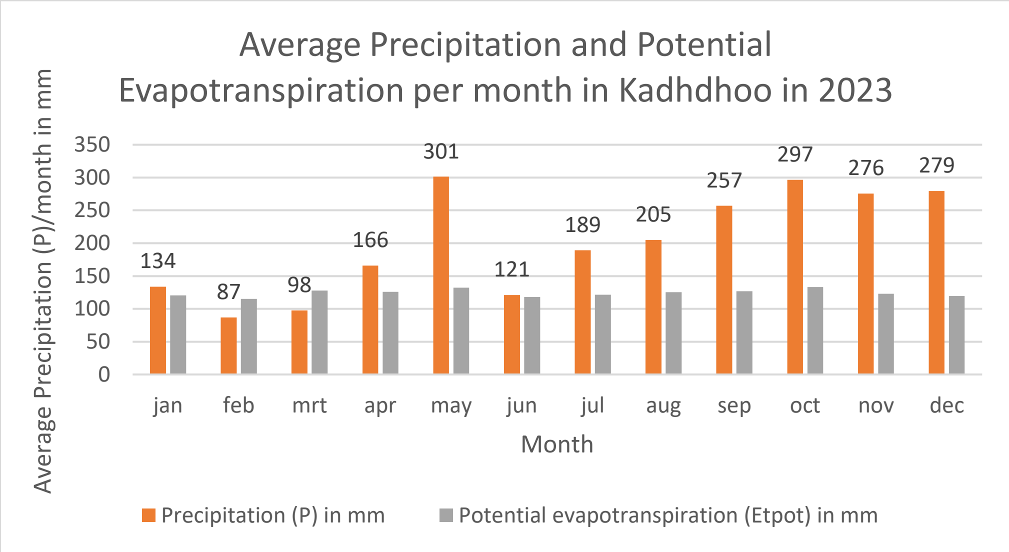


Figure 4.12: Average monthly precipitation and potential evaporation in Kadhdhoo in 2023 in the Maldives (source: Maldives Meteorological Service, 2024).



The average annual rainfall was 2409 mm, and the average annual evapotranspiration rate was 1490 mm in Kadhdhoo in 2023. Evapotranspiration plays a crucial role in the hydrological cycle of small islands and can amount to more than half of the rainfall annually. Often in other tropical climate countries, evapotranspiration exceeds precipitation for individual months or consecutive months during dry seasons or droughts (White & Falkland, 2010). However, it is notable that there is on average an excess of rainfall over evapotranspiration in the wet monsoon season from April until January in the Maldives.

The island's available freshwater resources besides rainfall patterns are also formed by the size, shape, and topography of Muli and Kolhufushi, specifically their width above sea level. In general, larger, higher, and wider islands are more likely to have more surface and groundwater resources than smaller and narrower islands (White & Falkland, 2010). Kolhufushi is considered a medium-sized island in the Maldives with 111.4 ha and Muli is slightly smaller and has 76.54 ha of land, making them more likely to have a smaller freshwater lens compared to bigger islands. In addition, Muli and Kolhufushi both have an island shape, which has a more narrow surface and specifically, islands with more narrow necks are more likely to suffer from seawater mixing and intrusion, which can increase the salinity of groundwater and make it unsuitable for use (White & Falkland, 2010). Both islands have a natural wetland, which also serves as an aquifer and supplies the groundwater. The one on Muli is relatively small and is called the turtle pond, see Figure 4.15.

Moreover, vegetation and soils are crucial factors for groundwater recharge possibilities, besides rainfall, due to their influence on infiltration and evapotranspiration. The interception storage of the vegetation captures rain and extracts water from the soil through transpiration. Coconut trees, grasses, and bushes are dominant vegetation types in Muli and Kolhufushi. On low-lying atolls such as Muli and Kolhufushi, groundwater recharge is often lower. Deep-rooted trees such as coconut palms can draw water directly from the freshwater lens, with evaporation as high as 150 litres per day per tree on the Tarawa atolls (White et al. 2002). This high transpiration can compete with human demand for freshwater. Selective felling of coconut palms can therefore increase groundwater recharge and reduce salinity since coconut trees grow in water with relatively high salinity levels (Foale 2003; White & Falkland, 2010). The closest soil category for the soil on Muli and Kolhufushi is ‘loamy sand’, however there is some soil compaction on the surface making the effective perviousness much less than that of loamy sand in case of surfaces like earthen roads, football fields, bare soil with some pedestrian traffic, etc.

4B. Humans: the local community at Kolhufushi and Muli

This section will first describe the general island community features, after it will give a description of the islands Kolhufushi and Muli separately. It will then address the different island actors on both islands. Lastly, it will look at the water needs of the actors.

Island community features

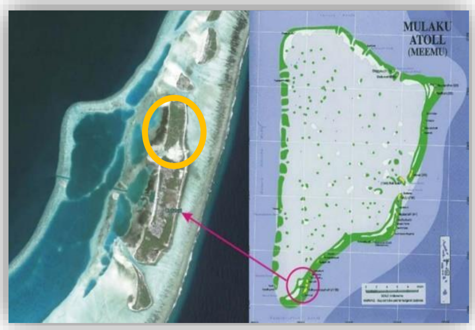
Islam has a profound influence on the lives of Maldivians. Muslims live according to the five pillars of Islam: (1) Shahada (profession of faith), (2) Salah (five daily prayers), (3) Sawm (fasting during Ramadan), (4) Zakat (charity for the poor), and (5) Hajj (pilgrimage to Mecca for those who can afford it). Notably, in the 1990s, most women did not wear a burqa. After translating the Quran into the Divehi in the 2000s, people began to interpret the Quran for themselves, leading to a shift towards wearing the burqa as the norm (04- female respondent Kolhufushi, personal communication, December 1, 2023). This was possibly reinforced by Saudi influences after the 2004 tsunami, leading to a more conservative approach to Islam, as noted by President Nasheed in 2014 (Wright, 2014).

Family is considered important in the Maldives; people spend much time with their family members, and it is common for parents or parents-in-law to live with their children. Household sizes are generally between three and eight people of extended families on both islands. However, household sizes are often slightly bigger at Muli than at Kolhufushi. There are traditional gender roles on the island: women do household tasks, while men usually earn the primary income. While conducting the interviews, mainly women were at home, therefore most respondents were women, 88% on Kolhufushi and 72% on Muli.

Resort island tourism was previously the norm. However, tourism on Muli and Kolhufushi has recently experienced significant growth due to a policy change allowing local islands to operate guesthouses, previously restricted to specific tourist islands. This development raises expectations among islanders of increased employment and economic progress but also raises concerns about cultural appropriateness, including issues such as appropriate dress and alcohol restrictions.

Kolhufushi

Figure 4.13: Location of Kolhufushi on the Meemu Atoll, the yellow circle is the agriculture zone (Zahir, 2004).



Kolhufushi has a population of 1471 people, making up 226 households (W. M. Wafir[2], personal communication, November 19, 2023). Originally, seven families were living on the island (M. Aqula[3], personal communication, November 20, 2023). Most islanders work in civil service, tourism, traditional coconut crafts, tailoring (for sale to tourist resorts), fishing and agriculture (W. M. Wafir, personal communication, November 19, 2023). Part of the island is only used for agriculture activity, no inhabitants live here (see the yellow circle in Figure 4.13).

Compared to Muli, more islanders work in the tourism, fishing and agriculture sector. Due to limited employment opportunities, many young people leave the island for work or study. Many men work in

[2] W. M. Wafir is the senior council officer of the Island Council of Kolhufushi

[3] M. Aqula is a pharmacist at Kolhufushi

tourist resorts, earning higher wages than local jobs, and returning home only once every three months. Moreover, their main job, side activities such as fishing and family businesses are common due to limited employment opportunities. Islanders generally experience socio-economic equality and consider themselves as socio-economically fairly equal. Once a year the IC registers residents' needs and provides assistance where needed, in line with the Islamic duty of charity. This year, no household was registered as poor, defined as being unable to meet basic needs. Also, no households reported vulnerable or poor groups on the island.

Kolhufsuhi has basic facilities, including a health centre, a school up to grade 10, an island court, a police centre, and four mosques: two men's mosques, one mosque for both men and women and one women's mosque, which is no longer in use. Figure 4.14 shows the main infrastructure of Kolhufushi to give an impression of the island. The island is extending its infrastructure by building 100 more houses, a new playground for children, and a waste centre office. Construction companies are hired to do so. In Kolhufushi, the biggest construction company is RCC, which has around 100 foreign employees. RCC has about 150 foreign workers, mainly men from Sri Lanka, Bangladesh, India, and Nepal, who are mostly younger than 50. They earn relatively low wages, usually between $300 and $500 a month (R. Ragupathi[4], personal communication, December 19, 2023). As of 2021, 60 Indian workers also worked for the Indian desalination company SMC, but by the end of 2023, only eight workers remained (Velus[5], personal communication, December 10, 2023).

Figure 4.14: Map of Kolhufushi with highlighted water and supply infrastructure. Note that the agricultural zone, which is also part of Kolhufushi is not portrayed on this map (author's work, 2023).

[4] R. Ragupathi is the project manager of the construction company RCC at Kolhufushi

[5] Velus is the desalination project manager of the company SMC at Kolhufushi i

On Figure 4.14, one can also see the tsunami memorial established in honour of the 16 people who lost their lives. In 2004, the island suffered extensive damage from a tsunami, significantly destroying infrastructure and the freshwater lens (Kan et al., 2007; Zahir, 2004). It was a traumatic experience for islanders, as one woman told me: *'The sea looked black, like a ghost, because the water had taken all the palm trees and sand. The whole island cried. People described it as judgment day, and it felt like the world had ended.' (04- female respondent Kolhufushi, personal communication, December 1, 2023).* Until 2013, most islanders lived in tents because government-built houses were not ready (see picture 4.3). Now, most houses look the same, each having three rooms, a toilet, and a shower, after the government's reconstruction efforts.

Picture 4.3: Post-tsunami damage on the island Kolhufushi (source: Aqula, 2023).

Muli

Muli has a 76.54 ha land area and 1,028 people were registered as inhabitants in 2023 (Sakif[6], personal communication, December 18, 2023; Kan et al., 2007). However, many people move around or are not registered (e.g. foreign people who work on the island). There are 147 households and there are 135 more household plots available, where people can build their own houses. More people, including more women, are employed in Muli than in Kolhfushi because there are more job opportunities and more people work in the public sector than Kolhufushi. Households in Muli generally have higher incomes than those in Kolhufushi, although the socio-economic differences are slightly larger. In 2023, only three people were registered as poor on the island, meaning they could not meet their basic needs, and about three families were considered more wealthy and rich, defined as having a more luxurious lifestyle and more financial resources. According to the vice president of the IC, people used to be more interconnected; now they are less dependent on each other because of higher living standards (Sakif, personal communication, December 18, 2023).

Muli offers more facilities than Kolhufushi, including a hospital, a bank and a school system extending to grade 12. Figure 4.15 illustrates the map of Muli with its current infrastructure and key features. The island also has three mosques and faces implementing several new development projects, including a new jetty, an airport and a waste processing centre. About 300 foreign construction workers are involved in these projects and reside on the island (IC, personal communication, 17 December 2023). The Maldives Transport and Contracting Company (MTCC) is the main construction company on Muli, with about 120 workers, mainly men from India, Sri Lanka and Bangladesh, mostly under 50.

The 2004 tsunami caused less damage to Muli's infrastructure than Kolhufushi, allowing residents to rebuild their homes relatively quickly after the disaster. However, still, six people lost their lives due to the tsunami on Muli.

[6] Sakif is the vice-president of the Island Council in Muli

Figure 4.15: Map of Muli with highlighted water and supply infrastructure (author's work, 2024).

Different island level actors

Several actors have been identified in the waterscape on the island., including the water and sanitation companies, the IC and the local community. The IC oversees the island's development plans, controls regulations, and monitors them. Hence, it is also involved in utility service provision to islanders, if people have complaints about the water or sanitation, they can go to the IC. The water, sanitation and energy utilities service provider in Kolhufushi and Muli, is Feneka Corporation Limited., a state-owned company providing utility services including water, to multiple island communities in the Maldives (Saeed & Ibna, 2021). The desalination plant company, the Indian company SMC Infrastructure PVT LTD, has been the water-providing company in Muli and Kolhufushi. Since 2021, it has been in charge of the design and build for construction of the desalination plants on the islands. They have 13 projects on different islands in the Maldives (Velus[7], personal communication, December 10, 2023). The former president of the Maldives had many affiliations with India and foreign investors, which resulted in many migrant workers from e.g. India and Bangladesh (cheap labour forces) on Kolhufushi and Muli. After completing the desalination water trial period and obtaining official water quality approval from the government, Feneka Corporation Limited will become responsible for the operation and maintenance of the desalination plant.

The local community on Muli and Kolhufushi can be divided into the Maldivian population and foreign workers on the island. This division is made based on the social and spatial definition of communities. Communities can be defined socially and spatially (Wellman, 2005). Spatially, communities can be formed by bounded groups of people living near each other in the same physical location. Socially, communities are also formed by networks of interpersonal ties that offer companionship, information, support, a sense of belonging, and social identity.

[7] Velus is the desalination project manager of the company SMC at Kolhufushi

The island community is formed by the people living on Muli and Kolhufushi. There is a physical division on the island segregating where Maldivians live and where foreign construction workers live. The construction companies built barracks for housing, and they have their own water and food supply, including rainwater tanks and groundwater wells (see Picture 4.4 and 4.5). A few foreigners rent houses from Maldivians or build their own houses, however, the majority of foreigners live in separate areas on the islands. The living standards of foreign construction workers can be considered lower in these areas than those of Maldivians. Moreover, most foreign construction workers earn less money (between 300 and 500 dollars/month on average) and work more days (six days a week instead of five).

Picture 4.4: Picture 4.4: Housing for foreign construction workers at the company RCC in Kolhufushi, where 80 people sleep in one barrack

Picture 4.5: Housing (barracks) for foreign construction workers at the company MTCC in Muli

Foreigners also form their own communities, and there is little interaction and mingling between the Maldivians and foreigners. Generally, they do not participate in island activities. As the project manager of RCC, on Kolhufushi stated, ''*the interactions with the Maldivians are only for work*'' (Ragupathi R., personal communication, December 19, 2023). The majority of Maldivians do not interact much with foreigners or construction workers. To illustrate, a woman mentioned: *''I do not talk to them (referring to construction workers), I do not feel the need to talk to them. But the work must go on, on the island, it is because of them there is development*.'' (23- female respondent Kolhufushi, personal communication, December 13, 2023). It becomes clear from these quotes that social interactions between island inhabitants and workers are strictly limited to work. There is no feeling of belonging to the local Maldivian culture, practices, and community. However, some foreigners are Muslim as well (mostly people from Bangladesh), and they meet the Maldivians in the mosques at prayer times. This can create more ties to the Maldivians and the community, which will be further discussed in Chapter 5D.

For understanding actions exerted by local communities, 25 households per island were seen as the key unit of analysis and taken as representative of the local community. However, during the research, it became clear that focusing on household units does not showcase the complexity of individual experiences, coping strategies, and access to water resources. The concept of intersectionality helps to understand how heterogeneous members in specific groups, such as households, might have different experiences depending on factors like someone's culture, class, ethnicity, gender, awareness, and socio-economic status. Intersectionality also determines someone's differentiated access to water resources and coping strategies (Atewologun, 2018). For example, wealthier households can afford bottled water better as a main drinking source throughout the year than poor households, creating different access possibilities. Only the most prevalent factors identified influencing access to water resources and coping strategies will be addressed in this study. It will help to create a better understanding of what works for whom and why in water management, and it also helps to identify which groups can be more vulnerable and potentially need more support in the community for accessing water resources.

Understanding the community water demand

Since 2011, it has been a human right to have access to safe water and sanitation. The general commitment, adopted in 2002 No. 15 by the UN Committee on Economic, Social and Cultural Rights, states "*The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses*" (UN-Water Decade Programme on Advocacy and Communication and Water Supply and Sanitation Collaborative Council, 2010). Sufficient water means between 50 and 100 litres per person per day. This is needed to ensure that the most basic needs are met and that few health concerns arise. Water should also be safe in terms of being free from chemical substances, micro-organisms, and radiological hazards that constitute a threat to a person's health, and it should meet the drinking water standards of the WHO (2013). Water should be acceptable in terms of colour, taste, and odour for each personal or domestic use. It should also be physically accessible within, or near the household, workplace, educational institution or health institution, within 1,000 metres of the home and collection time should not exceed 30 minutes, according to WHO (2013). Water and water services and facilities should also be affordable for everyone. Water costs should not exceed 3 per cent of household income, according to the United Nations Development Programme (UNW-DPAC, 2010). Sanitation is interlinked with water since it is one of the principal mechanisms for protecting the quality of water resources.

This research will focus on personal and domestic household water needs. There are different water quality preferences for each water purpose. Figure 4.16 gives an estimate of how many Litres every domestic water need costs and which ones are most crucial. Notably, the type of sanitation facility has a significant impact on water requirements; water-based sanitary facilities, such as flush toilets, require a significant amount of water (up to 7 Litres per person per flush), in contrast to, e.g. pit latrines. In addition, Figure 4.17 shows that a person needs between 7,5 and 15 Litres per day to fulfil the basic water requirements for drinking, cooking, and hygiene practices (WHO, 2013).

Figure 4.16: Hierarchy of water requirements - after Maslow's hierarchy of needs (WHO, 2013).

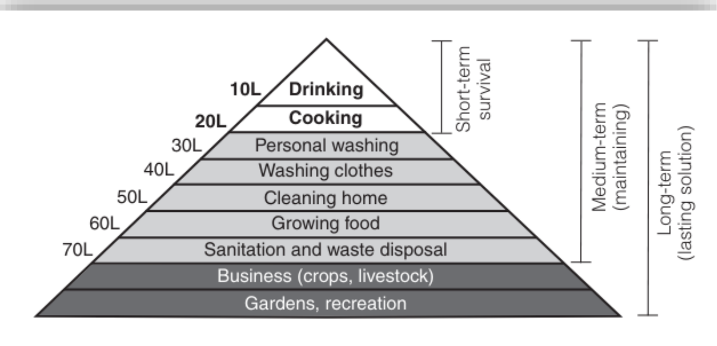


Figure 4.17: Simplified table of water requirements for survival per person per day (WHO, 2013).

Type of need	Quantity	Comments
Survival (drinking and food)	2.5 to 3 lpd	Depends on climate and individual physiology
Basic hygiene practices	2 to 6 lpd	Depends on social and cultural norms
Basic cooking needs	3 to 6 lpd	Depends on food type, social and cultural norms
Total	**7.5 to 15 lpd**	lpd: Litres per day

Water needs can differ per person and relate to culture (WHO, 2013). In certain cultural contexts, there can be specific needs regarding the use of water for anal hygiene for example. Or the need to clean sanitary pads or wash hands and feet before prayers may be considered of greater importance than other aspects of water use. Both women and men may have different priorities; for example, women may be concerned about basic water needs for domestic use and hygiene during menstruation, while men are more concerned about the needs of their livestock (WHO, 2013). It is, therefore, crucial to understand people's water needs, considerations, and preferences, which will be described in Chapter 5. Besides, accessibility also needs to be considered by the local community water demand. Even when plenty of water is provided, other constraints may hinder its use, such as the time it takes people to travel to the water source and queue to fetch water (WHO, 2013).

4C. Technology and Infrastructure Development

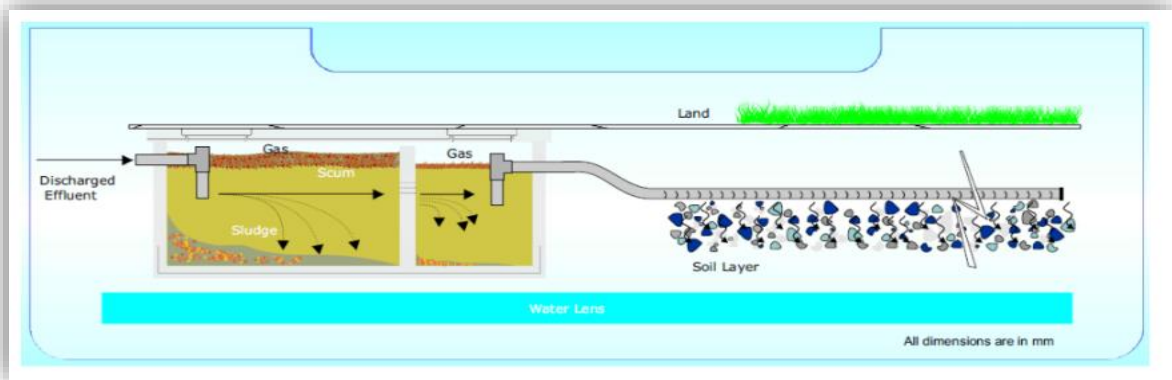
Sanitation and water are closely interconnected, as safeguarding public health and ensuring overall well-being requires access to clean water and adequate sanitation systems. This chapter will first describe the evolution of sanitation systems and technologies in the Maldives, followed by an analysis of current systems on Muli and Kolhufushi. The evolution of water systems in the Maldives is then discussed, including a focus on existing water supply infrastructure and technologies on both islands.

