DELFT UNIVERSITY OF TECHNOLOGY

CEGM3000
MULTIDISCIPLINARY PROJECT

Ceramic Microfiltration Wastewater Reclamation in Maputo for Industrial Reuse

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Abstract

This research explores the feasibility of implementing ceramic microfiltration (CMF) treatment in Maputo, Mozambique, to reclaim wastewater for industrial reuse, addressing the city's pressing water scarcity challenges. As rapid urbanization increases Maputo's reliance on potable water for industrial and agricultural needs, this study evaluates reclaimed wastewater as a sustainable alternative to alleviate demand on the city's limited freshwater resources. Using a CMF pilot plant, the project tested wastewater from the recently upgraded Infulene Wastewater Treatment Plant (WWTP) to assess whether CMF treatment could achieve quality standards suitable for applications such as cooling, concrete production, car washes, agricultural irrigation, and municipal park irrigation. Furthermore, the opportunity of scalability was tested through a water balance, while relevant stakeholders were interviewed and costs estimated to complete the feasibility assessment.

Laboratory results indicated that CMF treatment effectively reduces turbidity, chemical oxygen demand (COD), and biological pollutants like E. coli and coliforms. However, dissolved particles and heavy metals were not removed, limiting its efficacy for high-specification uses. While the treated effluent met quality standards for lower-specification applications, such as local car washes and park irrigation, it did not reach the stricter requirements needed for cooling water or concrete production. This underscores a need for process optimization, particularly through coagulation, to expand CMF's application range.

To assess sustainable water availability, a water balance analysis of the Infulene WWTP considered seasonal flows and local agricultural demands. The findings suggest that although the current water supply is insufficient during dry months, full capacity utilization and improved sewer network connections in the future could support CMF-based water reuse consistently across seasons, with potential scalability for additional users

Economic analysis compared CMF's capital and operational costs with revenue from reclaimed water sales, showing that while considerable initial investment is required, direct piping could potentially make CMF-treated water competitively priced against potable supplies under the condition of reaching maximum treatment capacity at a scaled up CMF plant. High costs associated with truck-based delivery, however, present a barrier to adoption for potential users. Stakeholder interest was strong across industrial users and developers, though contingent on achieving cost parity with the existing water network.

This study concludes that, while integrating CMF technology into Maputo's water management strategy offers promise, challenges remain in achieving quality standards for certain industrial applications and in lowering costs. Addressing these technical and economic barriers could open avenues for CMF's broader adoption, especially with future assessments that include alternative suppliers and configurations.

List of Abbreviations

AIAS:	Administração de Infraestruturas de Abastecimento de Água e Saneamento Water Supply and Sanitation Infrastructure Administration
ARA-Sul	Administração Regional de Águas do Sul Southern Regional Water Administration
BOD:	Biological Oxygen Demand
CBA:	Cost-Benefit Analysis
CEISA:	Centro de Estudos Industriais, Segurança e Ambiente Center for Industrial, Safety, and Environmental Studies
CFL:	Crossflow Loop
CFU:	Colony-Forming Units
CIP:	Cleaning in Place
CMF:	Ceramic Micro-filtration
COD:	Chemical Oxygen Demand
CTM:	Central Termoeletrica de Maputo Maputo Central Thermoelectric Power Station
CW:	Constructed Wetland
DNAAS:	Direcção Nacional de Abastecimento de Água e Saneamento National Directorate of Water Supply and Sanitation
DO:	Dissolved Oxygen
EC:	Electrical Conductivity
EMSD:	Empresa Municipal de Sanamento e Drenagem de Maputo Maputo Municipal Sanitation and Drainage Company
FIPAG:	Fundo de Investimento de Infraestrutura e Património de Abastecimento de Água Water Supply Infrastructure and Equity Investment Fund
HREC:	Human Research Ethics Committee
ICP:	Inductively Coupled Plasma Spectroscopy
INAM:	Instituto Nacional de Meterologica National Institute of Meteorology
ISO:	International Organization for Standardization
MF:	Microfiltration
MPN:	Most Probable Number
O&M:	Operation and Maintenance
P&ID:	Process and Instrumentation Diagram
SAR:	Sodium Adsorption Ratio
SDMP:	Sanitation and Drainage Master Plan
STD:	Standard Deviation
TDS:	Total Dissolved Solids
TSS:	Total Suspended Solids
TFF:	Tangential Flow Filtration
TMP:	Transmembrane Pressure
UEM	Universidade Eduardo Mondlane Eduardo Mondlane University
UF:	Ultrafiltration
WQ:	Water Quality
WW:	Wastewater
WWTP:	Wastewater Treatment Plant

Contents

1 Introduction

The country of Mozambique faces drinking water shortages due to several factors, among which population growth and climate change are the main drivers [1]. This fact is more pronounced in urban areas, given their rapid expansion. Therefore, the city of Maputo is expected to face such issues in the near future, which may be exacerbated by the fact that farmers and several industries, such as concrete and cooling, make use of drinking water.

To mitigate potential shortages, research has explored the use of treated wastewater for industrial applications [2–4]. Laboratory-scale studies have demonstrated that, after undergoing various treatment processes, wastewater can meet regulatory standards for uses such as cooling systems and concrete production, with ceramic microfiltration (CMF) among the promising treatment methods [1]. Research specific to Maputo has explored how CMF could be used to reclaim water and reduce the pressure on the city's already limited drinking water supply. Several potential applications for reclaimed wastewater from CMF treatment have been identified in Maputo, including its use in cooling systems for power plants and the Central Bank of Mozambique, concrete production, agricultural irrigation, and car wash services throughout the city [5–7]. However, the level of interest from industry in adopting these technologies to replace drinking water remains unclear, as do the costs involved in their development and the additional benefits they may provide. This highlights the need for further investigation into whether local organizations would be willing to use reclaimed wastewater, as well as an assessment of the associated costs and benefits.

Past research in Maputo has focused on setting up a CMF pilot plant, designed and built by the Dutch company Logisticon, to assess whether treated wastewater could meet the quality standards for industrial uses, such as cooling and concrete production. The plant is experimental and highly configurable, allowing users to adjust the treatment process as needed. Findings from previous research on the same technology indicated that the method showed promising potential for wastewater reclamation in Maputo [8].

Building on the work of Gulamussen et al., this research aims to further assess the feasibility of using CMF treatment to produce reclaimed wastewater in Maputo. The project will focus on implementing CMF as a secondary treatment at the Infulene wastewater treatment plant, the city's largest facility in terms of treated effluent flow. Given its capacity, Infulene is the ideal location to explore whether CMF can improve water quality enough for concrete production, cooling, and irrigation. The study will also evaluate the economic and social feasibility of this implementation, examining potential costs and stakeholder interest. Additionally, it will explore whether organizations in Maputo are willing to finance and operate a reclaimed wastewater system, and whether companies and farmers would purchase and use reclaimed water for these industrial and agricultural applications.

Given the scope of this project, the main research question is:

How feasible is it to establish a ceramic membrane treatment plant at the Infulene wastewater treatment plant to provide reclaimed wastewater as a water source?

To answer this, the project will investigate the following sub-questions:

- *What is the water quality of wastewater after undergoing secondary CMF treatment at the pilot plant?*
- *How much water is available for reclamation and what are future predictions for scalability opportunities?*
- *What is the current water demand of potential users and which conditions do regulators and users pose for possible application?*
- *What is the level of interest from regulatory figures and potential users, and what are the potential obstacles that they foresee?*
- *Is it economically feasible to implement a scaled-up version of the pilot plant's CMF technology at Infulene, using the same provider, to produce reclaimed wastewater for industrial and agricultural use?*

In addition to the research question, a significant effort was dedicated to the maintenance and repair of the CMF pilot plant. After not being operational for nearly three years, parts had to be tested, cleaned and replaced. This was necessary for the operation of this project and for future research on the same topic.

2 Background and Site Description

This study combines the facilities of two water treatment facilities in Maputo, Mozambique. On the larger scale is the fully operational, newly renovated, wastewater treatment plant (WWTP), located next to the Infulene river. The Infulene WWTP treats about 1500 m^3 per day of raw sewage. On a much smaller scale is the CMF pilot plant, located in Zimpeto. The pilot plant can treat a maximum of about 40 m^3 per day [9]. Figure 1 shows the location of both treatment facilities. They are roughly 10 kilometres apart.

Figure 1: Locations of Maputo and the WWTP (Infulene) and Pilot Plant (Zimpeto). Top left: Maputo in Southern Africa. Top right: WWTP and Pilot Plant in Maputo area. Bottom left: Waste Water Treatment Plant located near Infulene river. Bottom right: Pilot Plant located in Zimpeto.

2.1 Infulene WWTP

The Infulene WWTP was designed and built in 1987 to expand the sewer system of the Maputo area. After recent maintenance and upgrades, it has been operational since May 2024. The upgrades consist of a sludge treatment, maturation pond and several constructed wetlands. This WWTP biologically treats municipal gray water from the city's sewers and septic tanks. The quality of the treated water is monitored and, if sufficient, the effluent is discharged in the Infulene river. The latter is a water source for many neighbouring farmers and eventually leads to the Maputo bay.

The treatment consists of five stages. First, the wastewater is collected from the sewer system and trucks at the point A in Figure 2, after which it is cleared of larger particles. This is also where the sludge generated by the plant is treated and dried. The wastewater then enters, in series, an anaerobic, facultative and maturation pond, respectively B, C and D in Figure 2. Hereafter, the treated water can be put in a series of constructed wetlands, depending on the quality of the treated water. These wetlands are located at point E in the figure.

2.2 CMF Pilot Plant Zimpeto

The Ceramic Micro-Filtration Pilot Plant was originally built in 2009 by Logisticon as a dead end filter. In 2014 some alterations were made to make it a truly tangential flow system. After passing through different owners and receiving more alterations, the pilot plant was relocated to Zimpeto in the Maputo Area (see Figure 3). It

Figure 2: Aerial photo (left) and schematic view (right) of the Infulene WWTP.

was located at the Zimpeto wastewater treatment plant, but after the Zimpeto facility ceased operations, the pilot plant remained unused for nearly three years.

The pilot plant was designed to evaluate the possibility for CMF treatment to a given water source. As such, the plant is quite small and has a relatively low throughput. However, this makes the plant ideal for R&D purposes. Almost all operational details are configurable and the small size makes for a manageable experimental environment.

At the start of the project, the pilot plant was not operational due to the prolonged standstill. From the first visit, it became apparent that understanding plant operation, assessing of plant damage, and repair and maintenance of the plant would become a major part of this project. Next to this, significant changes to the pilot plant were only documented until 2014, so all new and old changes had to be documented and a new manual had to be written to account for certain differences. Once restored, it is meant to serve as a valuable resource for researchers at Eduardo Mondlane University (UEM) to test for various treatment results under different operational configurations.

Figure 3: Pilot plant: views of the tanks, crossflow loop (left), pre-filter, pumps and pipes (right)

3 Materials and Methods

To have an efficient and effective work organization, the project was divided into five main topics:

- *Pilot Plant*: A schematization of the principles of CMF treatment and of the pilot plant itself will be shown, along with some explanation
- *Water Quality*: Here all the water quality standards for our use cases and tested compounds are presented, including test methods
- *Water Balance*: The methodology for the development of the water balance for the Infulene WWTP is explained
- *Stakeholder Analysis*: The relevant stakeholders are introduced, including how the data for this topic was retrieved
- *Financial feasibility assessment*: An inventory of the considered costs of the project is outlined with an explanation of the assessment method.

3.1 Pilot Plant (CMF Treatment)

3.1.1 Equipment Description

The experimental portion of this report is centered on a CMF pilot plant. This installation was originally built for Evides, a Dutch drinking water company, by an engineering firm called Logisticon in 2009. It is intended to test different water sources to determine whether they are suitable for treatment by CMF. As such, its process parameters are highly configurable, such that different pressures, flow rates, membranes, and chemicals can be applied to the water depending on its composition. The system is based around the principle of tangential flow filtration (TFF), which is shown diagrammatically in Figure 4a. In this system, water flows parallel to the surface of a membrane. The water is pressurized, which causes water particles to pass through the pores of the membrane. Some contaminants are too large to pass through the pores, and thus remain in the main flow. Compared to dead-end filtration methods like that shown in Figure 4b, TFF systems experience reduced membrane fouling, since the tangential flow prevents contaminants from building up on the surface and blocking the pores [10]. This reduces maintenance costs and provides a more consistent outflow of filtered water [11].

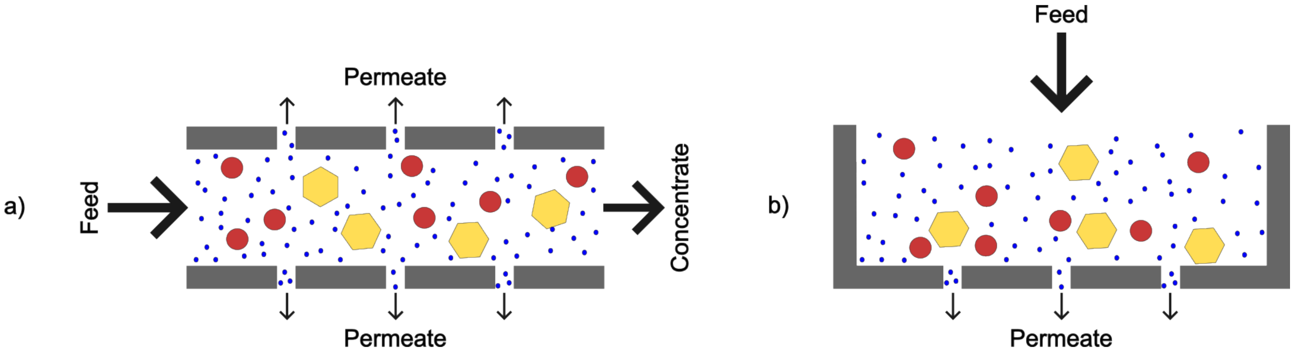

Figure 4: Filtration Methods a) Tangential Flow Filtration b) Dead End Filtration

In 2021, the plant was purchased by Eduardo Mondlane University and shipped to Maputo. It was eventually installed at a WWTP in Zimpeto, an outlying district of Maputo. This treatment plant was originally built to handle the wastewater from the adjacent residential area, but it fell into disrepair quickly after its construction. Although funds were raised in 2018 to rehabilitate the WWTP [12], it is still non-functional. As such, treated effluent is not available on site and must instead be brought from the Infulene WWTP. Additionally, the electricity has been cut off the site, so power for the pilot plant must be provided by a diesel-powered generator.

A simplified schematic of the pilot plant is shown in Figure 5, where the components related to the main filtration process are shown in black. In this diagram, the abbreviation PT refers to pressure transducers, while FT refers to flow transducers. DP refers to dosing points, where Pumps P-04, P-05 and P-06 can be attached to introduce additional chemicals. The numbered components correspond to those in the full Process and Instrumentation Diagram (P&ID), which is supplied in the additional manual. In normal operation, Pump P-01 pulls water from a supply tank into a pre-filter which removes any large particles. The water is then stored in Tank T-02, where chemicals can be mixed in using Pump P-04 if desired. From this point, the water is supplied to the ceramic membrane by Pump P-02. The filtered water, hereafter called permeate, leaves the filter through a side pipe and is collected in Tank T-03. From Tank T-03, the permeate can be sampled or dumped to the sewer. The remaining water, called retentate or concentrate, passes through the top of the filter. Most of this flow is recirculated using Pump P-07, which provides a high flow velocity across the membrane surface. Part of the concentrate flows out of this crossflow loop and into the sewer. The rate at which concentrate escapes is controlled by the inflow from Pump P-02 the amount by which Valve V-217 opens.

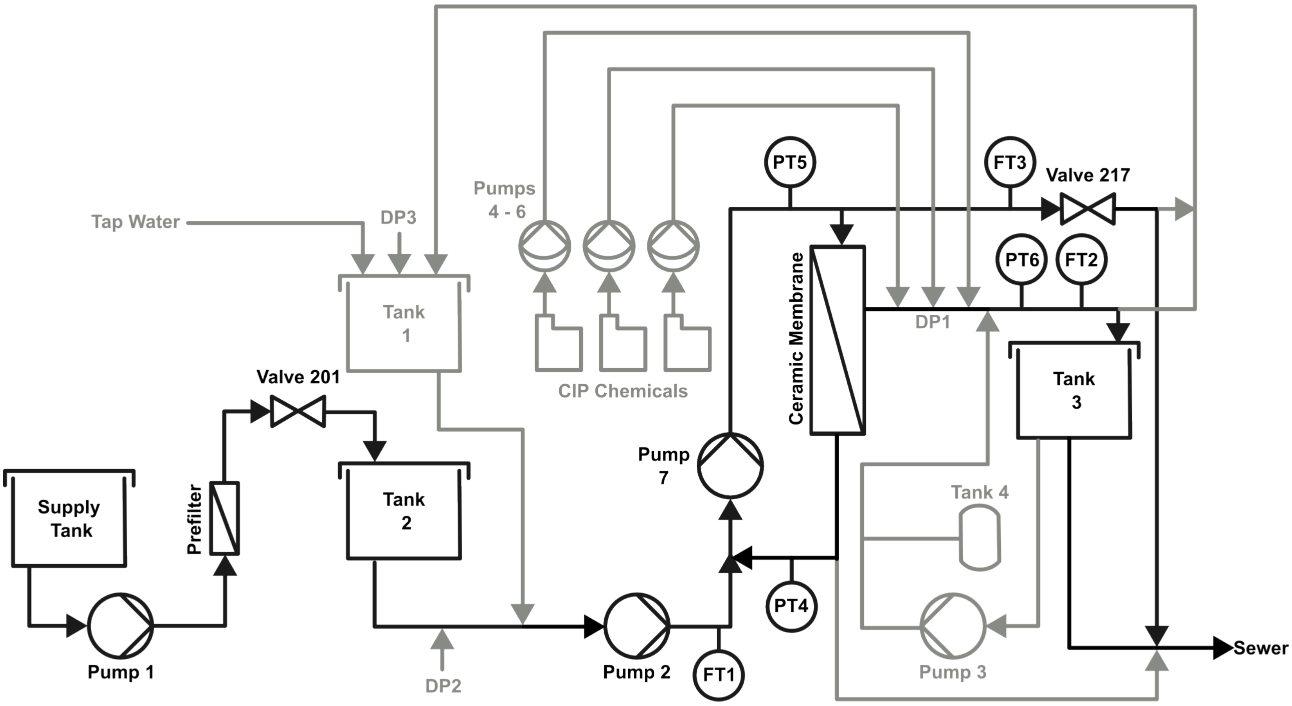

Figure 5: Diagram of Pilot Plant

The remaining components in Figure 5, drawn in grey, are related to various cleaning processes. The system has four cleaning protocols: auto-flush, forward flush, backwash, and CIP. These processes are described in further detail in the additional manual. Additionally, almost every pipe in the system includes both a computer-controlled valve and a hand-operated valve. This means that the processes can be entirely automated, but flow can still be manually stopped in case of a malfunction. The computer-controlled valves are actuated by compressed air, which is supplied by a compressor via a system of plastic air hoses.

There are several operations which are fundamental to the operation of the pilot plant, each of which is shown schematically in Figure 6, in which the active flow paths for each operation are highlighted in blue. Filtration is the main process by which clean water is produced as shown in Figure 4. Backwashing is performed intermittently throughout a filtration cycle to remove contaminants from the membrane pores and thereby restore its performance. Forward flushing fulfils a similar role to backwashing, but is performed on membranes that do not tolerate backwashing. Rinsing is the process by which cleaning chemicals are introduced to the membrane and then removed by dilution. This generally takes place as part of a Cleaning in Place (CIP) cycle, in which cleaning chemicals are introduced, the membrane is soaked, and then the chemicals are removed. A CIP cycle takes place after dozens to hundreds of filter-backwash cycles, and various chemicals may be used depending on the water being used.

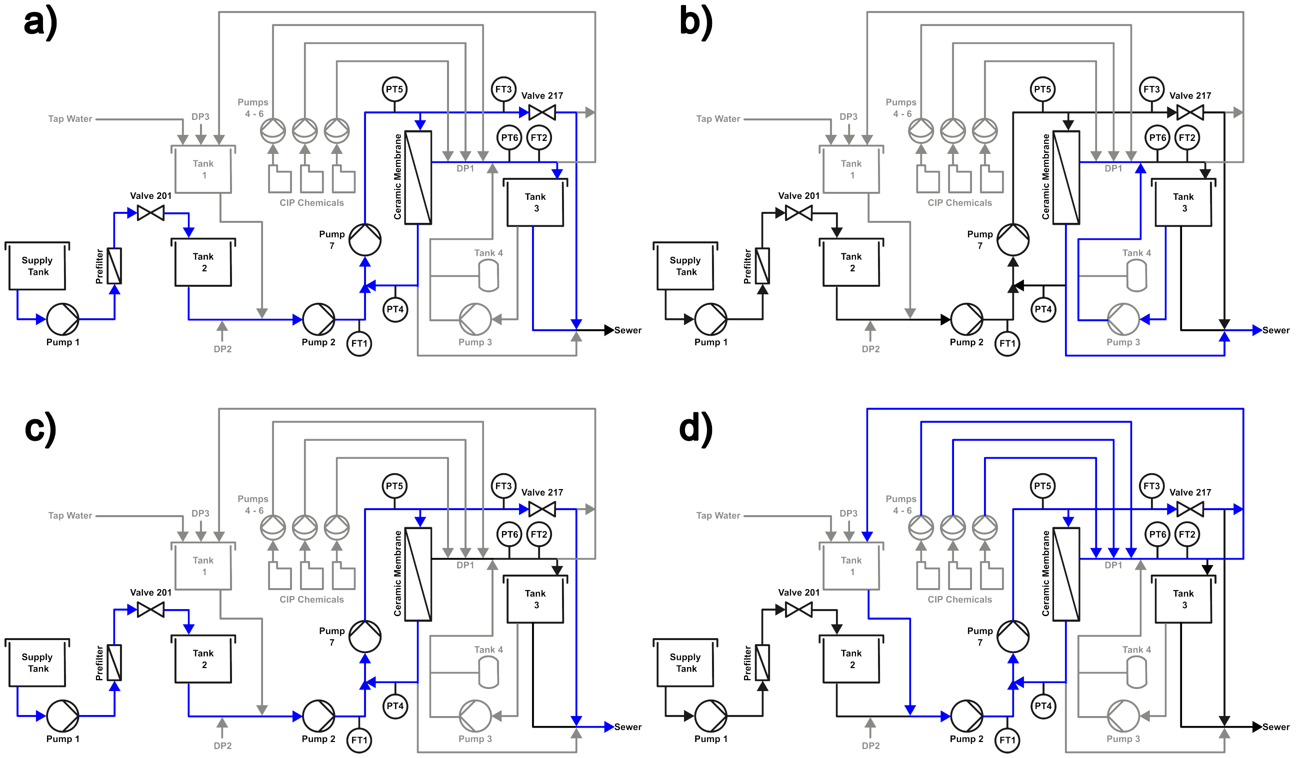

Figure 6: Pilot Plant Operations a) Filtration b) Backwash c) Forward Flush d) Rinse

The ceramic membranes within the pilot plant can be exchanged for different materials and geometries depending on the application, although it is quite an involved process. The membranes used for this project were produced by Inopor and are shown in Figure 7. They have several channels through their centers, which carry the main flow of concentrate while microscopic pores carry permeate horizontally to the collection pipes. The specifications of the membranes are provided in Table 1.

Figure 7: Ceramic Membranes

Table 1: Membrane Specifications

Material	Length	Number of Tubes	Tube Diameter	Channels per Tube	Channel Diameter	Specific Area
TiO_2	1200 mm	37	20 mm	4	6.1 mm	0.0767 $\frac{m^3}{m \cdot tube}$

3.1.2 Test Procedure

At the start of the project, the pilot plant was not operational due to sitting without maintenance in hot, dry conditions for several years. A significant effort was required to return the installation to working order. Some details on this process are described Annex G.

Two filtration cycles were performed using the pilot plant, the first using effluent from the Infulene WWTP and the second using influent. This way, the effectiveness of CMF as both a secondary and primary treatment method is evaluated. Since even a small amount of solids could damage the ceramic membrane, the influent was taken directly after solid removal and grit removal were completed at the Infulene WWTP. Both batches of water were transported to the pilot plant using the municipal water truck shown in Figure 8. Before filling, the water truck was flushed several times using the relevant wastewater. However, a more thorough cleaning was not possible due to logistical limitations, so there would likely be some contamination from the truck's previous contents. These contents cannot be known with certainty, but likely include the contents of domestic septic tanks.

Figure 8: Delivery of Wastewater

Before any wastewater was introduced to the pilot plant, the system was rinsed using tap water and household detergent. Prior to this cleaning, no tap water could pass through the membrane, but this started to occur during cleaning. Then, the system was drained and rinsed with tap water until no more foam was produced. Afterwards, a CIP cycle was performed using hydrochloric acid, which was added to the circulating tap water until the pH reached 2.5. The valves were then closed, and the system was allowed to soak overnight. Upon startup the next morning, the pH had increased to 3.5, indicating that some reactions had occurred. The system was then again drained and rinsed with tap water. Finally, a CIP cycle was performed with sodium hydroxide, which was added to the circulating tap water until the pH reached 10.5. Again, the valves were closed and the system was left to soak overnight. Upon startup, the pH had reached 9.7, indicating that reactions had occurred.

Between the two batches of wastewater, another CIP cycle was performed with sodium hydroxide. Due to limited time before the arrival of the second water truck, however, the solution was only allowed to soak for 30 minutes. However, the permeability of the membrane, as measured using tap water, was restored to the value it had before the test, indicating that the cleaning was successful.

Both batches of wastewater were subjected to the same filtration cycle, shown in Figure 9. Three filtrations were performed, each being twenty minutes long. During filtration, a 24 mg-Al/L solution of $Al(SO_4)_3$ was added to the line via dosing point 2 to act as a coagulant. The dosing rate was calculated such that the concentration of Al in the water was 1 ppm, based on the recommendations of the pilot plant supplier. After the first filtration, a two-minute backwash was performed. After the second filtration, a two-minute forward flush was performed. Both operations are intended to improve membrane performance, and coagulant dosing was stopped during these operations. When the first batch of wastewater was introduced, the pump and valve settings were adjusted until the inflow was near 400 L/h and around 80% was recovered as permeate. These settings were then kept constant for all filtrations. It should be noted that, under normal circumstances, the system can be set to automatically maintain the same flow rate and recovery rate. However, this was not possible for this research due to some broken sensors which are critical for the PID control, so the system was operated exclusively under manual control. More details are provided in the additional manual. Additionally, only one set of operating parameters was tested, which were based on the recommendations of a representative of Logisticon. It is highly possible that a more optimal set of parameters could be found via experimentation, but this was outside the scope of this research. The parameters used are summarized in Table 2.

The pumps are set by frequency in the software rather than flowrate. For Pumps P-02 and P-03, this is immediately related to flow by the flow sensors. For Pump P-07, however, there is no flow sensor. A rough approximation was made using the performance curve in the pump's manual, which indicates that at 2 bar of pressure, the pump can supply approximately 110m^3/h of water flow. Using the membrane geometry described in Table 1, this comes out a cross-flow velocity (CFV) of approximately 7 m/s. This is slightly higher than other literature, which typically uses CFVs of 4 m/s or less [10]. At the start of filtration, the TMP was approximately 1.9 bar and the feed rate was approximately 350 L/h. During the backwash, the pressure on the permeate side of the membrane was approximately 1.7 bar and the flow rate was 750 L/h. During the forward flush, the TMP was approximately 1.5 bar and the feed rate was 1300 L/h.

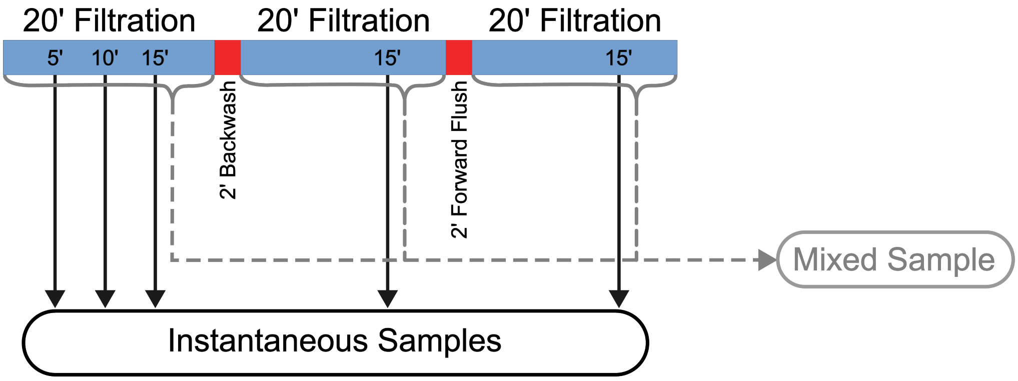

Figure 9: Filtration Cycle and Sample Times

Fifteen minutes into each filtration, a sample was taken from the permeate line, which represents the permeate quality at that instant during the process. During the first filtration, additional samples were taken after five and ten minutes. At the end of the whole process, a sample was taken from the permeate tank, which contains the mixed permeate from throughout the cycle and thus represents the average permeate quality. Using these samples, it can be determined whether the water quality changes as the membrane pores become clogged. The sampling scheme is shown schematically in Figure 9

Table 2: Filtration Cycle Settings

Filtration				Backwash	Forward Flush			
P-02	P-07	V-217	V-206	P-03	P-02	P-07	V-217	V-206
15 Hz	25 Hz	20%	Closed	30 Hz	15 Hz	45 Hz	100%	Open

Additionally, the pilot plant performance is monitored throughout the filtration cycles. The feed flow, permeate flow, membrane inlet and outlet pressures, feed temperature, and concentrate pH are measured at four-minute intervals throughout the process. Using these measurements, the recovery rate, transmembrane pressure (TMP), flux, and permeability can be calculated using Equations 1 through 4 [9]. In these equations, the subscripts refer to the sensor locations in Figure 5.

$$Recovery = \frac{Q_2}{Q_1} \tag{1}$$

$$Recovery = \frac{P_4}{P_5} - P_6 \tag{2}$$

$$Flux = \frac{Q_1}{A_membrane} \tag{3}$$

$$Permeability = \frac{Flux}{TMP} 1.022^{10-T_1} \tag{4}$$

Recovery is a measure of what percentage of the inflow is recovered by the filter. This can be controlled by adjusting the opening percentage of Valve V-217. TMP measures the pressure across the membrane pores. This measurement does not work quite as intended, as the pilot plant was designed for a much higher throughput and has since been adapted to a much lower flow. This means that there is not enough permeate flow to fully fill the permeate loop, so PT-6 is not submerged and does not read a higher pressure than atmospheric during a filtration cycle. Flux is a measure of how much water passes across the membrane, rather than through the pores. Permeability is a measure of how much water flows through the membrane at a given pressure. It should be noted that permeability is not an inherent property of the membrane, as it depends heavily on the contamination level of the process water and the degree of fouling the membrane has experienced.

3.2 Water Quality

The water quality (WQ) in the Infulene WWTP in Maputo has been measured and analyzed in previous research [6, 7, 13]. However, the findings in those studies are almost 10 years old. Since then, the WWTP has been significantly improved and expanded with additional capacity and treatment steps. Therefore, new measurements of the WQ are necessary due to the impact of the improvements at Infulene WWTP in regards to water quality.

3.2.1 Sample Locations

The relevant sample locations for this project are at the influent and effluent of the Infulene WWTP. In detail, the water from the influent was taken before it reaches the anaerobic ponds, but after solid and sludge removal to ensure no large particles enter the pilot plant system. This way, no biological treatment has happened, yet large sized particles and objects have been removed which could disrupt the CMF treatment process at the pilot plant. Although treatment of raw sewage has attracted attention in the literature, the process faces severe issues with membrane fouling [14–16] and thus is not recommended by Logisticon. However, using the influent of the Infulene WWTP as input for the pilot plant with CMF can give insights into the removal/treatment efficiency of both sites. Furthermore, the Infulene WWTP discharges its effluent into the nearby Infulene river. Here, samples of the upstream and downstream locations of the discharge point can show the impact of the WWTP on the nearby Infulene stream. Finally, the WQ of the treated water from the pilot plant is of interest in order to be able to compare it to the WQ of the input and thus determine the treatment efficiency.

Due to the short duration of the project, the WQ at the treatment plant and in the river was only measured on one day. Furthermore, the water transport between the two treatment facilities poses a significant challenge due to the distance between the two locations. The transport is organised through a water truck which takes the water from the influent and effluent of the Infulene WWTP and brings it to the pilot plant location in Zimpeto. Due to this logistical challenge and the delays in making the pilot plant operational, only one pair of filtrations was performed.

Both batches of water were treated according to the procedures described in Section 3.1.2. The same settings of the pilot plant were applied to both the effluent and influent water along all three filtration cycles. However, differences could still occur along a filtration cycle or in between, which is why multiple samples were taken during the process. In a real application, the water of multiple filtration cycles would mix in a big tank before it is reused or discharged. Therefore, the full analysis including ICP and coliform tests will be applied to the mixed water of each batch, while the samples of the filtration cycles will be assessed with fewer parameters.

The sample codes were created according to the following structure:

Type of Water - Batch/Source - Filtration Cycle - Time

Table 3 presents an overview of all samples. All samples were taken on October 11, 2024.