Evolution of the sanitation system in the Maldives, specifically at Muli and Kolhufushi

Traditional (open) defecation practices on the islands involved shallow burial of faeces in mostly beaches or bushes but sometimes also in the backyards of homes (Ministry of Environment Republic of Maldives, 2020). A cholera outbreak in the 1980s highlighted the need for good sanitation, and it was even more exacerbated after the tsunami in 2004 (Mohamed et al., 2020). The tsunami exerted external pressure on the aquifer, forcing water out of the ground and damaging septic tanks, sumps and other sewage infrastructure (United Nations Environment Programme, 2005). This resulted in excessive groundwater contamination. Hence, over time, different sanitation systems have evolved in the Maldives.

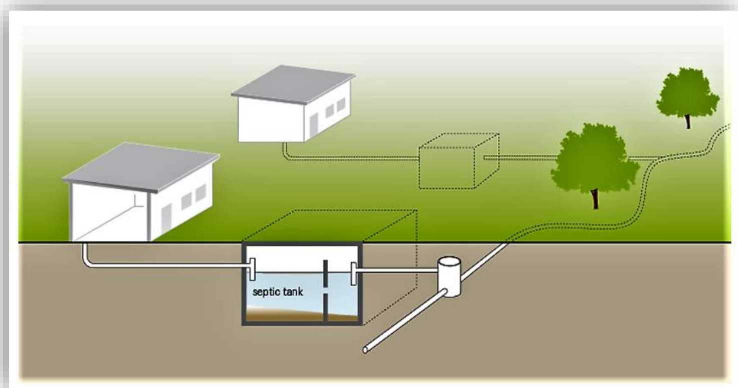
Initially, septic tanks were widely used in the Maldives for their suitability for small communities. These tanks separate solid waste from wastewater, with bacteria breaking down the organic material (see Figure 4.18). However, they also brought about a set of challenges. Regular maintenance is crucial to prevent blockages and groundwater contamination, which can occur with poor installations or maintenance, where untreated sewage can leak into the ground through overflows, resulting in the spread of chemicals from pathogens into groundwater (Utility Regulatory Authority, 2021). In addition, septic tanks posed challenges such as termination of sludge disposal by households and high installation and maintenance costs (Water Solutions Private Limited, 2016; Utility Regulatory Authority, 2021).

Figure 4.18: Cross-section showing the main feature of a typical septic tank (Maldives Water and Sanitation Authority, 2003).



In response, piped sewerage systems with individual household connections were installed and are present on most islands nowadays. The capital city, Malé, already has a functional piped sewerage system since 1988, but outer islands often made the tranisition to more advanced sanitation systems later. Those developments are mostly funded by external foreign aid and allocations from the national budget (Ministry of Environment Republic of Maldives, 2020). Kolhufushi transitioned from septic tanks to a conventional gravity sewage system in 2013, aiming to address the inadequate use of septic tanks in the past and prevent groundwater contamination. Muli, however, installed around the 2000s a small-bore sewer system (solid-free sewer systems), which uses septic tanks, see Figure 4.19 (Ministry of Environment Republic of the Maldives, 2020; Tilley et al., 2014).

Figure 4.19: Solid Free Sewer Systems (Tilley et al., 2014).



Muli

On Muli, almost every house has a connection to the sewer system. It is first collected in one of the seven bigger junctions on the island (lifting manhole pumps) with 11 manholes (see Appendix II). These lifting pumps are installed along the main sewer line to elevate the sewage and maintain a shallow depth. The 7 bigger junctions are cleaned once every three months (see Appendix II for pictures). According to the sanitation manager of Feneka, overflow has become a bigger problem since last year, because of more intense and heavy rains (Abdula[8], personal communication, December 19, 2023).

In the Maldives, there are separate systems for rainwater and sewage. During heavy rainfall, the sewerage system cannot handle the rainwater, leading to leaks and groundwater pollution. Human

[8] Abduala is the sanitation supervisor at Feneka at Muli

activities, such as connecting household rain drains to sewers or opening wells to drain water, exacerbate this problem. These habits reduce the efficiency of the sewerage system and it can be considered a cultural challenge (government official 1, personal communication, January 13, 2024).

In addition, the waste water treatment system has not been in use since approximately 2016 on Muli, because the compression pump broke down (see Picture 4.6). A company in Sri Lanka was previously in charge of the treatment system construction, and new materials needed to be imported from other countries. However, due to financial issues and import difficulties, the materials have not been replaced since. This failure to maintain existing facilities is a common issue on small outer islands in the Maldives. The sewerage waste is now directly discharged into the sea without treatment.

Picture 4.6: The wastewater treatment system on Muli, not in use since 2016

Kolhufushi

On Kolhufushi, the pipes of the conventional gravity sewage sanitation system, are conveyed to three main wet lifting pump stations on the island through gravity, and it is directly discharged into the sea beyond the reef without proper treatment, see Appendix II (Sadam[9], personal communication, November 20, 2023). The wastewater treatment system is here also not in use, due to maintenance problems. Most islands in the Maldives lack effective wastewater treatment (Utility Regulatory Authority, 2021

While these advanced sewer systems offer benefits, such as maintaining groundwater quality and suitability for flat terrain, they also come with additional costs. These include purchasing vacuum pumps and holding tanks and needing full-time operators because of the complex technology and limited service support. This results in high operating and maintenance costs (Water Solutions Private Limited, 2016). The government is subsidising the desalination plants projects and long—term maintenance.

Evolution of the water supply systems and technologies in the Maldives, specifically at Muli and Kolhufushi

Traditionally, residents relied on shallow aquifers for their domestic needs, including drinking and cooking. This water was drawn from hand-dug wells, since the freshwater lens is only 1 to 1.5 meters below the surface (Ministry of Environment Republic of the Maldives, 2020). For drinking water, they often used communal wells near mosques, which were considered safer because of their distance from septic tanks, often more than 10m from the toilet pits, preventing septic tank leakages and freshwater lens contamination (Wickramagamage, 2017). Islanders of Muli and Kolhufushi still consider the communal groundwater to be of better quality. Communal water was usually collected in the morning and evening, up to four times a day, a task for women that sometimes took up to 15 minutes per trip (06- female respondent Muli, personal communication, December 24, 2023). The bandiyaa pots which were used to store the water are still used in traditional dances to open ceremonies (see Picture 4.7). Since approximately the 1980s, many households had access to their own groundwater wells, which they built themselves. Due to the lack of electricity islanders could not make use of groundwater pumps back in the days and people used a small water bucket

Picture 4.7: The bandiyaa Jehun Dance at Naifaru island (Naifaru Bandiay Group, 2020).

[9] Sadam is the sanitation manager at Feneka at Kolhufushi

(Dhani in Divehi) to draw water from the well (see Figure 4.14). On Kolhufushi, a power plant was only built after the 2004 tsunami.

Around the 1980s groundwater became unfit for drinking due to a cholera epidemic possibly caused by inadequate sanitation, and due to increased salinity because of over-extraction with groundwater pumps. As a result, drinking rainwater or bottled water became the norm (Ministry of Environment, Republic of the Maldives, 2020). In 1904, the government began the first initiatives to use rainwater as a source of drinking water, and nationwide projects were started, mostly for ferro-cement communal rainwater tanks, supported by international donors such as UNICEF. Private HDPE rainwater harvesting tanks were also provided on a cost-recovery basis/loan (Ministry of Housing Transport and Environment Government of the Republic of Maldives & WHO, 2009). These national efforts resulted in more than 93% of island communities using rainwater as a source for drinking by 2000 (Ministry of Environment Republic of the Maldives, 2020). After the 2004 tsunami, the government, with international assistance, also provided free 2,500-Litre rainwater tanks to every household in the affected islands (Ministry of Housing, Transport and Environment of the Republic of Maldives & WHO, 2009).

Rainwater harvesting is collected through rainwater pipes and gutters on the roof connected to the tanks. After filling, the water tank is closed and reopened if necessary (Acciarri et al., 2021). Water flows out of the tank through a tap; sometimes, a pipeline connects to the kitchen. The tank is refilled during the rainy season and occasionally during off-season rains. Any overflow from these tanks is sometimes diverted to domestic groundwater wells, see Figure 4.20 and Picture 4.8.

Figure 4.20: Drawing of a typical rainwater harvesting installation in the Maldives (Ministry of Housing Transport and Environment Government of the Republic of Maldives, 2009).

Picture 4.8: A rainwater harvesting (2500L) with a rooftop pipeline connection by a household at Kolhufushi.

Picture 4.9: Boat supply delivery once a week on Kolhufushi

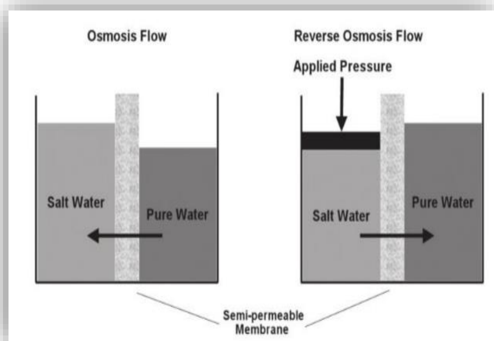
An alternative for drinking rainwater is plastic bottles, usually of 1.5 Litres. Bottled water is transported by supply boat to the islands and sold in small stores for an average of MVR 15 (€0.94) per 1,5 Litre, with price variations depending on supply and demand (see Pictures 4.9 and the cover photo). On Magoodhoo Island, bottled water costs about 1% of a household's annual income and according to UNW-DPAC (2010). it should not exceed 3% (Acciarri et al., 2021: UN). The two most common water bottle brands are TaZa (from the public company Malé Water and Sewerage Company) and Life (from the Indian private company ABL Water Solutions Private Limited) in the Maldives.

The empty water bottles form a major problem on Kolhufushi and Muli. This not only contributes to environmental pollution (see Picture 4.10), but also to the formation of mosquito breeding grounds by residual water in the bottles, which increases the risk of diseases such as dengue. However, waste disposal systems are being built on both islands. Plastic bottles are now collected (see the waste dumping on Figure 4.14) and sent to larger islands for recycling. Other waste is burned in landfills on both islands, which the IC regulates.

Picture 4.10: Plastic found at the beach of Muli

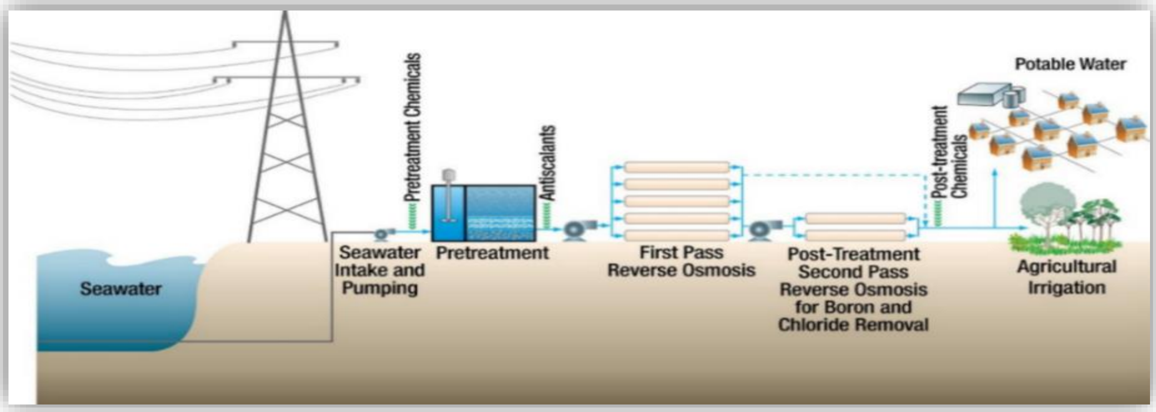
Providing desalination water also off-sets the reliance on bottled water. Although desalination plants already existed since 1985 in Malé and all the tourist resorts. The cost of desalination plants remained prohibitive for many small outer island communities (Ministry of Environment Republic of Maldives, 2020). However, after the tsunami in 2004, international donors, such as IFRC and UNICEF, installed more than 35 desalination plants on the hardest-hit outer islands to counter water and sewage destruction, including on Muli and Kolhufushi. By the end of 2017, 49% of the Maldivian population had access to piped water with metered house connections, where desalination water was mixed with rainwater (Mohamed et al., 2020).

Figure 4.21: Osmosis and reverse osmosis flow process (URS Australia, 2002; Chua and Rahimi, 2017).



All desalination plants in the Maldives use reverse osmosis (RO). In RO, pressure is applied to salt water to separate pure water through a semi-permeable membrane, see Figure 4.21 (Chua & Rahimi, 2017). For more explanation see Appendix III. Desalination plants include four main components: feed, pretreatment, desalination, and post-treatment. The byproduct, brine (highly concentrated feed or concentrate), is often discharged back into the sea (see Figure 4.22). Most energy in RO is used to pressurize the feedwater, and it can desalinate 30-80% of total feed water, depending on factors like the membrane type, technology, and feed water quality (URS Australia, 2002). However, in the Maldives there is no chemical pre-treatment and post-treatment second pass.

Figure 4.22: Seawater desalination using reverse osmosis for both potable and agricultural irrigation (Shaffer et al., 2012; Lesimple et al., 2020).



RO desalination plants offer several advantages, such as quick construction and easy operation, expandability by adding additional modules, low energy consumption and reduced use of cleaning chemicals. They do not require shutdown of the entire plant for scheduled maintenance. However, disadvantages are: high cost of membranes and limited service life (2-5 years), sensitivity to salinity variations in feedwater, requirement of high-quality materials and equipment, risk of bacterial contamination, need for premature treatment of feedwater, and operational complications under high pressure that can cause mechanical failures (URS Australia, 2002; El-Dessouky, 2005).

The desalination plants are subsidized by the government, but the users will need to pay per unit of desalinated water, which is a combination of treated rainwater and seawater. There is a standard price per water unit on each island. It differs per island depending on e.g. the desalination capacity and number of inhabitants. Future water prices were known in Kolhufushi but not in Muli in February 2024. Households will pay 22 MVR (€1.3) per 1,000 L, with higher rates for public buildings and the private sector. A household of 4 to 5 people is expected to have an average water bill of €40 per month if they consume around 30,000 Litre water (Velus[10], personal communication, December 10, 2023). Whether this will be too expensive for islanders on Kolhufushi remains the question, given that most respondents prefer a maximum payment of €29.87. However, possible cost savings could be realized in: the energy bill due to reduced use of the groundwater pump, reduced purchase of plastic bottles if desalination water is going to be used as drinking water, and reduction in cleaning supplies purchases because desalination water makes for cleaner toilets and showers. However, it remains to be seen whether these savings outweigh the cost of the water bill.

Muli

Muli has three communal wells, all located near mosques, since the water is used for Vudu (the ritual washing before prayers). Each household has at least one domestic groundwater well. Due to less infrastructural destruction after the 2004 tsunami compared to Kolhufushi, Muli has more diverse well constructions in various locations (see Picture 4.11). Households often have access to more than one well, although only one is usually connected to the water pump. Most wells are around 6 meters deep and wells are constructed through rocks placed at the bottom, topped with a concrete block with holes used as a filter.

Picture 4.11: Various domestic ground well constructions and locations on Muli

The IC has 10 communal rainwater tanks of 5,000 litres each, which are not used due to poor maintenance. When there are water shortages, the IC asks the Disaster Management Department to refill the tanks. There are also communal rainwater tanks at the three mosques and the hospital (see Figure 4.15).

A desalination plant has installed since 2021 on Muli. The collection method and treatment process are similar to Kolhuufshi. However, the desalination plant on Muli has a higher capacity. See Table 4.2, for a summary of the storage and distribution capacity of the desalination plants at Muli and Kolhufushi,

[10] Velus is the desalination project manager of the company SMC at Kolhufushi i

and Appendix III for more details and photographs. Rainwater is collected through 8 public roof buildings, such as hospitals, mosques, and schools. There is a total rainwater collection capacity of 920,000 Litres. The rainwater and seawater are treated and mixed in two tanks, then distributed to households through a piped water system. The desalination plant operates partly on solar energy. The brine water is discharged untreated 60-100 meters from the coast.

	Rainwater Storage Capacity in Litres	**Groundwater storage Capacity in Litres**	**Total aro-plant Capacity in Litres/day** (both islands have two)	**Degasser Tower-Chlorination-Storage-Distribution in Litres/day** (the treating and distribution water capacity of water in L/day)
Kolhufushi	610,000	770,000	900,000	140,000
Muli	920,000	570,000	160,000	210,000

Table 4.2: Overview of the storage and distribution capacity of the desalination plants on Kolhufushi and Muli (source: SMC Limited Desalination Plant Project Managers).

During the data collection phase, both islands were in a test phase of desalination water, in which residents could use the water for household needs, but not yet for cooking and drinking. Water quality was still being tested for compliance with WHO drinking water standards, and official government approval was still lacking. This approval was expected in February 2024, but currently (June 2024) residents still cannot drink the water. The desalination water is free during the trial period, after that islanders need to start paying. SMC transferred duties to Feneka employees during the trial period.

On Muli, almost all households (209 out of 215 households) were connected to the tap water system, of which 111 households have since turned on their taps (S. Swagath[11], personal communication, December 19, 2023). However, people rarely used it to fulfil their domestic household water needs with it. Registration for connection to the potable water system was also free on Muli. The desalinated water was gradually released by SMC, with about 7 homes connected and served weekly, unlike Kolhufushi, where all connections were opened simultaneously. Muli only used one aro-plant in the trial period.

Several challenges were identified by the water service provider SMC during the trial period. The main challenge was obtaining appropriate materials and equipment, besides some leakage incidents related to the rain system collection pipes, which were rectified after a month of effort (S. Swagath, personal communication, December 19, 2023). Future challenges pointed out by the desalination project manager were the high maintenance and concerns about the capacity of the system to meet the water needs of the 135 new households. He also raised concerns about potential high costs for end-users.

Kolhufushi

Kolhufushi has three communal groundwater wells. The well near the former women's mosque in Kolhufushi has fallen out of use. Households have at least one groundwater well connected to electric groundwater pumps. Most wells are also around 6 meters deep. Kolhufushi has mainly one type of well construction: inside the house, partly underground, with a corrugated metal plate on top, often in bathrooms or washrooms. This uniformity is the result of standardized reconstruction after the tsunami. The location and construction of domestic groundwater wells can also affect water quality through factors such as oxygenation, sunlight exposure, mud area locations, and ease of cleaning.

At the moment, the IC has six communal rainwater tanks, and three mosques have, in total, also 10 tanks. According to the vice president, islanders, specifically construction workers, use them mostly

[11] S. Swagath is the desalination project manager of the company SMC at Muli

during the dry season. In particular, the summer of 2023 was really hot (A. Fayaz[12], personal communication, December 13, 2023).

Since 2021, the desalination system is also installed on Kolhufushi (see Picture 4.12). Rainwater is collected through 10 public roofs, with a total collection capacity of 610,000 Litres (see Table 4.2). During heavy rainfall, 60,000 Litres per hour can be collected (Velus[13], personal communication, November 19, 2023). Seawater is also collected through two 35-meter-deep borehole and the treatment process is the same as in Muli. The brine is discharged into the sea without treatment.

Picture 4.12: Desalination Plant on Kolhufushi. The grey *tank* harvests rainwater and the blue tanks contain treated *rainwater and seawater (source: Sobeeb, 2023).*

Picture 4.13: Water tap with desalinated water not connected to the house piped water

During the trial period, nearly all households (211 out of 226) on Kolhufushi were connected to the metered water system. Of these, 178 households accessed desalinated tap water (see Picture 4.13), but only 80 households used the water for domestic purposes during the trial period. On Kolhufushi, the water utility company simultaneously opened water connections for all households. Registration for connection to the drinking water system was free.

Several challenges were identified by the water provider SMC in Kolhufushi during the trial period, including delays due to high water levels, turnover of project managers, high costs associated with fuel and pumps, inefficiencies in power supply, working safety concerns of employees, difficulties locating underground cables (which were up to three meters deep), prolonged leaks and repairs, and temporary malfunction of backup power generators. In addition, the free water usage during the trial period strained the capacity. The desalination plants could not meet demand, resulting in a one-month shutdown in October-November. They could only produce 540,000 Litres of water daily, while households required 960,000 Litres daily. Nevertheless, SMC plans to increase capacity to 100,000 Litres per day for all households in Kolhufushi. One contributing factor to the shortfall was that the installation was originally designed mainly for drinking and cooking water, and households used it for all their other domestic household needs in the trial period. According to the project manager at Kolhufushi, key future challenges are low productivity and high maintenance, particularly due to the need for continuous system monitoring, resulting in one assigned person per day (Velus, personal communication, December 10, 2023).

[12] A. Fayaz is the vice president of the Island Council at Kolhufushi
[13] Velus is the desalination project manager of the company SMC at Kolhufushi

4D. Meeting the water needs with Freshwater Resources and/or Technologies

On Kolhufushi and Muli, the average monthly rainfall, in the dry and wet monsoon season, is sufficient to meet the basic domestic water requirements of inhabitants on the islands of 100 litres per day according to WHO (2013) standards (see Table 4.3 and Appendix IV step 1,2 and 3). An estimation of the runoff in Liters/month on each island in the wet and dry monsoon period is made (see Appendix IV step 4), to show how much rainfall could potentially be captured if enough storage were available. The runoff represents the available water after accounting for losses due to infiltration, evaporation, and absorption by vegetation.