Table 3: Sample locations and comments for different water sources

Sample Code	Location	Comments
TW	Tap Water from Zimpeto	Sampled at 18:17h
RW-U	Infulene River Upstream of Discharge Point	Sampled at 9:45h
RW-D	Infulene River Downstream of Discharge Point	Sampled at 9:55h
WW-IE	Wastewater from Infulene WWTP, Effluent	Sampled at 9:30
WW-IE-F1-5	Treated Water (Infulene Effluent), Filtration Cycle 1, 5 min	
WW-IE-F1-10	Treated Water (Infulene Effluent), Filtration Cycle 1, 10 min	
WW-IE-F1-15	Treated Water (Infulene Effluent), Filtration Cycle 1, 15 min	
WW-IE-F2-15	Treated Water (Infulene Effluent), Filtration Cycle 2, 15 min	
WW-IE-F3-15	Treated Water (Infulene Effluent), Filtration Cycle 3, 15 min	
WW-IE-FM	Treated Water (Infulene Effluent), Fully Mixed	
WW-IE-FF-5	Second Filtration for treated Water (Infulene Effluent), 5 min	
WW-IE-FF-10	Second Filtration for treated Water (Infulene Effluent), 10 min	
WW-II	Wastewater from Infulene WWTP, Influent	Sampled at 13:15
WW-II-F1-5	Treated Water (Infulene Influent), Filtration Cycle 1, 5 min	
WW-II-F1-10	Treated Water (Infulene Influent), Filtration Cycle 1, 10 min	
WW-II-F1-15	Treated Water (Infulene Influent), Filtration Cycle 1, 15 min	
WW-II-F2-15	Treated Water (Infulene Influent), Filtration Cycle 2, 15 min	
WW-II-F3-15	Treated Water (Infulene Influent), Filtration Cycle 3, 15 min	
WW-II-FM	Treated Water (Infulene Influent), Fully Mixed	

3.2.2 Water Quality Requirements and Standards

As discussed in Section 1, it has been found that potential users of the reclaimed wastewater could be concrete producers, cooling for the central power plant, car washes, and watering of municipal parks. Additionally, farmers in the vicinity of the WWTP are currently using the effluent for irrigation. Therefore, water quality standards and requirements were researched in the available literature for these use cases.

Concrete Production

The standards for concrete production were retrieved from Reddy Babu et al. (2018) [17], Gulamussen at al. (2021) [7] and Fausta (2016) [13]. The latter was a study conducted in the city of Maputo as an earlier stage of this project in 2016, therefore several reference values were taken from this work. This research also shows extensive tables of requirements with more than 45 parameters and their respective thresholds. However due to time constraints and available facilities not all of them can be measured. Therefore a selection of these parameters was made, aiming to include several general WQ aspects, such as pH, COD, E. Coli, dissolved and suspended Solids and heavy metals. A comparison was done with the reference thresholds found in Gulamussen at al. (2021) [7], since this research is also directly linked to this project. All the above mentioned values are relevant because they can affect several characteristics of concrete, including deterioration, extended or accelerated settling time, hydration, long term strength, efflorescence, expansion and subsequent cracking. These characteristics might undermine concrete quality and therefore the stability of structures made with such concrete. The values selection and their relative thresholds are listed in Table 4.

Table 4: Water quality thresholds for concrete production (n.s.=not specified)

Parameter	**Threshold**	
	Fausta (2016)	*Gulamussen et al. (2021)*
pH	6.5 - 8.0	6.5 - 8.5
E. Coli	1000 CFU/100 mL	n.s.
TDS	100 mg/L	2000 mg/L (Total Solids)
TSS	67 mg/L	n.s.
COD	664 mg/L	500 mg/L
SO4	150 mg/L	2000 mg/L
NO3	10 mg/L	500 mg/L
NH3-N	n.s.	No limit
NH4	5.8 mg/L	n.s.
Pb	0.3 mg/L	n.s.
Zn	0.1 mg/L	n.s.
Cl	No limit for non-reinforced concrete	1000 mg/L
Color	Pale yellow or paler	Colorless or pale yellow
Odor	No smell except potable water	Odorless or similar to potable water

Industrial cooling

The standards for industrial cooling were retrieved from Magara (2009), a research supported by the UNESCO [18], the International Organization for Standardization (ISO) [19] and the Maputo Thermal Power Plant (CTM) [20]. From the table below it can be seen how several parameters overlap with the parameters for concrete production, and others differ. For industrial purposes the presence of Fe, Cu and Free CO_2 can lead to pipes corrosion, therefore making them relevant parameters to measure. Another factor to take into account is scale generation, which happens when a metal precipitates and attaches to the edges of a pipe. For this, heavy metals such as Fe and Cu are again critical. Therefore testing their presence in water gains high importance. The threshold values for certain parameters are highly dependent on the specific application, thus high differences in acceptable quality exists. Furthermore, a distinction is often made between circulation and make-up water, while the latter has stricter requirements since this water is added to the system to account for water losses [18]. For this project it is of strong relevance to meet the thresholds given by the CMT, as they would be one of the potential users of the reclaimed wastewater. Furthermore, values for make-up water are included from literature since compliance with the stricter values would mean full suitability. A list of several important parameters and their thresholds is presented below in table 5.

Table 5: Water quality standards for industrial cooling (n.s.=not specified)

Parameter	**Threshold**		
	Magara (2009)	*ISO (2020)*	*CTM (2020)*
pH	6.5 - 8.0	6.5 - 9	7.73
EC	800 μS/cm	3000 μS/cm	523 μS/cm
E. Coli	1000 CFU/100 mL	200 CFU/100ml	n.s.
TDS	n.s.	5000 mg/L	371 mg/L
TSS	n.s.	10 mg/L	10 mg/L (assumed)
Turbidity	n.s.	n.s.	3.1 NTU
Total Hardness	200 mgCaCO3/L	250 mgCaCO3/L	136 mgCaCO3/L
SO4	200 mg/L	800 mg/L	2000 mg/L
SiO2	50 mg/L	n.s.	11 mg/L (assumed)
NO3	10 mg/L	n.s.	500 mg/L
NH3	n.s.	1 mg/L	No limit
Fe	0.3 mg/L	0.3 mg/L	n.s.
Cu	0.1 mg/L	n.s.	n.s.
Cl	50 mg/L	300 mg/L	86 mg/L
Na	50 mg/L	n.s.	59 mg/L
Mg	n.s.	n.s.	19 mg/L
CO2	4 mg/L (free)	n.s.	5.2 mg/L

Agriculture

The standards for irrigation water quality standards were found in different sources, namely the UN's Food and Agriculture Organization, South Africa Water Quality Guidelines, and the Colorado State University [21–23]. Water quality is an important parameter in irrigation, since it affects several aspects: plant and human health, crop yield and environmental factors such as pollution and biodiversity. For these parameters it is challenging to derive only one threshold, as these can vary depending on the crop type and the soil type. Regardless of that, there are some key parameters that can cause several issues: (heavy) metals are a big cause of health problems for consumers, while bacteria such as E. Coli and microorganisms can greatly affect farmers that are exposed or in contact with the water. Another relevant factor is water salinity, since not all crops are suited to grow with brackish water. The water pH has an indirect effect on crops and a direct effect on the soil, which has a high ability to buffer against the extreme pH of the water. On the long term however, this can alter the soil ecosystem and has large impact on crops growth. Direct contact with highly basic or acidic water can damage crops and/or their marketable products. A list of some relevant parameters and their thresholds are presented in Table 6. The numbers used in this table represent the values when a low level of hazard is acceptable.

Table 6: Water quality standards for agriculture (n.s.=not specified, *=value varies with crop type)

Parameter	**Threshold**		
	FAO (2023)	*South Africa water quality guidelines (1996)*	*Colorado State University (2014)*
pH	n.s.	6.5-8.4	6.5-8.4
EC	3000 μS/cm	400 μS/cm	1500 μS/cm
SAR	9	2	n.s.
N (inorganic)	30 mg/L	5 mg/L	n.s.
HCO3	8.5 meq/L	n.s.	n.s.
TDS	2000 mg/L	n.s.	n.s.
Fecal coliforms	1000 CFU/100mL	1000 CFU/100mL	n.s.
Al	5 mg/L	5 mg/L	n.s.
As	n.s.	0.1	n.s.
B	n.s.	n.s.	0.76-6 mg/L*
Be	0.1 mg/L	0.1 mg/L	n.s.
Cd	n.s.	0.01 mg/L	n.s.
Cl	85 mg/L	100 mg/L	175-700 mg/L*
Co	0.05 mg/L	0.05 mg/L	n.s.
Cr	0.1 mg/L	0.1 mg/L	n.s.
Cu	0.2 mg/L	0.2 mg/L	n.s.
Fe	5 mg/L	5 mg/L	n.s.
Li	2.5 mg/L	2.5 mg/L	n.s.
Mn	0.2 mg/L	0.2 mg/L	n.s.
Na	69 mg/L	70 mg/L	46-460 mg/L*
Ni	0.2 mg/L	0.2 mg/L	n.s.
Pb	n.s.	0.2 mg/L	n.s.
Se	0.02 mg/L	0.02 mg/L	n.s.
U	n.s.	0.1 mg/L	n.s.
V	n.s.	0.1 mg/L	n.s.
Zn	2.0 mg/L	1.0 mg/L	n.s.

Small-scale applications

Car washes were also considered as a potential use case for reclaimed water. Mozambique currently does not have a water quality standard for car washing, nor do many other countries or international bodies. As such, the standards presented in Table 7 are for non-potable industrial applications with high human contact. Standards were taken from South Africa, Malaysia, and Australia [24–26]. The car-washing process is not very sensitive, so the standards do not generally correspond to process conditions as is the case for cooling water or concrete. Rather, they are meant to ensure the safety of the workers who will come into close contact with the water. As such, the most stringent requirements are on E. Coli and BOD. In addition to these requirements, the water must be aesthetically pleasing so as not to drive away customers. Therefore, it must have acceptable colour and odour.

Additionally, the watering of city parks by the municipality of Maputo was considered as a potential use case. For this application, the guidelines for agriculture in Table 6 were used for the most part, as there are similar concerns regarding soil health. However, the stricter requirement for E. Coli in Table 7 was considered in this case since a larger group of people would be exposed to the water in this scenario, thus posing a larger public health risk. The aesthetic requirements mentioned above also apply to this use case.

Table 7: Water quality standards for car washes and park watering (n.s. = not specified

Parameter	**Threshold**		
	Western Australia water reuse guidelines (2024)	*Malaysia water reuse standards (1996)*	*South Africa water quality guidelines (1996)*
pH	6.5 - 8.5	6.0 - 9.0	5.0 - 10.0
BOD	10 mg/L	10 mg/L	n.s.
E. Coli	1 CFU/100mL	b.d.l. for 100 mL sample	n.s.
TSS	n.s.	n.s.	25 mg/L
EC	n.s.	n.s.	2500 uS/cm
Turbidity	2 NTU	5 NTU	n.s.
NH4-N	n.s.	10 mg/L	n.s.
Cl	n.s.	>1 mg/L	500 mg/L
Hardness	n.s.	n.s.	1200 mg CaCO3/L
Fe	n.s.	n.s.	10 mg/L
Mn	n.s.	n.s.	10 mg/L
SO4	n.s.	n.s.	500 mg/L

3.2.3 Lab Measurements and Methods

The water from the sample location described in Section 3.2.1 were sampled with multiple 250 mL glass vials per location to ensure sufficient water quantity for the laboratory tests. The relevant parameters for the use cases were tested at different laboratories due to availability of equipment and materials. In total, three facilities were used; the lab at Infulene WWTP, the lab at the Faculty of Chemical Engineering and the Faculty of Chemistry at UEM. The following list gives an overview of what parameters were measured and in which lab.

Infulene WWTP Lab	**Faculty of Chemical Engineering**	**Faculty of Chemistry**
pH	Total Coliforms	Na
EC	E. Coli	Cl
Salinity	TSS	Mn
TDS		Al
COD		As
BOD		Pb
Turbidity		Fe
Nitrate (NO3)		Cu
Nitrite (NO2)		Ca
Dissolved Oxygen (DO)		Mg
Redox potential		Zn
Resistivity		Sulphates (SO4)
		Alkalinity
		TSS

Laboratory at Infulene WWTP

The parameters pH, EC, salinity, TDS, DO, redox potential and resistivity were measured with the WTW Multi 3630 IDS meter, which had three sensors connected. The WTW TetraCon 925 sensor measures EC, resistivity, salinity as well as TDS and is based on a four electrode measurement principle. The WTW SenTix 940 sensor measures pH and redoxpotential, whereas the WTW FDO 925 is an optical sensor to measure dissolved oxygen.

All sensors were calibrated before the use and placed into the sample water. After the measurement the sensors were cleaned with distilled water and a new beaker was used for the next sample.

The turbidity of the samples were measured with the WTW TURB 430 T meter, which is an optical method. The test vial was rinsed with distilled water before each new measurement.

For measuring NO_2, NO_3 and total COD the WTW photoLab 7600 UV-VIS spectrophotometer was used, which is based on an optical reagent-free analysis. The measuring ranges varied from 2.0 - 75.0 mg/L for COD, 0.1 - 4.0 mg/L for NO_2-N and 0.1 - 3.0 mg/L for NO_3-N. Depending on the quality of the water, the samples were diluted by a magnitude of 1:10.

Finally, the BOD measurements were conducted with the WTW OxiTop-i system. The device performs automatic measurements over a defined period. In total 250ml of water of the samples was filled into the bottles. Five drops of a nitrification inhibitor solution ($C_4H_8N_2S$) were added, while a magnet ensured mixing throughout the measurement duration, which was set to five days. Two pills of sodium hydroxide were added to a stopper at the top of the bottle before closing it off with the measurement device. The samples were placed in an incubator at 20°C for the set duration.

The same measurements are performed regularly by employees of the WWTP, following the same procedures. However, the results of these tests are recorded physically on paper and not digitized. A limited selection of papers was provided by the operators of the WWTP, covering the WQ data from May 28, 2024 to September 19, 2024. All the samples measured for this report were collected on October 11, 2024. The provided time series was used to compare with the values obtained for this research.

Laboratory at Faculty of Chemical Engineering

The laboratory at the Faculty of Chemical Engineering provided the equipment and materials to test for total coliforms and E. Coli. Normally, the measurement requires 100ml of the sample, although dilution is required for very polluted water to ensure results being within measurement range.

In total, 10 samples were tested as duplicates, while all samples except the tap water were diluted in a ratio of 1:10 to guarantee results would be in measuring range. If results were out of range, tests were repeated with dilution ratios of 1:100, 1:1000, 1:10000 and 1:100000. After dilution, Colilert-18 substrate was added to indicate and detect E. Coli and coliforms in the sample. Next, the solution was poured into a testplate (Quanti-Tray) and sealed, which allows to read the results after incubation at 35°C for 18 hours. Yellow wells indicate total coliforms, while yellow/fluorescent wells under UV light signify E. Coli. The total positive wells can be summed up and compared to the most probable number (MPN) table to show the total concentration. Some samples gave measurements which were out of range, indicating that they needed to be redone. Unfortunately, civil unrest made it impossible to return to the lab and remove these samples from the incubator at the designated time. Afterwards, there was not sufficient time to repeat them again. These samples are indicated specially in the relevant plots.

Laboratory at Faculty of Chemistry

The total suspended solids (TSS), alkalinity and chloride concentration as well as inductively coupled plasma spectroscopy (ICP) for total metal concentrations were tested at the Faculty of Chemistry at UEM. It was intended to test sulphate concentration as well, but civil unrest and commpresed time frames made this impossible.

The samples which underwent ICP testing were not diluted, and were first filtered with TSS filtering paper, then with a 0.45 micron syringe filter. Samples which were not visually clear yet (river samples, influent and effluent of the Infulene WWTP, and all the IE filtration cycles) were filtered another time with the 0.45 micron filter to prevent larger particles from clogging the ICP machine. After the second filtration, 15 mL were withdrawn from each sample and analysed with an ICPE-9820 from SHIMADZU manufacturer, which is based on Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

The machine was calibrated on a range within 0.25 and 4 ppm. From the 15 ml vial, the sample is collected by the machine which nebulizes it into aerosol and then transports it to the plasma chamber with Ar gas as a carrier. Subsequently a radio frequency (RF) field is applied on the Ar gas which is then passed through a torch, creating a plasma which can reach up to 10000 degrees K. Here the sample undergoes atomization and excitation. This makes it emit light which is separated by the spectrometer according to the wavelength, which are then simultaneously detected by the CCD. The intensity of a wavelength is then returned as a concentration of a certain element present in the sample.

For each element, several wavelengths are measured, which were determined through previous testing. Three measurements are taken using each wavelength. In general, a reference sample is used which has known concentrations of each relevant element. This allows the most representative wavelength to be selected for each element. Hoewever, no such reference sample was available at the time the testing was performed, so it was impossible to determine which wavelength performed best. Thus, the results for all wavelengths were averaged together. Measurements which were too far above the calibration range gave errors and were ignored. Measurements which were below the detection range were treated as zero. All measurements outside the calibration range (0.25 - 4 ppm) are generated by extrapolation within the machine software and are thus subject to higher error than measurements within the calibration range.

Alkalinity and chlorides were both measured using titration. For the chlorides, a 20 mL sample was measured, to which 1mL of potassium chromate was added as an indicator. A 0.05M solution of silver nitrate was then added in small steps until the color changed from yellow to red, which indicates that all of the chloride present in the sample has indicated to form silver chloride. The chloride content is then calculated using Equation 5, where V_{AgNO_3} is the volume of silver nitrate added, V_{blank} is the volume added to a blank sample of tap water, and C_{AgNO_3} is the concentration of the silver nitrate solution.

$$[Cl^-] = \frac{(V_{AgNO_3} - V_{blank}) \cdot C_{AgNO_3} \cdot M_{Cl^-}}{V_{sample}} \tag{5}$$

Alkalinity was also measured using a 20 mL sample, which was first checked with test strips to ensure that the pH was between 7 and 10. Then, three drops of phenolphthalein were added as an indicator. A 0.027 M solution of sulfuric acid was then added until the color changed from pink to grey. The volume of acid added to this point indicates the phenolphthalein alkalinity. Afterwards, three drops of methyl orange were added and titration continued until the color changed from blue to pink. The total amount of acid was used to calculate the total alkalinity. Both alkalinities were calculated using Equation 6 and the respective volumes.

$$Alkalinity = \frac{V_{H_2SO_4} \cdot C_{H_2SO_4} \cdot M_{CaCO_3}}{V_{sample}} \tag{6}$$

TSS was also measured in the same lab. This was performed by first drying Double Rings 102 paper filters, which are approximately equivalent in filtering capacity to Whatman Grade 1 filters [27], for 2 hours at 105°C. When the filters were removed from the oven, they immediately began picking up moisture from the air, causing an increase in mass to be measured by the analytical balance. Thus, a constant waiting time of 30 minutes was used before measuring each filter. After the dry weight was recorded, 100 mL of each sample was allowed to drain through the filter by gravity. Once all of the water had passed through, the filter was again dried for two hours and re-weighed. The increase in filter mass then corresponds to the suspended solids in 100 mL of water.

Calculated Parameters

Several WQ parameters were also calculated using the results of the tests above. Sodium Adsorption Ratio (SAR) is an important measure for irrigation water, indicating how much of the soil cation exchange capacity will be occupied by sodium ions. Excessive SAR damage crop yield and quality, as well as affect reduce soil permeability. SAR is calculated using Equation 7 with concentrations in mmol/L [24]. Additionally, bicarbonate concentration (in meq/L) is calculated using Equation 8, where P is the phenolphthalein alkalinity, T is the total alkalinity, and M_{CaCO_3} is the molar mass of bicarbonate [28]. Total hardness is calculated using Equation 9 with concentrations in mg/L. The results for NO_2-N and NO_3-N measurements have to be converted to NO_2 and NO_3 concentrations [mg/L] with equations 10 and 11 respectively.

$$SAR = \frac{[Na^+]}{\sqrt{[Ca^{2+}] + [Mg^{2+}]}} \tag{7}$$

$$HCO_3^- = \frac{T - 2P}{M_{HCO_3^-}} \tag{8}$$

$$Hardness = \frac{M_{CaCO_3}}{M_{Ca^{2+}}} \cdot [Ca^{2+}] + \frac{M_{CaCO_3}}{M_{Mg^{2+}}} \cdot [Mg^{2+}] \tag{9}$$

$$\mathrm{NO_2} = \mathrm{NO_2\text{-}N} \times \frac{\text{Molar mass of } \mathrm{NO_2}}{\text{Molar mass of N}} \tag{10}$$

$$NO_3 = NO_3\text{-N} \times \frac{\text{Molar mass of } NO_3}{\text{Molar mass of N}} \tag{11}$$

3.3 Stakeholder Analysis

The stakeholder analysis aimed to identify organizations that could be involved in the implementation of a reclaimed wastewater system using CMF technology in Maputo, as well as to understand their perspectives on the feasibility of the project. Furthermore, the stakeholder analysis was used to obtain data from water suppliers and potential consumers, which could be used in the water balance and financial feasibility assessment.

Stakeholders were identified through reports, websites, and consultations with professionals at the Centro de Estudos Industriais, Segurança e Ambiente (CEISA) of Eduardo Mondlane University in Maputo, resulting in a list of relevant organizations. Subsequently, questionnaires were developed, and invitation letters, translated into Portuguese by professionals at CEISA, were sent to the identified stakeholders to request interviews. Based on the roles of the stakeholders in the potential implementation of a reclaimed wastewater system, and the specific questions addressed in the interviews, the stakeholders were grouped into the following categories: experts in the water management sector, organizations overseeing funding and development of water projects, and non-domestic water consumers.

In accordance with the requirements of TU Delft's Human Research Ethics Committee (HREC), all interview participants were kept fully anonymous. As such, no personally identifying data was recorded. Additionally, findings are attributed to categories of stakeholders rather than particular organizations where possible, to avoid the possibility that any interviewees can be identified. Furthermore, no recordings were taken of the interviews and no word-for-word transcripts were recorded. Instead, hand-written notes were taken at each interview. To comply with HREC requirements, these notes are not reproduced in this report.

3.3.1 Experts in the Water Management Sector

Experts in the water management sector were considered to be professionals involved in research and consultation of water management projects in Maputo. The aim of meeting with such professionals was to obtain a clearer overview of other stakeholders that might be involved and impacted by a reclaimed wastewater system, and to understand the different conditions interested parties – information which may be used to guide the strategy of the financial feasibility assessment. One such question was the interest of farmers to use reclaimed wastewater, and if so, under what conditions. Furthermore, another question was whether there are possibilities for the government to use subsidies to cover the production costs of the reclaimed wastewater.

3.3.2 Funding and Development of Water Projects

The goal with these interviews was to understand the interest in reclaimed wastewater by organizations responsible for fundraising and project development of water infrastructure. The organizations of interest to interview were Administração de Infra-Estruturas de Águas e Saneamento (AIAS) and Fundo de Investimento e Património do Abastecimento de Água (FIPAG). AIAS is the governmental agency responsible for raising funds for water sanitation and overseeing water sanitation projects and assets in urban areas and towns across Mozambique. On the other hand, FIPAG is a fundraiser, asset holder and asset holder for water supply in large urban centers of the country.

It was also desired to interview the Direcção Nacional de Abastecimento de Água e Saneamento (DNAAS). This is the organization within the government which is responsible for establishing regulations and policies for both urban and rural water supply and sanitaion, and for investment planning and implementation through the provincial and district governments. They had the responsibility of the project coordination, planning and monitoring of the upgrade done to the Infulene WWTP finalized in 2024 [29]. Unfortunately, it proved impossible to schedule a meeting with any representatives of the organization despite repeated requests.

3.3.3 Operation and Maintenance of the Infulene Wastewater Treatment Plan

The current organization responsible for operating and maintaining the Infulene WWTP is Empresa de Saneamento e Drenagem de Maputo (ESDM). ESDM is a sub-organization of the Municipality of Maputo, specifically tasked with the responsibility of the Infulene WWTP. The organization was of interest to interview, to get insight into their capacity and willingness to manage an additional treatment system utilizing CMF.

3.3.4 Non-domestic Water Consumers

Organizations that were of interest were those involved in the potential use cases for the reclaimed wastewater: industrial cooling, concrete production, car washing, and watering of public spaces.

For the car wash use case, multiple car wash businesses across Maputo were asked for short interviews. The businesses were identified using Google Maps. Then, the businesses were visited, accompanied by a translator, to ask if they would be willing to partake in a short interview. The focus of the questionnaire was on the amount of water they consume, the price they pay for the water, and their water quality standards. Furthermore, another focus point was and their willingness to use reclaimed wastewater, and under what conditions, such if the water was supplied by trucks.

The Maputo municipality was interviewed regarding the use of water for irrigating public spaces, as they are the organization responsible for this task. The questionnaire sought to gather information on their water consumption, associated costs, and water sources. Additionally, it focused on the municipality's water transport methods to assess whether these could be effectively integrated with the production and supply of reclaimed wastewater.

The organizations reached out to for industrial cooling were the Central Thermal Power plant and the Central Bank of Mozambique. As mentioned in subsection 3.2.2, "Water Quality Requirements and Standards", quality standards for industrial cooling varies based on the specific application. Therefore, along with the quantities of water consumption and price, it was important to receive information from the Central Thermal Power Plant and the Central Bank of Mozambique on the required quality standards for their applications, which was an additional focus-point of these questionnaires.

Research on the water consumption of concrete producers and their willingness to use reclaimed wastewater had already been conducted by Fausta [13]. Since the findings from that research were deemed still relevant, no further interviews were conducted with concrete producers. Instead, Fausta's results were used to draw conclusions about their willingness to adopt reclaimed wastewater, their water consumption volumes, and the prices they pay.

3.4 Water Balance

The improvements around the Infulene WWTP changed not only the treatment capacity of the facility, but also inflows and outflows from the site. Before the construction works, connections between ponds as well as the general outflow were clogged and design flows were not reached. Besides that, farmers would pump water from the ponds to irrigate their fields [6].

With the expansion of the WWTP, the general area has been fenced off, treatment ponds have been repaired, and new connections have been installed. It is assumed that the facility works with designed flows and capacity as well as that surrounding farmers do not have access to the water and fully depend on the water from the river.

The water balance will assess the situation at the discharge point of the Infulene WWTP into the Infulene river. The main focus of the analysis is to calculate the amount of water remaining in the stream for farmers to use downstream of the Infulene WWTP. Depending on the irrigation demand of these farmers, more or less water will be available from the effluent for reuse. Furthermore, the inflows and outflows of the Infulene WWTP will be compared for assessing water losses in the system and availability of water for secnodary treatment. The scheme in Figure 10 indicates the different flows in the water balance, while the map shows the actual location.

Data
The required data for the water balance consists of:

- Inflow and Outflow Data of the Infulene WWTP
- Discharge Data of the Infulene River
- Precipitation
- Potential Evaporation
- Water Demand for the different Use Cases

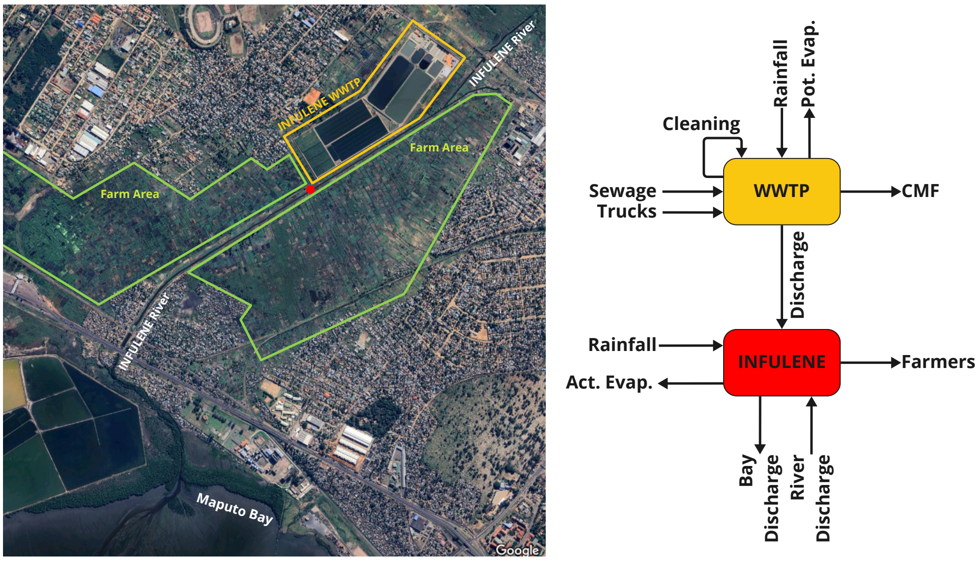

Figure 10: Targeted areas (left) and water balance overview (right)

3.4.1 Inflow of Infulene WWTP

The influent into the Infulene WWTP consists of sewage water piped directly from the network, as well as sewage water transported by water trucks. Together this water is screened, where solids are removed before the water flows into the first treatment step: the anaerobic ponds. This flow is monitored by a flow meter, however this measurement is only instantaneous and is not recorded over time. Consequently, a time series with measurements cannot be used for the water balance. Instead, calculated average flows will be used. The Empresa Municipal de Sanamento e Drenagem de Maputo (EMSD) provided inflow values based on canal widths and volumes, as well as water levels. The average daily inflow amounts to 1320 m^3/day. Additionally, an average of 550 m^3/day comes into the system from the sewage trucks, which can deliver around 3.5 m^3 each. This results in a total average inflow of 1870 m^3/day, while the maximum inflow capacity of the facility is 11718 m^3/day. Currently, on average the Infulene WWTP runs on 16 percent of its maximum design capacity. An expected estimation for a future inflow rate under normal conditions is 2800 m^3/d, according to the EMSD. In the expansion plan for the Infulene WWTP [29], different scenarios were presented for future inflow values. According to the report, 4533 m^3/d can be expected by 2030, while in 2040 the facility is almost running at maximum capacity with 9561 m^3 of daily inflow.

Only one average value was provided by the EMSD for the inflow into the WWTP. In order to get a proper overview of dynamics of the flows in the system throughout the year, it is necessary to determine how much the inflow into the plant variates on a seasonal basis. On the one hand, it seems safe to assume that domestic water usage is unlikely to vary significantly throughout the year. However, since it is a combined sewage system, yearly variations in precipitation may cause variations in the influent of the plant. The variability of the influent was assessed using a time series of discharges in a drainage canal located in the vicinity of the WWTP. The measurement coordinates are (-25.941, 32.570).

3.4.2 Outflow of Infulene WWTP

Similarly to the inflow into the Infulene WWTP, there is no historic data of the outflow. After treatment, the water is discharged directly into the Infulene river. From visual observations during multiple facility visits and sampling in the river, the discharge was relatively small compared to the river discharge. Again, EMSD provided an average discharge value for the current situation, where 1556 m^3/day of treated water flows into the Infulene river. This flow is reportedly constant throughout the day.

In the improved future scenario, a total daily average discharge of 2486 m^3/d can be expected. The outflow should be lower than the inflow, considering evaporation losses and water which is taken after treatment for reuse within the plant (for example for cleaning). In theory, the water losses under normal conditions and in the future scenario should be the same under the assumptions that the demand for cleaning water stays constant and ponds do not dry up, so that potential evaporation rates are always reached. Another important assumption here is that evaporation and precipitation rates will remain relatively constant in the near future.

3.4.3 Discharge Data of Infulene River

Data on the daily discharge of the Infulene river can give an insight into how much water farmers have available for irrigation in the Infulene valley. The main purpose of this data for the water balance is to estimate whether the river dries out at any point throughout the year, so that farmers become dependent on the discharge of the WWTP for irrigation supply.

Because of a lack of measurements, estimating the discharge of the Infulene river at the location of the treatment turned out to be quite a challenging task. Despite repeated enquiries to numerous agencies and experts, the only indications that could be obtained were a range of 0.2 to 7 m^3/s under normal flow conditions [30], and a time series of water levels provided by an employee of the Administração Regional de Águas do Sul (ARA-Sul) to estimate the fluctuations of discharge levels in the river throughout the year. These water levels were measured 8 km upstream of the WWTP, nearby the psychiatric hospital (coordinates: -25.862, 32.561). The lowest and highest possible flows (0.02 and 7 m^3/second) were matched to the lowest and highest "normal" water levels (0.19 m and 0.97 m) respectively. Then, the relationship of water levels and discharge was assumed linear within this range, in order to interpolate the discharges on each day for which a water level measurement was available. More details and illustrations of this analysis can be found in Annex B. Using this method, the average river discharge was estimated to be around 171 000 m^3/day, with a lowest "normal" flow of 17280 m^3/day.

3.4.4 Precipitation

Precipitation data in the water balance is used to identify how much water enters the WWTP through direct rainfall onto its surface area. It is also considered as an inflow into the river through run-off on the targeted agricultural area along the river (see Figure 10). In Mozambique, the Instituto Nacional de Meteorologia (INAM) operates weather stations throughout the country. They measure daily precipitation with rain gauges and have a record of over 50 years. For this water balance, the monthly precipitation sums from the last 10 years from a weather station in Maputo will be used. In order to assess the accuracy and credibility of the data from INAM, a dataset from CHIRPS, which spans globally over 35 years and combines rain gauge and satellite data, will be used for comparison. The monthly precipitation data of both datasets from 2013 to 2023 is visualized in the diagram below.

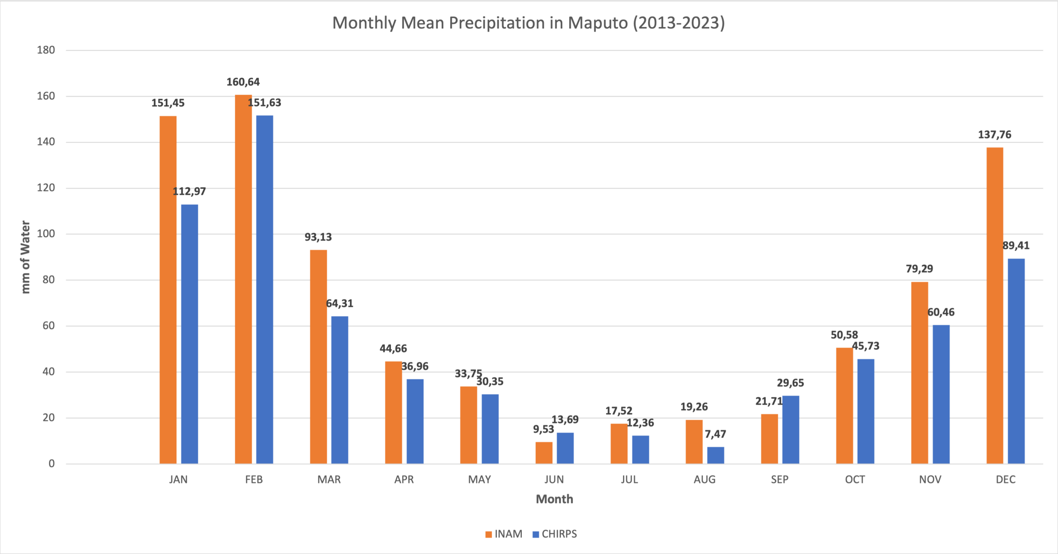

Figure 11: Comparison between Remote Sensing Data (CHIRPS) and Meteorological Data (EMSD)

The bar diagram above shows similar precipitation patterns throughout the year. The total average precipitation difference between both datasets amounts to 157mm, where INAM consistently recorded more precipitation except in the month of June. In the wet period from December to February, the difference is more significant, where discrepancies range from 28 to 48mm per month. The drier months (May to September) show less inconsistencies, which only range from 4 to 11mm per month.

3.4.5 Actual and Potential Evaporation

The Infulene WWTP operates with open surface ponds, which include anaerobic, facultative and maturation ponds as well as storage ponds for cleaning. These treatment steps cover substantial surface areas, where evaporation rates become significant for water losses in the system. In particular, the ponds have sufficient amounts of water for continuous evaporation, so that potential evaporation rates will be reached. This is significant for the water balance since actual evaporation is usually lower compared to potential rates. The weather station from INAM in Maputo records only actual evaporation, which cannot be used for the water balance inside the Infulene WWTP. Other parameters like net radiation, vapour pressure or temperature are also recorded and could be used with the Penman-Monteith equation to calculate the potential evaporation. Due to difficulties with the data acquisition from INAM, this approach was not feasible for the limited project duration. Instead, data from the satellite remote sensing application, MODIS16 was used. In the following graph, monthly potential and actual evaporation is shown. The actual evaporation rates were used for estimating the amount of water which evaporates on the farmland downstream of the Infulene WWTP.

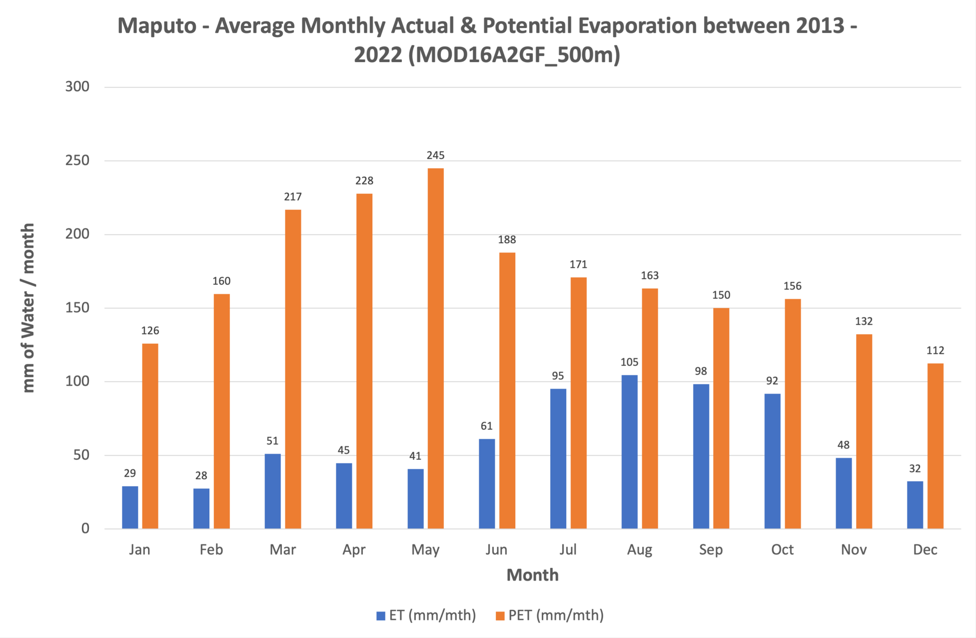

Figure 12: Actual and Potential Monthly Average Evaporation from MODIS16

3.4.6 Water Demand for Use Cases

The use cases which are suitable for water reuse and are considered in this study are; cooling water for a nearby power plant, concrete production, car wash businesses and the municipality of Maputo. Based on the results from the stakeholder analysis and the interviews of concrete producers conducted by N. Fausta, the water demands for all these use cases was estimated and used in the combination with the water balance analysis to assess the supply capacity of the WWTP.

The water demand for concrete production was calculated based on the findings of the interviews conducted by Fausta in 2016 [13]. She interviewed 11 companies, from which 10 were open towards the possibility of using reclaimed wastewater. The monthly water demand of those companies was used for the water balance, since they previously stated interest. Additional surveys and interviews were initially considered to estimate current water usages and interest, but were ultimately neglected due to other priorities during the short duration of the project. The final monthly water demand for the calculation amounted to 7720 m^3 with a standard deviation of 1970 m^3. Since the research was conducted years ago and water demands could have changed in the meantime, the upper limit of the standard deviation was added towards the total water demand in order to account for the time deviation.

3.5 Financial Feasibility Assessment

3.5.1 General description of the assessment method

The financial feasibility of this project was assessed by making an inventory of all the internal costs associated with the upscaling of the treatment technology and distribution of the reclaimed wastewater. The criteria used to assess the feasibility of this project is that the reselling price of the reclaimed wastewater should cover all the associated costs and be more affordable than the price currently paid by each end user for their water supply.

The costs comprise capital costs, operational costs and supply costs. Capital costs include all the investment costs that cover the building of a facility, such as land acquisition, machinery, construction workers and building materials. Operational costs comprise the costs of maintaining a facility, such as employees, energy supply and maintenance materials. Finally, supply costs are made up of the capital and operational costs of the required facilities and services for the distribution of the reclaimed wastewater to the end users.

For this case study, a life cycle of the proposed membrane of system of 20 years was considered, which is a common duration to use for membrane system in the existing literature [31–34]. The costs were thus evaluated over the span of this period.

3.5.2 Description of the costs

The costs considered relevant for this application of the framework are capital costs, operational costs and supply costs. Regarding the revenue, only the selling price of reclaimed water was considered. This is summarized in Table 8. This section provides more details on the types of costs and what they include.

Table 8: List of considered costs and revenues

Costs	**Revenue**
Capital costs Operational costs Supply costs	Reclaimed water selling price

Capital costs
Membrane technologies vary significantly in both price and treatment efficiency, making it difficult to identify the most suitable system for this water treatment application [35]. In addition, scientific literature often separates the cost of membranes from other system components, such as pipes, pumps, and valves. The cost of these components are often based on cost data from existing membrane systems in the country of origin of the research [36, 37]. However, for the case of Mozambique, data on the costs of such components is not easily available. Therefore, it was decided to use cost values for an all-in-one membrane treatment system, as it could provide comprehensive reference values. To establish reference values for capital and operational costs, a membrane system with the same characteristics as the pilot plant and from the same supplier was selected. The exact capacity of the system was determined based on the results of the water balance and stakeholder analysis.

An inquiry for a comprehensive price for a Logisticon membrane system container, shipment to Mozambique, and training of local staff was made. These costs were considered to be capital costs, as shown in Table 9. Logisticon's membrane systems are housed in containers designed for easy connection to external piping and ready for operation.

Additionally, information was gathered on the land area required for the container, and the cost of purchasing and installing concrete slabs for foundation. Information on land acquisition costs was found from the Sanitation and Drainage Master Plan for the Greater Maputo Metropolitan Area (SDMP) [38]. The concrete slab costs were calculated from the construction bill for the upgrade of the Infulene wastewater treatment plant. The price for concrete and construction of the concrete slabs was assumed to change linearly with surface area, so that the "$price - per - m^2$" rate could be used to calculate the concrete price for the surface area of the container.

Operational and Maintenance cost
For estimating operational and maintenance (O&M) costs, reference values were obtained through consultation

Table 9: Capital costs and their respective sources.

Capital costs	**Source**
Logisticon full system container	Consultation with Logisticon
Shipment of Logisticon container	Consultation with Logisticon
Training of local staff	Consultation with Logisticon
Supply and installation of concrete slabs	Infulene WWTP construction bill
Land acquisition	SDMP [38]
Pipe installation (only second scenario)	Own research and reference values provided by Prof. Nelson Matsinhe

with Logisticon, and by finding specific costs for Maputo in governmental reports. Reference values for the price of spare Logisticon system parts were obtained, as well as the power consumption of a container with the maximum treatment capacity considered. Furthermore, a reference price of electricity in Maputo was found from the SDMP [38]. Using the electricity consumption of the Logisticon container together with the Maputo electricity costs gave the cost of powering the Logisticon container. The salary for staff members was also taken from the SDMP, using the cost estimate for an Electromechanical Technician from this report [38].

Table 10: Operational and maintenance costs and their respective sources.

Operational and maintenance costs	**Source**
Logisticon system spare parts	Consultation with Logisticon
Logisticon system power consumption	Consultation with Logisticon and SDMP [38]
Staff cost	SDMP [38]
Maintenance and cleaning reagents	Consultation with Logisticon

Supply costs

Besides the capital and O&M costs which can be summarised into "Total production cost", water supply costs were also evaluated to assess the full internal costs present for upscaling the CMF technology. Here, two supply scenarios are outlined:

1. Water truck transport: includes the operational cost of paying the private water truck companies for delivering the reclaimed wastewater, or the combination of capital and operational cost of owning a fleet of water trucks which would deliver wastewater to the end users.
2. Pipeline transport: involves both the capital cost for installing the pipelines and operational expenses for system maintenance and operation.

Both scenarios include capital and O&M costs. For scenario 1, in the case of owning a fleet of water trucks the capital cost would be the cost of the trucks, while the O&M cost would include fuel price and employees salaries. In the case of using water trucks from a third party company, the only cost would be the cost of paying the company on a m^3 basis.

For scenario 2, considering the transport of the reclaimed wastewater by pipes, a final capital cost was calculated concerning the installation of the pipe system. The price of purchasing and installing piping was calculated based on an estimation provided by Prof. Nelson Matsinhe. Additional O&M costs were included to account for the power consumption of pumps and the maintenance of the infrastructure. Reference values for these elements were obtained from various online resources.

Table 11: Supply costs and their respective sources

Supply costs - Scenario 1	**Source**
1.1 - Owned truck fleet	Based on method from literature [13]; Prof. Nelson Matsinhe
1.1 - Fuel and employees salaries	Own observation; [39]
1.2 - Third party company fee	Prof. Nelson Matsinhe
Supply costs - Scenario 2	**Source**
Piping supply and installation cost	Prof. Nelson Matsinhe
Piping O&M cost (pumping, repair, etc.)	[38];

4 Results

4.1 Pilot Plant

The recovery rate over the duration of the filtration cycle is shown in Figure 13. The recovery rate for the effluent stayed approximately constant throughout the filtration at around 87%, although there was a gradual increase during the first filtration and a slight decrease after the forward flush. For the influent, on the other hand, there was a consistent increase in the recovery rate until it reached 100% during the third filtration. This indicates for a brief period, all of the water was passing directly through the membrane pores, and the system was thus operating essentially as a dead-end filter. When this was noticed, Valve V-217 was momentarily opened to 100% and then returned to its operating state of 20%. When this was done, the recovery rate returned to around 73%, where it was at the beginning of filtration, and then resumed its gradual increase.

This indicates that some sludge or large particles were likely building up on the valve until the entire flow path was blocked. This is a possible explanation given that there is a constriction in the pipe near this valve and the raw influent had quite a lot of particles in it. This problem could potentially be avoided by having Valve V-217 more open for future filtrations, meaning a lower recovery rate would be achieved.

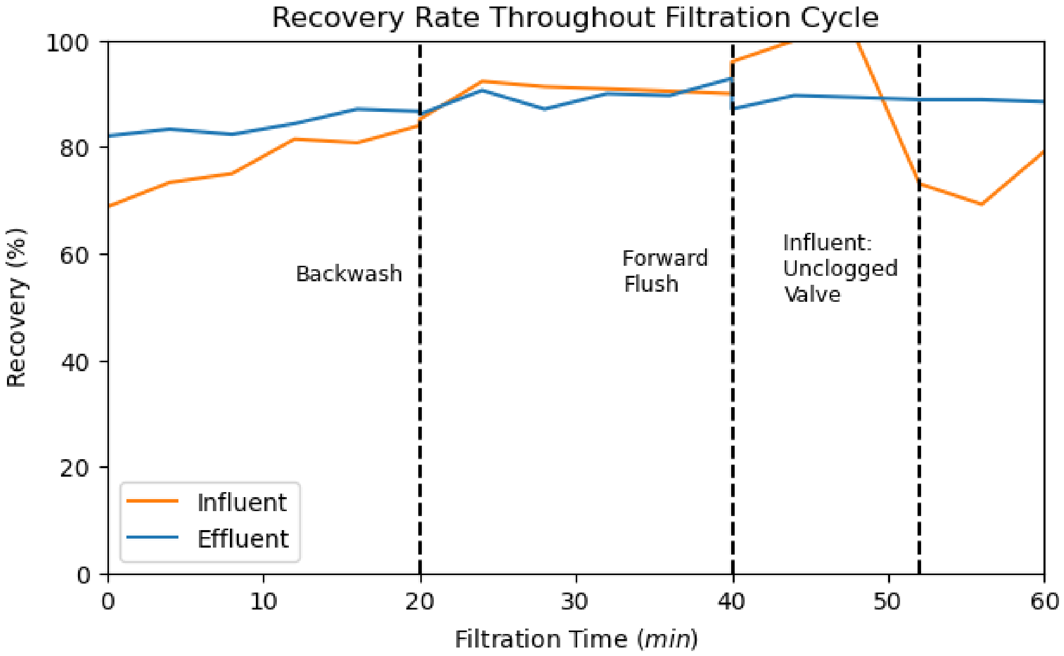

Figure 13: Recovery Rate During Filtration

The transmembrane pressure is shown in Figure 14. The TMP behaves as expected for the effluent, where it stays approximately constant throughout the process. Since the permeate flow is not high enough to result in a pressure on PT-6, the TMP is determined solely by PT-4 and PT-5 on either side of the membrane in the main flow path. For a given flow rate provided by Pumps P-02 and P-07, these pressures are determined by the resistance of the channels. Therefore, the pressure should stay constant unless channels become blocked, which should not normally happen due to the pre-filter. For the influent, on the other hand, the TMP decreased during the second filtration cycle until being restored by the forward flush. After this, it decreased again until Valve V-217 was unclogged, after which it remained constant. A similar trend was not seen in the feed rate. This could again be a sign that something in the system was clogging. In this case, the blockage may have occurred between Pump P-02 and the ceramic membrane, resulting in some of the feed pressure being consumed by the flow around the obstruction.

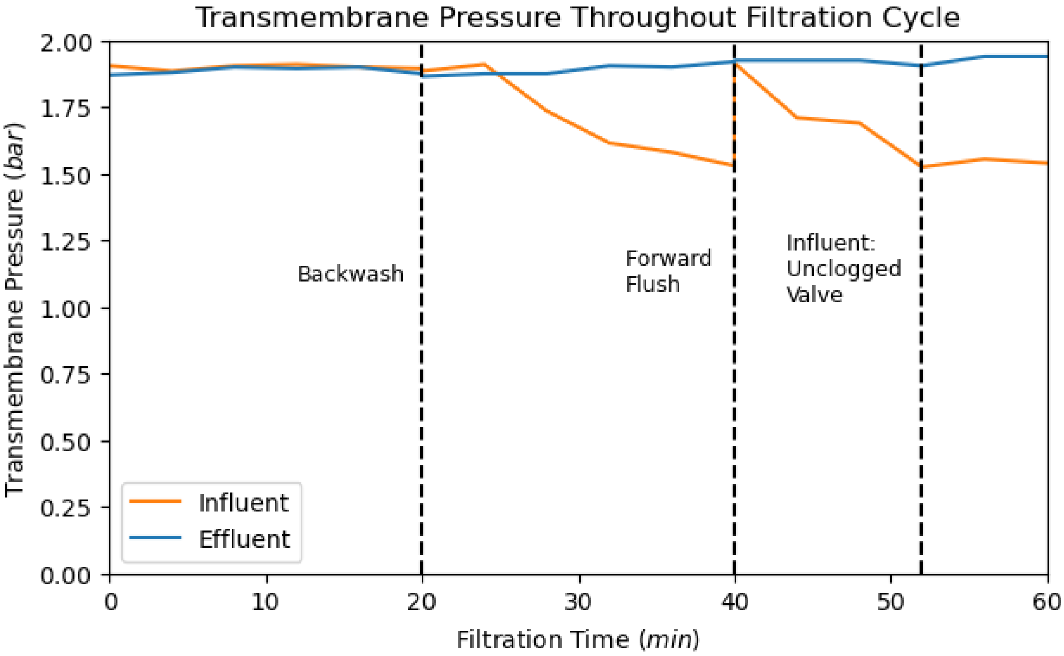

Figure 14: Transmembrane Pressure During Filtration

The membrane permeability is shown in Figure 15. In both cases, the permeability decreases throughout each filtration cycle, with a quick decrease at the beginning of the cycle that eventually slows down. After each cleaning step, the membrane permeability increases again, but not to the level that it had at the beginning of the test. For the effluent, the backwash restored the membrane permeability to a higher degree than the forward flush. For the influent, the forward flush did not improve the membrane permeability at all, but unclogging Valve V-217 did. Together, this indicates that backwashing is a more effective cleaning mechanism than forward flushing, at least with these settings. Additionally, the membrane permeability was consistently lower with the influent than with the effluent. This is logical, as permeability is not an inherent property of the membrane, but rather depends on what it is filtering. The influent was more contaminated than the the effluent, so it is less able to pass through the membrane.

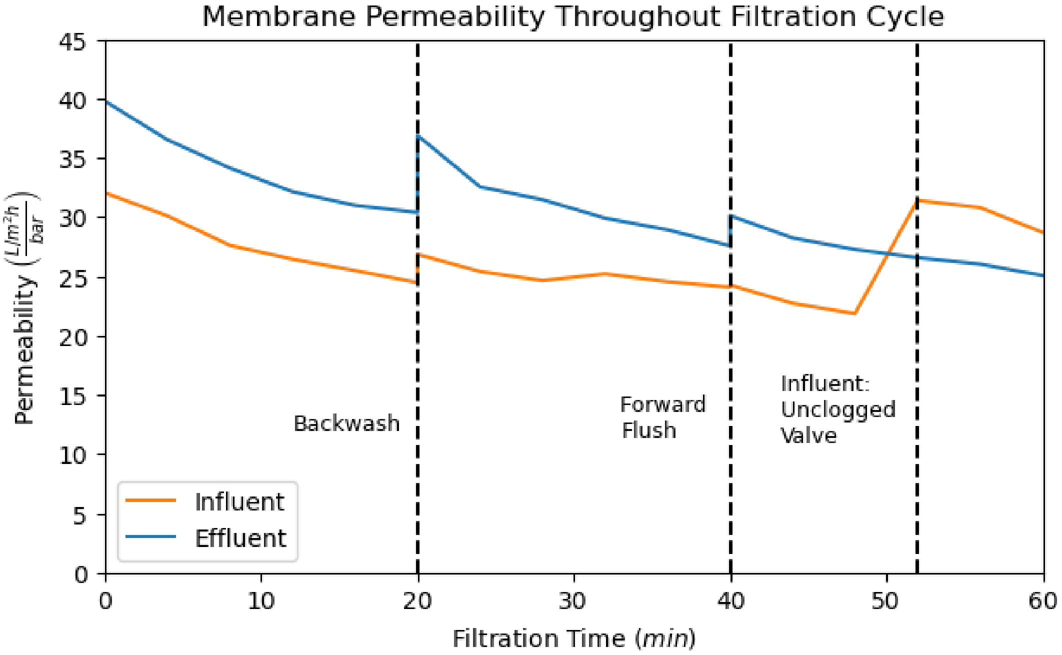

Figure 15: Membrane Permeability During Filtration

4.2 Water Quality

The results of basic WQ tests are summarized in Figure 16 below, with the alkalinity presented separately in Figure 17. In these figures, the filtered samples refer to the final sample from the permeate line (i.e. WW-IE-F3-15 and WW-II-F3-15). TSS and TDS were also measured, but the results are not presented here to avoid confusion as they were considered invalid. The results can still be found in Annex E Values from the literature are provided for comparison in Table 12. It should be noted that these values are taken from sources which consider municipal wastewater all around the world, so significant variability can be expected. Additionally, slightly different treatments were used at different facilities, although all the referenced studies considered traditional biological treatment as is used at the Infulene WWTP. This variability is indicated by the large standard deviations for each parameter.

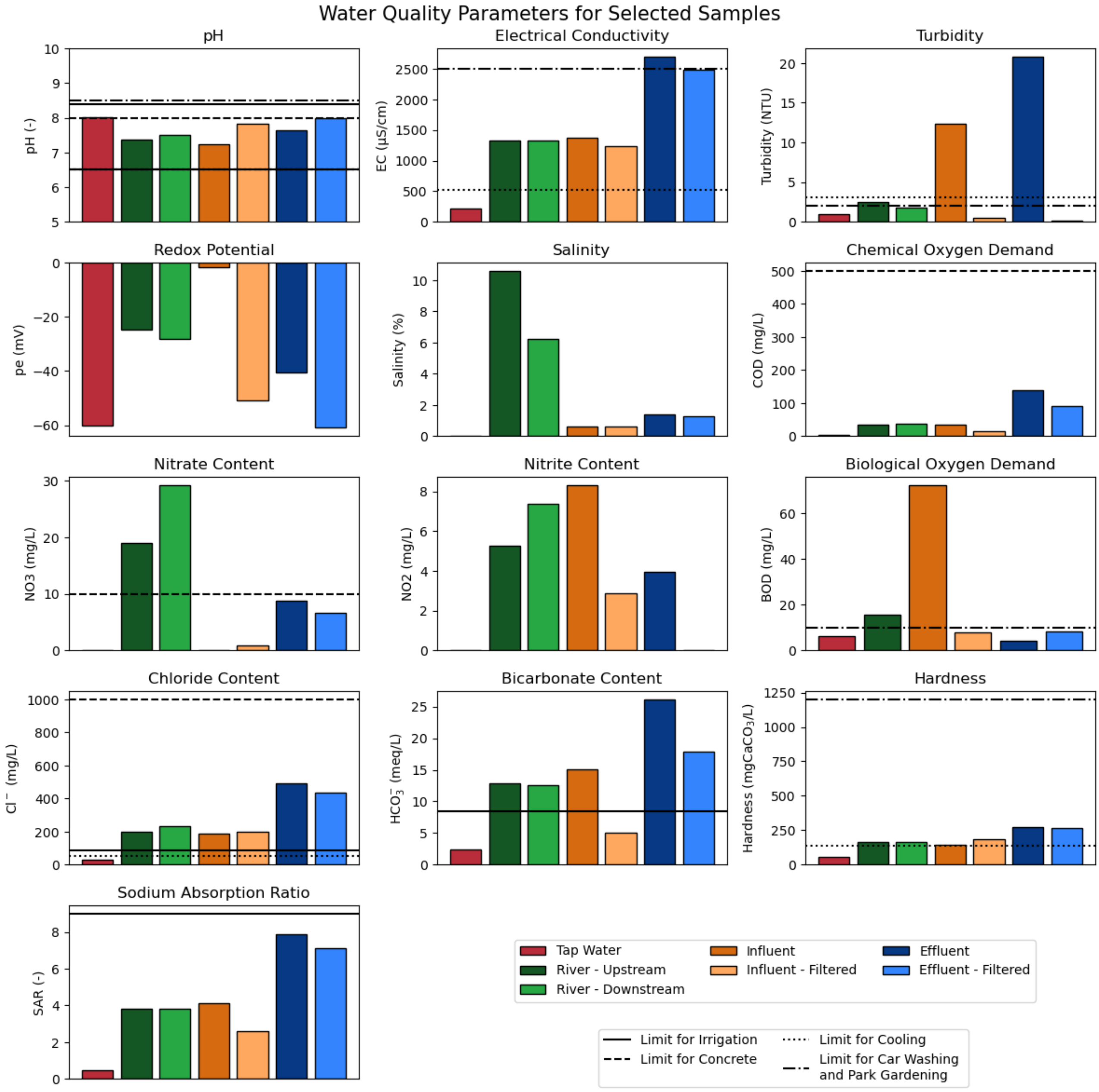

Figure 16: Basic Water Quality Parameters

Nevertheless, some of the measured WQ parameters do not align with those in the literature. The COD of the effluent is much lower than the range indicated while the literature, while the COD of the influent is much higher. Additionally, the COD should be expected to decrease after the WWTP rather than increase [40–42]. Similarly, zero nitrates and very low nitrates were measured in the influent, while a significant concentration should be expected from the literature. The hardness of the influent is also significantly higher than the literature would suggest. The alkalinity of both influent and effluent is higher than literature values by an order of magnitude. The alkalinity of the river samples is also much higher than indicated by literature, with values of 50 - 100 mg $CaCO_3$/L being more typical, and values of up to 500 being exceptional [43–45]. The EC, BOD, and turbidity are within the range indicated by the literature, but these parameters have very high variability between studies. In general, the values of these parameters measured in this research are far from the averages from the literature. The nitrate and nitrite concentrations of the effluent follow the same trend, as well as the hardness of the influent.

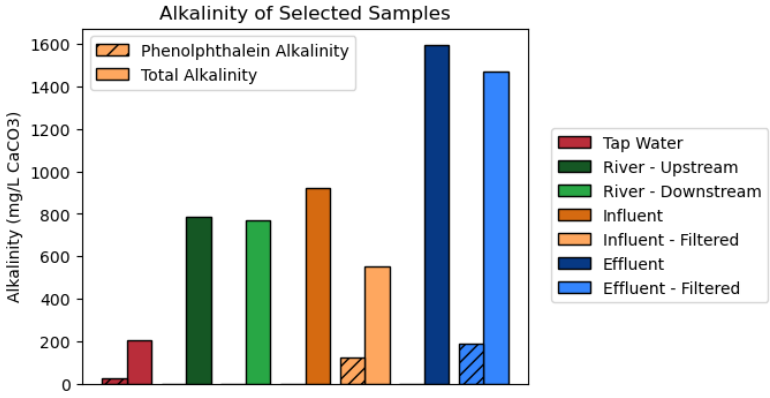

Figure 17: Alkalinity

It should be noted that BOD could not be measured for all samples due to limited materials in the laboratory. Comparing with Table 12, both values seem rather low. The BOD of the influent is just within one standard deviation of the mean, while that of the effluent is just outside one standard deviation. The BOD of the influent water is the highest, which is expected for raw sewage. The BOD decreases with the primary treatment at the Infulene WWTP, which aligns with previous research [41], but contrasts with the trend in COD. This trend is consistent over time, as shown in Figure 19 For the influent, the BOD also decreases with the CMF treatment, which is expected as most microbes are too large to fit through the pores of the membrane [46]. For the effluent, however, the opposite trend is observed, which does not match expectations. Another result to highlight is the fact that the BOD of the untreated influent exceeds the COD of the same sample, which should generally not be the case [47]. Furthermore, it can be seen that nitrate is produced when treating the raw influent, which also did not match expectations.

Table 12: Wastewater Quality from Literature

Parameter		WW Mean	STD	Sources	Treated WW Mean	STD	Sources
pH		7.41	0.35	[40–42, 48–56]	7.33	0.46	[40–42, 50, 55, 57–65]
EC	µS/cm	3041	1435	[40–42, 51]	1712	1232	[40, 42, 57–59, 61–63, 65]
COD	mg/L	381.8	249.6	[40–42, 48–50, 56, 66]	73.5	55.2	[40–42, 50, 58, 61–64]
Turbidity	NTU	163.4	170.1	[42, 48, 49, 51, 52, 66]	39.3	44.2	[40, 42, 61, 62, 64]
NO_3	mg/L	8.3	5.9	[40–42, 55, 56]	29.3	36.5	[40, 42, 55, 59–61, 67]
NO_2	mg/L	26.4	16.7	[42, 56]	6.3	6.0	[42, 61, 67]
BOD	mg/L	130.9	150.4	[41, 48, 61, 66]	16.5	9.3	[41, 42, 56, 58, 64]
Cl	mg/L	258	439.4	[40, 42, 51, 55]	75.3	58.9	[40, 42, 55, 57, 58, 60]
Alkalinity	meq/L	170.8	153.3	[42, 53–56]	13.6	6.9	[42, 55]
Hardness	mg$CaCO_3$/L	76.0	71.7	[40, 55]	84.6	61.8	[40, 55, 58, 65]

The quality of the permeate throughout the filtration cycle is shown in Figure 18, where BOD is excluded because it was not measured for the instantaneous permeate samples. Almost all parameters show a substantial initial decrease from the feed water and then a gradual increase throughout the rest of the cycle. None of these parameters appeared to have reached a steady state at the end of the filtration, but seemed to be trending towards the value held by the feed water. The one exception was turbidity, which decreased to essentially zero and remained constant. No literature could be found with which to compare these trends.

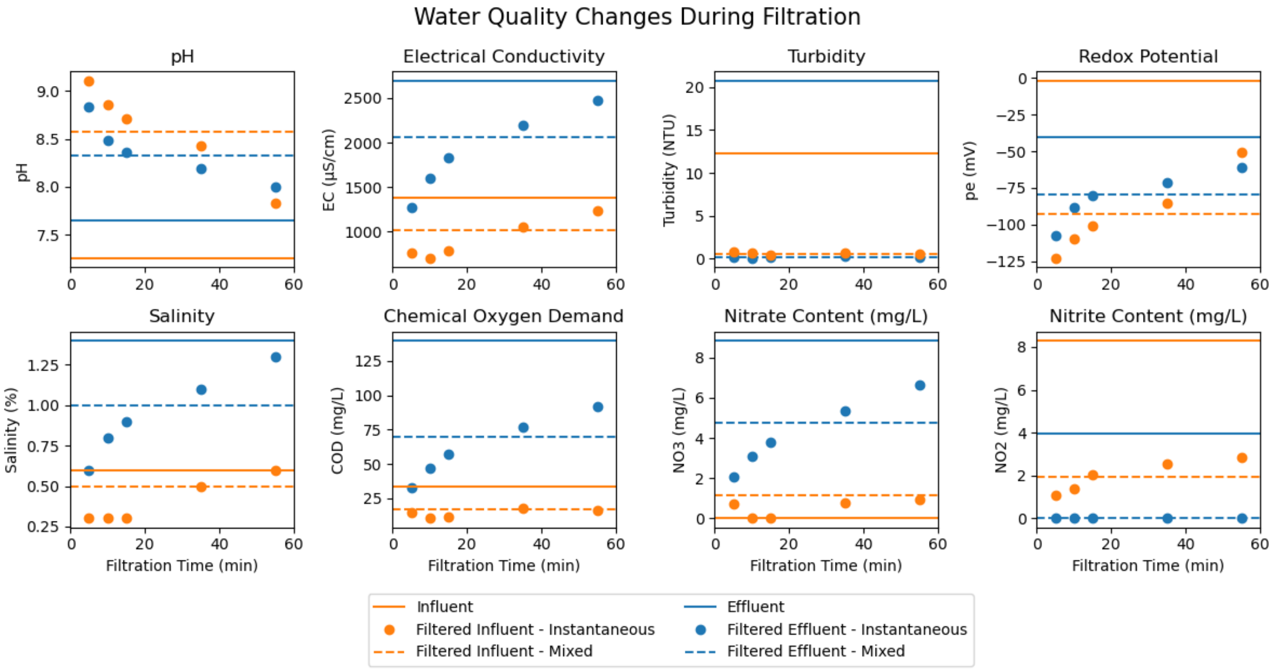

Figure 18: Water Quality Throughout Filtration

The time series measured by the Infulene WWTP is shown in Figure 19. In general, the water quality of the Influent shows higher variability than the effluent. This matches expectations because the composition of the sewage water depends on many factors, including weather and relative contribution of street sewage versus septic trucks. The effluent shows relatively constant COD, nitrate content, and BOD, but has an increasing trend in EC and high variability in turbidity. The values of EC measured in this study align with those represented in the Infulene time series, as does the COD of the effluent. For most of the other parameters, however, lower values were measured than should be indicated by the time series. However, the values are generally in the same range in both sets of measurements.

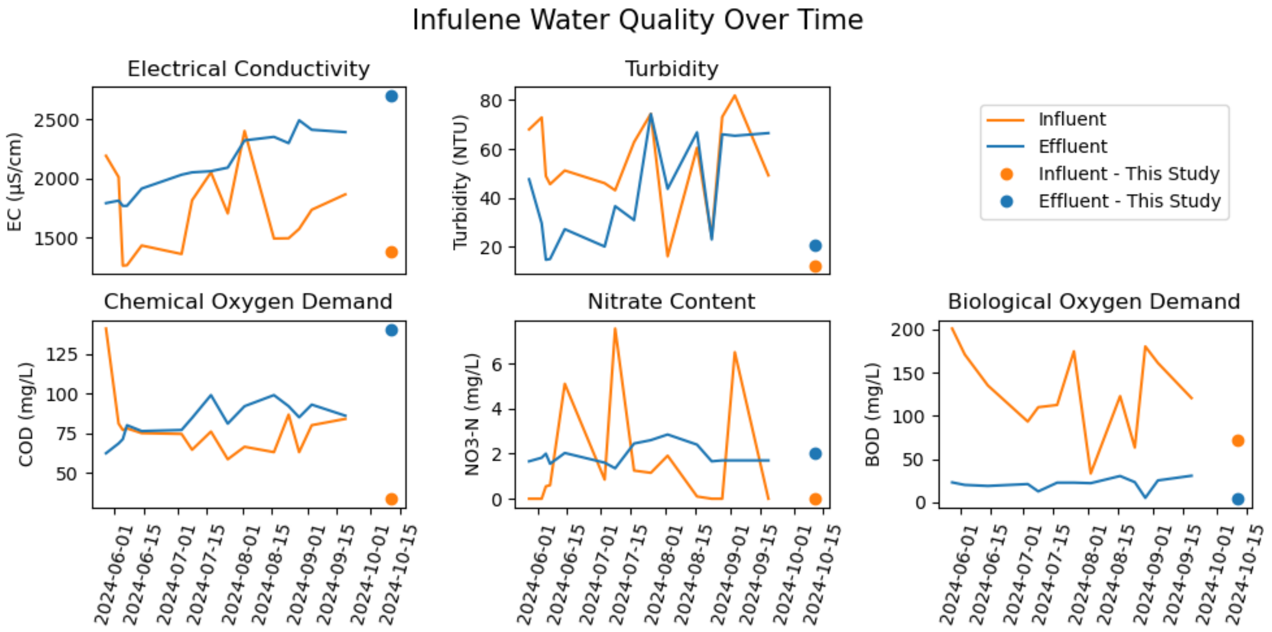

Figure 19: Water Quality Over Time at Infulene WWTP

4.2.1 ICP Analysis

The spectrometer reported concentrations of 24 elements, with key elements presented in Figure 20. The complete results are given in Annex E. One important note from this figure is the very high standard deviations indicated by the error bars. This is caused by the fact that the instrument measures the concentration of each element using several wavelengths, with three measurements being taken for each wavelength. Normally, a reference sample is used with known concentrations, so that the most representative wavelength can be selected and used for all samples. However, no such reference sample was available at the time the measurements were performed. Therefore, all the wavelengths which gave a valid results (within measurement range and consistent across the three repetitions) were averaged. It should be noted that for Ca, Mg, and Na, every sample had at least one wavelength which gave results above the measurement range. Thus, the actual concentrations of these elements may be much higher than calculated.