On Kolhufushi, the average monthly runoff is approximately 46,370,250 L, which could be captured during the dry season, enough to fulfil the basic domestic water needs of inhabitants of 4,413,000 Liters per month. On Muli, the average monthly runoff is approximately 46,039,175 L, which could be captured during the dry season, enough to fulfil the basic domestic water needs of inhabitants of 3,084,000 Liter per month. This illustrates that in theory, there should be enough rainfall and runoff that can be captured monthly on both islands to fulfil in the basic water needs of inhabitants of 100L/day/person on the island. However, the question of how much runoff the storage tanks can capture remains. Each household now has at least one 2,500-litre rainwater barrel, and communal rainwater storage tanks are available at mosques and the IC on both islands.

	Muli	**Kolhufushi**
Average precipitation during the rain monsoon season in Liter per month	170,301,500	247,165,000
Average precipitation during the dry season February and March (in mm)	70,799,500	103,045,000
Total runoff in Liters per month in the wet monsoon season	110,666,975	111,539,250
Total runoff in Liters per month in the dry season	46,039,175	46,370,250
Basic survival domestic water needs (100L/day/person) of island inhabitants per month in Liter	3,084,000	4,413,000
Basic water survival needs for drinking, food, basic cooking needs, and basic hygiene practices (15L/day/person) of inhabitants per month in Liter	462,600	661,950

Table 4.3: The monthly precipitation and runoff and the basic water needs of inhabitants on Muli and Kolhufushi. See Appendix IV for calculations (author's work, 2024).

The total private and communal rainwater harvesting capacity in Kolhufushi is approximately 1,000,000 Liter (see Appendix IV step 5), which if captured sufficiently every month the rainfall should be enough to meet the basic drinking and cooking water needs of the inhabitants of 661,950 L per month. To meet the additional demands of domestic water needs, 3,413,000 Litre extra storage capacity is required to capture the rainfall (see Appendix IV step 6). This equals 1366 additional 2500 Litre capacity tanks and would take up around 1.9 % of the total land (111,4 ha) in Kolhufushi (see Appendix IV step 7).

The total private and communal rainwater harvesting capacity on Muli is approximately 720,625 Liter (see Appendix IV step 5), which, if captured sufficiently every month, rainfall is more than capable of meeting basic drinking and cooking water needs of the inhabitants of 462,600 Liter per month. To further satisfy domestic water needs, 2,363,375 additional storage capacity tanks are required (see

Appendix IV step 6). This equals 946 rainwater tanks of 2500 Litre and would take up around 0.2% of the total 75,54 land ha on Muli (see Appendix IV step 7).

Nevertheless, the tank capacity is not necessarily representative for how much run-off there can be captured. This depends, for example, on the efficiency of the collection systems and the catchment areas (e.g. the roof space and pavements). Moreover, to capture the rainfall sufficiently, the tanks must be refilled monthly, as in the scenario and calculations s at depicted above. After one heavy rainfall, the 2500 Litre water tanks are completely filled, according to multiple respondents in Muli and Kolhufuhi. This is plausible during the wet monsoon season since one heavy monthly rainfall is common. However, those heavy rains are less likely during the dry season, although in theory there should be enough rainfall to capture even in the dry monsoon periods (see Table 4.3). Good rainwater harvesting management and weather predictions are needed to fulfil the water needs of islanders in the dry season.

In addition, the two-month dry monsoon period could also be bridged to fulfil mostly the drinking and cooking water needs of islanders if there is sufficient (private and/or communal) rainwater tank capacity. According to Acciarri et al. (2021), a family that only consumes rainwater for cooking will utilize a single 2500 Litre tanks' worth every three-four months. The estimation is that the family uses 23.81 Liters per day in the Faafu Atoll. Faafu Atoll is also located south of the Maldives and has weather and climate conditions similar to Muli and Kolhufushi's.

As demonstrated above, rainwater harvesting has the potential to fulfil basic water needs in both wet and dry season, subject to storage capacity. Moreover, the current storage capacity is not utilized fully. On average, households only clean their roof and open the roof pipeline connection to the rainwater harvesting tank only once or twice a year instead of monthly. Monthly roof cleaning is seen as inconvenient by households, and so sub-optimal rainfall collection is occuring. Therefore, more communal rainwater storage tanks could be considered, as this would share the cleaning workload among a larger population and can be institutionally arranged. However, the currently existing 10 tanks of 5000 Litre on Muli are suffering due to lack of maintenance, and so operating at a reduced capacity, additionally, residents dislike this option due to time required to walk and fetch the water. Piped systems could be a potential alternative solution.

Further benefits of increasing rainwater collection include protecting the sewerage system, and reducing overflow. The system is particularly vulnerable in the Maldives as there is no separation between runoff and sewerage systems on the islands. Overflow mainly occurs during heavy rain or by inflicting human actions such as connecting rainwater pipes to the sewage system or opening manholes to drain water during heavy rain. This overflow can also pollute the groundwater.

Currently, most islanders on Muli and Kolhufushi use rainwater for cooking. For drinking, islanders use rainwater or packaged bottled water. In the future, desalinated water can also be used for these purposes. In the desalination design plan on Muli and Kolhufushi, the average per capita water demand is 50 Liters per person per day. It encompasses more than just drinking and cooking, likely including other domestic needs. However, there is also an additional consideration for unaccounted water, which includes losses due to unauthorized connections, leaks, and other inefficiencies. This will be added to the 50 Liter per day per person. Furthermore, there is the expectation that water consumption rate of 120 Litres per capita will be drawn towards the later part of the design period based on the experience of Malé.

Even though the basic design of the desalination plants is the same as that of Kolhufushi and Muli, the treatment and distribution capacity differs based on e.g. additional consideration for unaccounted water, differing demographics and future island plans. Muli has a higher daily treating and distribution desalination capacity of 210,000 Litres, which is more than sufficient to meet additional daily domestic water needs of the island of 3,084,000 Litres (see Table 4.3), however with 135 additional homes planned, this might be challenged in the future (S. Swagath14, personal communication, December 19, 2023). At Kolhufushi, the daily treating and distribution desalination capacity is 140,000 Litres, and 4,413,000 Litres are needed to fulfil the most basic water needs (see Table 4.3). Thus, in Kolhufushi, there is insufficient water supply via desalination technology to fulfil the most basic water needs of 100 Liter per day per person, especially as further housing capacity of 100 homes is planned. 65 Litres per person per day has been accounted for with the desalination plant on Kolhufushi (Velus, personal communication, December 10, 2023).

In conclusion, rainwater harvesting is currently not fully utilized, despite having potential to satisfy the water needs of the islanders. In theory, rainwater can also be used for domestic water needs such as bathing, due to the runoff available for capture. In order to achieve this, re-evaluation of the storage capacity and good management practices with accurate weather predictions are needed. The government has proposed an alternative solution, namely desalination technology, to meet residents' drinking and water needs, which can be beneficial to meet the water needs of islanders for, specifically in the dry period. In Chapter 6, the islander's views on this will be discussed.

[14] . Swagath is the desalination project manager of the company SMC at Muli

5.Constructing local voices in the waterscape

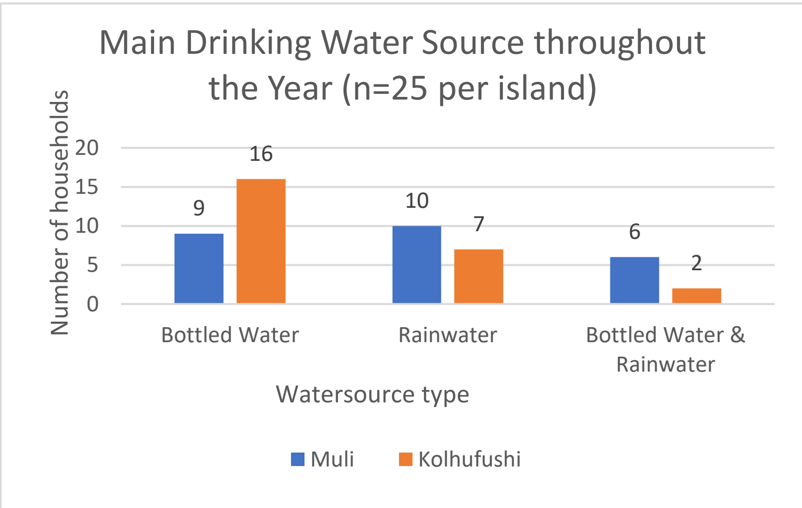
The previous chapter discussed the waterscape (water, humans and technology) on Kolhufushi and Muli. These elements provide the context in which individuals shape their environment, make choices, and develop coping strategies. People use these structures to perform social actions. This chapter examines how individuals cope with freshwater scarcity and quality challenges. It will also address general usage experiences, preferences, and considerations related to freshwater resources among islanders on Muli and Kolhufushi, since water knowledge and understanding the water knowledge of islanders is crucial for solving water-related problems (Dean et al., 2016). Assessing knowledge about water is crucial because community engagement initiatives will be more effective when they align with existing knowledge (Dean et al., 2016; McDuff et al., 2008; Buhr & Wibeck, 2014). This chapter first provides a general analysis of coping strategies and water knowledge, which is then deepened by looking at differences in households and their dynamics and the most prominent intersectionality factors that influence access to water and coping strategies of islanders and certain groups in the community will be outlined.

5A. Freshwater resource usage

Groundwater is used for all domestic household needs other than drinking and cooking. This includes cleaning the house, doing dishes, laundry, flushing the toilet, bathing, personal hygiene (like washing hands and brushing teeth), and gardening. Respondents had no idea about their average monthly water consumption or how much water they use for certain water needs, because rainwater use is not monitored and groundwater is often pumped with a groundwater pump, but electricity bills don't tell the volume of water pumped. However, desalinized water will be billed per volume of water consumed, in the future, so this might increase awareness of daily water consumption.

Rainwater is used for cooking and drinking by households. As shown in Figure 5.23, households' main drinking water source throughout the year is rainwater in Muli and bottled water in Kolhufushi of islanders. Rainwater is sometimes also used to take a shower, specifically for infants and the youth.

Figure 5.23: The main drinking water source throughout the year of households on Muli and Kolhufushi (author's work, 2024).



5B. Rainwater general experiences, preferences, and considerations, and coping strategies

Rainwater quality

Preferences

The majority of respondents prefer rainwater over bottled water on both islands, due to the softer and more 'natural' taste than bottled water. Traditionally and culturally, islanders are also used to drinking rainwater. However, as illustrated in the following quote: '*I like rainwater the most (for drinking), but it is not always the best or safest option since animals can be on roofs* (18- female respondent Muli, personal communication, January 1, 2024), many islanders specifically on Kolhufushi, consider water from the rainwater tanks as unsafe for drinking due to improper tank and roof cleaning or contamination from animal disposal on the roofs.

Considerations & Experiences

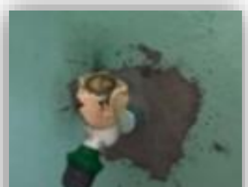
The main reason for islanders to switch to bottled water, despite their preference for rainwater, are concerns about rainwater quality and health. On Kolhufushi, 72% of households use bottled water or a combination of bottled water and rainwater as their primary source of drinking water year-round, because of safety reasons and concerns about rainwater quality. It is notable that of these households, 67% reported that rainwater caused stomach discomfort such as gastrointestinal complaints, which decreased after switching to bottled water. In Muli, 60% of households use bottled water or a combination of bottled water and rainwater year-round, with 81% saying they do so because of safety and quality concerns. Children and the sick in particular drink bottled water, which is also advised by doctors on the island.

Moreover, the expenditure for drinking water sources is also an important consideration in the water source selection of islanders. Bottled water comes at a very high price per Litre, while rainwater is for free. Whether people are able to switch to drinking bottled water depends on their financial capabilities. Affordability regarding rainwater harvesting only becomes an issue when the available rainwater storage capacity is limited, requiring people to buy extra tanks, which is expensive. Moreover, having more financial resources creates more flexibility and opportunities. For example, if people can't clean the tanks and roofs themselves, some hire others to do this of people can buy tap filters.

Coping Strategies

Four main **coping strategies** identified for ensuring better drinking rainwater quality are:

1. Using a **tap filter:** 60% of the respondents made use of a tapfilter in Muli and only 20% in Kolhufushi. One explanation can be the higher drinking rainwater usage in Muli than in Kolhufushi. Throw-away tap filters are often used for a maximum of one month because they will get dirty and dusty easily and cost around 15 MVR/ €0,9 (see Picture 5.14).



Picture 5.14: A throwaway tap filter

2. Use **clothing as a filtration system** by the rainwater harvesting tanks. All of the household respondents on Muli and Kolhufushi used pieces of clothes (e.g. scarfs) stuffed into the pipe hole to prevent dust and leaves from entering the tank (see Picture 5.15). Some also place the cloths between the tank and tap since they believe it is safer to consume the water this way. Even though this does not provide any protection against microbes. Most replace it while cleaning the rainwater tank and roof, once or twice a year.

Picture 5.15: Clothing used as rainwater tank filter in Kolhufushi

3. Another way to maintain rainwater quality is to **properly clean the tank, pipe, and roof** before opening the pipeline connection to (re)fill the rainwater tank. People usually only clean the roof after a heavy downpour since this cleans the roof naturally (pre-cleaning), and this happens approximately one or two times a year on Muli and Kolhufushi, which is in line with another case study at the Faafu Atoll the roof is cleaned occasionally, no more than once a year (Acciarri et al., 2021).

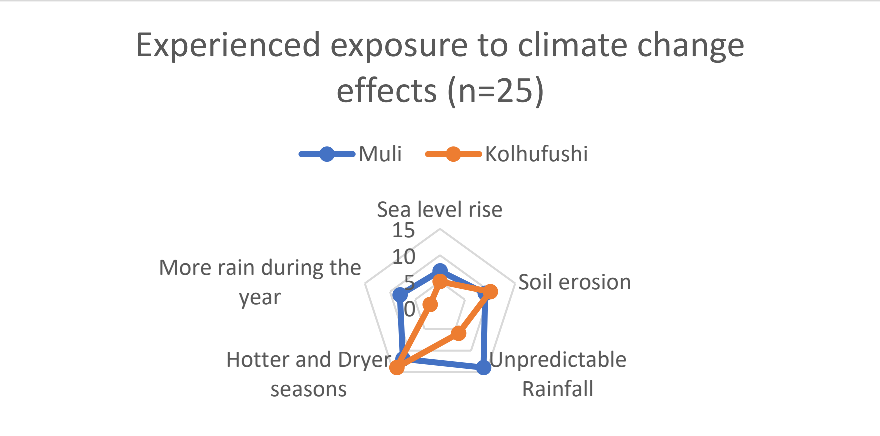
4. Households can also **switch to other drinking water sources**, which can be considered a way of coping with rainwater that is considered inadequate for drinking by islanders. Households now use bottled water as an alternative drinking water source, in the future households might switch to desalinated tap water. 68% of the respondents in Kolhufushi would be open to trying to drink desalination water in the future, and 88% were on Muli. This will be further discussed in Chapter 6.

Rainwater scarcity

Experiences

Climate change (future) impacts can increase the frequency and severity of droughts on islands (Ali et al., 2001). This can result in longer dry monsoon periods in Muli and Kolhufushi. *''Before, there were two monsoons, one of four months and one of eight months. Now, we cannot count on that anymore.''* (06- female respondent Muli, personal communication, December 24, 2023). As this quote illustrates, the islanders have already experienced these climate change impacts. Figure 5.24 illustrates the most commonly experienced impacts of climate change of islanders in 2023. Hotter and dryer seasons are outstanding on both islands.

Figure 5.24: The most experienced climate change impacts by islanders on Muli and Kolhufushi in 2023 (author's work, 2023).



However, the future impacts of climate change do not seem to be the main priority for most islanders on Kolhfushi and Muli at the moment. Instead, residents focus more on short-term developments and concerns. For example, the most frequently mentioned future concerns are better healthcare and education facilities on both islands. Since these short-term needs have to be met first, other long-term concerns, such as climate change, are more likely to remain in the background.

While water scarcity is often attributed to natural conditions such as weather and climate influences, water shortages can also result from various anthropogenic factors, as illustrated by the following quote:

'We have one rainwater tank (for a household of four people). Normally, this should be enough water, also for dry periods. However, after we cleaned the tank, there was no rain. We also had problems with the pipes and connection. At that moment, we faced water shortages and we then used the rainwater tank of family' (03- female respondent Kolhufushi, personal communication, November 30, 2023).

48% of the respondents in Muli and 43% in Kolhufushi mentioned to have experienced rainwater shortages in their household at least once in their lives. Water shortages can therefore,be seen as an interplay between humans, technology and climate. In theory, there should be sufficient collection capacity to meet drinking and cooking water needs during both monsoon periods, but this capacity is not optimally utilised. Water shortages are mainly caused by anthropogenic factors such as faulty or poorly maintained tanks, inadequately cleaned tanks and roofs, insufficient storage capacity, and limited manpower to clean the tank and open it for rainwater harvesting.

Coping Strategies

''Some people faced water shortages one or two years ago on the island, everyone would share their water then. To family, neighbours and friends. Some would also buy water.'' (22-male respondent Muli, personal communication, January 3, 2024).

Two main **coping strategies** are identified for ensuring sufficient access to rainwater drinking water security are:

1. As the above quote illustrates, making use of a **social network** can be a coping strategy for islanders in times of water scarcity, specifically in the dry season. Of the respondents who faced water shortages in their household, 80% in Kolhufushi and 82% in Muli relied on their social network to fetch rainwater from other houses, mostly from friends and family, in the vicinity, as a coping strategy. Some houses are known for having too much rainwater storage capacity, making it easy to fetch water from there. Communal rainwater tanks are often not used to fetch water in times of scarcity, since they are considered located too far away or less convenient for households to fetch water. On Muli, the communal tanks are not even in use by the IC. Some households are known to be more fortunate, so they can always afford to switch to drinking bottled water when necessary, also pointing out the next coping strategy.

2. The above quote also illustrates that some people **switch to alternative drinking water sources**: drinking bottled water and in the future potentially desalinated tap water. Only islanders who can afford to buy bottled water can and/or will do this.

Access Obstacles

The main obstacles in accessing rainwater for drinking and cooking identified are: financial resources e.g. buying filters or additional tanks, the division of labour within the household (men cleaning roof and tank), and not having available proper knowledge and perceptions about rainwater quality and use and having a social network to fetch water. However, having a social network for the Maldivian population rarely poses a barrier because of the island culture where most people have close ties within island communities with mainly family. It could potentially form a barrier for foreign construction workers.

Conclusion

Rainwater is mainly used for drinking and cooking and is considered better tasting than bottled water. Freshwater usage experiences often relate to water quality concerns and health issues for both rainwater and groundwater. On Kolhufushi, however, drinking rainwater is often associated with stomach (e.g. gastrointestinal complaints), which probably relates to the higher bottled water consumption on Kolhufufshi compared to Muli. Efforts are made to ensure rainwater quality by cleaning rainwater tanks and pipes, using tap filters, or clothing in pipes to keep dust and leaves out of the tanks. When in doubt about rainwater quality, people switch to bottled water, but not everyone can afford it all year round. During the dry monsoon period, islanders sometimes face rainwater scarcity. However, this is mainly due to human factors such as poorly maintained tanks, limited manpower to clean the roof for rainwater harvesting, or not making the best use of rainwater harvesting. In theory, there should be sufficient rainfall throughout the year to meet islanders' drinking and cooking needs, as described in Chapter 4D. Obstacles to obtaining and having access to rainwater include financial resources, social networks, division of labour within the household, and knowledge about water quality and use.

5C. Groundwater: general experiences, preferences, considerations, and coping strategies

Groundwater scarcity & quality

Freshwater lens scarcity results from insufficient rainfall patterns and groundwater pollution. Hence, groundwater quality and scarcity are intrinsically linked to each other.

Experiences

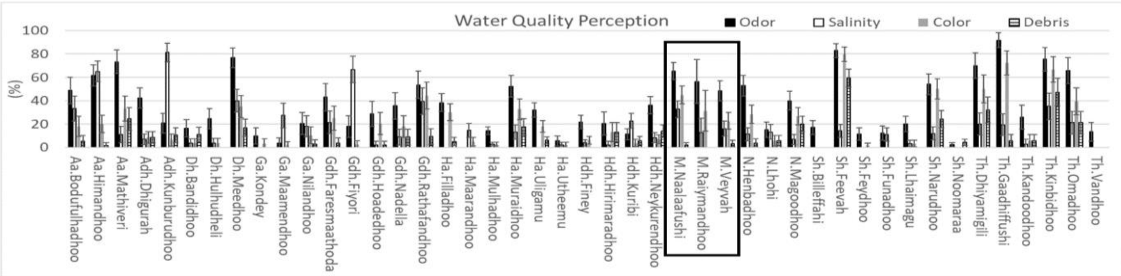
''When I take a shower, I can smell my skin.'' (17- female respondent Kolhufushi, personal communication, December 9. 2023).

''The toilet and shower are next to our bedrooms, and the AC is spreading the groundwater smell into their rooms.''(17- female respondent Kolhufushi, personal communication, December 9. 2023).