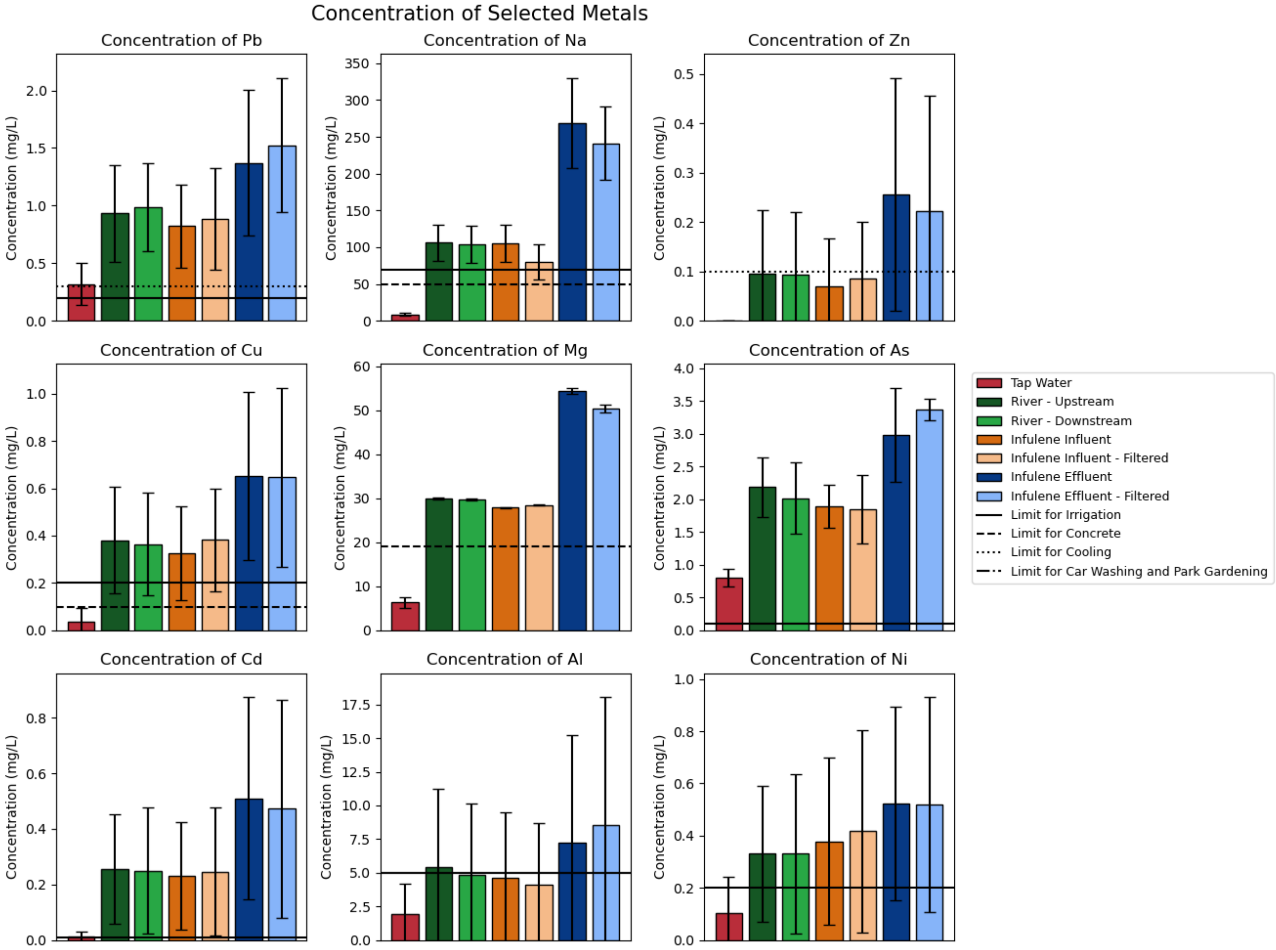

Figure 20: Key ICP results

The metal concentrations all show a similar trend. Levels in the tap water are very low, usually below the limits required for the various use cases. Concentrations in the Infulene river are higher, but are generally similar upstream and downstream of the WWTP. The concentration is usually higher in the effluent of the WWTP than in the influent, and filtering has a negligible effect on the concentration.

There is much less literature available to compare metal concentrations as with the more common WQ parameters discussed above. In general, however, much lower levels of heavy metals are measured. Cadmium, copper, and nickel are generally below 0.1 mg/L [68–70]. Arsenic and silver are generally even an order of magnitude lower than that [69, 71, 72]. Generally, the most abundant heavy metal in municipal wastewater is zinc, with concentrations up to a few ppm [68–71]. In this study, much higher concentrations of the usual trace metals were seen, while the level of zinc was very low. Additionally, treatment at a traditional WWTP should lower the concentrations of heavy metals [69, 71, 72], especially when constructed wetlands are used [73, 74], while the opposite trend was seen here.

4.2.2 Total Coliforms and E. Coli Count

The total coliform and E. Coli concentrations were measured with the colilert-18 method, as described in Section 3.2.3. The results are displayed in Figures 21 and 22 respectively.

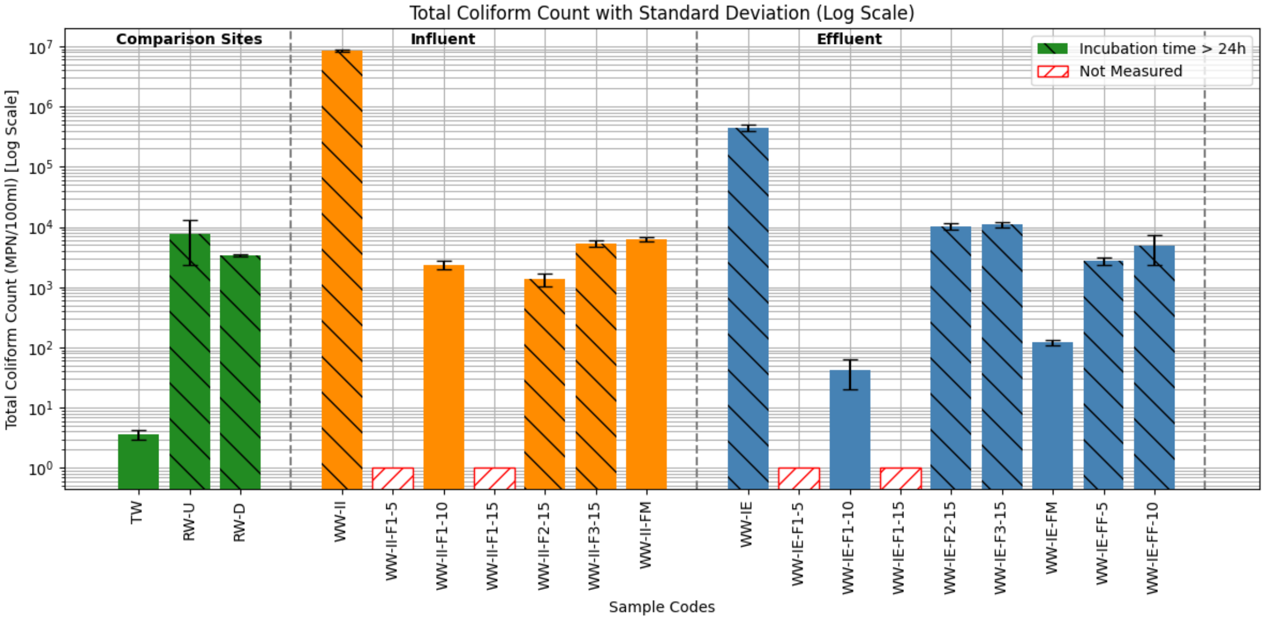

Figure 21: Total Coliform Count at different sample locations, the y-axis is log scale while error bars indicate standard deviation

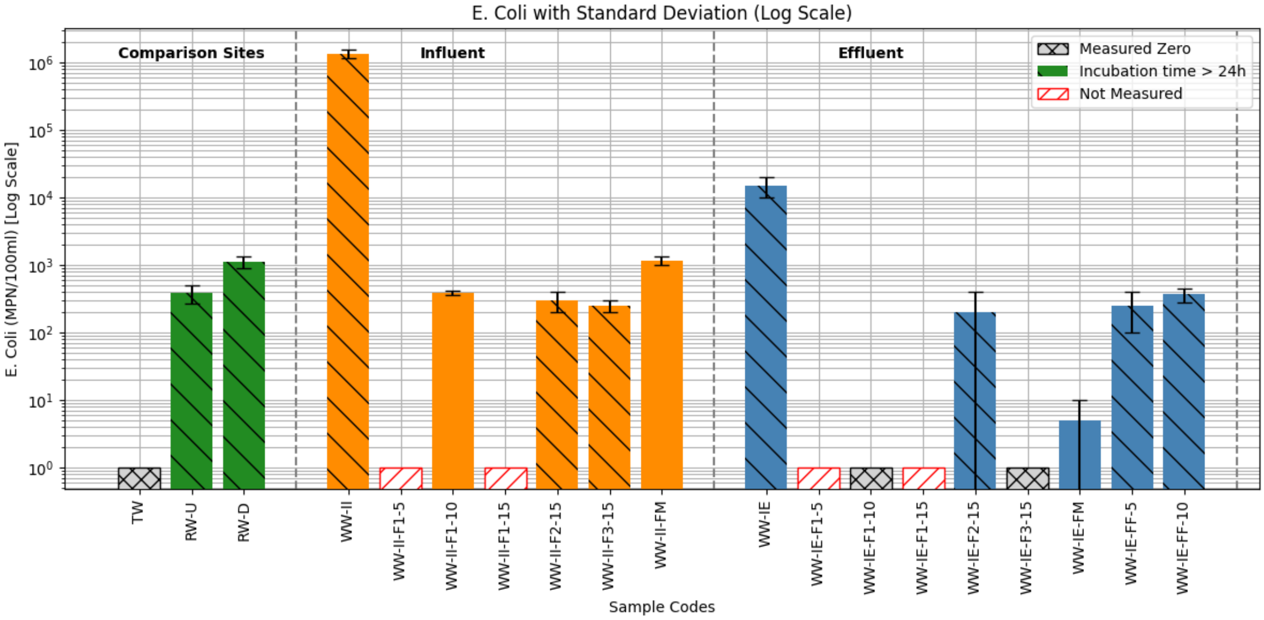

Figure 22: Total E. Coli Count at different sample locations, the y-axis is log scale while error bars indicate standard deviation

The results for the comparison sites are in the expected ranges, while the total coliform count for tap water (3.6 MPN/100mL) is near zero. Two river samples were taken, one upstream (RW-U) and one downstream (RW-D) of the effluent point (WW-IE) of the WWTP in the Infulene river. Interestingly, the total coliform count is higher at the upstream location before the discharge of the Infulene WWTP. However, the result for WW-IE is significantly higher (441,500 MPN/100mL) than the upstream river sampling point, which should result in a higher contamination downstream.

Furthermore, both filtration cycles in the pilot plant show significant reductions in total coliform count for both influent and effluent inputs from the Infulene WWTP. The total removal efficiencies amount to Log3 (99.93%) for the influent and Log2 (97.5%) for the effluent for the pilot plant tests. The removal efficiency of the Infulene WWTP is slightly lower, when comparing the raw influent and effluent water itself, which results in a Log1 (94.8%) removal.

Throughout the filtration cycles, varying counts were detected. Especially, the results for WW-IE-F2-15 and WW-IE-F3-15 stand out, since the other counts for the same batch are lower. The counts for the WW-IE-FF samples are higher then the count of WW-IE-FM, which is surprising considering the FF samples went through the membrane a second time, which should further decrease the count.

The result for tap water is 0 for E. Coli count, which is to be expected. The E. coli concentration in the Infulene river increases significantly from upstream (394.25 MPN/100mL) to downstream (1122.25 MPN/100mL), indicating that the effluent point contributes substantial contamination to the river water. The data also suggests that upstream areas in the river are already experiencing contamination, likely from agricultural run-off and urban drainage, which is exacerbated downstream.

The Infulene WWTP removal efficiency of the sampled water resulted in a Log2 (99%) removal of E. Coli count. Nevertheless, a significant amount of E. Coli (15177 ± 5009 MPN/100mL) remains in the effluent discharge (WW-IE), which in return pollutes the river water. Compared to the removal efficiency of the pilot plant with CMF for both the influent and effluent of the Infulene WWTP, the removal reached Log3 (99.91%) for the influent and between Log3 and Log4 (99.96-100%) for the effluent.

In some cases for the treated effluent, the E. Coli count was measured at zero, while results for WW-IE-F2-15 (400 MPN/100mL) and WW-IE-FM (5 MPN/100ml) indicate lower counts. However, in both cases the standard deviation is relatively high, due to one of the duplicates being measured at 0 MPN/100ml. Interestingly, the E. Coli count for the WW-IE-FF samples is higher again, even though the water was filtered twice through the membrane.

4.3 Stakeholder Analysis

From the list of stakeholders of interest, experts in the water sector, AIAS, FIPAG, the Municipality of Maputo and car wash businesses were successfully interviewed. Also, information about concrete producers, their water consumption levels and associated costs and their willingness to consume reclaimed wastewater, was found from the research of Fausta [13]. On the other hand, interviews with the central bank of Mozambique, the Central Thermal Power Plant and Empresa Nacional de Saneamento e Drenagem de Maputo were not conducted. Attempts to interview these organizations were hindered by difficulties to schedule meetings in late October due to civil unrest, or because the organizations did not respond to interview requests.

Following the guidelines of the HREC, the answered questionnaires are not attached this report and the results of the interviews are kept anonymous. Therefore, the particular representatives of each organisation interviewed are not identified, nor is their position within the organisation. The answered questionnaires can be provided upon request

4.3.1 Experts in the Water Sector

The interview with experts contributed in giving a clearer overview of the relevance of other stakeholders, and helped define the strategy of the financial feasibility assessment. An important insight provided by experts was the focus of making the system as affordable as possible, and that government subsidies for part of the reclaimed wastewater production should not be considered a viable option. Furthermore, they informed that consumers will most likely choose the cheapest option of water supply, even if other water supply options are more sustainable or contribute to mitigate water scarcity. Therefore, in order to make reclaimed wastewater a feasible solution for consumers, its price should be cheaper for consumers than their current water supply. Furthermore, subsidies are not considered a realistic option. In order to make reclaimed wastewater a feasible solution for water companies, the production and supply cost of the reclaimed wastewater should therefore be lower than their current production and supply costs.

Experts also informed that farmers in the Infulene valley would not be feasible consumers of reclaimed wastewater from the Infulene wastewater treatment plant. The farmers would not be willing to purchase reclaimed wastewater for their irrigation purposes, as they have free access to groundwater and surface water from the Infulene river. The reclaimed wastewater might be of improved water quality compared to the river water they use for irrigation, however, they would not be willing to pay for such quality.

4.3.2 Funding and Development of Water Projects

Administração de Infra-Estruturas de Águas e Saneamento (AIAS)
As previously described, AIAS is a fundraiser, project manager and asset holder of water sanitation infrastructure across the country. However, from the interviews it also became clear that the organization is responsible for the development and asset-holding of water supply in smaller towns in the country. The financing and funds obtained by AIAS for water sanitation infrastructure is mostly raised by donations from international organizations such as the World Bank and the African Development Bank, and from bilateral aid from the United States, Netherlands, and other European countries. The organization was also responsible for rasing funds, and overseeing the reconstruction of the Infulene WWTP in Maputo. After successful project completion and construction of a water sanitation infrastructure, AIAS tends to become asset holder. However, the long-term plan of the government is that AIAS passes over the responsibility of these assets to the local municipalities. Such transition of management from AIAS to EMSD is currently in progress for the Infulene WWTP.

The interviewee informed that the organization would be interested in reclaimed wastewater projects, and that such technology could accompany ongoing development plans for water sanitation infrastructure across the country. However, it would be important that the revenue from providing reclaimed wastewater would cover production and supply costs. Other sources of income to cover the reclaimed wastewater, from governmental subsidies, were stated to be an unrealistic option. For the potential production of reclaimed wastewater at the Infulene WWTP, an important consideration for the organization would be the impact of water availability for downstream farmers. In the case that the effluent of the WWTP significantly contributes to the downstream base flow of the Infulene river, farmers dependent on the river downstream might be affected. This potential impact would have to be assessed, and considered negligible, for the organization to be interested.

Fundo de Investimento e Património do Abastecimento de Água (FIPAG)
After interviewing a representative from FIPAG, their role in the water management sector became clarified, as well as their potential involvement to a reclaimed wastewater project. The organization is a sub-organization of the federal government, but is managed like a private company and can make profits which can be re-invested into new projects. Currently, the organization is only responsible for the development, management and asset holding of water supply infrastructure. However, with upcoming changes in water management regulation, the responsibilities of FIPAG might expand to include management and asset holding of water sanitation infrastructure as well.

The interviewee informed that FIPAG would be interested in producing and supplying reclaimed wastewater for non-domestic usages, as long as the production and supply costs would compete with their current drinking water production and supply costs. Furthermore, the interviewee expressed that the organization favours the idea of providing reclaimed wastewater by pipes rather than water trucks, as water trucks give higher risk of scams. One possible scam that could arise if FIPAG starts supplying more water with water trucks, is that people could use their own trucks and pretend to be FIPAG water suppliers, selling cheaper but dirtier water to households and businesses. However, the interviewee also expressed some concerns with using pipes, in the case that the reclaimed wastewater pipes lay parallel to drinking water pipes, as the dirtier reclaimed wastewater may leak and enter the drinking water pipes. Considering their concerns regarding water trucks and pipes, the interviewee encouraged to look further into decentralized reclaimed wastewater production, where businesses would have their own membrane technology to reuse their wastewater.

Data was also received on the water supply of FIPAG. The average monthly supply of water from FIPAG is 7,550,000 m^3/month, and out of this total supply, 16% is for industrial use. Furthermore FIPAG supplies 53% of the population of the city for domestic use.

4.3.3 Non-domestic Water Consumers

Watering of City Parks
A representative of the municipality of Maputo provided information on their watering methods, water consump-

tion and associated costs, and their views of using reclaimed wastewater. It became clear that the municipality uses two sources of water: tap water from the FIPAG water network, and groundwater from a well located in the Tunduru Gardens. From the location of the well and taps, the water is transported using tractors with water tanks. Irrigation is then performed using the same trucks. The interviewee stated that there are no water quality standards and regulations that the municipality must comply with for watering purposes.

The interviewee also said that the municipality would be interested in using reclaimed wastewater under certain conditions of price and water quality. First of all, the price of the reclaimed wastewater should not exceed the price they are currently paying for tapped water. Secondly, the water quality must not cause the water to smell, and the concentrations of chemical contaminants should be below a level harmful to the plants in the public spaces. In addition, the interviewee informed that the municipality tractors could be used to pick up water straight from the Infulene WWTP, reducing supply costs and allowing the price of the reclaimed wastewater to be lower for this potential use case.

The monthly water bill of the municipality is around 180 000 MZN for watering of public spaces, and they pay the tariff for water consumption for industries, provided by Águas da Região de Maputo, of 72.37 MZN/m^3. This means that the municipality uses around 2 486 m^3/month for watering purposes.

Car Wash Businesses

In total seven interviews were successfully conducted with car wash businesses. Out of the seven interviews, six companies used piped water supplied by FIPAG, while one company had a borehole on site. All companies had storage tanks, but not all knew the volume of their tanks. Table 13 shows the water source, monthly water cost, monthly water consumption and the volume of the storage tanks for the seven interviewed companies. In order to keep the identity of the the companies anonymous, they have been renamed with the pseudonyms "Company 1", "Company 2" etc.

Company	Water Source	Water Cost (MZN/month)	Water Consumption (m^3/month)	Storage Volume (m^3)
Company 1	Piped water	2000	27.64	4
Company 2	Piped water	2500	34.54	-
Company 3	Borehole	-	-	18.75
Company 4	Piped water	3500	48.36	9.5
Company 5	Piped water	7000	96.73	10
Company 6	Piped water	15000	207.27	-
Company 7	Piped water	5000	69.09	2.5

Table 13: Interviewed companies and their associated water source, water cost, water consumption and storage volume.

Table 14 lists the companies interested in using reclaimed wastewater, and under what conditions they would be interested. Five out of seven companies (Company 1, 2, 5, 6, 7) were interested in the idea of consuming reclaimed wastewater. Of the two companies who did not state their interest, one company had a borehole on-site, and was not interested due to the low cost of their current system. The interviewed representative of the other company did not want to express interests without the presence of their manager. All of the interested companies stated that they would use reclaimed wastewater on the condition that it was cheaper than their current piped water supply. Additionally, Company 6 would also use the reclaimed wastewater if it equalled their current water cost, as they would like to contribute to drinking water saving. However, they stated that they cannot afford the reclaimed wastewater if it was more expensive than their current water cost.

Company	Interest in Reclaimed Water	Preferred Pricing (Relative to Piped Water)	Quality Requirements	Water Truck Acceptance
Company 1	Yes	Lower cost	Transparent, odor-free	Yes
Company 2	Yes	Lower cost	Drinkable	If the water is much cheaper
Company 5	Yes	Lower cost	Transparent, odor-free	Yes
Company 6	Yes	Same or lower than piped water	Transparent, odor-free	Yes
Company 7	Yes	Lower cost	Transparent, odor-free	Yes

Table 14: Companies interested in using reclaimed wastewater, and the conditions for their interest.

Concrete Companies

Data from the research of Fausta [13] was used to estimate the prices that concrete producers pay for water. Since the names of these companies have already been published, they are not kept anonymous here. The responses of the companies, on the matters of water consumption, water costs and the source of their water, is shown in Table 15. As the research was published in 2016, the cost values adjusted for inflation from 2016 to 2024. Out of the eleven companies interviewed, only the company "Estaleiro JMS" expressed no interest in using reclaimed wastewater, due to the fear that reclaimed wastewater supply might be unreliable, and its cost higher than the price of tap water. The other companies expressed interest in trying to use reclaimed wastewater for a part of future research, to explore possible cost and benefits [13].

Company	Water Tariff (€/month)	Water Tariff (€/m^3)	Inflation Corrected Water Tariff (€/m^3)	Water Source
Estaleiro Julio J. Paunde	17	1.12	1.7897	Private supply
Estaleiro JMS (José Manuel Sacoto)	42	0.45	0.7191	Tap water
Estaleiro Antonio Bernardo Tamele	48	0.40	0.6392	Tap water
Resol	17.5	1.09	1.7417	Private supply
Cadin	2430	0.38	0.6072	Tap water and private supply
Prefangol	2700	0.38	0.6072	Private supply
Hidroblock, Lda.	509	0.38	0.6072	Tap water and private supply
Britanor, Lda.	822	0.37	0.5912	Private supply
Cimbetão	260	3.07	4.9056	Tap water
Bricon, Lda.	873	0.38	0.6072	Tap and private supply

Table 15: Water Consumption and Tariffs by Company [13] and Inflation-Adjusted Rates

Central Thermal Power Plant
Unfortunately, the central thermal power plant was not interviewed as they did not respond to interview request. However, through research existing literature their maximum daily water consumption was found to be 660 m^3, which results in 19800 m^3/month [20].

4.4 Water Balance

4.4.1 Infulene River

As explained in Section 3.4.3, the minimum river discharge under normal flow conditions is equal to approximately 17280 m^3/d. The maximum water demand for irrigation along the Infulene river downstream of the WWTP is equal to approximately 7500 m^3/d. It should be noted that this demand was determined under the conservative assumption that the entire agricultural area downstream of the WWTP is irrigated using water from the Infulene river. The lowest "normal" river discharge is thus more than twice as great as the maximum possible water demand for irrigation. In addition to this, the daily average discharge in the driest period of the year is around 117000 m^3/d (see Annex B), which is much greater than the water demand for irrigation. It can thus be concluded that all the effluent of the WWTP can safely be supplied to alternative users without compromising the productivity of the neighbouring agricultural activities. This aligns with findings from previous studies on this topic [6].

4.4.2 Infulene WWTP

The results of the water balance surrounding the Infulene WWTP show that more water leaves the system on a yearly basis than what is flowing into the system. This equals to around 190 m^3 on a daily basis, which flows out of the system. This error is to be expected due to the uncertainty of the used data. The main driver behind this negative balance are the high potential evaporation rates in the calculations. According to the MODIS16 and INAM data, more than double the amount of water potentially evaporates (2050 mm/yr) than precipitates (820 mm/yr) in Maputo over a whole year. This is part of the reason why outflow rates are lower than the inflow rates in the Infulene WWTP. However, the values provided by EMSD are values averaged over the whole year, with which the water balance nearly closes. Still, on a monthly basis these values are not accurate enough due to the varying evaporation and precipitation rates. Therefore, the flow rates of the Infulene WWTP have to be adjusted in order to calculate the available water for reuse.

Fluctuations of Inflow

The discharge in the drainage canal, which leads to the Infulene WWTP, remains relatively constant throughout the year (see Annex C). Therefore, for further calculations, it was decided to keep the inflow value provided by the EMSD and the inflow values from the construction report [29] for future scenarios constant throughout the year.

Water Demand for Uses Cases

Table 16 provides an overview of the different users and their individual monthly water demand. These water demand levels were obtained from the research conducted by N. Fausta for concrete producers, and from the Subsection 4.3, which describes the results of the Stakeholder Analysis [13]. For the purpose of the water balance calculation, these values were assumed to be constant throughout the year.

Table 16: Summary of design water demand for each use case, based on stakeholder analysis.

Potential User for Reclaimed Wastewater	**Monthly Water Demand (m^3)**
Concrete Producers	9690 [13]
Central Thermal Power Plant (Cooling Water)	19800
Car Wash Businesses	483
Municipality	2487
SUM	**34,947**

Estimation of Outflow

With the assumption of the inflow values being constant throughout each month, the discharge has been calculated with the only other two remaining flows in the system: precipitation and potential evaporation rates. An underlaying condition for the estimation was that the water balance closes for each month. This lead to varying outflow values throughout the year, which influences possible water supply for reuse. Figure 23 provides an overview of all possible average daily discharges per month.

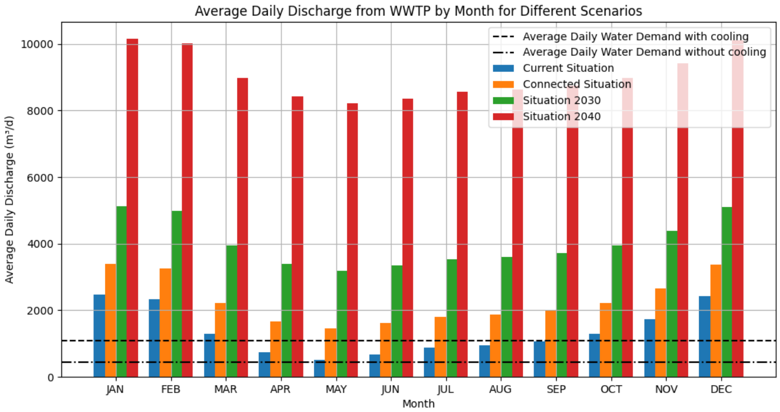

Figure 23: Average daily discharge values of the infulene WWTP for each month in combination with different water demands

It can be concluded that the discharge is significantly higher during the wet period (December - February) than during the drier months (May - July). For those months with less precipitation and more potential evaporation, the daily discharge in the current situation is not sufficient to supply the demand from all potential users. Only from October to March the demand can be supplied. As soon as the inflow situation improves, the water demand can be met in all months for all future scenarios. If the CMT is not supplied due to poor effluent water quality, the remaining potential users could be provided with enough water in each month even in the current situation.

For the future scenarios, there will be more than enough water available for reuse, so that more potential users could be identified and supplied.

4.5 Financial Feasibility Assessment

In this section, values are provided for all the components of the costs directly related to the project.

4.5.1 Capital costs of CMF

An inventory of the capital costs for this project was made in Section 3.5.2, with all the sources listed in Table 9. Table 17 highlights all the capital costs needed to upscale the pilot plant technology.

The full system container comprises the cost of a container having a CMF filter with same characteristics of the pilot plant, but with a maximum capacity of 180 m^3/h and a comfortable capacity of about 140 m^3/h. This would allow to treat the current maximum capacity of the Infulene WWTP of 112 m^3/h and keep room for the future when the WWTP would increase its capacity thanks to the improved sewage network of the city of Maputo.

The spare parts include a duplicate of most of the parts which are within the container. Given the fact that shipping replacements for broken parts would be very expensive and time-consuming, it would be more cost-effective to have spare parts in-situ. This allows for a faster reparation as well, avoiding a situation in which the plant is not working for an elongated period of time.

The land purchase is based on the relocation of one farmer which is currently cultivating crops in the land needed for the container, while the concrete slab foundation is the concrete needed for 100 m^2, the area of one container for the CMF treatment plant.

Table 17: Capital costs for the new filter.

Capital costs	**Value**	**Unit**
Logisticon full system container	815000	$
Logisticon system - Spare parts	400000	$
Shipment of Logisticon container	20000	$
Land purchase	60000	$
Concrete slab foundation	940	$

4.5.2 Operational and maintenance costs of CMF

Among the O&M costs, power consumption is the energy cost for the functioning of the CMF container. The value is expressed as a cost per m^3 produced, over the design service life of 20 years. Logisticon informed that 0.22 employees are needed on average to supervise and operate 1 container. Since only one container is considered for this application, 1 electromechanical engineer is needed to operate the installation. The cleaning reagents include the several chemicals needed to conduct the cleaning of the plant. All the O&M costs are listed in Table 18.

Table 18: Operational costs for the new filter.

Operational costs	**Value**	**Unit**
Logisticon system - Power consumption	0.015	$\frac{\$}{\mathrm{m}^3}$
Staff cost	5000	$\frac{\$}{year}$
Cleaning reagents	43500	$\frac{\$}{year}$

4.5.3 Supply costs

The supply costs comprehend all the costs needed to deliver the water to the potential users, and here the 2 scenarios presented in Section 3.5.2 are examined.

For Scenario 1 - Transport by water trucks, two possibilities were taken into account. The first possibility was transport by a third party private company, which charge 14.1 m^3 regardless of the distance covered. Another possibility is for the enterprise that would own the CMF treatment plant to own trucks. This would have a capital cost of 360000 $ since 9 trucks would need to be bought to supply at least 260 m^3/day, but decrease the operational costs, as the costs of fuel and salaries are lower than 14 $/$\mathrm{m}^3$. Scenario 1 would be suitable for delivering water to concrete companies, car washes and possibly farmers, since they would not have a constant water demand on a daily basis. It should be noted that these 2 possibilities do not apply for the case of providing water to the Municipality of Maputo for irrigating parks and plants present on public streets, since they would come with their own tractors to the facility and collect the water themselves.

For Scenario 2 - Transport by piping would consist of building a piping system between the treatment plant and the location of the potential user. This is most likely to be the supply system for the CTM due to the fact that they require a constant daily supply, and it is based only 2 km from the WWTP. Implementing a piping system includes the capital cost of building the piping system, and the maintenance cost of keeping it properly operational. The capital cost does not include excavation cost.

Table 19: Supply costs for the reclaimed wastewater.

Transport by water trucks - Scenario 1	**Value**	**Unit**
Third party private company	14	$\frac{\$}{\mathrm{m}^3 * km}$
Own trucks	0.85	$\frac{\$}{\mathrm{m}^3}$
Transport by piping - Scenario 2		
Capital costs for piping	150000	$\frac{\$}{\mathrm{km}}$
Maintenance costs for piping	930	$\frac{\$}{\mathrm{km*year}}$

More details on the calculation of the supply costs can be found in Annex D.

4.5.4 Reselling price of reclaimed wastewater

The reselling price of the reclaimed wastewater was set with the goal of covering the production costs and the supply costs per m^3 of the reclaimed wastewater and, given the magnitude of the total production and maintenance costs, a no-profit policy was applied. Hence, the sum of the total production-maintenance-supply costs equal the selling price of the reclaimed wastewater. The main objective of this feasibility study was to determine whether the reselling price of reclaimed wastewater could be lower than the average price of water paid by the targeted end users, which as of 2022 was 1.14 $/$\mathrm{m}^3$. Converting the costs listed in Sections 4.5.1, 4.5.2 and 4.5.3 into $/$\mathrm{m}^3$ for a 20 year life cycle and a treating capacity ranging from 112 m^3/h, which is the current treatment capacity of the Infulene WWTP, and 160 m^3/h, which is the maximum optimal treating capacity for the CMF plant from Logisticon, a total production cost of 1.27 $/$\mathrm{m}^3$ is derived, ranging between 0.96 $/$\mathrm{m}^3$ and 1.57 $/$\mathrm{m}^3$.

The derived cost for Scenario 1 - Transport by water trucks is 0.85 $/$\mathrm{m}^3$ in the case the water trucks would be owned by the same entity as the CMF treatment plant, which is greatly cheaper than transporting with a third party company.

On the other hand, Scenario - 2 provides a lower total cost for delivery, evaluated at 0.04 $\$/m^3$. This cost is based on a covered distance of 2 km, the distance between the Infulene WWTP and the CTM. Figure 24 summarizes the cost range of the reclaimed wastewater and the comparison with the FIPAG delivery price.

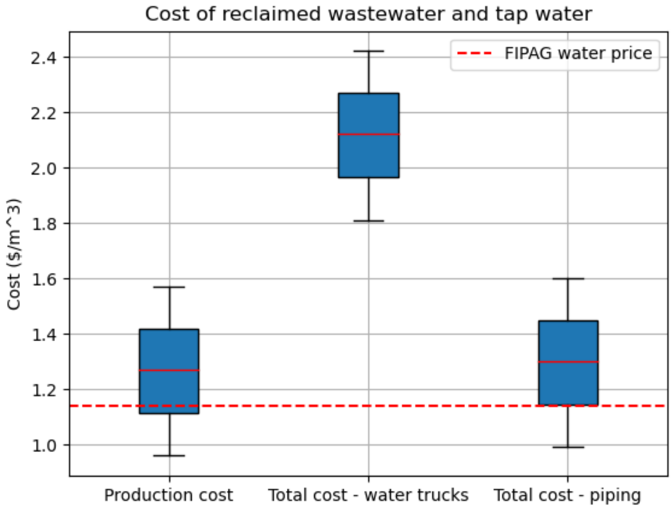

Figure 24: Reclaimed wasterwater costs and FIPAG water cost

It can be observed that the total cost of reclaimed wastewater is only potentially lower than the reference FIPAG water price when supplying water using a pipeline, or when no supply is necessary (i.e. when the end user collects the water at the WWTP directly).