On both islands, many islanders consider the experience groundwater to be smelly. On Muli, 68% experienced this, and on Kolhufushi, 88%. The groundwater smells like mud (chacka in Divehi), according to 40% of respondents on Muli and 56% of the respondents on Kolhufushi. Other smells referred to are rotten egg, bird poo, pond, moss fungi, mouldy and/or foul smells. A colour change of the groundwater is sometimes also experienced. On Muli, references were made to a white colour (by 12% of the respondents) and a brown-yellow-red colour (by 12% of the respondents). On Kolhufushi, most respondents referred to a brown-yellow-red colour (by 24% of the respondents). In addition, a muddy or salty taste of the groundwater was experienced by 24% of the respondents on both islands, while e.g. brushing their teeth or washing their face. Other issues with groundwater quality include changes in the color of certain materials, such as jewelry turning black, or clothing not getting completely clean after being washed with groundwater.

These experiences align with results from another study conducted on 45 islands ranging from North to South in the Maldives (Jaleel et al., 2020). Three islands of the Meemu Atoll, of which Kolhufushi and Muli are part of, are also included (see the black box in Figure 5.25).On these three islands, more than 50% of the respondents on each island experienced odour, next to experienced salinity colour and debris.

Figure 5.25: Groundwater quality perception of respondents. The margin of error for a 95% confidence level is indicates as error bars. The black box outlines islands on the Meemu Atoll (Jaleel et al., 2020).



Perceptions & Considerations

''My son gets skin problems, like pimples and dry skin, because of the groundwater. We wash our face and brush our teeth with rainwater then, which makes it better'' (13-female respondent Muli, personal communication, December 27, 2023).

As the quote above illustrates, some respondents also associated groundwater quality with health issues. On both islands, 12% of the respondents experienced themselves or had household members who experienced skin rashes, itchiness, dry skin, and even hair loss, which they related to bad groundwater quality. So far, little research has been done about watershed diseases and their relation to groundwater quality on the islands in the Maldives (Public Health communication coordinator, personal communication, December 20, 2023). The relationship between groundwater quality and health concerns, specifically watershed diseases, can be twisted and needs further examination. Skin problems can relate to various factors, such as sunburns and allergic reactions. However, the fact is that islanders do have concerns about it.

On both islands, most respondents rated the groundwater quality with a 5, on a scale up to 10. Grade 0 refers to atrocious groundwater quality experience and grade 10 refers to the perfect groundwater quality (see Figure 5.26). The average grade for the groundwater quality on Muli is 6,12 and on Kolhufushi 5,96. This can indicate worse groundwater quality on Kolhufushi than Muli, in combination with more references to bad smell and coloured water in Kolhufsuhi than Muli, as shown above.

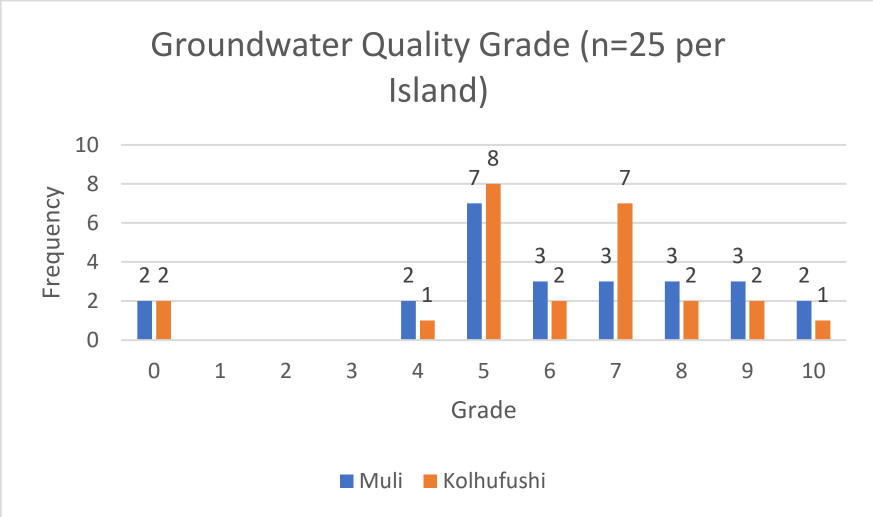


Figure 5.26: Groundwater Quality Grades by islanders on Muli and Kolhufushi. Grade 0 refers to atrocious groundwater quality experience, and grade 10 refers to the perfect groundwater quality (author's work, 2023).

The perception of water quality differs per area on the islands and in general, the islanders are aware of areas where groundwater quality is perceived as very poor or good. On Kolhufushi, the smell is worst in the centre of the island, which is considered muddy. This corresponds to household locations that had a low groundwater quality rating. Residents noted that cleaning wells brought up mud, which may explain the brown-yellow-red colour of the water. Before the tsunami, this area was used for agricultural activities, which may also explain groundwater pollution through the use of fertilisers (20-male respondent Kolhufushi, personal communication, December 12, 2023). On Muli, the worst water quality is experienced by houses close to the beach, probably due to more saltwater infiltration.

The quantity and quality of the groundwater lens on islands such as Muli and Kolhufushi are influenced by rainfall patterns that regulate freshwater lens recharge, interactions with the ocean affecting salinity rates of groundwater, and human activities affecting recharge, abstraction and pollution of the freshwater lens (Jaleel et al., 2020). These groundwater pollution causes align with islanders' perceptions of Muli and Kolhufushi. However, there are some differences in groundwater pollution causes and percptions between the islanders of the islands, those will be outlined.

The tsunami is cited as the main cause of groundwater pollution by 44% of respondents on Kolhufushi and 24% on Muli, due to significant damage to the freshwater lens and increased saltwater infiltration (Kan et al., 2007; Zahir, 2004). Over-usage and the high-pressure groundwater pump were also outlined as a cause of the groundwater smell on both islands. Excessive abstraction of groundwater is caused by using more high-pressure water pumps since they pump at higher speeds than normal pumps. This can decrease groundwater levels and allow seawater intrusion, which further pollutes the freshwater lens (Wickramagamage, 2017). The higher speeds of these pumps can also increase turbulence and erosion in the soil around the well, disturbing and dissolving more sediments and contaminants in the groundwater. In addition, using high-pressure pumps can also enable the construction of deeper wells, extracting groundwater from deeper layers where contaminants are more likely to be present.

On Muli, the majority of respondents reported that heavy and more rainfall reduced groundwater odour, which can be possible through groundwater dilution and infiltration with rainwater. However, some noted increased odour during rainy periods, possibly caused by septic tank leakages and/or overflow spreading contaminants in the groundwater. Septic tanks are seen as an important source for groundwater pollution on Muli, unlike Kolhufushi, where they do not have septic tanks. The proximity of domestic groundwater wells to septic tanks exacerbates this problem (Jaleel et al., 2020). In contrast, respondents on Kolhufushi were significantly less likely to notice a link between rainwater and groundwater pollution and odour.

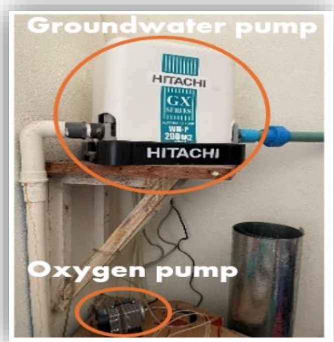
Picture 5.16: Construction works and the water level on Muli

More construction projects are also being carried out in Muli, with more construction sites than in Kolhufushi (see Picture 5.16). According to some respondents on Muli, this can also contribute to groundwater pollution due to the dumping of construction waste.

In Kolhufushi, respondents made more frequent references to the construction of the groundwater wells (inside the house without sunlight), which negatively impacted the groundwater quality. Households on Muli have more diverse groundwater well constructions compared to Kolhufushi as described in Chapter 3. The lack of sunlight in covered groundwater wells can cause poorer groundwater quality. It can for example, create conditions favourable to microbial growth, interfere with natural purification processes and affect the physical and chemical properties of the water, affecting groundwater quality.

Coping strategies

The main **coping strategies** for mitigating bad domestic groundwater quality are:



Picture 5.17: A groundwater and oxygen pump at Kolhufushi

1. Using **oxygen pumps** to prevent the water from becoming smelly (see Picture 5.17). An oxygen pump in the groundwater well aerates the water by injecting oxygen. This increases, oxygen levels, it addresses high levels of dissolved gasses (like hydrogen sulfide or methane), and it stimulates microbial activity that can aid in contamination remediation. 65% of the respondents on Muli made use of an oxygen pump, and 68% of the respondents on Kolhufushi.

2. **Boiling groundwater for treatment** is a common practice for bathing infants and young children, but not for adults, on Muli and Kolhufushi. Boiling groundwater is a common practice in the entire Maldives, as shown in a study done at 45 islands in the Maldives (Jaleel et al., 2020).

Picture 5.18: A tap filter for doing dishes with groundwater

3. Using a **tap filter** in the kitchen for doing dishes (see Picture 5.18).

4. **Mix the domestic groundwater well with rainwater** to dilute the water. Some households on both islands had the rainwater pipe connected to the groundwater well. Most of them only open this connection when they think the roof is clean or cleaned.

5. **Using an alternative groundwater well** in the household, either a newly constructed one or an existing one. On Muli, it is common to have access to multiple domestic groundwater wells. For example, one household on Muli constructed a specialized well in 2023, to

guarantee a continuous supply of fresh groundwater. They measured the freshwater lens themselves by observing the high and low tide, and they devised a system involving a perforated bowl, which is submerged in the freshwater lens, collecting the freshwater into a tank.

Some other less common strategies employed are using a little water bucket (Dhani in Divehi) instead of the groundwater pump; water is then only drawn from the surface, which gives less odour, according to the islanders. Another way of tackling unpleasant odours is adding disinfectants, like Detol to the water before usage, but this is rarely done on Kolhufushi and Muli. Occasionally, adults also use a bottle of rainwater for a final shower to eliminate the lingering odour on their bodies.

Access obstacles

The main obstacles identified in obtaining groundwater of adequate quality for its domestic purpose are knowledge about pollution sources and dealing with poor groundwater quality, as well as financial resources for an oxygen pump or building new wells, for example.

Conclusion

Experiences of groundwater use are often associated with poor water quality and sometimes health problems. Groundwater, essential for household needs such as personal hygiene and bathing, used to be the only source, but desalination water may be an alternative in the future (which will be discussed in Chapter 6). Groundwater quality is on average rated as inadequate on both islands, often smelly, and sometimes with a colour. It is also associated with health problems such as dry skin and rashes by some. This requires further research. Groundwater quality in Kolhufushi is worse than in Muli. Islanders use various strategies to improve poor groundwater quality, the most common is using an oxygen pump. Groundwater is also often boiled, especially for washing babies and young children or rainwater is used for this. In addition, rainwater is sometimes directed to the groundwater well through the downspout for dilution. A few households, mainly on Muli, make alternative wells, with different constructions and/or locations. Disinfectants for groundwater wells are rarely used. Scarcity for the freshwater lens results from insufficient rainfall patterns and groundwater pollution. Islanders identified the leading causes of groundwater pollution as the 2004 tsunami, and the overuse of high-pressure pumps. On Muli specifically, groundwater pollution was also associated with, rainfall patterns, leakage of septic tanks, and dumping of construction waste materials. On Kolhfusuhi specifically, the construction or location of the domestic groundwater well was emphasized as a bad groundwater cause, because they are often located inside the house without much light and oxygen.

5D. Intersectionality Factors influencing Access to water resources and Coping Mechanisms of islanders

Experiences with freshwater use, access barriers and coping strategies can differentiate among relevant social groups in Muli and Kolhufushi. The individual intersectionality factors play a role in (intra)household dynamics and can indicate how households with certain characteristics and certain groups in society are more likely to employ certain coping strategies. It is important to realise that intersectionality factors intersect and mutually influence each other and that a complex combination of different factors determines the final coping strategies of islanders. While that is the reality, the aim is to outline the most outstanding intersectionality factors that influence freshwater resource management by islanders. These can be seen as a guiding thread for how certain households and groups in the community cope with freshwater resources and why, since groups and households in communities cannot be tarred over by the same brush. Government officials and project managers could consider these more complex dynamics when seeking solutions to freshwater scarcity and quality challenges in the Maldives. This section, will first address each prevalent intersectionality factor and how it influences water needs, access obstacles, and coping mechanisms of people and then broad general conclusions will be drawn from this.

Culture

As scholar Evans (2017) outlines, expressions of limited freedom of action (agency) are influenced by the broader cultural and socio-economic context as well as by personal skills and the direct influences of work, family and community. Culture can be considered the way of life of people of a society and the status quo. Culture entails knowledge, art, believe and any other habits and capabilities acquired by people in society (White, 1959).

Culture has a significant impact on the water needs of people (WHO, 2013). It is for example common in the Maldives, and in Islam to have a cleaning ritual before prayer (Vudu) five times and day, which is considered of great importance. It is also common to have a bum gun for anal hygiene instead of using toilet paper. In contrast, in other cultures, other aspects of water use might be considered of greater importance (WHO, 2013). Moreover, culture can determine the status quo for certain water practices and preferences. For islanders on Kolhufushi and Muli, putting clothing in the rainwater harvesting tank to prevent dust and leaves from entering the tank, can be considered a cultural practice or to harvest rainwater for drinking on outer islands. This also results in getting used to certain drinking rainwater tastes which creates preferences. As already outlined, the majority of respondents on both islands preferred the taste of rainwater over bottled water. Culture and cultural practices can be significant factors for people to adapt or not to another coping strategy, for example, to start drinking bottled water.

In addition, culture can influence the degree of agency islanders experience and the freedom they feel (or not) to execute certain coping strategies. In Maldivian culture, thoroughly cleaning the tank and roof for rainwater obtainment is a task assigned to men and it can be considered the status quo. It is uncommon for women to this this, and it is also seen as a constraint for households to obtain and consume rainwater in a (more) safe manner when there are no men available in the household or in their social network. In that sense, the feeling of one's own agency can be bound to the status quo and is formed by culture and cultural practices. On Kolhufushi, this is more likely to happen when men of the family are away from home for longer times when they work in tourist resorts to earn an income for the family. This is portrayed in the following quote:

''We drink bottled water now because no men are at home, so cleaning the roof is more difficult to do'. Sidenote: all the men of the household work in a tourist resort. '' (24- female respondent Muli, personal communication, January 4, 2024)

Although not all women will not clean the roof and tank themselves, women generally prefer to find an alternative way to consume (safe) drinking water on Kolhufushi and Muli. Nevertheless, the cleaning process for rainwater obtainment often only happens once or twice a year, this low frequency makes it more likely that men will be available for cleaning at households. However the example illustrates that culture can form a status quo and constrain or enable people in their behaviour to act in a certain way, which is considered 'normal' or standardized.

''Many people prayed for water when there were water shortages on the island.'' (24- female respondent Kolhufsuhi, personal communication, December 14, 2023).

The quote illustrates that religion and believing in a God, can also be considered a form of a coping mechanism to deal with water scarcity and the (future) climate impacts for some, further illustrated by the following quotes: *''I'm afraid of soil erosion and sea level rise (regarding climate change), but Allah* *will protect us.''* (02-respondent Kolhufushi, personal communication, November 30, 2023) or *''I believe that the islands will be here in the future. We are 100% Muslim, and we trust our God. The islands will not be damaged, but the weather will change a little bit.''*(18-respondent Muli, personal communication, January 1, 2024). (Religious) beliefs can create a sense of hope and confidence in the future. One may feel that God will care for one's problems and future. Believing in a God can be considered a coping mechanism for (stress) issues in life (Pargament, 2010). It could be argued that having faith and religion can also help deal with freshwater scarcity and quality issues. However, it is important to note that not all believers share the same beliefs, and if and how religion is used as a coping mechanism can vary depending on personal interpretations and cultural contexts.

Gender

''My husband is a fisherman who also works in the fish market, selling mostly fish to people living in Malé. He uses a lot of rainwater to clean the fish and himself to get rid of the fish smell. Because of this, we sometimes do not have enough rainwater for cooking and drinking, and we go to friends to get more rainwater then.'' (05—female respondent Kolhufushi, personal communication, December 5, 2023).

The above quote showcases how a man is using the water for livelihood purposes while the woman is mostly focussed on rainwater for domestic needs. There can be differences in priorities and needs between men and women regarding water usage. Women tend to be more concerned about water for basic household needs and hygiene during menstruation, while men are more likely to focus on the water needs of their livestock (WHO, 2013).

The quote also points out that gender has a significant influence on intra-household relationships. Gender can be described as a social construction of the roles and responsibilities between men and women in society. It can change by shifting cultural and social norms in society (Connell, 2009). The division of responsibilities within each household, especially concerning labour and resource allocation, depends on negotiations among its members (Nsenga & Mwaseba, 2021). This negotiation process highly impacts water provision and usage within the household. In Maldivian culture, men are often responsible for earning the main income and women for performing the household tasks, such as cooking, doing dishes, laundry, bathing their children, and cleaning the house. Depending on the number of women in the household, these tasks can take a woman between 1.5 and 5 hours a day. Hence, men and women can have different (domestic) water experiences.

''Our clothes are also smelly. I don't like the (groundwater) smell, and when I'm doing dishes, I don't believe they are fully clean.'' (13- female respondent Muli, personal communication, December 27, 2023).

As illustrated by the quote above, a woman faces specific domestic groundwater quality struggles that men are less likely to face because it is uncommon to do dishes and laundry for them. Women have day-to-day experience of caring for family and running the household, which includes more domestic water usage and interaction (Water Supply and Sanitation Collaborative Council, 2006).

Women are also likely more exposed to poor ground and rainwater quality, which may increase their risk of health problems. This is because they are more likely to come into contact with poor domestic groundwater quality while performing household chores. Moreover, men usually perform their ritual cleansing (Vudu) in mosques, where groundwater quality is perceived to be and is better. Women, on the other hand, do Vudu mainly at home with groundwater. On Muli, domestic groundwater wells are close to septic tanks, which increases risk of groundwater contamination through leaks and overflow (Wickramagamage,2017). This difference in groundwater quality may contribute to a higher risk of health problems among women compared to men. In addition, women spend more time at home due to household chores. As a result, they are more likely to drink rainwater, unlike men who are more likely to consume bottled water at work or in cafes, where drinking water quality is guaranteed. Rainwater quality at households on Kolhufushi and Muli is unknown and less reliable than bottled water, meaning that drinking rainwater is at greater risk of health problems. Women, who are more likely to drink rainwater because they are home more, may face a greater health risk than men as a result.

However, the argumentation that women are more exposed to poor ground and rainwater quality, potentially increasing risks on health problems, was generally not confirmed by the respondents, as shown in the following quote:

''I interact most with groundwater, but I don't think that comes with more health risks than by others. We do not really have another option either. That is why I would like to connect to desalination water.'' (24- female respondent Kolhufushi, personal communication, December 14, 2023

Nevertheless, women generally interact most with domestic freshwater resources of bad perceived quality, which can potentially cause more health problems. However, the relation between gender, health and water quality should be further explored.

Socio-economic standard differences

Economic

Coping strategy choice can depend on the stability and diversity of household income sources, according to a study of households in Bangladesh (Rashid et al., 2006). In Muli and Kolhufushi, financial constraints can lead to no or little access to preferred (fresh)water resources (technology) use and quality and, therefore also lead to different coping strategies. For example, lower-income households cannot always afford an oxygen pump, new groundwater well, or extra rainwater harvesting tanks, or they do not have the financial freedom to switch to drinking bottled water. This latter point is illustrated by the following quotes:

''Sometimes we cook rainwater when we cannot afford bottled water.'' (06- female respondent Kolhufushi, personal communication, December 9, 2023).

''We used to drink mineral water before, but with a lower salary now, we have switched to drinking rainwater again at home.'' (19-male respondent Muli, personal communication, January 1, 2024).

Therefore, lower-income households are more likely to be restricted in their agency to apply their preferred coping strategy to deal with freshwater scarcity and quality issues. However, the Maldivian population on both islands generally have similar socioeconomic standards. Islanders on Kolhufushi, however, do have a lower socioeconomic standard compared to islanders on Muli, which might result in more financial struggles regarding water resources access and possibilities on Kolhufushi.

Nevertheless, health and hygiene considerations seem to have a higher priority than finances. Even with relatively low incomes, many households still buy bottled water because it safeguards better drinking quality on Muli and Kolhufushi. This shows that the priorities and preferences of individuals also matter highly in their source selection.

Social

''In this community, people will share water when water shortages are faced.'' (08- female respondent Muli, personal communication, December, 24, 2023).

This quote illustrates that islanders rely on their social networks to obtain rainwater in times of water scarcity, especially during dry periods. Resource access is closely linked to social relationships (Ribot & Peluso, 2003). On Muli and Kolhufushi, islanders rely heavily on their social networks to access rainwater when households face limited or faulty rainwater harvesting systems. Therefore, a strong social network can be seen as a coping mechanism that reduces vulnerability to water scarcity, especially during dry periods, for islanders on Muli and Kolhufushi. Social networks can also create (male) labour availability for cleaning rainwater tanks and roofs, essential for rainwater harvesting.

However, even if people have a strong social network, asking for rainwater, especially from neighbours and friends, can lead to feelings of shame, guilt or discomfort. A woman told me she felt guilty and embarrassed to ask for rainwater from her friends, and, therefore, went to the rainwater tanks at the mosque. Her friends advised her to stop doing this because of the longer walking distance. However, the feeling of bothering her friends and her embarrassment of asking for water did not disappear. She lived in a household with a relatively low income (14- female respondent Kolhufushi, personal communication, December 7, 2023). The feeling of shame or discomfort can also be rooted in socioeconomic class differences, for example, because someone cannot afford bottled water and feels embarrassed to ask friends for it. This exemplifies how intersectionality factors can intersect with socioeconomic differences and social networks.

In addition, the presence of a social network can also act as a medium for knowledge transfer. A foreigner who emigrated to Kolhufushi used groundwater for cooking in the first few months, not realising that this was unusual in the community. He said he was unaware of these local customs because he lacked a social network (islander Kolufushi, personal communication, December 10, 2023). In this example, the intersectionality factors of knowledge, social networks and ethnicity overlap and influence people's coping strategies. This points out the next two intersectionality factors that will be addressed.

Ethnicity

Ethnicity can be referred to as someone's cultural identity, which is often related to nationality. Having a social network and being part of a certain group or community also relates to ethnicity (Fuhse, 2012). On Muli and Kolhufushi, this can also lead to different drinking water access opportunities. Most foreign construction workers do not participate in Maldivian community activities like sports events or awareness programs. However, interacting within the Maldivian social network can create different water access opportunities for foreign construction workers. On Muli, construction workers sometimes go to the houses of Maldivians to fetch rainwater. Even though the employees should have enough water, according to the project supervisor of MTCC. Everyone gets a 2.5L bottle per day and a 5 L bottle per 4 persons when working on construction sides. If employees request for more water, the company will provide this. However, when employees work on the construction site, they sometimes go to houses to ask for more water out of convenience (H. Riyax[1], personal communication, January 1, 2024).

Notably, the construction workers who go to Maldivian houses to fetch water are primarily Muslim men. This social network can be created through knowing each other from the mosques (08- respondent Muli, personal communication, December 8, 2023; 09-respondent Muli, personal communication, December 25, 2023). These social interactions and networks are more likely to exist because people can feel more trust towards each other since there is a common ground based on the same religion and a similar culture. The degree of segregation of migrant groups within personal relationship networks determines the extent to which cultural differences can be bridged (Fuhse, 2012).

On Kolhufushi, construction workers from RCC, fetch rainwater for drinking from the mosques or the IC in the dry monsoon period (R. Ragupathi[15], personal communication, December 10, 2023). There is less interaction with construction workers on Kolhufushi than Muli, most likely because islanders on Kolhufushi are less exposed to foreigners and 'the other' than islanders on Muli since Muli is the main island of the Meemu Atoll, and more Maldivians as well as foreigners have migrated to the island.

Knowledge

Understanding water issues and knowledge in the community is considered a crucial ingredient for solving water related problems (Dean et al., 2016). Greater knowledge can enable community members to contribute to problem-solving and innovation (Davies & Simon, 2013). It is important to note that knowledge can be influenced by educational achievement and the factors that promote it, as well as by various life experiences and personal interests that contribute to associative learning (Ackerman, 1996; Beier, 2001). The concept of 'water Litreacy', like health Litreacy, combines topic knowledge with the ability to apply it in knowledge to decision-making (Daugs & Israelsen, 1984; Nutbeam, 2008). This can also result in better decision-making regarding coping strategies for freshwater scarcity and quality issues.

Creating water Literacy relates to education and awareness. A study in Australia about community knowledge about water shows that higher knowledge about water was associated with higher educational attainment (Dean et al., 2016). Higher water knowledge was also associated with water-saving and pollution-reducing behaviour and support for alternative water sources.

On Muli and Kolhufushi, having access to groundwater and rainwater of safe(r) user quality also relates to having water knowledge. For example, knowing safe rainwater obtainment and practices can ensure better rainwater quality. This knowledge can also translate itself into certain coping strategies. For example, a highly educated respondent with a master's degree built a homemade well. He measured the high and low water to determine the freshwater lens, which is related to his water knowledge. He and his wife created a groundwater well in which a sphere with holes only filters water from the freshwater lens (23- male respondent Muli, personal communication, January 3, 2024).

These findings highlight the importance of community knowledge and identify potential subgroups that need additional attention to increase their knowledge and support for water management initiatives. In addition, little research has been done about the quantity and quality of groundwater and rainwater in Muli and Kolhufushi. This would also help to create more water knowledge for islanders, to employ more specific and targeted strategies.

Conclusion

How households and certain groups in the local community cope with freshwater resource challenges also depends on intersectionality factors. Culture influences the status quo and someone's feeling of agency to manoeuvre in this created cultural structure. In Maldivian culture, it is not the status quo to clean the tank and roof for rainwater harvesting as a woman. In Kolhufushi and Muli, this can mean that a household with limited or no men available is more likely to look for alternatives than consuming rainwater. Moreover, culture can also go hand in hand with religion, and having certain beliefs and preferences influencing coping strategies. In Muli and Kolhufushi, islanders prefer the taste of

[15] Project manager of the MTCC construction company in Muli

rainwater, rooted in cultural practices, since people are used to drinking rainwater. This should be considered when alternative drinking water sources are provided as solutions for freshwater scarcity and quality.

Women are likely to have more specific domestic freshwater struggles and experiences, which might result in more hygiene and health concerns than men since they interact most with domestic freshwater. This can result in women employing different strategies to safeguard domestic water quality and being more likely to be open to alternative water resource options if better hygiene and quality are ensured.

Islanders can be restricted from employing preferred coping strategies due to their socioeconomic standards/class. Low-income households are likely to be restricted in their ability to apply their preferred coping strategy due to financial constraints, which might occur more in Kolhufushi than in Muli, due to lower average incomes of islanders. Nevertheless, it is also about the (financial) priorities of households, meaning that low-income households might still drink bottled water out of health safety considerations, even have relatively low incomes. In addition, households and islanders with strong and broad social networks will have more access opportunities to freshwater resources. During water scarcity in the dry season, many islanders rely on their social networks to get rainwater from other households.

Ethnicity leads to different water access opportunities due to limited access to relevant social networks. This can also lead to different coping mechanisms. If there is more common ground between the ethnicity of people freshwater access opportunities will be enlarged. For example, Muslim foreign construction workers are more likely to fetch rainwater from Muslim Maldivian households when they face water shortages than other construction workers.

Lastly, more knowledge about freshwater resource usage and good water fetching practices will likely create better-considered coping practices to mitigate or prevent freshwater scarcity and quality issues. Moreover, islanders can feel more agency to change certain practices themselves since they know how to do so. This also relates to socio-economic factors and the ability to study and pursue higher education and gain more knowledge. This also shows how different intersectionality factors intersect with each other.

6.Sociotechnical Imaginaries of islanders on Muli and Kolhufsuhi reflected in the Dominant water resource management Paradigm

This chapter will create a better understanding of the organisational forms, the governmental vision, and the regulations through which the dominant public water management paradigm in the Maldives can be assessed. The paradigm implies certain ideas that come with technologies. What are the sociotechnical imaginaries of local communities regarding this technology, and how does this align (or not) with the dominant public water management paradigm?

6A.Institutionalisation and Regulation of water and sanitation in the Maldives

In 2008, Article 23 of the Maldivian Constitution was endorsed, granting citizens the right to clean water and sanitation. The National Water and Sanitation Policy (NWSP) was introduced in 2017 with the aim of ensuring universal access to safe drinking water and sanitation (Ministry of Environment Republic of Maldives, 2020). This policy establishes specific rules and procedures to provide a safe water supply and a comprehensive sewerage network on inhabited islands. It has been in place for over a decade and is supported by the Water and Sewerage Act (8/2020). In addition, the National Water and Sewerage Strategic Plan (NWSSP 2020-2025) was adopted in 2020. With the NWSSP, the government strives to implement a piped drinking water system on all inhabitant islands using a combination of desalinated water and rainwater by the end of 2023.

The Utility Regulation Authority (URA) is responsible for implementing public policies and regulating legislation, including the Water and Sanitation Act in the Maldives. It was established in 2020 (government official 2, personal communication, January 13, 2024). The URA oversees utilities responsible for water, sanitation, energy and electricity supply. Its duties include enforcing regulations, promoting sustainable development, monitoring competition and licensing. In addition, the URA handles complaints, conducts inspections, promotes environmental protection and implements public policies.

Nonetheless, the URA in the Maldives faces significant challenges in regulating water and sanitation. Island governments are still not always aware of the recently installed URA, which requires travel and awareness campaigns (government official 2, personal communication, January 13, 2024). Conducting regular utility tests is complicated by staff limiations, combined with high transport costs and unpredictable weather conditions. Delegating tasks to ICs is an option but requires political approval. In addition, utility service-providing on local islands tends to be monopolistic, so handing out fines or revoking licences by the URA rarely happens since there are no alternative service providers at hand. Furthermore, political influence on service companies is a common challenge, as public companies appoint management, which puts pressure on managers and the management team (government official 2, personal communication, January 13, 2024).

6B. The Dominant Maldivian water management Paradigm

The dominant water scarcity management discourse in the Maldives is characterised by a technological fix, because desalination plant technology is considered the backbone of (fresh)water scarcity in the Maldives. In this paradigm, the technological fix is reflected by the fact that the society tends to rely on technological innovations to solve problems instead of addressing underlying institutional or social problems (Oelschlaeger, 1979).

''The influx of desalination technology was post-tsunami driven by donors. That actually gave a try to this technology. We believed that that was the most convenient way of getting water from the sea.'' (government official 1, personal communication, January 13, 2024).

As illustrated in the quote above, desalination technology gained momentum in the Maldives with the assistance of international donors after the tsunami in 2004. Efficient drinking and sanitation systems had already been present on larger islands and tourist resort islands in the Maldives for some time. For example, a desalination pipeline system has been operating in Malé since 1985. The outer islands were also to be provided with desalination plant installations. The rationale behind this desalination fix is that the tsunami in 2004, destroyed the freshwater lens and infrastructure (Kan et al., 2007; Zahir, 2004).

As the quote shows, desalination technology was seen as the most convenient way of getting water from the sea, indicating that desalination technology was seen as the primary means and solution for ensuring water supply provision. This also comes forward in the NWSSP 2020-2025 policy, which states: '*increasing water supply needs of the nation are largely met through desalinated seawater, which is either directly supplied to the households and communal tap-bays or bottled and distributed.'* (Ministry of Environment Republic of Maldives, 2020, p.8). Moreover, the government committed to providing every inhabitant island with desalination technology by the end of 2023. Due to the commitments and high focus on desalination technology of the government to cope with freshwater scarcity, it can be considered a dominant paradigm with a fixation on desalination technology. However, that does not mean the government does not address and consider alternatives to deal with freshwater scarcity, it is just less prevalent in their policies and practices. Below two significant factors will be outlined that are responsible for streamlining this desalination fix.

Given the significant financial investment required by desalination, the public-private partnership model proved essential for its implementation. The private sector is also motivated by the potential profit that can be made through such water projects (Swyngedouw, 2005; Bakker, 2011). A desalination project is a potential key commercial transaction, both in terms of capital investment and long-term export potential, as mentioned by the U.S. Trade and Development Agency by a desalination project in Puerto Peñasco (US Trade and Development Agency, 2008, cited in McEvoy, 2014). Moreover, there is a recurring revenue element through membrane replacement and maintenance activities. This presents significant business opportunities for (foreign) desalination technology manufacturers and engineering firms (Molle et al., 2009). In the Maldives, funding for desalination projects was also split between federal and private sources and the interests of the private sector are involved. As the quote above illustrates, the influx of desalination technology in the Maldives is also driven by donors and they also have interests.

Large-scale water infrastructure can also be crucial in strengthening state building, energy management and state legitimacy (Molle et al., 2009). Moreover, large-scale projects such as desalination plants provide more opportunities for rent seeking, otherwise known as a form of corruption (Rendón, 2011). Although corruption and mismanagement are often discussed, they are difficult to document. Bakker (2011) points out that water companies, as significant sources of revenue under municipal control, are often used for financial injections into the municipal budget and for the performance of patronage through the allocation of coveted government jobs. Rendón (2011), with 20 years of experience in the Mexican water sector, documents several corrupt practices, such as assigning jobs to unqualified people as political favours, approving permits for restricted zones, manipulating environmental impact assessments and allowing illegal use of permits without sanctions. However, he also stresses that some problems stem from poor management rather than blatant corruption, such as relying on incorrect information, missing data or making ill-considered investment decisions.

Interviews with government officials and households in the Maldives also reveal that a common challenge can be political influence on utility service companies. Many of these companies remain government institutions, with management positions appointed by the government. This creates considerable political pressure on these companies' managers and management teams, also at Feneka (the water supplier company at Muli and Kolhufushi (personal communication, government official 2, 13 January 2024).

Due to various factors, such as those depicted above, the status quo of using desalination technology is likely to be maintained. This can create a specific path dependency, as explained in Box 6.1. It illustrates that societies and governments can get trapped in specific regimes and technological (fix) paradigms, whereby potential alternatives are more likely to be overlooked.

Box 6.1: Path dependency theory: potential risks of dominant technological (fix) paradigm trajectories

With dominant water paradigms governments can get trapped in certain water regimes. The path dependency theory helps to understand why certain paths are taken and why they persist over time, often leading to outcomes that are difficult to change or reverse (Pierson, 2000). The idea of path dependency is that once a particular path is chosen or a specific course of action is adopted, subsequent developments and choices tend to become increasingly constrained by past decisions, creating a lock-in effect (Capoccia & Kelemen, 2007; Capoccia, 2015). The particular moments or decisions that set a trajectory in motion are called critical junctures (Pierson, 2000; Nicol, 2010).

Three phases can be described in path dependency: (1) a critical juncture is created by unconstrained choices where decisions become difficult to reverse, (2) options become more confined but are still available, and (3) the lock-in, alternative options become even more constrained (Sydow et al., 2013; Sydow, 2005). Lock-in occurs when a rigid structure is created by sequential patterns or activity that make it challenging to deviate from the specific technology, institutional regime or industry, leading to an over-commitment to that path (Martin & Sunley, 2006; Setterfield, 1997).

Different mechanisms influence path dependency. The more resources are invested in a certain technology or infrastructure, the more difficult it is to switch to alternative paths due to the costs and the accumulated invested capital (Pierson, 2000). Moreover, network effects also highly influence path dependency; when more actors choose a certain path, it becomes more valuable because of the widespread adaptation within a network. This can lead to a self-reinforcing cycle because the dominant option becomes even more entrenched (Gulati, 1995; Gulati & Gargiulo, 1999).

Nevertheless, desalination plants also hold great potential to benefit the Maldives' population and can serve as a (potential) solution to water scarcity. It is essential to remain constantly critical and examine the contexts in which this technology is and is not effective. For example, when Spain abandoned a river diversion project in 2004 and introduced desalination as a solution, this approach was mainly aimed at water shortages for irrigation of cash crops and high-end tourism (March et al., 2014). Questions arise: who benefits from desalination, and what problems are really being addressed? What are (hidden) interests and power relations? What are (forgotten) alternatives? What works for whom and why? Not all these questions will be answered in this study, but it gives food for thought. The later question, what works for whom and why will be addressed in the next part 6C, by looking at the sociotechnical representations of the islanders on Muli and Kolhufsuhi regarding desalination technology.

6C. Sociotechnical Imaginaries of the local people on Muli and Kolhufushi

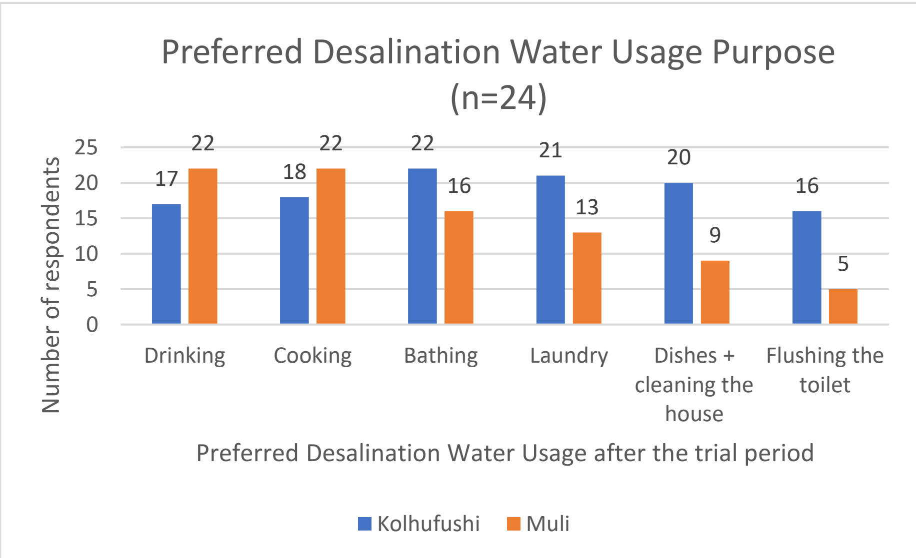
''The city dictates what needs to be done, but has no idea what is going on the ground.'' (government official 1, personal communication, November 30, 2023).

As the above quote illustrates, the governments has limited knowledge about the visions and beliefs of communities in outer islands. This part examines the collective beliefs and visions of communities in Muli and Kolhufushi about desalination technology. Reflecting a shared understanding of the interaction between technology and society, these perspectives influence technological developments, social norms and public policy. They act as narratives about the future impact of technology. The aim is to mirror sociotechnical representations against the dominant paradigm and explore the similarities and differences. Six prevalent social-technical imaginaries regarding desalination technology by islanders are identified and will be outlined.

1. *Favourable opinion towards desalination technology*

Islanders of Muli and Kolhufushi have a favourable opinion towards using desalination technology for their water needs, and they generally consider it a suitable water supply system that will improve access to better water quality. None of the respondents were against desalination technology. In both islands, 24 out of 25 respondents said they would like to use desalination water in the future. Figure 6.27 shows islanders' future use preferences for desalination water. On Kolhufushi, residents mainly want to use it for bathing (92%) and washing (88%). In addition, a majority want to use it for cooking (75%) and are considering using it for drinking water (71%). On Muli, residents want to use desalination water mainly for drinking and cooking (both 92%), bathing (67%) and washing (54%).

Figure 6.27: Preferred desalination water usage purpose after the trial period on Muli and Kolhufushi out of the 96% of respondents that want to use desalination water in the future (author's work, 2024).



The positive attitude towards desalination water on Kolhufushi stems from good experiences during the pilot period, when households were allowed to use desalination water for everything except cooking and drinking. *'Instead of cleaning the toilet 3x a week, I now only need to clean the toilet 1x a week.''* (17- female respondent Kolhufushi, personal communication, December 9, 2023). Respondents reported improvements such as the disappearance of odour and colour from groundwater and cleaner toilets and showers. Islanders also reported softer hair and better skin when using desalination water. On Muli, most households did not use desalination water for household purposes during the trial period, making experiences there rare. On both islands, most islanders prefer desalination water to groundwater.

2. Groundwater (health) concerns

''I mostly see it (referring to desalination water) as an alternative of back-up for when the groundwater is too bad.'' (17-respondent Muli, personal communication, December 31, 2023).

''The desalination water is installed to do something against the bad groundwater smell after the tsunami. So many people are in need of it and are requesting desalinated water on the island.'' (08-respondent Kolhufushi, personal communication, December 5, 2023).

''We have a foul smell and bad taste and sometimes a bit of a white colour if it didn't rain for a long time (referring to the groundwater). Making use of the desalination water is the solution for this.'' (11-responden Muli, personal communication, December 25, 2023).

The quotes above illustrate that many islanders see the desalination water as a solution to their groundwater quality problems. As described in Chapter 5, there are many complaints groundwater quality complaints and concerns, some also related to health on both islands. slanders on Kolhufushi experience relatively poorer groundwater quality than Muli residents (see Chapter 5). As a result, the need for solutions to daily problems of poor groundwater quality on Kolhufushi is considered higher. This could also explain why Kolhufushi islanders used more desalination water for their domestic water needs during the trial period than Muli residents.

3. Water supply pipeline infrastructure

In Figure 6.27, households indicate for which specific purposes they would like to use desalinated water in the future. However, in practice, most households experience limitations in their ability to differentiate in water sources for specific water usage, for example flushing the toilet with groundwater and showering with desalinated water. Most households have only one water pipeline, which can then either be connected to the desalination water system or to their groundwater well. If people want to diversify their water use with different sources, they must install additional pipes, often involving breaking through walls and high costs. The following quote illustrates what kind of trade-offs people will start to make then:

''We cannot change the pipe connection easily, therefore I´m not planning to flush the toilet with groundwater. However, when it may exceed 500 MVR a month with the water bill, I might look at it.'' (12-male respondent Kolhufushi, personal communication, December 6, 2023).

4. Affordability

It also becomes evident that affordability plays a significant role in considering whether households want to switch to desalination water, depending on their preferred use. Specifically on Kolhufushi, expenditure and financial feasibility are often cited as considerations and concerns, as illustrated by the following quotes:

''We want to look for one month how much water we use and if it is affordable. Depending on this, we will decide for what we will use it.'' (14- female respondent Kolhufushi, personal communication, December 7, 2023).