5 Discussion

5.1 Pilot Plant

The membrane performance data shows promising signs for the treatment of Infulene effluent with CMF. With minimal optimization of the process parameters, a high recovery rate was achieved and maintained, even as membrane permeability decreased. TMP also appears to be stable at a reasonably low pressure for microfiltration [75]. A lower pressure is beneficial as it reduces the cost of the process [76]. It is important to note, however, that only a few filtrations were performed during these tests. However, membranes in CMF installations often perform dozens to hundreds of filtrations and backwashes before a CIP cycle [77, 78]. Permeability continued to degrade throughout the test, so a longer test would be beneficial, with the intention of determining whether the system reaches a steady state or continues to degrade.

On the other hand, the Infulene influent did not perform well with the CMF treatment. It seems that two clogs were formed in the system, indicating that the water may be too contaminated for this method of treatment. On the other hand, this could be a result of improper aluminum sulphate dosing. The dosing rate used for this study was chosen based on the recommendations of the manufacturers of the pilot plant, but other literature uses concentrations of aluminum sulphate which are orders of magnitudes higher, even up to several grams per liter [48–50, 79–81]. In future research, it would be worthwhile to perform laboratory testing to determine the optimal dosing rate for flocculation before applying it to pilot scale.

It is again worth noting that only one set of process parameters was investigated due to time constraints. The parameters were initially chosen for the effluent and then applied to the influent for consistency. It is likely, however, that a different set of parameters would be better suited to the influent. In particular, a lower recovery rate would reduce the possibility of clogging. The rate of decrease of the membrane permeability would likely also be improved by such a change. Therefore, further process optimization should be attempted before this treatment method is discounted for the Infulene influent.

Additionally, literature on membrane filtration often attempts to classify the fouling mechanisms acting on the membrane. This can be helpful for optimizing fouling control strategies. However, the literature on this topic seems to be based on constant-flux filtration, where the ensuing increase in membrane pressure is analysed [14, 82, 83]. This filtration was carried out with a constant pump power, which corresponds more closely to a constant-pressure filtration with declining flux. The trends described in these papers thus cannot be directly applied to the filtration that was performed here.

5.2 Water Quality

5.2.1 CMF Filtration

There are several unexpected results in the WQ data shown in 16. Firstly, it is anomalous that such a significant decrease in the EC was seen after CMF. For the filtered influent and effluent, a decrease of 23.7% and 26.4% was measured respsectively, compared to values of around 10% which are typical in the literature for MF and UF [14, 63, 84–86]. In fact, many studies report no reduction in EC from MF and UF [87–89], which is logical because the size of the pores is too large to block dissolved ions [87, 90]. The salinity results also align with the EC results, as a decrease in the salinity is seen after CMF treatment for both influent and effluent.

One potential explanation is related to the construction of the crossflow loop (CFL). After Pump P-07, there is a check valve to prevent pressure from being applied to the wrong side of the pump. This means that, after the rinsing step of a CIP cycle, part of the CFL is filled with tap water which cannot be drained. This volume is approximately 30 L, compared to the full CFL volume of approximately 100 L. When the rest of the CFL is drained and refilled with feed water, the feed water will be somewhat diluted. Additionally, it is possible to make a mistake while draining the CFL by forgetting to manually open the air bleed valve. If this step is forgotten, the majority of the tap water in the CFL will not be drained.

To check whether this could account for the improved WQ of the permeate, a mixing model was developed using pH as an indicator, since the pH in the CFL is measured continuously throughout filtration. It was assumed that the CFL is perfectly mixed, which is reasonable considering the turbulence created by the high crossflow velocity. It is also assumed that the total outflow is equal to the feed rate, and that both the permeate and the concentrate have the same pH as the bulk pH of the water within the CFL. Thus it is not necessary to differentiate between the permeate and the concentrate. The initial pH once the CFL is then predicted based on Equation 12, and the pH at each time step is predicted using Equation 13.

$$pH_0 = -log\left[\frac{10^{-pH_{TW}} \cdot V_0 + 10^{-pH_{Feed}} \cdot (V_{Total} - V_0)}{V_{Total}}\right] \tag{12}$$

$$pH_t = -log\left[\frac{10^{-pH_{t-1}} \cdot V_{Total} + 10^{-pH_{Feed}} \cdot (Q_t \Delta t) - 10^{-pH_{t-1}} \cdot (Q_t \Delta t)}{V_{Total}}\right] \tag{13}$$

When it is assumed that the CFL was drained correctly, the model indicates that the pH stabilizes to that of the feed water within ten minutes. If the CFL is not drained properly however, there can be a significant dilution effect, as shown in Figure 25. In this iteration of the model, it was assumed that 80% of the CFL volume was filled with tap water. It can be seen that, for both filtrations, the pH does indeed follow the shape that would be expected if the WQ trends were caused by dilution. However, there is a large offset between the measured data and the model, with the model converging towards the feed pH much faster than the measured data, which does not reach the feed pH during either filtration cycle. The model parameters (tap water volume, total volume, feed and tap pH) were adjusted to see if the model could be made to match the observations, but this was unsuccessful. It should also be noted that this model assumes that the filtration cycle began immediately upon filling the CFL, while in reality there were a few minutes in between while the settings were input. Thus, the model should be even further from the observations than indicated on the plot.

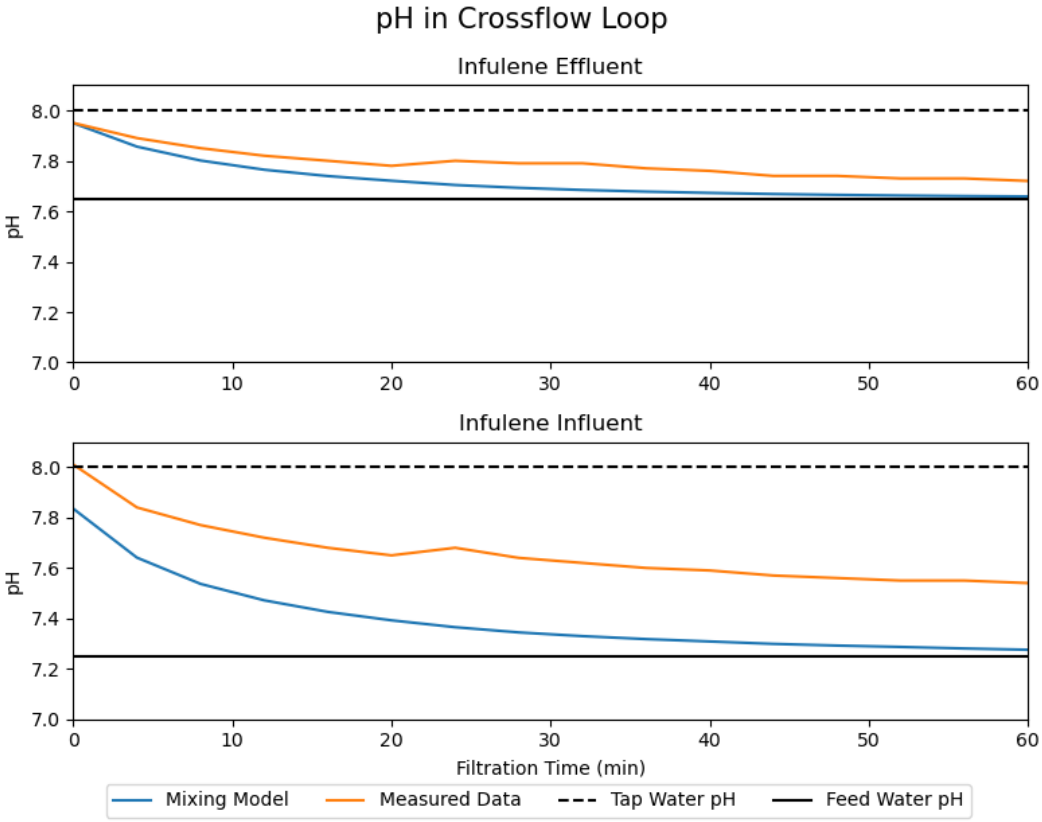

Figure 25: Dilution of Feed Water pH

This indicates that, while dilution may play a role in explaining these results, it cannot be the only factor. This is also supported by the increased pH observed in the permeate in Figure 18. In the first five minutes of both filtrations, a pH of around nine was measured in the permeate, which then decreased throughout the filtration. The pH of the feed water and the tap water was much lower than this, and the pH recorded in the CFL never reached this level during filtration. Similar trends are not observed in the literature [14, 63, 88, 89], nor should they be, considering the relatively large pore size of MF and UF membranes [90]. This could indicate that there was still sodium hydroxide somewhere in the system after the CIP process. While the rinsing was not finished until the pH in the CFL reached that of tap water, this is the only measuring location in the system. There is a possibility that CIP chemicals remained elsewhere in the system, such as in the permeate line, until filtration began. It is possible that these chemicals caused salts to precipitate, affecting the EC and other parameters once filtration began. However, similar flow rates were seen in the CFL and in the permeate line during rinsing as during filtration, and the volume of the line is quite small, so it should be expected that the line would be fully flushed by the flow. Still, there should not be a difference between the pH in the CFL and in the permeate line, so there must be some explanation.

One factor which could also contribute is that humic substances, which are abundant in wastewater [91], can be adsorbed by CMF membranes and become trapped in their pores [92]. These substances can in turn adsorb metals and salts [93–95]. This could also explain the fact that the EC increased throughout the filtration, as shown in Figure 18 – as the filtration cycle goes on, the adsorption sites become full and more ions are able to pass directly through the filter. These humic substances cannot be removed by a backwash [14, 77, 96], so the permeate quality is only restored after a CIP cycle. While this process may contribute to the measurements seen above, it is unlikely that it has an impact on the same order of magnitude as dilution or contamination with CIP chemicals.

The same processes could potentially explain the trend in the other parameters in Figure 18 as well. The filter acts as an absolute barrier to particles larger than its pores, which is why an increase in turbidity was never observed. Salinity, nitrate content, and nitrite content, however, are determined by dissolved charged species. Similar to EC, these can be diluted by tap water and adsorbed by humic substances which get trapped in the pores or in the cake layer. COD is partially determined by large particles and partially by dissolved species [97], so it also increases but not back to the level of the feed water. Similarly to COD, redox potential may be influenced by both dissolved and suspended particles, which could explain why it does not fully return to the feed value during filtration. However, no literature could be found on this topic.

If there was leftover sodium hydroxide left in the system which contaminated samples, it may be tempting to use this as an explanation for the very high alkalinity levels as well. However, very high alkalinity was also measured in tap water and river water. Additionally, the phenolphthalein alkalinity was generally very low compared to the total alkalinity and was often equal to zero. This indicates that the contribution of OH^- to the alkalinity is very low [98], which would not be expected if NaOH was a significant factor. No literature could be found which reported alkalinity in a comparable range for any of the sample types, which indicates that something may have gone wrong with the measurements. In particular, the titrant was prepared in advance by the lab technician. Several bottles were available around the lab, all of which had different concentrations. It is possible that the bottle of sulfuric acid used for this test was mislabelled and was weaker than indicated, which resulted in more acid being needed to reach the indicator pH.

Another interesting result is the high levels of many heavy metals in all samples. The concentration of aluminum, for example, was measured in the range of several mg/L in the wastewater samples and in the river, while other research in rivers in southern Mozambique found concentrations of 20 - 200 mug/L [99, 100]. Similar trends are seen for other heavy metals, including lead and arsenic [99, 101]. However, these studies were conducted in rural areas, and no literature could be found which focused on Maputo. Maputo has significant sources of potential heavy metal contamination, including leachate from open landfills [102, 103] and untreated industrial effluent which is discharged to the rivers, including the Infulene [104, 105]. Industrial pollution such as these can lead to very high levels of metals in surface waters, even levels significantly higher than the ones measured here [106–108]. A large part of Maputo's water supply comes from groundwater sources [109], which are particularly vulnerable to contamination due to the geology of the area [109, 110]. Since this water would eventually end up in the Infulene WWTP via the sewer system, this could explain the high levels of heavy metals.

5.2.2 Infulene WWTP

Besides the anomalies on the results regarding the CMF filtration of the pilot plant, there are several discussion points when comparing the water quality parameters of the influent and effluent of the WWTP and the Infulene river.

One anomaly in the WQ data, shown in Figure 16 is that the effluent of the WWTP has higher EC, turbidity, COD, and nitrate content than the influent of the WWTP. This means that the quality of the wastewater is actually worse after primary treatment. This is in agreement with the water quality data collected by the operators of the Infulene WWTP. This time series, shown in Figure 19 shows that, for each water quality parameter, the quality of the effluent can be worse than that of the influent, although it is not always such. An operator of the WWTP who was asked about this stated that they were aware of the issue and that it had been the case for quite some time, but they were not aware of what was causing the problem. It should be kept in mind that the wastewater is highly variable, as its composition depends on the amount of sewage generated, proportion of sewer drainage versus septic tank contents, and precipitation patterns, among other factors. Additionally, rapid changes in quality are reflected in the time series, and the time series ends more than a month before these samples were taken.

It appears anomalous that the effluent of the WWTP has a higher turbidity than raw sewage by 69%, since it was expected that the treatment would have decreased the turbidity [42]. Firstly, this is in disagreement with the general trend of the time series in Figure 19, where the effluent was more turbid than the influent only 2 times out of 14, once by 10% and by 170% . Figure 19 also shows the high variability of the inflowing WW, which shows a standard deviation of 19 NTU for the influent and 21 NTU for the effluent, highlighting the fact that inflowing sewage can vary greatly for the reasons explained in Section 4.2. Nevertheless, there might still be possible reasons for the increase in turbidity: one cause could be algae formation. Since the WWTP is biologically active and has an average hydraulic retention time of 14 days, algae can form if enough organic matter and nutrients are present in the water to create favourable conditions. Another promoter of algae growth is sun radiation [111], which increases the water temperature and stimulates algae to grow. This is a possible contributor given that the ponds at the WWTP are not covered. Besides algae growth, the constructed wetland can have an influence on the increased turbidity as well, since Water going through the beds of the CW can drag soil particles with it. Furthermore, between the endpoint of the CW and the effluent discharge point, water goes through a small stream where soil particles can also be brought into suspension and thereby increase the turbidity even further.

Another factor that did not meet the initial expectation is the increase of EC in the WWTP. EC gives indication on the ions' presence in water, and therefore of minerals, salts and pollutants as well. It was therefore hypothesised that the treatment would have decreased the EC, but it can also be seen in the time series that the EC of the effluent is generally higher than the influent. The available literature on this is contradicting, as different types of WWTP can increase or decrease the EC levels. Studies conducted by Gautam et al [112] and Gao et al. [113] show how wastewater can both increase and decrease after a WWTP and that soils irrigated with effluent of treated wastewater experience an increase in EC by up to 57%, while research conducted by Levlin [114] in Sweden shows how EC decreases throughout the WWTP. Besides the possible malfunctioning of the WWTP which in case would need to be further investigated, there are more possible explanations for this: the water spends about 45 days in the ponds of the WWTP being exposed to sunlight, which induces evaporation. This reduction of volume increases the elements concentrations, which might lead the EC to increase. Another factor which intertwines with evaporation is water temperature, as water's EC increases with rising temperature due to the increased movement of water particles, which are then able to carry more charged ions and therefore increase EC [115].

The EC result is in accordance with the salinity, being also higher in the effluent than in the influent. This could be related to the high evaporation rates in September and October (Figure 12), which cause evaporation in the ponds of the WWTP and therefore increase the salinity [116]. Another contributor to the salinity increase could be the evapotranspiration caused by the CW, which is also supported by the results obtained by Teixeira [117] in his research about effect of CW on water salinity. However, research performed on WWTPs in similarly dry areas has not reported such dramatic increases in EC [118–120].

5.2.3 Uncertainty and Difficulties in Water Quality Test

TDS

The TDS measurement was conducted at the Infulene WWTP lab. For various parameters like EC, pH and TDS, sensors were used as described in Section 3.2.3. The TDS and EC sensor was a combined one, where most of the time a correlation between these two measurements is used to convert EC results into TDS. This correlation was missing, which is why TDS measurements just had the same value as for EC. Literature suggests, a ratio of 0.5 to 0.7 can be used for conversion for most types of water [121]. However, this still leads to high uncertainties, which makes it difficult to conclude from, especially if certain thresholds or regulations have to be met.

Instead, the gravimetric method offers more reliable and accurate measurements. The method is time intensive and requires a stable working environment, where inconsistencies in filtration steps and incomplete sample drying can be avoided. Unfortunately, the conditions during the end of the project did not allow for these tests, due to time constraints and limited facility access. Additionally, samples should be tested in duplicates, which was not possible in the end because of little remaining sample water. In future tests with the pilot plant, the TDS should be tested with the gravimetric method to ensure representative results, which can be compared to regulatory thresholds and requirements of potential users.

TSS

The TSS measurements were conducted in the lab of the Faculty of Chemistry at UEM. The results were obtained using filtration with a paper filter with a diameter of 102 mm and a pore size of 1.5 micron. Unfortunately, the tests did not result in the expected outcome. While the tap water sample measured the overall highest TSS amount, the influent sample had less TSS than the filtered one after CMF treatment. From visual observations, it was clear that the filters for the WW-II and WW-IE samples retained the most solids, though this was not confirmed by the quantitative results. Therefore, the results cannot be used for the compliance assessment with the different regulations of the use cases.

These inaccuracies are most likely caused by certain factors during the testing procedure. First of all, the tests were performed in a working environment, where moisture and dust potentially had a high influence. Second of all, an additional error source could be the folding and transport process of the paper filters, where it was unavoidable to contact the filters. Even though the TSS tests were performed twice, a second repeat was not possible due to time and access constraints. For future research it should be ensured, that TSS measurements can be performed in a more isolated and protected environment.

Total Coliforms & E. Coli

The tests for total coliforms and E. Coli were performed at the microbiology lab of the chemical engineering faculty at UEM using the Colilert-18 method.

All samples were tested in duplicates, although some samples in the first test batch were not diluted enough and their results went out of range. In the second test batch, these samples were diluted for the expected ranges. However due to ongoing protests in Maputo, access to the facility for obtaining these results was denied. Consequently, the incubation time of these samples exceeded the recommended limit of 24 hours. Due to the extended time, colonies can form in wells in which they would have not developed under normal conditions. Thus, more wells develop colour, which increases the difficulty to make reliable counts, especially with the dilution effects. In the end, those results were still used because they were in similar ranges to the previous results from the first batch and can be used for qualitative assessment. Still, uncertainty remains about the exact quantitative value and tests should be repeated with correct incubation time.

ICP

The ICP tests were performed for all samples. Multiple standard samples were used for calibration, ranging from 0.25 to 4ppm. Each metal was measured at several different wavelengths for each sample, which resulted in vastly different results. Generally, the different wavelengths should all give comparable results, but this was not the case during this analysis.

Usually, a standard sample with a known concentration of metals is used for choosing the most accurate wavelength of the analysis, though this was not available during the tests. As a result, it is not possible to choose a correct value, since similar wavelengths result in values which are far apart from each other. Additionally, most of the results for alkali metals are out of range, since the calibration was only done until 4 ppm. Therefore, each result above 4 mg/L is measured out of calibration range and gets extrapolated. This leads to a lot of uncertainty, which does not allow quantitative statements. Conclusions can rather be drawn from a more qualitative perspective, where a threshold from a water regulation has been most likely reached or not.

For the following compliance assessment 5.2.4, the ICP results were still included, since they can still give an indication. These values were averaged over all measured wavelengths and should be viewed with caution and are not meant to be definitive. It should also be noted that the ICP results for sodium, magnesium, and calcium were used to calculate hardness and SAR. Since the initial ICP measurements cannot be trusted, the calculated values must also be viewed with scepticism.

5.2.4 Compliance with Water Standards and Regulations

As previously discussed, the results of the filtered samples indicate dilution with tap water in the beginning of filtration cycle 1 of both batches. Therefore, those results as well as the fully mixed are not suitable for comparison against regulation standards, since the values are positively influenced. Instead, the samples of filtration cycle 3 (WW-II/IE-F3-15) are used due to a better representation of actual values which can be expected in a fully applied solution.

The following tables indicate if certain thresholds are met or not. For comparison, multiple guidelines and standards are used since Mozambican regulations lack detailed thresholds. The following tables are colour coded in which; green equals satisfaction of all standards, while yellow indicates that the result is in the range of accepted values, but does not comply with all standards. Red denotes a lack of compliance.

Industrial cooling

As mentioned in the methodology for water quality requirements (Section 3.2.2), the standards for cooling water can differ greatly. The table below indicates thresholds from literature as well as from a potential user, the central thermal power plant in Maputo.

Cooling Water	**Requirement/Threshold**			**Results**		**Comments**
Parameter	*Magara (2009)*	*ISO (2020)*	*CTM (2020)*	WW-II-F3	WW-IE-F3	
pH	6.5 - 8.0	6.5 - 9.0	7.73	7.83	8.00	
EC [μS/cm]	800	3000	523	1239.00	2480.00	
E. Coli [CFU.MPN/100ml]	1000	200	n.s.	250.00	0.00	
TDS [mg/L]	n.s.	5000	371	1239.00	2480.00	Same results as EC, due to missing correlation
TSS [mg/L]	n.s.	10	10	n.m.	n.m.	
Turbidity [NTU]	n.s.	n.s.	3.10	0.56	0.19	
Total Hardness [mgCaCO3/L]	200	250	136	181.55	262.77	
SO4 [mg/L]	200	800	2000	n.m.	n.m.	
SiO2 [mg/L]	50	n.s.	11	n.m.	n.m.	
NO3 [mg/L]	10	n.s.	500	0.90	6.64	
NH3 [mg/L]	n.s.	1	no limit	n.m.	n.m.	
Fe [mg/L]	0.3	0.3	n.s.	0.00	0.00	
Cu [mg/L]	0.1	n.s.	n.s.	0.38	0.65	
Cl [mg/L]	50	300	86	199.41	438.69	
Na [mg/L]	50	n.s.	59	79.65	241.33	
Mg [mg/L]	n.s.	n.s.	19	28.52	50.50	
CO2 [mg/L]	4	n.s.	5.2	6.04	6.95	

Table 20: Comparison of Water Quality Results with Cooling Water Standards; n.s.: not specified; n.m.: not measured

In general, the results of both the effluent and influent show a lack of compliance with the standards for industrial cooling. In particular, the results for sodium and magnesium are high above the limit. This corresponds to the high EC values, which are not acceptable for most cooling applications. High electric conductivity is likely to cause impairment such as corrosion or scale deposition. Low values can also reduce evaporation losses, which is why this parameter is critical.

The requirements for the CTM are only met for pH, turbidity, nitrate and iron. Everything else is high above the accepted limit, which leads to the conclusion that the treated water from the CMF pilot plant is not suitable for this user at this moment. The CTM has on site treatment which includes desalination, but the presented values are pre-treatment requirements. Future improvements could be achieved with testing different settings at the pilot plant because the membrane performance is dependent on the type of configuration. In addition, the final water quality after CMF treatment is also dependent on the input. Overall, the influent from the Infulene WWTP achieved better water quality results than the effluent. This is contradicting since multiple treatment steps are in between, which are supposed to improve the quality. In a full scale application, a detailed assessment of the Infulene WWTP treatment efficiency should be considered, since the effluent will be the main source for the secondary CMF treatment. Nevertheless, the parameters which are determined by soluble compounds are unlikely to improve by a large enough margin to make the water suitable for the CTM.

Even though the water quality after CMF treatment is currently not sufficient for the CTM, more potential users for cooling applications could be identified, like the Central Bank of Mozambique. A user which does not perform evaporative cooling is likely to have much lower water quality standards. Some parameters are still in range for use at the CTM, but it is unlikely that any major improvements will be achieved in reducing EC, TDS and hardness due to the inherent characteristics of CMF. A potential user in the future should either have less strict water quality requirements or on-site treatment to account for the increased values.

Concrete Production

The relevant parameters for water in concrete production are listed below, including test results.

Concrete Production	**Requirement/Threshold**		**Results**		**Comments**
Parameter	*Fausta (2016)*	*Gulamussen et al. (2021)*	WW-II-F3	WW-IE-F3	
pH	6.5 - 8.0	6.5 - 8.0	7.83	8.00	
COD [mg/L]	664	500	16.00	91.40	
E. Coli [CFU;MPN/100ml]	1000	500	250.00	0.00	
TDS [mg/L]	100	5000	1239.00	2480.00	
TSS [mg/L]	67	10	n.m.	n.m.	TSS results were highly unreliable and inaccurate. thus not included
SO4 [mg/L]	150	2000	n.m.	n.m.	
NH4 [mg/L]	5.8	n.s.	n.m.	n.m.	
NO3 [mg/L]	10	500	0.90	6.64	
NH3 [mg/L]	n.s.	no limit	n.m.	n.m.	
Zn [mg/L]	0.1	n.s.	0.08	0.22	
Pb [mg/L]	0.3	n.s.	0.88	1.52	
Cl [mg/L]	no limit	1000	199.41	438.69	
Color	Pale yellow	Colorless or pale yellow	colorless	pale yellow	
Odor	no smell	Odorless	no smell	no smell	

Table 21: Comparison of Water Quality Results with Concrete Water Standards; n.s.: not specified; n.m.: not measured

Overall, most parameters are in line with the required ranges for concrete production. There is still some uncertainty regarding the TDS, since the sensor gave the same values as for EC due to a missing correlation between the two parameters. Additionally, the TSS results were unreliable for most samples and are not included for that reason. A repeat of the testing procedure was not possible because of the ongoing protests in Maputo during the last weeks of the research, which is the same reason why sulphate tests could not be conducted. These tests should be performed in future research. Tests for ammonia and ammonium were initially considered, but ultimately fell out of scope for this project. In water, ammonium reacts to ammonia, which makes it difficult to test. Since there are no threshold values for ammonia, tests were neglected.

As for heavy metals, zinc and lead have significantly higher concentrations in comparison to the researched limits. These increased concentrations could result in a decreased mechanical properties of the concrete and could also pose a health hazard to exposed workers or leach out of the concrete once it is in service. However, it has been shown that by properly implementing coagulation into the filtration process, more than 90% of heavy metals can be removed, including lead and zinc [52, 122, 123]. This may take some significant optimization, but could greatly expand the potential use cases for the treated wastewater.

Car Wash

The interviewed car wash businesses in Maputo used mostly tap water for their daily activities, while having no particular quality thresholds for the water they use. General requirements revolved around the water being transparent, having no smell or large particles. Overall, the treated CMF water can fulfil these requirements, even though the treated Infulene effluent had some pale yellow colour. One company demanded drinking water standards, since employees are consuming the water as well, which is realistically not achievable.

The authorities in Mozambique do not define any quality standards for water use in car wash businesses. However, regulations exist in other countries, which were used for comparison.

Car Wash	**Requirement/Threshold**			**Results**		**Comments**
Parameter	*Western Australia water reuse guidelines (2024)*	*Malaysia water reuse standards (1996)*	*South Africa water quality guidelines (1996)*	WW-II-F3	WW-IE-F3	
pH	6.5 - 8.5	6.0 - 9.0	5.0 - 10.0	7.83	8.00	
BOD [mg/L]	10	10	n.s.	≈7.8	≈8.4	Values were taken from FM samples, F3 samples should be in similar range
E. Coli [CFU;MPN/100ml]	1	bdl	n.s.	250.00	0.00	
TSS [mg/L]	n.s.	n.s.	25	n.m.	n.m.	
EC [μS/cm]	n.s.	n.s.	2500	1239.00	2480.00	
Turbidity [NTU]	2	5	n.s.	0.56	0.19	
NH4-N [mg/L]	n.s.	10	n.s.	n.m.	n.m.	
SO4 [mg/L]	n.s.	n.s.	500	n.m.	n.m.	
Fe [mg/L]	n.s.	n.s.	10	0.00	0.02	
Mn [mg/L]	n.s.	n.s.	10	0.00	0.00	
Cl [mg/L]	n.s.	1	500	199.41	438.69	
Total Hardness [mgCaCO3/L]	n.s.	n.s.	1200	181.55	262.77	

Table 22: Comparison of Water Quality Results with Car Wash Water Standards; n.s.: not specified; n.m.: not measured

From all analysed use cases, car wash seems to be already suitable based on the water quality results. Almost all results are in the acceptable parameter range. The samples from filtration cycle 3 of both batches were used for the comparison against water standards and regulations, yet these samples were not tested for BOD. However, the FM (fully mixed) samples were tested, whose results are presented in the table above. Across all tested parameters, the FM results were always slightly worse than the F3 results, which leads to the conclusion that BOD results should be at least in the same range. Some uncertainty still exists, but it is likely that BOD results are below the limit.

Similarly, the municipality stated equal water quality demands for the irrigation of parks as the car wash businesses. Furthermore, microbiological contamination, like E. Coli should be limited. From a water quality perspective, these requirements are met and thus this use case is suitable for reclaimed wastewater use.

Agriculture The irrigation water for agriculture in the Infulene valley stems mostly from the river or groundwater. Throughout the year, farmers have sufficient water supply to irrigate their crops, which makes them independent from the Infulene WWTP discharge. Additionally, farmers are most likely not willing to pay for water, which they previously accessed for free.

Therefore, the use case is not feasible and a comparison between the water quality of treated CMF wastewater and irrigation standards is not necessary. However, as part of the water quality analysis, the Infulene river water was tested. These findings can be important for analysing the irrigation water quality farmers use in the Infulene valley. This ultimately falls out of scope for this project because it does not directly contribute to answering the research questions. Regardless, the results can be found in Annex A.

5.2.5 Comparison with Logisticon's simulation

To have a broader overview on the functioning of the pilot plant, a simulation was run by a Logisticon's employee taking the quality parameters of the Infulene WWTP influent and effluent as inputs, and providing the expected quality parameters of the CMF treated water as outputs. The details of the model are not publicly available, so cannot be reported here. Due to data availability, this simulation was run according to 2 scenarios: Ultrafiltration (UF) and Nanofiltration (NF), 2 filtration treatments fairly similar to Microfiltration, with differences in pore size between each of them.

Table 23: Comparison of Logisticon's simulation with own influent (WW-II-F3-15) water quality data

Parameter	**Unit**	**WW-II/UF**	**WW-II/NF**	**WW-II-F3-15**
pH	-	7.3	7.3	7.83
EC	uS/cm			1239
Dissolved Oxygen	mg/L			6.04
TDS	mg/L	1100	800	1239
Turbidity	NTU	<1	<1	0.56
Redox-Potential	mV			-50.9
Resistivity	ohm.cm			807
Salinity	%			0.6
NO3-N	mg/L			0.21
NO2-N	mg/L			0.87
COD	mg/L	33.6	7.0	16
BOD	mg/L	72.2	12.0	
Ag	mg/L	0.2	0.2	0.56
Al	mg/L	4.6	0.4	4.09
As	mg/L	1.9	1.9	1.85
Ba	mg/L	0.0	0.0	0.01
Be	mg/L	0.0	0.0	0
Ca	mg/L	12.7	1.2	25.68
Cd	mg/L	0.2	0.2	0.25
Co	mg/L	0.0	0.0	0.01
Cr	mg/L	0.0	0.0	0.02
Cu	mg/L	0.3	0.3	0.38
Fe	mg/L	0.0	0.0	0
K	mg/L	26.6	26.6	25.39
Li	mg/L	0.2	0.2	0.38
Mg	mg/L	27.9	2.7	28.52
Mn	mg/L	0.0	0.0	0
Na	mg/L	105.0	105.0	79.65
Ni	mg/L	0.4	0.4	0.42
Pb	mg/L	0.8	0.8	0.88
Se	mg/L	1.2	1.2	1.16
Sr	mg/L	0.1	0.1	0.08
Tl	mg/L	8.5	8.5	7.66
U	mg/L	0.9	0.9	1.14
V	mg/L	0.0	0.0	0.01
Zn	mg/L	0.1	0.1	0.08
Cl	mg/L	190.0	190.0	199.4
Phenolphtalein Alkalinity	mg/L			5.7
Total Alkalinity	mg/L		50.0	8.4
HCO3-	meq/L		1.5	0.0
Hardness	mgCaCO3/L		14.6	181.6
SAR	-			2.6
TSS	mg/L	<1	0.0	
E.Coli	MPN/100ml	<100	0.0	250
Total Coliforms	MPN/100ml	<100	0.0	5355

Table 23 presents the comparison of the Logisticon's simulation with the results obtained from filtering Infulene's WWTP influent. The simulation is in agreement with the expected results, such as the bare removal of ions an metals, which happen to be too small in size to be filtered. Discrepancies can be found when comparing Alkalinity, where the filter appeared to operate better than expected. On the other hand, the Hardness of the wastewater came out to be greatly higher than expected by the simulation, which appeared to have increased during the filtration cycle, which might suggest unexpected mixing, dilution or contamination of reagents in the pilot plant. Furthermore, discrepancies between the expected and real E.Coli and Total Coliforms concentrations appear as well. One possible reason could be the initially very high concentration in the influent of those, supported also by the longer incubation time experienced by the samples.