''We want to keep rainwater for drinking in the future, because of the expenses.'' (10- male respondent Kolhufushi, personal communication, December 6, 2023).

However, desalination water is supposed to be cheaper than bottled water for drinking. It can therefore, be an outcome for islanders who cannot afford bottled water now all year round (A. Fayaz[16], personal communication, December 13, 2023). Also emphasized by the following quote:

''The desalination water is there to continue the water supply, when there is no rainwater available. Some people might have difficulties affording mineral water otherwise. Now, they can rely on desalination water. However, there are not many poor people on the island, 1 or 2 families, I think.'' (17- female respondent Muli, personal communication, December 31, 2023).

On Muli, affordability was a less prominent concern than on Kolhufushi. As illustrated in the quote above, few poor families are on the island. Households on Muli also have relatively higher incomes than Kolhufushi due to more employment opportunities, larger households and more people working (including women) in the household, and there are in general higher educated residents also leading to higher salaries. These higher incomes and the associated ability to bear the cost of desalination water can explain why fewer concerns were raised about the affordability on Muli. On Kolhufushi, the majority of respondents were willing to pay between MVR 300 and MVR 500 per month (500 = €29,87) for their water bill, while on Muli, the majority were willing to pay between MVR 900 and MVR 1200 (1200 = €71,68) per month. This difference could be attributed to the income difference between the two islands.

5. Drinking taste preference

''I like rainwater. I will mostly use desalinated water when there is no rainwater available, and maybe if I like the water as well I will use it for drinking.'' (03-female respondent Muli, personal communication, December 20, 2023).

That the drinking taste of the water matters is prevalent in the quote above. The assumption that desalination water on Muli and Kolhufushi will be used primarily for drinking water is subject to debate, given the preference of most islanders for the taste of rainwater, rooted in custom and cultural influences, as described in Chapter 5. In addition, drinking desalinated tap water comes at a cost compared to rainwater. The question arises whether this will be affordable for everyone and whether people are willing to pay for drinking water if they are (culturally) not used to it.

6. Desalination water quality (dis)trust

''I trust this water (desalination) more, since it will be checked.'' (18- male respondent Muli, personal communication, January 1, 2024).

Significant concerns about rainwater drinking quality were expressed on both islands, potentially leading to diseases. Islanders might also be receptive to switching to desalination water because of its superior water quality compared to rainwater. This diligence regarding desalination water quality is evident in the quote above. Moreover, 71% of the 24 respondents on Kolhufushi and 92% of the 24 respondents on Muli would be open to drinking desalination water.

[16] A. Fayaz is the vice president of the Island Council at Kolhufushi

However, there must be a basis of trust among islanders regarding the drinking quality of desalinated water, which is not always the case for islanders. The sense of distrust is perhaps reinforced by the fact that islanders were not allowed to use the water for drinking on either island during the trial period. Currently (June 2024), the water quality has still not been approved despite the expectations that desalination water could be used for drinking and cooking in February or March 2024. The islands are still waiting on approval from the government.

A lack of trust appears to be an important factor, even among those open to drinking desalinated water. For example, of those willing to drink desalination water, 47% of respondents on Kolhufushi and 45% of respondents on Muli indicated that they would like to use an additional household aro-filter to not only ensure water quality but also to improve taste, as illustrated by the following quote:

''We want to use desalination water for everything, besides drinking. But, when there will be a filter we will also drink the desalination water. I want assurance that the filter is good, I want to know what it filters exactly. We will not make use of rainwater then anymore, because we don't trust it, due to the animals on the roof like bets and cats.'' (23- female respondent Muli, personal communication, January 3, 2024).

Moreover, there is currently also the option of drinking bottled water, which many people have been using for some time (see Figure 5.23), from which they enjoy an assured drinking water quality. This option is familiar and well-known, which may make the transition to drinking desalinated tap water more difficult, as indicated in the following quote:

''Our government has made the mistake of introducing bottled water and has not talked about tap water for the last 30 years. It will take another 10 till 15 years to reverse that.'' (government official 1, personal communication, January 13, 2024).

In addition, it is notable that trust in the quality of desalination is strongly linked to trust in government and government utilities, as illustrated in the following quotes:

''Even though the government will test the water, we cannot trust everything that the government says.'' (01- female respondent Muli, personal communication, December 18, 2023).

''I don't trust them; there are no good technicians here. They don't have well-trained staff at Feneka.'' (19- male respondent Muli, personal communication, January 1, 2024).

Respondent 19 in Muli also reported leaks in Muli's water supply system in December 2023. He has concerns about a lack of monitoring, maintenance and trained technicians, which explains why he is reluctant to use the water for consumption. The distrust in water quality is not entirely unjustified. Concerns are also being raised from government officials about the drinking water quality of desalination water on the outer islands, as illustrated in the following quote:

''It is unfair for us to go to islands, ask people to drink, and say the water is safe, but we can't actually ensure it.'' (government official 2, personal communication, January 13, 2024).

Water testing is conducted daily in Malé, but is less consistently done in the outer islands. A government official noted during inspections, that systems in the outer islands are not adequately regulated, managed and maintained, possibly due to a lack of equipment (government official 2, personal communication, January 13, 2024). In addition, there is often a lack of technical expertise and workers are often not adequately trained for these services, given the expertise needed for the water and sewer system. Moreover, the URA itself faces challenges in testing and monitoring desalinated water from the outer islands due to limited capacity, high transportation costs, and weather conditions government official 2, personal communication, January 13, 2024).

Another advanced technology system, household aro-filtration systems, is being considered by NGOs and the government to address distrust in drinking water quality. There is currently a pilot project in Mulah, where 60 households use an aro-filtration system, to help people get used to drinking desalinated water (see Picture 6.19). However, two significant problems have been encountered: the maintenance of the filters and the limited quantity and reliability of the water produced. Only one person on the island manages the project, and no qualified technicians are available, for example, when households face leakages (01- female respondent Mulah, personal communication, January 4, 2024). Moreover, the aro plant provides only small amounts of drinking water, often insufficient for the entire household. Nevertheless, the water taste was considered good, according to the respondent. The aro-plant filter is now mainly used for the desalination water, but can also be used for only rainwater treatment, considering the health concerns related to drinking it as described in Chapter 5.

Picture 6.19: Household aro-plant water filter for drinking at Mulah

6D. The hidden costs of the Desalination-fix

Water policies from the 20th century are known for relying on constructing massive infrastructure, such as pipelines and complex centralized treatment plants, to meet human demands, also referred to as hard path solutions. These facilities can indeed bring tremendous benefits to people, but they also often have unanticipated and serious economic, social, and ecological costs (Gleick, 2003). As a technological fix to water scarcity, desalination does not always address the deeper-rooted socio-economic and institutional issues affecting water security (McEvoy, 2014). Swyngedouw (2013) notes that desalination in Spain is increasingly seen as a solution that maintains the productivist water logic which is the bedrock of Spain's eco-modernisation projects, so that in reality nothing really has to change (di Lampedusa, 1960, p. 268). In Baja California Sur, as in many parts of Mexico and the global South, the lack of long-term strategies for integrated water planning and transparency in water and urban planning institutions leads to poor water management, ultimately reducing water security (McEvoy, 2014).

In the case of Kolhufushi and Muli, the dominant paradigm of using desalination water works for some people but can potentially exclude others. For example, desalination technology is on both islands seen as the solution to solve groundwater quality issues regarding smell, colour and taste and associated health problems, like dry skin and rashes. However, the use of desalinated water comes with costs. The question is whether this will be affordable for every household, especially for low-income households. Between the two islands, islanders on Kolhufushi will be more susceptible to this because they generally have lower incomes than islanders on Muli.

In addition, if it is up to the people themselves, desalination water is not necessarily considered a godsend for drinking purposes, for which it was primarily designed. The majority of islanders prefer the taste of rainwater. Moreover, many respondents did not trust desalination water quality for drinking and the cultural bias against drinking piped water can be considered strong. It is also questionable whether the desalination quality for drinking can be fully guaranteed in the future given the limited water testing capabilities on the local islands and lack of technical expertise. To solve this distrust, implementing household aro-filters is considered now. Besides the technical complications this brings, not everyone will be able to afford this. Again, the lower-income households will be disadvantaged. Moreover, these households are already disadvantaged because they do not always have sufficient rainwater tank capacity to collect rainwater or they do not have the ability to switch to bottled water.

However, desalination technology is not the only infrastructure investment option for water managers to consider. Numerous scholars even stress the importance of considering desalination as a 'last resort' (Molle et al., 2009). The aim is not to demonstrate the superiority of other options but rather to underline that alternatives exist. More investment in soft infrastructure solutions should be considered (Gleick, 2003; Brandes et al., 2009).

6E. Soft Path infrastructural investments

Soft infrastructure investments include small-scale, decentralised facilities that complement centralised infrastructure with open decision-making, cheaper common systems, fair pricing, water markets, environmental protection and efficient technology (Gleick, 2003). The soft path approach focuses on improving water use efficiency and welfare per unit of water used, rather than always seeking new sources. This approach delivers water services and quality tailored to users, using economic instruments such as markets and pricing mechanisms to promote efficient use, equitable distribution and sustainable operation. Local communities are actively involved in water management decisions (Brooks, 2005; Gleick, 2003). In addition, this approach offers lower technical and financial risks than the traditional, hard path approach (Gleick, 2003).

For islanders on Kolhufushi and Muli, this would, for example, entail more and better wastewater management. For example, desalinated water used for cooking can be reused to flush the toilet, or groundwater can be used to flush the toilet. Rainwater can also be utilized more effectively for drinking, cooking, or showering. However, communal or household rainwater tank storage capacities should be increased when people want to use it for other means than drinking and cooking, as shown in Chapter 4. Moreover, another sanitation waste-water treatment system can be considered on the islands, which is less complex and only requires prior treatment. This would be more economically viable and can be maintained over time. (government official 1, personal communication, January 13, 2024).

In addition, more effort and fund could be invested in using technologies and policies appropriate to the scale of the problem. Economic instruments should be used to promote efficient water use and encourage the redistribution of water between different users. All stakeholders could be involved in long-term water planning, not just those with traditional engineering and hydrological sciences training.

7.Discussion

This section will consist of two parts. The first part will evaluate the conceptual framework and applied theories used, and the second part will discuss the validity of the applied methods.

7A. Theoretical evaluation

This part entails three sections. First, the conceptual framework and its novelty will be explored. Second, the completeness of the framework will be discussed. Third, the justifiability of the framework and the applied theories is examined.

The academic framework and relation to my academic training

The framework presented considers water and sanitation services, human interactions and technology as interconnected, whereby they cannot be viewed in isolation for planning and research purposes. It also looks at structure-agency relationships and how they manifest in the waterscape, seeking to bring more nuance to the coping strategies of specific individuals and groups in the community by addressing significant intersectionality factors. Finally, it looks at social-technical imaginaries and to what extent they correspond to public policies and visions related to water and desalination technology.

These theories and concepts cannot be considered original by themselves; many treatises have already been written on the waterscape, structure-agency relationships, intersectionality factors and social-technological imaginaries separately. However, I attempted to create a theoretical framework to offer a broader picture and understanding of reality by connecting and linking different concepts and theories. Efforts have also been made to connect different levels and actors. My framework provides macro- and meso-level insights and allows for generalizable conclusions, but it also leaves room for nuances and specific context factors. In this way, I have tried to add originality. In addition, I tried to paint a more complete picture of reality of the waterscape by being able to switch between different lenses through which reality can be viewed.

Moreover, the study's principle and the research direction stem from holistic thinking, in which the water cycle is seen as a continuous process of (re)production shaped by dominant governmental visions and human actions. Such a holistic approach is also not new within water management, with a focus on multi-disciplinary research being expected in my background. This research has a specific focus on the water, sanitation, and hygiene (WASH) sector, as opposed to the master programme, which focuses more on water and the link to the agricultural sector. I have tried to integrate the multi-disciplinary mindset from the master in this WASH focused thesis.

Theoretical framework completeness

My theoretical framework does not cover all perspectives and can be supplemented. The study supplemented, underplaying certain crucial aspects. First, only household water needs are included, not other water needs such as food and irrigation. Second, the environmental aspect of the waterscape has not been adequately addressed, as despite the inclusion of the island's geophysical characteristics and natural water availability, the impact on biodiversity, flora and fauna of water resource management has been overlooked. Further research could address questions such as, what it means for flora and fauna if more rainwater is collected by humans.

Water management on tourist islands is also not considered in this research. This also has a significant impact on the macro waterscape, where the Maldives already has a score of 2.9 out of 7 on the 'for tourists per resident in SIDS additional water stress in the context of tourism' scale (Gheuens et al., 2019). In addition, recent legal changes permitting tourism developments with guesthouses on previously designed local islands can also lead to higher water needs and more competition for water. Hence, it would be interesting to include the tourism sector in the waterscape as well.

The most common management strategies and the dominant public water management paradigm have now been examined. Better consideration could also be given to already existing water management projects and alternatives, both from the government and from the islanders themselves. More attention could be paid to the less dominant and opposing views within the government and between islanders.

Also, the influence of market forces on the macro and micro level are insufficiently addressed. For instance, a market for livelihoods is created by market demand, and its availability determines the extent to which materials or specific forms of water supply can develop. Further attention could also be paid to the existing and missing knowledge of islanders of water sources and use in relation to hygiene practices and health. There has also been too little attention to the political developments that shape this. The thesis shows that current and future water supplies and infrastructure largely depend on the government and the provision of subsidies, where a change in government and its plans can enable or prevent certain waterscapes. These relational power dynamics are an additional area of potential future research.

In addition, certain external factors that influence the waterscape, structure-agency relationships and sociotechnical imaginaries have not been sufficiently addressed, such as market forces. A livelihood market is created by demand and availability, which determines the extent to which materials or specific water supply forms can develop.

Lastly, I outlined the most prevalent intersectionality factors I observed in the field, but that does not mean that other intersectionality factors do not exist and influence islanders' access to (fresh)water resources and coping mechanisms. For example, sexual orientation and disability were not discussed because they were less directly visible to me on the islands. For example, in the Islamic religion, other sexualities than heterosexuality are forbidden. I have also been less in contact with disabled islanders. Hence, these factors can also be addressed to portray an even more complete picture.

The framework justifiability and usefulness of the concepts

In this part, I will shed light on the applied theories and concepts, highlight their pitfalls and discuss whether they were useful for this research.

There has been much research to date on water services on SIDS where the focus is mainly on climate change mitigation and adaptation (Thomas et al., 2020), disaster risk management (Belmar et al., 2016) resilient and adaptive water management (Belmar et al., 2016), the water-food-energy nexus (Winters et al., 2022), and more biophysical analyses and quantitative measurements (Chung et al., 2022). In contrast, there has so far been limited research on what is really happening on the ground, and to show the water user's main preferences, considerations in source selection, water access, and coping strategies of island residents. Therefore this research has aimed to gain further insights into these issues.

Within the overall theoretical framework, I have tried to make the waterscape tangible by focusing on water needs, challenges and coping strategies. However, I have also tried to add more nuance and complexity to the waterscape by placing it in the context of structure-agency relationships and by linking agency and intersectionality factors. The intersectionality factors also highlight the different water needs, challenges and coping strategies for various actors. This aspect is often overlooked in the waterscape, as shown, for example, in a case study in Jakarta on water services (Bakker et al., 2008), which does not consider differences between men and women and their water needs.

This research has also tried to add more spatial and temporal dimensions. Temporal, because I tried to include differences in water practices and challenges in the wet and dry season, and spatial because I tried to show the waterscape at different levels (macro, meso and micro) and by investigating two different locations/case studies. Even though other scientists (Bakker, 2003) do emphasise temporal and spatial aspects in the waterscape, these are not always included. For example, the Jakarta case study on water supplies does not address differences in the wet and dry seasons (Bakker et al., 2008).

In addition, water services and quality tailored to users' needs and quantity are also often not adequately considered. By highlighting water quality challenges and water needs based on water quality, I have shown that solutions to water scarcity do not always lie in finding new water sources and (additional) quantities. This is not a new finding, but a refreshing one in the debate often dominated on satisfying the increasing water demand of human populations (Gleick, 2003).

The waterscape concept offers a more holistic approach to water management. A question that arises here, is whether it was necessary to include the historical evolution of the waterscape. The underlying idea is that past decisions influence current choices (Swyngedouw, 1999; Swyngedouw, 2009). However, the main question focuses on how local communities currently cope with water scarcity and how they intend to address it in the future. Although historical evolution was not the primary objective, I believe it was relevant as it adds perspective, explaining the current situation and offering insight into changing water management practice over time.

Critics may argue that there is an overemphasis on structure and may disagree with my more critical realist approach. I believe that, even though islanders have agency and can create more sustainable and better water management practices, they depend, to a greater extent, on the existing structures, government policies, and subsidies to do so. Small-scale outer islands are marginalised from large cities and tourist islands, resulting in fewer available amenities and lower socio-economic standards. This marginalisation creates more limited opportunities and greater dependence on larger cities, other islands, and countries. That is why I believe structure has a more significant influence on agency in this context than vice versa. Moreover, a more critical realist approach considers more power dynamics and societal inequalities.

In addition, there may be criticism of reducing complex social realities to simple categories of agency and structure, which may miss the nuance and dynamics of social interactions and change. To introduce more nuance, I also addressed intersectionality factors. It can be seen as an indicator of particular action shaped by structure-agency relations. The aim is to offer more insight into inequality and the agency of individuals within the existing structure in society.

Intersectionality is a complex concept that is difficult to generalise and apply to a broader context because it reflects social complexity at the individual level (Ehrenreich, 2002). My use of intersectionality can, therefore, be criticised because I illustrated how outlier intersectionality factors can influence the water practices and coping strategies of islanders and community groups. Nevertheless, I believe that highlighting these intersectionality outliers is crucial to address. It provides more insights into who within the community may be left behind, which can help institutions and policymakers develop more effective and inclusive strategies. Moreover, it is challenging to examine and show how intersectionality factors intersect, however, I tried to emphasize on this reality and gave some examples.

Lastly, I have tried to contextualise the findings at both island and household levels within the framework of social-technical imaginaries and contrast them with the dominant national macro-level of public water management. I consider these concepts relevant to the situation, although some pitfalls exist. For instance, capturing collective visions in social-technical imaginaries can be challenging, as it is a snapshot in time, and visions can change rapidly. Nevertheless, it does provide a valuable overview of that time. Moreover, collective beliefs and a dominant paradigm leave little room for nuances between different opinions within island communities and government officials and institutions. This could be an interesting topic for follow-up research, for instance, through discourse analysis.

7B. Methodological reflections

The employed methodology was covered in detail and partially reflected in Chapter 3. This section will evaluate the methods used and the viability of the two case studies. In addition, I want to talk about the representativeness and justifiability of using these two case studies.

Evaluating the methods used and viability of the two case studies

Two case studies were conducted on outer islands in the southern Maldives to supplement the data and allow for better generalisation. Given the relative proximity of these islands, it was expected that their interactions with water and technology would be very similar, contributing to a more robust validation of the findings. However, comparing the two islands could also reveal differences in how island and resident characteristics relate to water management on an island. The comparison occurred by asking a set number of questions and comparing the outcomes. Moreover, the semi-structured interviews offered the flexibility to dig deeper and examine the reasoning behind certain acts and behaviours. Hence, I believe in-depth open and semi-structured interviews were a suitable and viable method for understanding what is happening on the ground exploring the water needs and practices of islanders in line with the main research question. This was complemented by participant observations and focus groups.

However, more interviews could have been conducted with men; most respondents were feMale. Also, more interviews could have been conducted with foreign construction workers to explore their waterscape further. However, I had limited access to them because of language barriers and the occupation of their work. Lastly, more insights could have been given on the island's geophysical characteristics by for example, making a complete transect diagram. Moreover, assumptions have been made in the calculations, which could be debated. However, I tried to explain them as much as possible.

The case study's representativeness

To what extent is this case study representative of the other islands in the Maldives, and to what extent is it justifiable to make generalisations about worldwide domestic water supply based on these small case study outcomes?

I wanted to explore what actually happens on the ground. Using a case study primarily answers how and why questions, observing and analysing real-life contexts. Unlike statistical research based on quantifiable variables, case studies are essentially based on logical inference and apply theories to the relationships between different factors. This research also focused on how people interact with water and technology and why they make these choices. Therefore, a case study was an appropriate approach in my opinion.

In addition, the question is whether the selected case study had sufficient explanatory power and intrinsic potential to discover patterns. Case studies should include a situation and/or population in which a wide diversity of data can be collected to meet high internal validity. In the two case studies, both islands were at a transformative stage in terms of their water resources and management due to the introduction of desalination technology. Over the years, water resources and their use have evolved on both islands using various technologies and different forms of institutional management. Moreover, both islands had socioeconomic conditions, households, ethnicity, and access to and quality of water resources. Furthermore, a sample size of 25 household interviews was done on each island, which covers 11% of the total households on Kolhufushi and 17% of the total households on Muli. Moreover, this data was further complemented with 5 key informants and focus group discussions. This all taken together, can be considered a sample size with enough diversity and coverage to represent the local community. Comparisons based on these characteristics were generally easier to make and can be considered illustrative.

This leads to the next topic, the representativeness of the case studies. Geographically, Kolhufushi and Muli are similar in size, size and population to other outer islands in the Maldives. However, major main islands and cities have a different water system than the outer islands. The population density is much higher on these main islands, often leaving insufficient space for adequate rainwater harvesting capacity. In addition, these islands have other facilities; for example, Malé has had a water supply system since 1985. Therefore, the case studies mainly represent the outer islands in the Maldives.

There is also a distinction between the outer islands in the northern, central and southern Maldives. The archipelago stretches 800 km from North to South, and weather conditions vary considerably. The North experiences a drier monsoon season and less rainfall during the year than the middle and south. As a result, islands in the North may have more difficulty meeting their drinking water needs with rainwater, especially during the dry monsoon period. However, during the wet monsoon period there is relatively more rainfall, which may be sufficient to cover the dry period.

Socioeconomic and political and historical development characteristics should also be included in the case study evaluation. The islands of Kolhufushi and Muli are comparable to other islands in the Maldives in terms of socioeconomic, political and historical development. The Maldives generally has a cultural homogeneity, primarily regarding language (Dhivehi) and religion (Islam). The islands are also comparable in lifestyle, infrastructure, and characteristics. This makes it more likely that island residents' water needs, challenges, and coping strategies will be similar to those of islanders in Muli and Kolhufushi.

In addition, the characteristics of the islands are similar to other islands worldwide in terms of their socioeconomic and environmental susceptibility to natural disasters and climate change and their often limited provisioning services and freshwater resources (Gheuens et al., 2019). SIDS have typical geophysical characteristics, remoteness, and often a large dependence on main islands, larger cities, and other countries. However, generalizations must be made cautiously because of differences in population density, island size, and limited access to various water sources for islanders. These factors are strongly related to the socioeconomic standards of the islands. In addition, I want to be cautious about generalizations about coping strategies and the water needs and problems of islanders because water-supply infrastructure, organization and payment are highly dependent on intra-household dynamics and intersectional factors, which are also culturally determined. In the Maldives, for example, Islam strongly influences lifestyle associated with specific water needs. This can vary greatly by country and culture.

I believe that the conclusions of this study can be largely representative of other outer islands of central and southern Maldives, and broadly representative of the northern Islands, due to their similar socio-economic conditions, culture, typical geographical features and infrastructure. However, it is important to recognise that each island has variations in community dynamics, intersectional factors, infrastructure and climatic conditions. Therefore, conducting similar research on another northern island atoll would be useful to strengthen or develop the argument.

In addition, I believe this research cannot be generalised to other or higher spatial levels and islands worldwide without question, as the study is exploratory in nature and mainly based on qualitative data and based on context-specific knowledge. Nevertheless, it can be illustrative of the discrepancy between the needs and challenges of local communities and proposed water innovations and technologies by the government. It can act as a tested hypothesis that demonstrates a discrepancy between the considerations and practices of water users and the conscious and unconscious assumptions of higher-level policy makers. Therefore, it is valuable to replicate this research on other outer islands worldwide to see if this hypothesis is supported or refuted.

Personal Reflection

It must be acknowledged that my own interests and involvement also influenced this research. To make my own biases, thoughts and perspectives as transparent as possible, I journaled them carefully. In addition, I worked with people from the 3SWater Project or IHE Delft and have been indirectly influenced by their interests and concerns, even though it always felt like the project members were very open for other ideas, feedback, and my approach. I try to be as transparent as possible about this.

Moreover, it was difficult for me as a researcher to distance myself from the data collected and the case study since I tried to immerse myself as much in the island culture. Therefore, after the data collection phase, I was stuck in a descriptive phase, and it took time to arrive at an analytical approach. I also took me some time to find my voice in this process and dare to speak out.

Furthermore, I am very grateful for the warm welcome and support I received from the islanders and people from the 3SWater Project during my stay. I look back on a very special time. However, adjusting to their lifestyle and environment also required a lot of flexibility, and I sometimes experienced moments of loneliness, mainly due to cultural differences and different views on life. My personal beliefs could sometimes clash with local views. Fortunately, many people were open to exchanging ideas and views. My participation in sports activities, such as the volleyball and handball teams, also provided a welcome distraction and opportunity for social interaction during the research.

Overall, I learned a lot from my experiences with the islanders and life on the island, both professionally and personally. This research not only increased my knowledge of the WASH sector but also contributed to my ability to challenge myself, adapt, and further develop my academic skills in writing and argumentation.

8. Conclusion

This research portrays an analysis of the waterscape, where islanders employ coping strategies to deal with freshwater scarcity and quality challenges, and socio-technological imaginaries form the way islanders perceive and want to use desalination water in the future. This creates an in-depth understanding of the local communities and their dynamics regarding water and technology, enriched with contextual insights. The analysis sheds light on crucial but often overlooked aspects of freshwater management and highlights the importance of investing in both infrastructure and governance structures to improve water security of sufficient quality for user needs.

The Waterscape and its Potential

The water landscape on Muli and Kolhufushi is highly dynamic and strongly influences islanders' way of life, which is determined by deep-rooted structures, culture, and community differences. Islanders have limited influence on the waterscape, but can also form it through their behaviour and actions. They use existing infrastructure and technologies, such as groundwater pumping and filtration mechanisms, depending on available water resources and their quality. Their agency is also influenced by cultural and social factors. Originally, groundwater was potable, but now rainwater or bottled water is used, and desalination water may be an option in the future.

Theoretically, there should be enough rainfall at Kolhufushi and Muli to meet basic domestic water needs in the wet monsoon period. Although storage capacity is insufficient to meet all water needs, it is enough for the inhabitants' basic drinking and cooking needs. This can be better utilized. It can even be considered to increase the rainwater storage capacity to use it for more domestic household needs.

Water user Voices and Freshwater Coping Strategies

Residents of Muli and Kolhufushi express concerns about both rainwater and groundwater quality. Although rainwater is usually preferred to bottled water because of its taste, there are concerns about drinking water quality. Especially on Kolhufushi, drinking rainwater is often associated with stomach and gastrointestinal complaints. Strategies such as cleaning rainwater tanks and roofs, and using tap filters are used to ensure rainwater quality better. When rainwater is considered unreliable, people often switch to bottled water, although not all households can afford it year-round. Access to rainwater for cooking and drinking purposes can be hampered by a lack of knowledge about rainwater quality and collection practices or funding for sufficient rainwater tanks to meet needs or purchase tap filters.

Groundwater quality for domestic use is generally rated as inadequate, with complaints of odour, taste and associated health problems. Groundwater quality is generally rated worse in Kolhufushi than in Muli. Residents use various strategies to improve groundwater quality, such as oxygen pumping and directing rainwater to wells for dilution. A few households also construct alternative wells for better groundwater quality, mainly in Muli. Barriers to obtaining groundwater of adequate quality for its purpose are knowledge about the sources of pollution and prevention/mitigation practices, as well as financial resources to address them, such as purchasing an oxygen pump.

Scarcity of water from the freshwater lens is attributed to insufficient rainfall and infiltration of rain combined with groundwater pollution, due to either natural disasters such as the 2004 tsunami or due to human actions such as septic tank leaks. Rainwater scarcity during the dry season affects several households. Water shortages are mainly caused by faulty tanks, inadequate cleaning of tanks and roofs, limited rainwater storage, and limited manpower. In rainwater scarcity periods, people fetch water from neighbours or relatives or switch to bottled water. Having a limited social network could also be an obstacle to accessing rainwater, however it rarely poses a barrier because most people have close ties within island communities.

The often-overlooked differentiation in voices within the community

Experiences with freshwater use, access barriers and coping strategies can differentiate among relevant social groups in Muli and Kolhufushi. Households with larger social networks have more access options, such as collecting rainwater from neighbours during times of scarcity. Low-income households face more financial constraints and are less likely to cope with freshwater challenges in a preferred way. Financial resources can limit water choices more for islanders on Kolhufushi, where incomes are lower on average than on Muli. Access to water sources is also linked to gender: in Maldivian culture, men clean the rainwater tanks and roofs, which can be an obstacle in their absence. Furthermore, women in society might be more likely to consider alternative (drinking) water sources since they interact most with domestic water and are, therefore, more likely to have more domestic hygiene and water concerns than men. In addition, more men at Kolhufushi work in tourist resorts, meaning households spend longer without them, making accessing properly cleaned rainwater tanks and roofs more difficult for female-headed households in Kolhufushi compared to Muli. Government officials and project managers could consider these aspects when implementing solutions to freshwater scarcity and quality issues. Attention to structural differences between actors can make solutions more inclusive and increase the degree of adaptation to new innovations.

The mismatch: in technology design and community water needs

In the future, desalination plants can also provide water for drinking, cooking, and other household uses. Desalination can potentially increase water security by increasing water availability with drinking quality standards for human use. This has been the main pillar and focus of Maldivan's water policy and management for the last few years. It can be considered the dominant water management paradigm in the Maldives.

Sociotechnical imaginaries of local communities revealed that even though islanders on Muli and Kolhufushi generally welcome the desalination technology and its use in the future to address their water needs, it is questionable whether the desalinated water will be used for drinking purposes for which it has originally designed. The majority of the population prefers the taste of rainwater. Moreover, many people only want to drink desalinated water if it has been filtered again, with a household ARO filter for example. Despite the water company's reassurance that the desalinated water will be drinkable in the future, distrust prevails among many users regarding the desalination process and/or the water distribution system. This finding shows that this high-tech and costly solution to water scarcity does not necessarily address the islanders' most basic water needs (i.e. drinking water). If residents do not consider the water fit for human consumption, they remain dependent on rainwater, bottled water or new expensive high-tech solutions with household purification systems. Therefore, the question is, to what extent and for what purpose does desalination really improve water security? And for whom?

In addition, existing water supply inequalities may be exacerbated in Muli and Kolhufushi. Wealthier households already have more options to address challenges related to freshwater resources through their financial resources, for example, by purchasing bottled water or purchasing oxygen pumps to improve the poor quality of groundwater. This advantage becomes more pronounce with desalinated water, as sizable wealthy households can afford to use it for household needs, while this remains uncertain for poorer households, which is more likely on Kolhufushi than on Muli. Also, there has traditionally been a culture of non-payment among water users through the non-paid nature of rainwater harvesting and groundwater usage, which can hamper the switch to paid-drinking water.

Existence of alternatives to complement the waterscape more according to the water user needs

With this thesis, I argue not to focus too narrowly on desalination technology to solve the Maldives' freshwater scarcity and quality issues. In principle, the available rainfall combined with increased storage of rainwater can provide the drinking water security everyone aspires on both islands, at low operational costs. Alternative water resource management and use can be considered, with a higher focus on improving water use efficiency and welfare per unit of water. It emphasises water services and quality tailored to the users to make it more effective rather than always seeking new sources. Furthermore, more soft path infrastructural investments can be considered to complement centralised desalination water infrastructure, such as economic instruments such as markets and pricing mechanisms to promote efficient use, equitable distribution, and sustainable operation. Moreover, active community engagement will help create a better understanding and adaptation to new innovations.

9. Recommendations

9A. Policy Recommendations

In essence, the thesis' conclusions mentioned above point to three broad policy implications that will be outlined first. There after some other broad crucial recommendations will be made.

1. While having sufficient and adequate water supply infrastructure is crucial, it is also essential to consider other aspects of water management, such as different water sources available, social interactions, and institutional arrangements. Instead of focusing solely on providing a continuous water supply, exploring how ***water management can be better tailored to specific water needs and required quality for users is recommended***. This helps to avoid mismatches between supply and demand. Hence, it is recommended that water project managers and policymakers let local communities participate more in the (water) projects planned for the islands and have pilot phases of water initiatives and projects that include feedback loops.

2. Water users' differing needs and capabilities are often overlooked in water supply evaluations. Planning specific water supply models (public/private or centralized/decentralized) requires understanding the preferences and outcomes for different groups, such as household wealth and gender, with ***targeted support for vulnerable groups improving inclusivity of the water supply.*** The government could for example provide subsidies and/or fair pricing mechanisms based on household incomes. Subsidies could be provided for tap filters or areo-filters for rainwater or to provide islands with more communal and private rainwater storage tanks. The community and IC could consider creating specific support institutions within the community could also be considered to help the more vulnerable. For example, other islanders or technicians from Feneka could install new technologies, connections and pipes in households, instead of residents having to do this themselves.

3. It is essential to provide islanders with sufficient water, but instead of focusing mainly on technological solutions, it is ***possible to capitalise on already existing water resources and optimise resources and practices, such as groundwater, rainwater, and wastewater***. Despite its potential, rainwater harvesting is limited, and could be promoted further to increase collection, storage and usage of rainwater. Rainwater can be used not only for drinking and cooking purposes but also for other domestic water needs. If rainwater is used for drinking purposes, it should be ensured that it meets drinking water quality standards. The government, research institutes and Feneka employees could conduct extensive testing to improve knowledge about rainwater quality and the accuracy of rainfall predictions. This will enable households to clean their roofs in time for optimal water collection. The IC could establish a roof cleaning group similar to the WDC's current waste management project for women, possibly on a voluntary basis or for a small fee. Such a project could be done by both men and women, although that is unusual for women now. In addition, the IC could organize "water knowledge groups" to educate islanders on the best collection methods and techniques, and to exchange knowledge on how to improve stormwater quality, such as through the use of specific filters. The government could offer subsidies or cost-reimbursable supplies of high-quality filters. Furthermore, domestic aero systems could be used for rainwater filtration instead of water treatment through desalination.

Legislation and policy

Appropriate policies and legislation are crucial for effective water resource management and protection. The government's water and sanitation department could **formulate effective groundwater extraction and rainwater catchment policies**. For example, groundwater pump extraction can be regulated to avoid over-extraction. This has been done in the construction industry recently, but on some islands, the groundwater pumps are still running 24/7 and used for water-consuming purposes like fish tanks.

Moreover, it is recommended that the water and sanitation department of the government develops a **policy direction for the simultaneous construction of sewerage and stormwater drainage** to avoid double excavation, environmental disruption, and groundwater pollution. It also avoids political points of contention about the construction works and supplies. Sometimes, the sewerage was constructed first, with water supply followed five years later because of political disagreements.

In addition, to achieve better coordination and minimize the waste of scarce resources, there is a need to **streamline agencies in the water and sanitation sector on small islands***,* including the IC, representatives of the local community, Feneka technicians and project managers, SMC (the desalination company), URA, and the water and sanitation department of the government. Clear definitions of roles and responsibilities are essential for this. This can be done by organizing events and meetings, and creating a better and more specific platform to exchange knowledge, e.g. by a website or an organisation where people can become member from. A clear distinction between suppliers and regulators is crucial, especially in the case of privatization and by islands with public water supplies. Moreover, regulations could be considered, since the interests of local communities and community input are essential for protecting and conserving water resources.

Assessment and monitoring of water resources

Research institutes, URA, and Feneka could **adequately evaluate water resources and monitor their performance under natural stresses (such as drought) and human activities (such as water detour and groundwater extraction)**. This will provide more insights into groundwater contamination, recharge, and maintenance, for example. It is also recommended to evaluate the capacity of rainwater storage tanks compared to precipitation data and their use by households. Creating more extensive and well-maintained monitoring networks are recommended, in addition to regular monitoring programs by well-trained personnel from (national) water agencies. Regular analysis and reporting of monitoring results are essential for water management, planning and policy.

Design and planning

For project managers and governmental agencies, **planning and designing water projects and technologies that use simple designs and have proven themselves in similar conditions is recommended.** Technical criteria from other regions can serve as guidelines, but could best be adapted to local conditions. Materials and equipment should be simple and standardized whenever possible to reduce operation, maintenance and training requirements. It is also recommended to use locally available materials as much as possible, this makes maintenance easier and minimizes import costs.

Land use design and planning

For landscaping architects, and governmental policy and project managers, **effective land use planning and management are critical to protect water resources from pollution, and water reserves and/or conservation areas,** are recommended. In addition, it is recommended that groundwater withdrawals take place centrally on the island, with sanitation and waste disposal at the edge.

Increased infrastructure development in the central areas of islands is disrupting the natural water flow patterns, where water flows from the central parts towards the sea. This disruption may threaten freshwater sources, which could result in saltwater intrusion from the sides and below. To solve this, new landscaping methods, such as installing retaining structures, can be considered. The reversal of the water flow is countered this way and it allows for more rainwater infiltration to refill the freshwater lens. Infiltration galleries on large open spaces such as playing fields or airports can be suitable areas for this, this is for example done on Lifuka Island, Tonga (Falkland, 1999). Moreover, these galleries need to be placed far from habitation and pollution sources to minimize the risk of biological contamination.

Pollution control of sanitation systems

Sanitary facilities must be located far enough away from groundwater extraction facilities to prevent cross-contamination with the groundwater. The government could enforce this by law, and IC members could try to control this on the islands. Alternative strategies are also needed to reduce pollution, such as source control of pollutants and water treatment. The existing waste water treatment systems are not in use at Kolhufushi and Muli islands at the moment due to a lack of maintenance and high operational costs. Policymakers and project managers are advised to consider (prior) more appropriate treatment systems, with less maintenance and lower operational costs.

Managing demand, creating knowledge exchange, and controlling leakages

Leaks are common in piped water supply systems, and ***proactive leak detection and repair are required*** to minimize this. This could be executed by Feneka staff members. Moreover, on small islands with public water supply systems, demand management is crucial for water management. Demand management strategies reducing pressure, the government could e.g.: introduce appropriate pricing policies with consumption metering, the government and the IC could educate the public about water conservation, and providing water-saving appliances. For example, desalination wastewater for toilet flushing could be considered as already practised in Malé. Households can also consider connecting rainwater pipes to groundwater wells or septic tanks to dilute contaminated groundwater. Domestic groundwater well constructions can by some households also best be reconsidered by e.g. the saniation department of Feneka. ***Knowledge exchange with local communities is crucial for effective water management.*** On Muli and Kolhufushi, for example, many islanders wanted separate pipes for toilet flushing. The IC on Kolhufushi requested separate toilet flush pipes for the newly constructed houses, but the government rejected this, making water saving and reuse difficult. That is why participation with the island residents is also crucial. As already mentioned, this can be executed through organizing meetings, events and by exchanging knowledge through platforms on e.g. social media.

9B. Follow-up research recommendations

As already mentioned, it is recommended that this study be repeated with a similar theoretical framework and/or research perspective in a different context, either in the Maldives or in other Small Developing Island States (SDIS). Moreover, this research was conducted during a specific period when the use of desalinated water for domestic purposes was at a pilot stage. As indicated earlier, socio-technological representations change over time. It would, therefore, be interesting to **reassess water needs and visions later in the project.** This could provide insight into any changes in people's strategies and visions and determine whether the desalination project has contributed to increased satisfaction among domestic water users.

More insight could also be provided into the **underlying reasons for the dominant public water management paradigm.** Some of these reasons have already been mentioned, such as the dominance of the public elite, corruption and private sector interests. However, the dominant paradigm may also be due to a lack of official field visits by water sector officials or public participation and consultation regarding domestic water management. Because of the reasons already discussed, it is also recommended to prevent governance failures and generate more insights into how to improve good governance in the water sector

More research could be done on **how to integrate alternative water management projects better** and how to accurately tailor them to the specific needs and concerns of islanders on outer islands. Examining what alternative water management projects have already been considered and/or implemented by the government, NGOs and the private sector is important, and a thorough evaluation and trade-off of these options is needed.

In addition, more insights need to be gained on the **quality of rainwater, groundwater and the thickness of freshwater lenses on the islands, as well as the use of wastewater.** More research is needed on the relationship between islanders' health problems and groundwater quality and use practices.

On the practical side, it would be valuable to **explore how different actors and institutions can better provide services and quality tailored to the needs and quantity of users**. This includes specifically targeting different water users and their constraints and needs. More cooperation and concrete action plans among the water and sanitation sector stakeholders are necessary to achieve this.

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Appendix I: Dutch Poem about positionality

[Dutch]

Kansen en keuzes zijn nou eenmaal niet eerlijk verdeeld,
Maar het is wel aan jou hoe jij je leven toebedeelt

Waar en in welk lichaam geboren raakt aan onze levenskansen,
Tegelijkertijd is het aan jou hoe je door het leven wilt dansen.

Onze identiteiten, hoe we worden ontvangen en hoe we onszelf proberen te presenteren zijn niet ons bezit,
Ze ontstaan in ontmoetingen, worden gesmeden en zijn veranderbaar wanneer verhit.

Ik ben door jou,
Door jouw blik die mij vormen zal.

Tegelijkertijd vorm ik ook mijn eigen identiteit,
Afhankelijk van mijn zelfbeeld, presentatie en mentaliteit.

Ik heb daarbij geen volledige controle over wie ik denk te zijn en ook niet op wie ik mag zijn,
Dat hangt af van het schouwspel zowel voor als achter het gordijn.

(source: author's work, 2023).

[English translation]

Opportunities and choices are simply not distributed fairly,
But it is up to you how you allocate your life.

Where and in which body we are born touches on our life chances,
At the same time, it is up to you how you want to dance through life.

Our identities, how we are received and how we try to present ourselves are not our possessions,
They arise in encounters, are forged and are changeable when heated.