Table 24: Comparison of Logisticon's simulation with own effluent (WW-IE-F3-15) water quality data

Parameter	**Unit**	**WW-IE/UF**	**WW-IE/NF**	**WW-IE-F3-15**
pH	-	7.7	7.7	8
EC	uS/cm			2480
Dissolved Oxygen	mg/L			6.95
TDS	mg/L	1100	800	2480
Turbidity	NTU	<1	<1	0.19
Redox-Potential	mV			-61
Resistivity	ohm.cm			402
Salinity	%			1.3
NO3-N	mg/L			1.5
NO2-N	mg/L			bdl
COD	mg/L		14	91.4
BOD	mg/L		0.5	
Ag	mg/L	0.7	0.7	0.47
Al	mg/L	7.2	0.7	8.56
As	mg/L	3.0	3	3.37
Ba	mg/L	0.0	0	0.02
Be	mg/L	0.0	0	0
Ca	mg/L	20.0	2	21.95
Cd	mg/L	0.5	0.5	0.47
Co	mg/L	0.0	0	0.04
Cr	mg/L	0.1	0	0.05
Cu	mg/L	0.7	0.7	0.65
Fe	mg/L	0.0	0	0.02
K	mg/L	79.0	79	88.8
Li	mg/L	0.4	0.4	0.35
Mg	mg/L	54.5	5.5	50.5
Mn	mg/L	0.0	0	0
Na	mg/L	268.0	268	241.33
Ni	mg/L	0.5	0.5	0.52
Pb	mg/L	1.4	1.4	1.52
Se	mg/L	1.9	1.9	2.15
Sr	mg/L	0.2	0.2	0.17
Tl	mg/L	15.3	15.3	16.73
U	mg/L	1.5	1.5	1.70
V	mg/L	0.0	0	0.03
Zn	mg/L	0.3	0.3	0.22
Cl	mg/L	491.0	491	438.69
Phenolphtalein Alkalinity	mg/L			189.17
Total Alkalinity	mg/L		70.0	1472.82
HCO3-	meq/L		3.4	17.94
Hardness	mgCaCO3/L		21.2	262.77
SAR	-			7.14
TSS	mg/L	<1	0.0	
E.Coli	MPN/100ml	<100	0.0	0
Total Coliforms	MPN/100ml	<100	0.0	10875

As for the effluent treatment comparison, similarities and discrepancies appear as well. The monovalent ions and heavy metals concentration fall around the expected range and order of magnitude, as it happened for the influent, while Hardness and bacterial concentration also show similar discrepancies which were faced with the influent. The treated effluent however shows a TDS concentration higher than expected, of which as of now the most reasonable explanation it the unreliability of the TDS measurements already explained in Section 5.2.3. On the other hand, there are some discrepancies which do not appear in the influent comparison, but do appear in the effluent comparison. The first one is regarding the COD level, which turned out to be higher than expected by the analysis. One possible reason could be the presence of organic compounds in the water that are not filtered by the CMF, which could also be seen from the supposedly post-dilution trend of COD in figure 18.

5.3 Stakeholder Analysis

5.3.1 Possible Change in Stakeholder Roles

Meeting with experts in the water sector, and interviewing AIAS and FIPAG, contributed to clarify the present and future relevance of government organizations in a reclaimed wastewater project. As AIAS is the current governmental organization responsible for developing water sanitation infrastructure across towns and urban centres of the country, their interest in reclaimed wastewater was considered of central relevance. However, for future development and management of water sanitation infrastructure, the responsibility might be divided between AIAS and FIPAG, with FIPAG being responsible for large urban centres of the country. Therefore, for continued research on the feasibility of developing and operating a reclaimed wastewater system in Maputo, FIPAG may play a central role in providing insights into funding and development opportunities.

5.3.2 Conditions of Stakeholder Interests

From the interview results of experts, AIAS and FIPAG, it became clear that a condition for their interest in a reclaimed wastewater system was that the project is financially sustainable, with capital and operational costs being covered by revenues, without considering possibilities of subsidies. In addition to this requirement, FIPAG considered to only be interested if the production and supply costs of the reclaimed wastewater compares to these costs for their current drinking water system. Considering that FIPAG likely would be a central stakeholder for funding and developing a reclaimed wastewater system, their conditions for interest should be considered critical for the feasibility of such a project.

From the interview results from the research of Fausta, ten out of eleven responses stated interest in trying to use reclaimed wastewater as a part of an experiment. However, in the research by Fausta there was no follow-up questions concerning their conditions of interest. Therefore, it is uncertain whether concrete producers would be interested in using reclaimed wastewater if the water was delivered by water trucks, considering that the majority of the companies receive water via pipes [13]. Also, it is uncertain what price conditions the companies have for using reclaimed wastewater. In order to have more insights to their interests of reclaimed wastewater, follow-up interviews with the companies would be needed.

5.3.3 Representativeness of Stakeholder Responses

In interviews with representatives from AIAS, FIPAG, and the Municipality of Maputo, interest in reclaimed wastewater was expressed with the condition that supply costs and price are competitive with the current supply and price of piped drinking water. However, it should be noted that differing opinions may exist within these organizations, and the responses from interviewees should be seen as an indication of interest rather than a definitive opinion for the organizations. If further progress is made in evaluating the feasibility of a reclaimed wastewater system, stakeholders should be re-engaged to confirm their level of interest.

Furthermore, the total amount of car wash businesses and concrete producers around Maputo is yet unknown, as is the representativeness of the sample of interviewed businesses. The results of the interest of the car wash businesses and concrete producers are therefore only an initial indication that there is interest in reclaimed wastewater in these industries, under certain conditions. In order to ensure that the interview responses are representative for all the businesses in the city, a statistical analyses has to be conducted with sufficient sample sizes.

5.4 Water Balance

5.4.1 Infulene River

5.4.2 Uncertainty of Data

Difficulties in data availability and accuracy were a main driver behind changing the water balance from a daily assessment to a monthly one. The informative value of the water balance benefits greatly from more reliable and daily data. This improvement has a direct effect on cost calculations, as well as statements about possible water supply for reuse and scalability. The following paragraphs show the challenges of the used data in detail.

Precipitation
The source for the precipitation data in the water balance is the national meteorology institute in Mozambique, which operates weather stations across the country. In comparison to the remote sensing data from the CHIRPS dataset, there were significant differences in total average precipitation. On a yearly basis, over the 11 years, the INAM dataset recorded 150mm more precipitation. While the pattern in monthly average precipitation is rather similar, the quantitative difference is significant, which can result in uncertain calculations for the water balance. Figure 26 shows the mean of both datasets for each month throughout the time series. The uncertainty interval shows the area where the true value most likely lies.

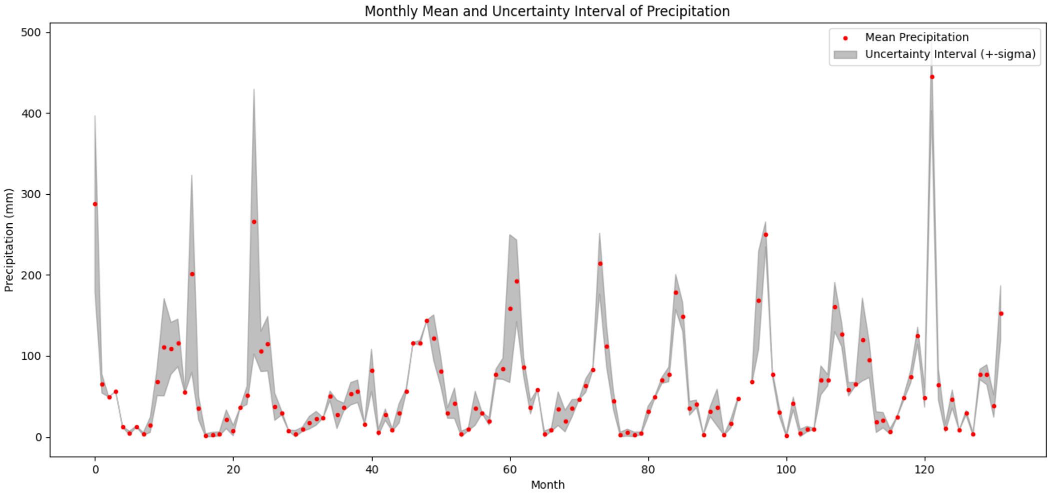

Figure 26: Uncertainty in Precipitation Data

In general, in months with high precipitation amounts the uncertainty increases, whereas months with low precipitation usually have lower uncertainty intervals. Since the main focus of the water balance is to assess the situation during drier months, where water is scarce, the precipitation data is more trustworthy. This makes estimations for those months more accurate than in the wet months. This is more important for the analysis, thus both datasets could have been chosen for the calculations due to similar values for dry months. Still, locally recorded data from INAM was selected, since measurements from actual rain gauges in the desired area are more reliable.

Evaporation
The evaporation data used from MODIS16 is a remote sensing application. The satellite records data over a certain area every 8 days. For the period in between, there are no actual recordings, which means that the value for each day in between is divided equally from the 8 day value. This creates uncertainty on a daily basis, since there are days without actual measurements. However, the water balance assesses the situation on a monthly basis, where sums of evaporation rates become more accurate. Furthermore, the actual MODIS16 dataset is refined after the completion of a full calender year, which further increases the accuracy of the data. This contributes to reducing the uncertainty surrounding the data.

However, the water balance did not close initially, which is due to uncertainties in all used data. Ultimately, the outcome of the balance was negative, indicating more water leaving the system of the Infulene WWTP than entering it. This may be because of high potential evaporation rates were used, which could be too high. This was not verified as no other usable dataset could be obtained due to time constraints and communication difficulties with INAM.

Inflow and Outflow of Infulene WWTP
Compared to previous research and analysis by Caltran (6912 m^3/d) [6] and Nessia (5682 m^3/d pm 1196 m^3/d) [13], the current inflow value seems low, especially considering the recent expansion of the facility. However, not the whole design area is connected at the time of this research – particularly the area surrounding Avenida Julius Nyerere is disconnected. Furthermore, pumps and mains need maintenance and repair around the sewage

network, which further reduces inflow rates. The sewage network in Maputo is combined, meaning rainfall runoff will enter the sewer as well. This dependency on rainfall events can lead to higher inflow rates similarly to observations and measurements from prior research. During the time of the research, precipitation events were scarce, thus further supporting the low inflow values.

The Infulene WWTP operates a flow meter at the inflow section after the main solids and sludge removal and before wastewater enters the anaerobic treatment ponds. This equals the total inflow, since water trucks discharge the water into the system before this point. Measurements are instantaneous, though flow measurements are recorded every three minutes. However, it was not possible to export this data, since the staff of the facility does not have access. A possibility to retrieve this data is to contact the contractor of the Infulene WWTP or the main manufacturer of the control system, which is a Chinese company. Initially, the inflow was a gravity based system, whereas nowadays the main dependency is the activation of two pumps (one on duty, one on standby) prior to the the measurement point. Each pump has a maximum capacity of 468 m^3/h and activation impacts flow measurements. This is important to note, since actual inflow values do not seem to be much dependent on the main drainage canal.

On the contrary, the outflow did not have a flow meter, so there is no data to be obtained by the contractor or manufacturer. Here, flow measurements could be conducted in future research with the required equipment. This data is equally as important since it determines the actual available water for reuse.

5.5 Financial Feasibility Assessment

From the results in Section 4.5.4, it can be seen that the price of reclaimed wastewater is on average higher than the price that companies currently pay for the FIPAG delivered water, both for the pure production cost and for the delivery by trucks. With the current situation, wastewater delivered by trucks and wastewater delivered with piping system are respectively on average 86% and 14% more expensive than tap water.

5.5.1 Relative contribution to total selling price

Total production cost
In Sections 4.5.1 and 4.5.2 the different prices for each item were shown, however it is of high relevance to see how much each item contributes to the total production cost. Figure 27 illustrates how the main costs are attributed to the Logisticon container cost, service and cleaning reagents and spare parts. Although the prices of service and cleaning reagents are difficult to change, the price of the Logisticon parts could be reduced by choosing another supplier. Having a (semi-)local supplier would also allow reduction of the shipping cost and the cost of spare parts. Most of the materials used to produce the container could also be supplied locally, which could allow for a local construction of the plant. Another opportunity is to ask for inquiries to other suppliers which deliver similar technologies and find less expensive solutions. However, since most of these suppliers are commonly European, American or Asian, relatively high fees might still be expected.

A more radical approach is to divert to another membrane technology. The high costs of such membranes are mainly due to the materials (alumina, zirconia, titanium oxide) in them, since they are expensive ceramics and titanium is also a critical raw material. Therefore, opting for a membrane composed of different materials could also cut down costs greatly. Plenty of research has been directed on developing ceramic membranes with cheaper materials [124–127], indicating potential for expanding this technology and making it more accessible for more cases, possibly including this one. Research conducted by Vegas et al. [128] shows how carbon-activated membranes can have an effect on wastewater effluent, and the reclaimed wastewater has a production cost of 0.21 $\$/m^3$.

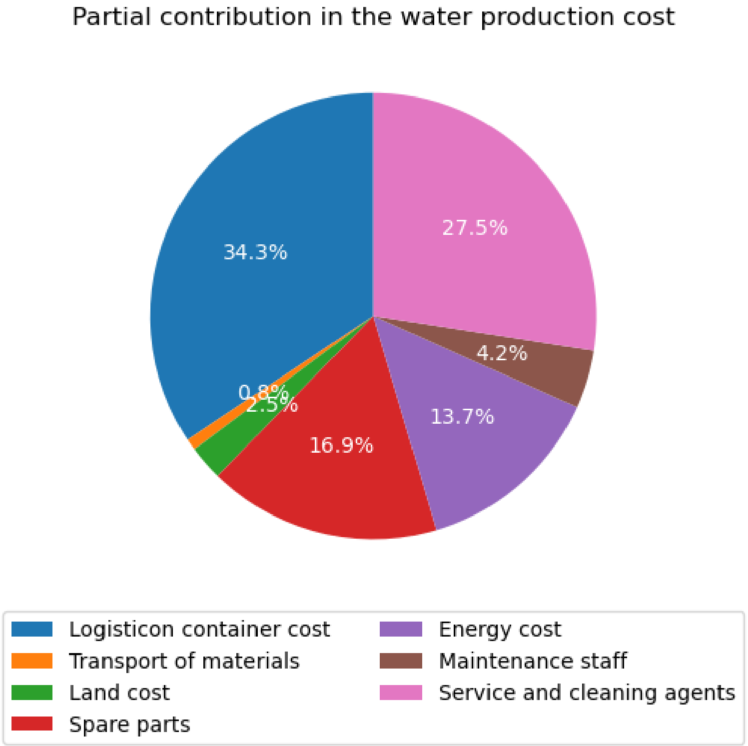

Figure 27: Relative contribution of each item to the total production cost

Total supply cost
Among the two different scenarios, the water truck delivery is about 20 times more expensive. A large contributor for that is fuel consumption, which accounts for about 50% of the O&M costs of the water trucks. Although this appears to be the most suitable scenario to deliver water to some use cases, its current price prohibits it unless the total production cost would be decreased drastically. This cost could be lowered by possibly having a decentralised CMF treatment in strategic locations between the users and have the effluent of the Infulene WWTP delivered by piping to the treatment locations. This would require a different treating capacity and different capital costs, therefore a new scenario for this should be studied if wanting to explore possibilities.

The piping cost is instead relatively low, as installation costs are contained as well as operational costs. This piping was designed to only delivered water to the CTM, therefore if wanting to explore different use cases for this solution, costs should be re-evaluated. However, the inconsistent water demand of use cases such as concrete producers and car washes makes it more challenging to implement this supply scenario. It is also important to take into account the possible expansion of the CTM, which might lead to increasing the discharge by designing a greater pipe or implementing 2 pipes.

5.5.2 Inclusion of external benefits

Because water is central to multiple sectors, it is important to take externalities into account to estimate the total impact of reusing reclaimed wastewater for new purposes. In the methodology presented by Molinos-Senante et al. [129] the external benefits translate all the positive and negative consequences of treating wastewater into monetary units, which might include environmental, social, economical and health factors. Interestingly, Molinos-Senante et al. observed that around 25% of the WWTPs investigated in Spain have a negative profit when considering only internal costs, but they all generate net positive profit when considering external benefits as well. In this case, treating the effluent of the Infulene WWTP has a positive effect on the environment, as the wastewater discharged into the river has a higher level of pollution than the river itself. Sub-section 4.2.2 shows how several parameters have an increased concentration in the location downstream of the WWTP, indicating that the WWTP worsens the water quality of the Infulene river.

Another factor which could be taken into consideration is the amount of drinking water saved thanks to delivering reclaimed wastewater to the local businesses. Although no water scarcity is currently present in Mozambique, only 65% of the people had access to adequate drinking water in 2021 [130], therefore alleviating pressure on the current drinking water supply can be seen as another positive external benefit of reclaiming wastewater. By assuming an average domestic water consumption of 80 litres/person/day [131], the total amount of saved drinking water could be potentially satisfy the needs of circa 14360 people. This could have a substantial impact on the local society, and could be potentially greater in the future when the sewage network would be further improved. However, it is important to note that the step between saving drinking water and making it available for the people is rather large, as parts of the city still lack a drinking water piping supply. Therefore to convert this potential available drinking water in actual available drinking water, several improvement works are necessary to allow for simpler access to a water supply for the people.

A major particularity of the methodology proposed by Molinas-Senante et al. and Färe is the introduction of the concept of shadow prices [129, 132] to account for undesirable outputs of water reclamation that are typically not attributed any market value, such as health benefits for local communities and environmental preservation.

Example of shadow price

Molinas-Senante et al. show how shadow prices can be used in cost-benefit analysis (CBA) to quantify externalities, which are often only described qualitatively. In wastewater treatment, resources like money and energy are spent to produce treated water (effluent) of higher quality than the incoming water (influent). Beyond cleaner water, pollutants are also removed during treatment. If these pollutants weren't filtered out, they would enter the environment, requiring future spending to mitigate their damage. Since the treatment process removes these pollutants, the need for these extra expenses is avoided. The authors account for these savings in the CBA as a negative cost, which essentially represents added income, alongside the income from selling the treated water.

Due to time constraints and the complexity of quantifying such indirect benefits, they were not included in the feasibility assessment presented in this report. It is possible that accounting for external benefits would positively impact the feasibility of this project.

6 Conclusions

This report has evaluated the feasibility of implementing ceramic microfiltration as a secondary treatment step for municipal wastewater. A CMF installation could potentially be installed at the Infulene WWTP, a major treatment station in Maputo which has recently been upgraded. The treatment plant is based around traditional biological treatment, including a new constructed wetland. If implemented, the CMF treatment would take place after the constructed wetlands and could improve the quality of the WWTP effluent sufficiently for industrial uses. In this way, drinking water can be diverted from industrial use and pressure on the system can be alleviated.

6.1 Pilot Plant

Over the course of this project, the CMF pilot plant in Zimpeto was restored to working order, although it it is currently only operable by manually controlling each component individually. Automatic operation remains impossible until certain sensors and valves are replaced with spare parts which must be specially imported to Mozambique. Still, this operation mode is sufficient for all basic filtration and cleaning functions. Additionally, documentation has been updated and a more hands-on manual has been created to assist future users in continuing work with the plant.

Filtration was performed with two batches of water – influent and effluent of the Infulene WWTP. With the effluent, a consistent transmembrane pressure was observed, along with a gradually declining membrane permeability. This indicates that the membrane was performing as expected during a CMF treatment. When filtering the WWTP influent, however, clogs formed in the system which had to be manually cleared by cycling one of the valves. This indicates that this water is not well suited to CMF treatment using the settings that were used for these tests. However, there is still plenty of room to adjust these settings and optimize the plant for this feed water.

One major limitation to the current experimental setup is the fact that the pilot plant is located at a defunct WWTP in Zimpeto and thus does not have direct access to treated wastewater. Water must be trucked in from Infulene and stored in a 500 liter tank. This means that there is not enough feed water to rinse the system between tests and tap water must be used instead. Since the system cannot be fully drained, there is inevitable dilution of the feed water at the beginning of a test. In addition, there is a potential to rinse the system insufficiently, resulting in cleaning chemicals being left behind in small quantities.

6.2 Water Quality

Water quality testing was performed on water samples before and after CMF treatment, as well as tap water and river water near the WWTP. The results of these tests were compared to standards for various industrial use cases, namely industrial cooling, concrete production, car washing, and the watering of municipal parks. Agricultural use was also considered, as the effluent of the WWTP is presently used by farmers for irrigation.

The water quality testing showed that there is a need for closer scrutiny at the Infulene WWTP. Despite the recent investments, the effluent of the plant is of worse quality than the influent in many respects, including EC, COD, and heavy metals. This may be a result of concentration by evaporation, since the WWTP is not yet at full capacity and the retention time is very long. The WWTP does, however, significantly decrease the BOD and the concentration of coliforms including E. Coli.

The treatment by CMF improved some factors of water quality, such as turbidity, COD, and coliforms. These are the parameters that correspond to larger particles. Factors such as EC and heavy metals were not improved by CMF treatment as they are determined by dissolved particles which are too small to be removed by the pores of the membrane. It should be possible to improve the removal of heavy metals by optimizing the coagulation process which is already built in to the pilot plant.

After CMF treatment, the water quality is still insufficient for industrial cooling and concrete production. For concrete, however, the critical parameters are heavy metals which could likely be brought into compliance with coagulation. For industrial cooling on the other hand, many parameters are far outside the allowable range and are not likely to be improved by further CMF treatment. The treated water is already sufficient for car washing and watering parks.

6.3 Stakeholder Analysis

The results of the stakeholder interviews showed interest in reclaimed wastewater technology among project funders, developers, and potential consumers. Representatives from Mozambican organizations involved in fundraising and project development, AIAS and FIPAG, expressed interest in creating water treatment and supply systems that incorporate reclaimed wastewater. However, a condition for their interest is financial sustainability: the revenue from producing reclaimed wastewater must cover production and supply costs, and these costs should be comparable to those of the existing drinking water system.

Potential consumers, including the car wash industry, the Municipality of Maputo, and concrete producers, also showed interest in using reclaimed wastewater. A common condition among these stakeholders is that reclaimed wastewater should be priced lower than their current water sources. The findings suggest that car wash businesses would be open to using water delivered by truck if this price condition is met. Similarly, the Municipality of Maputo indicated it could use its own fleet of tractor vehicles for supply which lowers supply costs. In general, stakeholders had few conditions on reclaimed wastewater usage outside of financial concerns.

6.4 Water Balance

The water balance assessed the monthly flows surrounding the expanded and improved Infulene WWTP, as well as the situation in the nearby Infulene river. The analysis showed that the Infulene river has sufficient discharge throughout the year for farmers to irrigate their fields. The farmers downstream of the Infulene WWTP are therefore not dependent on the effluent of the treatment plant, which in theory allows to use the total discharge for industrial reuse.

Furthermore, the Infulene WWTP in its current state has to deal with low inflow values due to disconnected areas in the sewage network, such as the Avenida Julius Nyerere. Therefore, current outflow values cannot sufficiently supply the water demand of the discussed use cases during the entirety of the year. Especially, in the drier months of April to August, there is not enough water available to supply the potential users. However, in the case of not supplying the central thermal power plant in Maputo due to insufficient water quality, the available reclaimed wastewater would meet the demand of the remaining use cases. In all future scenarios the Infulene WWTP discharges enough water for supplying the potential users, including the cooling water for the power plant. Additionally, the reclaimed wastewater supply can be scaled up, so that new users are identified since more water will be available.

6.5 Financial Feasibility Analysis

Conducting a Financial Feasibility Analysis shed light on the profitability of such a project by comparing the costs and revenues involved in the installation of CMF treatment at the Infulene WWTP capacity. The main capital costs appeared to be the cost of the Logisticon container including the filter and the spare parts, which together account for 50% of the total production cost. Besides, the maintenance of the CMF accounts for another 45% of total production cost, having service and cleaning agents as main contributor. This would account for a total production cost already higher than the drinking water cost, unless the CMF treating capacity would be brought to the maximum allowable value, which might be possible in the future thanks to the increasing capacity of the Infulene WWTP.

For the two supply scenarios investigated, the piping scenario appeared to be the most economically feasible. The supply with water trucks was found to be very costly, especially due to fuel costs.

Accounting for both production and supply costs it appears that only having a relatively high CMF treating capacity and supplying water by piping can be currently feasible, still accounting cost coverage and no profit. This currently excludes concrete producers and car washes as use cases, as for these trucks supply appears to be the most feasible. On the other hand, in the future it could be potentially feasible to consider the CTM as a user, given that the water quality would meet the standards.

6.6 Overall Conclusions

Combining the results of the different sections of this report, it seems that despite widespread interest in CMF treatment for industrial water reuse, there are some significant hurdles to be overcome before the technology can be implemented at scale. Water quality testing showed that the treated water was not suitable for use as cooling water at the power plant, but use for car washing and park watering would be possible. Use for concrete production requires some process optimization but should be achievable. On the other hand, the financial feasibility assessment showed that the delivery of water by truck made it much more expensive than tap water. The small scale of concrete producers and car washes makes piped connections impractical, while the municipality has its own tractors that can be used for park watering. This combination of quality factors and economic factors leaves only the municipality as a viable user, but the quantity of water they need is too small to justify the construction of a full-scale CMF plant.

Still, this is only an initial exploration of the feasibility of this concept. There is still significant improvement that can be done on the water quality through process optimization, and on the economics through consideration of other suppliers and membranes. Additionally, the water balance showed that the full outflow of the WWTP could be treated without compromising the ability of farmers to irrigate their crops and the stakeholder analysis showed that relevant governmental entities, water management experts, and end users are interested in the concept and willing to participate in further research. As such, the technology still shows promise for this context. While more work is needed to find the niche and the operating conditions for CMF treatment in Maputo, there is sufficient need and interest present to support this work.

7 Recommendations

There is still much work to be done to bring this project to fruition, as described in the following recommendations. It is worth noting that a number of these recommendations were intended to be part of this project, but were not possible because of civil unrest in Mozambique or because more work was needed than expected to repair the pilot plant. Future researchers should take into consideration the limitations of the current experimental setup and should be cautious about the political situation in Maputo.

7.1 Pilot Plant

There are still many opportunities for research with the pilot plant. This research focussed on making the plant operational and only did little testing regarding water quality. However, given the configurable nature of the operation, many things can still be improved. To facilitate experimentation with different operational settings, a more stable water supply is required. One option is to obtain a much larger supply tank, as the current 500 liter tank is only sufficient for one hour of filtration and does not allow the system to be rinsed with feed water. Alternatively, the whole installation could be moved to the Infulene WWTP so that it can be fed directly from the plant's outlet.

Similarly, there are still several critical broken components that prevent automatic operation of the pilot plant. Automatic operation is necessary for long-term testing, which is much more representative of how the technology would operate at scale. A priority should thus be made to replace or repair these components.

Once a stable setup is arranged, perhaps the most important factor to optimize is coagulation, as this determines the ability of the system to remove metals and other ions. Different coagulants should be experimented with, beginning with lab-scale jar testing. Coagulation should be optimized before other pilot plant settings, as the additional flocs in the water will likely affect the membrane fouling characteristics. After coagulation, the operation of the pilot plant can be optimized for the feed water by adjusting the recovery rate, feed rate, and crossflow velocity. The backwash interval and CIP interval can also be optimized. All of these parameters should be chosen to minimize operating costs per unit of filtered water, as well as minimizing the downtime of the plant.

Finally, only one batch of WWTP influent and effluent was tested during this project due to time constraints and political unrest. At the same time, it is known that there is significant variability in the quality of both streams. It would be beneficial to perform repeat filtrations with the same settings with different batches of water to see how consistently the system behaves.

7.2 Water Quality

Several of the water quality tests returned questionable results. In particular, the TSS values were inconsistent, the TDS sensor was not properly set up, the E. Coli tests could not be retrieved on the intended day, and the ICP results had very high variability due to the lack of a reference sample. It would be worthwhile to repeat these tests with the same samples to obtain more reliable results. Additionally, the Infulene WWTP already keeps time series for the parameters that are measured in their lab, but no such data is available for the other WQ indicators. To get a sense of the variability of E. Coli levels, alkalinity, and heavy metals, a long-term measurement campaign should be conducted.

At the same time, there is some concern about the operation of the Infulene WWTP, considering that many water quality variables are worse after treatment than before. To this end, an investigation should be conducted to determine how these factors change throughout the WWTP and test the hypothesis that evaporation is the cause. If indeed evaporation is a major contributor, it may be prudent to invest in coverings for the ponds. If the quality at the end of the primary treatment is improved, there is an increased likelihood that the water can be used for industrial purposes after secondary CMF treatment.

7.3 Stakeholder Analysis

The stakeholders that were of interest to interview in this project were experts in the water sector, AIAS, FIPAG, ESDM, the Central Thermal Power Plant and the Central Bank of Mozambique. However, ESDM, the Central Thermal Power Plant and the Central Bank of Mozambique were never interviewed as appointments were cancelled due to civil unrest, or because the interview requests never received a response.

Despite constant support and much appreciated efforts from colleagues at CEISA, the initial approach for contacting stakeholders in this project led to long delays and proved largely ineffective. This approach involved first sending formal letters and then visiting each organization's office to deliver the letter to the secretary's desk. When no responses were received after a considerable time, follow-up letters were delivered in person, which did not lead to more responses. Progress was only made after identifying people within the organizations and contacting them through phone calls or text messages. This more personal approach was generally well-received, led to quick replies and the successful scheduling of appointments. For the car wash businesses, the decision was made to visit the businesses without any prior appointment, to ask the daily manager spontaneously if they would be willing to partake in an interview. This method was also successful and proved effective.

For future stakeholder research, the approach to contacting organizations should be reconsidered. This project's experience showed that reaching out through formal channels, such as letters, led to long waiting times and limited response within a two-month project timeframe. In contrast, identifying specific contacts within organizations and reaching out directly by phone or text message was generally well-received and effective for scheduling meetings. Therefore, for future stakeholder analysis efforts building on this report, it is recommended to first find key contacts within the organizations of interest, then reach out directly by phone to arrange interviews.

For future research, it is recommended to retry efforts to interview the EMSD, the Central Thermal Power Plant and the Central Bank of Mozambique. Interviewing the EMSD would give insights into the conditions of interest from an operational point of view, as they are responsible for operating and managing the Infulene WWTP. Additionally, the Central Thermal Power Plant and the Central Bank of Mozambique are important potential users of reclaimed wastewater, but their specific water quality requirements and conditions for interest remain unknown.

7.4 Water Balance

Generally speaking, there is a need to improve the quality of the data required to establish the water balance of both the WWTP and the Infulene river. This concerns several components of the water balance, which are outlined below.

INAM records actual evaporation and other parameters, which could be used to calculate potential rates with the Penman-Monteith equation. For future research, acquiring this data from INAM is suggested in order to reduce the risks of over- or underestimating evaporation rates.

It is vital to acquire the measured inflow data of the WWTP, currently inaccessible (see Section 5.4.2), because it reduces the uncertainty of the inflow data and makes the water balance calculations more accurate. The only outflow data that could be provided by the staff of WWTP was one average value. In order to gain more insights about the fluctuations of water available for reuse throughout the year, it would be very beneficial to measure the outflow of the WWTP continuously and record this data as a time series. By improving the estimation of water availability through time, this could lead to more accurate cost estimations and forecasts for scalability. Generally, it should be noted that in order to identify potential losses throughout the treatment process, it would be good practice to systematically measure the piped input and output of each individual treatment facility within the WWTP. This data should also be recorded as a time series and analysed on a regular basis.

As explained in this work, collecting usable discharge data of the Infulene river was very difficult. One of the reasons was that the discharge measurements performed by ARA-Sul did not continue throughout the last decade. Also, when measurements were available, they were often collected at a location relatively far away from the WWTP. In order to be able to precisely assess the impact of the WWTP outflow onto the agricultural activities downstream of the effluent location, the discharge of the river up- and downstream of the effluent location should be measured. It is important to specify that the measurements should target the discharge rather than water levels, as the latter is harder to include in a water balance.

7.5 Financial Feasibility Analysis

The high total production cost appears to be an important contributor to the total water cost. In particular, the Logisticon-related costs greatly hamper the financial feasibility of this project. As future steps it is recommended to explore possibilities of having a different supplier, possibly more local. Furthermore, using a ceramic filter made with a different material could also decrease costs by a certain percentage.

Furthermore, the cost of water truck supply would make it non-feasible for several potential use cases. Therefore it is worthwhile to investigate further possibilities of lowering such a cost, such as a lower purchasing cost and the optimization of the truck driving route, since fuel is a major contributor as well. Possibly, having trucks with a higher capacity could also be an option to explore further.

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A Water Quality for Agriculture

Table 25: Threshold comparison for agricultural use (n.s. = not specified, n.m. = not measured)

Agriculture	**Requirement/Threshold**			**Result**	
Parameter	*FAO (2023)*	*South Africa water quality guidelines (1996)*	*Colorado State University (2014)*	**RW-U**	**RW-D**
pH	n.s.	6.5 - 8.4	6.5 - 8.4	7,37	7,49
EC [μS/cm]	3000	400	1500	1326,00	1335,00
SAR	9	2	n.s.	15,51	15,30
N (inorganic) [mg/L]	30	5	n.s.	n.m.	n.m.
HCO3 [meq/L]	8,5	n.s.	n.s.	n.m.	n.m.
TDS [mg/L]	2000	n.s.	n.s.	1326,00	1335,00
Fecal Coliforms (1000CFU/100ml]	1000	1000	n.s.	7777,00	3400,00
Al []mg/L]	5	5	n.s.	5,42	4,83
As [mg/L]	n.s.	0,1	n.s.	2,20	2,00
B [mg/L]	n.s.	n.s.	0.76 - 6	n.m.	n.m.
Be [mg/L]	0,1	0,1	n.s.	0,00	0,00
Cd [mg/L]	n.s.	0,01	n.s.	0,26	0,25
Cl [mg/L]	85	100	175 - 700	199,41	234,86
Co [mg/L]	0,05	0,05	n.s.	0,02	0,01
Cr [mg/L]	0,1	0,1	n.s.	0,02	0,02
Cu [mg/L]	0,2	0,2	n.s.	0,38	0,36
Fe [mg/L]	5	5	n.s.	0,00	0,00
Li [mg/L]	2,5	2,5	n.s.	0,30	0,26
Mn [mg/L]	0,2	0,2	n.s.	0,00	0,00
Na [mg/L]	69	70	46 - 460	106,03	103,73
Ni [mg/L]	0,2	0,2	n.s.	0,33	0,33
Pb [mg/L]	n.s.	0,2	n.s.	0,93	0,99
Se [mg/L]	0,02	0,02	n.s.	1,34	1,26
U [mg/L]	n.s.	0,1	n.s.	1,09	1,21
V [mg/L]	n.s.	0,1	n.s.	0,01	0,01
Zn [mg/L]	2	1	n.s.	0,09	0,09

The table above presents a comparison of the quality of the Infulene river with international standards for irrigation. The results show that the river exceeds threshold values for many important parameters, including E. Coli and various heavy metals which carry hazards for human health.

The permeate produced by the pilot plant is not a suitable replacement, as it also exceeds many of these thresholds. In many cases, it is worse than the river water. Additionally, local water management experts indicated that farmers would be unlikely to pay for clean water when contaminated water is available for free.

B Estimation of discharge fluctuations in the Infulene river

Fluctuations of the discharge of the Infulene river were estimated by combining water level data and a range of discharge "under normal flow conditions" obtained from literature [30].

The first step was to define a range of water levels considered to represent "normal flow conditions". In other words, extremely low or high water levels were filtered out using lower and upper thresholds at 2.5 and 97.5 percentiles (see Figure 28).

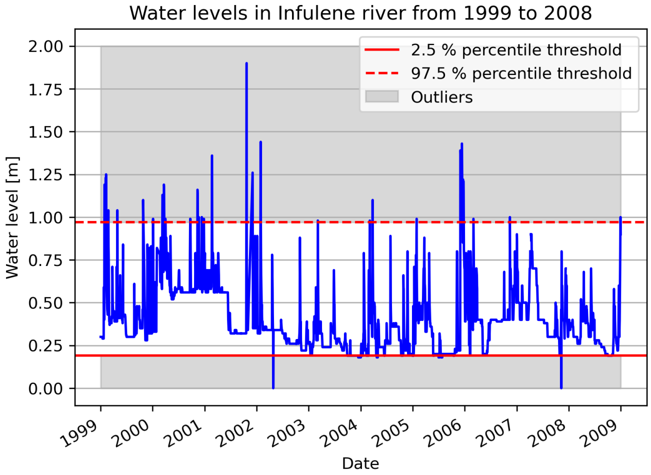


Figure 28: Definition of "normal" water levels in the Infulene river

Next, the lowest and highest remaining water levels were matched to the lower and upper boundary of the range of the discharge, respectively. The relationship between water level and discharge was assumed to be linear within their ranges. This provided an estimated time series of discharges from 1999 to 2008. This data was used to determine monthly averages of discharges over this period in order to gain insights about the seasonal fluctuations of the river flows. It can be observed in Figure 29 that the lowest average daily discharges occur in August and September. The corresponding discharge is around 117000 m^3/day. The overall daily discharge is around 171000 m^3/day.

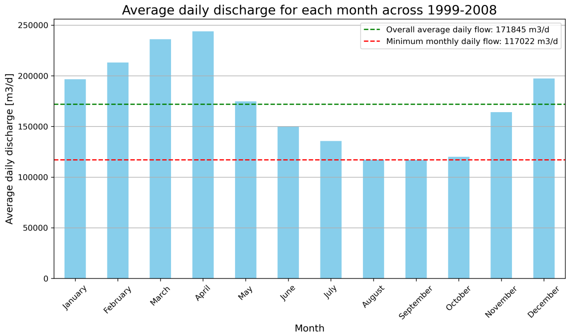


Figure 29: Estimated average daily discharge in the Infulene river for each month from 1999 to 2008

C Estimation of discharge fluctuations in the sewage system leading to the WWTP

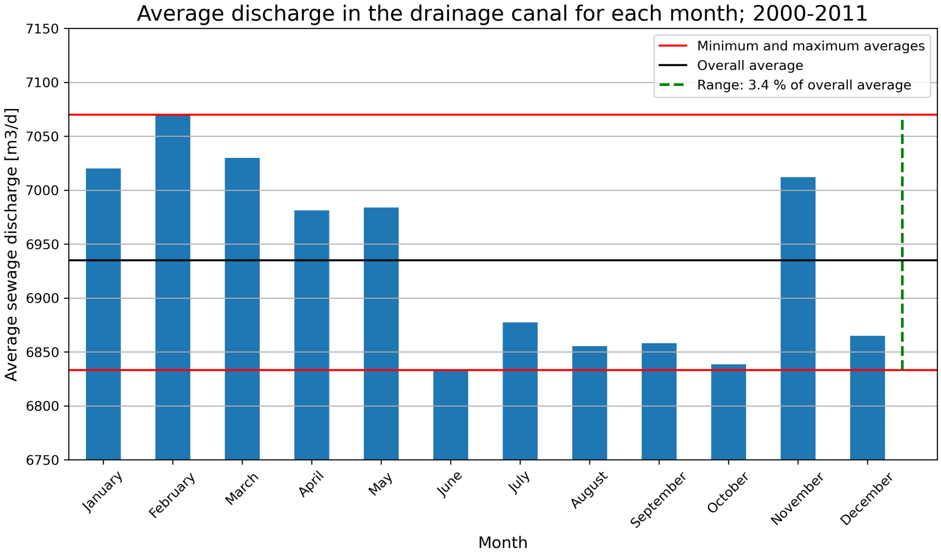


Figure 30: Average discharge in the drainage canal for each month; 2000-2011; based on measurements from ARA-Sul

Some fluctuations can be observed in the discharge of the sewage system leading to the WWTP. These fluctuations align with the seasonal weather fluctuations in the area of Maputo. However, the range of discharge values are contained within a range that represents less than 4 % of the overall average monthly discharge in the sewage. Therefore, the fluctuations in sewage flows, and accordingly in inflow of the WWTP, were kept constant throughout the year for water balance calculations.

D Supply cost calculation

The estimated costs of both supply scenarios are outlined in this appendix.

Piping

For piped supply, capital costs and O&M costs were considered. First, a reference value for the capital costs of the infrastructure, including both the purchase of PVC pipes and their installation, was provided by Professor Nelson Matsinhe. This value is equal to 53 \$/m. The approximate shortest distance between the WWTP and the power plant was measured on Google Earth and neared 2 km.

Next, the design flow was determined based on information provided by *Electricidade de Moçambique*. The water consumption of the central thermoelectric power plant of Maputo was reported to range between 7 and 25 \$/hour. Because this data was collected four years ago, and in order to ensure reliable water supply during high demand hours, the maximum boundary of this range was used as design flow.
In order to determine the necessary pumping power, the Darcy-Weisbach formula for friction head loss was used.

$$\Delta H = f \cdot \frac{LV^2}{2gD} \tag{14}$$

where:

- ΔH: head loss.
- L: length of the pipe.
- D: diameter of the pipe.
- V: velocity of the fluid.
- g: acceleration due to gravity.

Additionally, a constraint of required water pressure of 10 meters was added. Combined with an elevation difference of 1 meter between the WWTP and the power plant (i.e. the WWTP is located 1 meter lower than the power plant), the total head difference for supply was calculated. In order to keep the friction losses relatively low, a fixed flow velocity of 0.5 m/s in the pipe was assumed. This led to a pipe diameter of approximately 140 mm. Therefore, a standard PVC pipe diameter of 140 mm was selected.

Based on all of this, the power consumption of the pump needed to be estimated. The formula to calculate the hydraulic power required by a pump is given by:

$$P = \frac{\rho \cdot g \cdot Q \cdot H}{\eta} \tag{15}$$

where:

- ρ: Fluid density
- g: Gravitational acceleration constant
- Q: Volumetric flow rate
- H: Total head (sum of elevation, pressure, and friction head)
- η: Efficiency of the pump

This formula calculates the mechanical power P required by a pump to lift or move a fluid, factoring in density, gravitational force, flow rate, total head, and pump efficiency.

Finally, the cost associated with power consumption was calculated by multiplying the calculated power consumption with the unit price of electricity in Maputo (0.075 \$/kWh [38]). This resulted in a power consumption cost of almost 20000 \$ over the design service life of 20 years of the system.

Parameter	**Value**	**Unit**
Shortest distance WWTP - Power plant	2000	m
Diameter	0.140	m
Flow velocity	0.5	m/s
Darcy friction factor	0.025	-
Gravitational acceleration constant	9.81	m/s^2
Friction head loss	4.32	m
Delivery head	10	m
Elevation head difference	1	m
Total head	15.32	m
Pump efficiency	0.75	-
Power	1.50	kW
Price pump	515	$
Price electricity	*19613.66835*	*$ (over 20 years)*
PVC capital cost	*106000*	*$ (over 20 years)*
Maintenance	*37296*	*$ (over 20 years)*
Supply cost		**0.035 $/m^3**

Owned water trucks
To estimate supply costs using water trucks owned by the WWTP, only the water demand of concrete companies were considered as the interested companies were spatially identifiable and the stakeholder analysis concluded that concrete companies could not be supplied via piping due to sanitary concerns.

The combined water demand of 10 interested companies in Maputo was estimated by Fausta to be around 257 m^3/day and their combined shortest distance to the WWTP was measured at around 84 km [13]. The type of water trucks selected had a capacity of 15 m^3 each. Each truck was assumed to supply water twice a day. Therefore, it was calculated that 9 trucks were required for this service. The salaries of these trucks and their fuel consumption were based on online research [39] [133]. Furthermore, the price of fuel was based on observations at local gas stations.

Overall, all these costs were combined and expressed in $/m^3 of supplied water over the design service life of 20 years of the system.

Table 26: Summary of costs for water supply using water trucks

Component	**Value**	**Unit**
Service life	20	years
Unit cost of water trucks	40000	$
Unit capacity of water trucks	15	m^3
Water demand for concrete	257	m^3/day
Nb. of trucks required	9	-
Distance to companies	84	km
Total distance	336	km
Fuel consumption	0.27	l/km
Diesel price	1.2	$/l
Salary truck driver	2530	$/year
Total capital cost	*360000*	*$ (over 20 years)*
Total operational cost	*1240296*	*$ (over 20 years)*
Cost per m^3	**0.85**	**$/m^3**

E Complete Water Quality Results

The complete results of the water quality testing are shown in Tables 27 through 30. The results of the ICP testing are shown in Figures 31 through 53. Note that beryllium was also measured, but was below the detection limit for all samples so the resulting plot is not included.

Table 27: Water Quality Results Part 1 (b.d.l. = below detection limit, n.m. = not measured, * = measured in % instead of mg/L)

Sample Code	pH	EC	Dissolved Oxygen	TDS	Turbidity	Redox-Potential	Resistivity	Salinity
	-	uS/cm	mg/L	mg/L	NTU	mV	ohm.cm	%
TW	8.007	223	8.12	223	0.98	-60	4.48	0
RW-U	7.374	1326	66*	1326	2.46	-24.8	754	10.6
RW-D	7.493	1335	62.5*	1335	1.74	-28.3	749	6.25
WW-II	7.25	1379	54.5*	1383	12.3	-1.79	723	0.6
WW-II-F1-5	9.11	763	94.6*	763	0.8	-123.1	1311	0.3
WW-II-F1-10	8.86	695	85.1*	695	0.61	-109.8	1439	0.3
WW-II-F1-15	8.71	788	7.81	788	0.46	-100.6	1269	0.3
WW-II-F2-15	8.43	1047	7.23	1047	0.6	-85	955	0.5
WW-II-F3-15	7.83	1239	6.04	1239	0.56	-50.9	807	0.6
WW-II-FM	8.57	1015	6.45	1015	0.49	-92.8	958	0.5
WW-IE	7.65	2700	4.53	2700	20.8	-40.7	373	1.4
WW-IE-F1-5	8.83	1271	7.44	1271	0.22	-107.8	787	0.6
WW-IE-F1-10	8.48	1603	7.56	1603	<0.01	-88.6	624	0.8
WW-IE-F1-15	8.36	1835	7.02	1835	0.22	-80	545	0.9
WW-IE-F2-15	8.19	2190	7.78	2190	0.23	-71.6	456	1.1
WW-IE-F3-15	8	2480	6.95	2480	0.19	-61	402	1.3
WW-IE-FM	8.33	2060	7.93	2060	0.19	-79.2	486	1
WW-IE-FF-5	7.98	2540	7.71	2540	0.17	-60.2	394	1.3
WW-IE-FF-10	7.99	2540	7.74	2540	0.09	-59.2	395	1.3

Table 28: Water Quality Results Part 2 (b.d.l. = below detection limit, n.m. = not measured, * = measured in % instead of mg/L)

Sample Code	NO3	NO2	COD	BOD	Cl	Phenolphtalein Alkalinity	Total Alkalinity	HCO3-	Hardness	SAR	TSS
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	mgCaCO3/L	-	mg/L
TW	b.d.l.	b.d.l	2.9	6.4	31.0	27.0	202.7	2.4	53.7	0.49	565
RW-U	19.04	5.26	33.3	15.4	199.4	0.0	783.7	12.8	165.2	3.85	343
RW-D	29.22	7.36	38.6	n.m.	234.9	0.0	770.2	12.6	163.2	3.80	426
WW-II	b.d.l.	8.31	33.6	72.2	190.5	0.0	918.8	15.1	146.5	4.14	524
WW-II-F1-5	0.71	1.08	14.9	n.m.	n.m.	n.m.	n.m.	n.m.	124.2	1.89	n.m.
WW-II-F1-10	b.d.l.	1.38	10.3	n.m.	n.m.	n.m.	n.m.	n.m.	114.3	1.79	n.m.
WW-II-F1-15	b.d.l.	2.04	11.1	n.m.	n.m.	n.m.	n.m.	n.m.	131.6	2.02	n.m.
WW-II-F2-15	0.80	2.53	17.6	n.m.	n.m.	n.m.	n.m.	n.m.	151.1	2.64	n.m.
WW-II-F3-15	0.93	2.86	16	n.m.	199.4	124.7	554.0	5.0	181.6	2.61	n.m.
WW-II-FM	1.15	1.94	17.1	7.8	164.0	81.1	702.6	8.9	146.4	2.82	557
WW-IE	8.85	3.94	140	4	491.9	0.0	1594.4	26.1	274.3	7.90	573
WW-IE-F1-5	2.08	b.d.l	32.7	n.m.	243.7	121.6	851.3	10.0	150.7	3.81	n.m.
WW-IE-F1-10	3.10	b.d.l	47.2	n.m.	n.m.	n.m.	n.m.	n.m.	184.9	4.73	n.m.
WW-IE-F1-15	3.76	b.d.l	57.1	n.m.	341.2	202.7	1121.5	11.7	212.3	5.01	n.m.
WW-IE-F2-15	5.36	b.d.l	76.8	n.m.	n.m.	n.m.	n.m.	n.m.	235.5	6.34	n.m.
WW-IE-F3-15	6.64	b.d.l	91.4	n.m.	438.7	189.2	1472.8	17.9	262.8	7.14	n.m.
WW-IE-FM	4.78	b.d.l	69.9	8.4	394.4	94.6	1229.6	17.1	217.8	5.89	381
WW-IE-FF-5	8.41	b.d.l	102.5	n.m.	465.3	193.0	1067.5	11.2	259.4	7.58	n.m.
WW-IE-FF-10	7.88	b.d.l	102.5	n.m.	n.m.	n.m.	n.m.	n.m.	265.8	9.08	n.m.

Table 29: E. Coli results (* = incubated longer than 24 hours)

Sample Code	E.Coli - 1 MPN/100mL	E.Coli - 2 MPN/100mL	E.Coli - 3* MPN/100mL	E.Coli - 4* MPN/100mL	E.Coli - Average MPN/100mL	E.Coli - Std. MPN/100mL
TW	0	0	n.m.	n.m.	0	0.00
RW-U	243	504	520	310	394.25	120.24
RW-D	884	1145	980	1480	1122.25	226.66
WW-II	>24196	>24196	1180000	1580000	1380000	200000.00
WW-II-F1-5	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
WW-II-F1-10	364	420	n.m.	n.m.	392	28.00
WW-II-F1-15	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
WW-II-F2-15	n.m.	n.m.	400	200	300	100.00
WW-II-F3-15	n.m.	n.m.	300	200	250	50.00
WW-II-FM	1334	1014	n.m.	n.m.	1174	160.00
WW-IE	>24196	15531	20000	10000	15177	5009.39
WW-IE-F1-5	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
WW-IE-F1-10	0	0	n.m.	n.m.	0	0.00
WW-IE-F1-15	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
WW-IE-F2-15	n.m.	n.m.	410	0	205	205.00
WW-IE-F3-15	n.m.	n.m.	0	0	0	0.00
WW-IE-FM	10	0	n.m.	n.m.	5	5.00
WW-IE-FF-5	n.m.	n.m.	410	100	255	155.00
WW-IE-FF-10	309	345	310	520	371	87.24

Table 30: Coliform results (* = incubated longer than 24 hours)

Sample Code	Total Coliforms - 1 MPN/100mL	Total Coliforms - 2 MPN/100mL	Total Coliforms - 3* MPN/100mL	Total Coliforms - 4* MPN/100mL	Total Coliforms Average MPN/100mL	Total Coliforms Std. MPN/100mL
TW	3.1	4.1	n.m.	n.m.	3.6	0.71
RW-U	>24196	15531	3840	3960	7777	5483.12
RW-D	>24196	>24196	3500	3300	3400	100.00
WW-II	>24196	>24196	8050000	8880000	8465000	415000.00
WW-II-F1-5	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
WW-II-F1-10	2755	1956	n.m.	n.m.	2355.5	399.50
WW-II-F1-15	n.m.	n.m.	n.m.	n.m.		
WW-II-F2-15	n.m.	n.m.	1680	1050	1365	315.00
WW-II-F3-15	n.m.	n.m.	5980	4730	5355	625.00
WW-II-FM	5794	6867	n.m.	n.m.	6330.5	536.50
WW-IE	>24196	>24196	402000	481000	441500	55861.44
WW-IE-F1-5	n.m.	n.m.	n.m.	n.m.		
WW-IE-F1-10	63	20	n.m.	n.m.	41.5	21.50
WW-IE-F1-15	n.m.	n.m.	n.m.	n.m.		
WW-IE-F2-15	n.m.	n.m.	9100	11620	10360	1260.00
WW-IE-F3-15	n.m.	n.m.	11870	9880	10875	995.00
WW-IE-FM	135	110	n.m.	n.m.	122.5	12.50
WW-IE-FF-5	n.m.	n.m.	2330	3160	2745	415.00
WW-IE-FF-10	3654	9208	3500	2980	4835.5	2536.79