I am through you,
By your gaze that will shape me.

At the same time, I am also shaping my own identity,
Depending on my self-image, presentation and mentality.

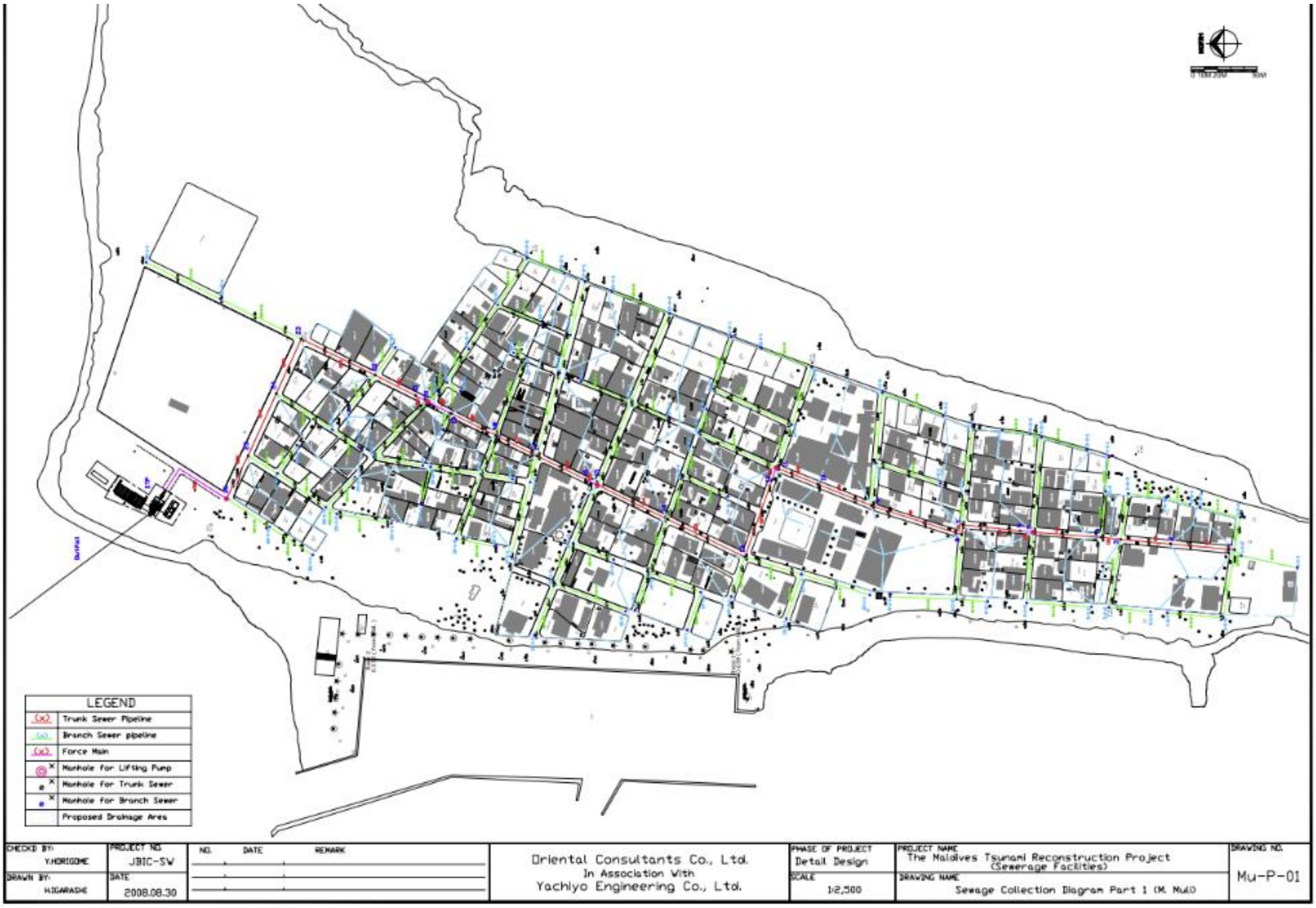
In doing so, I do not have complete control over whom I think I am, nor over who I may be,
That depends on the spectacle both in front of and behind the curtain.

Appendix II: Sewage systems in Muli and Kolhufushi Schematic Overviews

Muli

The small-bore sewage sanitation system has been in place since the 2000s in Muli.

Figure II.28: Schematic overview of the small-bore sewage sanitation system in Muli. (source: Feneka Kolhufushi)

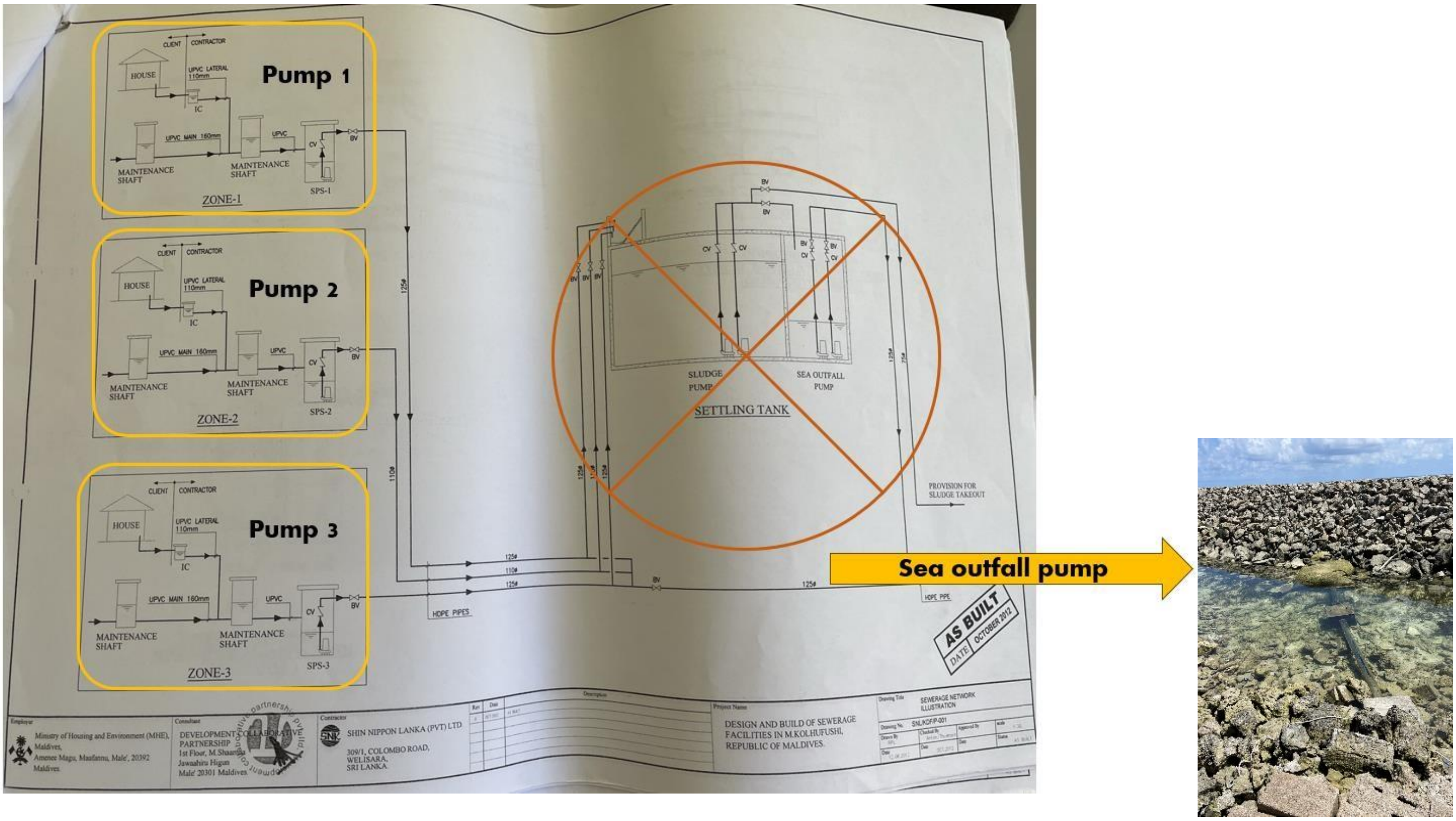


Picture II.20: Feneka staff cleaning one of the seven bigger junctions on Muli. They do this every two months.

Kolhufushi

The conventional gravity sewage system has been in place since 2013 in Kolhufushi. It includes three main wet lifting pumps and a wastewater treatment system, which is not in use at the moment. See Figure 4.14 for the locations of the three wetland pumps.

Figure II.29: Schematic overview of the conventional gravity sewage sanitation system in Kolhufushi (source: Feneka, 2023).



Appendix III: Desalination plant technology

Explanation reverse ssmosis process

All the desalination plants use a Reverse Osmosis (RO) method in the Maldives. Osmosis is the movement of solvent (pure water) from a low-concentration solution (freshwater) to a high-concentration solution (saline water) through a semipermeable membrane (Chua & Rahimi, 2017). Osmotic pressure creates this movement to achieve an equilibrium between the two mediums. By reverse osmosis, the pressure on the saline water side is increased (against the osmotic pressure direction) until the osmotic pressure equals the applied pressure. The water flow will be stopped through the membrane. At this point, further pressure increase on the saline water side reverses the flow. Instead of moving freshwater toward saline water, the freshwater is being separated from the saline water.

Explanation of desalination plant process and technologies on Muli and Kolhufushi

On Kolhufushi and Muli, the desalination treatment starts by collecting seawater through two boreholes about 35 metres deep in the ground. This water passes through a series of filters, including an MGF Multi Grey Filter (see Picture III.21), an Aro pressure cylinder and an RO membrane filter (microbiological filter see Picture III.22). At the same time, rainwater is collected from 10 roofs of public buildings (such as hospitals, mosques, schools, councils, and courts) on Kolhufushi and 8 public buildings on Muli. This is stored in a grey rainwater tank with a capacity of 610,000 litres on Kolhufushi and 920,000L on Muli (see Picture III.23). The treated rainwater and seawater are then combined in two blue tanks before being distributed to households via a piped water system.

Picture IV.21: The sand filter for the groundwater treatment at Kolhufushi

Picture IV.22: The RO membrane filter, as part of the groundwater treatment at Kolhufushi Kolhufushi

Picture IV.23: The rainwater treatment system at Kolhufushi. The blue tank is a sand filter, and the white tank a RO membrane filter

Appendix IV: Calculations of meeting the water needs of islanders with rainwater

Step 1

Calculation of Basic survival water needs for drinking, food, basic cooking needs, and basic hygiene practices of inhabitants (15L/day/person)

Inhabitants per island x 15L/day/person x 30 (per month)

Muli: 1028 x 15 x 30 = **462,600 Litre.** This is needed per month to fulfil basic drinking and cooking water needs of inhabitants on the island.

Kolhufushi: 1471 x 15 x 30 **= 661,950 Litre.** This is needed per month to fulfil basic drinking and cooking water needs of inhabitants on the island.

Step 2

Calculation of Basic domestic water needs (100L/day/person)

Inhabitants per island x 100L/day/person x 30 (per month)

Muli

There are 1028 Inhabitants on Muli. This number will be the departure point, even though there are around 1328 people living on the island, with 300 foreign construction workers. However, they live there temporarily, and the company is taking care of their water supply infrastructure.

1028 x 100 x 30 = **3,084,000 Litre.** This is needed per month to fulfil basic water survival water needs of 100L/person/day according to WHO standards.

Kolhufushi

1471 Inhabitants are registered on Kolhufsuhi, which will be the departure point. Even though there live approximately around 1571 people, including 100 more foreign construction workers.

1471 x 100 x 30 = **4,413,000 Litre.** This is needed per month to fulfil basic water survival water needs of 100L/person/day according to WHO standards.

Step 3

Calculation Average Monthly Rainfall in dry and wet monsoon season

Given

- Kolhufushi = 111,4 ha = 1,114,000 m^2
- Muli = 76.54 ha = 765,400 m^2

The average rainfall data of 2023 of the island Kadhdhoo is taken, see Figure 4.9. This island has similar weather conditions to those of Muli and Kolhufushi. Moreover, the data of 2023 is most accurate and also in line with the average rainfall monthly rainfall patterns from 1999-2021, see Figure 4.11.

Month	Average Precipitation (P) in mm
January	134
April	166
May	301
June	121
July	189
August	205
September	257
October	297
November	276
December	279
Total	2225
Total/month	222,5

*Table V.4: Overview of the Average precipitation and potential evapotranspiration in **dry** season/month in 2023 in Kadhdhoo (source: Maldives Meteorological Services, 2024).*

Month	Average Precipitation (P) in mm
February	87
March	98
Total	185
Total/month	92,5

Table V.5: Overview of the average precipitation in the dry season/month in 2023 in Kadhdhoo (source: Maldives Meteorological Services, 2024).

That needs to be calculated accordingly to the island hectares.

Kolhufushi

<u>Wet monsoon season</u>

Volume of rainfall = 222.5 mm/month × 1,114,000 m² (111.4 ha of Kolhufushi)= 247,165,000 Litre on Kolhufush in wet monsoon season

<u>Dry season</u>

Volume of rainfall = 92.5 mm/month × 1,114,000 m² = 103,045,000 Litre

Muli

<u>Wet monsoon season</u>

Volume of rainfall = 222.5 mm/month x 765,400 m² (76.54 ha of Muli) = 170,301,500 Litre

<u>Dry season</u>

Volume of rainfall = 92.5 mm/month x 765,400 m² = 70,799,500 Litre

Step 4

Calculation Runoff on Kolhufushi and Muli

Given:

- Total average precipitation in the wet monsoon season/month = 222,5 mm

- Total average precipitation in the dry season/month = 92,5 mm
- Sandy Loam soil: Hydraulic conductivity K=10 mm
- Sandy Loam soil: Suction head Hs=110 mm
- Kolhufushi = 111,4 ha = 1,114,000 m²
- Muli = 76.54 ha = 765,400 m²

There is chosen for a Hydraulic conductivity of landy soil, eventhough the closest soil category for the soil in the islands is 'loamy sand' (Hydraulic conductivity about 40 mm/h and Suction Head about 50 mm). However, islands in the Maldives have some soil compaction on the surface making the effective perviousness much less than that of loamy sand in case of surfaces like earthen roads, football fields, bare soil with some pedestrian traffic, etc. So to take an average of the soil properties for the whole of the pervious area of an island (all land other than buildings as there are no asphalt roads at the moment) there is chosen for a less permeable soil: sandy loam whit a hydraulic conductivity of (10 mm/h /110 mm).

1. **Monthly infiltration**

Infiltration rate=K×Time
Time=24 hours/day×30 days/month
Time=720 hours/month
Infiltration capacity=10 mm/h×720 hours/month= 7200 mm
Infiltration capacity=7200 mm/month

In the wet season there is 222,5 mm and in the dry season 92,5 mm of rainfall, which is significantly less than (7200 mm/month). Theoretically the rainfall can infiltrate on the permeable area. However, the rain can not infiltrate into the soil on the entire island, due to roads, housing and infrastructure.

Looking at the map of Kolufushi, let's assume that 45% of the total land area is covered with infrastructure, by taking into account the agricultural zone and yellow circle on Figure 4.13. This leads to an impermeable area.

Looking at the map of Muli, let's assume that 65% of the total land area is covered with infrastructure, leading to an impermeable area. I will come back to this point in step 4. First, the runoff for the Permeable Area needs to be calculated.

2. **Runoff for Permeable Area**

Kolhufushi
Permeable area = 55% of the total area
Permeable area=0.55×1,114,000 m² =612,700 m²

Given the sufficient infiltration capacity in both dry and wet monsoon months:
Runoff on permeable area=0

Muli
Permeable area= 35% of the total land area
Permeable area = 0.35×765,400 m2=267,890 m2

Given the sufficient infiltration capacity in both dry and wet monsoon months:
Runoff on permeable area=0

3. **Runoff for Impermeable Area**

Kolhufushi
Impermeable area = 45% of the total area
Impermeable area=0.45×1,114,000 m2=501,300 m^2

All rainfall on impermeable area becomes runoff:
Runoff (Litres)=Rainfall depth (mm)×Impermeable area (m^2)

<u>Wet season</u>
Runoff (Litres)=222.5 mm×501,300 m^2
Runoff (Litres)=222.5 mm/ m^2×501,300 m^2
Runoff (Litres)=222.5 Litres/ m^2 × 501,300 m^2
Runoff (Litres) =111,539,250 Litres

<u>Dry season</u>
Runoff (Litres)=92.5 mm×501,300 m^2
Runoff (Litres)=92.5 Litres/ m^2 ×501,300 m^2
Runoff (Litres)=46,370,250 Litres

Muli
Impermeable area= 65% of the total land area
Impermeable area = 0.65×765,400 m^2 =497,510 m^2

All rainfall on impermeable area becomes runoff:
Runoff (Litres)=Rainfall depth (mm)×Impermeable area (m^2)

<u>Wet season</u>
Runoff (Litres)=222.5 mm×497,510 m^2
Runoff (Litres)=222.5 Litres/ m^2 ×497,510 m^2
Runoff (Litres)=110,666,975 Litres

<u>Dry season</u>
Runoff (Litres)=92.5 mm×497,510 m^2
Runoff (Litres)=92.5 Litres/ m^2 ×497,510 m^2
Runoff (Litres)= 46,039,175 Litres

4. Total Runoff
Combining runoff from both areas:

Kolhufushi
Wet season: Total runoff=0+111,539,250 Litres=**111,539,250 Litres/month**
Dy season: Total runoff= 0+ 46,370,250 Litres = **46,370,250 Litres/month**

Muli
Wet season: Total runoff=0+ 110,666,975 Litres= **110,666,975 Litres/month**
Dry season: Total runoff= 0+ 46,039,175Litres = **46,039,175 Litres/month**

Step 5
Estimation total rainwater harvesting capacity already available on the islands
It can be assumed that every household has at least one 2500L rainwater tank, as this was a post-tsunami effort by the government. In addition, 75% of the 25 respondents on Muli and 50% of the 25 respondents on Kolhufushi had more than one 2500L rainwater harvesting tank. It can therefore be

assumed that 50% of households have a second 2500LL rainwater harvesting tank on Kolhufushi and 75% of households on Muli. Households are also generally larger on Muli than on Kolhufushi, so more rainwater tanks are needed per household.

Moreover, there are communal rainwater tanks.

Kolhufushi

- Kolhufushi has 256 households. So 256 x 2500 L is at least 640,000 Litre household rainwater capacity. Plus 50% of households have an additional 2500 Litre rainwater tank . So 128 x 2500 = 320,000 Litre additional household rainwater harvesting capacity. In total: 960,000 Litre domestic household capacity.
- There is also the communal rainwater harvesting capacity of at least 16 communal rainwater tanks on Kolhufushi. There are six communal rainwater tanks, and three mosques have, in total, also 10 tanks. So 16 x 2500 = 40,000 Litres of communal rainwater harvesting capacity.
- In **total** private and communal **rainwater harvesting capacity on Kolhufushi** is approximately **1,000,000 Litre.**

Muli

- Muli has 147 households. So 147 x 2500 Litre is at least 367,500 Litre household rainwater capacity. Plus 75% of households have an additional 2500 Litre rainwater tank. So 110.25 x 2500 = 275625 Litre additional household rainwater harvesting capacity. In total: 643,125 Litre domestic household capacity.
- Besides, there are 11 communal 2500 Litre tanks of : 6 tanks at mosques and 5 at hospital. In addition, there are 10 rainwater tanks of 5000L each available at the ICU (but not in use). So that would be 20 rain tanks of 2500L each converted. So in total another 31 communal rainwater tanks of 2500L = 77500L of communal rainwater harvesting capacity.
- In **total** private and communal **rainwater harvesting capacity on Muli** is approximately **720,625 Litre.**

Step 6

Calculate extra rainwater tanks needed to fulfill the basic monthly water needs of inhabitants

Kolhufushi

1,000,000 Litre can be captured per month and 4,413,000 Litre/month is needed to fulfil the basic monthly water needs of inhabitants. Hence, 3,413,000 Litre extra storage capacity is required. This would mean 1366 extra 2500 Litre tanks are needed.

Muli

720,625 Litre can be captured per month and 3,084,000 Litre is needed to fulfil the most basic water needs of inhabitants of the island per month. 2,363,375 extra Litre need to be captured.

Step 7

Calculate additional space for extra rainwater tanks to provide in basic monthly water needs of inhabitants

Kolhufushi

- One 2500 Litre tank occupies 1.54 sq m, with a diameter of 1400 mm (Enduramaxx Limited, 2023).
- 1366 additional rainwater tanks of 2500 Litre on Kolhufushi are needed.

- Total area in m^2=1366 tanks×1.54 m^2/tank= 2,103,64 m^2 = 0,210364 ha.
- That is 1.9 % of the total 111,4 ha on Kolhufushi

Muli

- One 2500 Litre tank occupies 1.54 sq m, with a diameter of 1400 mm (Enduramaxx Limited, 2023).
- 946 additional rainwater tanks of 2500 Litre on Muli are needed.
- Total area in m^2=946 tanks×1.54 m^2/tank= 1,456,84 m^2 = 0,145684 ha
- That is 0.20 % of the total 75,54 ha on Muli