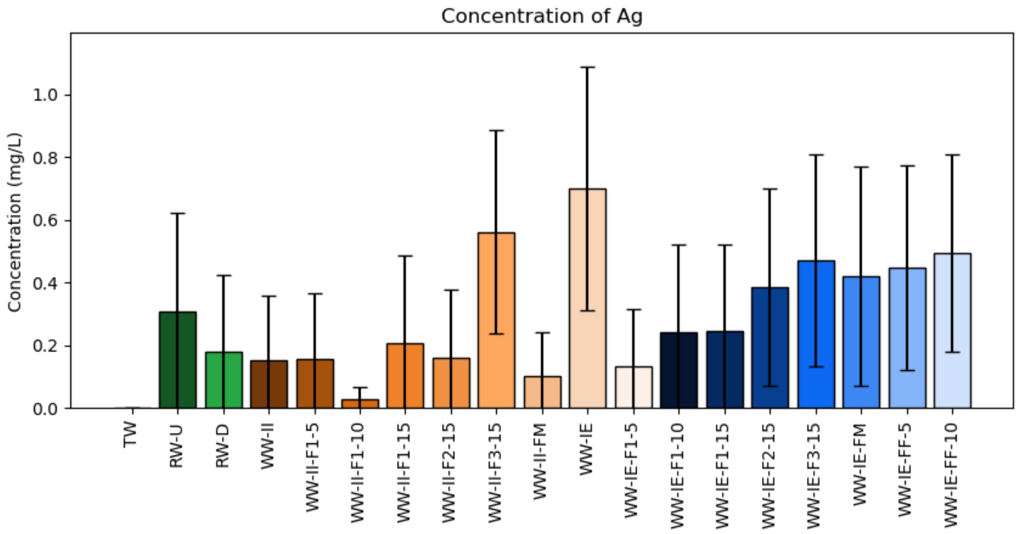


Figure 31: ICP Results: Silver

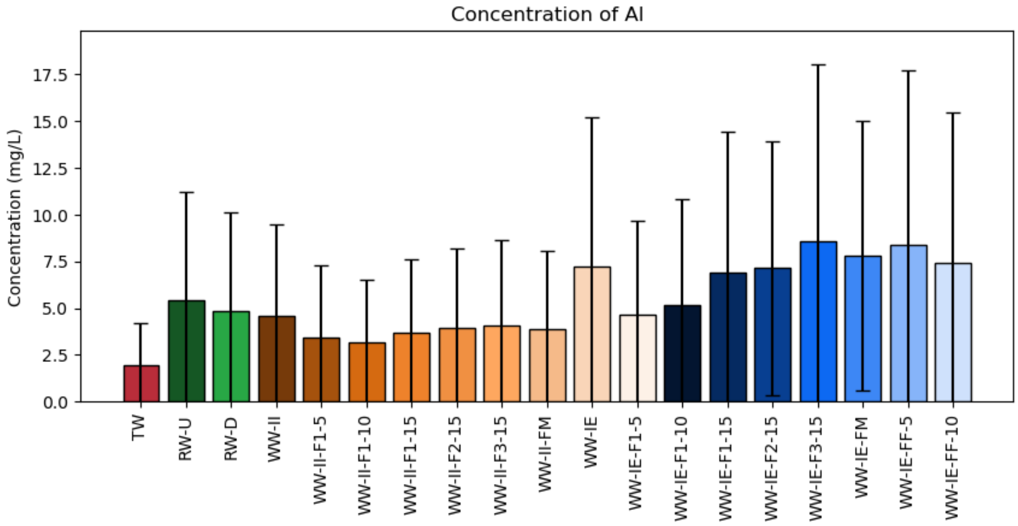


Figure 32: ICP Results: Aluminum

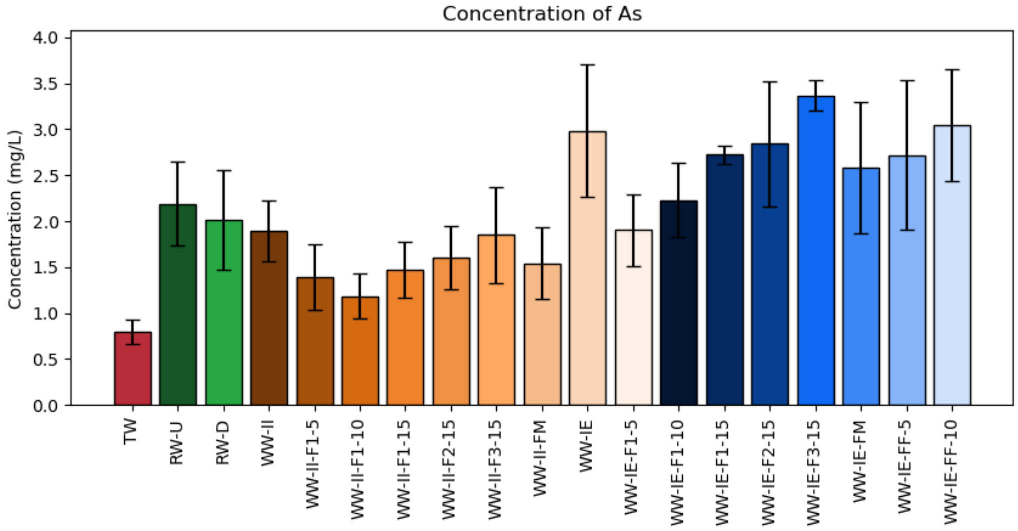


Figure 33: ICP Results: Arsenic

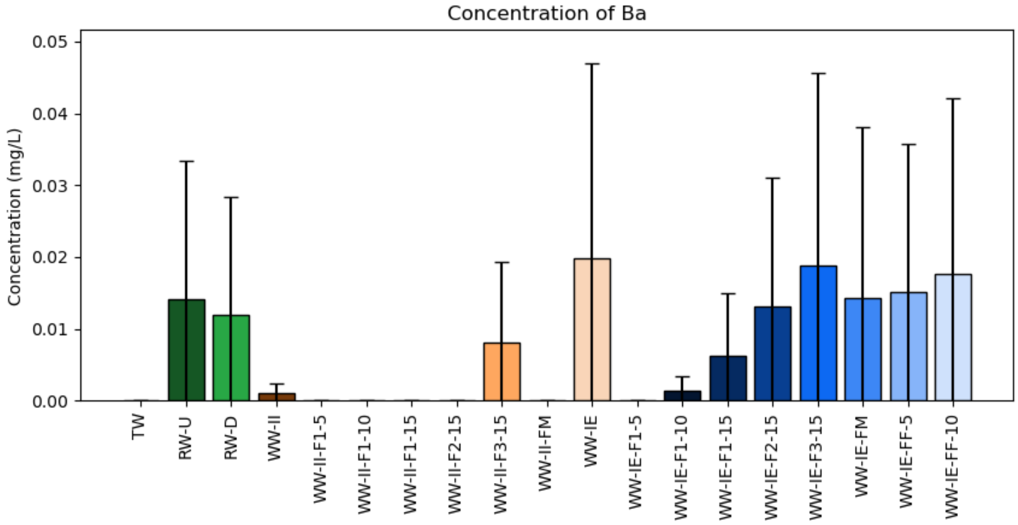


Figure 34: ICP Results: Barium

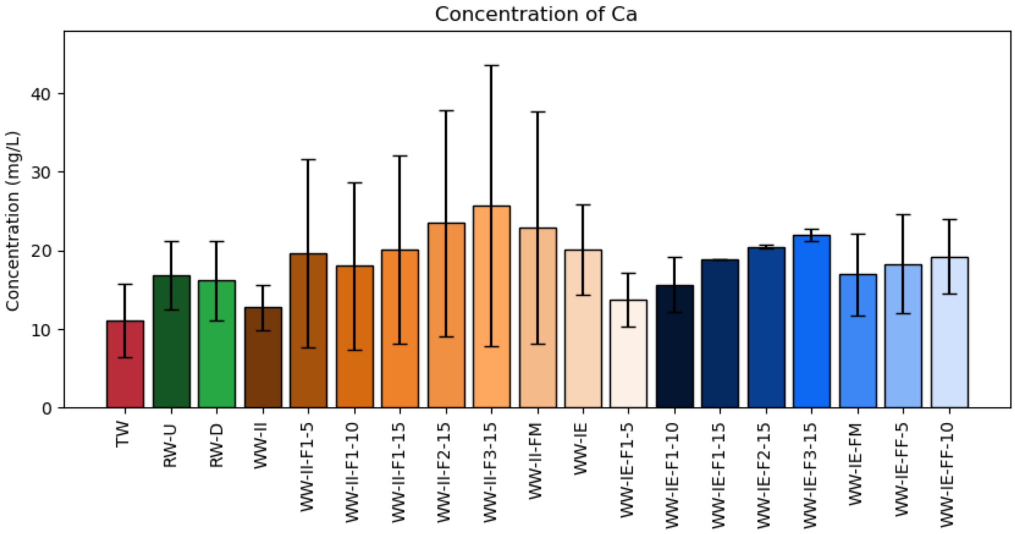


Figure 35: ICP Results: Calcium

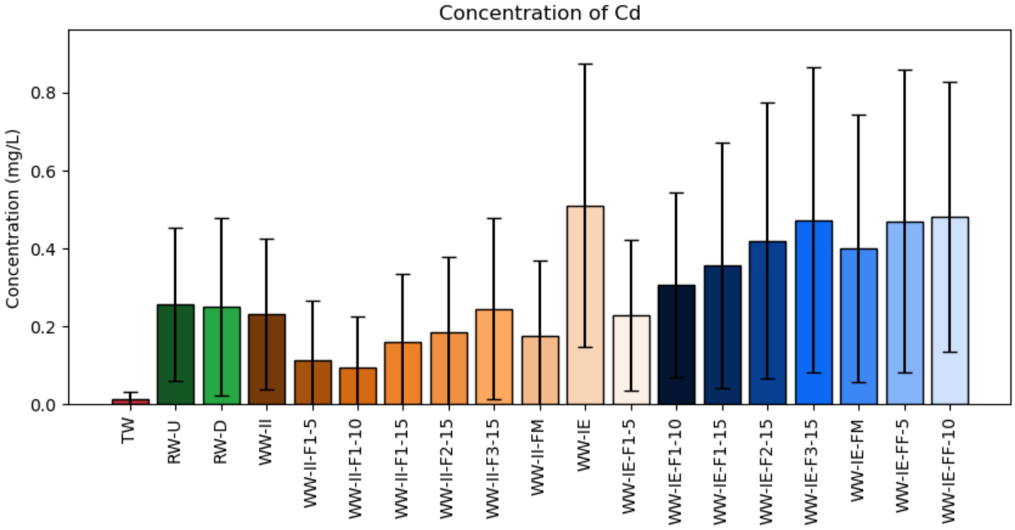


Figure 36: ICP Results: Cadmium

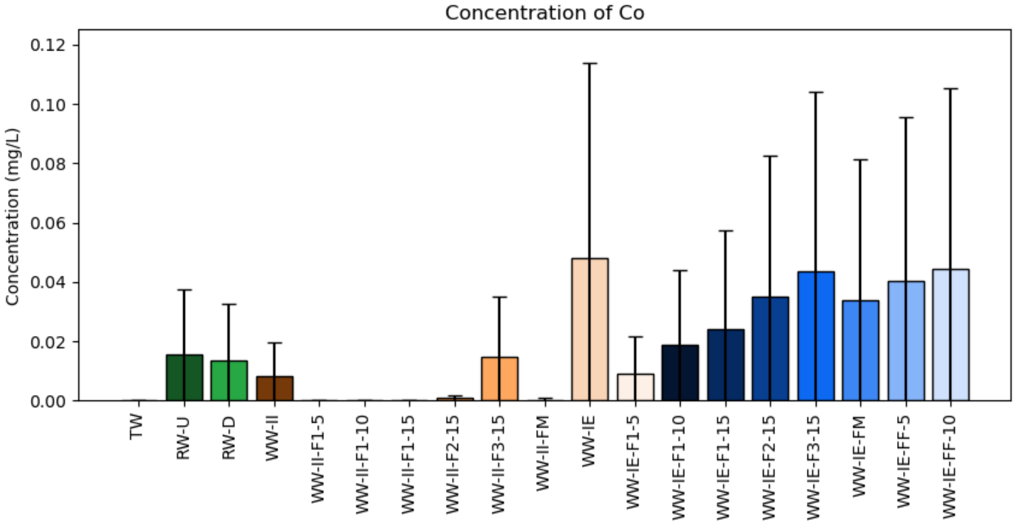


Figure 37: ICP Results: Cobalt

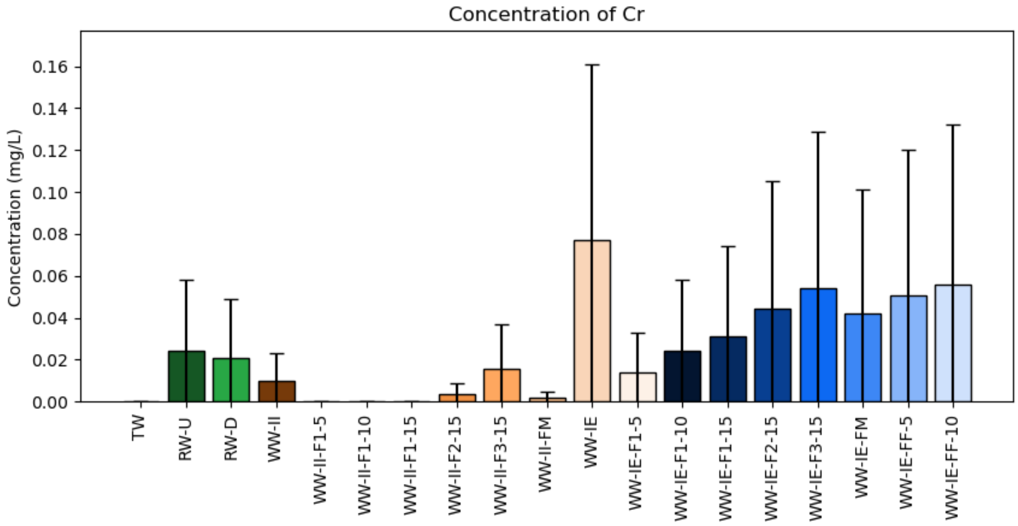


Figure 38: ICP Results: Chromium

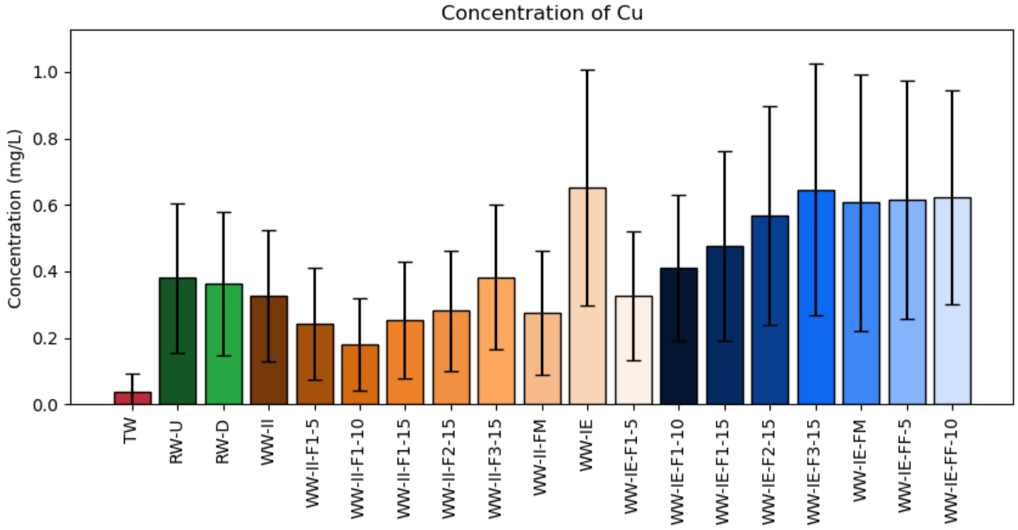


Figure 39: ICP Results: Copper

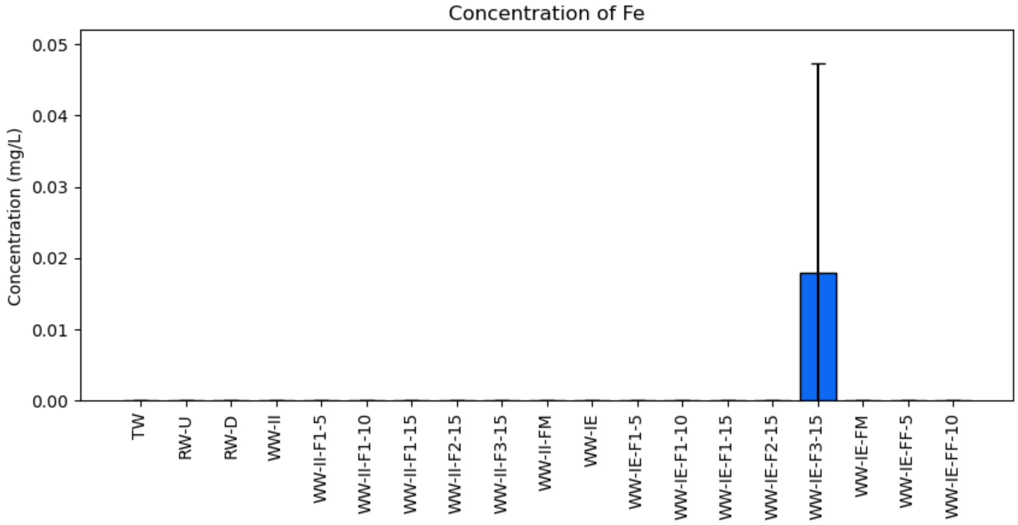


Figure 40: ICP Results: Iron

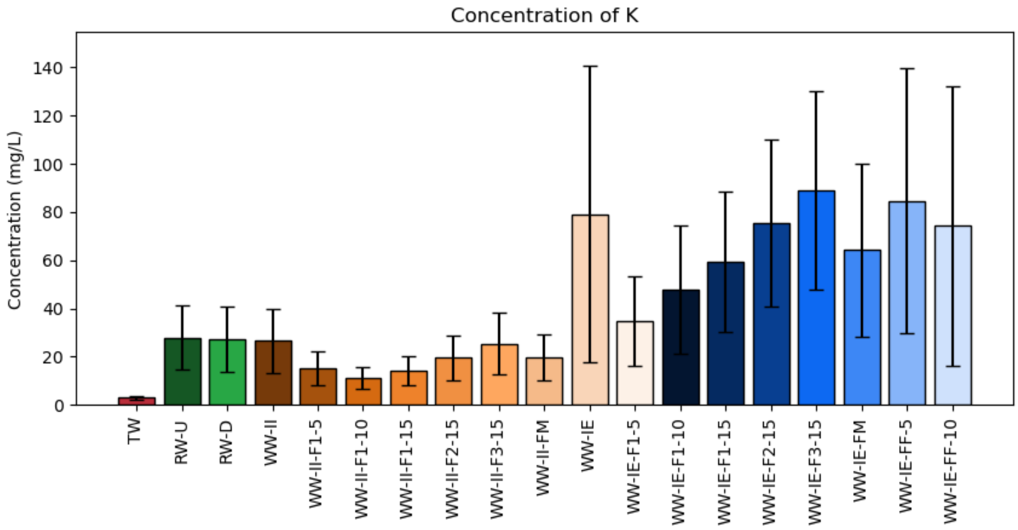


Figure 41: ICP Results: Potassium

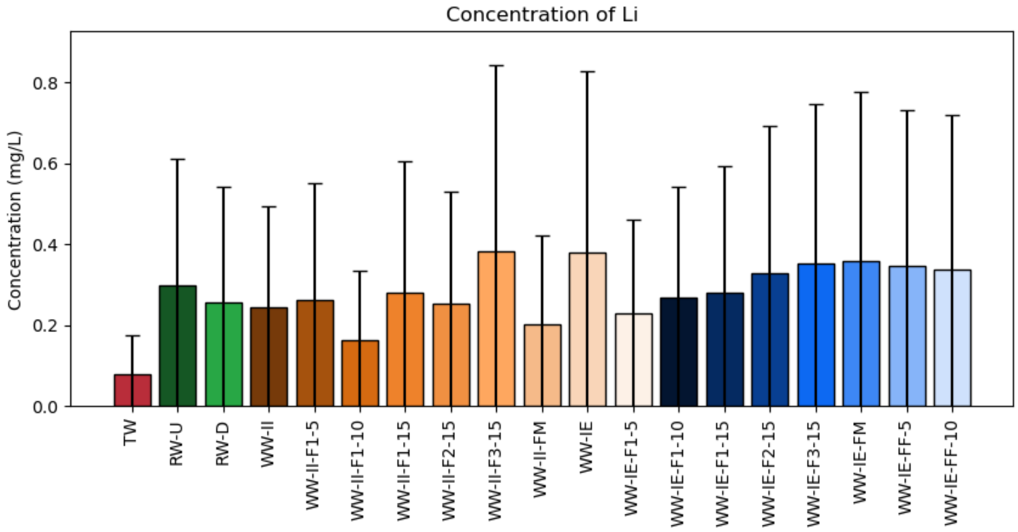


Figure 42: ICP Results: Lithium

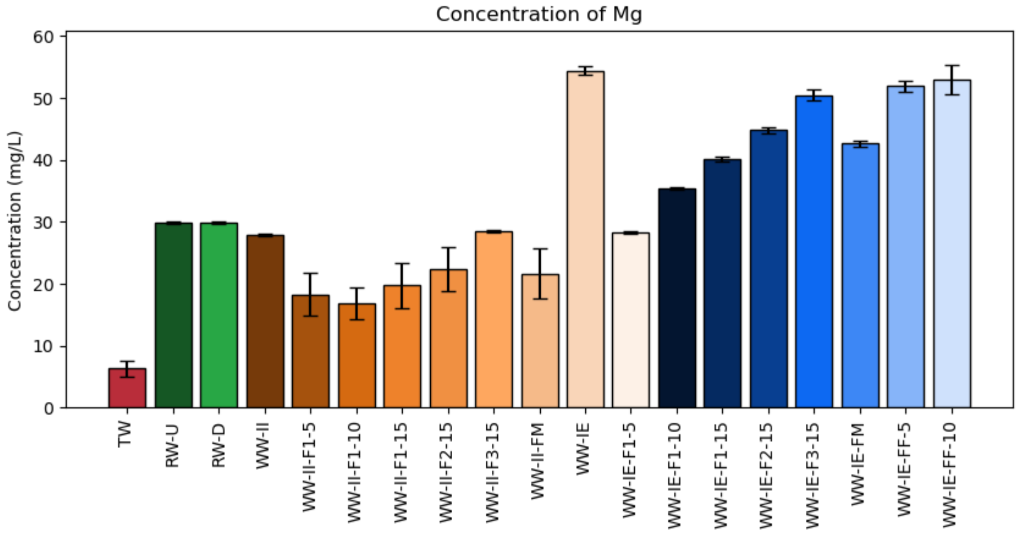


Figure 43: ICP Results: Magnesium

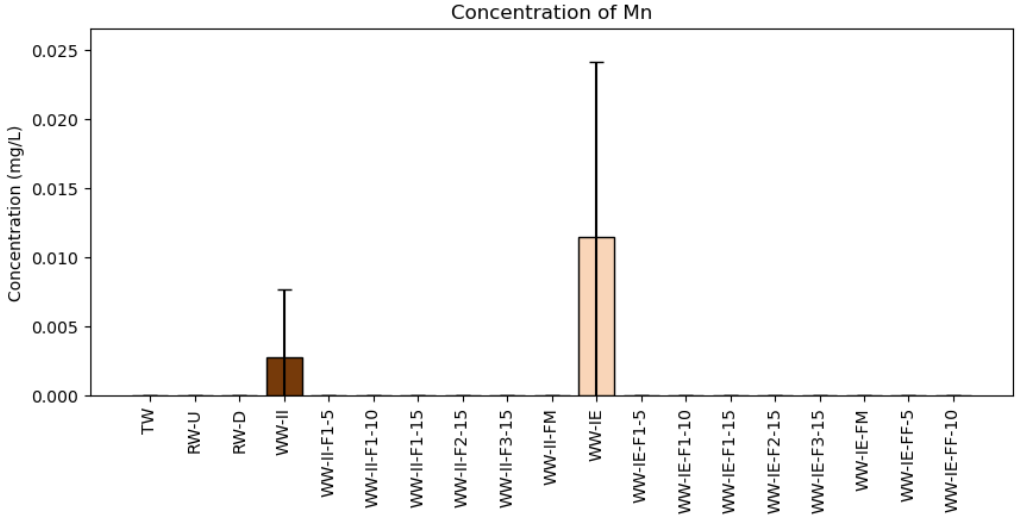


Figure 44: ICP Results: Manganese

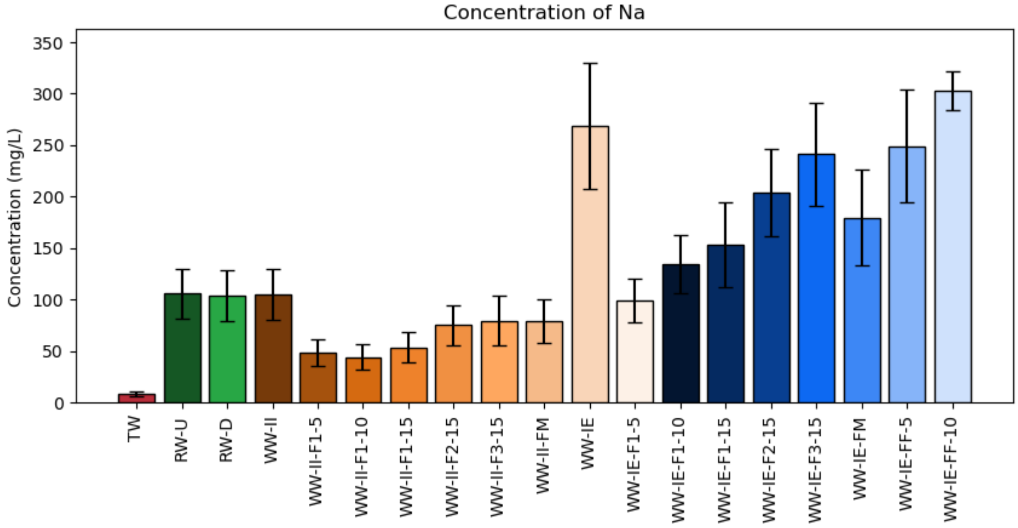


Figure 45: ICP Results: Sodium

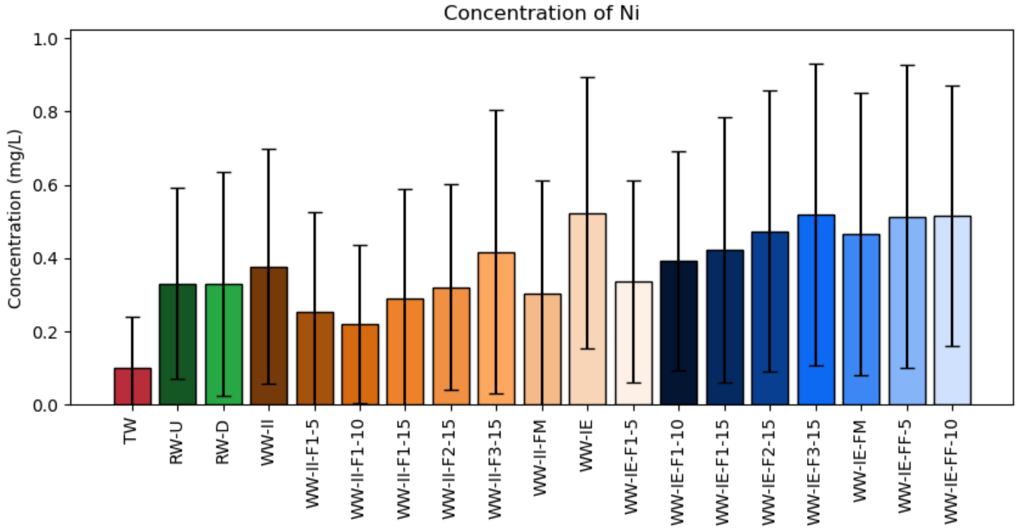


Figure 46: ICP Results: Nickel

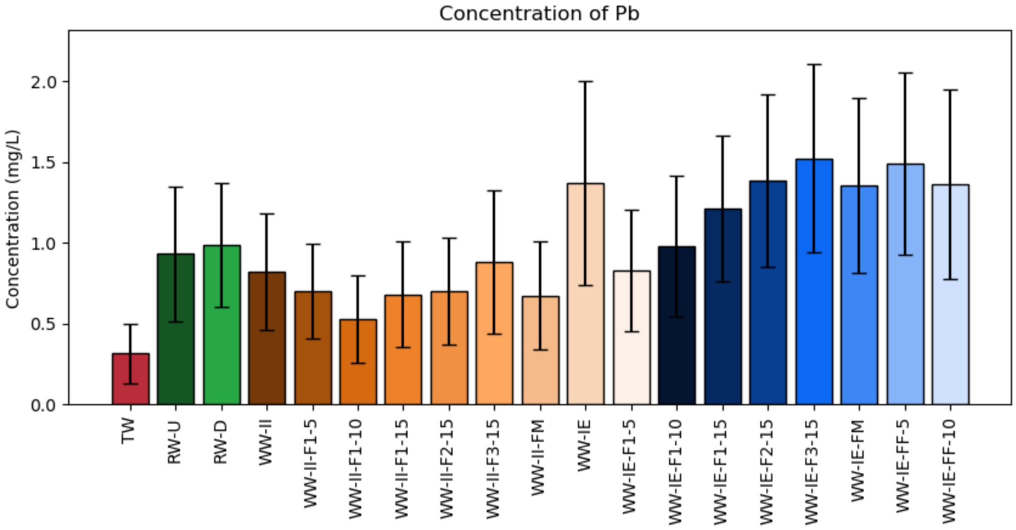


Figure 47: ICP Results: Lead

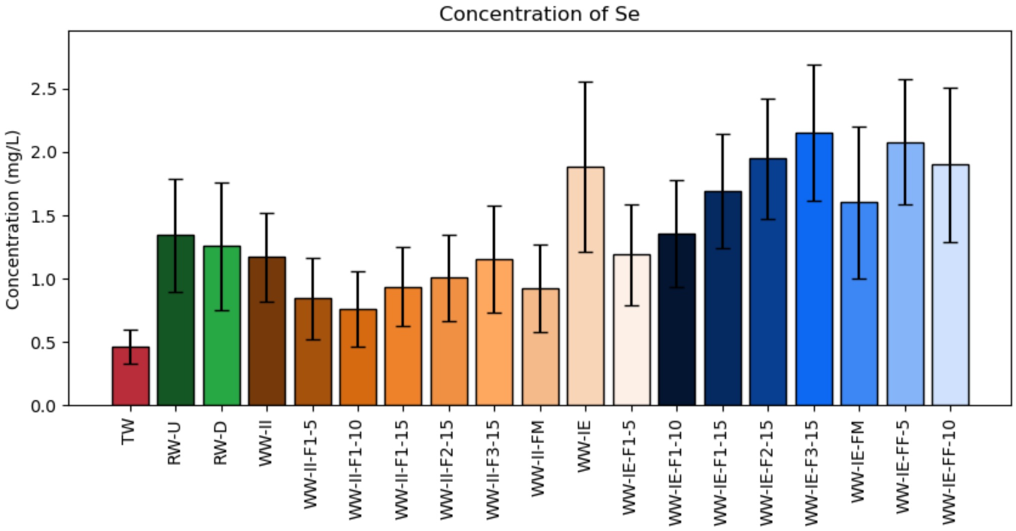


Figure 48: ICP Results: Selenium

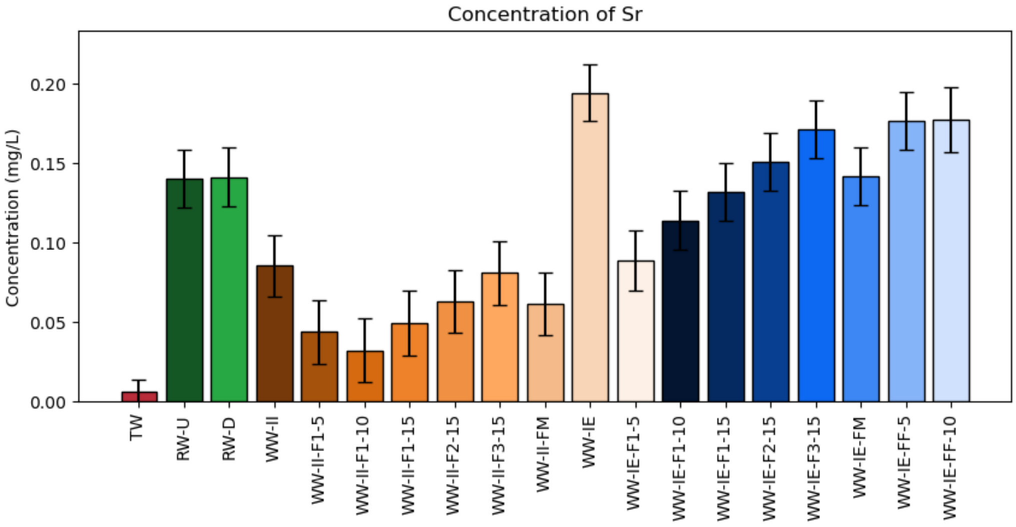


Figure 49: ICP Results: Strontium

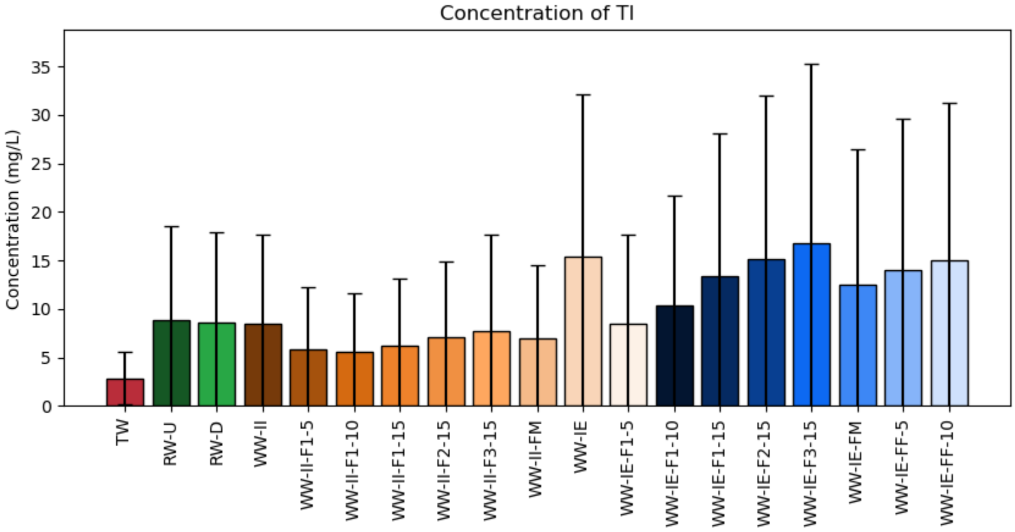


Figure 50: ICP Results: Thallium

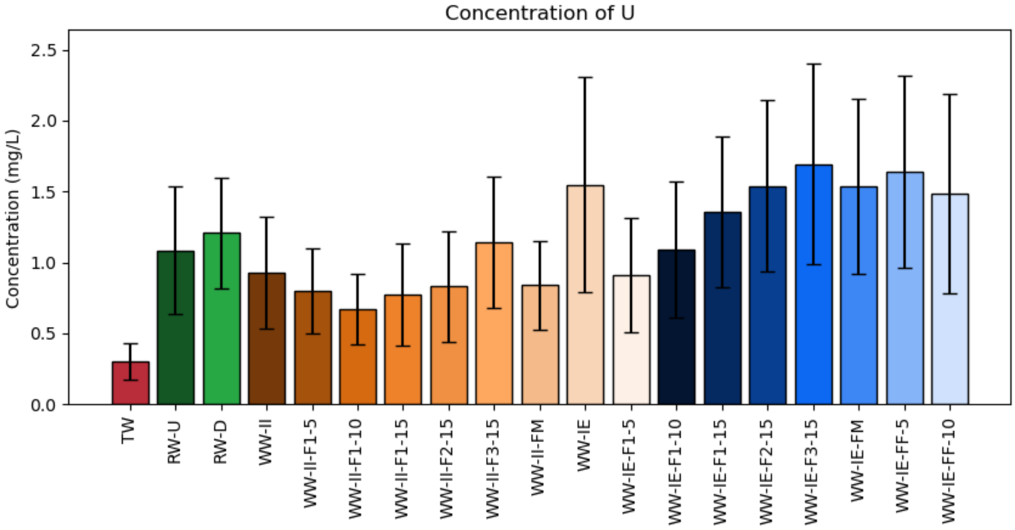


Figure 51: ICP Results: Uranium

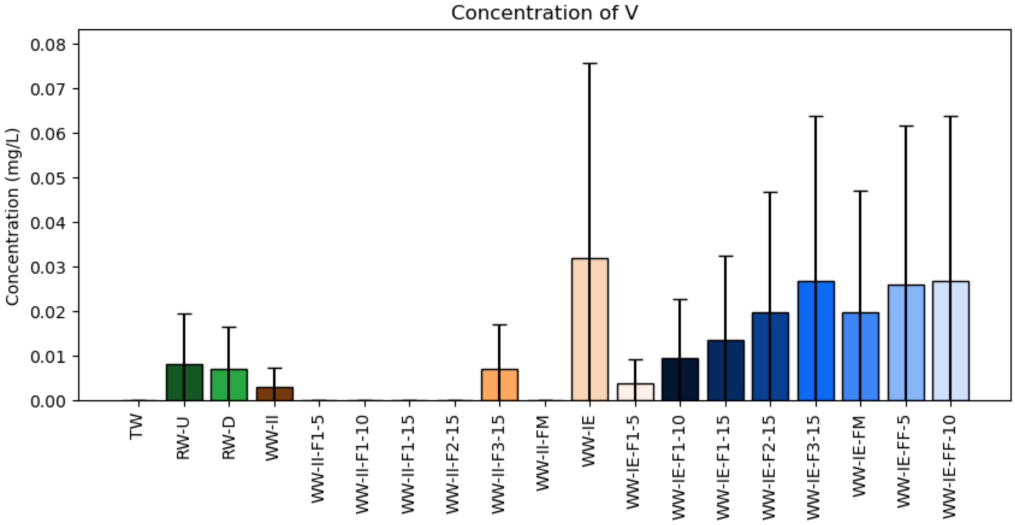


Figure 52: ICP Results: Vanadium

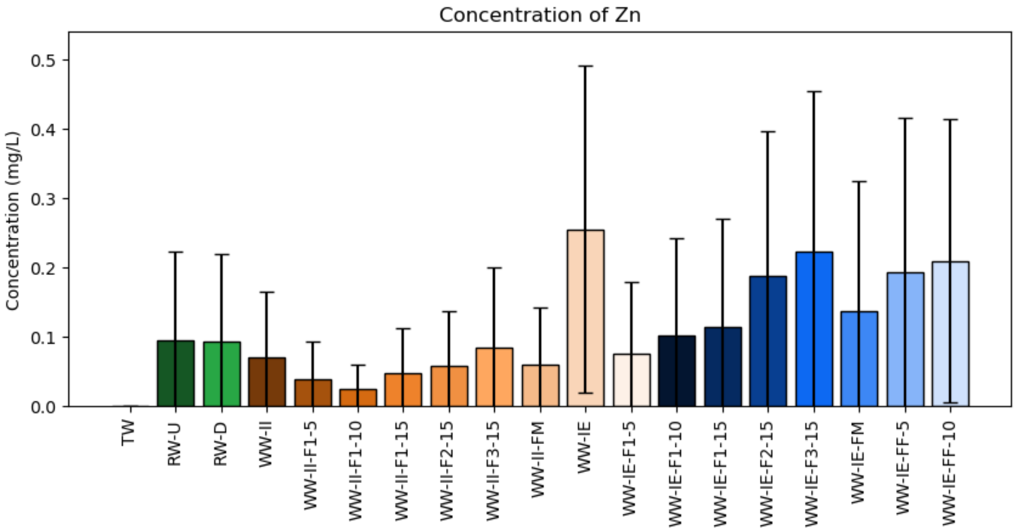


Figure 53: ICP Results: Zinc

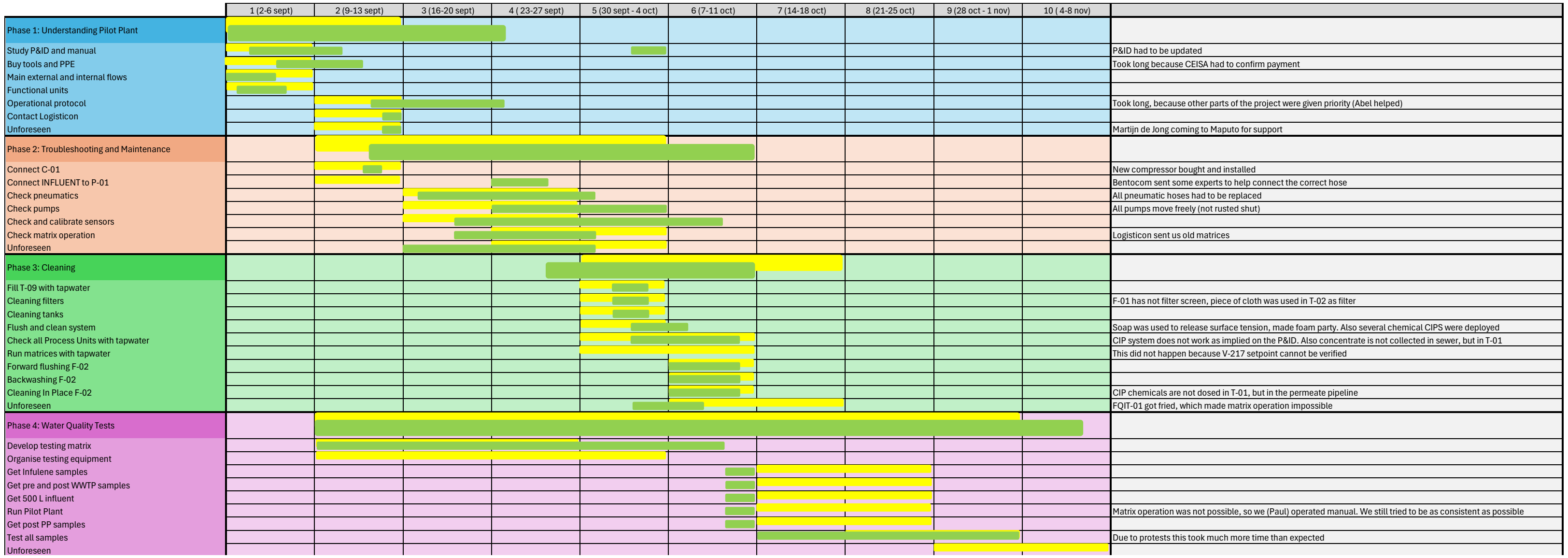
F Complete Water Balance Calculations

	Current Situation	**Connected Situation**	**Situation 2030**	**Situation 2040**		**Precipitation (mm)**	**Potential Evaporation (mm)**	**Actual Evaporation (mm)**
Average Daily Inflow into infulene WWTP (m3/d):	1870	2800	4533	9561	Source:	INAM	MODIS16	MODIS16
Percentage of Max. Capacity	15,96%	23,89%	38,68%	81,59%				
Water Demand per Use Case:	Concrete Production	Cooling Water (CMT)	Car Wash	Municipality	Area (m2) for total volume:	Infulene WWTP	Infulene WWTP Treatment Ponds	Farmland Downstream of WWTP
m3/month	9690	19800	2487	483		288653	205283	1100000
	Average Daily Discharge from infulene WWTP (m3/d)							
JAN	2465,03	3395,03	5128,03	10156,03		151,45	126	29,04
FEB	2320,80	3250,80	4983,80	10011,80		160,64	160	27,57
MAR	1281,19	2211,19	3944,19	8972,19		93,13	217	51,08
APR	739,56	1669,56	3402,56	8430,56		44,66	228	44,83
MAY	518,26	1448,26	3181,26	8209,26		33,75	245	40,86
JUN	675,26	1605,26	3338,26	8366,26		9,53	188	61,23
JUL	868,46	1798,46	3531,46	8559,46		17,52	171	95,33
AUG	939,94	1869,94	3602,94	8630,94		19,26	163	104,65
SEP	1052,47	1982,47	3715,47	8743,47		21,71	150	98,49
OCT	1289,20	2219,20	3952,20	8980,20		50,58	156	91,90
NOV	1729,66	2659,66	4392,66	9420,66		79,29	132	48,38
DEC	2429,10	3359,10	5092,10	10120,10		137,76	112	32,36

G Pilot Plant Planning and Roadmap

The planning as shown in figure 54 was made in week 2 when it became apparent that the Pilot Plant needed a lot of repair and maintenance. During the whole process some sub-steps for the phases were added.

On the next page a more detailed roadmap for each phase can be found. This was used to keep track of all to-do's regarding pilot plant maintenance and repair.



	1 (2-6 sept)	2 (9-13 sept)	3 (16-20 sept)	4 (23-27 sept)	5 (30 sept - 4 oct)	6 (7-11 oct)	7 (14-18 oct)	8 (21-25 oct)	9 (28 oct - 1 nov)	10 (4-8 nov)	
Phase 1: Understanding Pilot Plant											
Study P&ID and manual											P&ID had to be updated
Buy tools and PPE											Took long because CEISA had to confirm payment
Main external and internal flows											
Functional units											
Operational protocol											Took long, because other parts of the project were given priority (Abel helped)
Contact Logisticon											
Unforeseen											Martijn de Jong coming to Maputo for support
Phase 2: Troubleshooting and Maintenance											
Connect C-01											New compressor bought and installed
Connect INFLUENT to P-01											Bentocom sent some experts to help connect the correct hose
Check pneumatics											All pneumatic hoses had to be replaced
Check pumps											All pumps move freely (not rusted shut)
Check and calibrate sensors											
Check matrix operation											Logisticon sent us old matrices
Unforeseen											
Phase 3: Cleaning											
Fill T-09 with tapwater											
Cleaning filters											F-01 has not filter screen, piece of cloth was used in T-02 as filter
Cleaning tanks											
Flush and clean system											Soap was used to release surface tension, made foam party. Also several chemical CIPS were deployed
Check all Process Units with tapwater											CIP system does not work as implied on the P&ID. Also concentrate is not collected in sewer, but in T-01
Run matrices with tapwater											This did not happen because V-217 setpoint cannot be verified
Forward flushing F-02											
Backwashing F-02											
Cleaning In Place F-02											CIP chemicals are not dosed in T-01, but in the permeate pipeline
Unforeseen											FQIT-01 got fried, which made matrix operation impossible
Phase 4: Water Quality Tests											
Develop testing matrix											
Organise testing equipment											
Get Infulene samples											
Get pre and post WWTP samples											
Get 500 L influent											
Run Pilot Plant											Matrix operation was not possible, so we (Paul) operated manual. We still tried to be as consistent as possible
Get post PP samples											
Test all samples											Due to protests this took much more time than expected
Unforeseen											

Figure 54: Overall planning for pilot plant maintenance and repair.

Phase 1: Understanding Pilot Plant
Phase 2: Troubleshooting and Maintenance
Phase 3: Cleaning
Phase 4: Water Quality Tests

	dates
Not started	to start
In progress	started
Finished	done
Not relevant/solvable	

Phase 1	7-Oct	Phase 2	8-Oct	Phase 3	10-Oct	Phase 4	30-Oct
Study P&ID and manual	9-Sep	Connect C-01	12-Sep	Fill T-09 with tap water	3-Oct	Develop testing matrix	11-Oct
Buy tools and PPE	6-Sep	Connect INFLUENT to P-01	24-Sep			Organise testing equipment	14-Oct
Main external flows	4-Sep	Check pneumatic valves	30-Sep	Flush old water out	3-Oct	Test water up and downstream of Infulene discharge	30-Oct
Main internal flows	4-Sep	Check all pumps	7-Oct	Run all operation modes with tapwater	10-Oct		
Flush Filter	5-Sep	Check and calibrate all sensors	8-Oct			Get 500L INFLUENT tank filled with Infulene waste water	11-Oct
Feed Pump	5-Sep	Clean pH sensor QIA-01	7-Oct	Run operation matrix with tapwater	**10-Oct**		
Membrane	10-Sep	Check current water levels	16-Sep			Test water pre WWTP treatment	30-Oct
CIP	7-Oct	Check operation matrix	2-Oct	Get CIP chemicals	7-Oct	Test water post WWTP treatment	30-Oct
Make step-by-step plan for different operational modes	23-Sep	Check operation PU1	3-Oct	Clean F-01	2-Oct		
		Check operation PU2	3-Oct	Clean F-02	10-Oct	Run Pilot Plant with wastewater	11-Oct
Get into contact with Logisticon	13-Sep	Check operation PU3	8-Oct	Clean T-01	3-Oct	Test water post PP treatment	30-Oct
		Check operation PU4	7-Oct	Clean T-02	3-Oct		
		Check operation PU5	7-Oct	Clean T-03	3-Oct		
				Run backwash mode	8-Oct		
				Run CIP mode	10-Oct		
Unforeseen issues		**Unforeseen issues**		**Unforeseen issues**		**Unforeseen issues**	
P&ID needs to be updated	5-Oct	Most air hoses are broken, and thus need to be replaced. Hoses bought (17 sept)	18-Sep	Ceramic membrane should be checked, since water has been sitting in it for years now.	7-Oct		
		Connection C-01 is unclear and the connector needs to be bought or fabricated.	12-Sep	there is no screen in F-01. Martijn is gonna see if he can bring one. NEEDS TO BE ORDERED	**10-Oct**		
		Pressure sensor PS-01 has a broken electrical connection	19-Sep	How should we store the plant, while we are going/for longer periods of time?	30-Oct		
		Some tubing connections from the valve manifolds are disconnected and we are not sure where they are supposed to connect	27-Sep	Matrix operation cannot be performed because FQIT-03 is fried and that should control V-217	**10-Oct**		
		Main flow pathway appears to have an open tubing connection (covered by tape only) just past the ceramic filter	23-Sep				
		Valve V-306 appears to be missing	27-Sep				
		Steam trap ST-03 appears to be missing	27-Sep				
		Need a hose to connect the water tank	24-Sep				
		PT-04 and -05 are not connected	23-Sep				
		release extern (client) error	27-Sep				
		release installation error. It seems that cable X2_106 and X2_107 need to be connected in clamp holder unit X2. See picture. Need to ask software engineering for advice	27-Sep				
		40A3.01 (electrical unit p.41) connection WAN client is missing.	**24-Sep**				
		Use 5 bars of pressure for the valves, if they don't work use a bit more!!!	30-Sep				
		There is no saved operation matrix on the computer. Information must be acquired with Logisticon. Backwash and pulse are available	2-Oct				
		V-201 is not working fully	**10-Oct**				
		FQIT-03 is fried	**10-Oct**				
		LC-02, -03 do not work	**10-Oct**				
		P-06 does not work	**10-Oct**				
		PT-07 does not work	**10-Oct**				